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DESIGN OPTIMIZATION AND EVALUATION OF
INTEGRATING SOUND LEVEL METERS

by

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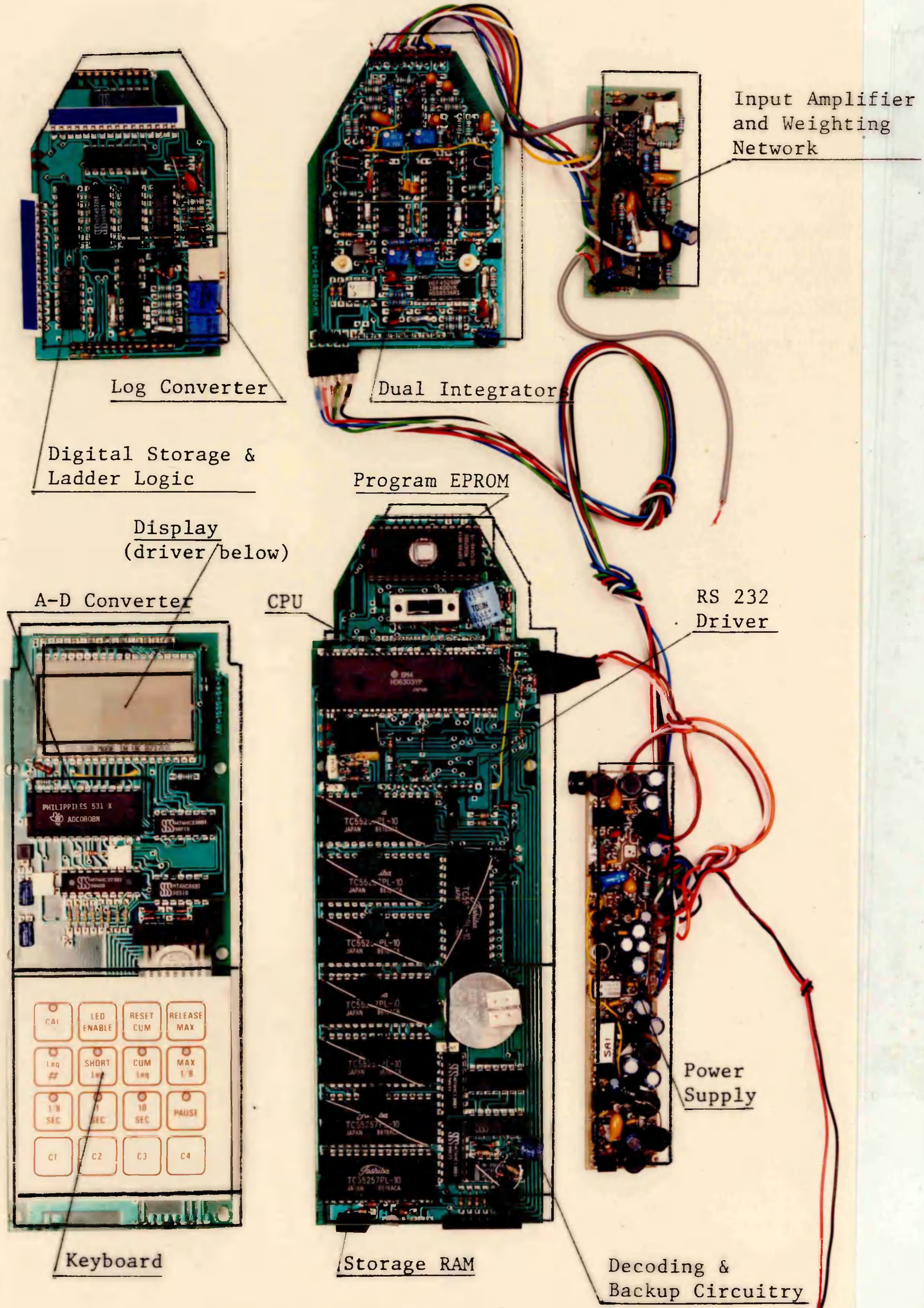

ADVANCED MICROPROCESSOR-BASED INSTRUMENT PCBs

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ABSTRACT

Design Optimization and Evaluation of Integrating Sound Level Meters

J M Holding

Previous work has shown that the risk of hearing loss is related to the cumulative sound energy received by the ear. The instrument which computes a measure of this parameter is an integrating sound level meter (ISLM). Optimum design requirements for ISLMs which meet a variety of demanding specifications have been determined. Evaluation procedures have been proposed and the necessary specialized tone burst signal sources have been designed. An early survey of instruments which were available revealed serious shortcomings in their ability to integrate accurately a typical impulsive signal. The aim of this work was to determine and critically evaluate the limiting mechanism, and to subsequently investigate design strategies leading to high performance instruments. Techniques for extending the performance of several standard circuits have been developed. In addition, a novel method for storing data in analogue and digital form and subsequently recovering a continuous output has been developed and is fully described. Combinations of analogue, random logic and microprocessor-based techniques have been investigated. Complete instruments which utilize different combinations have been designed and evaluated. The optimum performance for an instrument which meets the highest specification is shown to be achieved by the use of analogue techniques for the majority of the signal processing, with a combination of random logic and microprocessor-based techniques for control and data storage.

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CHAPTER ONE

INTRODUCTION

An increasing awareness of the risk of hearing damage due to noise has encouraged research into the mechanism of hearing loss. It is now generally accepted that the degree of hearing impairment is a function of the duration of the exposure as well as the level.

The concept of an Equivalent Continuous Sound Level, L_{eq} was introduced in the 1950's after animal and human experiments showed that the same degree of hearing damage could be obtained by doubling the sound intensity and halving the sound exposure or vice versa. The concept of the equivalent continuous sound level is to impart the same amount of energy to the ear as the impulsive or varying sounds which actually occur, over a given time interval.

L_{eq} is therefore defined as the mean-value of the sound intensity with respect to time, expressed in decibels:

$$L_{eq} = 10 \log_{10} \frac{1}{T} \int_0^T \frac{P^2(t)}{P_0^2} \, dt$$

where T is the measurement duration in seconds

P is the instantaneous sound pressure in pascals

P_0 is the reference sound pressure having an r.m.s. value of 2×10^{-5} pascal

The unreferenced integral represents the energy content of the sound and is called the dose $\left(\text{Dose} = \int_0^T P^2(t)dt\right)$. This is usually expressed in $(\text{pascal})^2$ hours.

The referenced integral can also be logged on its own and has the special name of sound exposure.

$$\text{Sound Exposure} = 10 \log_{10} \int_0^T \frac{P^2(t)}{P_0^2}\, dt$$

Sound Exposure (SE) can therefore be related simply to L_{eq}:

$$SE = L_{eq} + 10 \log_{10} T$$

It can be seen from this that sound exposure and L_{eq} are identical when the measurement duration is one second.

The principal advantage of an integrating sound level meter (ISLM) compared to a conventional sound level meter (SLM) is its ability to average stochastic sound signals of wide variance over long time periods. If the noise profile were to consist of several different, but constant, levels, the L_{eq} could be determined using a conventional SLM and stopwatch technique. However, noise sources such as are commonly found in industry, often contain impulsive or short bursts of high intensity sound. A practical ISLM must therefore be capable of integrating over a wide space of signal levels, and over a wide range of measurement periods.

The aim of this research was firstly to investigate and assess various techniques for the measurement of L_{eq} and thus to develop evaluation procedures and standards. Following this, an optimized design for an ISLM capable of accommodating the range of signals found in an industrial environment, was to be undertaken.

It was anticipated that the measurement techniques would initially capitalize on the analogue design experience of the collaborating body, and that the work would develop naturally through the use of hybrid techniques, to culminate in the design of a microprocessor-based digital instrument as the final phase of the PhD programme. The work was undertaken following this initial plan, however the value and subsequent effect on instrument performance of the optimized analogue stages was significantly greater than originally appreciated.

CHAPTER TWO

PHYSIOLOGICAL ACOUSTICS

In order to define and assess correctly the properties of an integrating sound level meter one must have some knowledge of the physiology of the hearing process and the mechanisms leading to hearing loss. A summary of basic anatomy and physical properties is followed by a description of normal and noise-induced hearing loss. Evidence from researchers performing experiments on animals together with a number of government reports is used to support the Equal Energy Hypothesis. This hypothesis forms the basic justification of the need for an integrating sound level meter.

2.1 Introduction

The constituent elements of the auditory system perform the translation from the pressure variations of the sounds reaching the ear into the nerve signals within the brain. The outer and middle ear amplify the air-borne pressure variations and couple them to the fluid of the inner ear.

The structures of the inner ear perform frequency analysis on these vibration signals and pass nerve impulses via the cochlear nerve fibres to the auditory receptive centres of the brain.

The construction of the ear is such that the internal background sources of noise are reasonably well rejected, allowing the ear to have a particularly high sensitivity to external sound signals.

2.2 Anatomy of the Ear

The acoustic pressure variations impinging on the outer ear or pinna (Figure 2.1) are scattered or focussed, depending upon wavelength, into the auditory canal or meatus. The meatus is a slightly tapered horn which helps match the impedance of the ear drum or tympanic membrance to the free field. A typical length for the meatus is 25 mm which accounts for the lightly damped resonance at about 3 kHz. The resonance produces an increase of up to 10 dB over a fairly broad range of frequencies centred around 3 kHz. This roughly corresponds with the important consonant sounds in human speech and is therefore of some benefit.

In ordinaryconversation the displacementof the tympanic membrane is about 10^{-10} m, ie the diameter of a hydrogen molecule. This displacement is amplified by three ossicles: the malleus, incus and stapes (Figure 2.1). The dimensions and physical arrangement of those bones is such that an increase in thrust by a factor of about 1.3 results. The stapes and associated ligaments form the oval window to the cochlea of the inner ear (Figure 2.1). As the area of the oval window is smaller than that of the tympanic membrane, the actual pressure at the foot of the stapes is further increased to about 25 dB above the received pressure level. This virtually compensates for the theoretical loss due to the transfer from air pressure to the fluid pressure of the inner ear.

Although the ossicles only provide a fairly modest increase in pressure, there are a number of advantages in this seemingly over-complex arrangement. Firstly, the asymmetrical arrangement of the malleus and incus contributes to the rejection of bone conducted signals, thus improving the basic system noise level. Secondly,

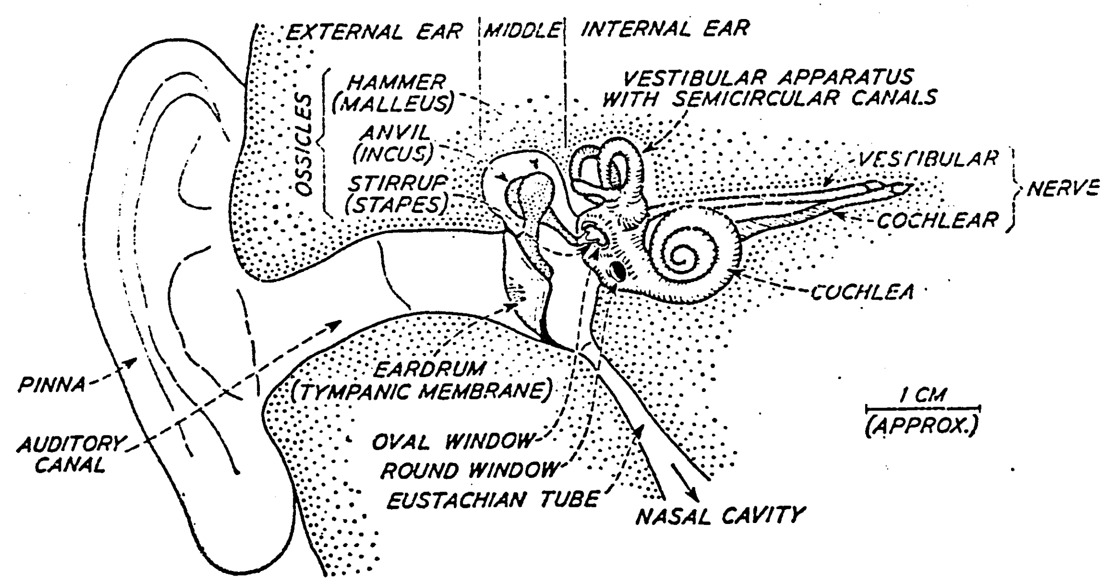

FIGURE 2.1 Anatomy of the Ear

the restriction of the bones to very small amplitude displacements, which is possible with this arrangement, helps minimize non-linearities and finally, the presence of three bones allows the inclusion of a protective overload device to limit damage to the hearing mechanism. This overload protection arises due to a change in vibration mode of the ossicles for very intense sounds (> 140 dB). A second protective device within the middle ear consists of two small muscles which draw the tympanic membrane inwards and the stapes outwards. These muscles are normally stimulated by reflex action to sounds of > 90 dB which last for longer than 10 ms. The effect of these muscles is to reduce low and medium frequency sounds by 30 dB.

The inner ear is a system of liquid filled canals, protected both mechanically and acoustically by being in the temporal bone of the skull. The cochlea is the part of the inner ear which contributes to the hearing process. It is a hollow coil of bone filled with liquid. It has a total length of about 40 mm and is divided along its length by the basilar membrane apart from a small gap at the end known as the helicotrema. The two main divisions of the canal are called the scala vestibuli and scala tympani. The oval window in the wall of the latter and the round window in the wall of the former. About 24000 nerve endings terminate in hair cells embedded within the basilar membrane. These hair cells are responsible for the frequency analysis of the vibration signal. The particular mechanism of the transformation from vibration energy to nerve impulse is the subject of debate beyond the scope of this thesis. Intense sounds can damage or destroy any of the moving parts of the ear, but when hearing damage results from prolonged exposure to high levels of noise, it is generally the hair cells that are damaged.

2.3 Characteristics of Normal Hearing

Otologically normal subjects have an amplitude hearing range of about 140 dB from the threshold of hearing, which is 20 μPa at 1 kHz, up to the threshold of pain where instantaneous damage or acoustic trauma can result. The range of frequencies which can be detected by the ear is roughly 20 Hz to 20 kHz. The ear is non-linear in both amplitude and frequency sensitivity; there is approximately 70 dB difference in the threshold of hearing between 3 kHz and 20 Hz. As the level increases the bandwidth of the ear generally increases. The threshold of hearing for normal subjects is shown in Figure 2.2.

In the midband region, where the ear is most sensitive, the minimum detectable sound pressure is only just greater than the pressure variation due to thermal agitation of the air molecules. This provides a noise floor for any hearing mechanism. Animals who can hear more than humans therefore do so as a result of greater bandwidth.

A significant problem in assessing characteristics of hearing is relating objective measurements to subjective responses. Attempts at obtaining objective responses are discussed later, but the techniques used are generally highly invasive in nature and are hence often used only in animal experiments.

As discussed earlier, the hearing process is extremely complex, and not fully understood, but some of the phenomena of hearing are of

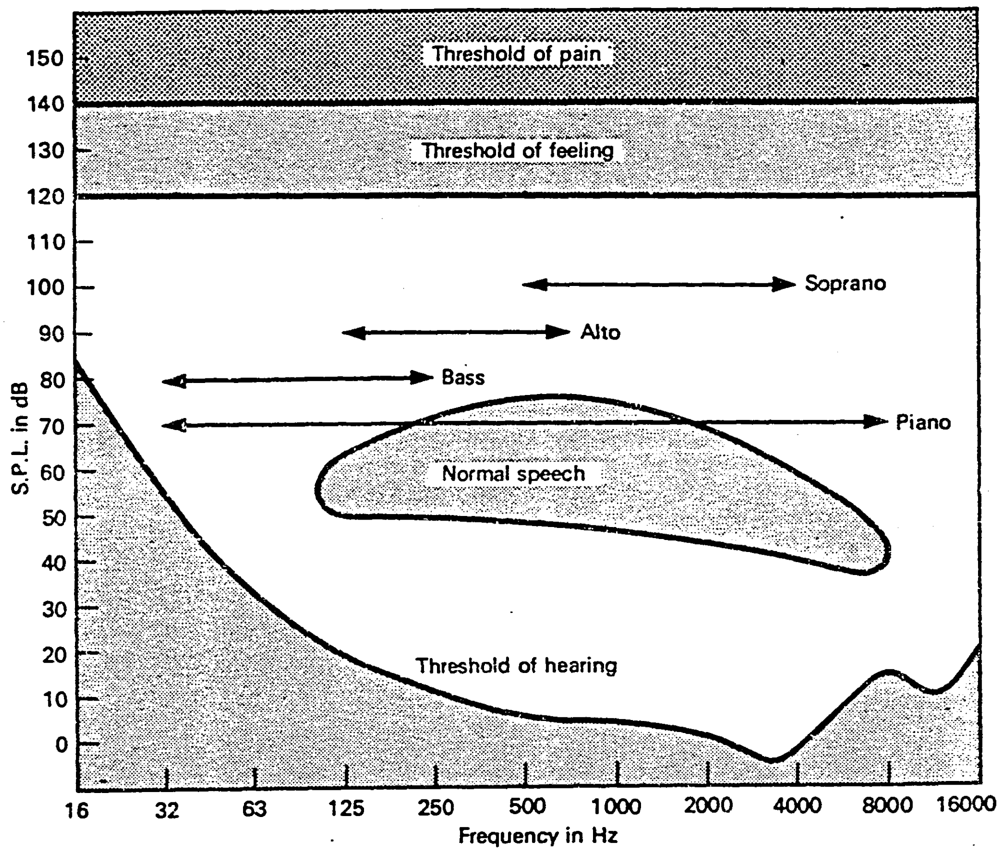

FIGURE 2.2 Threshold of Hearing for Normal Subjects

particular importance when designing a measuring instrument which is essentially trying to simulate the response of the human ear. The intensity of a sound is a precise physical quantity, capable of being defined analytically and measured practically. The subjective response to intensity, which is loudness, is a function of frequency as well as intensity. Equal loudness level contours are shown in Figure 2.3 .

The frequency selective hair cell process in the basilar membrane has critical bandwidths associated with its operation. This means that over a narrow bandwidth of input frequencies, exactly the same nerve stimulation will result from a particular input level. Further, if an input signal stimulates a number of hair cells, ie it has greater than the critical bandwidth, the loudness is greater than if the sound intensity were all within the critical bandwidth. This frequency weighting is also level dependant.

The equal loudness contours of Figure 2.3 do not represent a true loudness scale, ie equal increments in loudness level do not correspond to equal increments in subjective loudness. One true loudness scale has been determined by Fletcher [1] using the assumption that pure tones, of equal loudness, which stimulate different portions of the basilar membrane would have an additive effect. The perceived loudness of two such tones acting at once is taken as twice that of each individual component. The result of Fletcher's experiments is an empirical relationship between loudness level in phons and loudness in sones. The sone is the unit of loudness which is defined as being the loudness of a 1 kHz tone of 40 dB intensity level. This is equal to the loudness of any sound having a loudness level of 40 dB. A graph which summarises

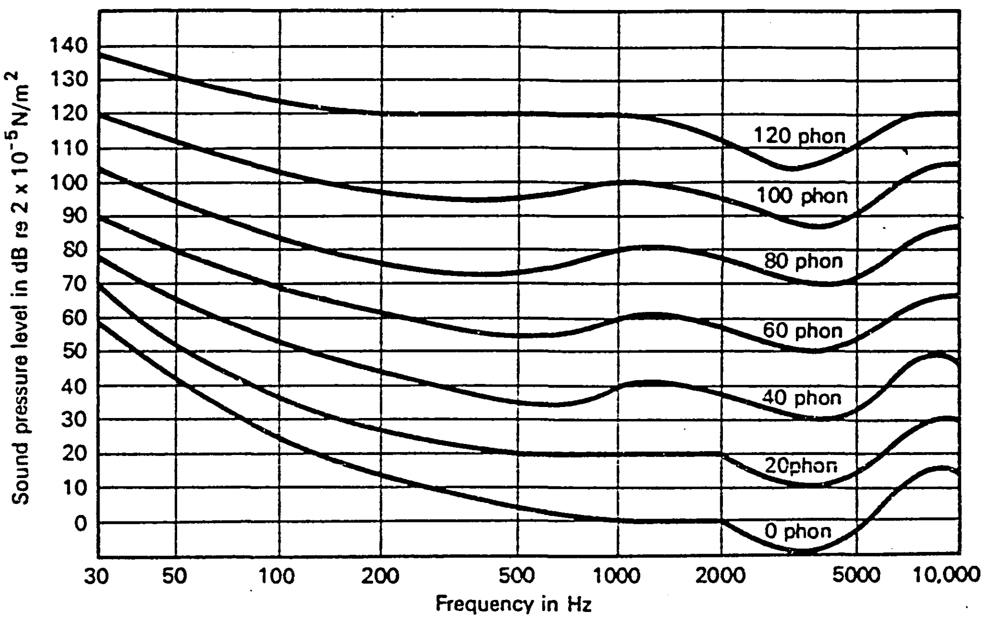

FIGURE 2.3 Equal Loudness Level Contours

the conclusions of Fletcher's work is shown in in Figure 2.4. The curve is represented by the following equation:

$$\log L = 0.033\,(LL - 40)$$
$$= 0.033\,LL - 1.32 \qquad (2.1)$$

where L is the loudness in sones

LL is the loudness level in phons

For a 1 kHz pure tone the loudness level in phons is numerically equal to the intensity level in dB:

$$LL = 10 \log \frac{I}{I_0}$$

where I is the intensity in Wm^{-2}

I_0 is the reference intensity of 10^{-12} Wm^{-2}

Therefore,

$$LL = 10 \log I + 120$$

Substituting this value of LL into equation 2.1 gives:

$$\log L = 0.033\,(10 \log I + 120 - 1.32)$$
$$= 0.33 \log I + 2.64$$

Therefore:

$$L = 445\, I^{0.33}$$

The subjective loudness L of a pure tone at 1 kHz therefore varies as the cube root of the intensity in Wm^{-2}. To achieve a doubling in subjective loudness, it is necessary to increase the sound power by a factor of eight.

In order to estimate the subjective response to a broad band signal the following procedure should be followed:

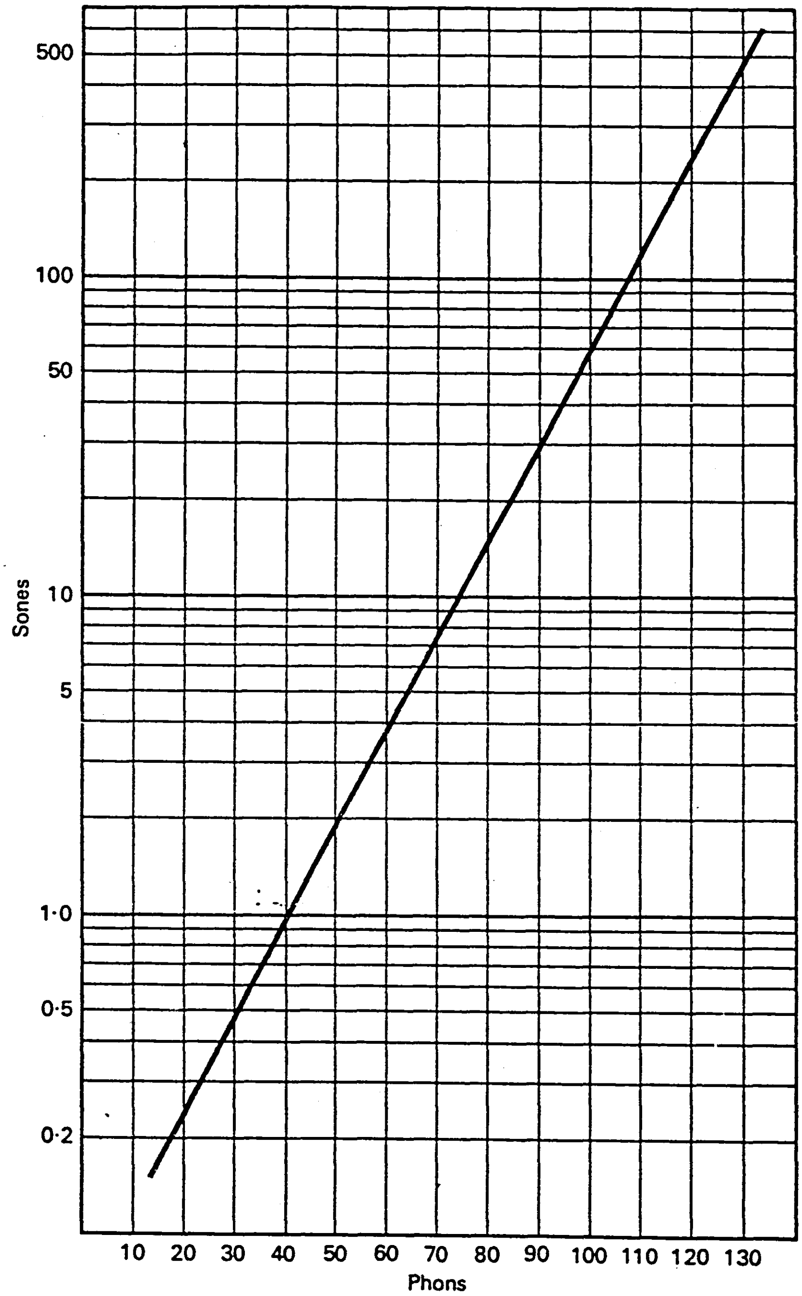

FIGURE 2.4 Relationship Between Sones and Phons

1 For each frequency component, or bandwidth less than the critical bandwidth, determine the loudness level in phons corresponding to the intensity level using the curves of Figure 2.3.

2 Use the empirical relationship of Figure 2.4 to determine the loudness levels in sones.

3 Add the individual values of loudness to determine the total loudness.

4 Use Figure 2.4 again to determine the overall loudness level in phons.

This is the intensity which a 1 kHz pure tone would need to have in order to produce the same apparent loudness.

A measuring instrument to measure loudness would be impractically complex as it would have to provide a continuously variable level and frequency sensitive weighting network. The generally accepted compromise is to use a sound level meter with a number of fixed frequency weighting networks which correspond to the response of the ear at different average sound levels. These are the A-, B- and C- weighting responses shown in Figure 2.5. Recent practice has been to rely almost solely on the A- weighting network for most noise measurements, independent of level. This is inconsistent with the risk of hearing damage predicted by the Equal-Energy Hypothesis discussed later in this chapter.

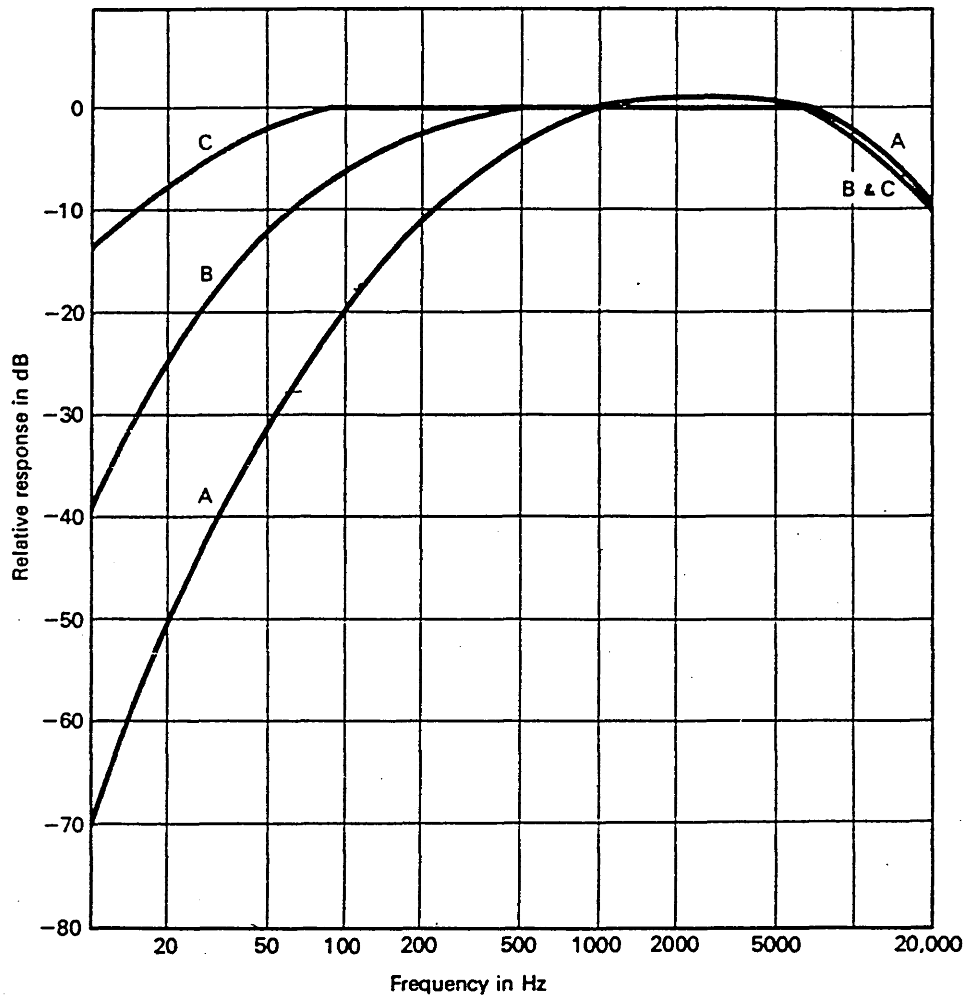

FIGURE 2.5 Frequency Weighting Curves

2.4 Hearing Defects not caused by noise

In attempting to analyse and validate theories which relate exposure to noise with hearing loss, it is important to determine the significance of the hearing loss. There are a number of natural causes of hearing defects which must be considered before ascribing a subject's hearing loss to noise exposure. Recent government legislation and codes of practice have encouraged companies to monitor their employees hearing on a regular basis, so that those with an initial hearing defect or with a particularly sensitive hearing mechanism can be identified and protected.

2.4.1 Presbycousis

The threshold of hearing for normal subjects, shown in Figure 2.2 represents the average threshold for adult subjects less than 25 years old with normal hearing. Presbycousis is the gradual degradation of hearing with age. It is characterised by a decrease in the hearing bandwidth at the high frequency limit. It is unclear whether presbycousis is a true ageing process or a noise induced hearing loss due to exposure to a normal acoustic environment. A survey of a primitive tribe who had been exposed only to low levels of environmental noise revealed that the typical hearing response of a 70 year old from this group had hearing acuity comparable with the average 30 year old American. It is usually very difficult to confidently separate the effect of presbycousis from any hearing loss which is noise induced.

2.4.2 Tinnitus

Tinnitus is characterised by a high-pitched ringing in the ear. Some people suffer from this condition permanently and as a result often have speech problems. The condition often occurs temporarily in most people, particularly after exposure to high noise levels.

2.4.3 Deafness

There are three identifiable classes of deafness : conductive, nerve and cortical.

Conductive deafness can result from thickening of the ear drum, stiffening of the joints of the ossicles or blocking of the external canal by wax. Bone conductive bypasses the defective elements and hence limits the hearing loss to between 50 and 55 dB, though this still represents a serious loss. Some causes of conductive hearing loss can be relieved by surgery. Otosclerosis which immobilises the stapes can be helped by fenestration, where a new window is introduced into the lateral semi-circular canals. Perforated ear drums which can be caused by disease or acoustic trauma may heal naturally or may be replaced by an artificial ear drum. Conductive deafness is characterised by an attenuation which is independent of amplitude.

Nerve deafness is due to a loss of sensitivity in the sensory cells in the inner ear or to a defect in the auditory canal. There is generally no cure and the hearing loss varies with frequencies.

Cortical deafness chiefly affects old people and is due to a defect in the brain centres.

2.5 **Noise induced hearing defects**

Immediate permanent deafness caused by noise is due to sound pressures of around 150 dB or greater. Such sound pressures are generally only the result of a blast or explosion, therefore a noise induced hearing loss is rarely caused traumatically. The more usual situation is for the hearing loss to occur gradually over a period of time with exposure level and duration being factors affecting the rate of loss.

2.5.1 Temporary and Permanent Threshold Shift

If a subject is exposed to a fairly high noise level the sensitivity of the hearing will reduce. This is determined by measuring the threshold of hearing at various frequencies and comparing these results with the average response of Figure 2.2. Unlike the effect of presbycousis which reduces the overall bandwidth, a noise induced threshold shift is normally observed. This threshold shift is almost invariably centred around 4 kHz, largely independent of the characteristics of the noise.

If sufficient time is allowed between exposures, the hearing recovers and the subject has suffered only a temporary threshold shift (TTS). However, if the exposure is repeated before the hearing recovers, and if the exposure is of a sufficiently high level, a permanent threshold shift (PTS) will result.

The initial dip in sensitivity at 4 kHz continues to increase for about 10 years. After this time the maximum hearing loss stabilises but the threshold shift then spreads out to affect a progressively greater portion of the hearing bandwidth. As discussed in section 2.2, the important speech energy of consonants is around the 4 kHz region and therefore these will be the first sounds to be affected. The widening of the affected bandwidth results in more and more of the speech energy being lost, with human speech becoming less and less intelligible.

2.6 Criteria for Assessing the Risk of Hearing Damage

Sound level meters with specified performance were available as long ago as 1944 [2]. Since that time it became apparent that there was a link between the duration and level of exposure in determining either the degree of TTS or PTS. Early animal studies led to an inconclusive debate about the relative importance of these two factors.

2.6.1 Equal Energy Hypothesis

The advent of the jet engine led to particularly noisy working environments for ground servicing personnel. These environments provided a focus for a number of research projects sponsored by the USAF. "Damage Risk Criteria" were proposed by Rosenblith and Stevens in 1952 [3]. The levels recommended by these criteria tended to be rather conservative as they were based on almost continuous exposure. A more realistic study which included the effects of short time exposure was published by Eldred, Gannon and Von Gierke in 1955 [4]. Although this work presented no specific results, it offered the work of Eldredge and Covell [5,6] as evidence to support the equal-energy hypothesis (EEH). The EEH is based on an exact equivalence between sound intensity and exposure duration, that is the total energy received by the ear is important, rather than the manner in which it was received. The work of Eldred et al was proposed as a code of practice for minimising hearing damage to the service personnel. In addition to the adoption of the EEH, it established 135 dB as the maximum exposure level for the unprotected ear on the basis that this represented the lower limit for the threshold of pain for subjects with tender ears.

The recommendations of this work were formally established in the United States by Air Force Regulation AFR 160-3, 1956. Other work [7,8,9,10,11] advanced arguments in favour of both the EEH and other intensity-exposure relationships. What was generally accepted was that the EEH would ensure better protection, particularly for exposure to impulsive noises. The exchange rate implied by the EEH is that a doubling of intensity or a doubling of exposure duration would lead to the same increase in received energy. The intensity is doubled by increasing the sound pressure by 3 dB, therefore the exchange rate implicit in the EEH is often referred to as 3 dB doubling. A number of pressure groups proposed different exchange rates. The Walsh-Healey Act (1969) formalised 5 dB doubling within the United States. Dixon Ward and Nelson [12] described the adoption of 5 dB doubling as being a "guesstimate" which was more political than scientific in nature.

Within the United States there remains a duality of standards for personal noise dosemeters, however, 3 dB doubling is universally accepted as being appropriate for integrating sound level meters.

In Britain, the route to adopting the principles of the EEH as part of noise legislation has been via the Wilson Committee Report (1963), which proposed various exposure damage risk criteria, and the "Noise in Industry" report of Burns and Robinson (1970). This lattter report formed a basis for the Code of Practice for Reducing the Exposure of Employed Persons to Noise (1972). The Health and Safety at Work Act (1974) was the legal instrument designed to enforce the principles of the code. These basic principles are a maximum of 90 dB, 8-hour equivalent continuous sound level (L_{eq}) and a maximum level of 135 dB for the unprotected ear, as proposed in 1955 by Eldred, Gannon and Von Gierke.

The only unresolved question relating to the EEH is what average intensity provides an acceptable risk of hearing damage. Most countries have accepted 90 dB as the maximum L_{eq} for an 8 hour day. Wealthier countries such as the United States and Sweden have reduced this level to 85 dB to minimise the risk for their workers. It is unlikely that there will be pressure to reduce exposure to less than this as there is evidence that no measurable hearing loss occurs as a result of exposure to sound levels of 80 dB and below. This is almost certainly due to masking by the normally occurring hearing degradation of presbycousis.

CHAPTER THREE

THE NATURE AND MEASUREMENT OF L_{eq}

Before the main body of the work on the design and evaluation of integrating sound level meters could begin, it was necessary to investigate the standard equation for L_{eq}, in order to understand how best to generate the constituent components of the L_{eq} function, and to determine whether an approximate solution based on numerical methods would be viable.

The standard equation for L_{eq} is defined by:

$$L_{eq} = 10 \log_{10} \frac{1}{T} \int_0^T \frac{P^2(t)}{P_0^2} \, dt$$

L_{eq} is therefore the mean value integral of the sound intensity expressed on a logarithmic scale. This can be contrasted with the equation for sound pressure level:

$$SPL = 20 \log_{10} \sqrt{\frac{\overline{P^2}}{P_0^2}}$$

The two functions are very similar, but the averaging time of sound level is one second or less. The averaging methods are also different; in that with sound pressure level, the averaging is an exponential function so that its integrating period is usually much less than the measurement period.

The long integrating capability implied in the L_{eq} equation is central to the value of L_{eq} in assessing the risk of hearing damage due to a varying noise climate. It is important for the integration to be continuous throughout the measurement period, as a short, high-level transient can form a large contribution to the final L_{eq} if the general level is low.

It is profitable to consider the general form of the mean value integral, as expressed in the mean-value theorem:

$$f(\xi) = \frac{1}{(b-a)} \int_a^b f(x)\,dx \qquad \text{where } a \leqq \xi \leqq b$$

This equation justifies the basis for L_{eq}, as it shows that a single value of the function, $f(\xi)$, can be used to represent the mean value of $f(x)$ over the integration range. In an ISLM, the function $f(x)$ is proportional to the sound intensity. The equation also shows that the mean value of the intensity corresponds to the actual value of the intensity at time ξ. In a typical noise pattern, the level may rise and fall many times during the integration period, so that ξ would probably correspond to a large number of elapsed times. Therefore the value of ξ has no physical significance for L_{eq} as it is generally a many valued function.

Reference to the block diagram of Figure 3.1 shows how the L_{eq} function can be constructed from basic analogue building blocks. The squaring element is performed by a combination of a logarithmic amplifier and an antilogarithmic amplifier. The input signal to the logarithmic amplifier must be unipolar, which explains the inclusion of the absolute value or precision full-wave rectifier stage. The square of the input signal can be integrated continuously with an analogue integrator to yield a stored value of the dose. A similar store representing the elapsed time can be constructed so that when the stored value of dose is divided by the stored value corresponding to the elapsed time and the logarithm of the quotient derived, the result is a representation of the L_{eq} of the input signal.

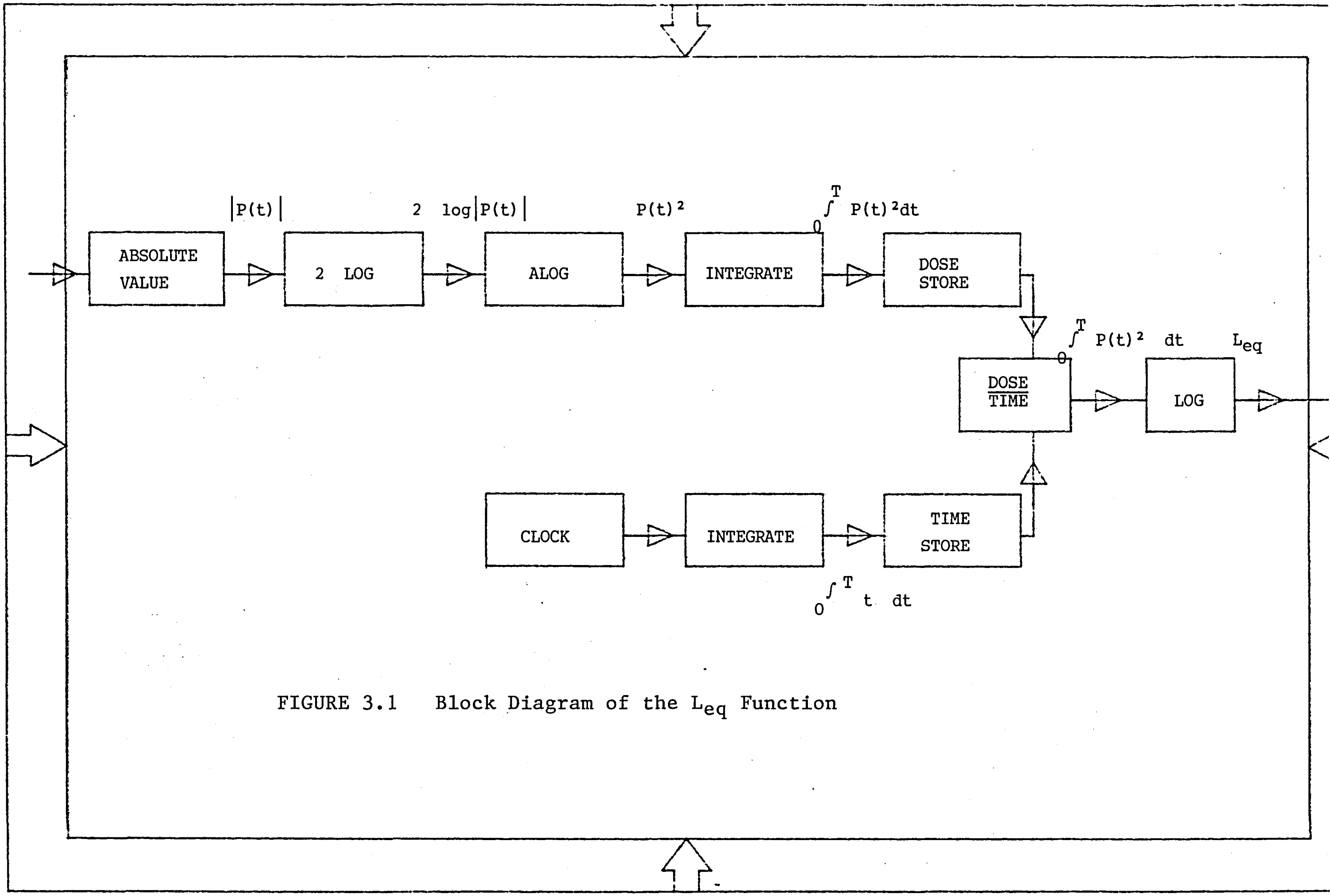

FIGURE 3.1 Block Diagram of the L_{eq} Function

The straightforward approach to generating L_{eq} when using analogue building blocks must be modified if an approximate solution is envisaged. If the input signal were digitized, the integration would have to be performed numerically. A good approximation can be gained by using Simpson's Rule for a range divided into n parts:

$$\int_a^b f(x)\, dx = \frac{h}{3}\{f_0 + f_n + 4(f_1+f_3+..f_{n-1}) + 2(f_2+f_4+..f_{n-2})\}$$

where n is the number of strips

h is the width of each strip

The two summation terms would represent very large numbers if a large number of samples were being integrated. This would generally be the case since, to ensure accurate resolution of a 24 kHz sinewave, which would be necessary for 1/3 octave frequency analysis, 10μsecond sampling would be required. The effect of an increasing number of samples on the store capacity needed to accommodate the summation terms would be to increase the storage length by one bit for each doubling of the number of samples. The conversion accuracy required to encompass the large dynamic range of industrial noise signals is approaching 20 bits. Therefore as the number of samples is increased, the size of digital stores required soon becomes extremely large.

The logarithmic conversion can also be performed using numerical methods. The usual method is to use a power series expansion as follows:

$$\frac{1}{2} \log_e \left[\frac{1+x}{1-x}\right] = x + \frac{x^3}{3} + \frac{x^5}{5} + \ldots \qquad \text{for } -1 < x < 1$$

To obtain the resolution which would be required for a precision grade instrument, a large number of terms would need to be evaluated. The dose integral could be a large number, and so the value of x in the power series expansion given above would be very close to unity. This leads to smaller differences between terms in the series and hence increases the number of terms which would need to be considered for a given resolution. Although the magnitude of the numbers involved would not be affected greatly by increasing the number of terms considered, it may lead to an increase in processing time for each logarithmic conversion.

When the plan of work was proposed, it was envisaged that significant advances in digital signal processing component technology would enable the difficulties outlined above to be overcome. The microelectronic industry has, however, tended to concentrate on the industrial controller microprocessors (microcontrollers), and there has been limited progress on the development of certain aspects of 8- and 16-bit microprocessors. A significant limitation of relevance to the present application was the lack of CMOS technology processors. The low power consumption of CMOS processors is essential to the development of a hand-held instrument. Thus it was realized that the section of the proposed plan which was concerned with total signal processing by the microprocessor would not be viable. Attention was therefore focused on the selective use of the microprocessor in a control function in those areas of the processing to which it would lend enhancement.

CHAPTER FOUR

EVALUATION METHODS FOR INTEGRATING SOUND LEVEL METERS

Integrating Sound Level Meters (ISLMs) are almost exclusively calibrated with a continuous input signal. This only confirms the meter's ability to measure sound pressure level, but tells nothing about the meter's ability to measure impulsive signals - the type of signals which require the use of an ISLM in place of a conventional sound level meter. When this work was started, there was no accepted method for testing ISLMs. Although this is still an issue for dispute, several proposals have since been put forward; one in particular was being considered in draft form for issue by the International Electrotechnical Commission (IEC) as an international standard. This has been issued subsequently as IEC 804.

In the absence of any standard, it was decided to test and evaluate ISLM designs using electrical signals substituted in place of the microphone, and to construct specialized signal sources so that these electrical signals would quantify certain parameters of particular relevance to the measurement of L_{eq}. Shortly after this time the Health and Safety Executive (HSE) proposed a draft standard for ISLMs as part of a commercial tender on behalf of H.M. Factory Inspectorate. The testing procedures embodied in this draft standard are broadly the same as those which had been considered previously for use in this work. The HSE-produced draft standard was therefore adopted so that results produced as part of this work could be compared readily with results from tests perfomed by the HSE and any other researchers who adopted the HSE draft standard. The principles embodied within the HSE draft standard subsequently formed a substantial part of IEC 804 draft standard referred to earlier. Constant interaction with the HSE and other professional acousticians at meetings and conferences has allowed the ideas resulting from this work to contribute to the current, and proposed, national (UK & USA) and international standards.

Instruments which generate the parameter L_{eq} are integrating sound level meters, so as well as performing tests to ascertain the amplitude linearity in the same way as with a conventional sound level meter, the integrating function of the meter must also be checked. The trading relationship between sound pressure level and time is usually referred to as the exchange rate. For an ISLM based on the Equal- Energy Hypothesis, the exchange rate is 3 dB. This means that for a constant value L_{eq}, if the measurement duration is halved, the sound pressure level must be increased by 3 dB, and conversely, if the measurement duration is doubled, the sound pressure level must be reduced by 3 dB. This is often referred to as 3 dB doubling.

It is usually overlooked that the value of 3 dB is derived from $10 \log_{10} 2$, which is more precisely 3.01 dB. This discrepancy is of little significance when dealing with conventional sound level meters with a fairly restricted dynamic range, but over the extended dynamic range of an ISLM, the discrepancy could exceed the measurement tolerance allowed. However, an exact relationship between measurement duration and level does exist, which is that an increase in measurement duration of an order of magnitude is equivalent to a decrease in level of 10 dB, and vice versa, since $10 \log_{10} 10 = 10$. It is this latter relationship which is employed in the tests described in this work.

For a single range instrument operating under the fairly well controlled environmental conditions of a laboratory, there are three basic parameters which characterize the performance of a particular ISLM.

These are the dynamic span, the exchange rate tolerance and the peak factor capability. These parameters are detailed below:

4.1 Dynamic Span

The dynamic span is a measure of the range of signal amplitudes and frequencies which can be applied to an ISLM so that it is capable of calculating L_{eq} to within a certain tolerance. Four different grades of instrument are recognized in the HSE draft standard in accordance with IEC 651, the consolidated revision of the sound level meter standards, these are designated Types 0, 1, 2 and 3; the different grades being required to respond with different accuracies and over different frequency ranges, as shown in Table 4.1.

ISLM Type	0	1	2	3
Frequency range	20Hz-16kHz	20Hz-12.5kHz	31.5Hz-8kHz	31.5Hz-8kHz
Within indicator range (dB)	±0.4	±0.6	±0.8	±1.5
Outside indicator range (dB)	±0.8	±1.0	±1.5	±3.0

TABLE 4.1 Dynamic Span Tolerances

The test procedure consists of applying a sinusoidal input signal of frequency within the range specified for the particular grade of meter to be tested. The amplitude of the input signal is adjusted in fine increments, say 0.1 dB, and the meter reading is noted after it has stabilized to better than 0.2 dB for Type 0 and 1 meters, better than 0.5 dB for Type 2 meters, and better than

1.0 dB for Type 3 meters. To test the linearity of the dynamic span above the indicator range, a sequence of tone bursts isused to give a value of L_{eq} within the indicator range. The dynamic span is then the difference in r.m.s. levels, expressed in decibels, between the upper and lower signal levels within which the tolerances of Table 4.1 are met. The dynamic span required for the different grades of instrument are shown in Table 4.2.

ISLM Type	0	1	2	3
Dynamic span (dB)	70	60	50	40

TABLE 4.2 Dynamic Span

For reasons discussed in Chapter Five concerning electrical circuit design, the higher frequencies usually present the greater problem to ISLMs, so in order to determine whether a particular meter satisfies the standard for its specified grade, testing would normally begin at the higher frequencies. However, to determine the performance characteristics of an ISLM over the whole range of input signal amplitudes and frequencies is very time consuming, so a restricted frequency range will probably have to be specified in an international standard for abbreviated testing of a meter's dynamic span.

4.2 Exchange Rate Tolerance

A test which is much quicker to perform, and does not require the use the use of expensive 0.1 dB step attenuators, is the exchange rate tolerance test. As described earlier, this test is based on the equivalence of a change in signal duration by an order of magnitude and a change in signal level of 10 dB. A specially constructed tone burst generator is used to alter the mark/space ratio of the signal. The signal amplitude is adjusted accordingly so as to maintain a constant value L_{eq} input.

Initially, a reference is established, using a continuous sinusoidal input of frequency 6 kHz, at a level 10 dB above the lowest point of the indicator range or the lowest point of the dynamic span, whichever is the higher. A sequence of tone bursts of 6 kHz sinusoids is then substituted at such a level as to give an input L_{eq} of identical value to that of the continuous signal. The readings obtained with the tone burst input should differ from the reference level by no more than the tolerances specified in Table 4.3. In this table there are two values corresponding to each tone burst duration and instrument category. The upper figure is that proposed by ths HSE and the lower figure is that adopted by IEC 804.

Intermediate mark/space ratios may be used to check that the exchange rate tolerance does not exceed that of the next higher ratio. Such a test would help reveal any non-linearities in the meter's response; a task which the exchange rate test can perform more speedily than the continuous signal linearity test.

The HSE standard demands that the tone bursts used in the exchange rate test should be of such a duration as to "ensure that there are no limitations incurred as a result of peak factor limitations". The peak factor test and the difference between peak and non-peak category meters will be explained fully in the next section, however it is necessary that in the peak factor test, tone bursts

ISLM Type		0		1		2		3	
Category		Peak	Non-Peak	Peak	Non-Peak	Peak	Non-Peak	Peak	Non-Peak
Input Signal	Relative Amplitude								
Tone Burst mark/space 1:9	+ 10 dB	± 0.2 ± 0.5	± 0.2 ± 0.5	± 0.2 ± 0.5	± 0.2 ± 0.5	± 0.3 ± 1.0	± 0.3 ± 1.0	± 0.3 ± 1.0	± 0.3 ± 1.0
Tone Burst mark/space 1:99	+ 20 dB	± 0.4 ± 0.5	± 0.4 ± 0.5	± 0.4 ± 0.5	± 0.6 ± 1.0	± 0.6 ± 1.0	± 1.0 ± 1.5	± 1.0 ± 2.0	
Tone Burst mark/space 1:999	+ 30 dB	± 0.6 ± 0.5	± 1.0 ± 1.0	± 0.6 ± 1.0		± 1.0 ± 1.5			
Tone Burst mark/space 1:9999	+ 40 dB	± 0.8 ± 1.0		± 1.0 ± 1.0					
Tone Burst mark/space 1:99999	+ 50 dB	± 1.0 ± 1.0							

TABLE 4.3 Exchange Rate Tolerance

have a duration between 1 millisecond and 1 second for peak meters, and between 200 milliseconds and 1 second for non-peak meters. Since the maximum amplitude signal used in the peak factor test is always 10 dB less than the corresponding maximum amplitude signal used in the peak factor test for a particular grade of instrument, it is assumed that if tone bursts used in the exchange rate test are not shorter than those used in the peak factor test, then the previously mentioned criterion will have been met.

It has been suggested that a further factor of ten times should be allowed by restricting the minimum exchange rate test tone burst to ten times the minimum peak factor test tone burst. This appears to be misunderstanding the usefulness of the exchange rate test. As well as confirming that a meter integrates according to the correct function, the exchange rate test also checks the impulse linearity of the meter over the lower section of the dynamic span, which the peak factor test fails to do.

The test frequency of 6 kHz used for the exchange rate test was probably chosen as it roughly coincides with the second frequency where the Linear and A-weighting network responses coincide; the first crossover frequency being 1 kHz, previously used in the sound level meter tests. As the frequency for the tests is not exactly the frequency where the two networks' responses coincide, there would appear to be little significance in its value, other than ensuring that if an ISLM is fitted with A-weighting response only, the full range of input signal amplitudes can be applied without overloading the input stage.

A tone burst of six complete cycles of 6 kHz provides the 1 millisecond tone burst duration required to test the peak category meters. Tone bursts of single cycles of 6 kHz have been used in some of these tests, but such tests are outside the scope of the draft standard.

It is important that although the tone bursts are of 6 kHz sinusoids, the overall frequency spectrum of the input also includes frequencies corresponding to the period of the tone burst and the period between the bursts. Thus the instrument is being subjected to a fairly broad-band input. A typical input signal is shown in Figure 4.1 and the corresponding frequency analysis is shown in Figure 4.2. It is clear that the exchange rate test is a fairly comprehensive one, providing information about many aspects of ISLM performance.

4.3 Peak Factor

Reference was made earlier to two categories of ISLM within each grade of instrument, namely peak and non-peak meters. The only difference between these two categories is in their capability to respond accurately to short duration input signals. The peak category meter's response is limited to signals having an amplitude which is considerably less than the upper extreme of its dynamic span.

The non-peak category ISLMs appear to be irrelevant, as the only advantage they have over the next lower grade of peak meter is a slight increase in frequency range and a marginal improvement on some of the test tolerances specified. Non-peak category meters have not been incorporated into IEC 804.

The peak factor test is performed by applying a single burst of

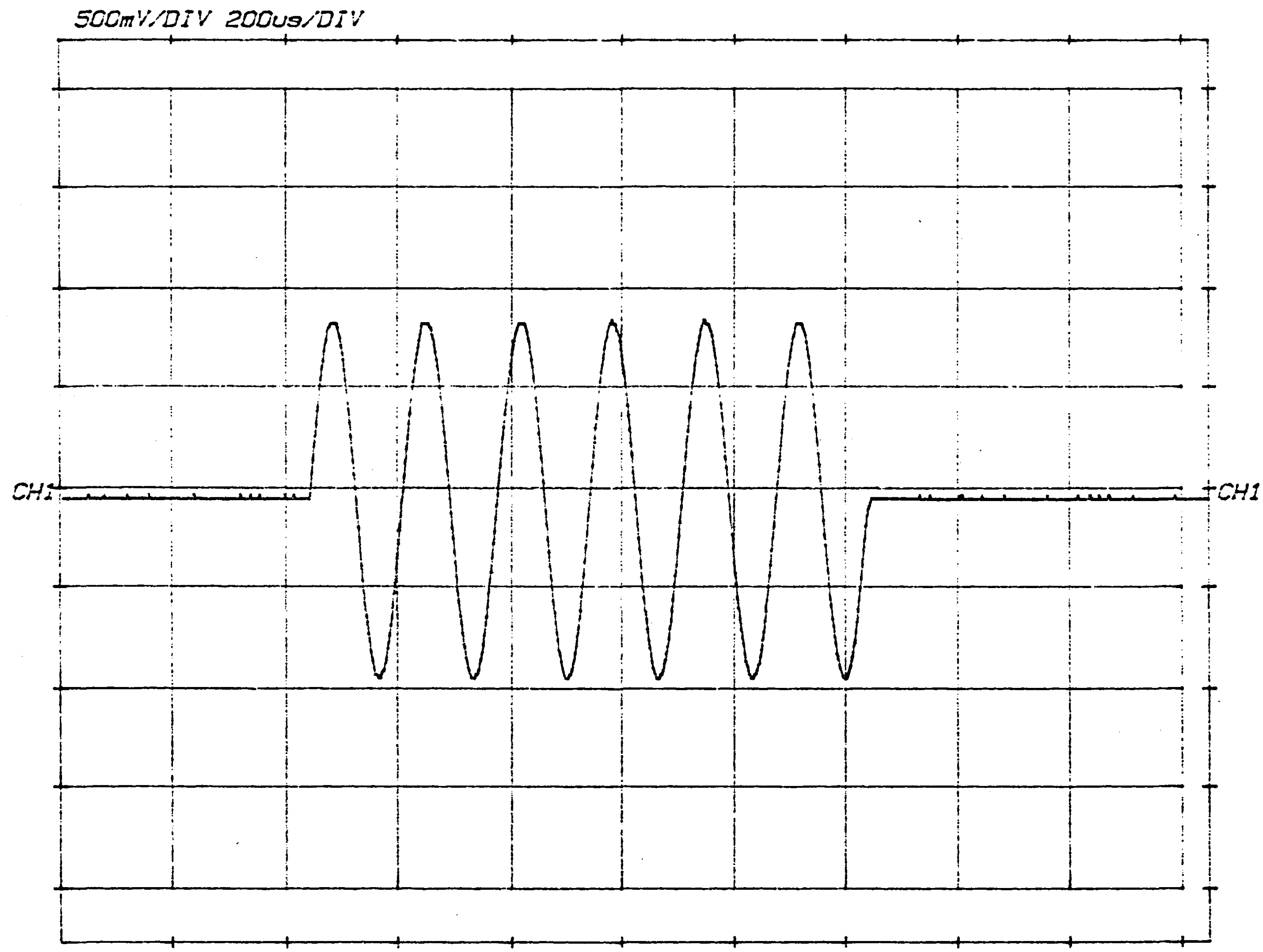

FIGURE 4.1 Tone Burst Used in Exchange Rate Test

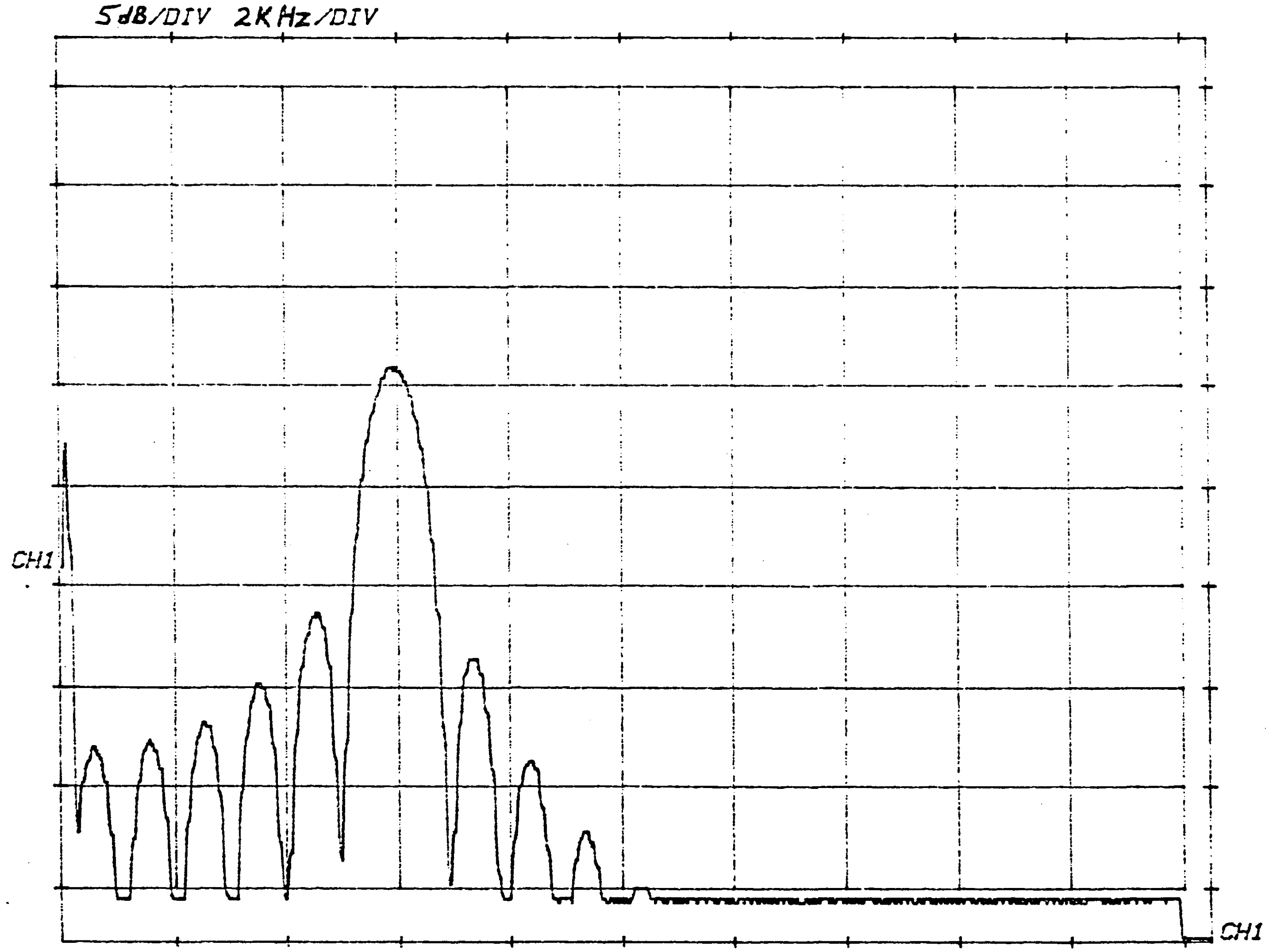

FIGURE 4.2 Input Spectrum for Exchange Rate Test

6 kHz sinusoid in the presence of a background of a continuous sinusoidal signal with a frequency of 6 kHz set to a level corresponding to the lower limit of the dynamic span. The background and the tone burst have to be in phase, as shown by the example waveform of Figure 4.3. The period of the tone burst should be, as mentioned earlier, between 1 millisecond and 1 second for peak meters and between 200 milliseconds and 1 second for non-peak meters.

The amplitude of the tone burst is increased in 1 dB steps until the indicated L_{eq} differs from the calculated L_{eq} by more than 0.5 dB (0.8 dB(A)) for Types 0,1 and 2, and 1.0 dB (1.0 dB(A)) for Type 3 meters than that permitted by the linearity tolerances. The ratio of the peak value of the lowest amplitude tone burst which reaches this limit to the r.m.s. level of the background signal is the peak factor for the particular ISLM. The peak factor test is normally performed with the ISLM set to Linear response, but some meters may be fitted with A-weighting only and this accounts for the increased tolerance shown in brackets. The peak factor capability required for the various grades and categories of meters are shown in Table 4.4.

ISLM Type	0	1	2	3
Peak category (dB)	73	63	53	43
Non-peak category (dB)	40	30	25	20

TABLE 4.4 Peak Factor Capability

The peak factor test not only quantifies the maximum level of short

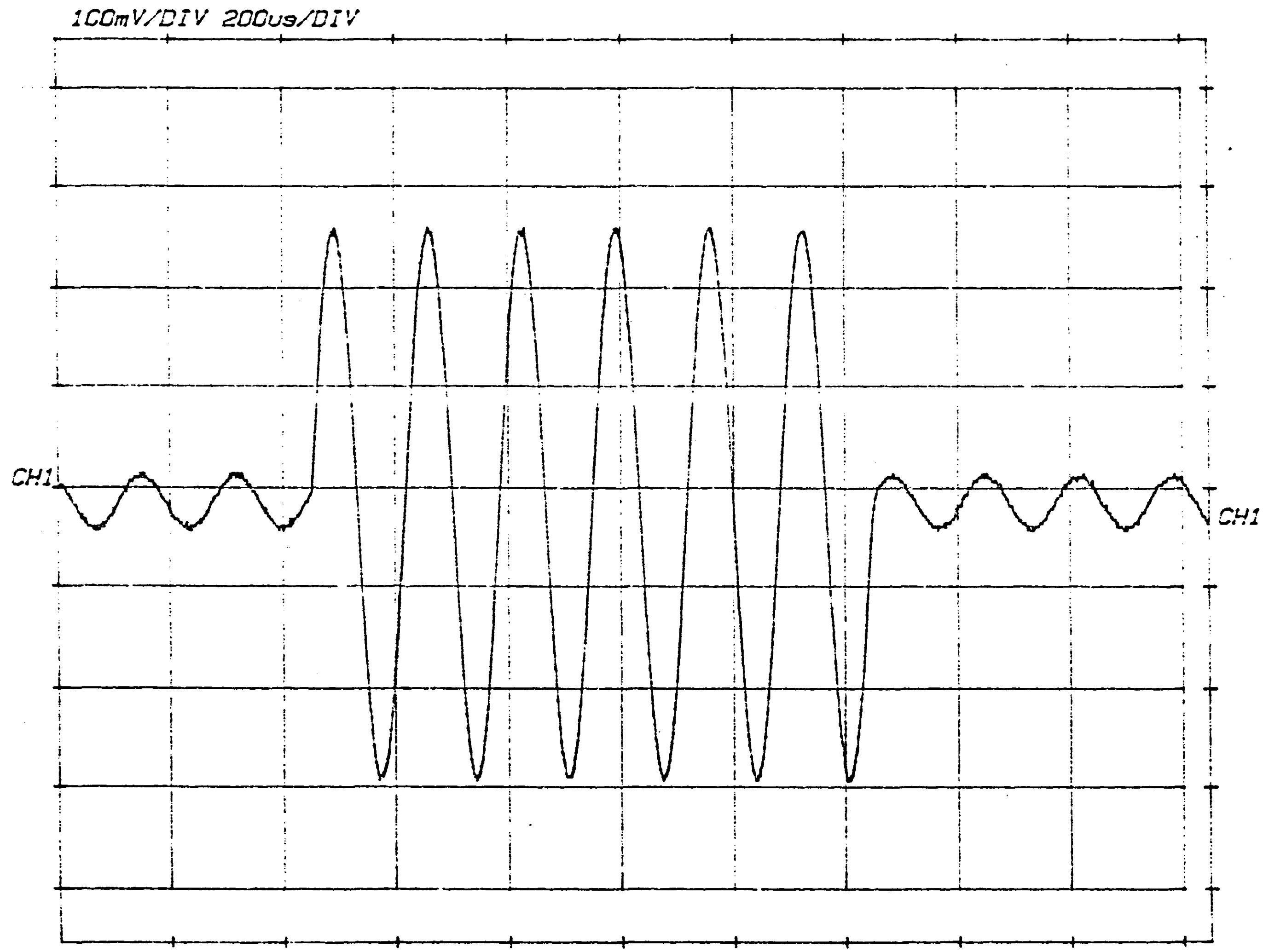

FIGURE 4.3 Tune Burst Used in Peak Factor Test

duration signal that the ISLM can measure, but also checks the impulse linearity over the upper section of the dynamic span. The test is difficult to perform on the non-peak meters due to the limitations of the tone burst duration and peak level. The non-peak meters do seem to be of limited use, providing little increased measuring capacity over a conventional sound level meter.

CHAPTER FIVE

DESIGN AND DEVELOPMENT OF AN ANALOGUE INSTRUMENT

The function L_{eq}, as discussed in the chapter on the evolution of L_{eq}, is the logarithm of a mean-value integral of the square of the sound pressure. As a result of the available expertise within the collaborating body, it was decided to investigate methods for generating this function using analogue techniques. It was realized that any meters or individual circuits developed as a result of this investigation could be used for comparison with designs embodying digital techniques, a development expected to form an extension of the basic work.

The squaring part of the function is usually formed by generating twice the logarithm of the input voltage, usually referred to as 2logV, and then antilogging the resultant current to give a final output current proportional to the square of the input voltage. Having the output in the form of a current is very convenient as it is easily integrated using a conventional Miller integrator. Unfortunately, it is only possible to construct a logarithmic amplifier which operates in one quadrant; this means that the input voltage and the reference must both be unipolar. The conversion from bipolar to unipolar input signal for the 2logV-alog stage is performed by an absolute value circuit.

5.1 Absolute Value Circuit

The absolute value circuit is a full-wave rectifier which avoids the usual forward voltage drop of a simple diode by incorporating it in the feedback loop of an operational amplifier. The forward voltage drop of this combination is the forward voltage drop of the diode divided by the open-loop gain of the operational amplifier;

which is considerable at low frequencies. An added advantage of placing the diode in the feedback loop of the operational amplifier is that the exponential forward conduction characteristic of the diode is linearized. The operation of the absolute value circuit, shown in Figure 5.1, is fully described elsewhere, but the heart of the absolute value circuit, which is the precision half-wave rectifier shown in Figure 5.2, needs to be considered in order to understand the limitations of the circuit. Diodes D1 and D2 change the feedback arrangement of A1 for different polarities of input. It is in the switching of diodes D1 and D2 that the problems arise, particularly with the combination of low signal level and high frequency. There is a deadband around zero resulting from the limited slew rate and gain in A1, and from capacitance and charge storage effects in the diodes. This deadband is a result of the finite time taken for A1 to swing through two diode voltage drops. The operational amplifier's limitations and the effects of the diodes, which compound the operational amplifier's problems, can cause this transition to be comparatively slow and hence introduce considerable distortion into the signal. An example of an input signal with its correctly formed absolute value trace is shown in Figure 5.3, and a sequence of absolute value traces, obtained using a constant low level input of increasing frequency is shown in Figure 5.4. The distortion of the waveform, even at modest frequencies, is quite evident, and this distortion would lead to a lower value of the energy integral and hence an underestimation of L_{eq}.

There are several ways of reducing the problems outlined above:

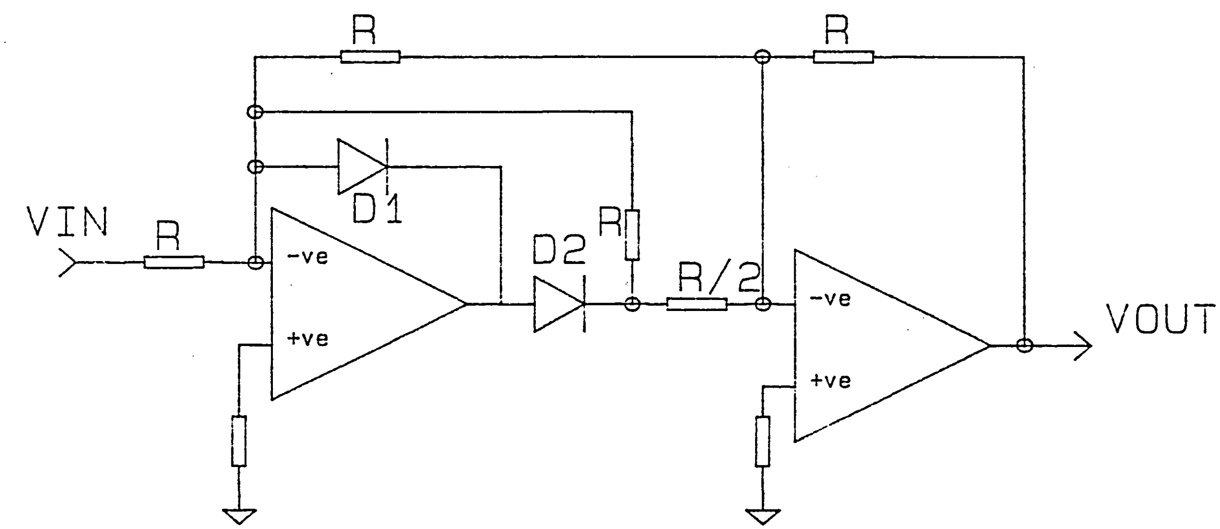

FIGURE 5.1 Absolute Value Circuit

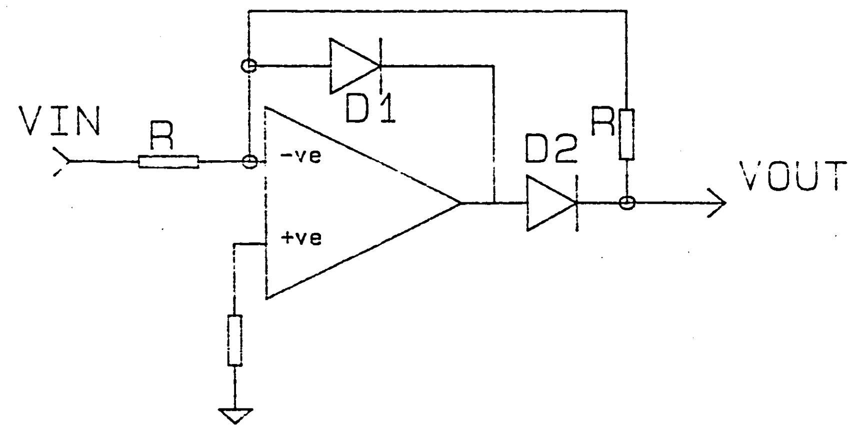

FIGURE 5.2 Precision Half-Wave Rectifier

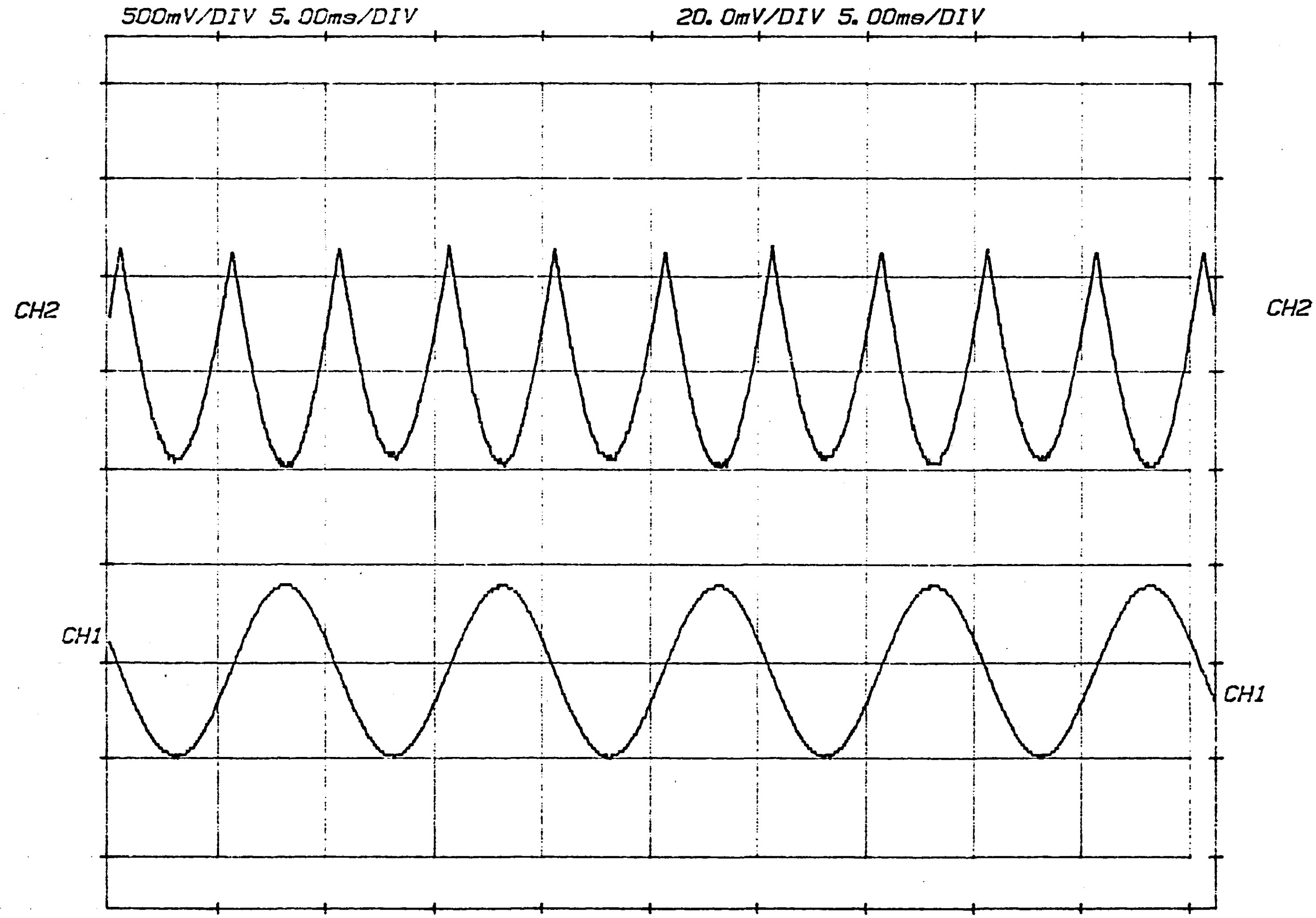

FIGURE 5.3 Input Signal (CH1) and Absolute Value (CH2)

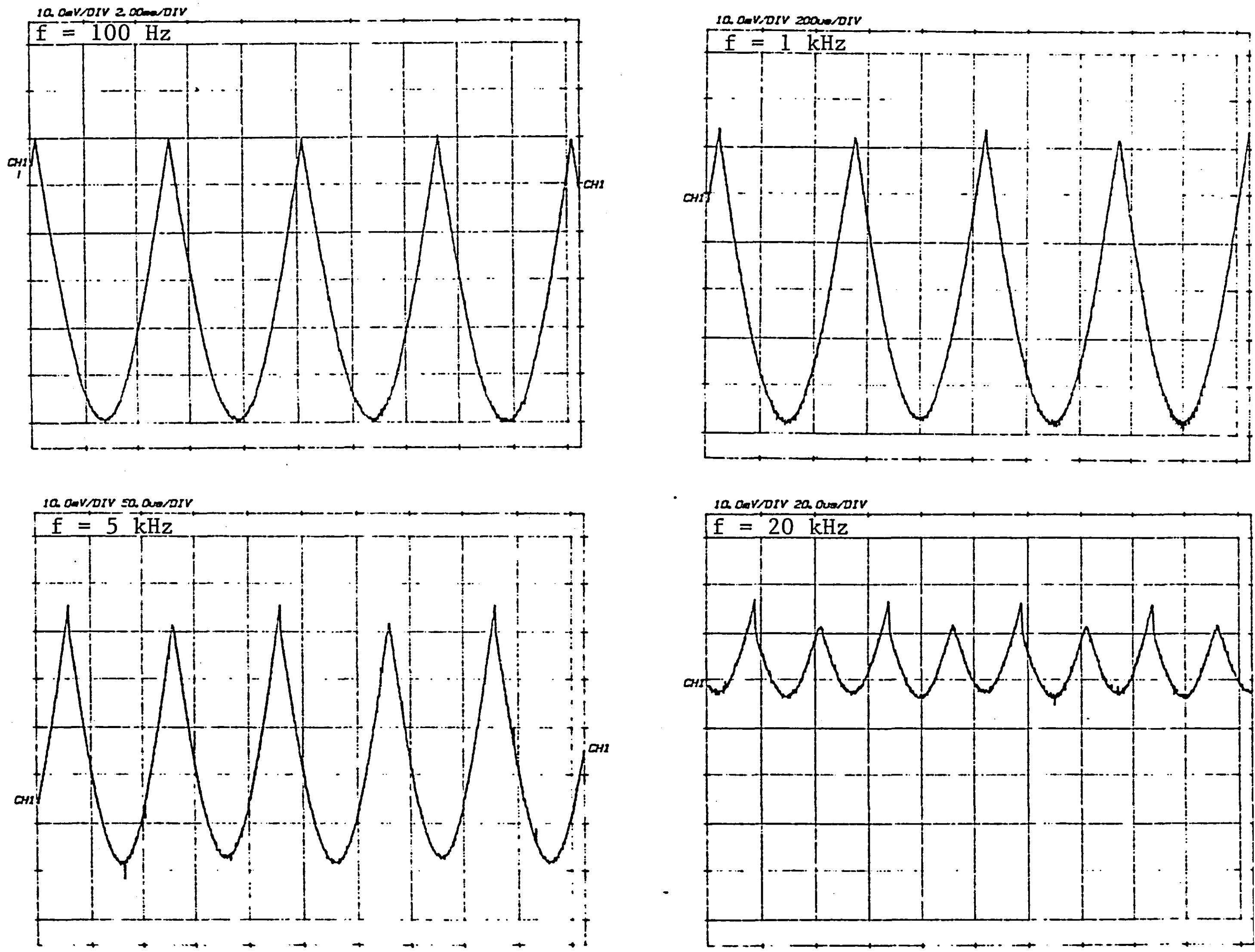

FIGURE 5.4 Performance of Absolute Value Stage as a Function of Frequency

1. A1 is chosen to have a high gain-bandwidth product and a high slewing rate.

2. Diodes D1 and D2 are chosen to have low reverse leakage, low forward voltage drop and a very short reverse recovery time.

3. The frequency compensation for the operational amplifier is carefully designed so as to keep the bandwidth as high as possible.

Initially, a fairly standard operational amplifier, an LM 301A, was used for A1, and 1N914 diodes were used for D1 and D2. Satisfactory performance was obtained at frequencies up to 100Hz, but severe shortcomings were apparent at higher frequencies.

To boost the gain-bandwidth of the operational amplifier, a complementary transistor stage was inserted between the operational amplifier and the diodes, as shown in Figure 5.5. The standard diodes were replaced by Fairchild FD700 computer diodes, chosen for their fast reverse recovery time. With the increased amplifier bandwidth and the improved diodes, it was possible to achieve about a 60 dB dynamic range at 10 kHz, however the circuit tended to oscillate and introduced a significant time delay. It became clear by using this circuit that in general, to achieve a larger dynamic range demands the use of higher static currents in the amplifier stage.

The LM 301A and transistor booster stage was therefore replaced by an operational amplifier with a high gain-bandwidth and high output current capability, an RCA CA3130 substituted for A1. This gave a 70 dB dynamic range at 2 kHz and between 60 dB and 70 dB at 20 kHz.

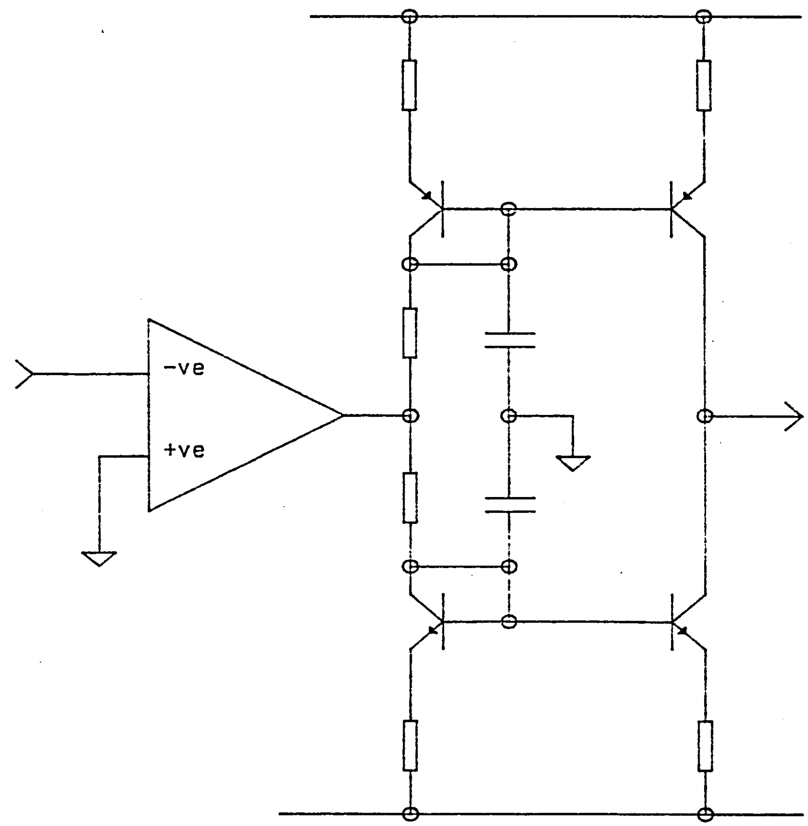

FIGURE 5.5 Complementary Transistor Booster Stage for Absolute Value Circuit

Unfortunately the CA3130 was running very hot as it was drawing 16.5 mA from the power rails, which is far too high for an instrument intended to run from battery power.

Changing the CA3130 to an exotic, that is expensive, Harris 2625 operational amplifier brought the current consumption down to under 5 mA and increased the stability of the circuit. The dynamic range at 2 kHz was now in the region 70 dB to 80 dB depending on how accurately the circuit was set up, and at 20 kHz the dynamic range was in the region 50 dB to 60 dB. One of the problems with the circuit was the phase error introduced. This becomes more apparent if the precision half-wave rectifier is coupled to a second operational amplifier to complete the full-wave rectification.

An application note from National Semiconductor [13] explains how their LM 108A family of operational amplifiers can be given higher gain at high frequencies by using a type of frequency compensation which they term feedforward compensation. The advantage of this type of compensation is that it allows the use of an operational amplifier with a low static current drain, typically 300 µA, but increases the standard gain-bandwidth of the operational amplifier by eliminating some relatively slow PNP transistors from the signal chain at high frequencies. At the same time as changing to this amplifier configuration, a number of different diode families were also considered. The most successful family tested was the Hewlett Packard range of hot carrier diodes.

The hot carrier diode is a very close approximation to an ideal diode; it has essentially zero forward voltage drop, an extremely fast reverse recovery time due to the absence of minority carrier charge storage and the only trade-off between different members of the family is reverse leakage versus forward resistance.

An optimized version of the absolute value circuit is shown in Figure 5.6. An LM 308A was used for A1 and A2 and the hot carrier diodes with the best compromise of parameters to give minimum gain error and maximum dynamic range were the Hewlett Packard 50822835. The amount of feedforward compensation in the final circuit is significantly larger than recommended in the application note, particularly in view of the 20 pF and 3.3 pF speed-up capacitors, but the pulse response of the circuit is not important in this application.

The dynamic range of the optimized circuit was about 90 dB at 6 kHz, falling to about 70 dB at 20 kHz; which is consistent with the performance required for a Type 0 meter, and significantly in excess of other published performance.

5.2 The Squaring Circuit

Having converted the input signal to unipolar form with the absolute value circuit, the squaring operation can be performed using the 2logV-alog stage mentioned in the introduction to the circuit design. The basic circuit is shown in Figure 5.7. The operation of the circuit relies on the logarithmic relationship between collector current and base-emitter voltage of a bipolar junction transistor. In this particular circuit, there are two transistors in the feedback loop of the operational amplifier to give a voltage at the emitter of Q2 which is twice the base-emitter voltage of a single transistor. Figure 5.8 shows the a.c. component of the waveform at this point (CH2) resulting from an

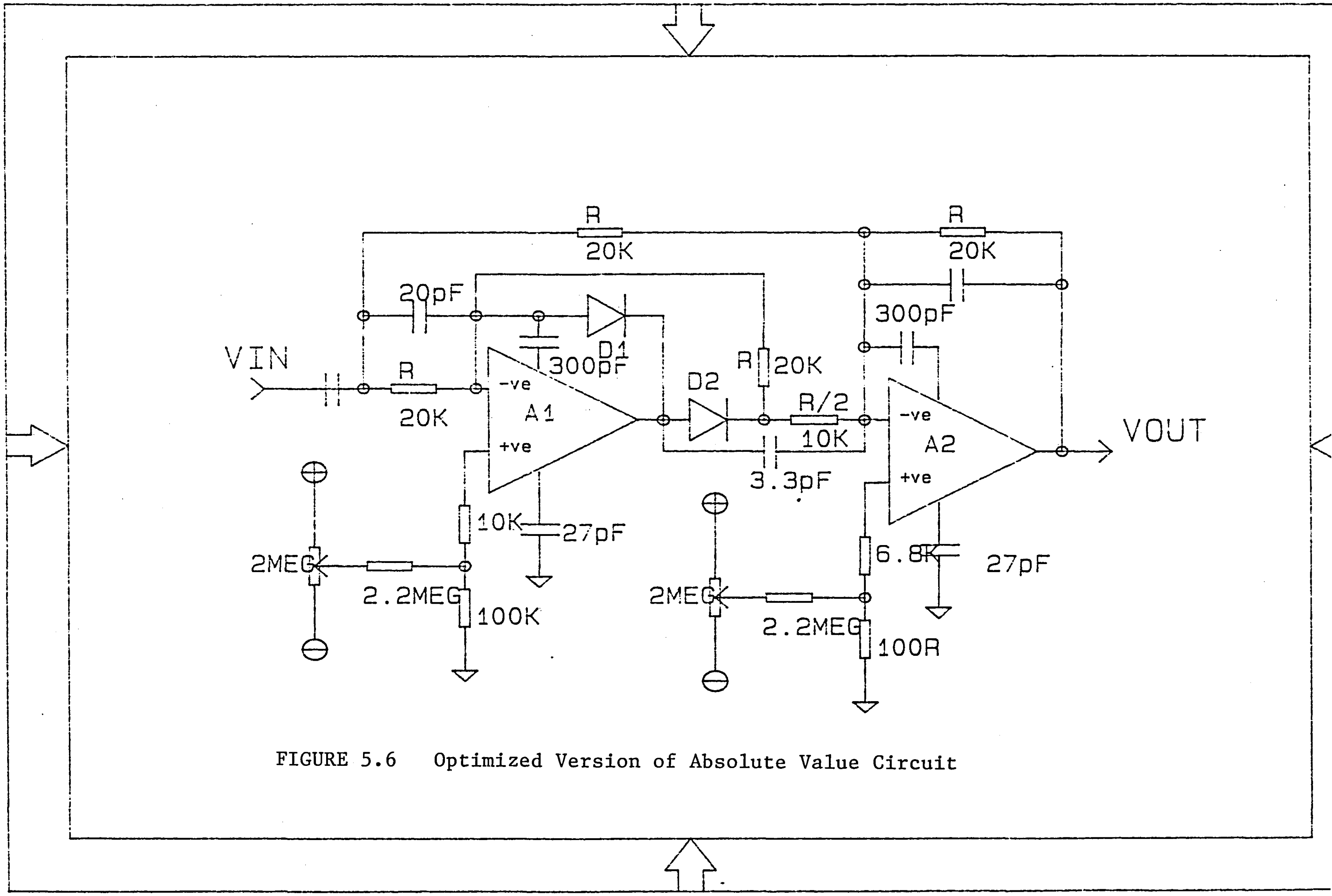

FIGURE 5.6 Optimized Version of Absolute Value Circuit

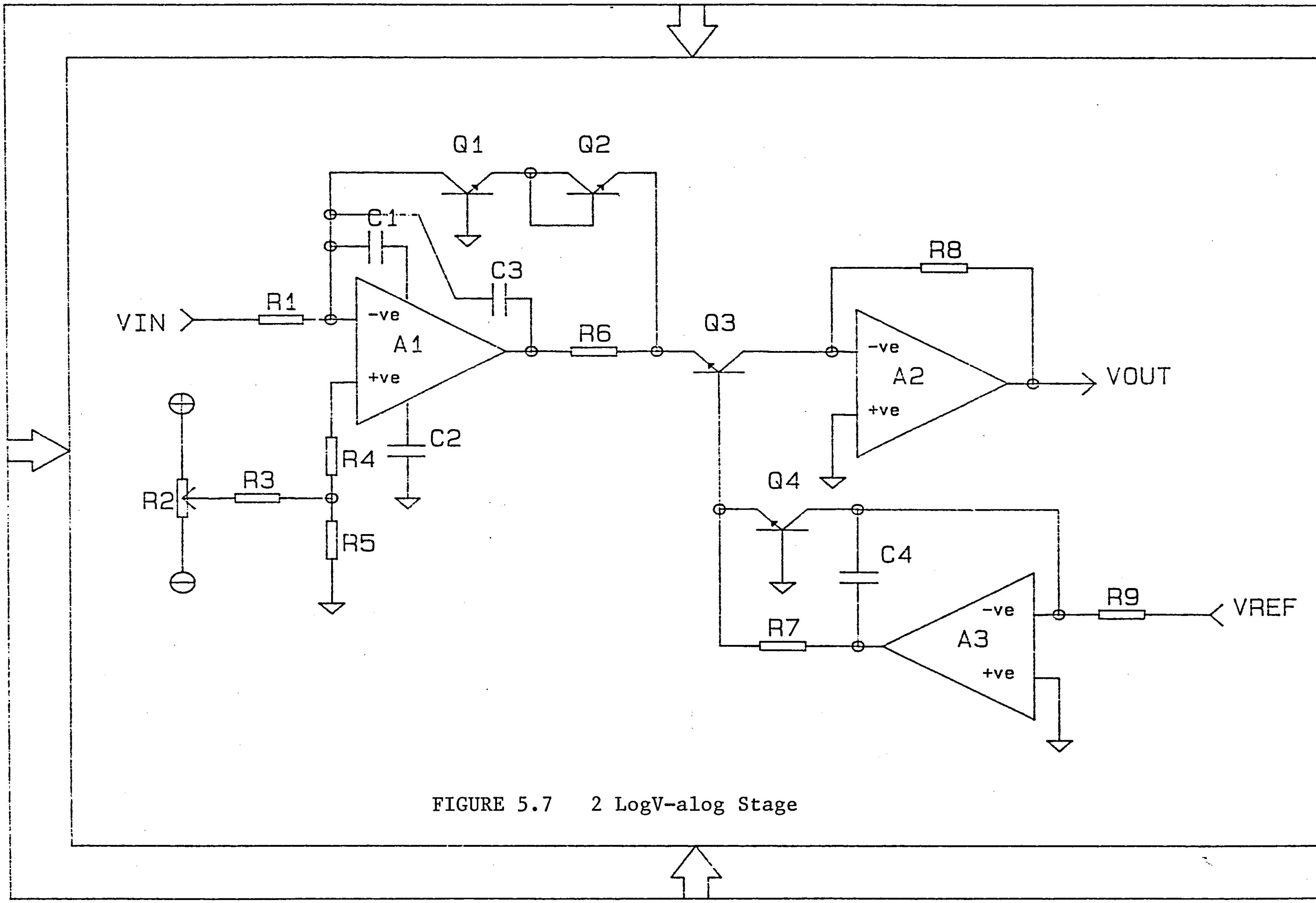

FIGURE 5.7 2 LogV-alog Stage

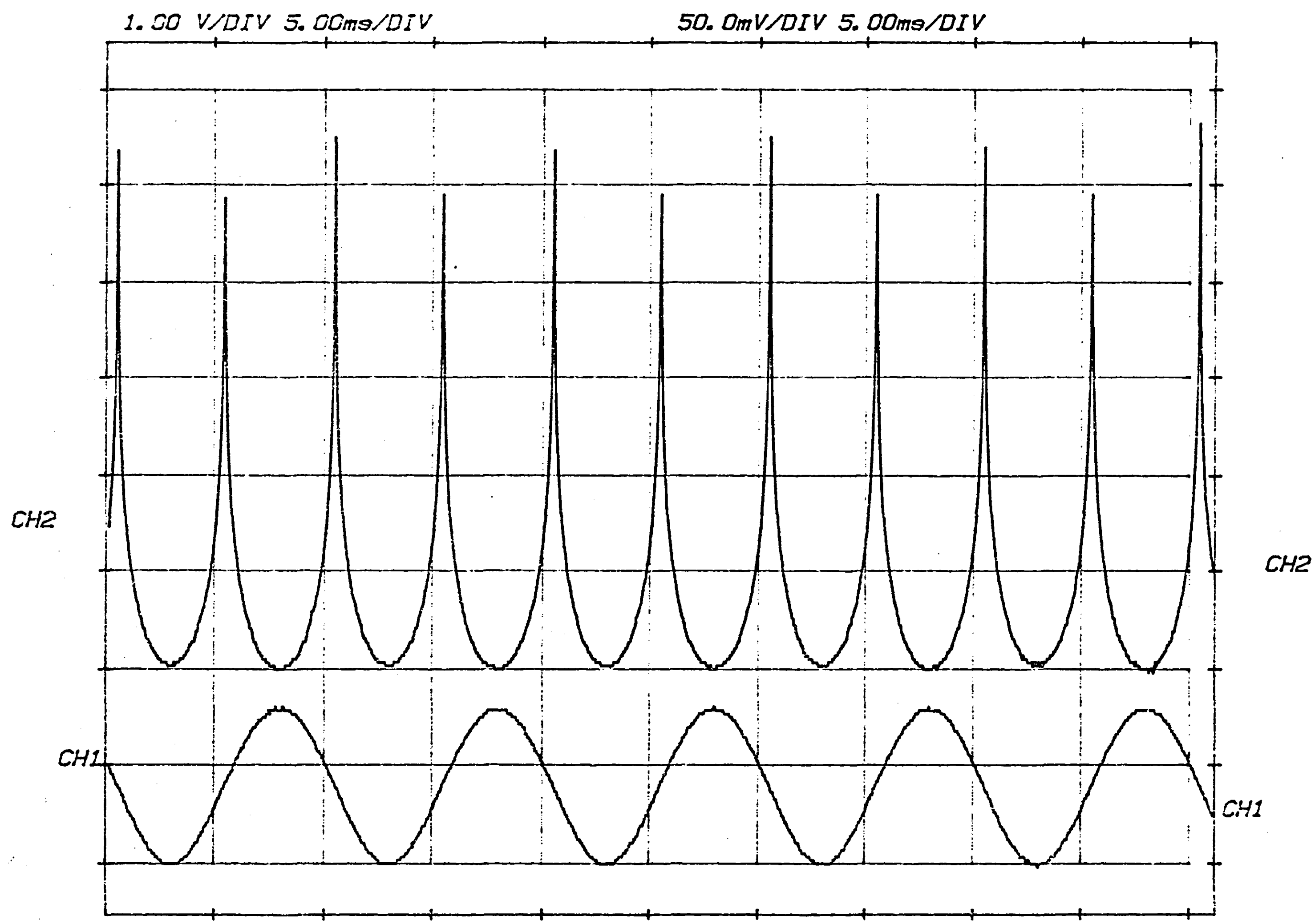

FIGURE 5.8 A.C. Component of 2 log V Signal (CH2) Resulting from Input Signal (CH1)

input signal of 100 Hz (CH1). The current drawn into the antilogging transistor, Q3, is therefore proportional to the square of the current passing through the logging transistors, Q1 and Q2.

A serious problem of logarithmic amplifiers, used to good advantage in semiconductor temperature transducers, is that the relationship between collector current and base-emitter voltage is highly temperature sensitive. This is due to two temperature sensitive components of the characteristics as shown below:

$$v_{be} = \eta V_T(\ln I_c - \ln I_s)$$

where

v_{be} is the base-emitter voltage

η is a device constant

V_T is the thermal voltage, given by $V_T = \frac{kT}{q}$

k is Boltzmann's constant

T is the absolute temperature in kelvin

q is the electronic charge

I_c is the collector current

I_s is the reverse saturation current

There is a temperature sensitive scale factor, ηV_T, and a temperature sensitive offset term, $\eta V_T \ln I_s$. The offset term is compensated for by feeding a constant current via Q4 and Q3 into A1. Q1-4 are identical types contained in a monolithic transistor array, so the current through Q4 and Q3 will match and thermally track the offset term of Q1 and Q2. The current into the collector of Q3 is therefore the antilogarithm of the combined base-emitter voltages of Q1 and Q2, but with the four offset terms exactly cancelling.

The constant current into Q4 and Q3 determines the scale factor, effectively the base of the logarithm, and the use of a transistor array helps overcome the problems of temperature sensitivity by the close thermal tracking of the devices. Initially, a simple resistor from the positive supply rail was used as the constant current source, but the seven decade range of collector current for Q3 resulted in large gain changes for Q3 which altered the reference current and hence the scale factor. This problem is overcome in the circuit of Figure 5.7 by supplying the reference current to the virtual earth of an operational amplifier so that the reference is stable, and so that any excess base current demands for Q3, as a result of gain changes, can be supplied from A2 without altering the scale factor.

The device selected for A1 was an LM 308A, as it had to overcome the problem of switching the transistors on and off at high frequencies and low signal levels. As in the absolute value circuit, the optimum performance was obtained with frequency compensation well in excess of the standard value. The performance requirements of A2 are that it should have as small an input offset voltage as possible, but more importantly, it should have a low input bias current. Both these requirements are so that the small reference current is not affected. The reference current is of the order of 1 μA, so the input bias current should be significantly less than this, over the full operating temperature range of the L_{eq} meter. A BIFET operational amplifier type TL062IN from Texas Instruments was selected as it has the lowest input offset voltage over the temperature range, coupled with the low input bias current of a JFET input.

With the circuit of Figure 5.7 coupled to the circuit of Figure 5.6, so that the summing function of A2, Figure 5.6, is replaced by A1, Figure 5.7, the dynamic range for accurate generation of 2logV-alog was in excess of 70 dB. This refers to the range of input signals, as the range of collector currents was therefore 140 dB or seven decades.

5.3 The Dose Integrator

The integral of the square of the sound pressure with respect to time, a measure of the total energy received by the microphone, is usually referred to as the dose. The operating requirements of an L_{eq} meter intended for use in measuring industrial noise impose stringent requirements on the performance of the dose integrator. These are that the 140 dB range of input currents should be capable of being integrated over a period at least as long as the working day. The two possible extremes of dose are a high level signal occurring for a long period, and a low level signal requiring to be resolved after a short measurement period. The limitation in the former case is the finite capacity of any integrator, and in the latter case it is the problem of ensuring that the integrator output can be resolved with a sufficiently high degree of accuracy. A combination of these extremes, where a high level signal occurs for a short period but the total measurement period is long, demands the use of an integrator with very low leakage and drift.

The linearity of better than 0.1 dB, about 1%, over a wide range of integrator speeds is also required for oscilloscope timebase generators, but typically in this case the input current is used to vary the speed over one decade only with one particular integration capacitor. In the case of the L_{eq} meter though, the speed of the integrator is a function of the varying voltage produced by the microphone, and therefore the integrator must be ready to respond at any speed within its capability.

A conventional analogue integrator, consisting of a capacitor in the feedback loop of an operational amplifier, has obvious limitations on its performance, particularly on its ability to integrate a constant current for long periods, due to finite power supply voltages, and in its ability to generate slow ramps with high precision, due to operational amplifier limitations and inevitable leakage currents.

Having constructed an analogue integrator using the latest, low input current operational amplifiers in combination with low leakage capacitors, it became clear that these limitations would preclude the design of an instrument which relied solely on analogue techniques. The development of the logarithmic amplifier, which would be needed as the stage following the integrator to complete the instrument, was postponed, so that attention could be focused on digital techniques for providing the required storage capacity.

CHAPTER SIX

EXTENSION OF THE PERFORMANCE OF THE ANALOGUE INSTRUMENT USING HYBRID TECHNIQUES

The circuits which were developed as part of the analogue instrument programme provided a sound basis for the design of a hybrid L_{eq} meter. The advantages to be gained by using digital techniques to store the dose information are that large amounts of data can be stored, and that the data is not corrupted so long as the power supply is maintained.

The combination of the digital store with the analogue signal conditioning which precedes it, needs to overcome the limitations of generating a slow ramp with high precision and integrating over long periods. In particular, the digital store should not introduce extra limitations due to quantization errors.

Many of these limitations can be overcome by the use of a novel technique, developed as part of this work, which effectively increases the maximum integration period, or allows a medium speed integrator to generate extremely slow ramps.

One way to overcome the problems of integrator drift and leakage would be to use the integrator as a sweep generator whose sweep speed is determined by the input current. This current to frequency converter would then have to be coupled to a digital store so that the dose information would remain stable so long as the power supply were maintained. To understand the difficulties associated with such a scheme, it is necessary to quantify the operating range of the current to frequency converter. To obtain accurate readings on the L_{eq} meter at the bottom end of the scale, it is necessary to have the linearity extend to about -5 dB relative to scale zero. If readings are required in a relatively short period, say 10 seconds, then a minimum of 10 counts would have to have been placed in the digital store to give 10% resolution, about 1 dB. At the top end of the dynamic span, again allowing a 5 dB margin to ensure linearity, the sweep speed would be increased by 70 dB, ie by a factor of 10^7, giving a maximum sweep frequency of 10 MHz. The problems associated with designing a sweep generator to operate over this frequency range would be immense, particularly at the 10 MHz sweep frequency, where the retrace circuitry would have to discharge the integration capacitor in the order of nano-seconds, to minimize the loss of dose information. In the new approach, the advantage of the semi-infinite store of the digital system is coupled with the advantages of a continuous analogue integrator to produce a system with any predetermined capacity, but which has a completely continuous output.

For an instrument with a 60 dB dynamic span, the variation in integrator speeds is in the ratio 10^6:1, however about an extra order of magnitude is required in the design of such an integrator to ensure linearity at the extremes of the range, and to allow for tolerance in components and other practical considerations. The maximum current which the integrator of a battery powered instrument can be expected to operate at is of the order of milliamps. This places the bottom end of the range in the nanoamp region. To make a practical integrator using an operational amplifier, the input bias current must be an order of magnitude lower than this; which therefore suggests the use of a FET input operational amplifier.

Due to finite power supply voltage available, the integrator has a finite maximum integration time. Once the upper limit for current has been set, the maximum integration time is a function of the value of the capacitor only. The dielectric leakage of the capacitor must be less than the input bias current of the operational amplifier in order to realize the full potential of the integrator. If a maximum integrator of 9 volts is assumed, the leakage resistance of the capacitor must at least be of the order of 10^{12} ohms. This puts an upper limit on the value of the integrator capacitor which can be used in practice. Typically, a polystyrene or teflon capacitor of about 0.47 μF is used. With the maximum current set at 1 mA, a maximum integrator output voltage of 9 volts and an integrator capacitor of 0.47 μF, the maximum integration period works out to be about 4 milliseconds, using CV=IT. Clearly this is nowhere near long enough for use as the sole means of integration in an L_{eq} meter, where a maximum integration period of 8 hours would be more typical. Provision has therefore been made in the integrator design to reset the integrator when the output reaches a present threshold. Each time the integrator is reset, a shift register is incremented so that no information is lost; each count corresponding to an identical value of energy having been stored on the capacitor.

If the conditions at the other extreme of the input range are considered, where the input current is 10^6 times smaller, the maximum integration period works out as 4000 seconds, or about 1.1 hours. Even if no readings were required from the L_{eq} meter with a continuous bottom scale input before the end of an 8 hour measurement period, there would only be seven counts in the shift register, which corresponds to an uncertainty in the final answer of about 8 dB. Means must therefore be provided to use the information from the integrator and the shift register so that accurate readings can be obtained within periods short in comparison with 8 hours. It is in the method of combination of these data which improves on the conventional integrator alone or on a current to frequency converter and shift register where only data from the shift register is used. The section of the instrument which performs the necessary combination and equalization is called the auto-ranging ladder network.

6.1 Auto-ranging Ladder Network

The information stored in the shift register is stable so long as the power supply is maintained and there is no breakthrough from other circuits. Therefore, when a significant number of counts have been incremented into the shift register, drift on the integrator can largely be ignored. It is the function of the auto-ranging ladder network to optimize the output from the shift register so that the information from the integrator can be utilized, but so that when sufficient counts have been accumulated in the shift register, the variation in output due to integrator drift is minimized. When decoding purely digital information into analogue form, the most common system employed is an R-2R ladder network. The advantage of such a ladder network is that the R-2R network uses only two values of resistance, whereas the values of the binary weighted resistor network vary over a very wide range, making matching and tracking very difficult. The price paid for using the R-2R ladder network is that it requires twice as many resistors for a given number of bits in the network.

The operation of the conventional R-2R ladder network is based on the current into each bit on the ladder splitting equally, half going towards the output of the ladder and half going towards the base of the ladder. This current splitting is repeated at every node where a new bit on the ladder joins, and gives the correct weighting to each bit on the ladder.

Since the least significant bit (LSB) on the ladder is equivalent to the integrator capacitor being completely charged, any method of combining the shift register output and the output from the integrator must maintain this equivalence. It can be seen by reference to Figure 6.1, that both ends of the ladder network are terminated by 2R resistors, one end to ground and the other to the virtual earth of the operational amplifier. If the 2R resistor terminating the ladder to ground is connected to a low impedance point having a voltage which is completely variable between 0 and $+V_{ref}$, then it can be shown that the output of the operational amplifier can be continuously varied between 0 and $+V_{ref}$, using this low impedance voltage source and the bits of the ladder network. Further, it is clear that there is no detectable different in operational amplifier output between having the low impedance voltage at $+V_{ref}$ with the LSB off, or having the low impedance voltage source at ground with the LSB on.

Referring to Figure 6.2, with the low impedance voltage source V such that $0 \leqq V \leqq V_{ref}$ and all the ladder bits off, the voltage at node n is:

$$V_{node\ n} = V.\frac{1}{3}.$$

Since the impedance looking down the ladder or towards the LSB switch is 2R. The voltage at node 1 is:

$$V_{node\ 1} = V.\frac{1}{3}.\frac{1}{2^{n-1}},$$

Hence the ouput voltage is:

$$V_{out} = V.\frac{1}{3}.\frac{1}{2^{n-1}}.\frac{3}{2} = V.\frac{1}{2^n}.$$

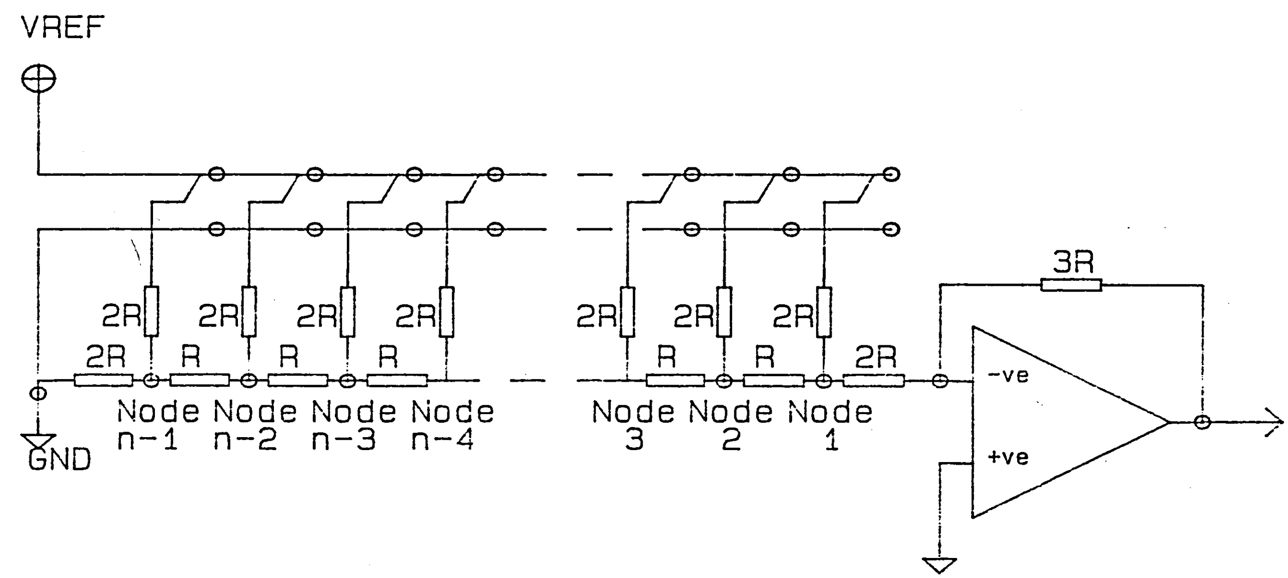

FIGURE 6.1 Conventional R-2R Ladder Network

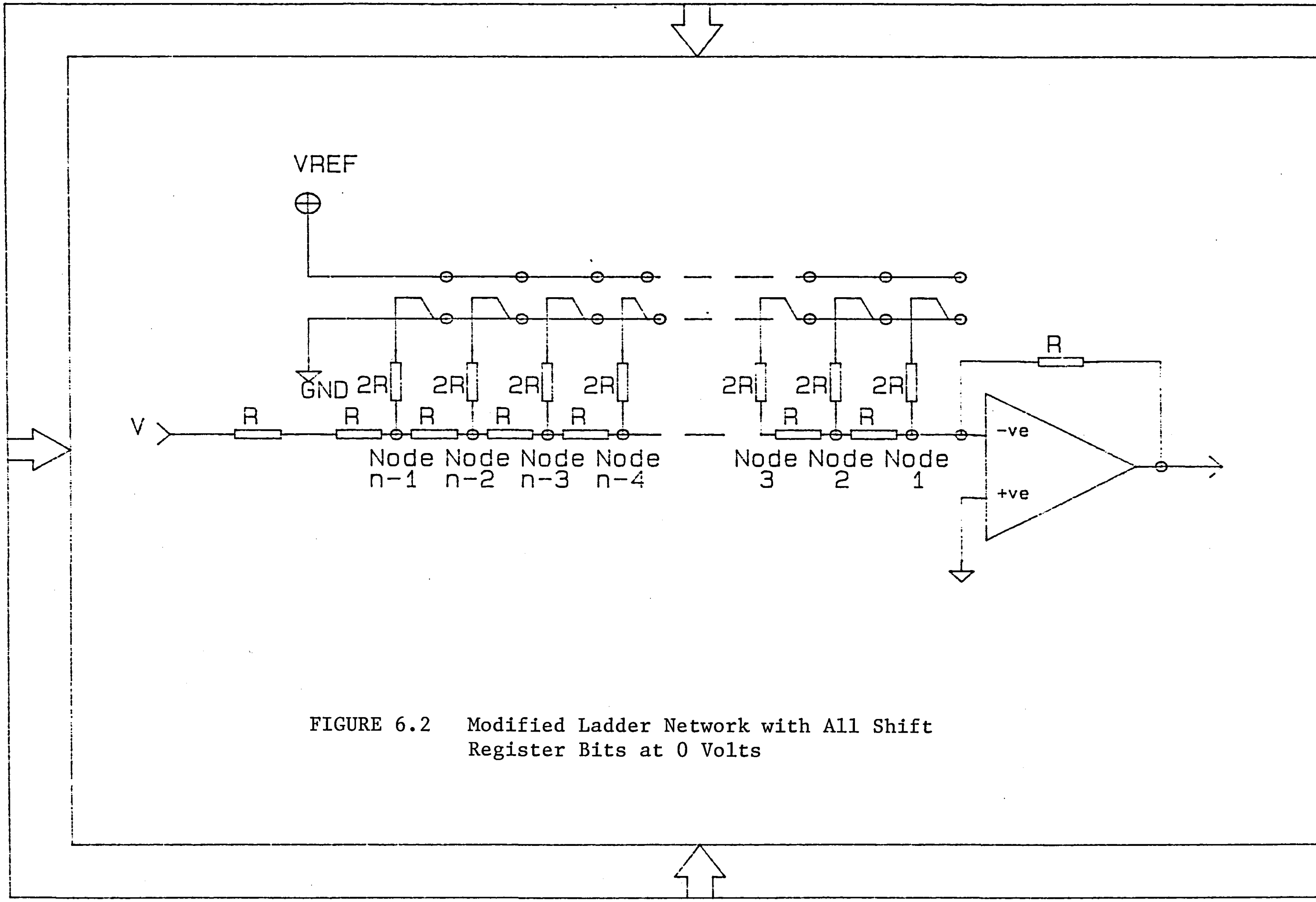

FIGURE 6.2 Modified Ladder Network with All Shift Register Bits at 0 Volts

Therefore the low impedance voltage source has the same weight as the LSB. As the integrator ramps up, is reset and the shift register incremented, the output of the operational amplifier increases monotonically and linearly as though the limitations of the integrator were increased by a factor 2^B, where B is the number of bits in the ladder.

The dynamic range of current from the ladder network is a function of the number of bits in the ladder and the required resolution of the analogue integrator's output. Typically, in a system where the extension of the analogue integrator is to be used to best advantage, this range of current will be large. It is likely that any stage which follows the ladder network will have an input signal dynamic range capability which is significantly less than the dynamic range which the integrator and shift register can produce. This mismatch problem can be overcome by restricting the range of current from the ladder to that which the following stage is capable of handling, and then compensating at a later stage.

The modifications required to be able to control the current from the ladder involves a fundamental change to the way in which the current is taken from the ladder. The 2R resistor which connected the ladder to the virtual earth of the operational amplifier is omitted, and to keep the output voltage as before, the 3R amplifier feedback resistor is changed to R. The ladder network is no longer symmetrical, so it is necessary to demonstrate that this arrangement will work.

With the MSB high and all the other bits low, the output voltage is as previously:

$$V_{out} = V_{ref} \cdot \frac{R}{2R} = \frac{V_{ref}}{2}$$

The other resistors connected to the virtual earth have no effect as they are all connected to zero volts at their other ends. With the second MSB high and the rest low, the voltage at node 2 (Figure 6.3) will be:

$$V_{node\ 2} = V_{ref} \cdot \frac{2}{3} \cdot \frac{3}{8} = \frac{V_{ref}}{4},$$

since the impedance to the left of the node 2 remains 2R and the parallel combination of R and 2R is $\frac{2R}{3}$. The gain of the amplifier from node 2 is unity, so the output voltage is $\frac{V_{ref}}{4}$ as before.

With the third MSB high and the rest low, the voltage at node 3 will be as shown in Figure 6.4. The impedance from node 2 to ground is $\frac{2R}{3}$ and the impedance from node 3 to ground is $2R//\frac{5R}{3} = \frac{10R}{11}$. The voltage at node 3 is:

$$V_{node\ 3} = V_{ref} \cdot \frac{10}{32} = V_{ref} \cdot \frac{5}{16}.$$

The voltage at node 2 is:

$$V_{node\ 2} = V_{ref} \cdot \frac{5}{16} \cdot \frac{2}{3} \cdot \frac{3}{5} = \frac{V_{ref}}{8}.$$

The gain of the amplifier from node 2 is unity, therefore the output voltage is:

$$V_{out} = \frac{V_{ref}}{8}.$$

The process can be continued to show that each bit on the ladder has exactly the same weighting as before.

An incidental advantage of using the R-2R ladder network in this way is that it is more electrically efficient. The proportion of current reaching the output of the ladder from a given bit is

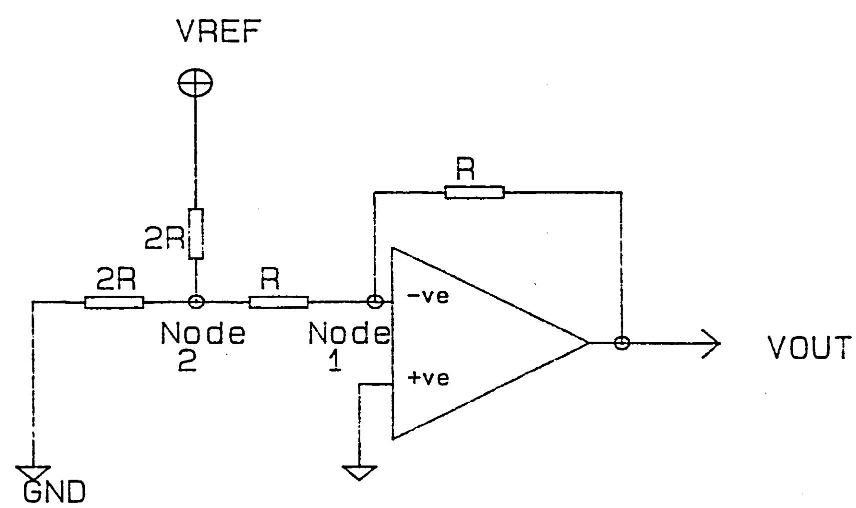

FIGURE 6.3 Equivalent Circuit of Ladder Network with Second MSB High and the Rest Low

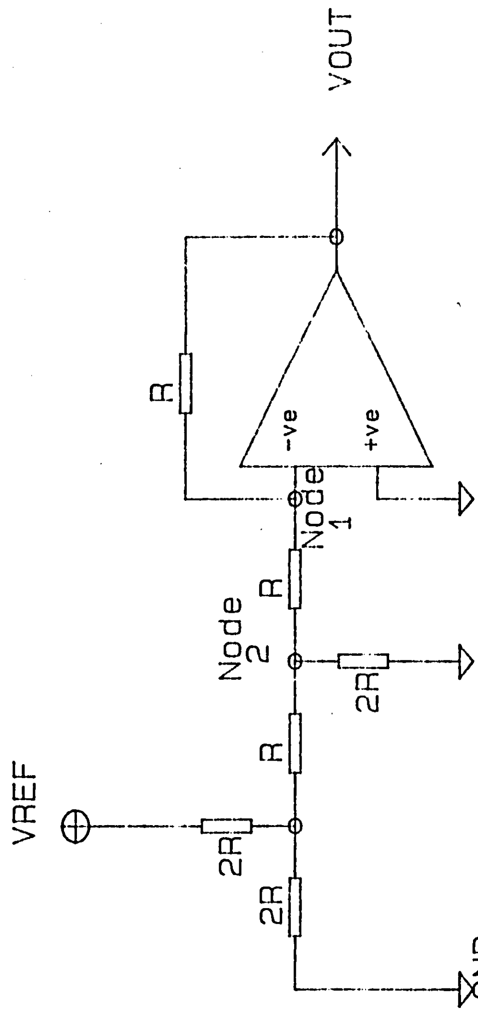

FIGURE 6.4 Equivalent Circuit of Ladder Network with Third MSB High and the Rest Low

always higher with this modified ladder; with the MSB high alone, 100% of the current arrives at the output, compared with 50% for the conventional arrangement.

The main advantage of this modified arrangement, however, is that any of the nodes on the ladder can be used as the output, so long as all the bits higher up the ladder than the output node are low. As long as this criterion is maintained, for every node that the output is moved down the ladder, the output current is doubled. Moving five bits down the ladder leads to an increase in output current of 2^5, about 30 dB.

The value for R is chosen so that the maximum current from the ladder, twice that due to the MSB alone, is equal to the upper limit of input to the following stage, assuming that current consumption limitations are not imposed. In order to minimize the number of taps on the ladder, to simplify the control circuitry, the positions of the taps are chosen so that the change in magnification between successive taps corresponds to just less than the dynamic range of the following stage.

The maximum amplification possible is when the analogue integrator is used as a tap. In this case, the node where the integrator couples to the ladder will not give the correct current; it will in fact give half that required. To obtain the correct current, the feed could be taken direct from the integrator's low impedance output via a resistor of value R. A more efficient approach would be to split the 2R resistor which couples the integrator to the ladder into two separate resistors of value R. The tap corresponding to using the integrator alone would therefore be the midpoint of these resistors. A further advantage would be that if a monolithic resistor pack of the ladder network were made, to ensure good matching and thermal tracking of the resistors, a tap in this position would also serve as the connection point for cascading several networks together.

To optimize the current from the ladder, the tap giving the highest amplification is selected until a bit beyond the tap in use goes high, at which point the next higher tap is selected, and so on until the shift register is full. Such control can be performed using fairly simple logic and switching.

The way in which the excess gain compensation is applied is completely dependent upon the type of stage which follows the enhanced integrator. If the stage following the enhanced integrator is a logarithmic amplifier, as it is in an L_{eq} meter, the auto-ranging system is easiest to implement and is most use. The auto-ranging circuitry helps optimize the large dynamic range of the integrator for the logarithmic amplifier's relatively small dynamic range, and the magnification of the input current to the logarithmic amplifier causes a simple level shift in the output which is easy to compensate. The situation is even better when calculating a parameter such as L_{eq}, which is derived from two signals only, dose and time, which affect the computed parameter in opposite senses. In these cases it is possible to arrange for two ladder networks to switch synchronously so that no further compensation is required. The tap on the ladders being used would be determined by the shift register with the largest accumulated count.

6.2 Elapsed Time Integrator

The elapsed time is required as an analogue signal, so the most obvious way to measure it is to employ the same integrator and shift register combination as used in the dose integrator. The input to the integrator is a constant current whose value can alter the scale of the final L_{eq}, but, since such a facility already exists by using the reference current to the antilogarithm stage, all that is required of the elapsed time integrator is that the ramp speed should be stable. The value for the constant current and the size of the capacitor are chosen so as to minimize leakage and offset errors and drift.

6.3 The Log-ratio Circuit & the Auto-ranging Output Circuit

The dose and time information are available as continuous analogue signals, so L_{eq} can be computed by taking the logarithm of dose divided by time. It is usual to do division of analogue signals by taking the logarithm of each signal, subtracting one from the other and then antilogging the result. Since L_{eq} is specified on a logarithmic scale, the antilogging can be omitted, and the difference between the log of the two integrals is L_{eq}.

In all published application notes for log-ratio circuits, the function is generated explicitly and serially, as above. A new approach has been devised as part of this project, in which instead of feeding each signal into its own logarithmic amplifier, each with a separate reference current, the two signals are fed into opposite sides of the same logarithmic amplifier, as shown in Figure 6.5. The reference current normally supplied to one input is replaced by one of the signals, so that the logarithm of the

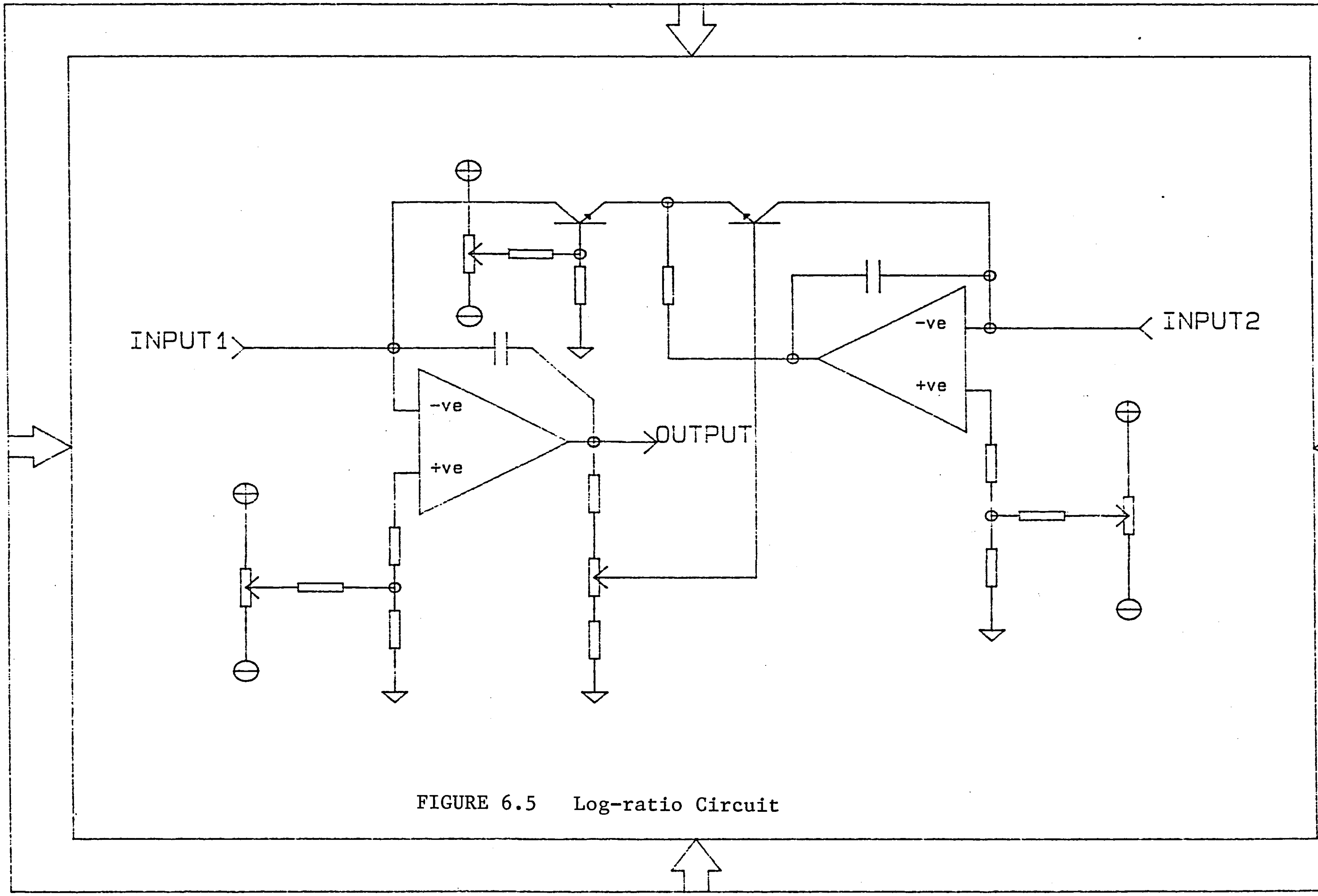

FIGURE 6.5 Log-ratio Circuit

other signal has a varying reference. The range of input signals which this modified log-ratio circuit can accept is about double (the number of dB) which the basic circuit can accept. A table of the results of a test on the log-ratio circuit of Figure 6.5 is shown in Table 6.1. With both inputs allowed to move over their extreme ranges, a dynamic range for the log-ratio circuit of 150 dB is obtained.

The auto-ranging control circuitry optimizes the current into the logarithmic amplifier so that it is operating with as high an input current as possible. The control circuitry performs this function by selecting the appropriate tap on the ladder network, such that the maximum output current is available but so that each bit on the ladder network maintains its correct weighting. The necessary algorithm is discussed in the section on the auto-ranging ladder network.

The optimized output of the logarithmic amplifier represents the correctly scaled value of L_{eq}, so that a conventional voltmeter can be used as the display device.

The performance of the hybrid ISLM is summarized in the Institute of Acoustics paper which is contained within Appendix D. The hybrid instrument shows an improvement over other commercially available instruments and demonstrates that a precision grade instrument, as defined in the draft standard, can be produced.

Left/dB	Right/dB	Output/Volts	Error/dB
0	0	0.001	+0.02
0	-10	-0.498	+0.04
0	-20	-1.000	0.0
0	-30	-1.502	-0.04
0	-40	-2.003	-0.06
0	-50	-2.507	-0.14
0	-60	-3.010	-0.20
0	-70	-3.518	-0.36
0	0	0.001	+0.02
-10	0	0.498	-0.04
-20	0	1.000	0.0
-30	0	1.501	+0.02
-40	0	2.002	+0.04
-50	0	2.504	+0.08
-60	0	3.005	+0.10
-70	0	3.501	+0.02
-80	0	3.980	-0.40

TABLE 6.1 Log-ratio Circuit Performance

CHAPTER SEVEN

MICROPROCESSOR BASED INTEGRATING SOUND LEVEL METER

The previous chapters highlighted the analogue and hybrid instrument development and showed how discrete stages were developed and evaluated. This basis was necessary for the development of a complete microprocessor-based instrument. This chapter describes development and evaluation of the integrating sound level meter and shows that it is feasible to design a microprocessor-based instrument with enhanced capabilities. As with the hybrid instrument, the performance of the constituent elements can be optimized to meet a wide variety of demanding design criteria.

7.1 Background Design Considerations

The problems of designing an analogue ISLM are that a totally digital solution based on microprocessor technology represents an impractical approach. This is evident by considering that to perform A-D conversion on the input signal requires about 19 or 20 bit resolution on the converter. Even if it were possible to perform the required accuracy of conversion in a short enough period, the subsequent processing of such a large digital word is beyond the scope of those current microprocessors which can be considered for inclusion in a hand-held integrating sound level meter. This is exacerbated by the further requirement to square the input signal.

Having assessed and rejected the approach involving direct conversion of the input signal, it was necessary to consider where to incorporate the microprocessor in the integrating sound level meter such that it could offer performance improvements over the hybrid instrument. Although the performance of the hybrid ISLM is capable of meeting the envisaged precision grade standard, it has limitations in the possible loss of dose information during integrator switchback and in the possible drift in the logarithmic amplifiers at extreme temperatures. A further advantage to accrue, if this latter stage were replaced by a microprocessor system, would be the elimination of the time consuming setting up procedure which is required to obtain optimum performance from the logarithmic amplifiers. The microprocessor should therefore be responsible for the signal processing after the proven 2logV-alog circuit, which was developed as part of the analogue L_{eq} meter.

To feed a signal proportional to the square of the microphone voltage into the microprocessor involves some form of analogue to digital conversion. Several digitizing techniques were considered; each requiring some form of integration to condition the signal.

A straight adaptation of the analogue integrator with switchback circuit would lead to a current to frequency converter. Neither the precision and linearity of the ramp, nor the possible delay in switchback, would detract from the performance of such a converter, so long as the current to frequency relationship were linear. As with the hybrid system, each count would represent a quantum of dose, so the total count fed into the L_{eq} meter would represent the total dose. The disadvantage of such a system would be that in order to achieve sufficient resolution of a low level input after a short period, the integrator would have to operate over a range of about 10 Hz to 10 MHz (60 dB). As the typical instruction cycle time of currently available microprocessors is greater than 1 µS, it was clear that such a current to frequency converter was not a viable solution.

A further development of the current to frequency converter system would be to operate the converter at a much slower speed and use an A-D converter to resolve the actual voltage of the ramp when required for calculation purposes. This would be essentially the same as the hybrid ISLM system, but with the microprocessor taking over the function of the special R-2R ladder network and the auto-ranging circuitry. Although the possible drift problems of the logarithmic amplifiers would be overcome by this arrangement, it would reintroduce problems associated with switchback of the integrator and would need a relatively complex hardware and software configuration.

The solution which was finally adopted for incorporating the microprocessor into the ISLM was again based on the original analogue integrator. Instead of switching back the integrator after the output has reached a preset level, as in the hybrid ISLM, the microprocessor is used to implement a charge-balancing algorithm. The advantage of charge-balancing is that there is no loss of dose information so long as the integrator output does not saturate, ie ensuring that the inverting input of the integrator remains at a virtual earth.

7.2 Outline Strategy for the Instrument

The digital accumulation of dose information, which in the hybrid ISLM was represented by the number of times the integrator had been reset, is performed by the microprocessor counting how many discrete quanta of charge it has injected into the integrator to restore the balance conditions. The microprocessor has to perform a relatively simple control function and requires only simple interfacing between itself and the integrator.

The quantum of charge is determined by the microprocessor switching on a constant current source for a preset period. To get adequate resolution of a low level signal after a short period suggests that either the current source is small or the on period is short. This is contrary to to the requirement of a much larger quantum needed to balance high level signals occurring over long periods. To cover this range of requirements, but without reintroducing the dynamic range problems of the current to frequency converter, two or more constant current sources have been used. The ratio between the currents was chosen to be 2^8 as this makes the dose register structure relatively simple. To fulfil commercial requirements of the collaborating body, the initial microprocessor-based instrument was designed to meet an industrial grade specification. Although this would initially preclude direct comparison with the precision grade hybrid instrument, it offered the challenge of optimizing the analogue stages against a different set of criteria. It soon became evident that the overall system performance was strongly influenced by the analogue stages and therefore the software developed for an industrial grade ISLM would be easily adaptable to more stringent requirements at a later date. The particular requirement was for an educational instrument, an application of particular interest to the author.

For the industrial grade meter, the dose register consists of a three-byte word. The major task of the ISLM is now to process this word by dividing by the elapsed time and taking the logarithm. The problem of taking the logarithm of a three-byte (or greater) word is the more demanding of the two problems, as the division can be implemented by subtracting the logarithms of the two quantities.

Logarithmic conversion would not normally be attempted on an 8-bit microprocessor single chip system, as there is insufficient processing power to perform the power series approximations usually employed. An algorithm has been developed as part of this work for performing logarithmic conversion within the single-chip microprocessor. The technique has not been seen elsewhere by the author or the supervisors, but the method is powerful and should find many applications in signal processing where it is necessary to compress or expand an M byte word into an N byte word logarithmically.

In the particular application of the industrial grade meter, it is necessary to compress a possible three byte word into a single byte. The algorithm relies on the equivalence of rotating a bit pattern to left and multiplying by two. This results in an offset addition or subtraction to the final logarithm. The particular bit pattern that exists is rotated left until it is fully left hand justified. The most significant eight bits are then used to form the address for a look-up table. The resultant logarithm is adjusted to account for the number of non-zero bytes and the number of rotations performed. The look-up table only needs to contain 128 values, corresponding to addresses 80_{16} to FF_{16}.

Having acquired the logarithm of both dose and time, and having subtracted the logarithm of the elapsed time from that of dose, it is a simple matter to make the result available on an output port so that a suitable display device can be driven.

7.3 Detailed Circuit Description

The front end of the instrument, ranging, weighting and gain stages including the generation of 2 log V are derived from those of the hybrid ISLM. The subsequent antilogarithmic stage is similar but unswitched and the units diverge at the integrator. In the microprocessor-based instrument a charge-balancing integrator is used.

7.3.1 Charge Balancing Integrator

The output current from the antilog transistor emitter is fed into the summing junction of the charge-balancing integrator, Figure 7.1. This integrator is essentially the same as that used in the hybrid instrument, but is not based on the principle of allowing the voltage across the integration capacitor 'C', Figure 7.1, to build up to a finite value before switching back the integrator. Instead the action of the antilog transistor current, which is attempting to ramp the output of the integrator in a positive direction, is balanced by a switched constant current, under the control of a microprocessor, which acts in the opposite sense so as to maintain the integrator output as near zero volts as possible.

The critical parameters affecting the performance of the circuit are: the input bias current of the operational amplifier, the leakage current of the antilog transistor, the printed circuit board leakage, the leakage of the capacitor, the size of the capacitor and hence the range of

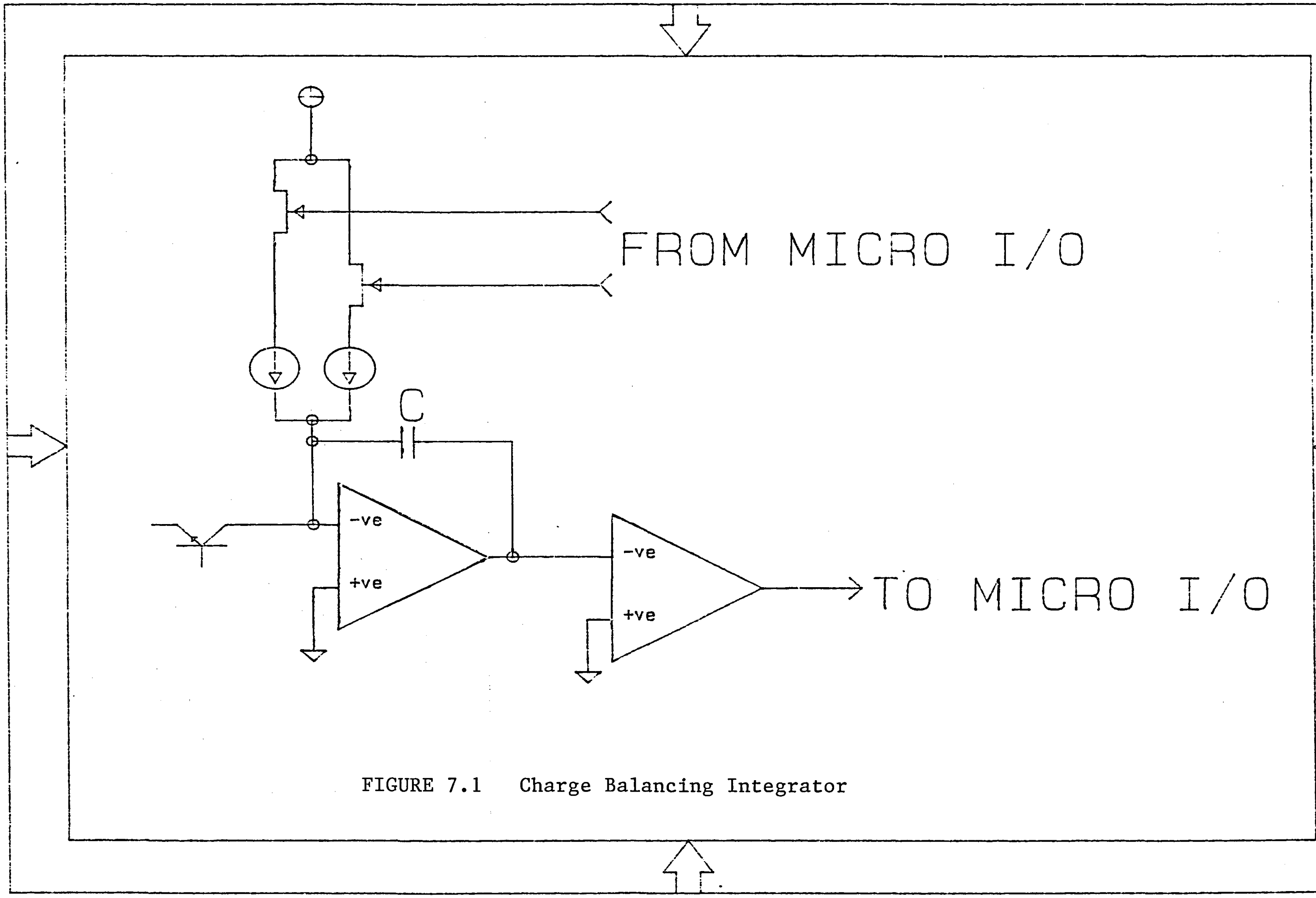

FIGURE 7.1 Charge Balancing Integrator

the input currents. The offset voltage of the operational amplifier is not particularly important as the integrator will centre on the offset voltage instead of absolute zero. The range of values for the critical parameters can be best determined by considering the equivalent ramp speed which the hybrid instrument integrator would operate at so that the "reservoir" capacity of the charge balancing integrator can be calculated. Knowing that the microprocessor which controls the switched constant current into the integrator is also sampling the sound level for the L_{10} and L_{90} computation, and that a reasonable sampling rate to capture the FAST response would be of the order of 10 ms, it seems sensible to choose the fastest equivalent ramp speed to be 10 ms also. This implies that if the L_{10}/L_{90} data acquisition can be done in a time which is short in comparison with the 10 ms sampling rate, the magnitude of switched constant current will be approximately the same as the maximum current from the antilog transistor.

Having made a decision on the maximum current it is worthwhile trying typical values for the power supply voltage rail and the integration capacitor size to determine whether this decision leads to any inconsistencies. If the operational amplifier of the integrator is constrained within the usual +5 V supply for the microprocessor, and the largest practical capacitor size of 0.47 µF is chosen, the maximum current can be worked out from $I = \frac{CV}{T}$. Substituting in the values gives I = 235 µA.

As the dynamic range of the ISLM was to be 40 dB and as the voltage from the microphone is squared before being fed into the integrator as a current, the input current to the integrator corresponding to the bottom of the dynamic span must therefore be 235 μA x 10^{-4} ie 23.5 nA. The algebraic sum of all the errors previously mentioned must therefore be less than this, preferably by about one order.

The capacitor leakage problem is relatively small as a result of the balancing technique used; if the capacitor has no voltage across it, there can be no leakage current. However, taking the worst case of 5 volts across the capacitor and the worst case insulation resistance of 10^{10} Ω, still only gives a leakage of 500 pA. An examination of operational amplifier data sheets reveals that devices are available with picoamp input bias currents at a reasonable cost combined with fairly modest power consumptions. If the printed circuit board leakage is reduced to minimal levels by careful layout, the only remaining critical parameter is that of antilog transistor leakage current. In the CRL 2.22, an industrial grade variant of the hybrid design, the transistors used in the absolute value and 2log-alog stages have a typical leakage of 2 nA. This is within the range determined by setting the capacitor size, the range of currents and so on. If the antilog transistor leakage current did prove to be a problem, then the range of input currents could be shifted upwards without exceeding the maximum current for the transistor. The main detrimental effect of such an action would be to increase current consumption and therefore decrease the battery life of the instrument.

A comparator connected to the output of the integrator operational amplifier and to the zero volts line detects whether the integrator output is positive or negative and signals this to the microprocessor so that it may modify its control of the switched constant current appropriately. There are no particularly critical parameters; the offset voltage of the comparator has the same effect as the offset voltage of the integrator operational amplifier, so that the integrator will actually balance at a voltage equal to the algebraic sum of the two offsets. As with any comparator, the device must be capable of coming out of saturation at a reasonable speed, but there is no particularly stringent performance requirements.

The control for this integrator can therefore be effected with only two parts of the microprocessor; one to receive data from the comparator and one to send instructions to the constant current switch. If the microprocessor records how much charge it has injected into the integrator summing junction to restore the balance condition, this will be a measure of the dose received by the microphone. By measuring the time in which this dose was received, a value for L_{eq} can be computed.

7.4 Microprocessor Control Strategy

The microprocessor has several functions to perform:

1 Acquisition of the sound level time history for the L_{10}/L_{90}

computation.

2 Control of the charge-balancing integrator and the recording of dose.

3 Calculation of L_{eq}.

4 Calculation of L_{10}/L_{90}.

In view of the particular educational application, it was considered preferable to be able to measure L_{eq} and L_{10}/L_{90} from the same data. This implies that the microprocessor would have to acquire sound level and dose data simultaneously. Estimates of likely software processing cycles showed that this was possible and that the L_{eq} calculation could be updated constantly. However, in order to execute a large number of statements in a given period necessitates increasing the microprocessor operating frequency and hence increase the current consumption. It was therefore not considered important to attempt any L_{10}/L_{90} computation until the end of the measurement period.

During the measurement period, the microprocessor is in a program loop where it acquires a value of sound level, spends a predetermined period balancing the integrator and accumulating dose data, makes a calculation of the current L_{eq} value and then outputs this value. At the end of the measurement period, the microprocessor calculates the values of L_{10} and L_{90} and stores them.

7.4.1 Sound Level Time History Recording

The dc logged output from the standard sound level meter circuitry is digitized and fed into the microprocessor. An 8-bit I/O port is used to feed a byte from the microprocessor through an R-2R ladder network and one to one input of a comparator. The other comparator input is fed with the dc logged sound level signal and its output is fed back to the microprocessor. The comparator output signal is detected by the microprocessor which implements either a counter ramp or successive approximation technique to perform the A-D conversion. The advantages of using the microprocessor's I/O ports to perform the D-A conversion directly and feed the comparator, are that the chip count and hence the current consumption are kept small. The conversion time is minimized because the final value is always in a microprocessor register when the conversion is complete.

7.4.2 Dose Data Recording

To optimize the dynamic range of the L_{eq} calculation it is important that the microprocessor spends a large proportion of its time controlling the charge-balancing integrator. It is equally important that a full scale input would generate a large amount of data over the full measurement period so that if a signal corresponding to the bottom of the range is fed in to the meter, it will be capable of generating enough data to allow the L_{eq} calculation to be made reasonably accurately after a short period.

In controlling the integrator, the microprocessor must repeatedly test the state of the comparator until it detects that an input to the integrator has caused the output to ramp in a positive direction. When such a signal has been received, the microprocessor enables the switched constant current to cause the integrator to ramp back towards zero.

The microprocessor must retest the state of the comparator until the signal is received indicating to the microprocessor that the integrator output is zero, or very slightly negative. The time between testing and retesting the state of the comparator, when the current is enabled, corresponds to a quantum of dose. For each quantum of dose, the contents of a register are incremented. A further register, which records elapsed time since the reset button was last pressed and hence determines the measurement period, is used in conjunction with this dose register to compute L_{eq}. The size of dose register required can be determined by considering the condition of minimum output to the integrator, combined with the requirement for a reliable answer in a short time, say 10 seconds. To get within ±1 dB of the final answer, one needs at least 10% resolution. Therefore a minimum of 10 quanta must be recorded in 10 seconds at the bottom of the indicator range. The number of quanta which would correspond to this acquisition rate for a number of input signal levels over the minimum and maximum measurement durations is shown in Table 7.1.

Level	0 dB	25 dB	40 dB
Duration	Number of Quanta		
10 seconds	10	3.16×10^3	10^5
10 minutes	600	1.89×10^5	6×10^7

TABLE 7.1 Dose Register Size

It is clear that a 3 byte register would be needed for a constant level at the proposed top of the indicator range (25 dB), but that 3 bytes is insufficient to accommodate a top of the dynamic range signal for 10 minutes. This measurement duration was considered to be appropriate for capturing a representative sample of the signal, both for L_{eq} measurements and for the satatistical analysis of sound level data. The use of a three-byte register would however accommodate all signal levels which would eventually result in an on-scale reading.

To determine the time corresponding to the size of dose quanta, one has to divide the total number of counts corresponding to the maximum input by the total measurement time:

$$\frac{6 \times 10^6}{6 \times 10^2} = 10^4 \qquad \text{counts per second}$$

To complete the testing, incrementing and any necessary switching in 100 μs is by no means impractical, but when the machine code is determined it requires running the microprocessor at a high speed and consequent high current. One technique which would reduce the need for such a high data acquisition rate is to use two separate constant current sources with a known, preferably binary based, ratio between them. This option is shown Figure 7.1.

The quanta of each need to be recorded in separate registers, but the data acquisition rate can be reduced because the low current can be used when the input from the antilog transistor is low and similarly the higher current source can be selected if the antilog transistor output current is high. The microprocessor initially chooses the lower constant current and tests to see if the comparator has changed state. If after some predetermined period the comparator has not changed state, then the higher constant current is selected until the comparator changes state. The two separate data registers have to be combined to give an overall value for the dose.

7.4.3 L_{eq} Calculation

As previously discussed, it is desirable for L_{eq} to be calculated from the dose and elapsed time during the measurement period and to be continuously updated. As L_{eq} is the result of the logarithm of dose divided by elapsed time, it appears that the microprocessor needs to be capable of division. This is not necessarily so as the individual dose and elapsed time registers can be logged and then the result of subtracting the logarithm of elapsed time from the logarithm of dose gives the correct value for L_{eq}.

The logarithmic conversion must condense the possible 3-byte register to a scale which still allows small amounts of data to have their correct weighting. The simplest and therefore probably the quickest way to perform the logarithmic conversion would be to use a look-up table. It is not necessary to convert all the significant bits of register, as this would lead to an impractically large look-up table. To minimize the number of bits to convert and to choose the appropriate bits, one first needs to determine the most significant bit of the register which is in the high state. The bits in the register immediately below this highest enabled bit always have the same weighting relative to this bit independent of its position in the register. The number of the highest enabled bit is therefore combined with a value derived from the look-up table based on the bits immediately below it.

The look-up table is situated in ROM and occupies a maximum of 256 locations as this provides sufficient resolution. The result of subtracting the two logged registers is condensed to less than a single byte; thus the result can be output via an I/O port and subsequently converted by a DAC to allow display on the analogue meter.

7.4.4 L_{10} and L_{90} Calculation

At the end of the measurement period there is an array of registers whose contents correspond to the frequency of occurrence of each sound level, and a separate register which has recorded the elapsed time or the number of sound level samples taken. The microprocessor then adds the total number of counts in each register, starting from the top, until the sum is equal to one tenth of the total number of samples taken. The register which contained the last counts to be added in before this condition was met represents the value of L_{10}. Similarly, starting from the bottom of the array and working upwards, L_{90} may be evaluated. The values of L_{10} and L_{90} are stored in separate registers ready for access when a request is signalled to the microprocessor.

In order that the conversion may be performed as quickly as possible it is possible to convert with less than 8-bit resolution. To achieve ±1 dB accuracy in the final answer, it is possible to convert using only 6 bits. Each time the microprocessor increments the register which is being output from the port, it has to subsequently test the state of the comparator. To minimize the number of program steps in the loop the comparator output generate a signal for the external interrupt, thereby eliminating the need to read and logically test an input port during the cycle.

The total conversion time needs to be less then the time taken for the charge-balancing integrator to ramp up to the supply rail with the maximum input current. This is because when the microprocessor is recording the sound level time history it is not providing a balance current for the integrator. As the fastest ramp speed has been chosen nominally to be 10 ms, this condition will be met quite easily. A sensible target for the conversion time would be under 1 ms, remembering that CMOS microprocessor power consumption is virtually proportional to the clock frequency.

The result of the conversion corresponds to a particular sound level, so a number of classes or bins are provided, one for each level. If 6-bit conversion is performed this requires 64 bins. As the conversion is performed every 10 ms, a constant sound level would fill one bin at a rate of 100 counts per second. Given the required 10 minute measuring period, this would correspond to a total of 60,000 counts. This implies the use of 2 x 8-bit bytes for each bin, that is a total capacity of 65,536 counts at each level. However, if 2 bytes were allocated for each of the 64 levels this would take up all the available RAM space of a typical single chip microprocessor (8049). Several techniques may be employed to overcome this difficulty. They include reducing the conversion to 40 levels, ie 1 dB resolution or only allocating 2 bytes to a restricted range of sound levels, eg the indicator range. If the class widths for the L_{10} and L_{90} calculation are increased beyond 1 dB, even greater savings in RAM space can be made and the conversion could be reduced to say 5 bit accuracy, giving 1.25 dB resolution. This would give a battery life improvement as well. In the prototype instrument a 1 dB class width was used, needing 80 bytes of RAM.

7.4.5 Output Display of the Data

Although one might assume that having calculated L_{eq}, L_{10} and L_{90} using a digital microprocessor, a digital display would be the most appropriate, this is not so. The sound level needs to be displayed, so a special digital panel meter would have to be provided. The signal from the digital panel meter and the output from a suitable display decoder/driver would have to be combined and the appropriate one selected for display. However, if an analogue meter is used for the display, the selection of the sound level signal or an output from the microprocessor can be made by a simple switch and the output from the microprocessor can be readily D-A converted by several simple techniques. These techniques include using an R-2R ladder from an I/O port on the microprocessor or by using a single bit output port on the microprocessor and pulse width modulating its output to obtain the desired meter deflection. A digital display could be provided in addition to the analogue meter, but the heavy current consumption incurred would make it an expensive option. The draft international standard requires that if a digital display is provided, it should resolve to 0.1 dB. This hardly seems consistent with a design requirement for only ±1 dB accuracy. A 30 dB analogue meter was used, fed from the microprocessor I/O port via an R-2R ladder network.

The final version of the software for this design is included within Appendix C.

7.5 The Advanced Microprocessor-based Instrument

When the design specification for the initial microprocessor-based instrument was determined, it was envisaged that a precision grade instrument would result subsequently. This section describes the development of such an instrument.

The basic specification was that it should at least equal the performance of the precision grade hybrid instrument by developing the principles of the earlier microprocessor-based instrument. Specifically this implies a 60 dB dynamic span together with the capacity to integrate over a measurement period at least equal to the normal working day (8 hours).

Re-evaluation of the design constraints considered previously showed that a charge-balancing integrator using two balancing currents would not provide the necessary dynamic span. A logical extension was therefore to investigate the use of three balance currents. Similarly, examination of Table 7.2 shows that changing from a 3 byte to a 4 byte register would provide sufficient capacity for the dose data. This should be accomplished by relatively minor software modifications.

Level	0 dB	34 dB	60 dB
Duration	Number of Quanta		
10 seconds	10	2.5×10^4	10^7
10 minutes	600	1.5×10^6	6×10^9
10 hours	3.6×10^4	9×10^7	3.6×10^{10}

TABLE 7.2 Dose Register Requirements for the Advanced Instrument

A prototype embodying these principles was constructed. The maximum balance current was selected to be 3 mA, as this was sufficient to balance the maximum available current from the 2logV-alog stage. The two lower currents were initially set to be 2^8 submultiples of the maximum, but the resulting minimum quanta of charge were too small. The ratio of currents was changed to 2^7. This arrangement proved capable of balancing a wide range of input signals, but the circuit was particularly prone to drift problems.

The fundamental problem was to control the lowest balance current accurately. As in the earlier microprocessor-based instrument, the 5 volt supply was used as the reference for the balance currents. This presented no problems for the higher currents, but no stable method could be found to determine the lowest balance current of 183 nA. One method was to employ a potential divider to step the reference supply down in order that a high stability resistor could be used. The shortcoming with this arrangement was that the FET input operational amplifier, which had been selected for its low input bias current, had a significant temperature-sensitive input offset voltage. Although the circuit could be set up, the integrator soon started to drift, in either direction.

7.5.1 Short L_{eq}

An exciting development presented in a definitive paper in 1981 [14], was the introduction of the concept of Short L_{eq}. In this method, numerous short term L_{eq} measurements are recorded in a data store. Subsequent processing allows synthesis of Global L_{eq}s over any desired period within the total measurement period, together with all the statistical parameters. The principal advantage of this method is that the raw data is stored. The decision about which acoustic descriptor to apply is deferred until the data has been stored. This new method was considered to be of such importance that the specification of the advanced microprocessor-based instrument was amended to include the Short L_{eq} facility.

The elemental period selected for the generation of Short L_{eq} was 125 ms, as this would result in time history data with comparable resolution to a conventional SLM. Requiring the instrument integrator to have only sufficient capacity for this short period eased a number of difficulties which were experienced with the current prototype. However, as the basis of the Short L_{eq} method is for post-capture processing, it is necessary for the instrument to be able to respond to an even greater dynamic range of input signals. One application which demands this high dynamic range is unattended airport monitoring, where a very low background may be interrupted by a high level noise event.

To facilitate the increased dynamic span, a further prototype was developed which used three independent integrators. The microprocessor controlled each of the integrators during the elemental period and then selected the data from the most appropriate integrator. For a mid-range signal, one integrator would overload, one would have the correct L_{eq} and the other would not have acquired sufficient data to resolve accurately the input signal.

Although the microprocessor could balance the three integrators, it had no spare capacity to format and store the data or process keyboard, display and interface routines.

7.5.2 The Final Instrument

The balance between hardware and software processing needed to be optimized. In order to achieve this, the three integrators were replaced by two of the proven switch-back integrators and digital dose store of the hybrid design. As in the hybrid design, the dose data is recovered with a modified R-2R ladder network. Each of the integrators has three possible ladder network taps. The output of the appropriate integrator is selected by a controller, implemented in CMOS random logic. This selected output is then fed to a logarithmic amplifier. Since a reading is only required after the preset elemental period, there is no need for a signal corresponding to elapsed time. Instead, a fixed current is supplied to the logarithmic amplifier. The value of this current can be varied over a small range to allow for system calibration.

At the end of the elemental period, an analogue to digital conversion is performed on the output of the logarithmic amplifier. This, combined with a three-bit word which specifies which tap was connected to the logarithmic amplifier, provides all the necessary data to the microprocessor. The selected output parameter from the microprocessor is displayed on a 4-digit display as the instrument does not compute sound level.

7.5.3 Analogue Refinements

Whilst developing the final prototype, the previously designed analogue stages were also re-examined. Experience gained from "in the field" operation of a number of the designs, coupled with recent component developments showed that the performance could be extended even further.

The majority of the improvements related to the operation of the analogue integrator. This stage had been identified earlier as a possible weak link, due to finite switchback and leakage. The leakage problem was largely eliminated by the adoption of Short L_{eq} and its implied short measuring duration. Use of an operational amplifier as a comparator in the retrace circuitry was the cause of some of the speed problems. The use of passive components alone to determine the integrator hold-off also led to a reduction in possible operating speed by having to over design to allow for component tolerancing. The retrace circuitry was therefore re-designed to incorporate a very high speed, yet low current consumption, comparator together with an integrated circuit monostable multivibrator and the latest low impedance FETs. With this new arrangement the retrace and hold-off could be accomplished reliably in only a few microseconds.

A further problem relating to the operation of the integrator was the current wasted in providing the reference current for the antilog stage. Although it is within the antilog stage, this current is used to set the scale of currents into the integrator. This constant reference current is passed through a logging transistor to offset the base of the antilog transistor. By offsetting the base of the logging transistor slightly negative, the current through it can be reduced considerably, yet still maintaining the base of the antilog transistor at its correct value.

A shortcoming of the hybrid instrument which the microprocessor-based instrument was intended to overcome, was the possible loss of dose information during retrace of the integrator. This possibility had been greatly reduced with the upgraded circuitry, but a further improvement was made. This improvement consisted of placing a low value resistor in series with the transistors of the 2log stage. During normal operation, at low signal levels, the voltage drop across the combination of the transistors and resistor is almost solely determined by the base emitter drop of the transistors. Hence the circuit operation is unchanged. At high signal levels, where loss of dose information is possible, appreciable currents are flowing in the transistor resistor combination. The contribution of the resistor therefore increases and the overall voltage drop is greater than would be expected under normal operation. This increased voltage drop results in a higher integrator current and hence faster sweep speed. If the value of this resistor is selected carefully, its effect is to exactly compensate for the possible loss of dose information during retrace. Without the resistor the integrator sweep speed is slightly slow. Adding the resistor allows the performance at the top of the dynamic span to be improved so that the range of input signals is increased by about 10 dB.

7.5.4 Data Retrieval

The large quantities of data which the instrument was capable of acquiring (256 k) needed to be retrieved for subsequent reprocessing. This was identified as a secondary but nevertheless important task for the microprocessor. In collaboration with the proposers of the Short L_{eq} concept a protocol for data transfer was proposed, together with the definition of an interface for acoustic applications [15,16,17,18].

Each measurement session which is recorded in the instruments memory is preceded by a header which gives information about the session. This information includes the number of samples within each session, the type of acquisition and the offsets between headers. This allows for scanning of the headers to determine which, if any of the sessions are to be transferred. A more complete summary of the header format and content is presented in Appendix B.

Complete circuit diagrams of the final instrument are presented in Appendix A. Pseudo-code used in the development of the software is included in Appendix B. Listings of the major programs, including those used to generate the look-up tables, are included in Appendix C.

CHAPTER EIGHT

EVALUATION PROCEDURES

The assessment of individual circuit performance and that of complete instruments was a necessary and integral part of the study. The findings of such assessments were invaluable in optimizing individual circuit parameters, and in determining the interactive effects of combining these circuits into working instruments.

Special test equipment was constructed so that the full range of the three important L_{eq} meter parameters could be presented to the instrument. As discussed in Chapter Four, the parameters are: the dynamic span, the exchange rate tolerance and the peak factor capability. Each of these gives additional information about a given circuit design or instrument's suitability to accurately integrate the wide span of possible input signal levels and measurement durations. The method for applying these signals and the method for interpreting the results is also given in Chapter Four.

Tests were carried out on a number of different manufacturers' ISLMs, and the results were compared with those obtained using the hybrid L_{eq} meter which had been produced as part of this project. The results of these tests were reported at the Institute of Acoustics Spring Conference 1980. A copy of the relevant extract from the proceedings is included in Appendix D. In the table of exchange rate tolerance errors, the ISLM produced as part of this project is instrument number 5.

The assessment procedures used in this work have included both tone burst and single-cycle input signals. A paper discussing the relative merits of the two methodologies was presented at the 12th International Congress on Acoustics, Toronto, 1986 [19]. This paper highlighted the need for specialized signal sources, and the value of the special interface developed for the advanced microprocessor-based instrument.

The dedicated system developed as part of this work has a signal to noise ratio of greater than 80 dB. This is the limit of the frequency analyser which has been available. The final version of the instrument has a dynamic range in excess of this, and approaching the 110 dB maximum of the control range of the attenuators. It is therefore clear that the evaluation equipment and procedures need constant updating in order to correctly assess the latest instruments.

8.1 Instrumentation

The following instrumentation was used during the final assessment stage of the project. This arrangement is representative of the wide range of equipment used throughout the development and earlier assessment stages of the work.

1. Specialized tone burst generator developed as part of this work.
2. 2 x Enertec Programmable Function Generators Type 4431.
3. Marconi MF Attenuator Type TF 2162.
4. Gould Digital Storage Oscilloscope Type 4035.
5. Bruel & Kjaer High Resolution Signal Analyser Type 2033.
6. Hewlett Packard Plotter Type 7470A
7. Farnell Dual Power Supply Type LT 30-1.

The Enertec programmable function generators were used in combination, with one device determining therepetition ratefor the tone burst sequences and the other determining the tone burst duration and signal frequency. Although this was an easy arrangement to control, particularly via the IEEE 488 interface bus, the signal quality and range of signals was not as great as the dedicated system developed as part of this work. This latter system was therefore used for all measurements other than initial evaluations.

CHAPTER NINE

RESULTS

As with any project of this nature, the principal results are the new circuit techniques and applications embodied within the designs which have been presented. The performance of the principal constituent elements has been described within each section. Therefore this chapter will only present results which quantify overall instrument performance or indicate the response of the complete instrument to the test stimuli.

In each of the following figures, the input signal is not shown correctly scaled. This signal was derived from a point before the attenuator, as connecting a probe directly to the sensitive instrument input caused problems of earth loops and increased the background noise.

Figure 9.1 shows the output voltage of the switch-back integrator when subjected to a mid-range constant level on the instrument input.

Figure 9.2 shows the output of the same integrator with a high level input signal. The increase in output due to each half-cycle can be seen clearly. A system phase shift can be detected.

Figure 9.3 shows the output of the switch-back integrator in response to the tone burst test stimulus for the exchange rate test.

The data stored in the advanced microprocessor-based instrument is downloaded to an IBM PC compatible computer for analysis. Figure 9.4 shows the output of data recorded by manually increasing the input signal in 0.1 dB steps.

The overall performance of the instruments and prototypes produced as part of this work is summarised in Table 9.1.

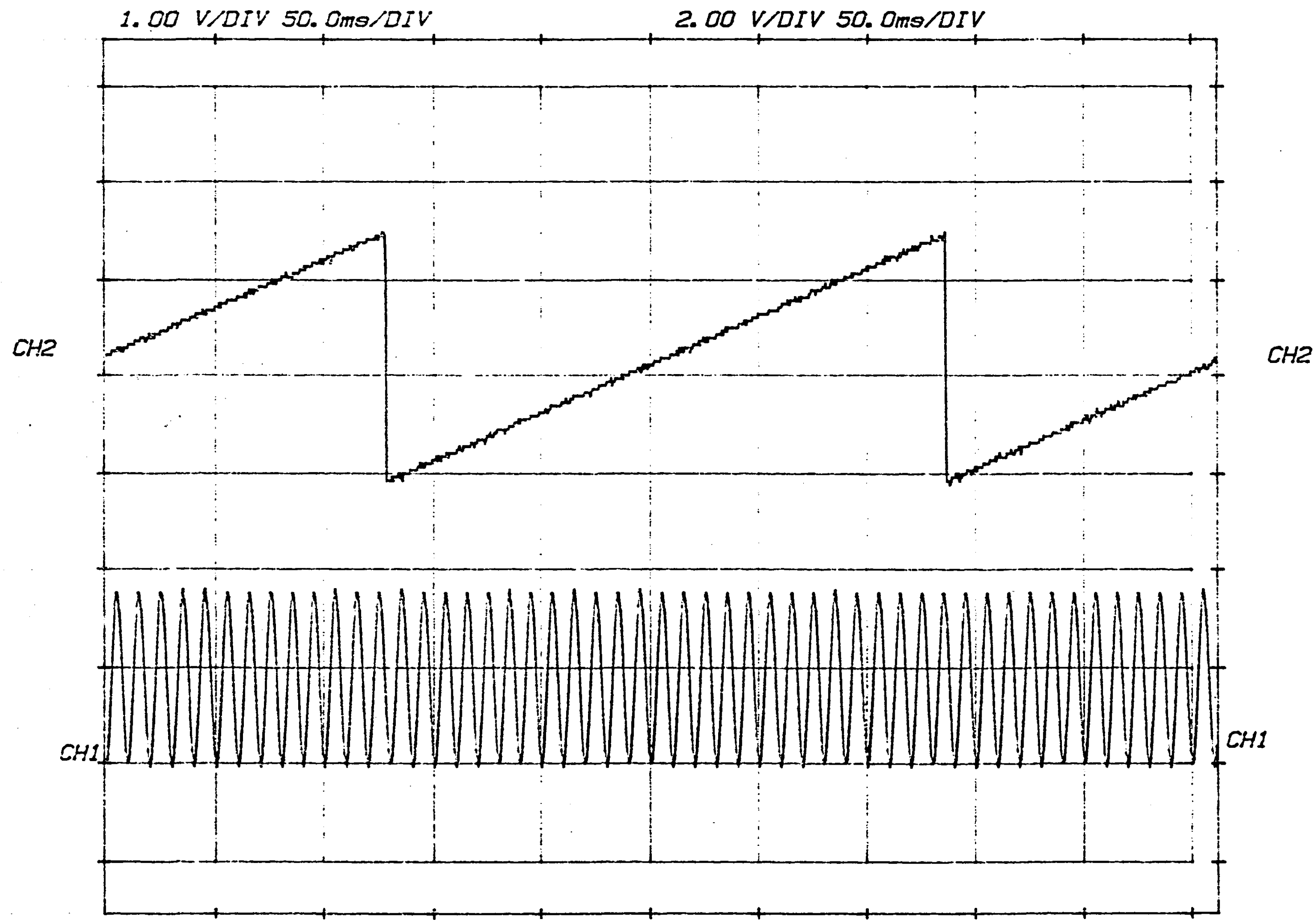

FIGURE 9.1 Switch-back Integrator Output (CH2) with Mid-range Input (CH1)

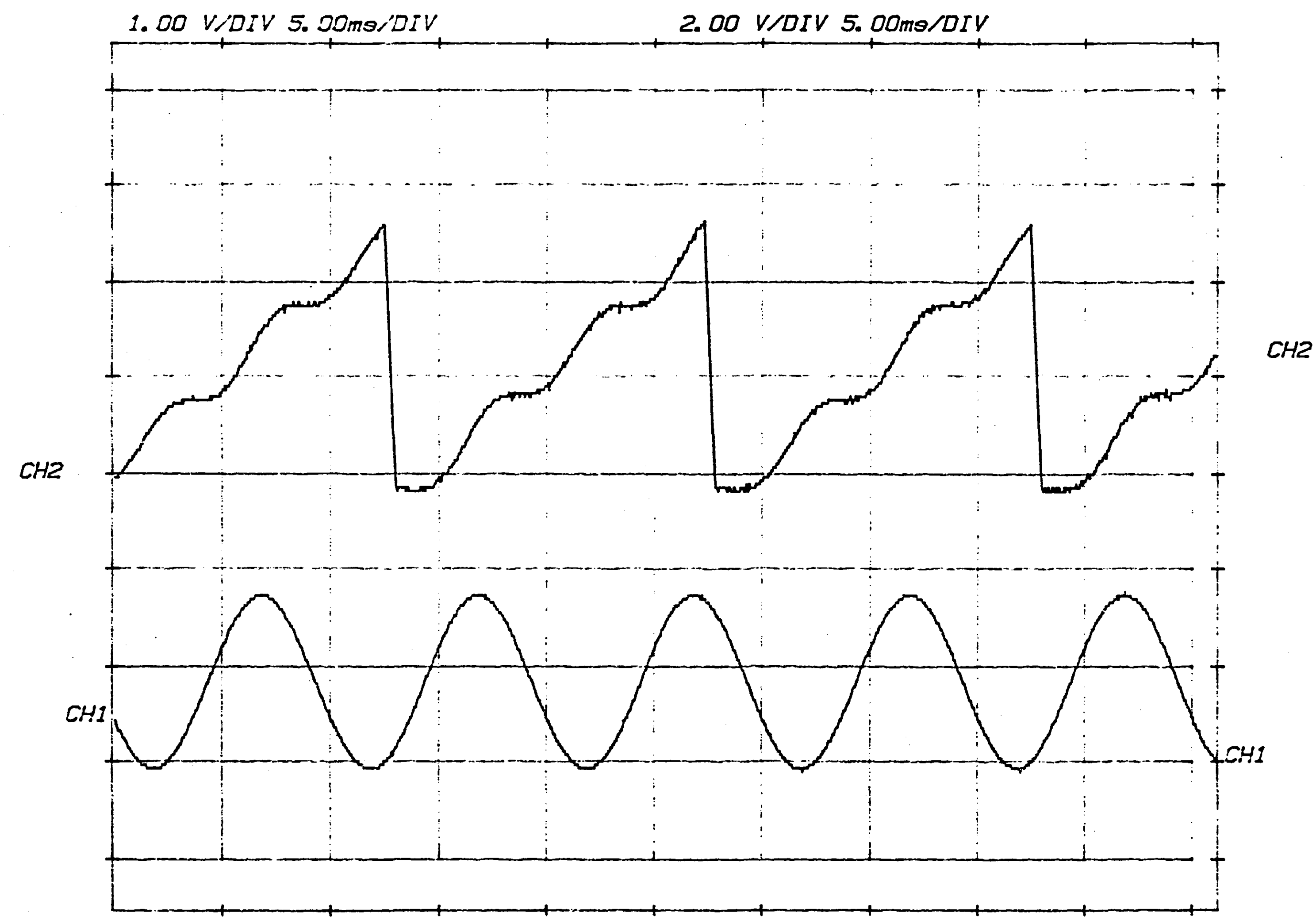

FIGURE 9.2 Switch-back Integrator Output (CH2) with High Level Input Signal (CH1)

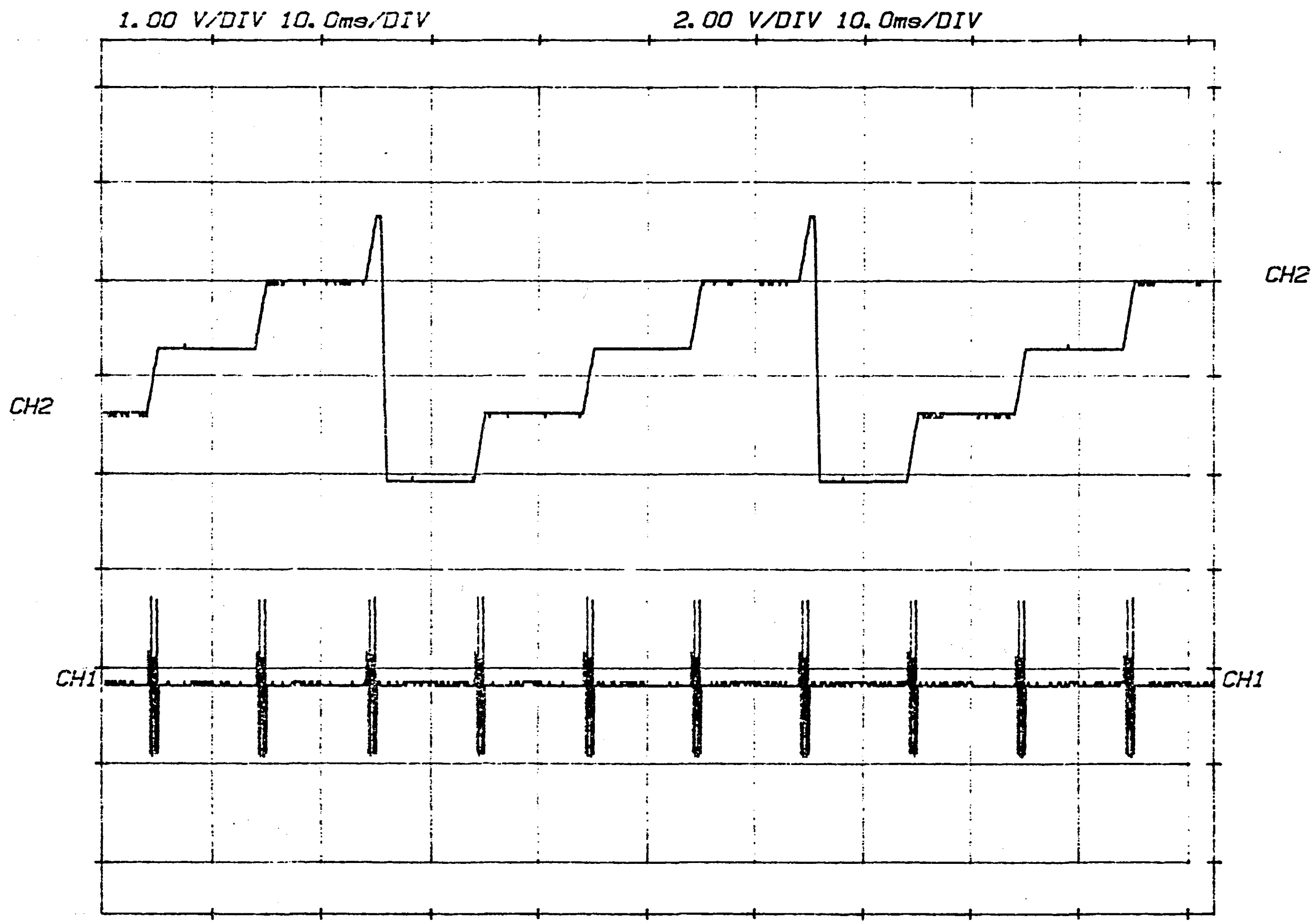

FIGURE 9.3 Switch-back Integrator Output (CH2) with Tone Burst Input (CH1)

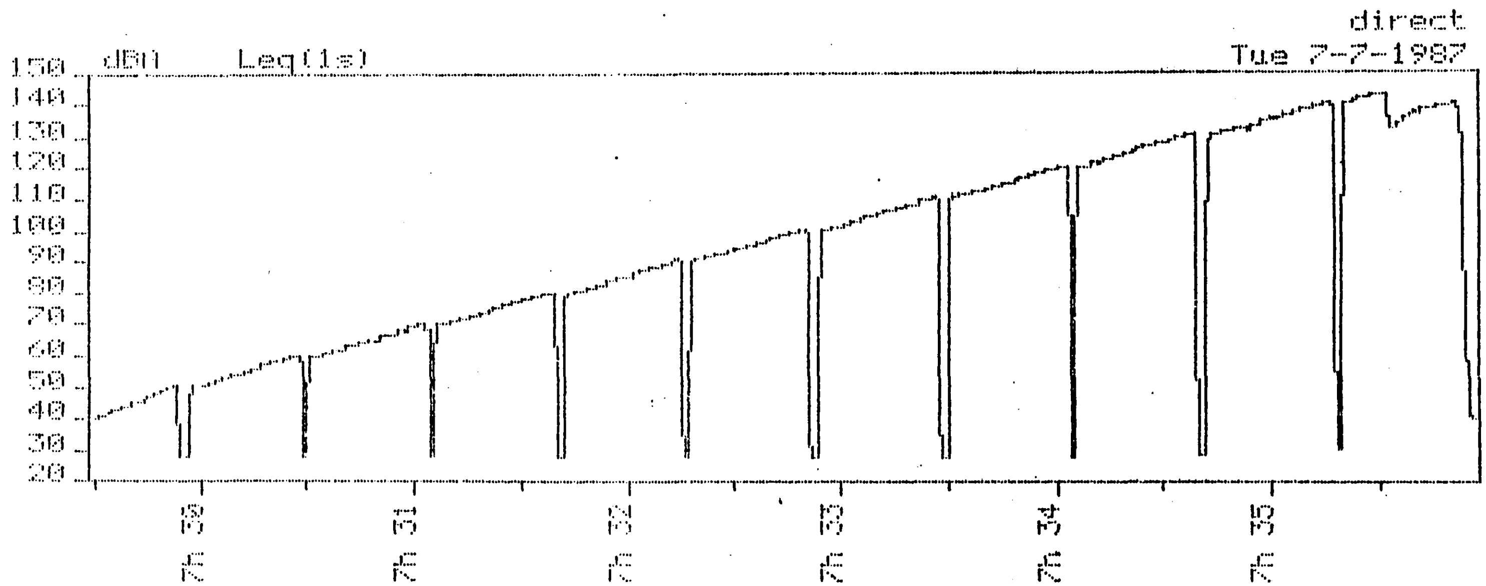

FIGURE 9.4 Data Downloaded from the Advanced Microprocessor-based Instrument

Instrument Number		1	2	3	4
Exchange Rate Error					
Input Signal	Relative Amplitude				
Tone Burst mark/space 1:9	+ 10 dB	0.0	0.0	0.0	0.0
Tone Burst mark/space 1:99	+ 20 dB	0.0	+ 0.1	+ 0.1	- 0.1
Tone Burst mark/space 1:999	+ 30 dB	0.0	+ 0.1	- 0.2	+ 0.2
Tone Burst mark/space 1:9999	+ 40 dB	< 0.1	+ 0.3		+ 0.2
Tone Burst mark/space 1:99999	+ 50 dB				- 0.1
Dynamic Span		65	55	43	~ 110
Peak Factor		68	58	46	> 80
Instrument Type		1	2	3	0

TABLE 9.1 Summary of Complete Instrument Performance

CHAPTER TEN

DISCUSSION OF RESULTS

As expected, the constant input gives rise to a steadily increasing integrator output voltage (Figure 9.1). The quantisation noise evident on the trace is due to the digital storage oscilloscope. One of the major difficulties in assessing the integrator performance of the advanced microprocessor-based instrument is that this form of response only occurs at very low signal levels. At higher signal levels the integrator behaves as a voltage to frequency convertor, with the integrator switching many times within one cycle of the input signal. This makes linearity measurements of the integrator alone very difficult. However, as demonstrated with the final instrument, optimization of the complete instrument is not necessarily achieved by setting the constituent elements in isolation. The level of performance of an instrument is strongly determined by the setting up procedure. A good design should incorporate a repeatable and rapidly convergent adjustment scheme.

Although the input waveform for the tone burst test (Figure 9.3) is not resolved particularly well, it indicates the position of the impulses and serves to highlight the difficulties presented to an ISLM in capturing impulsive signals. The trace for Figure 9.3 was taken from an instrument which had an intentionally slow retrace, but had the compensation resistor fitted in the 2log stage (section 7.5.3). The uniform step size, despite an impulse occurring at switch back, demonstrates the value of this modification.

The software package which produced Figure 9.4 was part of a parallel development programme with the French company Soeur-Anne. Although developed for combined use with the final instrument as a powerful data acquisition and analysis system, it also provides a convenient tool for assessing the performance of the hardware. The glitches in Figure 9.4 are due to the attenuator passing through its -∞ position. With the attenuator in this position the noise floor resulting from the limits of the instrumentation system is evident. It is not completely determined whether this is due to the instrument alone or as a result of attenuator breakthrough and other external noise. Under these conditions most of the measurement system is operating at the extreme of its operating limits as the input corresponding to this instrument reading is less than 4 μV.

Although the trace was obtained manually, there is obvious scope to automate instrument evaluation and documentaion. This is greatly assisted by the command and data structure associated with the DP37 interface system [17].

At the upper extreme of the trace, the overload condition was not trapped so that the limit of the dynamic range could be readily identified for the purposes of this thesis. A dynamic range of around 110 dB can be identified.

The results presented in Table 9.1 represent four identifiable stages of development of the project. The performance of the earliest hybrid instrument is still a significant achievement, several years after its design. However, it did not fulfil the criterion, discussed earlier in this chapter, that the setting up procedure should not be too critical. The performance of the hybrid instrument outlined in Table 9.1 (instrument number 1) could not be maintained over a wide temperature range. This design was therefore not considered suitable for manufacture.

Instrument number 2 is a hybrid instrument which is a simplified version of the first instrument which was designed to meet the needs of an Open University course. Specifically the major simplification in this instrument is to use a ladder network control strategy which locks the dose and time registers together. Although the earlier, more elegant, design could compute L_{eq} from a wider range of dose and time information, this increased range of accuracy only applied to readings which could not be displayed due to the meter limitations.

The intended application meant that the instrument had to be reliable and easy to operate as it was to form part of the home experiment kit. In addition to this it had to meet a non-trivial design specification within the restricted budget of the Open University. As is evident from the results from this instrument, its Type 2 classification is due to dynamic span rather than exchange rate errors. Since this is limited by the use of only two batteries, it is probably capable of improvement. This design has been manufactured successfully and is now used by a number of public bodies throughout the world.

Instrument number 3 in Table 9.1 is the microprocessor-based prototype using a charge balancing algorithm described in the early sections of Chapter Seven. It was developed to provide an alternate to the instrument 2 for use by the Open University. The performance of this instrument in computing L_{eq} is not as good as the previous one, however this instrument offered the additional feature of providing the statistical levels, a feature particularly sought after by the couse team. The cost penalty of including a microprocessor embodied within the instrument was a major factor against this unit. The second hybrid instrument was eventually adapted for interface to the analogue to digital convertors of the BBC model B microcomputer and special software was prepared to facilitate generation of the statistical indices.

The performance of the final instrument is that of instrument 4 in Table 9.1. The exchange rate tolerance errors are well within the limitations imposed by a Type 0 classification. The uncertainties in the dynamic span and peak factor figures are as a result of the limits imposed by the instrumentation system, however they also represent performance which is consistent with a Type 0 classification.

CHAPTER ELEVEN

CONCLUSIONS

Evaluation procedures developed as part of this work and the standards demanded by the allowed tolerances could not be attained by previous instrumentation. These procedures require the use of dedicated hardware to assess fully the important characteristics of integrating sound level meters.

The limitations of earlier instruments' response to impulsive signals has been attributed to both the squaring and integrating stages. These limitations have been assessed and the critical mechanisms have been identified. Techniques have been developed which overcome these limitations. Specifically, these include maximizing the gain-bandwith and slew rate limit within the absolute value and 2log stages, together with careful selection of the diodes and transistors.

A novel technique, developed for use in the hybrid instrument, is to combine both analogue and digital elements for storing the dose information. This combines the advantages of the stability of digital storage with the continuous nature of analogue processing.

The optimum configuration for an instrument which attains a high performance against the demanding specification, is formed by the use of analogue techniques for the majority of the signal processing, with a combination of random logic and microprocessor-based techniques for control and data storage.

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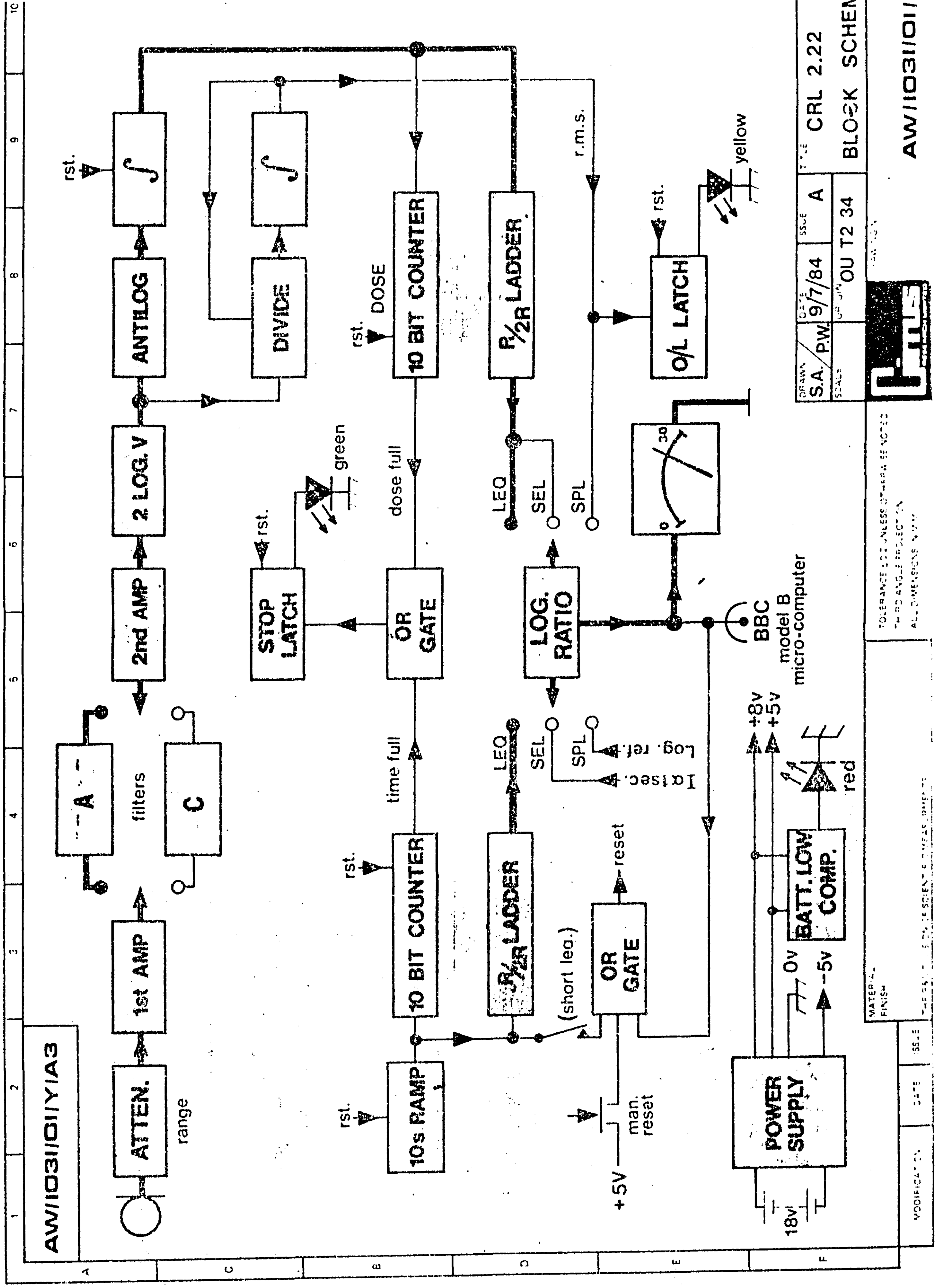
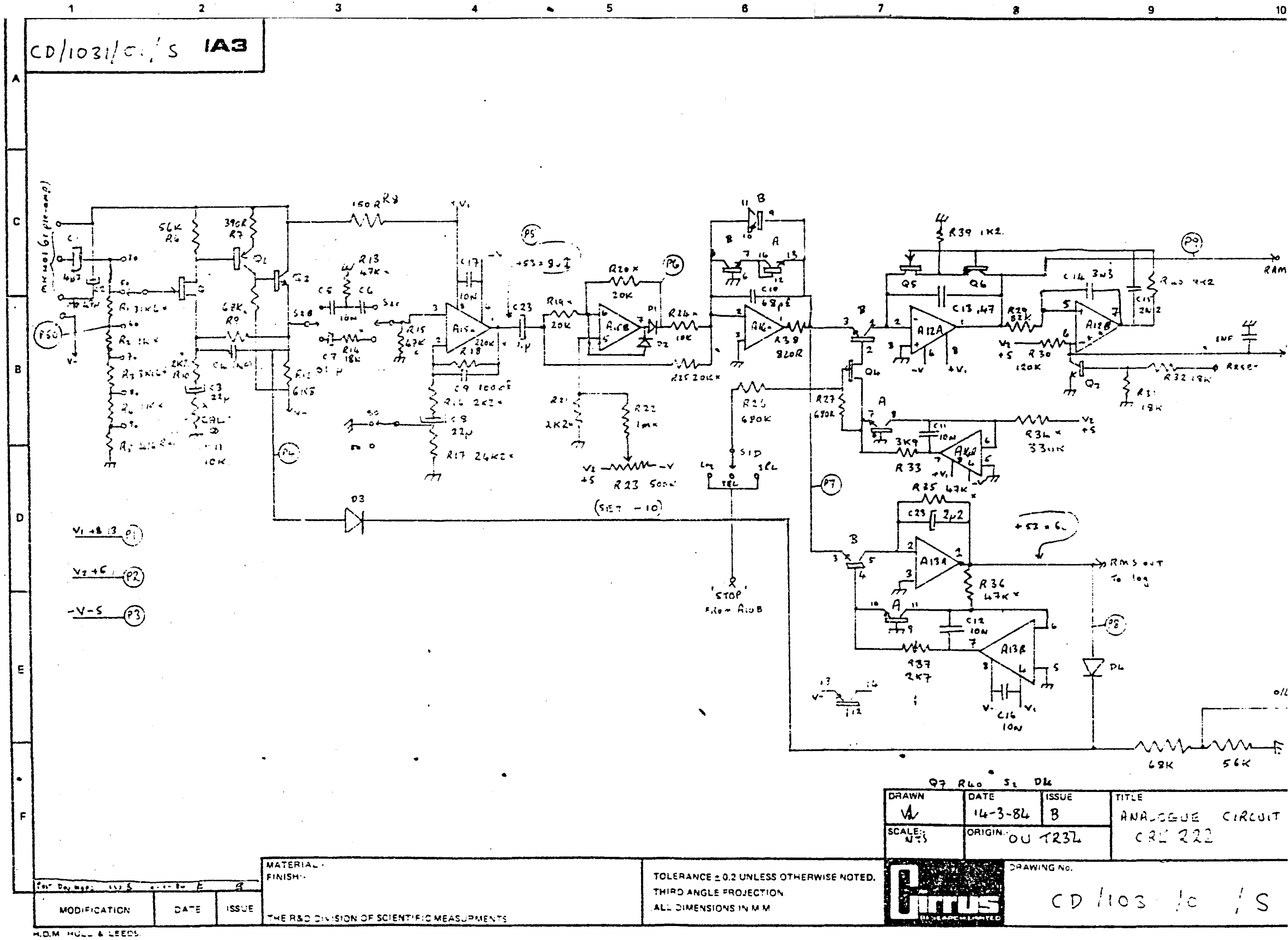
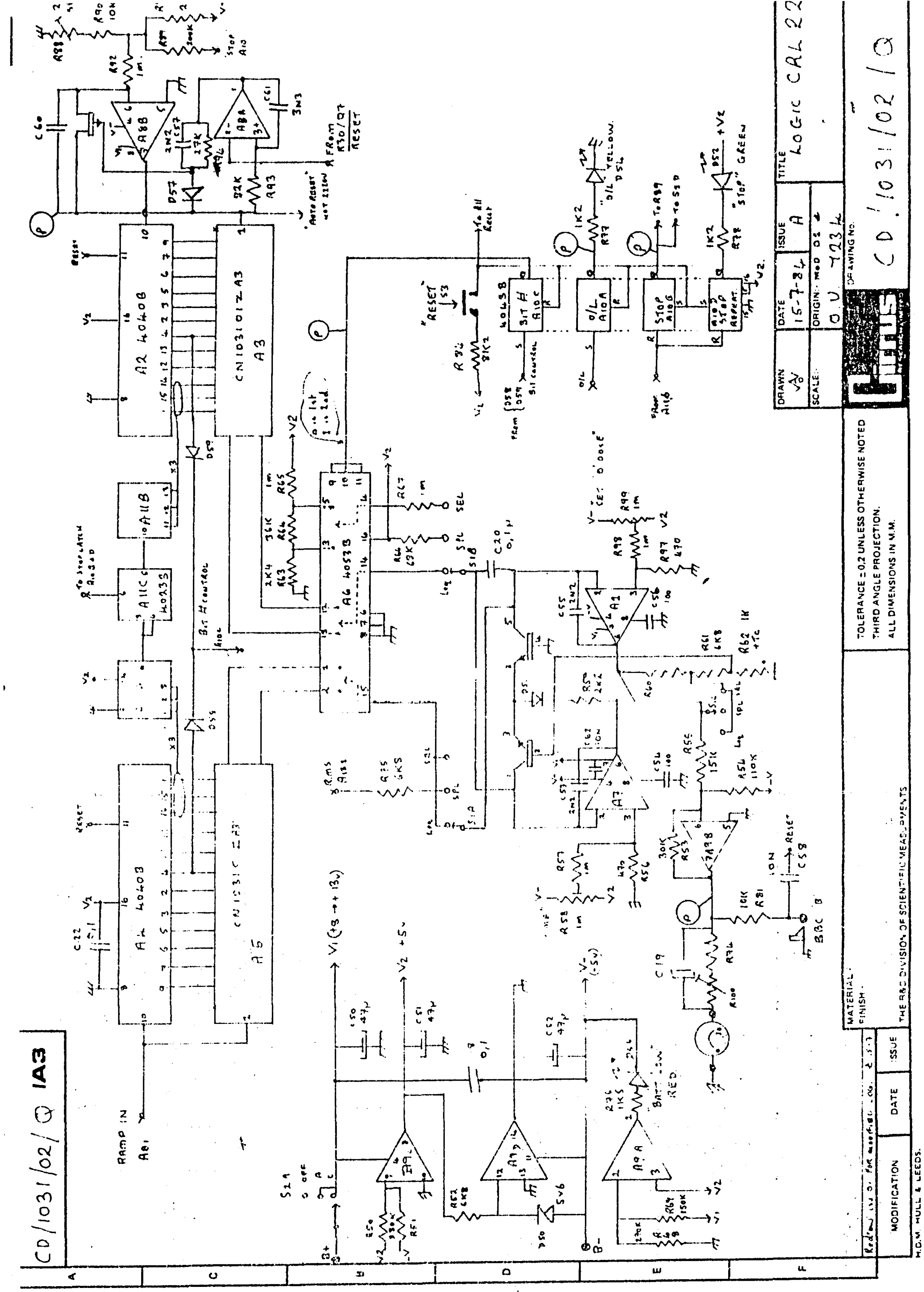
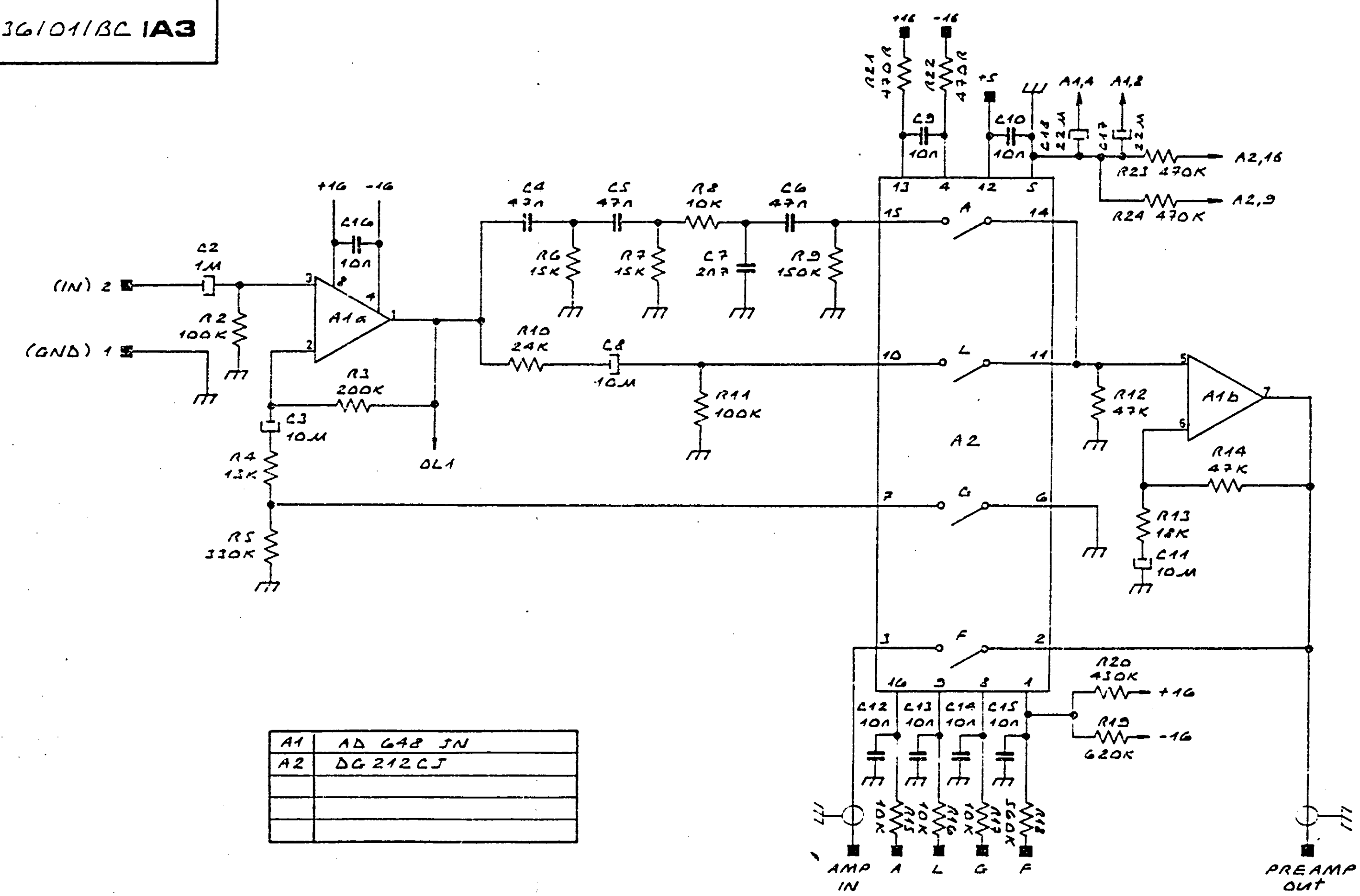

AW/1031/01/Y/A3
ATTEN.
range
1st AMP
filters
A
C
2nd AMP
2 LOG. V
ANTILOG
rst.
DIVIDE
10s RAMP
rst.
10 BIT COUNTER
time full
10 BIT COUNTER
DOSE
dose full
OR GATE
STOP LATCH
green
R/2R LADDER
R/2R LADDER
LEQ
SEL
SPL
LOG. RATIO
Iatsec.
Log. ref.
r.m.s.
O/L LATCH
yellow
BBC model B micro-computer
(short lea.)
OR GATE
reset
man. reset
+5V
POWER SUPPLY
18v
0v
-5v
+8v
+5v
BATT. LOW COMP.
red
CRL 2.22
BLOCK SCHEM
AW/1031/01/
S.A.
P.W.
9/7/84
A
OU T2 34


CD/1031/c.'/S IA3
V1 +8.13 (P1)
V2 +6 (P2)
-V-5 (P3)
(P5) +53 = 9v1
(P6)
(P7)
(P8)
(P9)
+53 = 6v
RMS out To log
RESET
INF
RAM
(SET -10)
'STOP' From A10B
Q7 R40 S1 D4
DRAWN
DATE 14-3-84
ISSUE B
TITLE ANALOGUE CIRCUIT CRL 222
SCALE: NTS
ORIGIN: OU T234
DRAWING No. CD/103 /c /S
MATERIAL:
FINISH:
THE R&D DIVISION OF SCIENTIFIC MEASUREMENTS
TOLERANCE ± 0.2 UNLESS OTHERWISE NOTED.
THIRD ANGLE PROJECTION
ALL DIMENSIONS IN MM
Cirrus Research Limited
MODIFICATION
DATE
ISSUE
H.D.M. HULL & LEEDS


CD/1031/02/Q IA3
LOGIC CAL 22
CD/1031/02/Q
TOLERANCE ± 0.2 UNLESS OTHERWISE NOTED
THIRD ANGLE PROJECTION.
ALL DIMENSIONS IN M.M.
THE R&D DIVISION OF SCIENTIFIC MEASUREMENTS
H.G.M. HULL & LEEDS.
MODIFICATION
DATE
ISSUE
DRAWN
SCALE
DATE
15-7-84
ISSUE
A
TITLE
DRAWING No.

CD/1036/01/BC IA3



A1	AD 648 JN
A2	DG 212 CJ

DRAWN	DATE	ISSUE	TITLE
A.J.B	23. 3. 87.	B	'CRL 236' FRONT END CIRCUIT DIAGRA[M]
SCALE: /	ORIGIN: CIRRUS		

DRAWING No. CD/1036/01/BC

Cirrus Research Limited

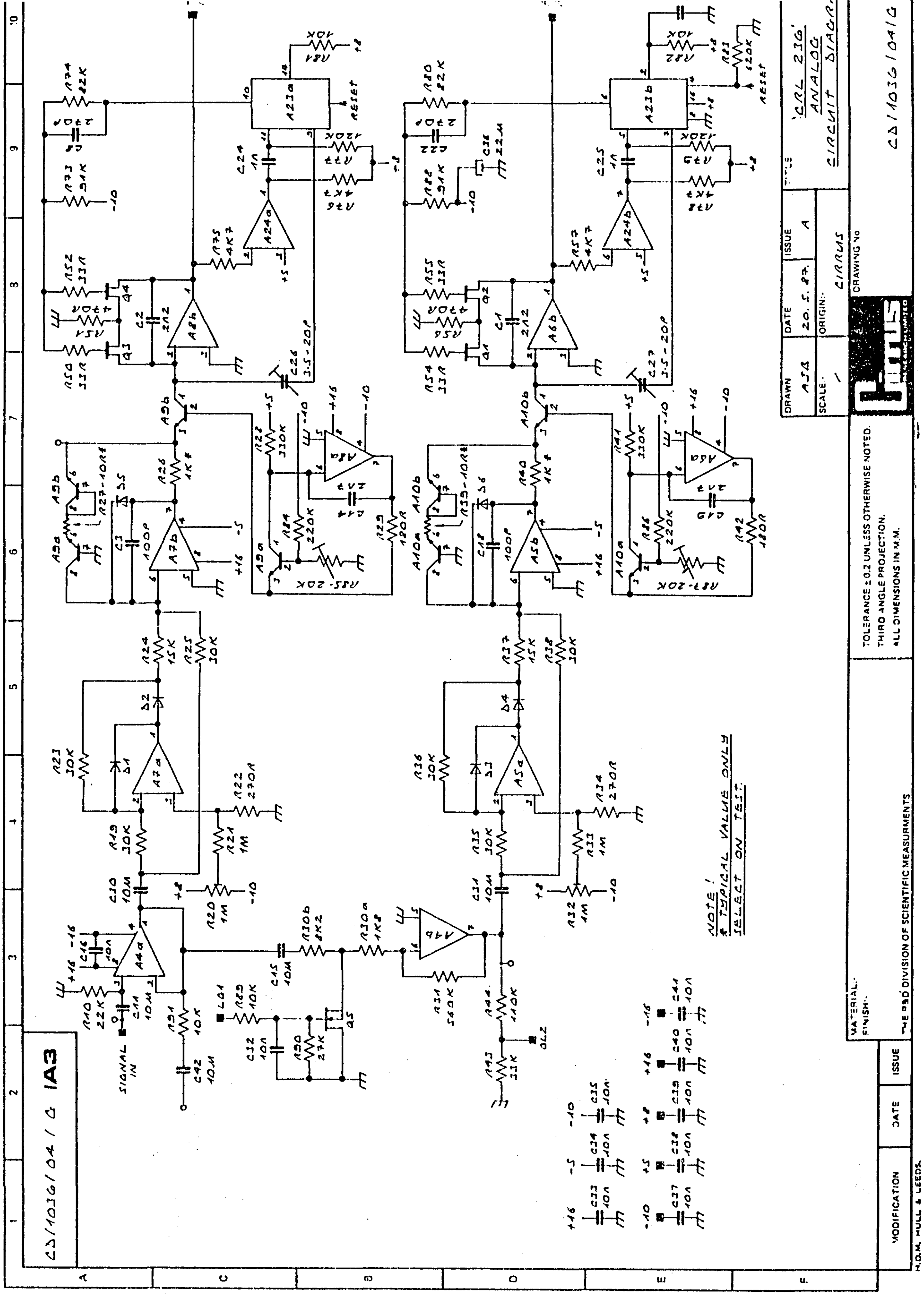
TOLERANCE ± 0.2 UNLESS OTHERWISE NOTED.
THIRD ANGLE PROJECTION.
ALL DIMENSIONS IN M.M.

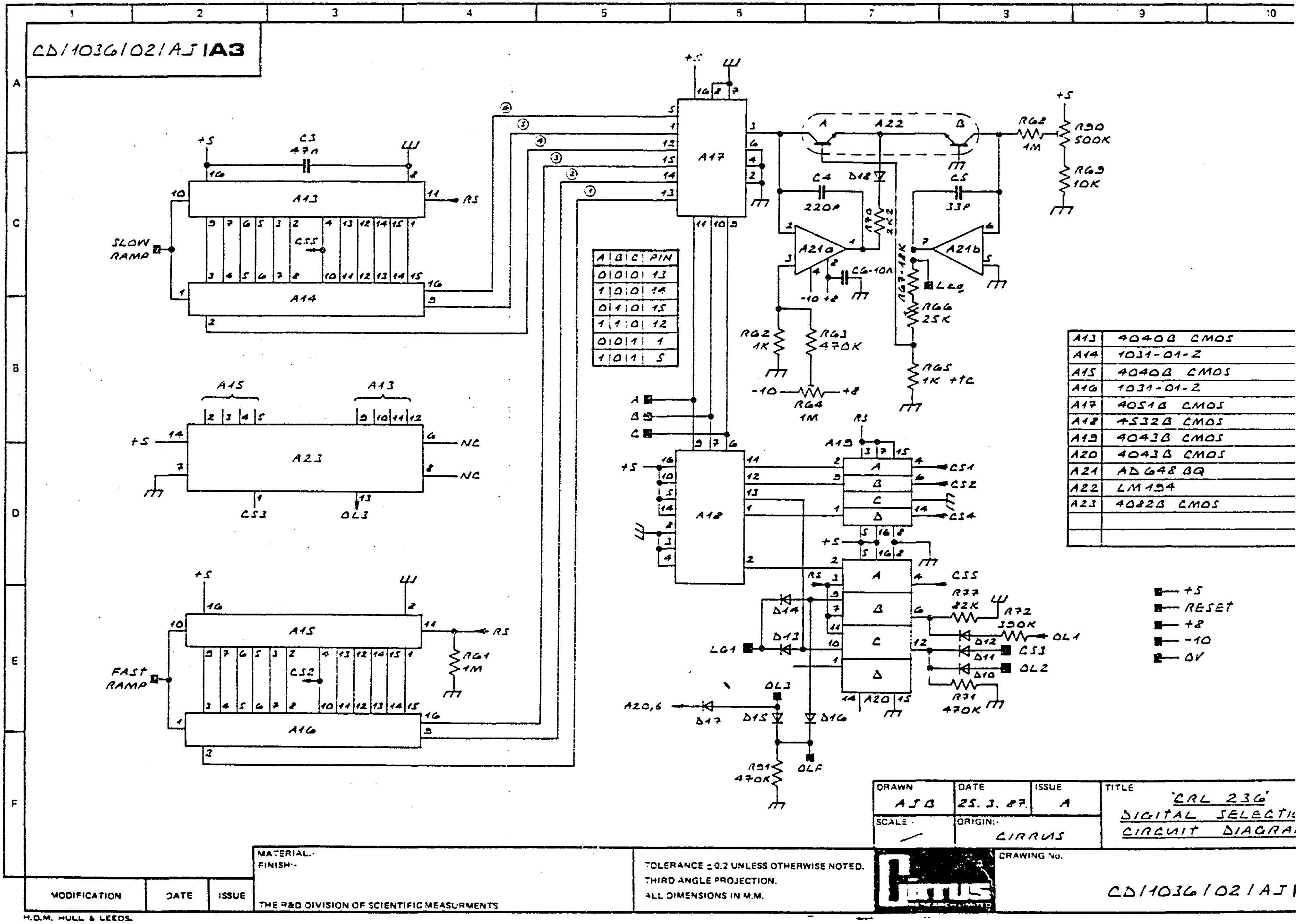
MATERIAL:-
FINISH:-

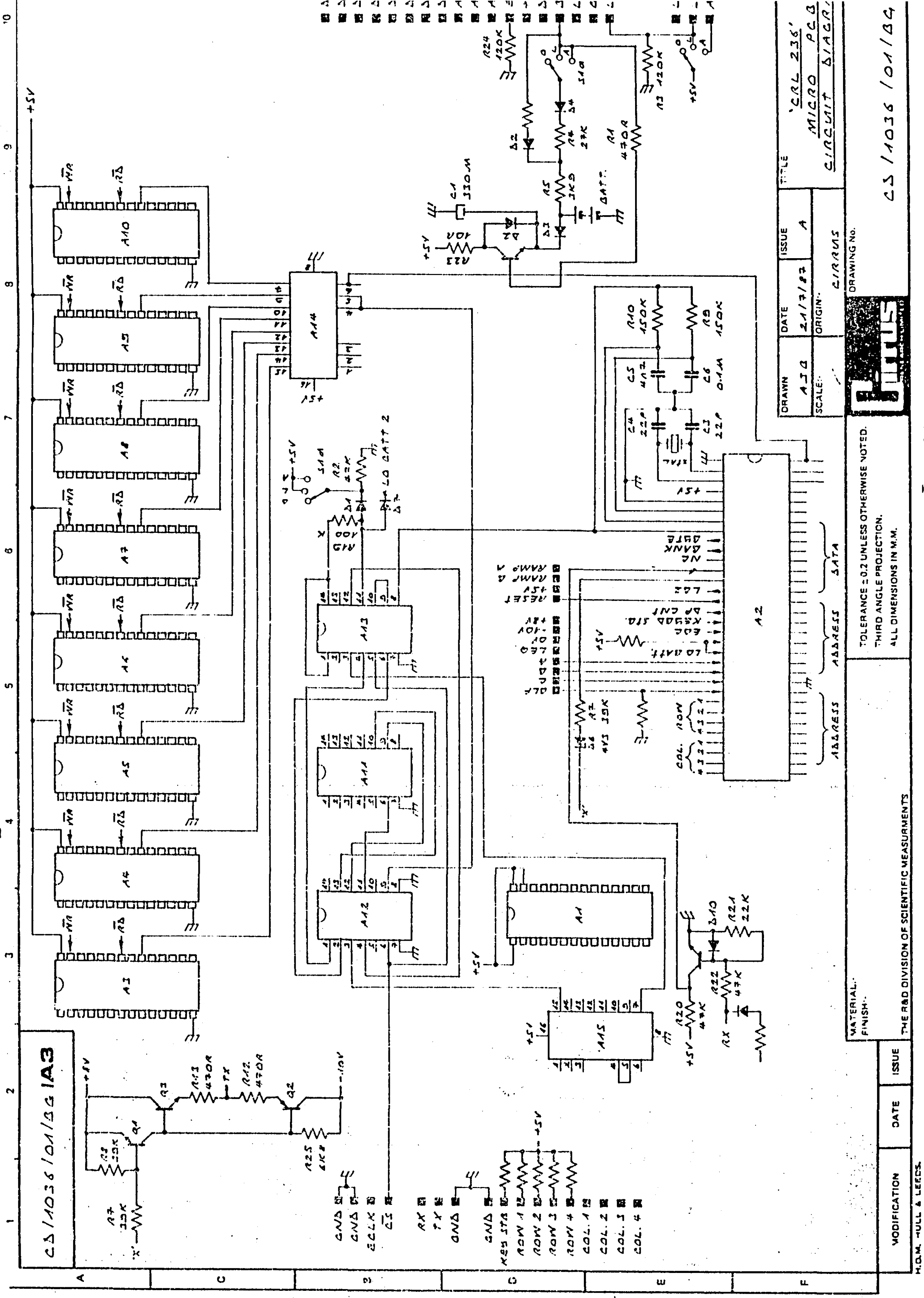
THE R&D DIVISION OF SCIENTIFIC MEASURMENTS

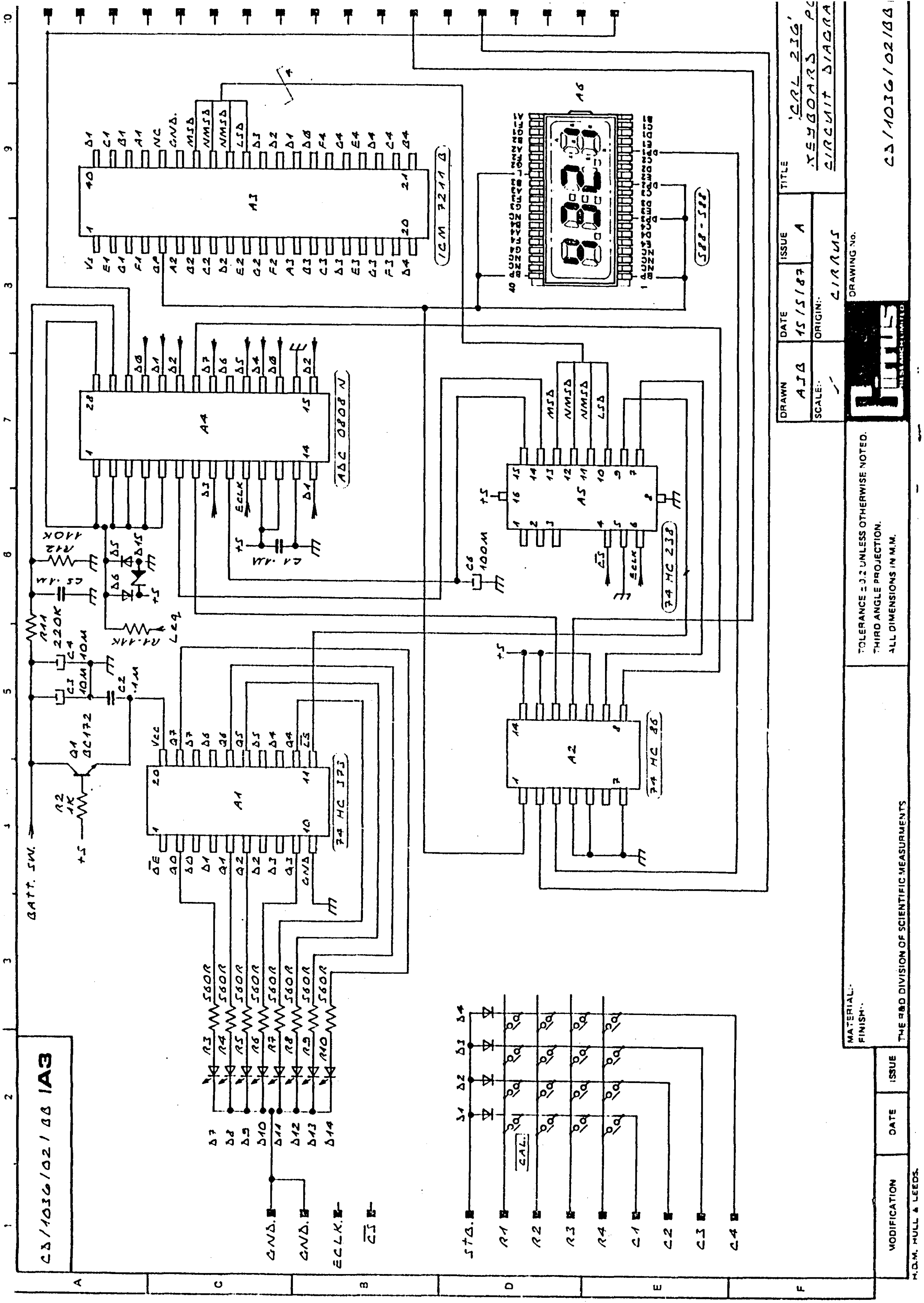
MODIFICATION	DATE	ISSUE
REMOVED R18 & C1	12/6/87	B

H.D.M. HULL & LEEDS.

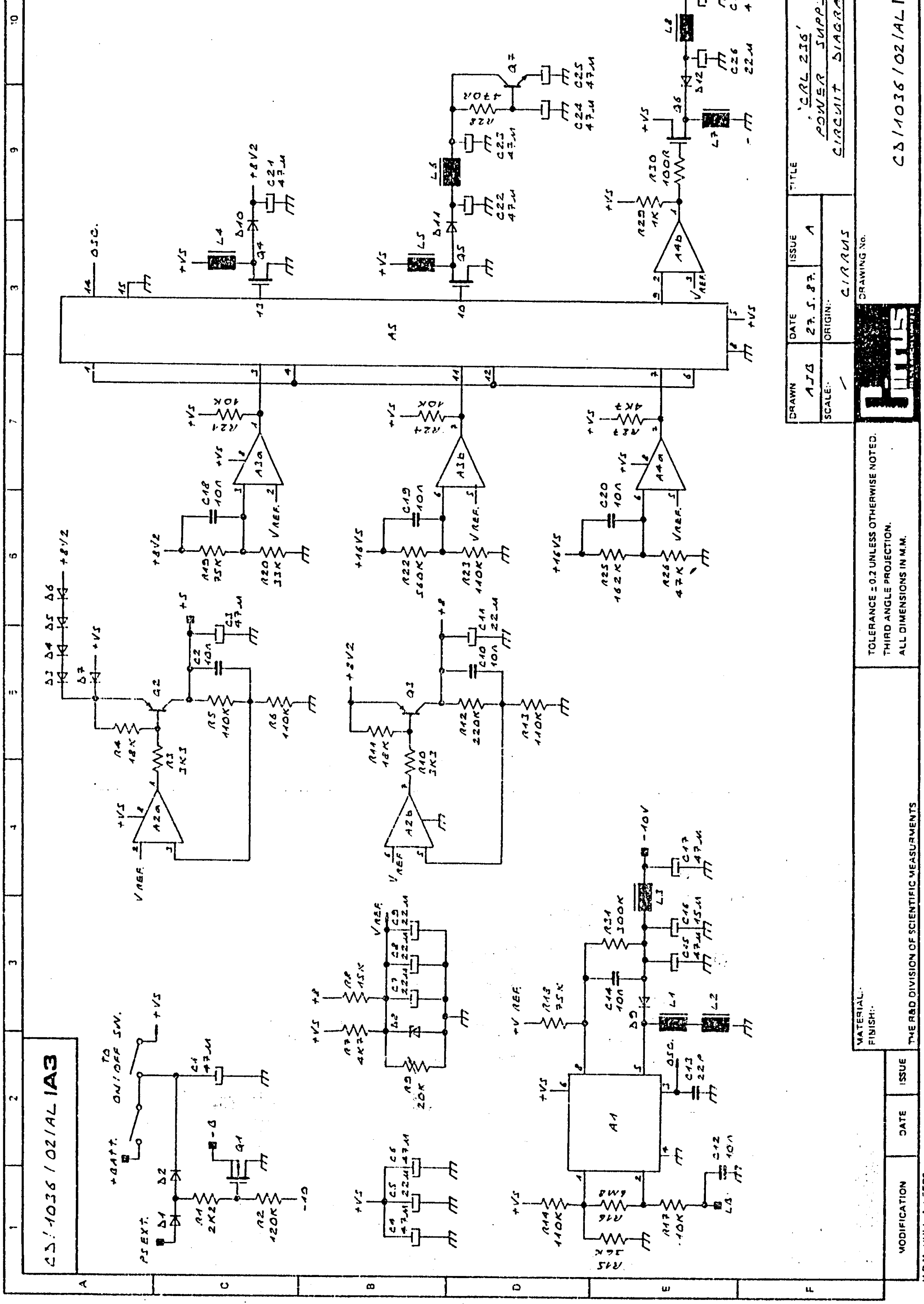

CRL 236'
ANALOG
CIRCUIT DIAGR.
CD/103G/04/G
IA3
DRAWN AJB
DATE 20.5.87
ISSUE A
ORIGIN: CIRRUS
TOLERANCE ± 0.2 UNLESS OTHERWISE NOTED.
THIRD ANGLE PROJECTION.
ALL DIMENSIONS IN M.M.
NOTE !
* TYPICAL VALUE ONLY
SELECT ON TEST.
SIGNAL IN
RESET
THE R&D DIVISION OF SCIENTIFIC MEASUREMENTS
MODIFICATION
DATE
ISSUE
MATERIAL:
FINISH:
H.D.M. HULL & LEEDS.

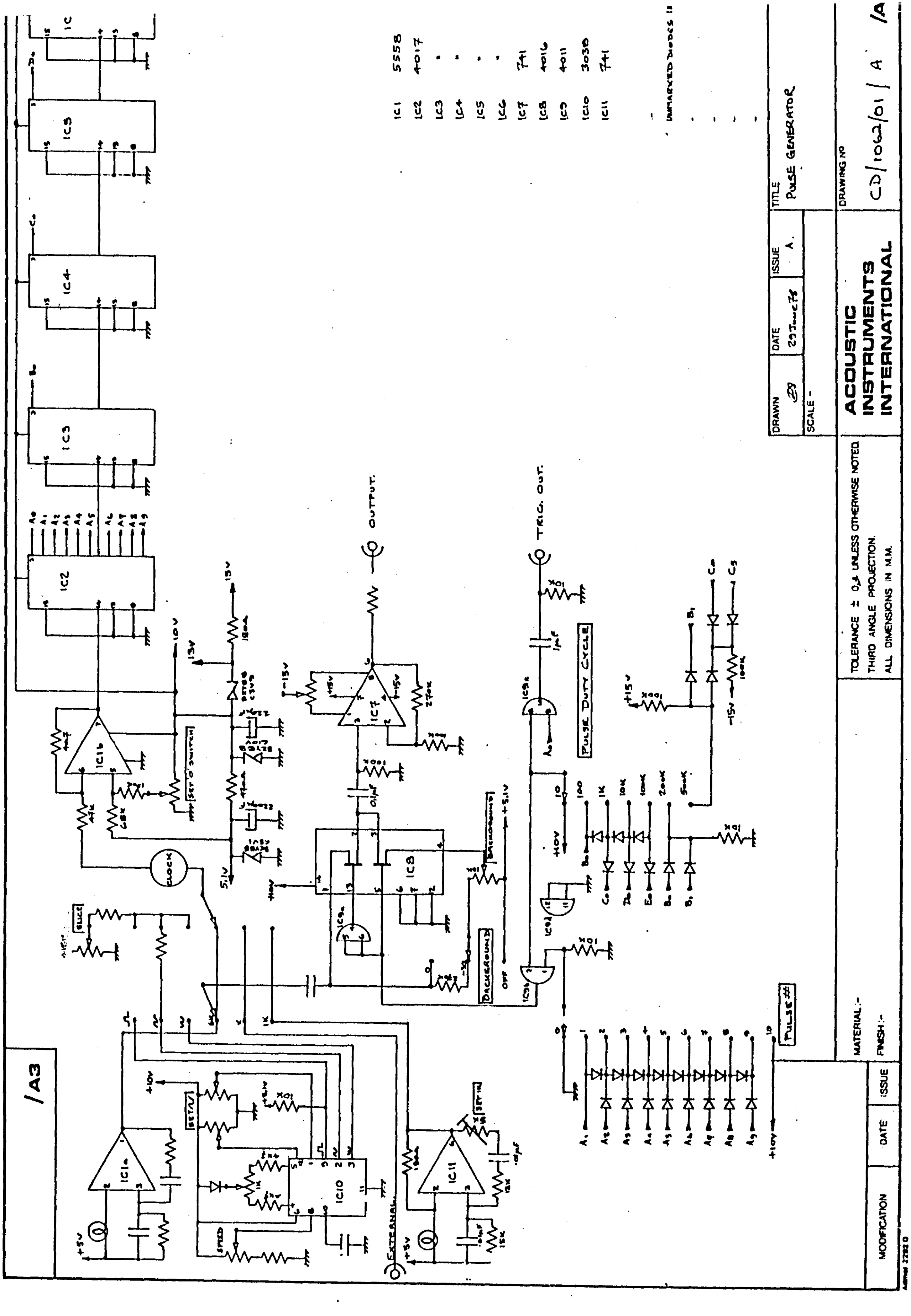

CD/1036/02/AJ A3
A13 40408 CMOS
A14 1031-01-Z
A15 40408 CMOS
A16 1031-01-2
A17 40518 CMOS
A18 45328 CMOS
A19 40438 CMOS
A20 40438 CMOS
A21 AD648 BQ
A22 LM194
A23 40828 CMOS
SLOW RAMP
FAST RAMP
+5
RESET
+8
-10
0V
DRAWN AJB
DATE 25. 3. 87
ISSUE A
SCALE: /
ORIGIN: CIRRUS
TITLE 'CRL 236' DIGITAL SELECTION CIRCUIT DIAGRAM
DRAWING No. CD/1036/02/AJ
MATERIAL:-
FINISH:-
TOLERANCE ± 0.2 UNLESS OTHERWISE NOTED.
THIRD ANGLE PROJECTION.
ALL DIMENSIONS IN M.M.
THE R&D DIVISION OF SCIENTIFIC MEASURMENTS
MODIFICATION
DATE
ISSUE
H.D.M. HULL & LEEDS.


'CRL 236' MICRO PCB CIRCUIT DIAGRAM
CS/1036/01/BG
CS/1036/01/BG IA3
TOLERANCE ± 0.2 UNLESS OTHERWISE NOTED.
THIRD ANGLE PROJECTION.
ALL DIMENSIONS IN M.M.
THE R&D DIVISION OF SCIENTIFIC MEASUREMENTS
MODIFICATION
DATE
ISSUE



TOLERANCE ± 0.2 UNLESS OTHERWISE NOTED.
THIRD ANGLE PROJECTION.
ALL DIMENSIONS IN M.M.
THE R&D DIVISION OF SCIENTIFIC MEASUREMENTS
MODIFICATION
DATE
ISSUE
MATERIAL:
FINISH:
DRAWN
DATE
ISSUE
TITLE
SCALE:
ORIGIN:
DRAWING No.


CS/1036/02/AL IA3
'CRL 236'
POWER SUPP
CIRCUIT DIAGRA
DRAWN AJD
DATE 27.5.87
ISSUE A
ORIGIN: CIRRUS
DRAWING No. CS/1036/02/AL
TOLERANCE ± 0.2 UNLESS OTHERWISE NOTED.
THIRD ANGLE PROJECTION.
ALL DIMENSIONS IN M.M.
THE R&D DIVISION OF SCIENTIFIC MEASUREMENTS
MODIFICATION
DATE
ISSUE



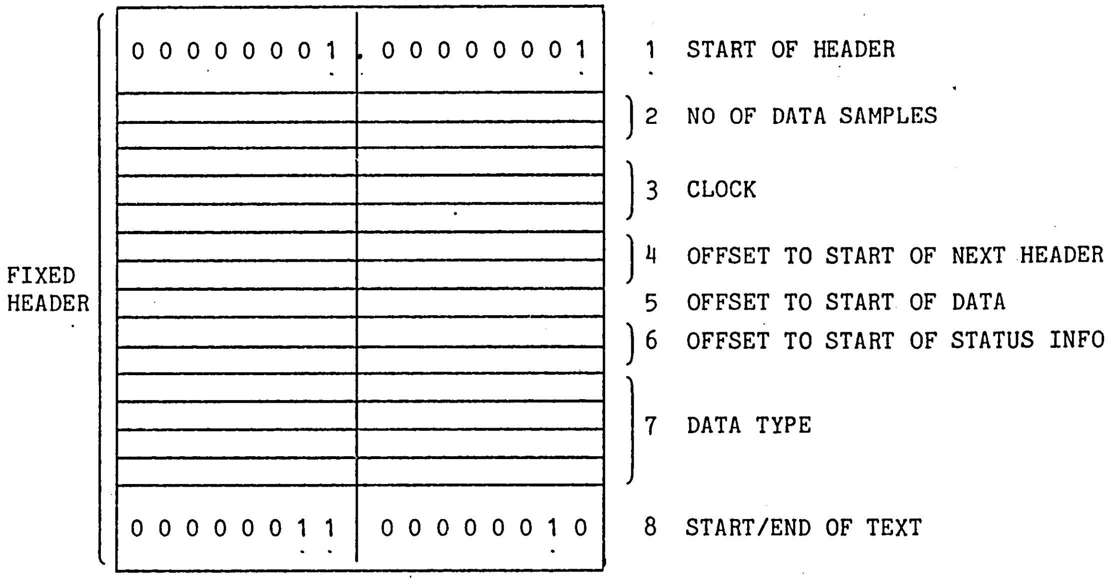
/A3
OUTPUT.
TRIG. OUT.
CLOCK
SET 'O' SWITCH
PULSE DUTY CYCLE
BACKGROUND
PULSE #
EXTERNAL
SPEED
IC1 555B
IC2 4017
IC7 741
IC8 4016
IC9 4011
IC10 3030
IC11 741
UNMARKED DIODES
TOLERANCE ± 0.1 UNLESS OTHERWISE NOTED.
THIRD ANGLE PROJECTION.
ALL DIMENSIONS IN M.M.
MATERIAL:-
FINISH:-
MODIFICATION
DATE
ISSUE
DRAWN
DATE
29 June 78
ISSUE
A.
TITLE
PULSE GENERATOR
SCALE -
DRAWING No
CD/1062/01 / A
ACOUSTIC INSTRUMENTS INTERNATIONAL

DATA STRUCTURE FOR DATA FORMAT AND STORAGE

This structure runs within the timer interrupt after a/d conversion and integrator reset.

```
IF ACMODE == 0
THEN    RETURN
*** DO A/D ETC HERE ***
PACK TWO BYTES OF DATA INTO DATA WORD
IF DATA WORD > MAX WORD
THEN    MAX WORD = DATA WORD
        IF LCD_MAX_UPDATE == 1
        THEN    CONVERT MAX WORD TO BCD
LOG ADD DATA WORD TO CUM TOTAL WORD
IF LCD_CUM_UPDATE == 1
THEN    CONVERT CUM TOTAL WORD TO BCD
LOG ADD DATA WORD TO RUNNING TOTAL WORD
TOTAL COUNTER
IF TOTAL COUNTER == ACTYPE (EG 80)
THEN    TOTAL COUNTER = 0
        IF LCD_LEQ_UPDATE == 1
        THEN    CONVERT RUNNING TOTAL WORD TO BCD
        RAM VALUE = RUNNING TOTAL WORD + CODE + ERRORFLAG
        STORE RAM VALUE AT RAM POINTER
        INC RAM POINTER (24 BIT)
        INC DATA COUNTER (24 BIT)
```

HEADER INFORMATION



1 Start of header ASCII code x 2.

2 No of data samples, NB not including non-data bounded by 0000H, 0000H.

3 Clock gives start time in seconds from .....

4 Offset to start of next header, from start of this header.

5 Offset to start of data, from start of this header.

6 Offset to start of status information, from start of this header, 00 = no info

7 Basic data type information.

3	2	1	0
7	6	5	4
B	A	9	8
F	E	D	C

NIBBLE 0: Source of data - coded - normally refers to bits 0 -> 10.

0 Not in use or not relevant - coding could be in use.
1 Sound
2 Vibration
3 Voltage
.
:
F Go to data type extension for more information

NIBBLE 1: Intentionally left blank.

NIBBLE 2: Frequency weighting.

0 Not in use or not relevant
1 A weighting
2 B weighting
3 C weighting
4 D weighting
5 Lin weighting
6 Integral
7 Double Integral
8 Differential
.
:
F Go to data type extension for more information

NIBBLE 3: Intentionally left blank

NIBBLE 4: Filters

0 Not in use or not relevant
1 All 8^{ve} filters in use, each channel sampled sequentially
2 All $\frac{1}{3}8^{ve}$ filters in use, each channel sampled sequentially
3 All 8^{ve} filters in use, each channel sampled simultaneously
4 All $\frac{1}{3}8^{ve}$ filters in use, each channel sampled simultaneously
.
:
F Go to data type extension for more information.

NIBBLE 5: Intentionally left blank.

NIBBLE 6: Time response applied

0 Not in use or not relevant
1 True Integral
2 Peak Hold
3 Impulse Hold
4 Fast Hold
5 Slow Hold
6 Impulse normal
7 Fast normal
8 Slow normal
.
:
F Go to data type extension for more information

NIBBLE 7: Intentionally left blank

NIBBLE 8: Code buttons used $B_3B_2B_1B_0 \equiv C_4C_3C_2C_1$

NIBBLE 9: Intentionally left blank

NIBBLE A: Sample time

0 Not in use or not relevant
1 100 ms
. .

2 125 ms
3 1 s
4 2 s
5 10 s
6 60 s
.
.
.
F Go to data type extension for more information

NIBBLE B: Intentionally left blank

NIBBLE C:
Calibration offset
NIBBLE D:

NIBBLE E: Bit 0 set if calibrated since last pause, otherwise cleared

NIBBLE F: Bit 3 signifies if there is another data type (0 = NO, 1 = YES)

8 Delimiters for textual information. Default is START OF TEXT - END OF TEXT.

Extended Header

If any of the nibbles in the basic data type is set to 'F', the data type extension is inserted before the text. The data type extensions are placed in the order in which they were called, eg NIBBLE 0, NIBBLE 2, etc. The data type extensions are terminated by a "zero" word. If the data type says that a non-standard form is in use (F), the extension may only consist of the zero word, to say that no further explanation is possible. The number of "zero" words must equal the number of data type extensions requested.

DATA STRUCTURE FOR KEYBOARD INTERPRETATION

This structure runs within the main loop.

```
GET A KEY VALUE
IF KEY == LED ENABLE
THEN     SET LEDS_ON_FLAG
ELSE IF KEY == SHORT LEQ
THEN     LCD_LEQ_UPDATE = 1
         LCD_MAX_UPDATE = 0
         LCD_CUM_UPDATE = 0
         LCD_NO_UPDATE = 0
         UPDATE_LEDS BYTE
ELSE IF KEY == MAX LEQ
THEN     LCD_LEQ_UPDATE = 0
         LCD_MAX_UPDATE = 1
         LCD_CUM_UPDATE = 0
         LCD_NO_UPDATE = 0
         UPDATE_LEDS BYTE
ELSE IF KEY == CUM LEQ
THEN     LCD_LEQ_UPDATE = 0
         LCD_MAX_UPDATE = 0
         LCD_CUM_UPDATE = 1
         LCD_NO_UPDATE = 0
         UPDATE_LEDS BYTE
ELSE IF KEY == LEQ NO
THEN     LCD_LEQ_UPDATE = 0
         LCD_MAX_UPDATE = 0
         LCD_CUM_UPDATE = 0
         LCD_NO_UPDATE = 1
         UPDATE_LEDS BYTE
ELSE IF ACMODE == 1
THEN     IF KEY == PAUSE
         THEN     ACMODE = 0
                  FINISH HEADER
                  UPDATE LEDS BYTE
         ELSE IF KEY == RESET CUM
         THEN     CUM VALUE = 0
         ELSE IF KEY == RELEASE MAX
         THEN     MAX VALUE = 0
         ELSE IF KEY ROW == CODES ROW
         THEN     CODE STORE = KEY COLUMN NIBBLE
ELSE (IF ACMODE == 0)
THEN     IF KEY == CAL
         THEN     DO NOTHING
         ELSE IF KEY == "1/8" OR KEY == "1" OR KEY == "10"
         THEN     UPDATE LEDS BYTE
                  IF KEY == "1/8"
                  THEN     ACTYPE = 1
                  ELSE IF KEY == "1"
                  THEN     ACTYPE = 8
                  ELSE IF KEY == "10"
                  THEN     ACTYPE = 80
                  ACMODE = 1
ELSE     DO NOTHING
IF LCD_NO_UPDATE == 1
THEN     CONVERT LCD NO TO DISPLAY FORMAT
ELSE IF LCD_LEQ_UPDATE == 1
THEN     CONVERT LEQ VALUE TO DISPLAY FORMAT
DISPLAY DATA SELECTED BY LCD UPDATE FLAGS
```

COMMS INTERRUPT STRUCTURE DESIGN

```
IF INTERRUPT DUE TO TXREADY
THEN    IF TXFLAG !=1
        THEN    RTI
        IF RAMFLAG == 0
        THEN    GET CHAR FROM TXPTR
                PUT CHAR INTO TXD
                CLI
                TXPTR++
                IF TXPTR == TXEND
                THEN    TXFLAG = 0
                RTI
        ELSE    SAVE PORT2
                P2.0 = TXBANK
                P2.1 = TXPAGE
                GET CHAR FROM TXPTR
                PUT CHAR INTO TXD
                RESTORE PORT2
                CLI
                IF TXHFLG == 1
                THEN    IF TXBANK == 0
                        THEN    IF HDRCTR == 6
                                THEN    OFF2 = CHAR
                                ELSE    IF HDRCTR == 7
                                        THEN    OFF4 = CHAR
                        ELSE    IF HDRCTR == 6
                                THEN    OFF1 = CHAR
                                ELSE    IF HDRCTR == 7
                                        THEN    OFF3 = CHAR
                IF TXBANK == 01
                THEN    TXBANK = 0
                        RTI
                ELSE    TXBANK = 1
                        TXPTR++
                        IF TXPTR == E000
                        THEN    TXPTR = RAMSTRT
                                TXPAGE = 1
                        IF TXHFLG !=0
                        THEN    IF TXPTR == TXEND
                                THEN    IF TXPAGE == TXENDPG
                                        THEN    TXFLAG = 0
                                RTI
                        ELSE    HDRCTR++
                                IF HDRCTR == 16
                                THEN    IF OFF1 == 0
                                        THEN IF OFF2 == 0
                                             THEN IF OFF3 == 0
                                                  THEN IF OFF4 == 0
                                                       THEN TXFLAG = 0
                                                            TXHFLG = 0
                                                            RTI
                                        HDRSTRT += OFF2.OFF1 DOUBLE
                                        HSTRTPG += OFF3 + CARRY
                                        TXPAGE = HSTRTPG
                                        TXPTR = HDRSTRT
                                RTI
ELSE (IF INTERRUPT DUE TO RXREADY OR OVF)
THEN    READ CHAR
        CLI
```

```
IF CHAR == ESC
THEN    TXPTR = START OF ESC MESSAGE IN ROM
        TXPAGE = 0
        TXEND = END OF ESC MESSAGE IN ROM + 1
        TXENDPG = 0
        NUMBER MODE = 0
        RAMFLAG = 0
        TXHFLG = 0
        TXFLAG = 1
        RTI
ELSE IF NUMBER MODE == 1
THEN    PUT CHAR IN RXPTR
        INC RXPTR
        IF RXPTR >= RXBUF+20
        THEN    NUMBER MODE = 0
                CALCULATE RAMSTART AND RAMEND FROM 16 DIGITS
                  FROM RXPTR+2 IE IGNORE THE LG CHARACTERS
                TXPTR = CALCULATED RAMSTART
                TXPAGE = CALCULATED RAMSTART
                TXEND = CALCULATED RAMEND
                TXENDPG = CALCULATED RAMEND
                TXHFLG = 0
                RAMFLAG = 1
                TXFLAG = 1
                TXBANK = 0
                RXPTR = RXBUF
        RTI
ELSE    PUT CHAR INTO RXPTR
        INC RXPTR
        IF RXPTR >= RXBUF+4
        THEN    IF MESSAGE IN RXBUF == PR
                THEN    TXFLAG = 1
                        TXHFLG = 1
                        TXPTR = START OF RAM
                        HEADER START = TXPTR
                        HDRCTR = 0
                        RAMFLAG = 1
                        TXPAGE = 0
                        HSTRTPG = 0
                        TXBANK = 1
                        RXPTR = RXBUF
                        NUMBER MODE = 0
                        RTI
                ELSE IF MESSAGE IN RXBUF == ID
                THEN    TXPTR = START OF ID MESSAGE IN ROM
                        TXPAGE = 0
                        TXEND = END OF ID MESSAGE IN ROM + 1
                        TXENDPG = 0
                        TXFLAG = 1
                        TXHFLG = 0
                        RAMFLAG = 0
                        TXBANK = 0
                        RXPTR = RXBUF
                        NUMBER MODE = 0
                        RTI
                ELSE IF MESSAGE IN RXBUF == LG
                THEN    NUMBER MODE = 1
                        RTI
```

```
          ELSE      TXPTR = START OF ERROR MESSAGE IN ROM
                    TXPAGE = 0
                    TXEND = END OF ERROR MESSAGE IN ROM + 1
                    TXENDPG = 0
                    TXFLAG = 1
                    TXHFLG = 0
                    RAMFLAG = 0
                    TXBANK = 1
                    RXPTR = RXBUF
                    NUMBER MODE = 0
                    RTI
     RTI
```

```
LOC  OBJ         LINE        SOURCE STATEMENT

                   $ PAGEWIDTH(80) PAGELENGTH(69) DEBUG
                   ;
                   ;
                   ;PROGRAM TO MEASURE DOSE BY CONTROLLING A CHARGE
                   ;  BALANCING INTEGRATOR WITH TWO SELECTABLE BALANCING
                   ;  CURRENTS, & TO CALCULATE EITHER LEQ OR SOUND EXPOSURE
                   ;  FROM THE DOSE & TIME DATA.
                   ;THE CURRENT SOUND LEVEL IS SAMPLED EVERY 10MS USING AN
                   ;  A/D CONVERTER, & A SERIES OF 1DB WIDE BINS ARE USED
                   ;  TO ACCUMULATE DATA FOR CALCULATION OF TWO
                   ;  SYMMETRICAL PERCENTILES: L10 & L90.
                   ;
                   ;
0003                       HITIM EQU 03H    ;INITIALIZE VARIABLES
0017                       LPC10H EQU 17H
0070                       LPC10L EQU 70H
                   ;
                   ;
0000                       ORG 00H          ;SA=00H
0000 040A                  JMP RESET        ;JUMP TO RESET ROUTINE
000A                       ORG 0AH
000A 27            RESET:  CLR A
000B 9A0F                  ANL P2,#0FH      ;CLEAR STOP SIGNAL &
                                            ;  LO & HI CURRENTS
000D 02                    OUTL BUS,A       ;CLEAR BUS
000E 39                    OUTL P1,A        ;CLEAR PORT 1
000F B87F                  MOV R0,#7FH      ;CLEAR ALL DATA MEMORY
0011 A0            CLEAR:  MOV @R0,A
0012 E811                  DJNZ R0,CLEAR
0014 3614          WAIT:   JT0 WAIT         ;WAIT UNTIL CHARGE BALANCING
                                            ;  IS REQU'D BEFORE STARTING
                                            ;  TIMER - INTEGRATOR DOES NOT
                                            ;  RESET PROPERLY
                   ;
                   ;
                   ;MAIN PROGRAM FOR CONTROLLING METER FUNCTIONS
0016 D5            MAIN:   SEL RB1          ;INITIALIZE R4 TO TIME
0017 BC20                  MOV R4,#20H      ;  LEQ CALCULATIONS
0019 2383          STARTT: MOV A,#83H       ;INITIALIZE TIMER FOR
001B 62                    MOV T,A          ;  10MS PERIOD
001C 55                    STRT T
001D 148C                  CALL SLCONV      ;PERFORM SOUND LEVEL CONVERSION
001F EC31                  DJNZ R4,LEQINT   ;EVERY 320MS UPDATE METER O/P
0021 BC20                  MOV R4,#20H      ;RESET R4 TO TIME LEQ CALCS
0023 341E                  CALL DOSCON      ;CONVERT DOSE VALUE
0025 0A                    IN A,P2          ;LEQ OR SOUND EXPOSURE?
0026 37                    CPL A            ; (INVERT SWITCH LOGIC)
0027 322F                  JB1 SEXREQ       ;  SE, JUMP TO SE ROUTINE
0029 3494                  CALL TIMCON      ;  LEQ, CONVERT TIME VALUE
002B 5400                  CALL LEQCAL      ;CALCULATE & O/P LEQ ON BUS
002D 0431                  JMP LEQINT       ;BALANCE THE INTEGRATOR
002F 542D          SEXREQ: CALL SEXCAL      ;CALCULATE & O/P SE ON BUS
0031 145B          LEQINT: CALL LEQDA       ;PERFORM CHARGE BALANCING
0033 FC                    MOV A,R4         ;IS MEASUREMENT TIME FINISHED?
0034 0316                  ADD A,#16H
0036 9619                  JNZ STARTT       ;  NO, RESTART TIMER
```

```
LOC  OBJ         LINE        SOURCE STATEMENT

                  58 ;
0038 341E         59            CALL DOSCON      ;  YES, UPDATE DOSE & TIME
003A 3494         60            CALL TIMCON
003C FC           61            MOV A,R4
003D 37           62            CPL A
003E 17           63            INC A
003F 6F           64            ADD A,R7
0040 0332         65            ADD A,#32H
0042 B81A         66            MOV R0,#1AH      ;STORE UPDATED LEQ VALUE IN
0044 A0           67            MOV @R0,A        ;  R2, REGISTER BANK 1
0045 14C2         68            CALL L1090       ;CALCULATE L10 & L90
0047 8A4F         69            ORL P2,#4FH      ;SIGNAL END OF PERIOD & DATA
                  70                             ;  READY FOR PRESENTATION
0049 0A           71 SERREQ: IN  A,P2            ;TEST FOR REQUESTED DATA
004A 37           72            CPL A            ; (INVERT SWITCH LOGIC)
004B 1253         73            JB0 L10OUT       ;BIT 0 SET, L10 REQUESTED
004D 3257         74            JB1 L90OUT       ;BIT 1 SET, L90 REQUESTED
004F FA           75            MOV A,R2         ;BIT 2 SET, LEQ REQUESTED
0050 02           76            OUTL BUS,A       ;OUTPUT LEQ
0051 0449         77            JMP SERREQ       ;  & RETURN TO SERVICE REQUESTS
0053 FC           78 L10OUT: MOV A,R4
0054 02           79            OUTL BUS,A       ;OUTPUT L10
0055 0449         80            JMP SERREQ       ;  & RETURN TO SERVICE REQUESTS
0057 FB           81 L90OUT: MOV A,R3
0058 02           82            OUTL BUS,A       ;OUPUT L90
0059 0449         83            JMP SERREQ       ;  & RETURN TO SERVICE REQUESTS
                  84 ;
                  85 ;
                  86 ;LEQ DATA AQUISITION
005B C5           87 LEQDA:  SEL RB0
005C 35           88            DIS TCNTI        ;DISABLE INTERUPTS
005D 15           89            DIS I            ;
005E B903         90            MOV R1,#HITIM    ;SET MAX NO OF LORAMPS
                  91                             ;BEFORE SELECTING HIRAMP
0060 1686         92 LEQTST: JTF TIMINT          ;TEST TIME OVERFLOW FLAG
                  93                             ;  BEFORE A COMPLETE
                  94                             ;  INTEGRATION CYCLE BEGINS
0062 2666         95            JNTO LOCNT       ;TEST INTEGRATOR COMPARATOR
0064 0460         96            JMP LEQTST       ;  UNTIL BALANCING REQUIRED
0066 E975         97 LOCNT:  DJNZ R1,LORAMP      ;IF HITIM IS NOT EXCEEDED USE
                  98                             ;  LORAMP, OTHERWISE CONTINUE
                  99 ;
                 100 ;
0068 8A20        101 HIRAMP: ORL P2,#20H         ;SWITCH ON HI CURRENT
                 102                             ;  VIA PORT 2 BIT 5
006A 14BD        103            CALL DELAY       ;HI CURRENT ON FOR PREDTERMINED
                 104                             ;  PERIOD
006C 9A0F        105            ANL P2,#0FH      ;SWITCH OFF HI CURRENT
006E 1E          106            INC R6           ;INCREMENT SECOND BYTE OF
                 107                             ;  LEQ COUNT
006F FE          108            MOV A,R6         ;SECOND BYTE OVERFLOW?
0070 965E        109            JNZ LEQTST-2     ;  NO, NEXT INTEGRATION
0072 1F          110            INC R7           ;  YES, INCREMENT THIRD BYTE
0073 045E        111            JMP LEQTST-2     ;NEXT INTEGRATION
                 112 ;
                 113 ;
0075 8A10        114 LORAMP: ORL P2,#10H         ;SWITCH ON LO CURRENT
                 115                             ;  VIA PORT 2 BIT 4
```

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LOC  OBJ        LINE      SOURCE STATEMENT

0077 14BD                          CALL DELAY     ;LO CURRENT ON FOR PREDETERMINED
                                                  ; PERIOD
0079 9A0F                          ANL P2,#0FH    ;SWITCH OFF LO CURRENT
007B 1D                            INC R5         ;INCREMENT FIRST BYTE OF
                                                  ;  LEQ COUNT
007C FD                            MOV A,R5       ;FIRST BYTE OVERFLOW?
007D 9660                          JNZ LEQTST     ;  NO, NEXT INTEGRATION
007F 1E                            INC R6         ;  YES, INCREMENT SECOND BYTE
0080 FE                            MOV A,R6       ;SECOND BYTE OVERFLOW?
0081 9660                          JNZ LEQTST     ;  NO, NEXT INTEGRATION
0083 1F                            INC R7         ;  YES, INCREMENT THIRD BYTE
0084 0460                          JMP LEQTST     ;NEXT INTEGRATION
0086 1B                    TIMINT: INC R3         ;INCREMENT LO BYTE OF TIME STORE
0087 FB                            MOV A,R3
0088 968B                          JNZ TIMCNT     ;  & ON OVERFLOW
008A 1C                            INC R4         ;  INCREMENT HI BYTE
008B 83                    TIMCNT: RET            ;RETURN TO MAIN
                           ;
                           ;
                           ;SOUND LEVEL CONVERSION FOR L10/L90 COMPUTATION
008C D5                    SLCONV: SEL RB1        ;SELECT REGISTER BANK 1
008D 35                            DIS TCNTI      ;DISABLE INTERUPTS
008E 15                            DIS I
008F BF06                          MOV R7,#06H    ;COUNTER R7=6
0091 27                            CLR A          ;CLEAR A,R6
0092 AE                            MOV R6,A
0093 BD40                          MOV R5,#40H    ;SET TEST BIT IN R5
                           ;
                           ;
                           ;6 BIT SUCCESSIVE APPROXIMATION ALGORITHM
0095 FD                    LOOP:   MOV A,R5       ;MOVE TEST BIT RIGHT
0096 77                            RR  A          ;  FROM MSB TO LSB
0097 AD                            MOV R5,A
0098 4E                            ORL A,R6       ;ADD IT TO PRESENT VALUE IN R6
0099 39                            OUTL P1,A      ;  AND OUTPUT VIA PORT 1
009A BA04                          MOV R2,#04H    ;TEMP DELAY FOR TESTING
009C EA9C                  TIMDEL: DJNZ R2,TIMDEL
009E 56A1                          JT1 DROP       ;OUTPUT TOO LARGE?
                                                  ;  YES, DROP NEW VALUE
00A0 AE                            MOV R6,A       ;  NO, SAVE NEW VALUE
00A1 EF95                  DROP:   DJNZ R7,LOOP   ;GO ON TO NEXT BIT
                                                  ;WITH CONVERTED VALUE IN R6
00A3 23FF                          MOV A,#0FFH    ;SET PORT 1 HI TO FORCE
00A5 39                            OUTL P1,A      ;  COMPARATOR HI
                           ;
                           ;
                           ;INCREMENT THE APPROPRIATE BIN
00A6 97                            CLR C          ;CLEAR CARRY BIT
00A7 FE                            MOV A,R6       ;IS CONVERTED VALUE
00A8 03D8                          ADD A,#0D8H    ;  WITHIN 40 DB RANGE?
00AA F6B8                          JC OLOAD       ;  NO, INCREMENT OVERLOAD BIN
00AC FE                            MOV A,R6       ;  YES, RESTORE VALUE
00AD 6E                            ADD A,R6       ;FORM ADDRESS OF TWO BYTE BIN
00AE 0320                          ADD A,#20H     ;ADD OFFSET ADDRESS
00B0 A8                            MOV R0,A       ;LOAD ADDRESS TO MEM POINTER
00B1 10                            INC @R0        ;INCREMENT BIN CONTENTS
00B2 F0                    OVFLOW: MOV A,@R0      ;HAS LO BYTE OVERFLOWED?
00B3 96B7                          JNZ SLFIN      ;  NO, JUMP TO END OF SUBROUTINE
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LOC  OBJ         LINE       SOURCE STATEMENT

00B5 18                       INC R0          ;  YES, MOVE MEM POINTER
00B6 10                       INC @R0         ;  & INCREMENT HI BYTE
00B7 83               SLFIN:  RET             ;RETURN TO MAIN
00B8 B870             OLOAD:  MOV R0,#70H     ;FORM ADDRESS OF OVERLOAD
00BA 10                       INC @R0         ;  & INCREMENT LO BYTE
00BB 04B2                     JMP OVFLOW      ;RETURN TO TEST LO BYTE
                      ;
                      ;
00BD BA9D             DELAY:  MOV R2,#9DH     ;PRESET TIME OF 800US
00BF EABF             CHBTIM: DJNZ R2,CHBTIM  ;  FOR CHARGE BALANCING
00C1 83                       RET             ;RETURN TO LEQDA
                      ;
                      ;
                      ;L10/L90 COMPUTATION FROM BINNED DATA
                      ;L10 COMPUTATION
00C2 97               L1090:  CLR C           ;CLEAR CARRY BIT
00C3 D5                       SEL RB1         ;SELECT REGISTER BANK 1
00C4 35                       DIS TCNTI       ;DISABLE INTERUPTS
00C5 15                       DIS I
00C6 BE17                     MOV R6,#LPC10H  ;LOAD LPC10 TO R6,R7
00C8 BF70                     MOV R7,#LPC10L
00CA B872                     MOV R0,#72H     ;LOAD BIN FINNISH ADDRESS
00CC C8               DECBIN: DEC R0          ;  TO MEM POINTER
00CD C8                       DEC R0
00CE F8                       MOV A,R0        ;IS MEM POINTER IN RANGE?
00CF 03E0                     ADD A,#0E0H     ;  YES, CONTINUE
00D1 C6DB                     JZ STL10        ;  NO, STORE THIS VALUE!
00D3 3408                     CALL DSUB       ;SUBTRACT (@R0+1)(@R0)
                                              ;  FROM R6,R7
00D5 E6DB                     JNC STL10       ;STORE BIN ADDRESS IF CY=0
00D7 FF                       MOV A,R7        ;R6,R7=0?
00D8 4E                       ORL A,R6        ;  YES, STORE ADDRESS
00D9 96CC                     JNZ DECBIN      ;  NO, TRY NEXT BIN
00DB 2320             STL10:  MOV A,#20H      ;USING TWO'S COMPLEMENT
00DD 37                       CPL A           ;  & ADDITION, SUBTRACT
00DE 17                       INC A           ;  BIN OFFSET ADDRESS
00DF 68                       ADD A,R0        ;  FROM MEM POINTER
00E0 97                       CLR C           ;CLEAR CARRY BIT
00E1 67                       RRC A           ;DIVIDE ADDRESS BY 2
00E2 E3                       MOVP3 A,@A      ;SCALE & OFFSET USING
                                              ;  LOOK UP TABLE
00E3 03FA                     ADD A,#0FAH     ;L1090/LEQ BALANCE
00E5 AC                       MOV R4,A        ;STORE L10 IN R4
                      ;L90 COMPUTATION
00E6 97                       CLR C           ;CLEAR CARRY BIT
00E7 BE17                     MOV R6,#LPC10H  ;LOAD LPC10 TO R6,R7
00E9 BF70                     MOV R7,#LPC10L
00EB B81E                     MOV R0,#1EH     ;LOAD BIN START ADDRESS
00ED 18               INCBIN: INC R0          ;  TO MEM POINTER
00EE 18                       INC R0
00EF F8                       MOV A,R0        ;IS MEM POINTER IN RANGE?
00F0 0390                     ADD A,#90H      ;  YES, CONTINUE
00F2 C6FC                     JZ STL90        ;  NO, STORE THIS VALUE!
00F4 3408                     CALL DSUB       ;SUBTRACT (@R0+1)(@R0)
                                              ;  FROM R6,R7
00F6 E6FC                     JNC STL90       ;STORE BIN ADDRESS IF CY=0
00F8 FF                       MOV A,R7        ;R6,R7=0?
00F9 4E                       ORL A,R6        ;  YES, STORE ADDRESS
```

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LOC  OBJ         LINE        SOURCE STATEMENT

00FA 96ED                      JNZ INCBIN        ; NO, TRY NEXT BIN
00FC 2320              STL90:  MOV A,#20H        ;USING TWO'S COMPLEMENT
00FE 37                        CPL A             ; & ADDITION, SUBTRACT
00FF 17                        INC A             ; BIN OFFSET ADDRESS
0100 68                        ADD A,R0          ; FROM MEM POINTER
0101 97                        CLR C             ;CLEAR CARRY BIT
0102 67                        RRC A             ;DIVIDE ADDRESS BY 2
0103 E3                        MOVP3 A,@A        ;SCALE & OFFSET USING
                                                 ; LOOK UP TABLE
0104 03FA                      ADD A,#0FAH       ;L1090/LEQ BALANCE
0106 AB                        MOV R3,A          ;STORE L90 IN R3
0107 83                        RET               ;RETURN TO MAIN
                       ;
                       ;
                       ;SUBROUTINE FOR SUBTRACTION OF TWO 16 BIT NUMBERS
0108 F0                DSUB:   MOV A,@R0         ;FORM TWO'S COMPLEMENT
0109 960C                      JNZ NONZ1         ; OF LO BYTE
010B 17                        INC A             ;OFFSET ZERO BINS
010C 37                NONZ1:  CPL A
010D 0301                      ADD A,#01H
010F AD                        MOV R5,A          ;TEMP STORE (@R0) COMPLEMENT
0110 18                        INC R0            ;INCREMENT MEM POINTER
0111 F0                        MOV A,@R0         ;FORM TWO'S COMPLEMENT
0112 37                        CPL A             ; OF HI BYTE & PICK UP
0113 1300                      ADDC A,#00H       ; OVERFLOW
0115 AB                        MOV R3,A          ;TEMP STORE (@R0+1) COMPLEMENT
0116 FD                        MOV A,R5          ;BEGIN ADDITION
0117 6F                        ADD A,R7          ;STORE LO ORDER DIFFERENCE
0118 AF                        MOV R7,A          ; IN R7
0119 FB                        MOV A,R3
011A 7E                        ADDC A,R6         ;STORE HI ORDER DIFFERENCE
011B AE                        MOV R6,A          ; IN R6
011C C8                        DEC R0            ;DECREMENT MEM POINTER
011D 83                        RET               ;RETURN TO L1090
                       ;
                       ;
                       ;LEQ COMPUTATION FROM ELAPSED TIME DATA STORED IN R3,R4
                       ; AND DOSE DATA STORED IN R5,R6,R7
011E C5                DOSCON: SEL RB0           ;SELECT REGISTER BANK 0
011F 35                        DIS TCNTI         ;DISABLE INTERUPTS
0120 15                        DIS I
0121 B879                      MOV R0,#79H       ;TEMP STORE R3-R7 @ LOC 79-7D
0123 FB                        MOV A,R3
0124 A0                        MOV @R0,A
0125 18                        INC R0
0126 FC                        MOV A,R4
0127 A0                        MOV @R0,A
0128 18                        INC R0
0129 FD                        MOV A,R5
012A A0                        MOV @R0,A
012B 18                        INC R0
012C FE                        MOV A,R6
012D A0                        MOV @R0,A
012E 18                        INC R0
012F FF                        MOV A,R7
0130 A0                        MOV @R0,A
0131 FF                        MOV A,R7          ;IS M S BYTE=0?
0132 963B                      JNZ THRBYT        ; NO, 3 BYTE CONVERSION REQU'D
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LOC  OBJ          SOURCE STATEMENT

0134 FE                   MOV A,R6        ;  YES, IS SECOND BYTE=0?
0135 963F                 JNZ TWOBYT      ;  NO, 2 BYTE CONVERSION REQU'D
0137 BA01                 MOV R2,#01H     ;  YES, 1 BYTE CONVERSION REQU'D
0139 2441                 JMP DOSLOG      ;LOAD APPROPRIATE NUMBER OF
013B BA03         THRBYT: MOV R2,#03H     ;  BYTES AND PERFORM LOG
013D 2441                 JMP DOSLOG      ;  CONVERSION
013F BA02         TWOBYT: MOV R2,#02H
0141 97           DOSLOG: CLR C           ;CLEAR CARRY BIT
0142 B901                 MOV R1,#01H     ;SET R1=1
0144 FA                   MOV A,R2        ;SET MEM POINTER TO
0145 0304                 ADD A,#04H      ;  THE M S NON ZERO BYTE
0147 A8                   MOV R0,A
0148 F0                   MOV A,@R0       ;WHICH IS THE MSB OF THIS
0149 F25E                 JB7 ROTAT1      ;  REGISTER THAT IS SET?
014B 19                   INC R1          ;USE THIS DATA TO SET
014C D25E                 JB6 ROTAT1      ;  NUMBER OF REQUIRED
014E 19                   INC R1          ;  ROTATIONS IN R1
014F B25E                 JB5 ROTAT1
0151 19                   INC R1
0152 925E                 JB4 ROTAT1
0154 19                   INC R1
0155 725E                 JB3 ROTAT1
0157 19                   INC R1
0158 525E                 JB2 ROTAT1
015A 19                   INC R1
015B 325E                 JB1 ROTAT1
015D 19                   INC R1
015E B87F         ROTAT1: MOV R0,#7FH     ;CLEAR MEM LOC 7FH
0160 B000                 MOV @R0,#00H
0162 B87F         ROTAT2: MOV R0,#7FH     ;STORE NUMBER OF ROTATIONS
0164 10                   INC @R0         ;  PERFORMED+1 @ LOC 7FH
0165 C9                   DEC R1          ;ARE ANY MORE ROTATIONS
0166 F9                   MOV A,R1        ;  REQU'D?
0167 C675                 JZ  LOOKUP      ;  NO, LOOK UP LOG OF THIS BYTE
0169 FA                   MOV A,R2        ;  YES, SET NO OF BYTES IN ACC
016A B804                 MOV R0,#04H     ;SET MEM POINTER TO L S BYTE-1
016C 18           INCBYT: INC R0          ;INCREMENT MEM POINTER
016D 20                   XCH A,@R0       ;ROTATE BYTE LEFT WITH CARRY
016E F7                   RLC A
016F 20                   XCH A,@R0
0170 07                   DEC A           ;HAVE ALL BYTES BEEN ROTATED?
0171 966C                 JNZ INCBYT      ;  NO, ROTATE NEXT BYTE
0173 2462                 JMP ROTAT2      ;  YES, TEST IF MORE ROTATIONS
                                          ;  ARE NEEDED
0175 FA           LOOKUP: MOV A,R2        ;LOAD NUMBER OF BYTES USED FOR
0176 A9                   MOV R1,A        ;  CONVERSION INTO R1
0177 2304                 MOV A,#04H      ;LOAD LEFT LEFT HAND JUSTIFIED
0179 6A                   ADD A,R2        ;  M S BYTE INTO ACC
017A A8                   MOV R0,A
017B F0                   MOV A,@R0
017C 9680                 JNZ NONZ2       ;IF BYTE=0,
017E 2380                 MOV A,#80H      ;  LOAD 80H TO ACC
0180 E3           NONZ2:  MOVP3 A,@A      ;LOOK UP LOG OF THIS BYTE
0181 03B0                 ADD A,#0B0H
0183 0350         BYTMUL: ADD A,#50H      ;COMPENSATE FOR NUMBER OF
0185 E983                 DJNZ R1,BYTMUL  ;  BYTES USED IN CONVERSION
0187 29                   XCH A,R1
0188 B87F                 MOV R0,#7FH
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LOC  OBJ         SOURCE STATEMENT

018A F0                   MOV A,@R0
018B 29                   XCH A,R1        ;LOAD NUMBER OF ROTATIONS
018C 030A                 ADD A,#0AH      ;  PERFORMED IN R1 &
018E 03F6        BITMUL:  ADD A,#0F6H     ;  SUBTRACT 10 FROM ACC FOR
0190 E98E                 DJNZ R1,BITMUL  ;  EACH ROTATION PERFORMED
0192 AF                   MOV R7,A        ;STORE CONVERTED VALUE IN R7
0193 83                   RET             ;RETURN TO MAIN
                 ;
                 ;
0194 FC          TIMCON:  MOV A,R4        ;IS TIME HI BYTE=0?
0195 969B                 JNZ TWOTIM      ;  NO, 2 BYTE CONVERSION REQU'D
0197 BD01                 MOV R5,#01H     ;  YES, 1 BYTE CONVERSION REQU'D
0199 249D                 JMP TIMLOG      ;LOAD NUMBER OF BYTES IN R5
019B BD02        TWOTIM:  MOV R5,#02H     ;  & PERFORM LOG CONVERSION
019D B901        TIMLOG:  MOV R1,#01H     ;SET R1=1
019F FD                   MOV A,R5        ;SET MEM POINTER TO THE
01A0 0302                 ADD A,#02H      ;  M S NON ZERO BYTE
01A2 A8                   MOV R0,A
01A3 F0                   MOV A,@R0       ;WHICH IS THE MSB OF THIS
01A4 F2B9                 JB7 ROTAT3      ;  REGISTER THAT IS SET?
01A6 19                   INC R1          ;USE THIS DATA TO SET NUMBER
01A7 D2B9                 JB6 ROTAT3      ;  OF REQU'D ROTATIONS IN R1
01A9 19                   INC R1
01AA B2B9                 JB5 ROTAT3
01AC 19                   INC R1
01AD 92B9                 JB4 ROTAT3
01AF 19                   INC R1
01B0 72B9                 JB3 ROTAT3
01B2 19                   INC R1
01B3 52B9                 JB2 ROTAT3
01B5 19                   INC R1
01B6 32B9                 JB1 ROTAT3
01B8 19                   INC R1
01B9 B87E        ROTAT3:  MOV R0,#7EH     ;CLEAR MEM LOC 7EH
01BB B000                 MOV @R0,#00H
01BD B87E        ROTAT4:  MOV R0,#7EH     ;STORE NUMBER OF ROTATIONS
01BF 10                   INC @R0         ;  PERFORMED+1 @ LOC 7EH
01C0 C9                   DEC R1          ;ARE ANY MORE ROTATIONS REQU'D?
01C1 F9                   MOV A,R1
01C2 C6D0                 JZ  LUKUP       ;  NO, LOOK UP LOG OF THIS BYTE
01C4 FD                   MOV A,R5        ;  YES, SET NO OF BYTES IN ACC
01C5 B802                 MOV R0,#02H     ;SET MEM POINTER TO L S BYTE-1
01C7 18          INKBYT:  INC R0          ;INCREMENT MEM POINTER
01C8 20                   XCH A,@R0       ;ROTATE BYTE LEFT WITH CY
01C9 F7                   RLC A
01CA 20                   XCH A,@R0
01CB 07                   DEC A           ;HAVE ALL BYTES BEEN ROTATED?
01CC 96C7                 JNZ INKBYT      ;  NO, ROTATE NEXT BYTE
01CE 24BD                 JMP ROTAT4      ;  YES, TEST IF MORE ROTATIONS
                                          ;  ARE NEEDED
01D0 FD          LUKUP:   MOV A,R5        ;LOAD NUMBER OF BYTES IN R1
01D1 A9                   MOV R1,A
01D2 2302                 MOV A,#02H      ;LOAD LH JUSTIFIED M S BYTE
01D4 6D                   ADD A,R5        ;  INTO ACC
01D5 A8                   MOV R0,A
01D6 F0                   MOV A,@R0
01D7 96DB                 JNZ NONZ3       ;IF BYTE=0,
01D9 2380                 MOV A,#80H      ;  LOAD 80H TO ACC
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LOC  OBJ         SOURCE STATEMENT

01DB E3          NONZ3:  MOVP3 A,@A       ;LOOK UP LOG OF THIS BYTE
01DC 03B0                ADD A,#0B0H
01DE 0350        BYTCOM: ADD A,#50H       ;COMPENSATE FOR NUMBER OF BYTES
01E0 E9DE                DJNZ R1,BYTCOM   ;  USED IN CONVERSION
01E2 29                  XCH A,R1
01E3 B87E                MOV R0,#7EH
01E5 F0                  MOV A,@R0
01E6 29                  XCH A,R1         ;LOAD NUMBER OF ROTATIONS
01E7 030A                ADD A,#0AH       ;  PERFORMED IN R1 &
01E9 03F6        BITCOM: ADD A,#0F6H      ;  SUBTRACT 10 FROM ACC FOR
01EB E9E9                DJNZ R1,BITCOM   ;  EACH ROTATION PERFORMED
01ED AC                  MOV R4,A         ;STORE CONVERTED VALUE IN R4
01EE 83                  RET              ;RETURN TO MAIN
                 ;
                 ;
0200                     ORG 200H         ;START LEQCAL AT TOP OF PAGE 2
                                          ;  TO OBVIATE CROSS PAGE JUMPS
0200 BD00        LEQCAL: MOV R5,#00H      ;INITIALISE OVERFLOW COUNTER
0202 FC                  MOV A,R4         ;SUBTRACT TIMLOG FROM DOSLOG
0203 37                  CPL A
0204 17                  INC A
0205 6F                  ADD A,R7
0206 E609                JNC OFSET1       ;IF CY=1,
0208 1D                  INC R5           ;  INCR OVERFLOW COUNTER
0209 0332        OFSET1: ADD A,#32H       ;ADD OFFSET
020B AF                  MOV R7,A         ;TEMP STORE LEQ IN R7
020C E60F                JNC MAGT1        ;IF CY=1,
020E 1D                  INC R5           ;  INCR OVERFLOW COUNTER
020F FD          MAGT1:  MOV A,R5         ;IS LEQ IN CORRECT RANGE?
0210 121A                JB0 OUT1         ;  YES, OUTPUT THIS VALUE
0212 3218                JB1 FSCAL1       ;  NO, IS LEQ OVER OR UNDER
0214 BF00                MOV R7,#00H      ;  RANGE?
0216 441A                JMP OUT1         ;  UNDER RANGE, OUTPUT -5DB
0218 BFFF        FSCAL1: MOV R7,#0FFH     ;  OVER RANGE, OUTPUT +68DB
021A FF          OUT1:   MOV A,R7         ;RETURN MODIFIED LEQ TO ACC
021B 02                  OUTL BUS,A       ;OUTPUT LEQ VIA BUS
021C B879                MOV R0,#79H      ;RESTORE R3-7 FROM LOC 79-7D
021E F0                  MOV A,@R0
021F AB                  MOV R3,A
0220 18                  INC R0
0221 F0                  MOV A,@R0
0222 AC                  MOV R4,A
0223 18                  INC R0
0224 F0                  MOV A,@R0
0225 AD                  MOV R5,A
0226 18                  INC R0
0227 F0                  MOV A,@R0
0228 AE                  MOV R6,A
0229 18                  INC R0
022A F0                  MOV A,@R0
022B AF                  MOV R7,A
022C 83                  RET              ;RETURN TO MAIN
                 ;
                 ;
022D BD00        SEXCAL: MOV R5,#00H      ;INITIALISE OVERFLOW COUNTER
022F 239C                MOV A,#9CH       ;SUBTRACT LOG OF 10 SECONDS
0231 6F                  ADD A,R7         ;  FROM DOSLOG
0232 E635                JNC OFSET2       ;IF CY=1,
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LOC  OBJ          LINE        SOURCE STATEMENT

0234 1D            464           INC R5             ;  INCR OVERFLOW COUNTER
0235 0332          465 OFSET2:  ADD A,#32H          ;ADD OFFSET
0237 AF            466           MOV R7,A           ;TEMP STORE SE IN R7
0238 E63B          467           JNC MAGT2          ;IF CY=1,
023A 1D            468           INC R5             ;  INCR OVERFLOW COUNTER
023B FD            469 MAGT2:   MOV A,R5            ;IS SE IN CORRECT RANGE?
023C 1246          470           JB0 OUT2           ;  YES, OUTPUT THIS VALUE
023E 3244          471           JB1 FSCAL2         ;  NO, IS SE OVER OR UNDER
0240 BF00          472           MOV R7,#00H        ;  RANGE?
0242 4446          473           JMP OUT2           ;  UNDER RANGE, OUTPUT -5DB
0244 BFFF          474 FSCAL2:  MOV R7,#0FFH        ;  OVER RANGE, OUTPUT +68DB
0246 FF            475 OUT2:    MOV A,R7            ;RETURN MODIFIED SE TO ACC
0247 02            476           OUTL BUS,A         ;OUTPUT SE VIA BUS
0248 B879          477           MOV R0,#79H        ;RESTORE R3-7 FROM LOC 79-7D
024A F0            478           MOV A,@R0
024B AB            479           MOV R3,A
024C 18            480           INC R0
024D F0            481           MOV A,@R0
024E AC            482           MOV R4,A
024F 18            483           INC R0
0250 F0            484           MOV A,@R0
0251 AD            485           MOV R5,A
0252 18            486           INC R0
0253 F0            487           MOV A,@R0
0254 AE            488           MOV R6,A
0255 18            489           INC R0
0256 F0            490           MOV A,@R0
0257 AF            491           MOV R7,A
0258 83            492           RET                ;RETURN TO MAIN
                   493 ;
                   494 ;
                   495 ;LOOK UP TABLE FOR SCALING & OFFSET OF L10 & L90,
                   496 ;  & FOR LOG COVERSION, ON PAGE 3 OF PROG MEM
0300               497           ORG 0300H
0300 11            498           DB 17,20,23,27,30,33,36,40
0301 14
0302 17
0303 1B
0304 1E
0305 21
0306 24
0307 28
0308 2B            499           DB 43,47,50,53,56,60,63,66
0309 2F
030A 32
030B 35
030C 38
030D 3C
030E 3F
030F 42
0310 45            500           DB 69,73,76,80,83,86,90,93
0311 49
0312 4C
0313 50
0314 53
0315 56
0316 5A
0317 5D
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LOC  OBJ         LINE        SOURCE STATEMENT

0318 61           501         DB 97,100,103,106,110,113,116,119
0319 64
031A 67
031B 6A
031C 6E
031D 71
031E 74
031F 77
0320 7B           502         DB 123,126,130,133,136,139,143,146
0321 7E
0322 82
0323 85
0324 88
0325 8B
0326 8F
0327 92
0328 95           503         DB 149,00,00,00,00,00,00,00
0329 00
032A 00
032B 00
032C 00
032D 00
032E 00
032F 00
0330 00           504         DB 00,00,00,00,00,00,00,00
0331 00
0332 00
0333 00
0334 00
0335 00
0336 00
0337 00
0338 00           505         DB 00,00,00,00,00,00,00,00
0339 00
033A 00
033B 00
033C 00
033D 00
033E 00
033F 00
0340 00           506         DB 00,00,00,00,00,00,00,00
0341 00
0342 00
0343 00
0344 00
0345 00
0346 00
0347 00
0348 00           507         DB 00,00,00,00,00,00,00,00
0349 00
034A 00
034B 00
034C 00
034D 00
034E 00
034F 00
0350 00           508         DB 00,00,00,00,00,00,00,00
0351 00
```

```
LOC  OBJ         LINE        SOURCE STATEMENT

0352 00
0353 00
0354 00
0355 00
0356 00
0357 00
0358 00           509          DB 00,00,00,00,00,00,00,00
0359 00
035A 00
035B 00
035C 00
035D 00
035E 00
035F 00
0360 00           510          DB 00,00,00,00,00,00,00,00
0361 00
0362 00
0363 00
0364 00
0365 00
0366 00
0367 00
0368 00           511          DB 00,00,00,00,00,00,00,00
0369 00
036A 00
036B 00
036C 00
036D 00
036E 00
036F 00
0370 00           512          DB 00,00,00,00,00,00,00,00
0371 00
0372 00
0373 00
0374 00
0375 00
0376 00
0377 00
0378 00           513          DB 00,00,00,00,00,00,00,00
0379 00
037A 00
037B 00
037C 00
037D 00
037E 00
037F 00
0380 46           514          DB 70,70,70,70,70,71,71,71
0381 46
0382 46
0383 46
0384 46
0385 47
0386 47
0387 47
0388 47           515          DB 71,71,71,71,71,71,71,72
0389 47
038A 47
038B 47
```

```
LOC  OBJ        LINE        SOURCE STATEMENT

038C 47
038D 47
038E 47
038F 48
0390 48          516         DB 72,72,72,72,72,72,72,72
0391 48
0392 48
0393 48
0394 48
0395 48
0396 48
0397 48
0398 48          517         DB 72,73,73,73,73,73,73,73
0399 49
039A 49
039B 49
039C 49
039D 49
039E 49
039F 49
03A0 49          518         DB 73,73,73,73,74,74,74,74
03A1 49
03A2 49
03A3 49
03A4 4A
03A5 4A
03A6 4A
03A7 4A
03A8 4A          519         DB 74,74,74,74,74,74,74,75
03A9 4A
03AA 4A
03AB 4A
03AC 4A
03AD 4A
03AE 4A
03AF 4B
03B0 4B          520         DB 75,75,75,75,75,75,75,75
03B1 4B
03B2 4B
03B3 4B
03B4 4B
03B5 4B
03B6 4B
03B7 4B
03B8 4B          521         DB 75,75,75,75,76,76,76,76
03B9 4B
03BA 4B
03BB 4B
03BC 4C
03BD 4C
03BE 4C
03BF 4C
03C0 4C          522         DB 76,76,76,76,76,76,76,76
03C1 4C
03C2 4C
03C3 4C
03C4 4C
03C5 4C
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

03C6 4C
03C7 4C
03C8 4C            523          DB 76,77,77,77,77,77,77,77
03C9 4D
03CA 4D
03CB 4D
03CC 4D
03CD 4D
03CE 4D
03CF 4D
03D0 4D            524          DB 77,77,77,77,77,77,77,77
03D1 4D
03D2 4D
03D3 4D
03D4 4D
03D5 4D
03D6 4D
03D7 4D
03D8 4D            525          DB 77,78,78,78,78,78,78,78
03D9 4E
03DA 4E
03DB 4E
03DC 4E
03DD 4E
03DE 4E
03DF 4E
03E0 4E            526          DB 78,78,78,78,78,78,78,79
03E1 4E
03E2 4E
03E3 4E
03E4 4E
03E5 4E
03E6 4E
03E7 4F
03E8 4F            527          DB 79,79,79,79,79,79,79,79
03E9 4F
03EA 4F
03EB 4F
03EC 4F
03ED 4F
03EE 4F
03EF 4F
03F0 4F            528          DB 79,79,79,79,79,79,79,79
03F1 4F
03F2 4F
03F3 4F
03F4 4F
03F5 4F
03F6 4F
03F7 4F
03F8 50            529          DB 80,80,80,80,80,80,80,80
03F9 50
03FA 50
03FB 50
03FC 50
03FD 50
03FE 50
03FF 50
```

```
  LOC  OBJ         LINE        SOURCE STATEMENT

                    530          END

USER SYMBOLS
BITCOM 01E9     BITMUL 018E     BYTCOM 01DE     BYTMUL 0183     CHBTIM 00BF
CLEAR  0011     DECBIN 00CC     DELAY  00BD     DOSCON 011E     DOSLOG 0141
DROP   00A1     DSUB   0108     FSCAL1 0218     FSCAL2 0244     HIRAMP 0068
HITIM  0003     INCBIN 00ED     INCBYT 016C     INKBYT 01C7     L1090  00C2
L100UT 0053     L900UT 0057     LEQCAL 0200     LEQDA  005B     LEQINT 0031
LEQTST 0060     LOCNT  0066     LOOKUP 0175     LOOP   0095     LORAMP 0075
LPC10H 0017     LPC10L 0070     LUKUP  01D0     MAGT1  020F     MAGT2  023B
MAIN   0016     NONZ1  010C     NONZ2  0180     NONZ3  01DB     OFSET1 0209
OFSET2 0235     OLOAD  00B8     OUT1   021A     OUT2   0246     OVFLOW 00B2
RESET  000A     ROTAT1 015E     ROTAT2 0162     ROTAT3 01B9     ROTAT4 01BD
SERREQ 0049     SEXCAL 022D     SEXREQ 002F     SLCONV 008C     SLFIN  00B7
STARTT 0019     STL10  00DB     STL90  00FC     THRBYT 013B     TIMCNT 008B
TIMCON 0194     TIMDEL 009C     TIMINT 0086     TIMLOG 019D     TWOBYT 013F
TWOTIM 019B     WAIT   0014

ASSEMBLY COMPLETE,    NO ERRORS
```

```
LOCATION OBJECT CODE LINE    SOURCE LINE

                "6805" EXPAND
                ;TABSET 1 17 24 40 43
                ;****************************************************************
                ;DEFINE LABELS
                ;****************************************************************
      <0000>    PORTA           EQU     00H             ;DEFINE PORT LOC
      <0001>    PORTB           EQU     01H
      <0002>    PORTC           EQU     02H
      <0003>    PORTD           EQU     03H
      <0008>    TDR             EQU     08H             ;TIMER DATA REG
      <0009>    TCR             EQU     09H             ;TIMER CONTROL REG
      <0010>    LOTIM           EQU     10H             ;LOTIM MEM LOC
      <0011>    MDTIM           EQU     11H             ;MDTIM MEM LOC
      <0012>    IN1HB           EQU     12H             ;INTEGRATOR BYTE LABELS
      <0013>    IN1MB           EQU     13H
      <0014>    IN1LB           EQU     14H
      <0015>    IN2HB           EQU     15H
      <0016>    IN2MB           EQU     16H
      <0017>    IN2LB           EQU     17H
      <0018>    IN3HB           EQU     18H
      <0019>    IN3MB           EQU     19H
      <001A>    IN3LB           EQU     1AH
      <001B>    OLOAD           EQU     1BH             ;OUT OF RANGE MEM LOC
      <001C>    TIMCNT          EQU     1CH             ;TIMER OVERFLOW COUNTER
      <001D>    TIMBT1          EQU     1DH             ;TIME STORE BYTES
      <001E>    TIMBT2          EQU     1EH
      <001F>    TIMBT3          EQU     1FH
      <0020>    BYTCNT          EQU     20H             ;BYTE & ROTATION STORES
      <0021>    ROTCNT          EQU     21H
      <0022>    DOSHB           EQU     22H             ;DOSE WORD STORES
      <0023>    DOSLB           EQU     23H
      <0001>    MAXRMP          EQU     01H             ;DEFINE MAX NO OF RAMPS
      <0080>    TAB             EQU     80H             ;ADDRESS FOR LOOK UP TABLE
                ;****************************************************************
                ;PORT ALLOCATIONS
                ;               PORT A          PORT B          PORT C          PORT D
                ;BIT 0          LEQ LO BYTE     LEQ HI BYTE     LO  - HIGH
                ;BIT 1            "               "             MID /
                ;BIT 2            "               "             INT 1 \
                ;BIT 3            "             STRT OF LEQ     INT 2  >BAL EN
                ;BIT 4            "             TEST LIGHT      INT 3 /
                ;BIT 5            "               "             INT 1 \
                ;BIT 6            "               "             INT 2  >BAL REQ
                ;BIT 7            "               "             INT 3 /
                ;****************************************************************
                ;
                                ORG     07FEH           ;SET RESET VECT ADDR
07FE 0100                       FDB     START
                ;
                                ORG     100H            ;SET PROG START ADDR
0100 3F 07      START           CLR     07H             ;CLEAR PORT CONT REG
                ;                                         68705R3 SIM QUIRK
                ;
0102 3F 00                      CLR     PORTA           ;CLEAR PORT A,B,C,D
0104 3F 01                      CLR     PORTB           ; DATA REGS
0106 3F 02                      CLR     PORTC
0108 3F 03                      CLR     PORTD
```

```
LOCATION OBJECT CODE LINE     SOURCE LINE

                         ;
010A AE 14                          LDX    #014H            ;CLEAR ALL RAM LOC
010C 6F 0F               RAMCLR     CLR    0FH,X
010E 5A                             DECX
010F 26 FB                          BNE    RAMCLR
                         ;
0111 A6 FF                          LDA    #0FFH
0113 B7 04                          STA    04H              ;SET PORT A & B FOR OUTPUT
0115 B7 05                          STA    05H
0117 A6 1F                          LDA    #1FH             ;SET PORT C DDR
0119 B7 06                          STA    06H
                         ;
011B A6 04                          LDA    #04H             ;INITIALIZE TIMCNT
011D B7 1C                          STA    TIMCNT
011F A6 F4                          LDA    #0F4H
0121 B7 08                          STA    TDR              ;INITIALIZE TDR TO 244
0123 A6 48                          LDA    #48H             ;CLEAR PRESCALER
0125 B7 09                          STA    TCR
                         ;
0127 A6 02               MAIN       LDA    #(MAXRMP+1)
0129 B7 11                          STA    MDTIM            ;RESTORE MDTIM
012B A6 04                          LDA    #(MAXRMP+3)
012D B7 10                          STA    LOTIM            ;RESTORE LOTIM
012F 0F09 18             LEQDA      BRCLR  7,TCR,INTTST     ;TIMER OVERFLOW?
                                                            ; NO, TEST INTEGRATORS
0132 A6 48                          LDA    #48H             ; YES, IS 125 MS UP?
0134 B7 09                          STA    TCR              ;(CLEAR PRESCALER & TIMER
0136 3A 1C                          DEC    TIMCNT           ; OVERFLOW FLAG)
0138 26 10                          BNE    INTTST           ; NO, TEST INTEGRATORS
                                                            ; YES, UPDATE VALUES & DISPLAY
013A CD 0241                        JSR    TIMINT           ;RESET TIMER
013D CD 0260                        JSR    DOSCON           ;CONVERT DOSE VALUE
0140 CD 039E                        JSR    OUTPUT           ;OUTPUT VALUE
0143 AE 0A                          LDX    #0AH             ;CLEAR INTEGRATOR REGISTERS
0145 6F 11               REGCLR     CLR    11H,X         ;  AND CLOAD
0147 5A                             DECX
0148 26 FB                          BNE    REGCLR
                         ;
014A B6 02               INTTST     LDA    PORTC            ;INPUT VIA PORT C
014C A4 ED                          AND    #0EDH            ;MASK UNWANTED BITS
                                                            ;IS CHARGE BALANCING REQU`D?
014E 27 D7                          BEQ    LEQDA-8          ; NO, RETURN & RETEST
0150 44                             LSRA                    ; YES, SET APPROPRIATE
0151 44                             LSRA                    ; BALANCE CURRENT ENABLES
0152 44                             LSRA
0153 CC 015A                        JMP    LOCNT            ;****************DELETE AFTER TEST
0156 43                             COMA                    ;DISREGARD OUT OF RANGE INTEGRATORS
0157 BA 1B                          ORA    CLOAD
0159 43                             COMA
                         ;
015A 3A 10               LOCNT      DEC    LOTIM            ;LO CURRENT?
015C 27 03                          BEQ    MDCNT            ; NO, TRY MID CURRENT
015E CC 01EC                        JMP    LORAMP           ; YES, JUMP TO LORAMP
                         ;
0161 3A 11               MDCNT      DEC    MDTIM            ;MID CURRENT?
0163 27 03                          BEQ    HIRAMP           ; NO, USE HI CURRENT
0165 CC 01A7                        JMP    MDRAMP           ; YES, JUMP TO MDRAMP
```

```
LOCATION OBJECT CODE LINE     SOURCE LINE

                     115 ;
0168 AA 03           116 HIRAMP      ORA    #03H         ;SWITCH ON HI CURRENTS VIA
016A B7 02           117             STA    PORTC        ; PORT C FOR PRE-DETERMINED
016C CD 0233         118             JSR    DELAY        ; PERIOD
                     119 ;
                     120 ;
016F 44              121             LSRA                ;TEST IF HI CURRENTS WERE USED
0170 44              122             LSRA                ; ON EACH INTEGRATOR, & IF SO
0171 44              123             LSRA                ; INCREMENT APPROPRIATE MEM LOC
0172 24 0C           124             BCC    NOTHI1
0174 97              125             TAX
0175 B6 13           126             LDA    IN1MB
0177 AB 40           127             ADD    #40H
0179 B7 13           128             STA    IN1MB
017B 9F              129             TXA
017C 24 02           130             BCC    NOTHI1
017E 3C 12           131             INC    IN1HB        ;PICK UP OVERFLOWS
0180 44              132 NOTHI1      LSRA
0181 24 0C           133             BCC    NOTHI2
0183 97              134             TAX
0184 B6 16           135             LDA    IN2MB
0186 AB 40           136             ADD    #40H
0188 B7 16           137             STA    IN2MB
018A 9F              138             TXA
018B 24 02           139             BCC    NOTHI2
018D 3C 15           140             INC    IN2HB
018F 44              141 NOTHI2      LSRA
0190 24 0C           142             BCC    NOTHI3
0192 97              143             TAX
0193 B6 19           144             LDA    IN3MB
0195 AB 40           145             ADD    #40H
0197 B7 19           146             STA    IN3MB
0199 9F              147             TXA
019A 24 02           148             BCC    NOTHI3
019C 3C 18           149             INC    IN3HB
019E A6 04           150 NOTHI3      LDA    #(MAXRMP+3)  ;RESTORE MDTIM
01A0 B7 11           151             STA    MDTIM
01A2 3C 10           152             INC    LOTIM        ;PREVENT LOTIM GOING -VE
01A4 CC 012F         153             JMP    LEQDA
                     154 ;
01A7 AA 02           155 MDRAMP      ORA    #02H         ;SWITCH ON MID CURRENTS VIA
01A9 B7 02           156             STA    PORTC        ; PORT C FOR PRE-DETERMINED
01AB CD 0233         157             JSR    DELAY        ; PERIOD
                     158 ;
                     159 ;
01AE 44              160             LSRA                ;TEST IF MID CURRENTS WERE USED
01AF 44              161             LSRA                ; ON EACH INTEGRATOR, & IF SO
01B0 44              162             LSRA                ; INCREMENT APPROPRIATE MEM LOC
01B1 24 10           163             BCC    NOTMD1
01B3 97              164             TAX
01B4 B6 14           165             LDA    IN1LB
01B6 AB 80           166             ADD    #80H
01B8 B7 14           167             STA    IN1LB
01BA 9F              168             TXA
01BB 24 06           169             BCC    NOTMD1
01BD 3C 13           170             INC    IN1MB
01BF 26 02           171             BNE    NOTMD1
```

```
LOCATION OBJECT CODE LINE    SOURCE LINE

01C1 3C 12                         INC    IN1HB        ;PICK UP OVERFLOWS
01C3 44               NOTMD1       LSRA
01C4 24 10                         BCC    NOTMD2
01C6 97                            TAX
01C7 B6 17                         LDA    IN2LB
01C9 AB 80                         ADD    #80H
01CB B7 17                         STA    IN2LB
01CD 9F                            TXA
01CE 24 06                         BCC    NOTMD2
01D0 3C 16                         INC    IN2MB
01D2 26 02                         BNE    NOTMD2
01D4 3C 15                         INC    IN2HB
01D6 44               NOTMD2       LSRA
01D7 24 10                         BCC    NOTMD3
01D9 97                            TAX
01DA B6 1A                         LDA    IN3LB
01DC AB 80                         ADD    #80H
01DE B7 1A                         STA    IN3LB
01E0 9F                            TXA
01E1 24 06                         BCC    NOTMD3
01E3 3C 19                         INC    IN3MB
01E5 26 02                         BNE    NOTMD3
01E7 3C 18                         INC    IN3HB
01E9 CC 012B          NOTMD3       JMP    LEQDA-4
                      ;
01EC AA 01            LORAMP       ORA    #01H         ;SWITCH ON LO CURRENTS VIA
01EE B7 02                         STA    PORTC        ; PORT C FOR PRE-DETERMINED
01F0 CD 0233                       JSR    DELAY        ; PERIOD
                      ;
                      ;
01F3 44                            LSRA                ;TEST IF LO CURRENTS WERE USED
01F4 44                            LSRA                ; ON EACH INTEGRATOR, & IF SO
01F5 44                            LSRA                ; INCREMENT APPROPRIATE MEM LOC
01F6 24 0A                         BCC    NOTLO1
01F8 3C 14                         INC    IN1LB
01FA 26 06                         BNE    NOTLO1
01FC 3C 13                         INC    IN1MB        ;PICK UP OVERFLOWS
01FE 26 02                         BNE    NOTLO1
0200 3C 12                         INC    IN1HB        ;PICK UP OVERFLOWS OF OVERFLOWS
0202 44               NOTLO1       LSRA
0203 24 14                         BCC    NOTLO2
0205 3C 17                         INC    IN2LB
0207 26 10                         BNE    NOTLO2
0209 3C 16                         INC    IN2MB
020B 97                            TAX                 ;STOP BALANCING INTEGRATOR 1
020C B6 1B                         LDA    CLOAD
020E AA 04                         ORA    #04H
0210 B7 1B                         STA    CLOAD
0212 9F                            TXA
0213 3D 16                         TST    IN2MB
0215 26 02                         BNE    NOTLO2
0217 3C 15                         INC    IN2HB
0219 44               NOTLO2       LSRA
021A 24 14                         BCC    NOTLO3
021C 3C 1A                         INC    IN3LB
021E 26 10                         BNE    NOTLO3
0220 3C 19                         INC    IN3MB
```

```
LOCATION OBJECT CODE LINE     SOURCE LINE

0222 97                                 TAX                  ;STOP BALANCING INTEGRATOR 2
0223 B6 1B                              LDA     OLOAD
0225 AA 08                              ORA     #08H
0227 B7 1B                              STA     OLOAD
0229 9F                                 TXA
022A 3D 19                              TST     IN3MB
022C 26 02                              BNE     NOTLO3
022E 3C 18                              INC     IN3HB
0230 CC 012F             NOTLO3         JMP     LEQDA
                         ;
                         ;
0233 AE 14               DELAY          LDX     #14H         ;SUBROUTINE TO PROVIDE
0235 5A                  DELLP          DECX                 ;  DELAY OF 96 E-6 S  (* 0AH)
0236 26 FD                              BNE     DELLP
0238 97                                 TAX
0239 B6 02                              LDA     PORTC
023B A4 E0                              AND     #0E0H        ;TURN BALANCE CURRENTS OFF
023D B7 02                              STA     PORTC
023F 9F                                 TXA
0240 81                                 RTS                  ;RETURN TO MAIN
                         ;
0241 B6 01               TIMINT         LDA     PORTB        ;SIGNAL END OF PERIOD BY SETTING
0243 AA 08                              ORA     #08H         ;  A 1 ON PORT B BIT 3
0245 B7 01                              STA     PORTB
0247 A6 04                              LDA     #04H         ;RESET TIMCNT
0249 B7 1C                              STA     TIMCNT
024B B6 08                              LDA     TDR          ;FIND TIME SINCE INT WAS FLAGGED
024D AB F4                              ADD     #0F4H        ;  SUBTRACT THIS FROM 244 ...
024F B7 08                              STA     TDR          ;  ... & RESET THE TIMER
0251 A6 48                              LDA     #48H
0253 B7 09                              STA     TCR
0255 3C 1D                              INC     TIMBT1       ;TIME REGISTERS NOT USED ON
0257 26 06                              BNE     TIMRET       ;  FIRST PROTOTYPE - SHORT LEQ
0259 3C 1E                              INC     TIMBT2       ;  ONLY
025B 26 02                              BNE     TIMRET
025D 3C 1F                              INC     TIMBT3
025F 81                  TIMRET         RTS                  ;RETURN TO MAIN
                         ;
0260 041B 03             DOSCON         BRSET   2,OLOAD,IN2TST ;INT 1 O/LOAD?
                                                             ;  YES, TEST INT 2
0263 CC 0266                            JMP     IN1OK        ;  NO, USE INT 1 OR 2
0266 061B 61             IN2TST         BRSET   3,OLOAD,IN2OK ;INT2 O/LOAD?
0269 CC 02CA                            JMP     IN2OK        ;  NO, USE INT 2 OR 3
026C 3F 21               IN3OK          CLR     ROTCNT       ;  YES, USE INT 3
026E 3F 23                              CLR     DOSLB
0270 3F 22                              CLR     DOSHB
0272 98                                 CLC
0273 A6 02                              LDA     #02H         ;INITIALIZE BYTCNT
0275 B7 20                              STA     BYTCNT
0277 B6 18                              LDA     IN3HB
0279 26 10                              BNE     IN33B
027B B6 19                              LDA     IN3MB
027D 26 0A                              BNE     IN32B
027F B6 1A                              LDA     IN3LB
0281 26 04                              BNE     IN31B        ;IF ALL BYTES ARE ZERO
0283 A6 01                              LDA     #01H         ;  SET IN3LB=1
0285 B7 1A                              STA     IN3LB
```

```
LOCATION OBJECT CODE LINE     SOURCE LINE

  0287 3A 20          286 IN31B       DEC    BYTCNT          ;STORE NUMBER OF NON-ZERO
  0289 3A 20          287 IN32B       DEC    BYTCNT          ;  BYTES-1 IN BYTCNT
  028B 5F             288 IN33B       CLRX
  028C 5C             289 IN3ROT      INCX                   ;STORE REQUIRED NUMBER OF
  028D 48             290             LSLA                   ;  ROTATIONS IN X
  028E 24 FC          291             BCC    IN3ROT
  0290 3C 21          292 ROT3        INC    ROTCNT          ;ROTATE ALL BYTES THE REQUIRED
  0292 5A             293             DECX                   ;  NUMBER OF TIMES
  0293 27 09          294             BEQ    LOOK3
  0295 38 1A          295             LSL    IN3LB
  0297 39 19          296             ROL    IN3MB
  0299 39 18          297             ROL    IN3HB
  029B CC 0290        298             JMP    ROT3
  029E B6 20          299 LOOK3       LDA    BYTCNT
  02A0 AB 1A          300             ADD    #IN3LB          ;LOOK-UP THIS BYTE
  02A2 97             301             TAX
  02A3 FE             302             LDX    X
  02A4 F6             303             LDA    X
  02A5 AB 1E          304             ADD    #01EH
  02A7 A0 1E          305 RTCM3       SUB    #01EH           ;COMPENSATE FOR NUMBER OF
  02A9 3A 21          306             DEC    ROTCNT          ;  ROTATIONS PERFORMED
  02AB 26 FA          307             BNE    RTCM3
  02AD 3D 20          308             TST    BYTCNT
  02AF 27 0E          309             BEQ    OUTP3
  02B1 AB F1          310 BYTCM3      ADD    #0F1H           ;COMPENSATE FOR NUMBER OF
  02B3 97             311             TAX                    ;  BYTES USED IN CONVERSION
  02B4 B6 22          312             LDA    DOSHB
  02B6 A9 00          313             ADC    #00H
  02B8 B7 22          314             STA    DOSHB
  02BA 9F             315             TXA
  02BB 3A 20          316             DEC    BYTCNT
  02BD 26 F2          317             BNE    BYTCM3          ;EXITS WITH DOSE DATA IN
  02BF AB A8          318 OUTP3       ADD    #0A8H           ;  DOSHB,DOSLB
  02C1 B7 23          319             STA    DOSLB           ;ADD OFFSET BETWEEN INTEGRATORS
  02C3 B6 22          320             LDA    DOSHB
  02C5 A9 02          321             ADC    #02H
  02C7 B7 22          322             STA    DOSHB
  02C9 81             323             RTS                    ;RETURN TO MAIN
  02CA 3F 21          324 IN2OK       CLR    ROTCNT          ;USE INT 2
  02CC 3F 23          325             CLR    DOSLB
  02CE 3F 22          326             CLR    DOSHB
  02D0 98             327             CLC
  02D1 A6 02          328             LDA    #02H            ;INITIALIZE BYTCNT
  02D3 B7 20          329             STA    BYTCNT
  02D5 97             330             TAX
  02D6 B6 01          331             LDA    PORTB           ;TEMP LINE FOR DEBUG
  02D8 A8 80          332             EOR    #080H           ;  TOGGLE BIT 7 PORT B IF IT
  02DA B7 01          333             STA    PORTB           ;  GETS HERE!
  02DC 9F             334             TXA
  02DD B6 15          335             LDA    IN2HB
  02DF 26 28          336             BNE    IN23B
  02E1 97             337             TAX
  02E2 B6 01          338             LDA    PORTB           ;TEMP LINE FOR DEBUG
  02E4 A8 40          339             EOR    #040H           ;  TOGGLE BIT 6 PORT B IF IT
  02E6 B7 01          340             STA    PORTB           ;  GETS HERE!
  02E8 9F             341             TXA
  02E9 B6 16          342             LDA    IN2MB
```

```
LOCATION OBJECT CODE LINE     SOURCE LINE

02EB 26 1A                        BNE    IN22B
02ED 97                           TAX
02EE B6 01                        LDA    PORTB      ;TEMP LINE FOR DEBUG
02F0 A8 20                        EOR    #020H      ; TOGGLE BIT 5 PORT B IF IT
02F2 B7 01                        STA    PORTB      ; GETS HERE!
02F4 9F                           TXA
02F5 B6 17                        LDA    IN2LB
02F7 26 0C                        BNE    IN21B      ;IF ALL BYTES ARE ZERO
02F9 A6 01                        LDA    #01H       ; SET IN2LB=1
02FB B7 17                        STA    IN2LB
02FD 97                           TAX
02FE B6 01                        LDA    PORTB      ;TEMP LINE FOR DEBUG
0300 A8 10                        EOR    #010H      ; TOGGLE BIT 4 PORT B IF IT
0302 B7 01                        STA    PORTB      ; GETS HERE!
0304 9F                           TXA
0305 3A 20              IN21B     DEC    BYTCNT     ;STORE NUMBER OF NON-ZERO
0307 3A 20              IN22B     DEC    BYTCNT     ; BYTES-1 IN BYTCNT
0309 5F                 IN23B     CLRX
030A 5C                 IN2ROT    INCX              ;STORE REQUIRED NUMBER OF
030B 48                           LSLA              ; ROTATIONS IN X
030C 24 FC                        BCC    IN2ROT
030E 3C 21              ROT2      INC    ROTCNT     ;ROTATE ALL BYTES THE REQUIRED
0310 5A                           DECX              ; NUMBER OF TIMES
0311 27 09                        BEQ    LOOK2
0313 38 17                        LSL    IN2LB
0315 39 16                        ROL    IN2MB
0317 39 15                        ROL    IN2HB
0319 CC 030E                      JMP    ROT2
031C B6 20              LOOK2     LDA    BYTCNT
031E AB 17                        ADD    #IN2LB
0320 97                           TAX
0321 FE                           LDX    X          ;LOOK-UP THIS BYTE
0322 F6                           LDA    X
0323 AB 1E                        ADD    #01EH
0325 A0 1E              RTCM2     SUB    #01EH      ;CMPENSATE FOR NUMBER OF
0327 3A 21                        DEC    ROTCNT     ; ROTATIONS PERFORMED
0329 26 FA                        BNE    RTCM2
032B 3D 20                        TST    BYTCNT
032D 27 0E                        BEQ    OUTP2
032F AB F1              BYTCM2    ADD    #0F1H      ;CMPENSATE FOR NUMBER OF
0331 97                           TAX               ; BYTES USED IN CONVERSION
0332 B6 22                        LDA    DOSHB
0334 A9 00                        ADC    #00H
0336 B7 22                        STA    DOSHB
0338 9F                           TXA
0339 3A 20                        DEC    BYTCNT
033B 26 F2                        BNE    BYTCM2     ;EXITS WITH DOSE DATA IN
033D AB 54              OUTP2     ADD    #054H      ; DOSHB,DOSLB
033F B7 23                        STA    DOSLB      ;ADD OFFSET BETWEEN INTEGRATORS
0341 B6 22                        LDA    DOSHB
0343 A9 01                        ADC    #01H
0345 B7 22                        STA    DOSHB
0347 81                           RTS               ;RETURN TO MAIN
0348 3F 21              IN1OK     CLR    ROTCNT     ;USE INT 1
034A 3F 23                        CLR    DOSLB
034C 3F 22                        CLR    DOSHB
034E 98                           CLC
```

```
LOCATION OBJECT CODE LINE     SOURCE LINE

034F A6 02                    LDA    #02H        ;INITIALIZE BYTCNT
0351 B7 20                    STA    BYTCNT
0353 B6 12                    LDA    IN1HB
0355 26 10                    BNE    IN13B
0357 B6 13                    LDA    IN1MB
0359 26 0A                    BNE    IN12B
035B B6 14                    LDA    IN1LB
035D 26 04                    BNE    IN11B       ;IF ALL BYTES ARE ZERO
035F A6 01                    LDA    #01H        ; SET IN1LB=1
0361 B7 14                    STA    IN1LB
0363 3A 20          IN11B     DEC    BYTCNT      ;STORE NUMBER OF NON-ZERO
0365 3A 20          IN12B     DEC    BYTCNT      ; BYTES-1 IN BYTCNT
0367 5F             IN13B     CLRX
0368 5C             IN1ROT    INCX               ;STORE REQUIRED NUMBER OF
0369 48                       LSLA               ; ROTATIONS IN X
036A 24 FC                    BCC    IN1ROT
036C 3C 21          ROT1      INC    ROTCNT      ;ROTATE ALL BYTES THE REQUIRED
036E 5A                       DECX               ; NUMBER OF TIMES
036F 27 09                    BEQ    LOOK1
0371 38 14                    LSL    IN1LB
0373 39 13                    ROL    IN1MB
0375 39 12                    ROL    IN1HB
0377 CC 036C                  JMP    ROT1
037A B6 20          LOOK1     LDA    BYTCNT
037C AB 14                    ADD    #IN1LB
037E 97                       TAX
037F FE                       LDX    X           ;LOOK-UP THIS BYTE
0380 F6                       LDA    X
0381 AB 1E                    ADD    #01EH
0383 A0 1E          RTCM1     SUB    #01EH       ;COMPENSATE FOR NUMBER OF
0385 3A 21                    DEC    ROTCNT      ; ROTATIONS PERFORMED
0387 26 FA                    BNE    RTCM1
0389 3D 20                    TST    BYTCNT
038B 27 0E                    BEQ    OUTP1
038D AB F1          BYTCM1    ADD    #0F1H       ;COMPENSATE FOR NUMBER OF
038F 97                       TAX                ; BYTES USED IN CONVERSION
0390 B6 22                    LDA    DOSHB
0392 A9 00                    ADC    #00H
0394 B7 22                    STA    DOSHB
0396 9F                       TXA
0397 3A 20                    DEC    BYTCNT
0399 26 F2                    BNE    BYTCM1      ;EXITS WITH DOSE DATA IN
039B B7 23          OUTP1     STA    DOSLB       ; DOSHB,DOSLB
039D 81                       RTS                ;RETURN TO MAIN
                    ;
039E B6 23          OUTPUT    LDA    DOSLB       ;OUTPUT VALUE - LO BYTE
03A0 B7 00                    STA    PORTA       ; VIA PORT A ...
03A2 B6 01                    LDA    PORTB
03A4 A4 F0                    AND    #0F0H       ; ... AND HI BYTE VIA PORT B
03A6 BA 22                    ORA    DOSHB       ; SETTING BIT 3 TO 0 TO SIGNAL
03A8 B7 01                    STA    PORTB       ; NEW VALUE OUTPUT
03AA 81                       RTS                ;RETURN TO MAIN
                    ;
                    ;
                    ;DECIDE WHICH INTEGRATOR IS TELLING THE TRUTH
                    ;
                    ;PERFORM LOG CONVERSION ON THE APPRORIATE DOSE STORES
```

```
;
;PERFORM LOG CONVERSION ON THE TIME REGISTERS  *** NOT REQUIRED FOR
;                                                 SHORT LEQ ***
;FORM THE CORRECT VALUE OF LEQ
;
;OVERALL OR LAST LEQ?  *** SHORT LEQ ONLY FOR FIRST TEST ***
;
;OUTPUT THE CORRECT VALUE OF LEQ
```

```
LOCATION OBJECT CODE LINE     SOURCE LINE

                   ;*****************************************************************
                   ;LOOK-UP TABLE FOR LOG CONVERSION       A <- 100*LOG10(A)
                   ;*****************************************************************
                   ;                 ORG    TAB
 0080 D3D3D3D4D4                      FCB    211,211,211,212,212
 0085 D4D5D5D5D6                      FCB    212,213,213,213,214
 008A D6D6D7D7D7                      FCB    214,214,215,215,215
 008F D8D8D8D8D9                      FCB    216,216,216,216,217
 0094 D9D9DADADA                      FCB    217,217,218,218,218
 0099 DADBDBDBDC                      FCB    218,219,219,219,220
 009E DCDCDCDDDD                      FCB    220,220,220,221,221
 00A3 DDDDDEDEDE                      FCB    221,221,222,222,222
 00A8 DFDFDFDFE0                      FCB    223,223,223,223,224
 00AD E0E0E0E1E1                      FCB    224,224,224,225,225
 00B2 E1E1E2E2E2                      FCB    225,225,226,226,226
 00B7 E2E2E3E3E3                      FCB    226,226,227,227,227
 00BC E3E4E4E4E4                      FCB    227,228,228,228,228
 00C1 E5E5E5E5E5                      FCB    229,229,229,229,229
 00C6 E6E6E6E6E7                      FCB    230,230,230,230,231
 00CB E7E7E7E7E8                      FCB    231,231,231,231,232
 00D0 E8E8E8E8E9                      FCB    232,232,232,232,233
 00D5 E9E9E9E9EA                      FCB    233,233,233,233,234
 00DA EAEAEAEAEB                      FCB    234,234,234,234,235
 00DF EBEBEBEBEC                      FCB    235,235,235,235,236
 00E4 ECECECECED                      FCB    236,236,236,236,237
 00E9 EDEDEDEDED                      FCB    237,237,237,237,237
 00EE EEEEEEEEEE                      FCB    238,238,238,238,238
 00F3 EFEFEFEFEF                      FCB    239,239,239,239,239
 00F8 EFF0F0F0F0                      FCB    239,240,240,240,240
 00FD F0F0F1                          FCB    240,240,241
                   ;
                                      END

Errors=   0
```

MODULE LIST

```
 1 A.LABELS
 2 A.RESET
 3  A.RDKEYBD
 4  A.BCDCONV
 5 A.MAIN
 6  A.RDKEYBD
 7  A.CALMOD
 8  A.KEYINT
 9   A.PAUSE
10  A.DISPLAY
11   A.BCDCONV
12   A.BCDCONV
13   A.BCDCONV
14   A.LCDISP
15 A.TIMINT
16  A.BCDCONV
17  A.BCDCONV
18 A.SERIAL
19  A.ROMTX
20  A.ROMTX
21  A.ROMTX
22  A.ROMTX
23 A.TEST
24 A.TABLES
25 A.STRING
26 A.MONITOR
27 A.INTVECT
```

```
00000001                    LIST      ON
                  ;LIST  ON ENABLES LISTING AND MAY BE USED BEFORE ONE MOD
                  ULE TO PRINT THAT ONE ONLY. USE LIST    OFF TO DISABLE A
                  FTER THE MODULE(S) TO BE LISTED.

                  ;MODULE   ON SENDS ANY PRINT OUTPUT TO PRINTER INSTEAD O
                  F THE SCREEN

00000000                    HEADER    "CRL 2.36 SHO
00000000                              RT Leq DATA A
00000000                              QUISITION UNI
00000000                              T"
00000001                    SYMTAB    ON            symbol table enabled

00000000          EPROM     =         0

00000000                    IF        EPROM=1
                            OBSEND    1,0,0,"2360BJ send object code to disc
                                      "
                            OBFORM    1
                  no load or exec address specified
                  ;        OBSEND   6,2764,128,0,0
                  ;        OBSEND   4,7
00000000                    ELSE

00000006                    OBSEND    6,2764,128,0,
00000006                              0
00000001                    OBFORM    1             straight binary (1,0,0,"
00000001                                            2360BJ")

00000000                    ENDIF

                  ;FOR EPROM, STORE OBJECT CODE ON DISK  USING OBSEND 1,0,
                  0,"2360BJ"/OBFORM 2   THEN WHEN THE EPROMER SOFTWARE PRO
                  MPTS FOR FILENAME, GIVE "2360BJ".         FOR PORTAL U
                  SE OBSEND   6,2764,128,0,0   AND OBSEND    1.

                  ******************************

0000E000                    ORG       $E000         origin for program code

0000E000                    A.LABELS                module to define labels
```

```
                A.LABELS   MODULE
                ;module to define all the labels used  in the CRL236 pro
                gram ......these will be GLOBAL

                *********************************

                ;labels used to refer to HD6303X      internal register
                s

                ;         I/O registers + control

00000001        PORT2DDR   =        $01          port2 data direction reg
00000001                                         ister
00000003        PORT2      =        $03
00000014        RAMPORT5   =        $14          internal RAM & port5 con
00000014                                         trol register
00000015        PORT5      =        $15
00000016        PORT6DDR   =        $16          port6 data direction reg
00000016                                         ister
00000017        PORT6      =        $17
                ;         timer 1 registers

00000009        FRC        =        $09          free-running counter (hi
00000009                                         gh byte)

0000000B        OCR1       =        $0B          output compare register
0000000B                                         1 (high byte)

00000019        OCR2       =        $19          output compare register
00000019                                         2 (high byte)

0000000D        ICR        =        $0D          input capture register

00000008        TCSR1      =        $08          timer control/status reg
00000008                                         ister 1

0000000F        TCSR2      =        $0F          timer control/status reg
0000000F                                         ister 2

                ;         timer 2 registers

0000001D        T2CNT      =        $1D          timer 2 up counter

0000001C        TCONR      =        $1C          time constant register

0000001B        TCSR3      =        $1B          timer control/status reg
0000001B                                         ister

                ;         serial communications interface registers

00000011        TRCSR1     =        $11          transmit/receive control
00000011                                          status        register
00000010        RMCR       =        $10          transmit rate/mode contr
00000010                                         ol register

00000013        TDR        =        $13          transmit data register

00000012        RDR        =        $12          receive data register
```

```
0000001E        TRCSR2    =       $1E

                *******************************

                ;labels used to refer to external      peripherals

                ;A-D start conversion/read location

00000031        ADST      =       $31

00000030        ADRD      =       $30

00000037        ADLOAD    =       $37

                ;LCD display driver digits

00000032        LCDIG     =       $32
                ;               $33
                ;               $34
                ;               $35

                ;LED latch

00000036        LEDS      =       $36

                *******************************

                ;labels used for HD6303X internal RAM  locations

                ;location used to count the number of  time loops
00000040        TLOOPCNT  =       $40
                ;keyboard press storage locations
00000041        KEYVAL    =       $41           row data in low nibble,
00000041                                        column data in high nibb
00000041                                        le
00000042        KEYCNT    =       $42           location used to count n
00000042                                        o of key tests
00000043        KEYTEMP   =       $43           temp store of key press
                ;LCD display output value location
00000044        LCDWORD   =       $44           low byte location
                ;               $45
                ;timer phase flag
00000046        TFLAG     =       $46
                ;locations for leq computation
00000047        ACTYPE    =       $47
00000048        CODE      =       $48
00000049        CHDSTRT   =       $49
                ;               $4A
                ;               $4B
0000004C        CUMBIN    =       $4C
                ;               $4D
0000004E        CUMBCD    =       $4E
                ;               $4F
00000050        DATA      =       $50
                ;               $51
00000052        DATACNT   =       $52
                ;               $53
                ;               $54
00000055        ERRFLAG   =       $55
```

```
00000056            HDWCTR      =          $56
00000057            HLPTR       =          $57
                    ;                 $58
00000059            LEDSREG     =          $59
0000005A            MAXBIN      =          $5A
                    ;                 $5B
0000005C            MAXBCD      =          $5C
                    ;                 $5D
0000005E            NOBIN       =          $5E
                    ;                 $5F
00000060            RAMPNTR     =          $60
                    ;                 $61
00000062            RAMPNTB     =          $62
00000063            RAMPSTR     =          $63
                    ;                 $64
00000065            RAMPBSTR    =          $65
00000066            RUNBIN      =          $66
                    ;                 $67
                    ;                 $68
00000069            TOTALCNT    =          $69
                    ;operating mode flags
0000006A            ACMODE      =          $6A
0000006B            DBLANKF     =          $6B
0000006C            HDRFLD      =          $6C
0000006D            LCDMAXUP    =          $6D
0000006E            LCDCUMUP    =          $6E
0000006F            LCDLEQUP    =          $6F
00000070            NOTYPE      =          $70

00000071            LCDNOUP     =          $71

00000072            LEDSONF     =          $72
00000073            RAMFULL     =          $73

                    ;communications scratch & buffers
00000074            DSCRTCH     =          $74
                    ;                 $75
00000076            HI32VL1     =          $76
                    ;                 $77
00000078            LO32VL1     =          $78
                    ;                 $79
0000007A            HI32VL2     =          $7A
                    ;                 $7B
0000007C            LO32VL2     =          $7C
                    ;                 $7D
0000007E            NUMMODE     =          $7E
0000007F            P2SAVE      =          $7F
00000080            RXBUF       =          $80
                    ;RXBUF IS 20H BYTES LONG
000000A0            TXPTR       =          $A0
                    ;                 $A1
000000A2            TXEND       =          $A2
                    ;                 $A3
000000A4            TXFLAG      =          $A4
000000A5            TXHFLG      =          $A5
000000A6            HDRSTRT     =          $A6
                    ;                 $A7
000000A8            HDRCTR      =          $A8
000000A9            RXPTR       =          $A9
```

```
                    ;                    $AA
000000AB            TXBYTE      =            $AB
000000AC            TXBANK      =            $AC
000000AD            TXENDPG     =            $AD
000000AE            RAMFLAG     =            $AE
000000AF            SCRATCH     =            $AF
000000B0            OFFSET4     =            $B0
000000B1            OFFSET3     =            $B1
000000B2            OFFSET2     =            $B2
000000B3            OFFSET1     =            $B3
000000B4            HSTRTPG     =            $B4
000000B5            BYTCTR      =            $B5
000000B6            LINCTR      =            $B6
000000B7            PENDFLG     =            $B7
000000B8            TXPPEND     =            $B8
                    ;                    $B9
000000BA            TXPBPEND    =            $BA
000000BB            TXEPEND     =            $BB
                    ;                    $BC
000000BD            TXEBPEND    =            $BD
000000BE            KENCNT      =            $BE
000000BF            ROTCNT      =            $BF
000000C0            MONFLG      =            $C0
000000C1            NOBCD       =            $C1
                    ;                    $C2
000000C3            BCDOVF      =            $C3
000000C4            CODUSE      =            $C4
000000C5            KENFLG      =            $C5
000000C6            TOGLCNT     =            $C6
000000C7            CALFLG      =            $C7
000000C8            RUNBCD      =            $C8
                    ;                    $C9
000000CA            DATADIF     =            $CA
                    ;                    $CB
000000CC            CUMDOSE     =            $CC
                    ;                    $CD
                    ;                    $CE
000000CF            CUMTIME     =            $CF
                    ;                    $D0
                    ;                    $D1
000000D2            LOGTIME     =            $D2
                    ;                    $D3
                    ;                    $D4
000000D5            CALOFF      =            $D5
                    ;                    $D6
000000D7            ERRSTAT     =            $D7
000000D8            ERRHOLD     =            $D8
000000D9            P2BACK      =            $D9
000000DA            CALDNF      =            $DA
000000DB            LINASTR     =            $DB
000000DC            CALVAL      =            $DC
                    ;                    $DD
000000DE            STAKPTR     =            $DE
                    ;                    $DF
000000E0            CALKCNT     =            $E0
000000E1            MEMLBIN     =            $E1
                    ;                    $E2
000000E3            MEMLBCD     =            $E3
                    ;                    $E4
```

```
                        ;               $E5

                        ******************************

                        ;constants
00000000                ADPSU     =     %00000000
00000001                ADLINA    =     %00000001
00000002                ADLEQ     =     %00000010
000000B1                SCALOF    =     177            set instrument scale zer
000000B1                                               o (adj for 10mVrms input
000000B1                                                and 94 dB)
00000140                RAMSTRT   =     $140           ram start address
0000E000                RAMEND    =     $E000          ram end address low word
00000001                RAMENDB   =     1              ram end bank
0000E000                SER_NO    ALIAS "000001"
00000001                CIRRUS    =     1
00000001                HD6303Y   =     1
00000001                PARITY    =     1

                        ;key values
00000011                CAL       =     $11
00000021                LEDENABL  =     $21
00000041                RESETCUM  =     $41
00000081                RELMAX    =     $81
00000012                LEQNO     =     $12
00000022                SHORTLEQ  =     $22
00000042                CUMLEQ    =     $42
00000082                MAXLEQ    =     $82
00000014                EIGTH     =     $14
00000024                ONESEC    =     $24
00000044                TENSEC    =     $44
00000084                PAUSE     =     $84
00000018                CODE1     =     $18
00000028                CODE2     =     $28
00000048                CODE3     =     $48
00000088                CODE4     =     $88

                        ******************************

0000E000                          MEND
```

```
0000E000                A.RESET                reset/restart module
```

```
                   A.RESET    MODULE
                   ;module to detect warm/cold start
                   ;and temporarily to set ports
                   RES
                   TRAP
0000E000 71E014               AIM       %11100000,RAM
0000E003                                PORT5
0000E003 724014               OIM       %01000000,RAM
0000E006                                PORT5
0000E006 7B8014               TIM       %10000000,RAM if stanby bit is still s
0000E009                                PORT5         et batt bak ok
0000E009 2603                 BNE       RAMOK
0000E00B 7EE0C2               JMP       NRAMOK
0000E00E 716014    RAMOK      AIM       %01100000,RAM
0000E011                                PORT5
0000E011 8600                 LDAA      #%00000000
0000E013 9717                 STAA      PORT6
0000E015 860F                 LDAA      #%00001111    set port 6 for input/out
0000E017                                              put
0000E017 9716                 STAA      PORT6DDR
0000E019                      A.RDKEYBD
```

```
                          A.RDKEYBD  MODULE
0000E019                             LOCAL
                          ******************************
                          ;scan keyboard
0000E019 8603                        LDAA      #$03        initialise KEYCNT
0000E01B 9742                        STAA      KEYCNT
0000E01D 7F0041                      CLR       KEYVAL      clear KEYVAL location
0000E020 4F               KEYLOOP    CLRA                  clear temp store in acc
0000E021                                                   A
0000E021 C6F7                        LDAB      #$F7        output test bit to row 4
0000E023 D717                        STAB      PORT6
0000E025 9617                        LDAA      PORT6       read column values
0000E027 43                          COMA
0000E028 84F0                        ANDA      #%11110000  (mask row data)
0000E02A 2622                        BNE       KEYTST      yes, return with values
0000E02C C6FB                        LDAB      #$FB        no, output test bit to r
0000E02E                                                   ow 2 etc....
0000E02E D717                        STAB      PORT6
0000E030 9617                        LDAA      PORT6
0000E032 43                          COMA
0000E033 84F0                        ANDA      #%11110000  (mask row data)
0000E035 2617                        BNE       KEYTST
0000E037 C6FD                        LDAB      #$FD
0000E039 D717                        STAB      PORT6
0000E03B 9617                        LDAA      PORT6
0000E03D 43                          COMA
0000E03E 84F0                        ANDA      #%11110000  (mask row data)
0000E040 260C                        BNE       KEYTST
0000E042 C6FE                        LDAB      #$FE
0000E044 D717                        STAB      PORT6
0000E046 9617                        LDAA      PORT6
0000E048 43                          COMA
0000E049 84F0                        ANDA      #%11110000  (mask row data)
0000E04B 2601                        BNE       KEYTST
0000E04D 5F                          CLRB
0000E04E 9743             KEYTST     STAA      KEYTEMP     store column data in KEY
0000E050                                                   TEMP
0000E050 53                          COMB
0000E051 DA43                        ORAB      KEYTEMP     OR this data into acc B
0000E053 D743                        STAB      KEYTEMP     store row and col data i
0000E055                                                   n KEYTEMP
0000E055 9641                        LDAA      KEYVAL      has a key been detected
0000E057                                                   before?
0000E057 2603                        BNE       KEYCOMP     yes, compare with new va
0000E059                                                   lue
0000E059 D741                        STAB      KEYVAL      no, put KEYTEMP in KEYVA
0000E05B                                                   L
0000E05B 17                          TBA                   force values to be the s
0000E05C                                                   ame
0000E05C 10               KEYCOMP    SBA                   are values the same?
0000E05D 2705                        BEQ       KEYOK       yes, proceed
0000E05F 7F0041                      CLR       KEYVAL
0000E062 2005                        BRA       KEYRET      don't count this keypres
0000E064                                                   s
0000E064 7A0042           KEYOK      DEC       KEYCNT      debounce using KEYCNT
0000E067 26B7                        BNE       KEYLOOP
0000E069 7F0017           KEYRET     CLR       PORT6       return port6 to initial
0000E06C                                                   value
```

```
                    *******************************
0000E06C                      MEND
```

```
0000E06C 9641                 LDAA    KEYVAL
0000E06E 81C1                 CMPA    #RESETCUM BOR
0000E070                               #RELMAX
0000E070 2750                 BEQ     NRAMOK
0000E072 9EDE                 LDS     STAKPTR
0000E074 96D9                 LDAA    P2BACK        set dec pt and SIO rec'v
0000E076                                            e line
0000E076 9703                 STAA    PORT2
0000E078 86FF                 LDAA    #%11111111    set port 2 for output
0000E07A 9701                 STAA    PORT2DDR
0000E07C 8600                 LDAA    #%00000000
0000E07E 9717                 STAA    PORT6
0000E080 860F                 LDAA    #%00001111    set port 6 for input/out
0000E082                                            put
0000E082 9716                 STAA    PORT6DDR
0000E084 8602                 LDAA    #$2           set timer 2 baud rate
0000E086 971C                 STAA    TCONR         9600
0000E088                      IF      HD6303Y=1
0000E088 8624                 LDAA    #%00100100
0000E08A 9710                 STAA    RMCR
0000E08C 861A                 LDAA    #%00011010
0000E08E 9711                 STAA    TRCSR1
0000E090                      IF      PARITY=1
0000E090 8604                 LDAA    #%00000100
0000E092 971E                 STAA    TRCSR2
0000E094                      ELSE
                              LDAA    #%00000001
                              STAA    TRCSR2
0000E094                      ENDIF
0000E094                      ELSE
                              LDAA    #%01110100
                              STAA    RMCR
                              LDAA    #%00011010
                              STAA    TRCSR1
0000E094                      ENDIF
0000E094 8610                 LDAA    #%00010000
0000E096 971B                 STAA    TCSR3
0000E098 8604                 LDAA    #%00000100
0000E09A 9708                 STAA    TCSR1
0000E09C 8601                 LDAA    #$1
0000E09E 9772                 STAA    LEDSONF
0000E0A0 7D00C7               TST     CALFLG
0000E0A3 2712                 BEQ     OLDCAL
0000E0A5 CCFFBC               LDD     #$FFBC
0000E0A8 DD05                 STD     CALOFF
0000E0AA 4F                   CLRA
0000E0AB 97DA                 STAA    CALDNF
0000E0AD 97C7                 STAA    CALFLG
0000E0AF 30                   TSX
0000E0B0 C607                 LDAB    #$7
0000E0B2 3A                   ABX
0000E0B3 35                   TXS
0000E0B4 7EE1AF               JMP     START
0000E0B7 8684        OLDCAL   LDAA    #PAUSE
0000E0B9 9741                 STAA    KEYVAL
0000E0BB CC0000               LDD     #$0000
0000E0BE DD09                 STD     FRC
0000E0C0 0E                   CLI
0000E0C1 3B                   RTI
```

```
0000E0C2 8E013F     NRAMOK    LDS        #$013F          set stack pointer
0000E0C5 CE0040               LDX        #$40
0000E0C8 4F                   CLRA
0000E0C9 A700       RAMCLR    STAA       0,X
0000E0CB 08                   INX
0000E0CC 8C0140               CPX        #$140
0000E0CF 26F8                 BNE        RAMCLR
0000E0D1 86A8                 LDAA       #%10101000      set dec pt and SIO rec'v
0000E0D3                                                 e line
0000E0D3 9703                 STAA       PORT2
0000E0D5 86FF                 LDAA       #%11111111      set port 2 for output
0000E0D7 9701                 STAA       PORT2DDR
0000E0D9 8600                 LDAA       #%00000000
0000E0DB 9717                 STAA       PORT6
0000E0DD 860F                 LDAA       #%00001111      set port 6 for input/out
0000E0DF                                                 put
0000E0DF 9716                 STAA       PORT6DDR
0000E0E1 8602                 LDAA       #$2             set timer 2 baud rate
0000E0E3 971C                 STAA       TCONR           9600
0000E0E5                      IF         HD6303Y=1
0000E0E5 8624                 LDAA       #%00100100
0000E0E7 9710                 STAA       RMCR
0000E0E9 861A                 LDAA       #%00011010
0000E0EB 9711                 STAA       TRCSR1
0000E0ED                      IF         PARITY=1
0000E0ED 8604                 LDAA       #%00000100
0000E0EF 971E                 STAA       TRCSR2
0000E0F1                      ELSE
                              LDAA       #%00000001
                              STAA       TRCSR2
0000E0F1                      ENDIF
0000E0F1                      ELSE
                              LDAA       #%01110100
                              STAA       RMCR
                              LDAA       #%00011010
                              STAA       TRCSR1
0000E0F1                      ENDIF
0000E0F1 8610                 LDAA       #%00010000
0000E0F3 971B                 STAA       TCSR3
0000E0F5 8604                 LDAA       #%00000100
0000E0F7 9708                 STAA       TCSR1
0000E0F9 4F                   CLRA
0000E0FA 9747                 STAA       ACTYPE
0000E0FC 97C7                 STAA       CALFLG
0000E0FE 97DA                 STAA       CALDNF
0000E100 4C                   INCA
0000E101 976B                 STAA       DBLANKF
0000E103 9772                 STAA       LEDSONF
0000E105 976F                 STAA       LCDLEQUP
0000E107 97BE                 STAA       KENCNT
0000E109 9770                 STAA       NOTYPE
0000E10B 9746                 STAA       TFLAG
0000E10D 976A                 STAA       ACMODE
0000E10F 97C6                 STAA       TOGLCNT
0000E111 CCE000               LDD        #RAMEND
0000E114 830140               SUBD       #RAMSTRT
0000E117 DDE1                 STD        MEMLBIN
0000E119                      A.BCDCONV  MEMLBIN;MEMLB
0000E119                                 CD+1
```

```
                  A.BCDCONV  MACRO     BINVAL;BCDVAL
                  ;macro to convert values stored in      parameter BINVAL
                   to bcd values in parameter BCDVAL ........bcd digits 4+
                  5 are also placed in BCDOVF.......BINVAL & BCDVAL 16-bi
                  t registers              (CCR contents destroyed)

                  ********************************

0000E119 36                  PSHA                          temp store accumulator A
0000E11A 4F                  CLRA
0000E11B 97C3                STAA      BCDOVF
                  ;units
0000E11D 96E2                LDAA      MEMLBIN+1
0000E11F 840F                ANDA      #$0F
0000E121 810A                CMPA      #$0A
0000E123 2502                BCS       LOSTR
0000E125 8B06                ADDA      #$06
0000E127 97E5     LOSTR      STAA      MEMLBCD+1+1
                  ;multiples of 16
0000E129 D6E2                LDAB      MEMLBIN+1
0000E12B C4F0                ANDB      #$F0
0000E12D 54                  LSRB
0000E12E 54                  LSRB
0000E12F 54                  LSRB
0000E130 CEF15D   LOMIDST    LDX       #BCDTAB1
0000E133 3A                  ABX
0000E134 EC00                LDD       0,X
0000E136 36                  PSHA
0000E137 17                  TBA
0000E138 33                  PULB
0000E139 9BE5                ADDA      MEMLBCD+1+1
0000E13B 19                  DAA
0000E13C 97E5                STAA      MEMLBCD+1+1
0000E13E 36                  PSHA
0000E13F 17                  TBA
0000E140 33                  PULB
0000E141 8900                ADCA      #$00
0000E143 19                  DAA
0000E144 97E4                STAA      MEMLBCD+1
                  ;multiples of 256
0000E146 D6E1                LDAB      MEMLBIN
0000E148 C40F                ANDB      #$0F
0000E14A 58                  ASLB
0000E14B CEF17D   HIMIDST    LDX       #BCDTAB2
0000E14E 3A                  ABX
0000E14F EC00                LDD       0,X
0000E151 36                  PSHA
0000E152 17                  TBA
0000E153 33                  PULB
0000E154 9BE5                ADDA      MEMLBCD+1+1
0000E156 19                  DAA
0000E157 97E5                STAA      MEMLBCD+1+1
0000E159 36                  PSHA
0000E15A 17                  TBA
0000E15B 33                  PULB
0000E15C 99E4                ADCA      MEMLBCD+1
0000E15E 19                  DAA
0000E15F 97E4                STAA      MEMLBCD+1
                  ;multiples of 4096 (4 dig only)
```

```
0000E161 D6E1                 LDAB    MEMLBIN
0000E163 C4F0                 ANDB    #$F0
0000E165 54                   LSRB
0000E166 54                   LSRB
0000E167 54                   LSRB
0000E168 CEF19D     HIST      LDX     #BCDTAB3
0000E16B 3A                   ABX
0000E16C EC00                 LDD     0,X
0000E16E 36                   PSHA
0000E16F 17                   TBA
0000E170 33                   PULB
0000E171 9BE5                 ADDA    MEMLBCD+1+1
0000E173 19                   DAA
0000E174 97E5                 STAA    MEMLBCD+1+1
0000E176 36                   PSHA
0000E177 17                   TBA
0000E178 33                   PULB
0000E179 99E4                 ADCA    MEMLBCD+1
0000E17B 19                   DAA
0000E17C 97E4                 STAA    MEMLBCD+1
0000E17E 96C3                 LDAA    BCDOVF
0000E180 8900                 ADCA    #$00
0000E182 97C3                 STAA    BCDOVF
                    ;other dig of 4096 multiple
0000E184 D6E1                 LDAB    MEMLBIN
0000E186 C4F0                 ANDB    #$F0
0000E188 54                   LSRB
0000E189 54                   LSRB
0000E18A 54                   LSRB
0000E18B 54                   LSRB
0000E18C CEF1BD               LDX     #BCDTAB4
0000E18F 3A                   ABX
0000E190 A600                 LDAA    0,X
0000E192 9BC3                 ADDA    BCDOVF
0000E194 19                   DAA
0000E195 97C3                 STAA    BCDOVF
0000E197 32                   PULA

                    ********************************
0000E198                      MEND
0000E198 96C3                 LDAA    BCDOVF
0000E19A 97E3                 STAA    MEMLBCD
0000E19C CCFFBC               LDD     #$FFBC
0000E19F DDD5                 STD     CALOFF
0000E1A1 8612                 LDAA    #%00010010
0000E1A3 9759                 STAA    LEDSREG
0000E1A5 CE0080               LDX     #RXBUF
0000E1A8 DFA9                 STX     RXPTR
0000E1AA CE0140               LDX     #RAMSTRT
0000E1AD DF60                 STX     RAMPNTR
0000E1AF 8684       START     LDAA    #PAUSE
0000E1B1 9741                 STAA    KEYVAL          pause
0000E1B3 724003               OIM     %01000000,POR
0000E1B6                              T2
0000E1B6 71BF03               AIM     %10111111,POR
0000E1B9                              T2
0000E1B9 CC0000               LDD     #$0000
0000E1BC DD09                 STD     FRC
```

```
0000E1BE 0E                 CLI
0000E1BF                    MEND

0000E1BF                    A.MAIN
```

```
                         A.MAIN      MODULE

                         ;main module

                         *******************************

                         MLOOP
0000E1BF 1A                          SLP
0000E1C0 7D00C0                      TST      MONFLG
0000E1C3 2706                        BEQ      NMON
0000E1C5 7F00C0                      CLR      MONFLG
0000E1C8 7EF90A                      JMP      MONITA
                         NMON
0000E1CB 7A00BE                      DEC      KENCNT
0000E1CE 2608                        BNE      NKEYEN
0000E1D0 8610                        LDAA     #$10
0000E1D2 97BE                        STAA     KENCNT
0000E1D4 4F                          CLRA
0000E1D5 4C                          INCA
0000E1D6 97C5                        STAA     KENFLG
                         NKEYEN
0000E1D8 9641                        LDAA     KEYVAL
0000E1DA 2703                        BEQ      TRYREAD
0000E1DC 7EE315                      JMP      INTRPRT
0000E1DF 7D0072          TRYREAD     TST      LEDSONF
0000E1E2 2603                        BNE      ROW3OK
0000E1E4 720417                      OIM      %00000100,POR
0000E1E7                                      T6
0000E1E7 9615            ROW3OK      LDAA     PORT5          poll keyboard
0000E1E9 8401                        ANDA     #%00000001     if no key...
0000E1EB 2653                        BNE      NOKEY              ...go back to sleep
0000E1ED                             A.RDKEYBD
```

```
                        A.RDKEYBD   MODULE
0000E1ED                            LOCAL
                        *******************************
                        ;scan keyboard
0000E1ED 8603                       LDAA      #$03          initialise KEYCNT
0000E1EF 9742                       STAA      KEYCNT
0000E1F1 7F0041                     CLR       KEYVAL        clear KEYVAL location
0000E1F4 4F             KEYLOOP     CLRA                    clear temp store in acc
0000E1F5                                                    A
0000E1F5 C6F7                       LDAB      #$F7          output test bit to row 4
0000E1F7 D717                       STAB      PORT6
0000E1F9 9617                       LDAA      PORT6         read column values
0000E1FB 43                         COMA
0000E1FC 84F0                       ANDA      #%11110000    (mask row data)
0000E1FE 2622                       BNE       KEYTST        yes, return with values
0000E200 C6FB                       LDAB      #$FB          no, output test bit to r
0000E202                                                    ow 2 etc....
0000E202 D717                       STAB      PORT6
0000E204 9617                       LDAA      PORT6
0000E206 43                         COMA
0000E207 84F0                       ANDA      #%11110000    (mask row data)
0000E209 2617                       BNE       KEYTST
0000E20B C6FD                       LDAB      #$FD
0000E20D D717                       STAB      PORT6
0000E20F 9617                       LDAA      PORT6
0000E211 43                         COMA
0000E212 84F0                       ANDA      #%11110000    (mask row data)
0000E214 260C                       BNE       KEYTST
0000E216 C6FE                       LDAB      #$FE
0000E218 D717                       STAB      PORT6
0000E21A 9617                       LDAA      PORT6
0000E21C 43                         COMA
0000E21D 84F0                       ANDA      #%11110000    (mask row data)
0000E21F 2601                       BNE       KEYTST
0000E221 5F                         CLRB
0000E222 9743           KEYTST      STAA      KEYTEMP       store column data in KEY
0000E224                                                    TEMP
0000E224 53                         COMB
0000E225 DA43                       ORAB      KEYTEMP       OR this data into acc B
0000E227 D743                       STAB      KEYTEMP       store row and col data i
0000E229                                                    n KEYTEMP
0000E229 9641                       LDAA      KEYVAL        has a key been detected
0000E22B                                                    before?
0000E22B 2603                       BNE       KEYCOMP       yes, compare with new va
0000E22D                                                    lue
0000E22D D741                       STAB      KEYVAL        no, put KEYTEMP in KEYVA
0000E22F                                                    L
0000E22F 17                         TBA                     force values to be the s
0000E230                                                    ame
0000E230 10             KEYCOMP     SBA                     are values the same?
0000E231 2705                       BEQ       KEYOK         yes, proceed
0000E233 7F0041                     CLR       KEYVAL
0000E236 2005                       BRA       KEYRET        don't count this keypres
0000E238                                                    s
0000E238 7A0042         KEYOK       DEC       KEYCNT        debounce using KEYCNT
0000E23B 26B7                       BNE       KEYLOOP
0000E23D 7F0017         KEYRET      CLR       PORT6         return port6 to initial
0000E240                                                    value
```

```
                    ********************************
0000E240                          MEND
```

```
                    NOKEY

0000E240 7D00C7                TST      CALFLG
0000E243 2603                  BNE      CALPH
0000E245 7EE30E                JMP      NCALMOD
0000E248 7B0146     CALPH      TIM      $1,TFLAG
0000E24B 2606                  BNE      CALMOD
0000E24D 7F0041                CLR      KEYVAL
0000E250 7EE30E                JMP      NCALMOD
0000E253            CALMOD     A.CALMOD
```

```
                    A.CALMOD   MODULE
0000E253 9641                  LDAA     KEYVAL
0000E255 81F8                  CMPA     #$F8
0000E257 2617                  BNE      NCALCLR
0000E259 4F                    CLRA
0000E25A 97C7                  STAA     CALFLG
0000E25C 97DA                  STAA     CALDNF
0000E25E CCFFBC                LDD      #$FFBC
0000E261 DDD5                  STD      CALOFF
0000E263 71BFD7                AIM      %10111111,ERR
0000E266                                STAT
0000E266 71F259                AIM      %11110010,LED
0000E269                                SREG
0000E269 8622                  LDAA     #SHORTLEQ
0000E26B 9741                  STAA     KEYVAL
0000E26D 7EE30E                JMP      CALEND
                    NCALCLR
0000E270 8114                  CMPA     #EIGTH
0000E272 2607                  BNE      N94DB
0000E274 CC03AC                LDD      #$03AC
0000E277 DDDC                  STD      CALVAL
0000E279 205D                  BRA      TSTOFF
0000E27B 8124       N94DB      CMPA     #ONESEC
0000E27D 2607                  BNE      N104DB
0000E27F CC0410                LDD      #$0410
0000E282 DDDC                  STD      CALVAL
0000E284 2052                  BRA      TSTOFF
0000E286 8144       N104DB     CMPA     #TENSEC
0000E288 2607                  BNE      N117DB
0000E28A CC0492                LDD      #$0492
0000E28D DDDC                  STD      CALVAL
0000E28F 2047                  BRA      TSTOFF
0000E291 8184       N117DB     CMPA     #PAUSE
0000E293 2605                  BNE      N124DB
0000E295 CC04D8                LDD      #$04D8
0000E298 DDDC                  STD      CALVAL
0000E29A D6E0       N124DB     LDAB     CALKCNT
0000E29C 5C                    INCB
0000E29D D7E0                  STAB     CALKCNT
0000E29F C108                  CMPB     #8
0000E2A1 2635                  BNE      TSTOFF
0000E2A3 5F                    CLRB
0000E2A4 D7E0                  STAB     CALKCNT
0000E2A6 8118                  CMPA     #CODE1
0000E2A8 2609                  BNE      NUP1DB
0000E2AA DCDC                  LDD      CALVAL
0000E2AC C3000A                ADDD     #10
0000E2AF DDDC                  STD      CALVAL
0000E2B1 2025                  BRA      TSTOFF
0000E2B3 8128       NUP1DB     CMPA     #CODE2
0000E2B5 260B                  BNE      NDN1DB
0000E2B7 DCDC                  LDD      CALVAL
0000E2B9 271D                  BEQ      TSTOFF
0000E2BB 83000A                SUBD     #10
0000E2BE DDDC                  STD      CALVAL
0000E2C0 2016                  BRA      TSTOFF
0000E2C2 8148       NDN1DB     CMPA     #CODE3
0000E2C4 2607                  BNE      NUPPT1DB
0000E2C6 DEDC                  LDX      CALVAL
```

```
0000E2C8 08                      INX
0000E2C9 DFDC                    STX      CALVAL
0000E2CB 200B                    BRA      TSTOFF
0000E2CD 8188        NUPPT1DB    CMPA     #CODE4
0000E2CF 2607                    BNE      TSTOFF
0000E2D1 DEDC                    LDX      CALVAL
0000E2D3 2703                    BEQ      TSTOFF
0000E2D5 09                      DEX
0000E2D6 DFDC                    STX      CALVAL
0000E2D8 DED5        TSTOFF      LDX      CALOFF
0000E2DA 8C007F                  CPX      #$007F
0000E2DD 230E                    BLS      CALOK
0000E2DF 8CFF80                  CPX      #$FF80
0000E2E2 2209                    BHI      CALOK
0000E2E4 8601                    LDAA     #$01
0000E2E6 9755                    STAA     ERRFLAG
0000E2E8 7240D7                  OIM      %01000000,ERR
0000E2EB                                  STAT
0000E2EB 2016                    BRA      DOCAL
                     CALOK
0000E2ED 71BFD7                  AIM      %10111111,ERR
0000E2F0                                  STAT
0000E2F0 81C1                    CMPA     #RESETCUM BOR
0000E2F2                                   #RELMAX
0000E2F2 260F                    BNE      DOCAL
0000E2F4 4F                      CLRA
0000E2F5 97C7                    STAA     CALFLG
0000E2F7 4C                      INCA
0000E2F8 97DA                    STAA     CALDNF
0000E2FA 71F259                  AIM      %11110010,LED
0000E2FD                                  SREG
0000E2FD 8622                    LDAA     #SHORTLEQ
0000E2FF 9741                    STAA     KEYVAL
0000E301 200B                    BRA      CALEND
                     DOCAL
0000E303 DC50                    LDD      DATA
0000E305 D3D5                    ADDD     CALOFF
0000E307 93DC                    SUBD     CALVAL
0000E309 DDD5                    STD      CALOFF
0000E30B 7F0041                  CLR      KEYVAL
                     CALEND
0000E30E                         MEND
```

```
                  NCALMOD
0000E30E 9641               LDAA      KEYVAL
0000E310 2603               BNE       INTRPRT
0000E312 7EE6CD             JMP       NINTRPRT
0000E315          INTRPRT   A.KEYINT
```

```
                    A.KEYINT   MODULE
0000E315 8121                  CMPA   #LEDENABL      LEDENABLE
0000E317 2612                  BNE    NLEDKEY
0000E319 7D00C5                TST    KENFLG
0000E31C 270D                  BEQ    NLEDKEY
0000E31E 4F                    CLRA
0000E31F 97C5                  STAA   KENFLG
0000E321 8610                  LDAA   #$10
0000E323 97BE                  STAA   KENCNT
0000E325 750172                EIM    $01,LEDSONF
0000E328 7EE6C7                JMP    NSTRT
0000E32B 8122       NLEDKEY    CMPA   #SHORTLEQ
0000E32D 2618                  BNE    NSHRTLEQ
0000E32F 4F                    CLRA
0000E330 976D                  STAA   LCDMAXUP
0000E332 976E                  STAA   LCDCUMUP
0000E334 9771                  STAA   LCDNOUP
0000E336 9770                  STAA   NOTYPE
0000E338 4C                    INCA
0000E339 976F                  STAA   LCDLEQUP
0000E33B 728003                OIM    %10000000,POR
0000E33E                              T2
0000E33E 71F059                AIM    %11110000,LED
0000E341                              SREG
0000E341 720259                OIM    %00000010,LED
0000E344                              SREG
0000E344 7EE6C7                JMP    NSTRT
                    NSHRTLEQ
0000E347 8182                  CMPA   #MAXLEQ
0000E349 2618                  BNE    NMAXLEQ
0000E34B 4F                    CLRA
0000E34C 976F                  STAA   LCDLEQUP
0000E34E 976E                  STAA   LCDCUMUP
0000E350 9771                  STAA   LCDNOUP
0000E352 9770                  STAA   NOTYPE
0000E354 4C                    INCA
0000E355 976D                  STAA   LCDMAXUP
0000E357 728003                OIM    %10000000,POR set dec pt
0000E35A                              T2
0000E35A 71F059                AIM    %11110000,LED
0000E35D                              SREG
0000E35D 720859                OIM    %00001000,LED
0000E360                              SREG
0000E360 7EE6C7                JMP    NSTRT
                    NMAXLEQ
0000E363 8142                  CMPA   #CUMLEQ
0000E365 2618                  BNE    NCUMLEQ
0000E367 4F                    CLRA
0000E368 976D                  STAA   LCDMAXUP
0000E36A 976F                  STAA   LCDLEQUP
0000E36C 9771                  STAA   LCDNOUP
0000E36E 9770                  STAA   NOTYPE
0000E370 4C                    INCA
0000E371 976E                  STAA   LCDCUMUP
0000E373 728003                OIM    %10000000,POR set dec pt
0000E376                              T2
0000E376 71F059                AIM    %11110000,LED
0000E379                              SREG
0000E379 720459                OIM    %00000100,LED
```

```
0000E37C                            SREG
0000E37C 7EE6C7             JMP     NSTRT
                  NCUMLEQ
0000E37F 8112               CMPA    #LEQNO
0000E381 2626               BNE     NLEQNO
0000E383 7D00C5             TST     KENFLG
0000E386 2721               BEQ     NLEQNO
0000E388 4F                 CLRA
0000E389 97C5               STAA    KENFLG
0000E38B 976D               STAA    LCDMAXUP
0000E38D 976E               STAA    LCDCUMUP
0000E38F 976F               STAA    LCDLEQUP
0000E391 4C                 INCA
0000E392 9771               STAA    LCDNOUP
0000E394 8610               LDAA    #$10
0000E396 97BE               STAA    KENCNT
0000E398 717F03             AIM     %01111111,POR set three dots
0000E39B                            T2
0000E39B 9670               LDAA    NOTYPE
0000E39D 8401               ANDA    #%00000001
0000E39F 8801               EORA    #%00000001
0000E3A1 9770               STAA    NOTYPE
0000E3A3 71F059             AIM     %11110000,LED
0000E3A6                            SREG
0000E3A6 7EE6C7             JMP     NSTRT
0000E3A9 7D006A   NLEQNO    TST     ACMODE
0000E3AC 2603               BNE     RUNKEYS
0000E3AE 7EE5C3             JMP     NRUNKEYS
0000E3B1 8184     RUNKEYS   CMPA    #PAUSE
0000E3B3 2703               BEQ     DOPAUSE
0000E3B5 7EE58F             JMP     NPAUSE
0000E3B8          DOPAUSE   A.PAUSE
```

```
                    A.PAUSE     MODULE
0000E3B8 7F006A                 CLR       ACMODE
                    ;was the 2.36 running?
0000E3BB 9647                   LDAA      ACTYPE
0000E3BD 2713                   BEQ       CONVCMP
                    ;was there 1 complete conversion?
0000E3BF DC60                   LDD       RAMPNTR        prevents endless empty h
0000E3C1                                                 eaders if
0000E3C1 830010                 SUBD      #$0010         a conversion is interrup
0000E3C4                                                 ted before
0000E3C4 18                     XGDX                     the first data is stored
0000E3C5 9C4A                   CPX       CHDSTRT+1
0000E3C7 2609                   BNE       CONVCMP
0000E3C9 9662                   LDAA      RAMPNTB
0000E3CB 9149                   CMPA      CHDSTRT
0000E3CD 2603                   BNE       CONVCMP
0000E3CF 7EE578                 JMP       NLASTEND
                    CONVCMP
                    ;build new header
0000E3D2 7F006C                 CLR       HDRFLD
0000E3D5 7F0056                 CLR       HDWCTR
0000E3D8 CEF1CD                 LDX       #HLOOK
0000E3DB DF57                   STX       HLPTR
0000E3DD 9603                   LDAA      PORT2
0000E3DF 8402                   ANDA      #%00000010
0000E3E1 44                     LSRA
0000E3E2 9762                   STAA      RAMPNTB
0000E3E4 DE60                   LDX       RAMPNTR
0000E3E6 DF63                   STX       RAMPSTR
0000E3E8 9662                   LDAA      RAMPNTB
0000E3EA 9765                   STAA      RAMPBSTR
0000E3EC 7D0073     NXEMPTY     TST       RAMFULL
0000E3EF 2706                   BEQ       NFULL1
0000E3F1 8601                   LDAA      #$01
0000E3F3 976C                   STAA      HDRFLD
0000E3F5 204E                   BRA       DOLAST
0000E3F7 DE60       NFULL1      LDX       RAMPNTR
0000E3F9 8CE000                 CPX       #RAMEND
0000E3FC 2625                   BNE       DOWRT
0000E3FE 7D0062                 TST       RAMPNTB
0000E401 2708                   BEQ       OTHRPG
0000E403 8601                   LDAA      #$01
0000E405 976C                   STAA      HDRFLD
0000E407 9773                   STAA      RAMFULL
0000E409 203A                   BRA       DOLAST
0000E40B 8601       OTHRPG      LDAA      #RAMENDB
0000E40D 2608                   BNE       TOGL1
0000E40F 8601                   LDAA      #$01
0000E411 976C                   STAA      HDRFLD
0000E413 9773                   STAA      RAMFULL
0000E415 202E                   BRA       DOLAST
0000E417 8601       TOGL1       LDAA      #$01
0000E419 9762                   STAA      RAMPNTB
0000E41B 720203                 OIM       %00000010,POR
0000E41E                                  T2
0000E41E CE0140                 LDX       #RAMSTRT
0000E421 DF60                   STX       RAMPNTR
0000E423 9656       DOWRT       LDAA      HDWCTR
0000E425 4C                     INCA
```

```
0000E426 9756                     STAA    HDWCTR
0000E428 8111                     CMPA    #$11
0000E42A 2719                     BEQ     DOLAST
0000E42C DE57                     LDX     HLPTR
0000E42E 71FE03                   AIM     %11111110,POR
0000E431                                  T2
0000E431 EC00                     LDD     0,X
0000E433 08                       INX
0000E434 08                       INX
0000E435 DF57                     STX     HLPTR
0000E437 DE60                     LDX     RAMPNTR
0000E439 E700                     STAB    0,X
0000E43B 720103                   OIM     %00000001,POR
0000E43E                                  T2
0000E43E A700                     STAA    0,X
0000E440 08                       INX
0000E441 DF60                     STX     RAMPNTR
0000E443 20A7                     BRA     NXEMPTY
                        DOLAST
                        ;finish last header if there was one
0000E445 DE60                     LDX     RAMPNTR
0000E447 8C0150                   CPX     #RAMSTRT+16
0000E44A 260F                     BNE     DOLAST1
0000E44C 9662                     LDAA    RAMPNTB
0000E44E 260B                     BNE     DOLAST1
0000E450 CE0140                   LDX     #RAMSTRT
0000E453 DF4A                     STX     CHDSTRT+1
0000E455 4F                       CLRA
0000E456 9749                     STAA    CHDSTRT
0000E458 7EE578                   JMP     NLASTEND
0000E45B 9649           DOLAST1   LDAA    CHDSTRT
0000E45D 2605                     BNE     CHDB1
0000E45F 71FD03                   AIM     %11111101,POR
0000E462                                  T2
0000E462 2003                     BRA     CHDBDN
0000E464 720203         CHDB1     OIM     %00000010,POR
0000E467                                  T2
                        CHDBDN
0000E467 DE4A                     LDX     CHDSTRT+1
0000E469 08                       INX                     chdstrt + 1
0000E46A 8CE000                   CPX     #$E000
0000E46D 2606                     BNE     NHDOVF1
0000E46F CE0140                   LDX     #RAMSTRT
0000E472 720203                   OIM     %00000010,POR
0000E475                                  T2
                        NHDOVF1
0000E475 DC53                     LDD     DATACNT+1
0000E477 71FE03                   AIM     %11111110,POR
0000E47A                                  T2
0000E47A E700                     STAB    #0,X            no of data samples
0000E47C 720103                   OIM     %00000001,POR
0000E47F                                  T2
0000E47F A700                     STAA    #0,X
0000E481 9652                     LDAA    DATACNT
0000E483 71FE03                   AIM     %11111110,POR
0000E486                                  T2
0000E486 08                       INX                     chedstrt + 2
0000E487 8CE000                   CPX     #$E000
0000E48A 2606                     BNE     NHDOVF2
```

```
0000E48C CE0140                LDX     #RAMSTRT
0000E48F 720203                OIM     %00000010,POR
0000E492                               T2
                   NHDOVF2
0000E492 A700                  STAA    0,X            no of data samples hi wo
0000E494                                              rd
0000E494 08                    INX
0000E495 08                    INX
0000E496 08                    INX
0000E497 08                    INX
0000E498 8CE000                CPX     #$E000
0000E49B 250B                  BCS     NHDOVF3
0000E49D 18                    XGDX
0000E49E 83E000                SUBD    #$E000
0000E4A1 CE0140                LDX     #RAMSTRT
0000E4A4 3A                    ABX
0000E4A5 720203                OIM     %00000010,POR
0000E4A8                               T2
0000E4A8 5F        NHDOVF3     CLRB
0000E4A9 9649                  LDAA    CHDSTRT
0000E4AB 9865                  EORA    RAMPBSTR
0000E4AD 2706                  BEQ     NPGCHNG
0000E4AF CC2000                LDD     #$2000         fudge....offset to start
0000E4B2                                               of next
0000E4B2 C30140                ADDD    #RAMSTRT
0000E4B5 C30010    NPGCHNG     ADDD    #$10           allows for prog gap but
0000E4B8 D353                  ADDD    DATACNT+1      extended headers
0000E4BA DD53                  STD     DATACNT+1      not catered for
0000E4BC 9652                  LDAA    DATACNT
0000E4BE 8900                  ADCA    #0
0000E4C0 9752                  STAA    DATACNT
0000E4C2 7D006C                TST     HDRFLD
0000E4C5 2707                  BEQ     NNULL
0000E4C7 4F                    CLRA
0000E4C8 9752                  STAA    DATACNT
0000E4CA 9753                  STAA    DATACNT+1
0000E4CC 9754                  STAA    DATACNT+2
0000E4CE DC53      NNULL       LDD     DATACNT+1
0000E4D0 71FE03                AIM     %11111110,POR
0000E4D3                               T2
0000E4D3 E700                  STAB    0,X
0000E4D5 720103                OIM     %00000001,POR
0000E4D8                               T2
0000E4D8 A700                  STAA    0,X
0000E4DA 9652                  LDAA    DATACNT
0000E4DC 71FE03                AIM     %11111110,POR
0000E4DF                               T2
0000E4DF 08                    INX
0000E4E0 8CE000                CPX     #$E000
0000E4E3 2606                  BNE     NHDOVF4
0000E4E5 CE0140                LDX     #RAMSTRT
0000E4E8 720203                OIM     %00000010,POR
0000E4EB                               T2
                   NHDOVF4
0000E4EB A700                  STAA    0,X
0000E4ED 08                    INX
0000E4EE 08                    INX
0000E4EF 08                    INX
```

```
0000E4F0 08                     INX
0000E4F1 8CE000                 CPX      #$E000
0000E4F4 250B                   BCS      NHDOVF5
0000E4F6 18                     XGDX
0000E4F7 83E000                 SUBD     #$E000
0000E4FA CE0140                 LDX      #RAMSTRT
0000E4FD 3A                     ABX
0000E4FE 720203                 OIM      %00000010,POR
0000E501                                 T2
0000E501 720103      NHDOVF5    OIM      %00000001,POR
0000E504                                 T2
0000E504 96DB                   LDAA     LINASTR
0000E506 A700                   STAA     0,X
0000E508 08                     INX
0000E509 8CE000                 CPX      #$E000
0000E50C 2506                   BCS      NHDOVF6
0000E50E CE0140                 LDX      #RAMSTRT
0000E511 720203                 OIM      %00000010,POR
0000E514                                 T2
0000E514 08          NHDOVF6    INX
0000E515 8CE000                 CPX      #$E000
0000E518 2606                   BNE      NHDOVF7
0000E51A CE0140                 LDX      #RAMSTRT
0000E51D 720203                 OIM      %00000010,POR
0000E520                                 T2
0000E520 71FE03      NHDOVF7    AIM      %11111110,POR
0000E523                                 T2
0000E523 96C4                   LDAA     CODUSE
0000E525 44                     LSRA
0000E526 44                     LSRA
0000E527 44                     LSRA
0000E528 A700                   STAA     0,X
0000E52A 720103                 OIM      %00000001,POR
0000E52D                                 T2
0000E52D 9647                   LDAA     ACTYPE
0000E52F 8101                   CMPA     #1
0000E531 2606                   BNE      N18
0000E533 8602                   LDAA     #2
0000E535 A700                   STAA     0,X
0000E537 200E                   BRA      DCALWRT
0000E539 8108        N18        CMPA     #8
0000E53B 2606                   BNE      N1
0000E53D 8603                   LDAA     #3
0000E53F A700                   STAA     0,X
0000E541 2004                   BRA      DCALWRT
0000E543 8605        N1         LDAA     #5
0000E545 A700                   STAA     0,X
                     DCALWRT
0000E547 08                     INX
0000E548 8CE000                 CPX      #$E000
0000E54B 2606                   BNE      NHDOVF8
0000E54D CE0140                 LDX      #RAMSTRT
0000E550 720203                 OIM      %00000010,POR
0000E553                                 T2
0000E553 71FE03      NHDOVF8    AIM      %11111110,POR
0000E556                                 T2
0000E556 96D6                   LDAA     CALOFF+1
0000E558 A700                   STAA     0,X
0000E55A 720103                 OIM      %00000001,POR
```

```
0000E55D                                 T2
0000E55D 96DA                LDAA        CALDNF
0000E55F A700                STAA        0,X
0000E561 71FE03   NEWHDST    AIM         %11111110,POR
0000E564                                 T2
0000E564 DC63                LDD         RAMPSTR
0000E566 DD4A                STD         CHDSTRT+1
0000E568 9665                LDAA        RAMPBSTR
0000E56A 9749                STAA        CHDSTRT
0000E56C 9662                LDAA        RAMPNTB
0000E56E 2705                BEQ         SETP2
0000E570 720203              OIM         %00000010,POR
0000E573                                 T2
0000E573 2003                BRA         NLASTEND
0000E575 71FD03   SETP2      AIM         %11111101,POR
0000E578                                 T2
                  ;EXTENDED HEADERS NOT ACCOMMODATED

                  NLASTEND
0000E578 710F59              AIM         %00001111,LED
0000E57B                                 SREG
0000E57B 721059              OIM         %00010000,LED
0000E57E                                 SREG
0000E57E 728003              OIM         %10000000,POR
0000E581                                 T2
0000E581 4F                  CLRA
0000E582 97DA                STAA        CALDNF
0000E584 9752                STAA        DATACNT
0000E586 9753                STAA        DATACNT+1
0000E588 9754                STAA        DATACNT+2
0000E58A 97C4                STAA        CODUSE
0000E58C                     MEND
```

```
0000E58C 7EE6C7                  JMP     NSTRT
                   NPAUSE
0000E58F 8141                    CMPA    #RESETCUM
0000E591 2614                    BNE     NRSTCUM
0000E593 4F                      CLRA
0000E594 974C                    STAA    CUMBIN
0000E596 974D                    STAA    CUMBIN+1
0000E598 97CC                    STAA    CUMDOSE
0000E59A 97CD                    STAA    CUMDOSE+1
0000E59C 97CE                    STAA    CUMDOSE+2
0000E59E 97CF                    STAA    CUMTIME
0000E5A0 97D0                    STAA    CUMTIME+1
0000E5A2 97D1                    STAA    CUMTIME+2
0000E5A4 7EE6C7                  JMP     NSTRT
0000E5A7 8181      NRSTCUM       CMPA    #RELMAX
0000E5A9 2609                    BNE     NRELMAX
0000E5AB 7F005A                  CLR     MAXBIN
0000E5AE 7F005B                  CLR     MAXBIN+1
0000E5B1 7EE6C7                  JMP     NSTRT
0000E5B4 7B0841    NRELMAX       TIM     %00001000,KEY
0000E5B7                                 VAL
0000E5B7 2707                    BEQ     NCODE
                   ;NOTE!! ONLY THE MOST RECENT VALID CODE IS STORED
0000E5B9 9641                    LDAA    KEYVAL
0000E5BB 84F0                    ANDA    #$F0
0000E5BD 44                      LSRA
0000E5BE 9748                    STAA    CODE
                   NCODE
0000E5C0 7EE6C7                  JMP     NSTRT
                   NRUNKEYS
0000E5C3 8111                    CMPA    #CAL
0000E5C5 2625                    BNE     NCAL
0000E5C7 4F                      CLRA
0000E5C8 97D5                    STAA    CALOFF
0000E5CA 97D6                    STAA    CALOFF+1
0000E5CC 97E0                    STAA    CALKCNT
0000E5CE 976D                    STAA    LCDMAXUP
0000E5D0 976E                    STAA    LCDCUMUP
0000E5D2 9771                    STAA    LCDNOUP
0000E5D4 9770                    STAA    NOTYPE
0000E5D6 4C                      INCA
0000E5D7 976F                    STAA    LCDLEQUP
0000E5D9 97C7                    STAA    CALFLG
0000E5DB CC03AC                  LDD     #$03AC
0000E5DE DDDC                    STD     CALVAL
0000E5E0 728003                  OIM     %10000000,POR set dec pt
0000E5E3                                 T2
0000E5E3 71F059                  AIM     %11110000,LED
0000E5E6                                 SREG
0000E5E6 720159                  OIM     %00000001,LED
0000E5E9                                 SREG
0000E5E9 7EE6C7                  JMP     NSTRT
0000E5EC 7D0073    NCAL          TST     RAMFULL
0000E5EF 2703                    BEQ     NFULL2
0000E5F1 7EE6C7                  JMP     NSTRT
0000E5F4 8114      NFULL2        CMPA    #EIGTH
0000E5F6 2642                    BNE     NEIGTH
0000E5F8 710F59                  AIM     %00001111,LED
```

```
0000E5FB                          SREG
0000E5FB 728059           OIM     %10000000,LED
0000E5FE                          SREG
0000E5FE 4F               CLRA
0000E5FF 974C             STAA    CUMBIN
0000E601 974D             STAA    CUMBIN+1
0000E603 97CC             STAA    CUMDOSE
0000E605 97CD             STAA    CUMDOSE+1
0000E607 97CE             STAA    CUMDOSE+2
0000E609 97CF             STAA    CUMTIME
0000E60B 97D0             STAA    CUMTIME+1
0000E60D 97D1             STAA    CUMTIME+2
0000E60F 975A             STAA    MAXBIN
0000E611 975B             STAA    MAXBIN+1
0000E613 9766             STAA    RUNBIN
0000E615 9767             STAA    RUNBIN+1
0000E617 9768             STAA    RUNBIN+2
0000E619 4C               INCA
0000E61A 976A             STAA    ACMODE
0000E61C 9747             STAA    ACTYPE
0000E61E 9769             STAA    TOTALCNT
0000E620 9615     ADWAIT2 LDAA    PORT5
0000E622 8402             ANDA    #%00000010
0000E624 26FA             BNE     ADWAIT2
0000E626 9630             LDAA    ADRD
0000E628 817F             CMPA    #$7F
0000E62A 2207             BHI     LINPOS1
0000E62C 8601             LDAA    #$01
0000E62E 97DB             STAA    LINASTR
0000E630 7EE6C7           JMP     NSTRT
0000E633 8605     LINPOS1 LDAA    #$05
0000E635 97DB             STAA    LINASTR
0000E637 7EE6C7           JMP     NSTRT
0000E63A 8124     NEIGTH  CMPA    #ONESEC
0000E63C 2644             BNE     NONESEC
0000E63E 710F59           AIM     %00001111,LED
0000E641                          SREG
0000E641 724059           OIM     %01000000,LED
0000E644                          SREG
0000E644 4F               CLRA
0000E645 974C             STAA    CUMBIN
0000E647 974D             STAA    CUMBIN+1
0000E649 97CC             STAA    CUMDOSE
0000E64B 97CD             STAA    CUMDOSE+1
0000E64D 97CE             STAA    CUMDOSE+2
0000E64F 97CF             STAA    CUMTIME
0000E651 97D0             STAA    CUMTIME+1
0000E653 97D1             STAA    CUMTIME+2
0000E655 975A             STAA    MAXBIN
0000E657 975B             STAA    MAXBIN+1
0000E659 9766             STAA    RUNBIN
0000E65B 9767             STAA    RUNBIN+1
0000E65D 9768             STAA    RUNBIN+2
0000E65F 4C               INCA
0000E660 976A             STAA    ACMODE
0000E662 8608             LDAA    #$8
0000E664 9747             STAA    ACTYPE
0000E666 9769             STAA    TOTALCNT
0000E668 9615     ADWAIT3 LDAA    PORT5
```

```
0000E66A 8402                ANDA     #%00000010
0000E66C 26FA                BNE      ADWAIT3
0000E66E 9630                LDAA     ADRD
0000E670 817F                CMPA     #$7F
0000E672 2207                BHI      LINPOS2
0000E674 8601                LDAA     #$01
0000E676 97DB                STAA     LINASTR
0000E678 7EE6C7              JMP      NSTRT
0000E67B 8605      LINPOS2   LDAA     #$05
0000E67D 97DB                STAA     LINASTR
0000E67F 7EE6C7              JMP      NSTRT
0000E682 8144      NONESEC   CMPA     #TENSEC
0000E684 2641                BNE      NTENSEC
0000E686 710F59              AIM      %00001111,LED
0000E689                              SREG
0000E689 722059              OIM      %00100000,LED
0000E68C                              SREG
0000E68C 4F                  CLRA
0000E68D 974C                STAA     CUMBIN
0000E68F 974D                STAA     CUMBIN+1
0000E691 97CC                STAA     CUMDOSE
0000E693 97CD                STAA     CUMDOSE+1
0000E695 97CE                STAA     CUMDOSE+2
0000E697 97CF                STAA     CUMTIME
0000E699 97D0                STAA     CUMTIME+1
0000E69B 97D1                STAA     CUMTIME+2
0000E69D 975A                STAA     MAXBIN
0000E69F 975B                STAA     MAXBIN+1
0000E6A1 9766                STAA     RUNBIN
0000E6A3 9767                STAA     RUNBIN+1
0000E6A5 9768                STAA     RUNBIN+2
0000E6A7 4C                  INCA
0000E6A8 976A                STAA     ACMODE
0000E6AA 8650                LDAA     #$50
0000E6AC 9747                STAA     ACTYPE
0000E6AE 9769                STAA     TOTALCNT
0000E6B0 9615      ADWAIT4   LDAA     PORT5
0000E6B2 8402                ANDA     #%00000010
0000E6B4 26FA                BNE      ADWAIT4
0000E6B6 9630                LDAA     ADRD
0000E6B8 817F                CMPA     #$7F
0000E6BA 2207                BHI      LINPOS3
0000E6BC 8601                LDAA     #$01
0000E6BE 97DB                STAA     LINASTR
0000E6C0 7EE6C7              JMP      NSTRT
0000E6C3 8605      LINPOS3   LDAA     #$05
0000E6C5 97DB                STAA     LINASTR
                   NTENSEC
0000E6C7 7F0041    NSTRT     CLR      KEYVAL
0000E6CA 7F0017              CLR      PORT6
0000E6CD                     MEND
```

```
                    NINTRPRT
0000E6CD                      A.DISPLAY
```

```
                    A.DISPLAY  MODULE
0000E6CD 5F                    CLRB
0000E6CE 9672                  LDAA      LEDSONF
0000E6D0 2702                  BEQ       NLEDS
0000E6D2 D659                  LDAB      LEDSREG
0000E6D4 D736       NLEDS      STAB      LEDS
0000E6D6 7B0171                TIM       $01,LCDNOUP
0000E6D9 2603                  BNE       NOUP
0000E6DB 7EE7A7                JMP       NONOUP
                    NOUP
0000E6DE DC60                  LDD       RAMPNTR
0000E6E0 830140                SUBD      #RAMSTRT
0000E6E3 DD5E                  STD       NOBIN
0000E6E5                       A.BCDCONV NOBIN;NOBCD
                    A.BCDCONV  MACRO     BINVAL;BCDVAL
                    ;macro to convert values stored in      parameter BINVAL
                     to bcd values in parameter BCDVAL ........bcd digits 4+
                    5 are also placed in BCDOVF.......BINVAL &  BCDVAL 16-bi
                    t registers               (CCR contents destroyed)

                    ********************************

0000E6E5 36                    PSHA                          temp store accumulator A
0000E6E6 4F                    CLRA
0000E6E7 97C3                  STAA      BCDOVF
                    ;units
0000E6E9 965F                  LDAA      NOBIN+1
0000E6EB 840F                  ANDA      #$0F
0000E6ED 810A                  CMPA      #$0A
0000E6EF 2502                  BCS       LOSTR
0000E6F1 8B06                  ADDA      #$06
0000E6F3 97C2       LOSTR      STAA      NOBCD+1
                    ;multiples of 16
0000E6F5 D65F                  LDAB      NOBIN+1
0000E6F7 C4F0                  ANDB      #$F0
0000E6F9 54                    LSRB
0000E6FA 54                    LSRB
0000E6FB 54                    LSRB
0000E6FC CEF15D     LOMIDST    LDX       #BCDTAB1
0000E6FF 3A                    ABX
0000E700 EC00                  LDD       0,X
0000E702 36                    PSHA
0000E703 17                    TBA
0000E704 33                    PULB
0000E705 9BC2                  ADDA      NOBCD+1
0000E707 19                    DAA
0000E708 97C2                  STAA      NOBCD+1
0000E70A 36                    PSHA
0000E70B 17                    TBA
0000E70C 33                    PULB
0000E70D 8900                  ADCA      #$00
0000E70F 19                    DAA
0000E710 97C1                  STAA      NOBCD
                    ;multiples of 256
0000E712 D65E                  LDAB      NOBIN
0000E714 C40F                  ANDB      #$0F
0000E716 58                    ASLB
0000E717 CEF17D     HIMIDST    LDX       #BCDTAB2
0000E71A 3A                    ABX
```

```
0000E71B EC00                    LDD     0,X
0000E71D 36                      PSHA
0000E71E 17                      TBA
0000E71F 33                      PULB
0000E720 9BC2                    ADDA    NOBCD+1
0000E722 19                      DAA
0000E723 97C2                    STAA    NOBCD+1
0000E725 36                      PSHA
0000E726 17                      TBA
0000E727 33                      PULB
0000E728 99C1                    ADCA    NOBCD
0000E72A 19                      DAA
0000E72B 97C1                    STAA    NOBCD
                  ;multiples of 4096 (4 dig only)
0000E72D D65E                    LDAB    NOBIN
0000E72F C4F0                    ANDB    #$F0
0000E731 54                      LSRB
0000E732 54                      LSRB
0000E733 54                      LSRB
0000E734 CEF19D   HIST           LDX     #BCDTAB3
0000E737 3A                      ABX
0000E738 EC00                    LDD     0,X
0000E73A 36                      PSHA
0000E73B 17                      TBA
0000E73C 33                      PULB
0000E73D 9BC2                    ADDA    NOBCD+1
0000E73F 19                      DAA
0000E740 97C2                    STAA    NOBCD+1
0000E742 36                      PSHA
0000E743 17                      TBA
0000E744 33                      PULB
0000E745 99C1                    ADCA    NOBCD
0000E747 19                      DAA
0000E748 97C1                    STAA    NOBCD
0000E74A 96C3                    LDAA    BCDOVF
0000E74C 8900                    ADCA    #$00
0000E74E 97C3                    STAA    BCDOVF
                  ;other dig of 4096 multiple
0000E750 D65E                    LDAB    NOBIN
0000E752 C4F0                    ANDB    #$F0
0000E754 54                      LSRB
0000E755 54                      LSRB
0000E756 54                      LSRB
0000E757 54                      LSRB
0000E758 CEF1BD                  LDX     #BCDTAB4
0000E75B 3A                      ABX
0000E75C A600                    LDAA    0,X
0000E75E 9BC3                    ADDA    BCDOVF
0000E760 19                      DAA
0000E761 97C3                    STAA    BCDOVF
0000E763 32                      PULA

                  ********************************
0000E764                         MEND
0000E764 9603                    LDAA    PORT2
0000E766 8402                    ANDA    #%00000010
0000E768 2603                    BNE     PGCORR
0000E76A 7EE782                  JMP     NPGCORR
```

```
0000E76D 96C2      PGCORR     LDAA      NOBCD+1
                   ;ADD RAMEND-RAMSTRT
0000E76F 9BE5                 ADDA      MEMLBCD+2
0000E771 19                   DAA
0000E772 97C2                 STAA      NOBCD+1
0000E774 96C1                 LDAA      NOBCD
0000E776 99E4                 ADCA      MEMLBCD+1
0000E778 19                   DAA
0000E779 97C1                 STAA      NOBCD
0000E77B 96C3                 LDAA      BCDOVF
0000E77D 99E3                 ADCA      MEMLBCD
0000E77F 19                   DAA
0000E780 97C3                 STAA      BCDOVF
                   NPGCORR
0000E782 9670                 LDAA      NOTYPE
0000E784 270B                 BEQ       PAGEUP
0000E786 96C1                 LDAA      NOBCD
0000E788 840F                 ANDA      #$0F
0000E78A 8AD0                 ORAA      #$D0
0000E78C 97C1                 STAA      NOBCD
0000E78E 7EE79D               JMP       DONOUP
                   PAGEUP
0000E791 96C3                 LDAA      BCDOVF
0000E793 D6C1                 LDAB      NOBCD
0000E795 04                   LSRD
0000E796 04                   LSRD
0000E797 04                   LSRD
0000E798 04                   LSRD
0000E799 8AE0                 ORAA      #$E0
0000E79B DDC1                 STD       NOBCD
0000E79D DCC1      DONOUP     LDD       NOBCD
0000E79F DD44                 STD       LCDWORD
0000E7A1 717F03               AIM       %01111111,POR
0000E7A4                                T2
0000E7A4 7EE8E9               JMP       DOLCD
                   NONOUP
0000E7A7 7D006D               TST       LCDMAXUP
0000E7AA 2603                 BNE       DOMAXUP
0000E7AC 7EE842               JMP       NMAXUP
                   DOMAXUP
0000E7AF DC5A                 LDD       MAXBIN
0000E7B1 2705                 BEQ       ZERMAX
0000E7B3 7F006B               CLR       DBLANKF
0000E7B6 2004                 BRA       NZMAX
0000E7B8 8601      ZERMAX     LDAA      #$01
0000E7BA 976B                 STAA      DBLANKF
0000E7BC           NZMAX      A.BCDCONV MAXBIN;MAXBCD
                   A.BCDCONV  MACRO     BINVAL;BCDVAL
                   ;macro to convert values stored in      parameter BINVAL
                    to bcd values in parameter BCDVAL ........bcd digits 4+
                   5 are also placed in BCDOVF.......BINVAL & BCDVAL 16-bi
                   t registers                (CCR contents destroyed)

                   ********************************

0000E7BC 36                   PSHA                          temp store accumulator A
0000E7BD 4F                   CLRA
0000E7BE 97C3                 STAA      BCDOVF
                   ;units
```

```
0000E7C0 965B                 LDAA    MAXBIN+1
0000E7C2 840F                 ANDA    #$0F
0000E7C4 810A                 CMPA    #$0A
0000E7C6 2502                 BCS     LOSTR
0000E7C8 8B06                 ADDA    #$06
0000E7CA 975D     LOSTR       STAA    MAXBCD+1
                  ;multiples of 16
0000E7CC D65B                 LDAB    MAXBIN+1
0000E7CE C4F0                 ANDB    #$F0
0000E7D0 54                   LSRB
0000E7D1 54                   LSRB
0000E7D2 54                   LSRB
0000E7D3 CEF15D   LOMIDST     LDX     #BCDTAB1
0000E7D6 3A                   ABX
0000E7D7 EC00                 LDD     0,X
0000E7D9 36                   PSHA
0000E7DA 17                   TBA
0000E7DB 33                   PULB
0000E7DC 9B5D                 ADDA    MAXBCD+1
0000E7DE 19                   DAA
0000E7DF 975D                 STAA    MAXBCD+1
0000E7E1 36                   PSHA
0000E7E2 17                   TBA
0000E7E3 33                   PULB
0000E7E4 8900                 ADCA    #$00
0000E7E6 19                   DAA
0000E7E7 975C                 STAA    MAXBCD
                  ;multiples of 256
0000E7E9 D65A                 LDAB    MAXBIN
0000E7EB C40F                 ANDB    #$0F
0000E7ED 58                   ASLB
0000E7EE CEF17D   HIMIDST     LDX     #BCDTAB2
0000E7F1 3A                   ABX
0000E7F2 EC00                 LDD     0,X
0000E7F4 36                   PSHA
0000E7F5 17                   TBA
0000E7F6 33                   PULB
0000E7F7 9B5D                 ADDA    MAXBCD+1
0000E7F9 19                   DAA
0000E7FA 975D                 STAA    MAXBCD+1
0000E7FC 36                   PSHA
0000E7FD 17                   TBA
0000E7FE 33                   PULB
0000E7FF 995C                 ADCA    MAXBCD
0000E801 19                   DAA
0000E802 975C                 STAA    MAXBCD
                  ;multiples of 4096 (4 dig only)
0000E804 D65A                 LDAB    MAXBIN
0000E806 C4F0                 ANDB    #$F0
0000E808 54                   LSRB
0000E809 54                   LSRB
0000E80A 54                   LSRB
0000E80B CEF19D   HIST        LDX     #BCDTAB3
0000E80E 3A                   ABX
0000E80F EC00                 LDD     0,X
0000E811 36                   PSHA
0000E812 17                   TBA
0000E813 33                   PULB
0000E814 9B5D                 ADDA    MAXBCD+1
```

```
0000E816 19                 DAA
0000E817 975D               STAA      MAXBCD+1
0000E819 36                 PSHA
0000E81A 17                 TBA
0000E81B 33                 PULB
0000E81C 995C               ADCA      MAXBCD
0000E81E 19                 DAA
0000E81F 975C               STAA      MAXBCD
0000E821 96C3               LDAA      BCDOVF
0000E823 8900               ADCA      #$00
0000E825 97C3               STAA      BCDOVF
                 ;other dig of 4096 multiple
0000E827 D65A               LDAB      MAXBIN
0000E829 C4F0               ANDB      #$F0
0000E82B 54                 LSRB
0000E82C 54                 LSRB
0000E82D 54                 LSRB
0000E82E 54                 LSRB
0000E82F CEF1BD             LDX       #BCDTAB4
0000E832 3A                 ABX
0000E833 A600               LDAA      0,X
0000E835 9BC3               ADDA      BCDOVF
0000E837 19                 DAA
0000E838 97C3               STAA      BCDOVF
0000E83A 32                 PULA


                 ********************************
0000E83B                    MEND
0000E83B DC5C               LDD       MAXBCD
0000E83D DD44               STD       LCDWORD
0000E83F 7EE8E9             JMP       DOLCD
                 NMAXUP
0000E842 7D006E             TST       LCDCUMUP
0000E845 2603               BNE       DOCUMUP
0000E847 7EE8DD             JMP       NCUMUP
                 DOCUMUP
0000E84A DC4C               LDD       CUMBIN
0000E84C 2705               BEQ       ZERCUM
0000E84E 7F006B             CLR       DBLANKF
0000E851 2004               BRA       NZERCUM
0000E853 8601    ZERCUM     LDAA      #$01
0000E855 976B               STAA      DBLANKF
0000E857         NZERCUM    A.BCDCONV CUMBIN;CUMBCD
                 A.BCDCONV  MACRO     BINVAL;BCDVAL
                 ;macro to convert values stored in      parameter BINVAL
                  to bcd values in parameter BCDVAL ........bcd digits 4+
                 5 are also placed in BCDOVF.......BINVAL & BCDVAL 16-bi
                 t registers                  (CCR contents destroyed)

                 ********************************

0000E857 36                 PSHA                           temp store accumulator A
0000E858 4F                 CLRA
0000E859 97C3               STAA      BCDOVF
                 ;units
0000E85B 964D               LDAA      CUMBIN+1
0000E85D 840F               ANDA      #$0F
0000E85F 810A               CMPA      #$0A
```

```
0000E861 2502                     BCS       LOSTR
0000E863 8B06                     ADDA      #$06
0000E865 974F        LOSTR        STAA      CUMBCD+1
                     ;multiples of 16
0000E867 D64D                     LDAB      CUMBIN+1
0000E869 C4F0                     ANDB      #$F0
0000E86B 54                       LSRB
0000E86C 54                       LSRB
0000E86D 54                       LSRB
0000E86E CEF15D      LOMIDST      LDX       #BCDTAB1
0000E871 3A                       ABX
0000E872 EC00                     LDD       0,X
0000E874 36                       PSHA
0000E875 17                       TBA
0000E876 33                       PULB
0000E877 9B4F                     ADDA      CUMBCD+1
0000E879 19                       DAA
0000E87A 974F                     STAA      CUMBCD+1
0000E87C 36                       PSHA
0000E87D 17                       TBA
0000E87E 33                       PULB
0000E87F 8900                     ADCA      #$00
0000E881 19                       DAA
0000E882 974E                     STAA      CUMBCD
                     ;multiples of 256
0000E884 D64C                     LDAB      CUMBIN
0000E886 C40F                     ANDB      #$0F
0000E888 58                       ASLB
0000E889 CEF17D      HIMIDST      LDX       #BCDTAB2
0000E88C 3A                       ABX
0000E88D EC00                     LDD       0,X
0000E88F 36                       PSHA
0000E890 17                       TBA
0000E891 33                       PULB
0000E892 9B4F                     ADDA      CUMBCD+1
0000E894 19                       DAA
0000E895 974F                     STAA      CUMBCD+1
0000E897 36                       PSHA
0000E898 17                       TBA
0000E899 33                       PULB
0000E89A 994E                     ADCA      CUMBCD
0000E89C 19                       DAA
0000E89D 974E                     STAA      CUMBCD
                     ;multiples of 4096 (4 dig only)
0000E89F D64C                     LDAB      CUMBIN
0000E8A1 C4F0                     ANDB      #$F0
0000E8A3 54                       LSRB
0000E8A4 54                       LSRB
0000E8A5 54                       LSRB
0000E8A6 CEF19D      HIST         LDX       #BCDTAB3
0000E8A9 3A                       ABX
0000E8AA EC00                     LDD       0,X
0000E8AC 36                       PSHA
0000E8AD 17                       TBA
0000E8AE 33                       PULB
0000E8AF 9B4F                     ADDA      CUMBCD+1
0000E8B1 19                       DAA
0000E8B2 974F                     STAA      CUMBCD+1
0000E8B4 36                       PSHA
```

```
0000E8B5 17                  TBA
0000E8B6 33                  PULB
0000E8B7 994E                ADCA    CUMBCD
0000E8B9 19                  DAA
0000E8BA 974E                STAA    CUMBCD
0000E8BC 96C3                LDAA    BCDOVF
0000E8BE 8900                ADCA    #$00
0000E8C0 97C3                STAA    BCDOVF
                 ;other dig of 4096 multiple
0000E8C2 D64C                LDAB    CUMBIN
0000E8C4 C4F0                ANDB    #$F0
0000E8C6 54                  LSRB
0000E8C7 54                  LSRB
0000E8C8 54                  LSRB
0000E8C9 54                  LSRB
0000E8CA CEF1BD              LDX     #BCDTAB4
0000E8CD 3A                  ABX
0000E8CE A600                LDAA    0,X
0000E8D0 9BC3                ADDA    BCDOVF
0000E8D2 19                  DAA
0000E8D3 97C3                STAA    BCDOVF
0000E8D5 32                  PULA

                 ********************************
0000E8D6                     MEND
0000E8D6 DC4E                LDD     CUMBCD
0000E8D8 DD44                STD     LCDWORD
0000E8DA 7EE8E9              JMP     DOLCD
                 NCUMUP
0000E8DD 7D006F              TST     LCDLEQUP
0000E8E0 2603                BNE     DOLEQUP
0000E8E2 7EE8E9              JMP     NLEQUP
                 DOLEQUP
0000E8E5 DCC8                LDD     RUNBCD
0000E8E7 DD44                STD     LCDWORD
                 NLEQUP
                 DOLCD
0000E8E9                     A.LCDISP                output value to display
                 A.LCDISP    MACRO
                 ;macro to output values stored in      parameter LCDWORD
                  to locations LCDIG,LCDIG+1,LCDIG+2,LCDIG+3    (CCR cont
                 ents destroyed)

                 ********************************

0000E8E9                     IF      CIRRUS=1
0000E8E9         LOBATW      ALIAS   #$D0FE          LO P
0000E8E9                     ELSE
                 LOBATW      ALIAS   #$E1DB          P1LE
0000E8E9                     ENDIF

0000E8E9 36                  PSHA                    temp store accumulator A
0000E8EA 9655                LDAA    ERRFLAG
0000E8EC 2747                BEQ     NERDISP
0000E8EE 96D7                LDAA    ERRSTAT
0000E8F0 2727                BEQ     NERRDET
0000E8F2 7F00D8              CLR     ERRHOLD
0000E8F5 717F03              AIM     %01111111,POR
```

```
0000E8F8                              T2
0000E8F8 8580              BITA       #%10000000
0000E8FA 2707              BEQ        NOVLERR
0000E8FC CC0ADF            LDD        #$0ADF          O-L
0000E8FF DD44              STD        LCDWORD
0000E901 2052              BRA        NLEDZER
0000E903 8540    NOVLERR   BITA       #%01000000
0000E905 2707              BEQ        NCALERR
0000E907 CCBF01            LDD        #$BF01          E 01
0000E90A DD44              STD        LCDWORD
0000E90C 2047              BRA        NLEDZER
0000E90E 8520    NCALERR   BITA       #%00100000
0000E910 2707              BEQ        NBATTLO
0000E912 CCD0FE            LDD        #$D0FE
0000E915 DD44              STD        LCDWORD
0000E917 203C              BRA        NLEDZER
                 NBATTLO
                 NERRDET
0000E919 4F                CLRA
0000E91A 9755              STAA       ERRFLAG
0000E91C 4C                INCA
0000E91D 976B              STAA       DBLANKF
0000E91F 717F03            AIM        %01111111,POR
0000E922                              T2
0000E922 2011              BRA        NERDISP
0000E924 717F03            AIM        %01111111,POR
0000E927                              T2
0000E927 96D8              LDAA       ERRHOLD
0000E929 4C                INCA
0000E92A 97D8              STAA       ERRHOLD
0000E92C 8108              CMPA       #$8
0000E92E 2639              BNE        NUPDATE
0000E930 4F                CLRA
0000E931 9755              STAA       ERRFLAG
0000E933 97D8              STAA       ERRHOLD
                 NERDISP
0000E935 7B0171            TIM        $01,LCDNOUP
0000E938 261B              BNE        NLEDZER
0000E93A 7B016B            TIM        $01,DBLANKF
0000E93D 2708              BEQ        NDBLANK
0000E93F 86AA              LDAA       #$AA
0000E941 9744              STAA       LCDWORD
0000E943 9745              STAA       LCDWORD+1
0000E945 200E              BRA        NLEDZER
0000E947 9644    NDBLANK   LDAA       LCDWORD         suppress leading zero
0000E949 84F0              ANDA       #$F0
0000E94B 2608              BNE        NLEDZER
0000E94D 9644              LDAA       LCDWORD
0000E94F 840F              ANDA       #$0F
0000E951 8AF0              ORAA       #$F0
0000E953 9744              STAA       LCDWORD
                 NLEDZER                              load high byte to accumu
                                                      lator A
0000E955 9644              LDAA       LCDWORD
0000E957 9733              STAA       LCDIG+1         output low nibble of hig
0000E959                                              h byte
0000E959 44                LSRA                       shuffle accumulator
0000E95A 44                LSRA
0000E95B 44                LSRA
```

```
0000E95C 44                    LSRA
0000E95D 9732                  STAA      LCDIG           output high nibbleof hig
0000E95F                                                 h byte

0000E95F 9645                  LDAA      LCDWORD+1       load low byte to accumul
0000E961                                                 ator A
0000E961 9735                  STAA      LCDIG+3         output low nibble of low
0000E963                                                  byte
0000E963 44                    LSRA                      shuffle accumulator
0000E964 44                    LSRA
0000E965 44                    LSRA
0000E966 44                    LSRA
0000E967 9734                  STAA      LCDIG+2         output high nibble of lo
0000E969                                                 w byte
                    NUPDATE
0000E969 32                    PULA                      restore accumulator A

                    ********************************
0000E96A                       MEND
0000E96A                       MEND
0000E96A 7EE1BF                JMP       MLOOP

                    ********************************

                    NMI
0000E96D 9FDE                  STS       STAKPTR
0000E96F 9603                  LDAA      PORT2
0000E971 97D9                  STAA      P2BACK
0000E973 728014                OIM       %10000000,RAM
0000E976                                 PORT5
0000E976 71BF14                AIM       %10111111,RAM
0000E979                                 PORT5
0000E979 86FF                  LDAA      #$FF
0000E97B C6FF       SELF1      LDAB      #$FF
0000E97D 5A         SELF2      DECB
0000E97E 26FD                  BNE       SELF2
0000E980 4A                    DECA
0000E981 26F8                  BNE       SELF1
                    IRQ2
                    CMI
                    ICI
                    OCI
                    IRQ1
0000E983 0E                    CLI
0000E984 3B                    RTI


0000E985                       MEND

0000E985                       A.TIMINT                  timer interrupt service
0000E985                                                 routines
```

```
                        A.TIMINT   MODULE
                        ********************************
                        ;timer interupt routines
                        TOI
0000E985 9646                      LDA       TFLAG
0000E987 270F                      BEQ       PHASE2
0000E989 710046                    AIM       0,TFLAG
0000E98C 8600                      LDAA      #ADPSU
0000E98E 9737                      STAA      ADLOAD
0000E990 9731                      STAA      ADST
0000E992 9608                      LDAA      TCSR1
0000E994 9609                      LDAA      FRC
0000E996 0E                        CLI
0000E997 3B                        RTI

0000E998 720146         PHASE2     OIM       1,TFLAG
                        ;        #$4B2F
0000E99B CC4B2F                    LDD       #$4B2F
0000E99E DD09                      STD       FRC
0000E9A0 9630                      LDAA      ADRD
0000E9A2 8153                      CMPA      #83            WITH 2:1 RESISTORS 83=4.
0000E9A4                                                    9V
0000E9A4 2305                      BLS       BATTLOW
0000E9A6 71DFD7                    AIM       %11011111,ERR
0000E9A9                                     STAT
0000E9A9 2007                      BRA       DOCONV
0000E9AB 8601           BATTLOW    LDAA      #$1
0000E9AD 9755                      STAA      ERRFLAG
0000E9AF 7220D7                    OIM       %00100000,ERR
0000E9B2                                     STAT
0000E9B2 9615           DOCONV     LDAA      PORT5
0000E9B4 8470                      ANDA      #%01110000
0000E9B6 9750                      STAA      DATA
0000E9B8 8602           ADSTRT     LDAA      #ADLEQ
0000E9BA 9737                      STAA      ADLOAD
0000E9BC 9731                      STAA      ADST
0000E9BE 9615           ADWAIT     LDAA      PORT5
0000E9C0 8402                      ANDA      #%00000010
0000E9C2 26FA                      BNE       ADWAIT
0000E9C4 9630           ADMISS     LDAA      ADRD
0000E9C6 9751                      STAA      DATA+1
0000E9C8 9615                      LDAA      PORT5
0000E9CA 8470                      ANDA      #%01110000
0000E9CC 9150                      CMPA      DATA
0000E9CE 2709                      BEQ       NOCHNGE
0000E9D0 9750                      STAA      DATA
0000E9D2 C603                      LDAB      #$03
0000E9D4 5A             TDEL1      DECB
0000E9D5 26FD                      BNE       TDEL1
0000E9D7 20DF                      BRA       ADSTRT
0000E9D9 9615           NOCHNGE    LDAA      PORT5
0000E9DB 8480                      ANDA      #%10000000
0000E9DD 270A                      BEQ       NOLOAD
0000E9DF 9AD7                      ORAA      ERRSTAT
0000E9E1 97D7                      STAA      ERRSTAT
0000E9E3 8601                      LDAA      #$01
0000E9E5 9755                      STAA      ERRFLAG
0000E9E7 2003                      BRA       INTRES
0000E9E9 717FD7         NOLOAD     AIM       %01111111,ERR
```

```
0000E9EC                                  STAT
0000E9EC 724003   INTRES      OIM         %01000000,POR
0000E9EF                                  T2
0000E9EF 71BF03               AIM         %10111111,POR
0000E9F2                                  T2
0000E9F2 8601                 LDAA        #ADLINA
0000E9F4 9737                 STAA        ADLOAD
0000E9F6 9731                 STAA        ADST
0000E9F8 D650                 LDAB        DATA
0000E9FA 54                   LSRB
0000E9FB 54                   LSRB
0000E9FC 54                   LSRB
0000E9FD CEF14D               LDX         #INTOF
0000EA00 3A                   ABX
0000EA01 EC00                 LDD         0,X
0000EA03 DB51                 ADDB        DATA+1
0000EA05 2401                 BCC         NDATOVF
0000EA07 4C                   INCA
0000EA08 18       NDATOVF     XGDX
0000EA09 9603                 LDAA        PORT2
0000EA0B 8420                 ANDA        #%00100000
0000EA0D 2603                 BNE         NGCOMP
0000EA0F C6C9                 LDAB        #$C9
0000EA11 3A                   ABX
                  NGCOMP
0000EA12 7D00C7               TST         CALFLG
0000EA15 2705                 BEQ         TSTAUTO
0000EA17 71DF03               AIM         %11011111,POR
0000EA1A                                  T2
0000EA1A 2017                 BRA         RUNTST
                  TSTAUTO
0000EA1C 7B2003               TIM         %00100000,POR
0000EA1F                                  T2
0000EA1F 270A                 BEQ         LOGAIN
0000EA21 8C0467               CPX         #SCALOF+950
0000EA24 2D0D                 BLT         RUNTST
0000EA26 71DF03               AIM         %11011111,POR
0000EA29                                  T2
0000EA29 2008                 BRA         RUNTST
0000EA2B 8C01AB   LOGAIN      CPX         #SCALOF+250
0000EA2E 2203                 BHI         RUNTST
0000EA30 722003               OIM         %00100000,POR
0000EA33                                  T2
                  RUNTST
0000EA33 18                   XGDX
0000EA34 93D5                 SUBD        CALOFF
0000EA36 18                   XGDX
0000EA37 DF50                 STX         DATA
0000EA39 7D006A               TST         ACMODE
0000EA3C 2703                 BEQ         NRUNING
0000EA3E 7EEACE               JMP         RUNNING
                  NRUNING
0000EA41 DF66                 STX         RUNBIN
0000EA43 7F006B               CLR         DBLANKF
0000EA46                      A.BCDCONV   RUNBIN;RUNBCD
                  A.BCDCONV   MACRO       BINVAL;BCDVAL
                  ;macro to convert values stored in      parameter BINVAL
                   to bcd values in parameter BCDVAL ........bcd digits 4+
                  5 are also placed in BCDOVF.......BINVAL & BCDVAL 16-bi
```

```
                           t registers              (CCR contents destroyed)

                           ********************************

0000EA46 36                          PSHA                       temp store accumulator A
0000EA47 4F                          CLRA
0000EA48 97C3                        STAA      BCDOVF
                           ;units
0000EA4A 9667                        LDAA      RUNBIN+1
0000EA4C 840F                        ANDA      #$0F
0000EA4E 810A                        CMPA      #$0A
0000EA50 2502                        BCS       LOSTR
0000EA52 8B06                        ADDA      #$06
0000EA54 97C9              LOSTR     STAA      RUNBCD+1
                           ;multiples of 16
0000EA56 D667                        LDAB      RUNBIN+1
0000EA58 C4F0                        ANDB      #$F0
0000EA5A 54                          LSRB
0000EA5B 54                          LSRB
0000EA5C 54                          LSRB
0000EA5D CEF15D            LOMIDST   LDX       #BCDTAB1
0000EA60 3A                          ABX
0000EA61 EC00                        LDD       0,X
0000EA63 36                          PSHA
0000EA64 17                          TBA
0000EA65 33                          PULB
0000EA66 9BC9                        ADDA      RUNBCD+1
0000EA68 19                          DAA
0000EA69 97C9                        STAA      RUNBCD+1
0000EA6B 36                          PSHA
0000EA6C 17                          TBA
0000EA6D 33                          PULB
0000EA6E 8900                        ADCA      #$00
0000EA70 19                          DAA
0000EA71 97C8                        STAA      RUNBCD
                           ;multiples of 256
0000EA73 D666                        LDAB      RUNBIN
0000EA75 C40F                        ANDB      #$0F
0000EA77 58                          ASLB
0000EA78 CEF17D            HIMIDST   LDX       #BCDTAB2
0000EA7B 3A                          ABX
0000EA7C EC00                        LDD       0,X
0000EA7E 36                          PSHA
0000EA7F 17                          TBA
0000EA80 33                          PULB
0000EA81 9BC9                        ADDA      RUNBCD+1
0000EA83 19                          DAA
0000EA84 97C9                        STAA      RUNBCD+1
0000EA86 36                          PSHA
0000EA87 17                          TBA
0000EA88 33                          PULB
0000EA89 99C8                        ADCA      RUNBCD
0000EA8B 19                          DAA
0000EA8C 97C8                        STAA      RUNBCD
                           ;multiples of 4096 (4 dig only)
0000EA8E D666                        LDAB      RUNBIN
0000EA90 C4F0                        ANDB      #$F0
0000EA92 54                          LSRB
0000EA93 54                          LSRB
```

```
0000EA94 54                 LSRB
0000EA95 CEF19D   HIST      LDX      #BCDTAB3
0000EA98 3A                 ABX
0000EA99 EC00               LDD      0,X
0000EA9B 36                 PSHA
0000EA9C 17                 TBA
0000EA9D 33                 PULB
0000EA9E 9BC9               ADDA     RUNBCD+1
0000EAA0 19                 DAA
0000EAA1 97C9               STAA     RUNBCD+1
0000EAA3 36                 PSHA
0000EAA4 17                 TBA
0000EAA5 33                 PULB
0000EAA6 99C8               ADCA     RUNBCD
0000EAA8 19                 DAA
0000EAA9 97C8               STAA     RUNBCD
0000EAAB 96C3               LDAA     BCDOVF
0000EAAD 8900               ADCA     #$00
0000EAAF 97C3               STAA     BCDOVF
                  ;other dig of 4096 multiple
0000EAB1 D666               LDAB     RUNBIN
0000EAB3 C4F0               ANDB     #$F0
0000EAB5 54                 LSRB
0000EAB6 54                 LSRB
0000EAB7 54                 LSRB
0000EAB8 54                 LSRB
0000EAB9 CEF1BD             LDX      #BCDTAB4
0000EABC 3A                 ABX
0000EABD A600               LDAA     0,X
0000EABF 9BC3               ADDA     BCDOVF
0000EAC1 19                 DAA
0000EAC2 97C3               STAA     BCDOVF
0000EAC4 32                 PULA

                  ********************************
0000EAC5                    MEND
0000EAC5 728003             OIM      %10000000,POR
0000EAC8                             T2
0000EAC8 9608               LDAA     TCSR1
0000EACA 9609               LDAA     FRC
0000EACC 0E                 CLI
0000EACD 3B                 RTI

                  ********************************

                  RUNNING
0000EACE 9C5A               CPX      MAXBIN
0000EAD0 2502               BCS      MAXOK
0000EAD2 DF5A               STX      MAXBIN
                  MAXOK
0000EAD4 9669               LDAA     TOTALCNT
0000EAD6 9147               CMPA     ACTYPE
0000EAD8 2609               BNE      NRUNCLR
0000EADA 7F0066             CLR      RUNBIN
0000EADD 7F0067             CLR      RUNBIN+1
0000EAE0 7F0068             CLR      RUNBIN+2
                  NRUNCLR
```

```
                           ********************************
                           ;log add data to cumulative dose
0000EAE3 DECC                        LDX       CUMDOSE
0000EAE5 9C50                        CPX       DATA
0000EAE7 251E                        BCS       BIGDAT1
0000EAE9 18                          XGDX
0000EAEA 9350                        SUBD      DATA
0000EAEC 8101                        CMPA      #$01
0000EAEE 2304                        BLS       SMDATA1         difference = 255
0000EAF0 8601                        LDAA      #$01
0000EAF2 C6FF                        LDAB      #$FF
0000EAF4 05                SMDATA1   ASLD
0000EAF5 C3F1ED                      ADDD      #LOGTAB1
0000EAF8 18                          XGDX
0000EAF9 EC00                        LDD       0,X
0000EAFB D3CD                        ADDD      CUMDOSE+1
0000EAFD DDCD                        STD       CUMDOSE+1
0000EAFF 96CC                        LDAA      CUMDOSE
0000EB01 8900                        ADCA      #$00
0000EB03 97CC                        STAA      CUMDOSE
0000EB05 2023                        BRA       CUMCNEND
0000EB07 DC50              BIGDAT1   LDD       DATA
0000EB09 93CC                        SUBD      CUMDOSE
0000EB0B DDCA                        STD       DATADIF
0000EB0D 2304                        BLS       SMCUM
0000EB0F 8601                        LDAA      #$01
0000EB11 C6FF                        LDAB      #$FF
0000EB13 05                SMCUM     ASLD
0000EB14 C3F1ED                      ADDD      #LOGTAB1
0000EB17 18                          XGDX
0000EB18 EC00                        LDD       0,X
0000EB1A D3CD                        ADDD      CUMDOSE+1
0000EB1C DDCD                        STD       CUMDOSE+1
0000EB1E 96CC                        LDAA      CUMDOSE
0000EB20 8900                        ADCA      #$00
0000EB22 97CC                        STAA      CUMDOSE
0000EB24 DCCC                        LDD       CUMDOSE
0000EB26 D3CA                        ADDD      DATADIF
0000EB28 DDCC                        STD       CUMDOSE
                           CUMCNEND
                           ********************************
                           ;increment cumulative time
0000EB2A DCD0                        LDD       CUMTIME+1
0000EB2C C30001                      ADDD      #$01
0000EB2F DDD0                        STD       CUMTIME+1
0000EB31 DCCF                        LDD       CUMTIME
0000EB33 8900                        ADCA      #$00
0000EB35 97CF                        STAA      CUMTIME
                           ;log convert cumulative time
0000EB37 DCCF                        LDD       CUMTIME
0000EB39 4D                          TSTA
0000EB3A 272B                        BEQ       NTHREEB
0000EB3C 7F00BF                      CLR       ROTCNT
0000EB3F 7C00BF            NXTROT1   INC       ROTCNT
0000EB42 05                          ASLD
0000EB43 24FA                        BCC       NXTROT1
0000EB45 04                          LSRD
0000EB46 8A80                        ORAA      #%10000000
0000EB48 7A00BF                      DEC       ROTCNT
```

```
0000EB4B 16                      TAB
0000EB4C C080                    SUBB     #$80
0000EB4E 58                      ASLB
0000EB4F CEF5ED                  LDX      #LOGTAB2
0000EB52 3A                      ABX
0000EB53 EC00                    LDD      0,X
0000EB55 DDD3                    STD      LOGTIME+1
0000EB57 CEF6ED                  LDX      #ROTOFF
0000EB5A D6BF                    LDAB     ROTCNT
0000EB5C 58                      ASLB
0000EB5D 3A                      ABX
0000EB5E 16                      TAB
0000EB5F 4F                      CLRA
0000EB60 E300                    ADDD     0,X
0000EB62 DDD2                    STD      LOGTIME
0000EB64 7EEB96                  JMP      DTIMCMP
                   NTHREEB
0000EB67 7F006B                  CLR      DBLANKF
0000EB6A DCD0                    LDD      CUMTIME+1
0000EB6C 7F00BF                  CLR      ROTCNT
0000EB6F 7C00BF    NXTROT2       INC      ROTCNT
0000EB72 05                      ASLD
0000EB73 24FA                    BCC      NXTROT2
0000EB75 04                      LSRD
0000EB76 8A80                    ORAA     #%10000000
0000EB78 7A00BF                  DEC      ROTCNT
0000EB7B 16                      TAB
0000EB7C C080                    SUBB     #$80
0000EB7E 58                      ASLB
0000EB7F CEF5ED                  LDX      #LOGTAB2
0000EB82 3A                      ABX
0000EB83 EC00                    LDD      0,X
0000EB85 DDD3                    STD      LOGTIME+1
0000EB87 CEF6ED                  LDX      #ROTOFF
0000EB8A D6BF                    LDAB     ROTCNT
0000EB8C CB08                    ADDB     #$08
0000EB8E 58                      ASLB
0000EB8F 3A                      ABX
0000EB90 16                      TAB
0000EB91 4F                      CLRA
0000EB92 E300                    ADDD     0,X
0000EB94 DDD2                    STD      LOGTIME
                   ONLY1
                   DTIMCMP
0000EB96 DCCD                    LDD      CUMDOSE+1
0000EB98 93D3                    SUBD     LOGTIME+1
0000EB9A 16                      TAB
0000EB9B 96CC                    LDAA     CUMDOSE
0000EB9D 92D2                    SBCA     LOGTIME
0000EB9F DD4C                    STD      CUMBIN

                   ********************************
                   ;log add data word to running total
                   RUNCONV
0000EBA1 DE66                    LDX      RUNBIN
0000EBA3 9C50                    CPX      DATA
0000EBA5 251E                    BCS      BIGDAT2
0000EBA7 18                      XGDX
0000EBA8 9350                    SUBD     DATA
```

```
0000EBAA 8101                CMPA     #$01
0000EBAC 2304                BLS      SMDATA2      difference = 255
0000EBAE 8601                LDAA     #$01
0000EBB0 C6FF                LDAB     #$FF
0000EBB2 05       SMDATA2    ASLD
0000EBB3 C3F1ED              ADDD     #LOGTAB1
0000EBB6 18                  XGDX
0000EBB7 EC00                LDD      0,X
0000EBB9 D367                ADDD     RUNBIN+1
0000EBBB DD67                STD      RUNBIN+1
0000EBBD 9666                LDAA     RUNBIN
0000EBBF 8900                ADCA     #$00
0000EBC1 9766                STAA     RUNBIN
0000EBC3 2023                BRA      RCONVEND
0000EBC5 DC50     BIGDAT2    LDD      DATA
0000EBC7 9366                SUBD     RUNBIN
0000EBC9 DDCA                STD      DATADIF
0000EBCB 2304                BLS      SMRUN
0000EBCD 8601                LDAA     #$01
0000EBCF C6FF                LDAB     #$FF
0000EBD1 05       SMRUN      ASLD
0000EBD2 C3F1ED              ADDD     #LOGTAB1
0000EBD5 18                  XGDX
0000EBD6 EC00                LDD      0,X
0000EBD8 D367                ADDD     RUNBIN+1
0000EBDA DD67                STD      RUNBIN+1
0000EBDC 9666                LDAA     RUNBIN
0000EBDE 8900                ADCA     #$00
0000EBE0 9766                STAA     RUNBIN
0000EBE2 DC66                LDD      RUNBIN
0000EBE4 D3CA                ADDD     DATADIF
0000EBE6 DD66                STD      RUNBIN
                  RCONVEND
                  ********************************

0000EBE8 7A00C6              DEC      TOGLCNT
0000EBEB 2607                BNE      NTOGL
0000EBED 8604                LDAA     #$4
0000EBEF 97C6                STAA     TOGLCNT
0000EBF1 758003              EIM      %10000000,POR
0000EBF4                              T2
                  NTOGL
0000EBF4 7A0069              DEC      TOTALCNT
0000EBF7 2703                BEQ      STORE
0000EBF9 7EECFA              JMP      NSTORE
0000EBFC 9647     STORE      LDAA     ACTYPE
0000EBFE 9769                STAA     TOTALCNT
0000EC00 8101                CMPA     #$1
0000EC02 2714                BEQ      TCOMPDN
0000EC04 8108                CMPA     #$8
0000EC06 2609                BNE      TENSCMP
0000EC08 DC66                LDD      RUNBIN
0000EC0A 83005A              SUBD     #$5A
0000EC0D DD66                STD      RUNBIN
0000EC0F 2007                BRA      TCOMPDN
0000EC11 DC66     TENSCMP    LDD      RUNBIN
0000EC13 8300BE              SUBD     #$BE
0000EC16 DD66                STD      RUNBIN
                  TCOMPDN
```

```
0000EC18 DC66                LDD        RUNBIN
0000EC1A C30064              ADDD       #100
0000EC1D 18                  XGDX
0000EC1E 96D7                LDAA       ERRSTAT
0000EC20 8480                ANDA       #%10000000
0000EC22 9A48                ORAA       CODE
0000EC24 9748                STAA       CODE
0000EC26 18                  XGDX
0000EC27 9A48                ORAA       CODE
0000EC29 DE60                LDX        RAMPNTR
0000EC2B 71FE03              AIM        %11111110,POR
0000EC2E                                T2
0000EC2E E700                STAB       0,X
0000EC30 720103              OIM        %00000001,POR
0000EC33                                T2
0000EC33 A700                STAA       0,X
0000EC35 DE53                LDX        DATACNT+1
0000EC37 08                  INX
0000EC38 DF53                STX        DATACNT+1
0000EC3A 2603                BNE        NDTAOVF
0000EC3C 7C0052              INC        DATACNT
                   NDTAOVF
0000EC3F DE60                LDX        RAMPNTR
0000EC41 08                  INX
0000EC42 8CE000              CPX        #RAMEND
0000EC45 2626                BNE        NRAMOVF
0000EC47 8601                LDAA       #RAMENDB
0000EC49 2706                BEQ        FULL
0000EC4B 9603                LDAA       PORT2
0000EC4D 8402                ANDA       #%00000010
0000EC4F 2712                BEQ        NFULL
0000EC51 8601      FULL      LDAA       #1
0000EC53 9773                STAA       RAMFULL
0000EC55 8684                LDAA       #PAUSE
0000EC57 9741                STAA       KEYVAL
0000EC59 860F                LDAA       #%00001111
0000EC5B 9717                STAA       PORT6
0000EC5D 9608                LDAA       TCSR1
0000EC5F 9609                LDAA       FRC
0000EC61 0E                  CLI
0000EC62 3B                  RTI
0000EC63 CE0140    NFULL     LDX        #RAMSTRT
0000EC66 8601                LDAA       #1
0000EC68 9762                STAA       RAMPNTB
0000EC6A 720203              OIM        %00000010,POR
0000EC6D                                T2
0000EC6D DF60      NRAMOVF   STX        RAMPNTR
0000EC6F 7F006B              CLR        DBLANKF
0000EC72                     A.BCDCONV  RUNBIN;RUNBCD
                   A.BCDCONV MACRO      BINVAL;BCDVAL
                   ;macro to convert values stored in parameter BINVAL
                    to bcd values in parameter BCDVAL ........bcd digits 4+
                   5 are also placed in BCDOVF.......BINVAL &  BCDVAL 16-bi
                   t registers                (CCR contents destroyed)

                   ********************************

0000EC72 36                  PSHA                        temp store accumulator A
0000EC73 4F                  CLRA
```

```
0000EC74 97C3                    STAA     BCDOVF
                     ;units
0000EC76 9667                    LDAA     RUNBIN+1
0000EC78 840F                    ANDA     #$0F
0000EC7A 810A                    CMPA     #$0A
0000EC7C 2502                    BCS      LOSTR
0000EC7E 8B06                    ADDA     #$06
0000EC80 97C9        LOSTR       STAA     RUNBCD+1
                     ;multiples of 16
0000EC82 D667                    LDAB     RUNBIN+1
0000EC84 C4F0                    ANDB     #$F0
0000EC86 54                      LSRB
0000EC87 54                      LSRB
0000EC88 54                      LSRB
0000EC89 CEF15D      LOMIDST     LDX      #BCDTAB1
0000EC8C 3A                      ABX
0000EC8D EC00                    LDD      0,X
0000EC8F 36                      PSHA
0000EC90 17                      TBA
0000EC91 33                      PULB
0000EC92 9BC9                    ADDA     RUNBCD+1
0000EC94 19                      DAA
0000EC95 97C9                    STAA     RUNBCD+1
0000EC97 36                      PSHA
0000EC98 17                      TBA
0000EC99 33                      PULB
0000EC9A 8900                    ADCA     #$00
0000EC9C 19                      DAA
0000EC9D 97C8                    STAA     RUNBCD
                     ;multiples of 256
0000EC9F D666                    LDAB     RUNBIN
0000ECA1 C40F                    ANDB     #$0F
0000ECA3 58                      ASLB
0000ECA4 CEF17D      HIMIDST     LDX      #BCDTAB2
0000ECA7 3A                      ABX
0000ECA8 EC00                    LDD      0,X
0000ECAA 36                      PSHA
0000ECAB 17                      TBA
0000ECAC 33                      PULB
0000ECAD 9BC9                    ADDA     RUNBCD+1
0000ECAF 19                      DAA
0000ECB0 97C9                    STAA     RUNBCD+1
0000ECB2 36                      PSHA
0000ECB3 17                      TBA
0000ECB4 33                      PULB
0000ECB5 99C8                    ADCA     RUNBCD
0000ECB7 19                      DAA
0000ECB8 97C8                    STAA     RUNBCD
                     ;multiples of 4096 (4 dig only)
0000ECBA D666                    LDAB     RUNBIN
0000ECBC C4F0                    ANDB     #$F0
0000ECBE 54                      LSRB
0000ECBF 54                      LSRB
0000ECC0 54                      LSRB
0000ECC1 CEF19D      HIST        LDX      #BCDTAB3
0000ECC4 3A                      ABX
0000ECC5 EC00                    LDD      0,X
0000ECC7 36                      PSHA
0000ECC8 17                      TBA
```

```
0000ECC9 33                     PULB
0000ECCA 9BC9                   ADDA      RUNBCD+1
0000ECCC 19                     DAA
0000ECCD 97C9                   STAA      RUNBCD+1
0000ECCF 36                     PSHA
0000ECD0 17                     TBA
0000ECD1 33                     PULB
0000ECD2 99C8                   ADCA      RUNBCD
0000ECD4 19                     DAA
0000ECD5 97C8                   STAA      RUNBCD
0000ECD7 96C3                   LDAA      BCDOVF
0000ECD9 8900                   ADCA      #$00
0000ECDB 97C3                   STAA      BCDOVF
                    ;other dig of 4096 multiple
0000ECDD D666                   LDAB      RUNBIN
0000ECDF C4F0                   ANDB      #$F0
0000ECE1 54                     LSRB
0000ECE2 54                     LSRB
0000ECE3 54                     LSRB
0000ECE4 54                     LSRB
0000ECE5 CEF1BD                 LDX       #BCDTAB4
0000ECE8 3A                     ABX
0000ECE9 A600                   LDAA      0,X
0000ECEB 9BC3                   ADDA      BCDOVF
0000ECED 19                     DAA
0000ECEE 97C3                   STAA      BCDOVF
0000ECF0 32                     PULA


                    ******************************
0000ECF1                        MEND
0000ECF1 96C4                   LDAA      CODUSE
0000ECF3 9A48                   ORAA      CODE
0000ECF5 97C4                   STAA      CODUSE
0000ECF7 7F0048                 CLR       CODE
                    NSTORE
                    FIDLTST
0000ECFA 9615       ADWAIT1     LDAA      PORT5
0000ECFC 8402                   ANDA      #%00000010
0000ECFE 26FA                   BNE       ADWAIT1
0000ED00 9630                   LDAA      ADRD
0000ED02 817F                   CMPA      #$7F
0000ED04 2208                   BHI       LINPOS
0000ED06 96DB                   LDAA      LINASTR
0000ED08 8101                   CMPA      #$1
0000ED0A 2710                   BEQ       NFIDDLE
0000ED0C 2006                   BRA       FIDDLE
0000ED0E 96DB       LINPOS      LDAA      LINASTR
0000ED10 8105                   CMPA      #$5
0000ED12 2708                   BEQ       NFIDDLE
0000ED14 8684       FIDDLE      LDAA      #PAUSE
0000ED16 9741                   STAA      KEYVAL
0000ED18 8601                   LDAA      #$01
0000ED1A 9772                   STAA      LEDSONF
0000ED1C 9608       NFIDDLE     LDAA      TCSR1
0000ED1E 9609                   LDAA      FRC
0000ED20 0E                     CLI
0000ED21 3B                     RTI
0000ED22                        MEND
```

```
00000001                    LIST      ON
0000ED22                    A.SERIAL
```

```
                      A.SERIAL     MODULE
0000ED22 9611         SIO          LDAA       TRCSR1
0000ED24 84C0                      ANDA       #%11000000
0000ED26 2603                      BNE        DORX
0000ED28 7EEFA3                    JMP        DOTX

0000ED2B 9610         DORX         LDAA       RMCR
0000ED2D 9612                      LDAA       RDR
0000ED2F 811B                      CMPA       #$1B
0000ED31 2704                      BEQ        DOESC
0000ED33 8107                      CMPA       #$07
0000ED35 2627                      BNE        NOTESC
0000ED37              DOESC        A.ROMTX    ESCSTR
                      ROMTX        MACRO      ROMSTRG
0000ED37 CEF71D                    LDX        #ESCSTR
0000ED3A E600                      LDAB       0,X
0000ED3C 08                        INX
0000ED3D DFA0                      STX        TXPTR
0000ED3F 3A                        ABX
0000ED40 DFA2                      STX        TXEND
0000ED42 5F                        CLRB
0000ED43 D7AC                      STAB       TXBANK
0000ED45 D7AB                      STAB       TXBYTE
0000ED47 D77E                      STAB       NUMMODE
0000ED49 D7A5                      STAB       TXHFLG
0000ED4B D7AD                      STAB       TXENDPG
0000ED4D D7AE                      STAB       RAMFLAG
0000ED4F D7B7                      STAB       PENDFLG
0000ED51 5C                        INCB
0000ED52 D7A4                      STAB       TXFLAG
0000ED54 720411                    OIM        %00000100,TRC
0000ED57                                      SR1
0000ED57 CE0080                    LDX        #RXBUF
0000ED5A DFA9                      STX        RXPTR
0000ED5C 0E                        CLI
0000ED5D 3B                        RTI
0000ED5E                           MEND
0000ED5E 8113         NOTESC       CMPA       #$13
0000ED60 260A                      BNE        NCTRLS
0000ED62 CE0080                    LDX        #RXBUF
0000ED65 DFA9                      STX        RXPTR
0000ED67 71FB11                    AIM        %11111011,TRC
0000ED6A                                      SR1
0000ED6A 0E                        CLI
0000ED6B 3B                        RTI
0000ED6C 8111         NCTRLS       CMPA       #$11
0000ED6E 260A                      BNE        NCTRLQ
0000ED70 CE0080                    LDX        #RXBUF
0000ED73 DFA9                      STX        RXPTR
0000ED75 720411                    OIM        %00000100,TRC
0000ED78                                      SR1
0000ED78 0E                        CLI
0000ED79 3B                        RTI
0000ED7A 0E           NCTRLQ       CLI
0000ED7B D67E                      LDAB       NUMMODE
0000ED7D 2603                      BNE        DONUM
0000ED7F 7EEE9E                    JMP        NOTNUM
0000ED82 DEA9         DONUM        LDX        RXPTR
0000ED84 A700                      STAA       0,X
```

```
0000ED86 08                   INX
0000ED87 DFA9                 STX       RXPTR
0000ED89 CE0080               LDX       #RXBUF
0000ED8C C614                 LDAB      #20
0000ED8E 3A                   ABX
0000ED8F 9CA9                 CPX       RXPTR
0000ED91 2701                 BEQ       DODIGS
0000ED93 3B                   RTI
0000ED94 5F         DODIGS    CLRB
0000ED95 D77E                 STAB      NUMMODE
0000ED97 D7A5                 STAB      TXHFLG
0000ED99 D7AB                 STAB      TXBYTE
0000ED9B D7AE                 STAB      RAMFLAG
0000ED9D D7AC                 STAB      TXBANK
0000ED9F D7AD                 STAB      TXENDPG
0000EDA1 5C                   INCB
0000EDA2 D7B7                 STAB      PENDFLG
0000EDA4 D7A4                 STAB      TXFLAG
0000EDA6 CEF738               LDX       #WELCOME
0000EDA9 E600                 LDAB      0,X
0000EDAB 08                   INX
0000EDAC DFA0                 STX       TXPTR
0000EDAE 3A                   ABX
0000EDAF DFA2                 STX       TXEND
0000EDB1 CE0080               LDX       #RXBUF
0000EDB4 DFA9                 STX       RXPTR
0000EDB6 CE0000               LDX       #0
0000EDB9 DF78                 STX       LO32VL1
0000EDBB DF76                 STX       HI32VL1
0000EDBD DF7C                 STX       LO32VL2
0000EDBF DF7A                 STX       HI32VL2
0000EDC1 5F                   CLRB
0000EDC2 37         NXTDIG1   PSHB
0000EDC3 CE0080               LDX       #RXBUF
0000EDC6 3A                   ABX
0000EDC7 37                   PSHB
0000EDC8 E602                 LDAB      2,X
0000EDCA C030                 SUBB      #$30
0000EDCC D7AF                 STAB      SCRATCH
0000EDCE 860A                 LDAA      #10
0000EDD0 33                   PULB
0000EDD1 3D                   MUL
0000EDD2 DBAF                 ADDB      SCRATCH
0000EDD4 8900                 ADCA      #0
0000EDD6 05                   ASLD
0000EDD7 05                   ASLD
0000EDD8 C3F7AC               ADDD      #HEXTBL
0000EDDB DD74                 STD       DSCRTCH
0000EDDD DE74                 LDX       DSCRTCH
0000EDDF EC00                 LDD       0,X
0000EDE1 D378                 ADDD      LO32VL1
0000EDE3 DD78                 STD       LO32VL1
0000EDE5 2407                 BCC       NO32CR1
0000EDE7 3C                   PSHX
0000EDE8 DE76                 LDX       HI32VL1
0000EDEA 08                   INX
0000EDEB DF76                 STX       HI32VL1
0000EDED 38                   PULX
0000EDEE DC76       NO32CR1   LDD       HI32VL1
```

```
0000EDF0 E302                ADDD    2,X
0000EDF2 DD76                STD     HI32VL1
0000EDF4 33                  PULB
0000EDF5 5C                  INCB
0000EDF6 C108                CMPB    #8
0000EDF8 26C8                BNE     NXTDIG1
0000EDFA 5F                  CLRB
0000EDFB 37        NXTDIG2   PSHB
0000EDFC CE0080              LDX     #RXBUF
0000EDFF 3A                  ABX
0000EE00 37                  PSHB
0000EE01 E60A                LDAB    10,X
0000EE03 C030                SUBB    #$30
0000EE05 D7AF                STAB    SCRATCH
0000EE07 860A                LDAA    #10
0000EE09 33                  PULB
0000EE0A 3D                  MUL
0000EE0B DBAF                ADDB    SCRATCH
0000EE0D 8900                ADCA    #0
0000EE0F 05                  ASLD
0000EE10 05                  ASLD
0000EE11 C3F7AC              ADDD    #HEXTBL
0000EE14 DD74                STD     DSCRTCH
0000EE16 DE74                LDX     DSCRTCH
0000EE18 DC7C                LDD     LO32VL2
0000EE1A E300                ADDD    0,X
0000EE1C DD7C                STD     LO32VL2
0000EE1E 2407                BCC     NO32CR2
0000EE20 3C                  PSHX
0000EE21 DE7A                LDX     HI32VL2
0000EE23 08                  INX
0000EE24 DF7A                STX     HI32VL2
0000EE26 38                  PULX
0000EE27 DC7A      NO32CR2   LDD     HI32VL2
0000EE29 E302                ADDD    2,X
0000EE2B DD7A                STD     HI32VL2
0000EE2D 33                  PULB
0000EE2E 5C                  INCB
0000EE2F C108                CMPB    #8
0000EE31 26C8                BNE     NXTDIG2
0000EE33 DC78                LDD     LO32VL1
0000EE35 C30140              ADDD    #RAMSTRT
0000EE38 DD78                STD     LO32VL1
0000EE3A 2405                BCC     NO32CR3
0000EE3C DE76                LDX     HI32VL1
0000EE3E 08                  INX
0000EE3F DF76                STX     HI32VL1
0000EE41 CEE000    NO32CR3   LDX     #$E000
0000EE44 9C78                CPX     LO32VL1
0000EE46 220F                BHI     NPGJMP
0000EE48 DC78                LDD     LO32VL1
0000EE4A C32000              ADDD    #$2000
0000EE4D C30140              ADDD    #RAMSTRT
0000EE50 DD78                STD     LO32VL1
0000EE52 DE76                LDX     HI32VL1
0000EE54 08                  INX
0000EE55 DF76                STX     HI32VL1
0000EE57 DC78      NPGJMP    LDD     LO32VL1
0000EE59 DDB8                STD     TXPPEND
```

```
0000EE5B 4F                     CLRA
0000EE5C DE76                   LDX     HI32VL1
0000EE5E 2701                   BEQ     NOPAGE
0000EE60 4C                     INCA
0000EE61 97BA       NOPAGE      STAA    TXPBPEND
0000EE63 DC78                   LDD     LO32VL1
0000EE65 D37C                   ADDD    LO32VL2
0000EE67 DDBB                   STD     TXEPEND
0000EE69 2405                   BCC     NOENDP1
0000EE6B DE76                   LDX     HI32VL1
0000EE6D 08                     INX
0000EE6E DF76                   STX     HI32VL1
0000EE70 CEE000     NOENDP1     LDX     #$E000
0000EE73 9CBB                   CPX     TXEPEND
0000EE75 220F                   BHI     NOENDP2
0000EE77 DCBB                   LDD     TXEPEND
0000EE79 C32000                 ADDD    #$2000
0000EE7C C30140                 ADDD    #RAMSTRT
0000EE7F DDBB                   STD     TXEPEND
0000EE81 DE76                   LDX     HI32VL1
0000EE83 08                     INX
0000EE84 DD76                   STD     HI32VL1
0000EE86 DC76       NOENDP2     LDD     HI32VL1
0000EE88 D37A                   ADDD    HI32VL2
0000EE8A 2706                   BEQ     NOENDP3
0000EE8C 8601                   LDAA    #1
0000EE8E 97BD                   STAA    TXEBPEND
0000EE90 2003                   BRA     ENDPG
0000EE92 4F         NOENDP3     CLRA
0000EE93 97BD                   STAA    TXEBPEND
                    ENDPG
                    DORTI
0000EE95 CE0080                 LDX     #RXBUF
0000EE98 DFA9                   STX     RXPTR
0000EE9A 720411                 OIM     %00000100,TRC
0000EE9D                                SR1
0000EE9D 3B                     RTI

                    NOTNUM
0000EE9E DEA9                   LDX     RXPTR
0000EEA0 A700                   STAA    0,X
0000EEA2 08                     INX
0000EEA3 DFA9                   STX     RXPTR
0000EEA5 CE0080                 LDX     #RXBUF
0000EEA8 C604                   LDAB    #4
0000EEAA 3A                     ABX
0000EEAB 9CA9                   CPX     RXPTR
0000EEAD 2701                   BEQ     DOMESS
0000EEAF 3B                     RTI
                    DOMESS
0000EEB0 CE0080                 LDX     #RXBUF
0000EEB3 A600                   LDAA    0,X
0000EEB5 8150                   CMPA    #'P'
0000EEB7 263A                   BNE     NOTPR
0000EEB9 A601                   LDAA    1,X
0000EEBB 8152                   CMPA    #'R'
0000EEBD 2703                   BEQ     MESSOKO
0000EEBF 7EEF7C                 JMP     BADMESS
0000EEC2 4F         MESSOKO     CLRA
```

```
0000EEC3 977E                STAA     NUMMODE
0000EEC5 97AB                STAA     TXBYTE
0000EEC7 97AC                STAA     TXBANK
0000EEC9 97A8                STAA     HDRCTR
0000EECB 97B4                STAA     HSTRTPG
0000EECD 97AE                STAA     RAMFLAG
0000EECF 97BA                STAA     TXPBPEND
0000EED1 4C                  INCA
0000EED2 97A4                STAA     TXFLAG
0000EED4 97B7                STAA     PENDFLG
0000EED6 97A5                STAA     TXHFLG
0000EED8 CE0140              LDX      #RAMSTRT
0000EEDB DFB8                STX      TXPPEND
0000EEDD DFA6                STX      HDRSTRT
0000EEDF CE0080              LDX      #RXBUF
0000EEE2 DFA9                STX      RXPTR
0000EEE4 CEF738              LDX      #WELCOME
0000EEE7 E600                LDAB     0,X
0000EEE9 08                  INX
0000EEEA DFA0                STX      TXPTR
0000EEEC 3A                  ABX
0000EEED DFA2                STX      TXEND
0000EEEF 720411              OIM      %00000100,TRC
0000EEF2                              SR1
0000EEF2 3B                  RTI
                   NOTPR
0000EEF3 8149                CMPA     #'I'
0000EEF5 2630                BNE      NOTID
0000EEF7 A601                LDAA     1,X
0000EEF9 8144                CMPA     #'D'
0000EEFB 2703                BEQ      MESSOK1
0000EEFD 7EEF2D              JMP      NOTID1
0000EF00           MESSOK1   A.ROMTX  IDMESS
                   ROMTX     MACRO    ROMSTRG
0000EF00 CEF74D              LDX      #IDMESS
0000EF03 E600                LDAB     0,X
0000EF05 08                  INX
0000EF06 DFA0                STX      TXPTR
0000EF08 3A                  ABX
0000EF09 DFA2                STX      TXEND
0000EF0B 5F                  CLRB
0000EF0C D7AC                STAB     TXBANK
0000EF0E D7AB                STAB     TXBYTE
0000EF10 D77E                STAB     NUMMODE
0000EF12 D7A5                STAB     TXHFLG
0000EF14 D7AD                STAB     TXENDPG
0000EF16 D7AE                STAB     RAMFLAG
0000EF18 D7B7                STAB     PENDFLG
0000EF1A 5C                  INCB
0000EF1B D7A4                STAB     TXFLAG
0000EF1D 720411              OIM      %00000100,TRC
0000EF20                              SR1
0000EF20 CE0080              LDX      #RXBUF
0000EF23 DFA9                STX      RXPTR
0000EF25 0E                  CLI
0000EF26 3B                  RTI
0000EF27                     MEND
                   NOTID
0000EF27 8149                CMPA     #'I'
```

```
0000EF29 2630                      BNE       NOTIT
0000EF2B A601                      LDAA      1,X
0000EF2D 8154         NOTID1       CMPA      #'T'
0000EF2F 2703                      BEQ       MESSOK2
0000EF31 7EEF7C                    JMP       BADMESS
0000EF34              MESSOK2      A.ROMTX   ITMESS
                      ROMTX        MACRO     ROMSTRG
0000EF34 CEF77A                    LDX       #ITMESS
0000EF37 E600                      LDAB      0,X
0000EF39 08                        INX
0000EF3A DFA0                      STX       TXPTR
0000EF3C 3A                        ABX
0000EF3D DFA2                      STX       TXEND
0000EF3F 5F                        CLRB
0000EF40 D7AC                      STAB      TXBANK
0000EF42 D7AB                      STAB      TXBYTE
0000EF44 D77E                      STAB      NUMMODE
0000EF46 D7A5                      STAB      TXHFLG
0000EF48 D7AD                      STAB      TXENDPG
0000EF4A D7AE                      STAB      RAMFLAG
0000EF4C D7B7                      STAB      PENDFLG
0000EF4E 5C                        INCB
0000EF4F D7A4                      STAB      TXFLAG
0000EF51 720411                    OIM       %00000100,TRC
0000EF54                                     SR1
0000EF54 CE0080                    LDX       #RXBUF
0000EF57 DFA9                      STX       RXPTR
0000EF59 0E                        CLI
0000EF5A 3B                        RTI
0000EF5B                           MEND
                      NOTIT
0000EF5B 814C                      CMPA      #'L'
0000EF5D 260E                      BNE       NOTLG
0000EF5F A601                      LDAA      1,X
0000EF61 8147                      CMPA      #'G'
0000EF63 2703                      BEQ       MESSOK3
0000EF65 7EEF7C                    JMP       BADMESS
0000EF68 8601         MESSOK3      LDAA      #1
0000EF6A 977E                      STAA      NUMMODE
0000EF6C 3B                        RTI
                      NOTLG
0000EF6D 814D                      CMPA      #'M'
0000EF6F 260B                      BNE       BADMESS
0000EF71 A601                      LDAA      1,X
0000EF73 814F                      CMPA      #'O'
0000EF75 2605                      BNE       BADMESS
0000EF77 8601                      LDAA      #1
0000EF79 97C0                      STAA      MONFLG
0000EF7B 3B                        RTI
                      BADMESS
0000EF7C                           A.ROMTX   ERMESS
                      ROMTX        MACRO     ROMSTRG
0000EF7C CEF797                    LDX       #ERMESS
0000EF7F E600                      LDAB      0,X
0000EF81 08                        INX
0000EF82 DFA0                      STX       TXPTR
0000EF84 3A                        ABX
0000EF85 DFA2                      STX       TXEND
0000EF87 5F                        CLRB
```

```
0000EF88 D7AC                STAB    TXBANK
0000EF8A D7AB                STAB    TXBYTE
0000EF8C D77E                STAB    NUMMODE
0000EF8E D7A5                STAB    TXHFLG
0000EF90 D7AD                STAB    TXENDPG
0000EF92 D7AE                STAB    RAMFLAG
0000EF94 D7B7                STAB    PENDFLG
0000EF96 5C                  INCB
0000EF97 D7A4                STAB    TXFLAG
0000EF99 720411              OIM     %00000100,TRC
0000EF9C                             SR1
0000EF9C CE0080              LDX     #RXBUF
0000EF9F DFA9                STX     RXPTR
0000EFA1 0E                  CLI
0000EFA2 3B                  RTI
0000EFA3                     MEND

0000EFA3 96A4       DOTX     LDAA    TXFLAG
0000EFA5 2605                BNE     DOTX1
0000EFA7 71FB11              AIM     %11111011,TRC
0000EFAA                             SR1
0000EFAA 0E                  CLI
0000EFAB 3B                  RTI
0000EFAC 8601       DOTX1    LDAA    #$1
0000EFAE 4A         TRWAIT   DECA
0000EFAF 26FD                BNE     TRWAIT
0000EFB1                     IF      HD6303Y=1
0000EFB1                     ELSE
                             LDAA    RMCR
                             ORAA    #%01000000
                             STAA    RMCR
0000EFB1                     ENDIF
0000EFB1 96AE                LDAA    RAMFLAG
0000EFB3 262E                BNE     DO16BIT
0000EFB5 DEA0                LDX     TXPTR
0000EFB7 A600                LDAA    0,X
0000EFB9 9713                STAA    TDR
0000EFBB 0E                  CLI
0000EFBC 08                  INX
0000EFBD DFA0                STX     TXPTR
0000EFBF 9CA2                CPX     TXEND
0000EFC1 261F                BNE     MOREMES
0000EFC3 96B7                LDAA    PENDFLG
0000EFC5 2715                BEQ     NOPEND
0000EFC7 8601                LDAA    #1
0000EFC9 97AE                STAA    RAMFLAG
0000EFCB DEB8                LDX     TXPPEND
0000EFCD DFA0                STX     TXPTR
0000EFCF 96BA                LDAA    TXPBPEND
0000EFD1 97AC                STAA    TXBANK
0000EFD3 96BD                LDAA    TXEBPEND
0000EFD5 97AD                STAA    TXENDPG
0000EFD7 DEBB                LDX     TXEPEND
0000EFD9 DFA2                STX     TXEND
0000EFDB 3B                  RTI
0000EFDC 4F         NOPEND   CLRA
0000EFDD 97A4                STAA    TXFLAG
0000EFDF 71FB11              AIM     %11111011,TRC
0000EFE2                             SR1
```

```
0000EFE2 3B          MOREMES    RTI
                     DO16BIT
0000EFE3 9603                   LDAA     PORT2
0000EFE5 977F                   STAA     P2SAVE
0000EFE7 96AB                   LDAA     TXBYTE
0000EFE9 2705                   BEQ      NOBANK
0000EFEB 720103                 OIM      %00000001,POR
0000EFEE                                 T2
0000EFEE 2003                   BRA      BNKDONE
0000EFF0 71FE03      NOBANK     AIM      %11111110,POR
0000EFF3                                 T2
0000EFF3 96AC        BNKDONE    LDAA     TXBANK
0000EFF5 2705                   BEQ      NOPGE
0000EFF7 720203                 OIM      %00000010,POR
0000EFFA                                 T2
0000EFFA 2003                   BRA      PGDONE
0000EFFC 71FD03      NOPGE      AIM      %11111101,POR
0000EFFF                                 T2
0000EFFF DEA0        PGDONE     LDX      TXPTR
0000F001 A600                   LDAA     0,X
0000F003 9713                   STAA     TDR
0000F005 97AF                   STAA     SCRATCH
0000F007 967F                   LDAA     P2SAVE
0000F009 9703                   STAA     PORT2
0000F00B 0E                     CLI
0000F00C 96A5                   LDAA     TXHFLG
0000F00E 272E                   BEQ      NOTHDR1
0000F010 96AB                   LDAA     TXBYTE
0000F012 2616                   BNE      HDRBNK1
0000F014 96A8                   LDAA     HDRCTR
0000F016 8106                   CMPA     #6
0000F018 2606                   BNE      NOT6
0000F01A 96AF                   LDAA     SCRATCH
0000F01C 97B3                   STAA     OFFSET1
0000F01E 201E                   BRA      NOTHDR1
0000F020 8107        NOT6       CMPA     #7
0000F022 261A                   BNE      NOTHDR1
0000F024 96AF                   LDAA     SCRATCH
0000F026 97B1                   STAA     OFFSET3
0000F028 2014                   BRA      NOTHDR1
0000F02A 96A8        HDRBNK1    LDAA     HDRCTR
0000F02C 8106                   CMPA     #6
0000F02E 2606                   BNE      NOT16
0000F030 96AF                   LDAA     SCRATCH
0000F032 97B2                   STAA     OFFSET2
0000F034 2008                   BRA      NOTHDR1
0000F036 8107        NOT16      CMPA     #7
0000F038 2604                   BNE      NOTHDR1
0000F03A 96AF                   LDAA     SCRATCH
0000F03C 97B0                   STAA     OFFSET4
0000F03E 96AB        NOTHDR1    LDAA     TXBYTE
0000F040 2604                   BNE      DOBNK0
0000F042 4C                     INCA
0000F043 97AB                   STAA     TXBYTE
0000F045 3B                     RTI
0000F046 4F          DOBNK0     CLRA
0000F047 97AB                   STAA     TXBYTE
0000F049 DEA0                   LDX      TXPTR
0000F04B 08                     INX
```

```
0000F04C DFA0                STX     TXPTR
0000F04E 8CE000              CPX     #$E000
0000F051 260F                BNE     NOFLIP
0000F053 96AC                LDAA    TXBANK
0000F055 8101                CMPA    #RAMENDB
0000F057 2719                BEQ     DATADN
0000F059 CE0140              LDX     #RAMSTRT
0000F05C DFA0                STX     TXPTR
0000F05E 8601                LDAA    #1
0000F060 97AC                STAA    TXBANK
0000F062 96A5     NOFLIP     LDAA    TXHFLG
0000F064 2613                BNE     DOHDR
0000F066 9CA2                CPX     TXEND
0000F068 2701                BEQ     TESTPG
0000F06A 3B                  RTI
0000F06B 96AC     TESTPG     LDAA    TXBANK
0000F06D 91AD                CMPA    TXENDPG
0000F06F 2701                BEQ     DATADN
0000F071 3B                  RTI
0000F072 4F       DATADN     CLRA
0000F073 97A4                STAA    TXFLAG
0000F075 71FB11              AIM     %11111011,TRC
0000F078                             SR1
0000F078 3B                  RTI
0000F079 96A8     DOHDR      LDAA    HDRCTR
0000F07B 4C                  INCA
0000F07C 97A8                STAA    HDRCTR
0000F07E 8110                CMPA    #16
0000F080 2701                BEQ     NXTHDR
0000F082 3B                  RTI
0000F083 4F       NXTHDR     CLRA
0000F084 97A8                STAA    HDRCTR
0000F086 96B3                LDAA    OFFSET1
0000F088 2615                BNE     NXTHDR1
0000F08A 96B2                LDAA    OFFSET2
0000F08C 2611                BNE     NXTHDR1
0000F08E 96B1                LDAA    OFFSET3
0000F090 260D                BNE     NXTHDR1
0000F092 96B0                LDAA    OFFSET4
0000F094 2609                BNE     NXTHDR1
0000F096 4F                  CLRA
0000F097 97A4                STAA    TXFLAG
0000F099 71FB11              AIM     %11111011,TRC
0000F09C                             SR1
0000F09C 97A5                STAA    TXHFLG
0000F09E 3B                  RTI
0000F09F DCB2     NXTHDR1    LDD     OFFSET2
0000F0A1 D3A6                ADDD    HDRSTRT
0000F0A3 DDA6                STD     HDRSTRT
0000F0A5 DDA0                STD     TXPTR
0000F0A7 96B4                LDAA    HSTRTPG
0000F0A9 99B1                ADCA    OFFSET3
0000F0AB 97B4                STAA    HSTRTPG
0000F0AD 97AC                STAA    TXBANK
0000F0AF 3B                  RTI

0000F0B0                     MEND
0000F0B0                     A.TEST
```

```
                        A.TEST     MODULE
0000F0B0 FE0100         RAMDUMP    LDX        DMPSTRT
0000F0B3 BDF0B9                    JSR        TEST
0000F0B6 7EF913                    JMP        MONITA+9

                        TEST
                        ;SEI
0000F0B9 3C                        PSHX
0000F0BA 4F                        CLRA
0000F0BB 97B6           NXTLIN     STAA       LINCTR
0000F0BD 4F                        CLRA
0000F0BE 97B5           NXTBYT     STAA       BYTCTR
0000F0C0 9611           TXWT1      LDAA       TRCSR1
0000F0C2 8420                      ANDA       #%00100000
0000F0C4 27FA                      BEQ        TXWT1
0000F0C6 9610                      LDAA       RMCR
0000F0C8 8A40                      ORAA       #%01000000
0000F0CA 9710                      STAA       RMCR
0000F0CC A600                      LDAA       0,X
0000F0CE 84F0                      ANDA       #%11110000
0000F0D0 44                        LSRA
0000F0D1 44                        LSRA
0000F0D2 44                        LSRA
0000F0D3 44                        LSRA
0000F0D4 8109                      CMPA       #9
0000F0D6 2304                      BLS        NOTASC1
0000F0D8 8B37                      ADDA       #55
0000F0DA 2002                      BRA        ASCDN1
0000F0DC 8B30           NOTASC1    ADDA       #48
0000F0DE 9713           ASCDN1     STAA       TDR
0000F0E0 9611           TXWT2      LDAA       TRCSR1
0000F0E2 8420                      ANDA       #%00100000
0000F0E4 27FA                      BEQ        TXWT2
0000F0E6 9610                      LDAA       RMCR
0000F0E8 8A40                      ORAA       #%01000000
0000F0EA 9710                      STAA       RMCR
0000F0EC A600                      LDAA       0,X
0000F0EE 840F                      ANDA       #%00001111
0000F0F0 8109                      CMPA       #9
0000F0F2 2304                      BLS        NOTASC2
0000F0F4 8B37                      ADDA       #55
0000F0F6 2002                      BRA        ASCDN2
0000F0F8 8B30           NOTASC2    ADDA       #48
0000F0FA 9713           ASCDN2     STAA       TDR
0000F0FC 08                        INX
0000F0FD 9611           TXWT3      LDAA       TRCSR1
0000F0FF 8420                      ANDA       #%00100000
0000F101 27FA                      BEQ        TXWT3
0000F103 9610                      LDAA       RMCR
0000F105 8A40                      ORAA       #%01000000
0000F107 9710                      STAA       RMCR
0000F109 8620                      LDAA       #$20
0000F10B 9713                      STAA       TDR
0000F10D 96B5                      LDAA       BYTCTR
0000F10F 4C                        INCA
0000F110 8108                      CMPA       #8
0000F112 26AA                      BNE        NXTBYT
0000F114 9611           TXWT4      LDAA       TRCSR1
0000F116 8420                      ANDA       #%00100000
```

```
0000F118 27FA                BEQ      TXWT4
0000F11A 9610                LDAA     RMCR
0000F11C 8A40                ORAA     #%01000000
0000F11E 9710                STAA     RMCR
0000F120 860D                LDAA     #$0D
0000F122 9713                STAA     TDR
0000F124 9611       TXWT5    LDAA     TRCSR1
0000F126 8420                ANDA     #%00100000
0000F128 27FA                BEQ      TXWT5
0000F12A 9610                LDAA     RMCR
0000F12C 8A40                ORAA     #%01000000
0000F12E 9710                STAA     RMCR
0000F130 860A                LDAA     #$0A
0000F132 9713                STAA     TDR
0000F134 96B6                LDAA     LINCTR
0000F136 4C                  INCA
0000F137 810A                CMPA     #10
0000F139 2680                BNE      NXTLIN
0000F13B 9611       TXWT6    LDAA     TRCSR1
0000F13D 8420                ANDA     #%00100000
0000F13F 27FA                BEQ      TXWT6
0000F141 9610                LDAA     RMCR
0000F143 8A40                ORAA     #%01000000
0000F145 9710                STAA     RMCR
0000F147 860A                LDAA     #$0A
0000F149 9713                STAA     TDR
0000F14B 38                  PULX
                    ;CLI
0000F14C 39                  RTS

0000F14D                     MEND
```

```
0000F14D                    A.TABLES
```

```
                    A.TABLES   MODULE
                    ;module to define all the tables used  in the CRL236 pro
                    gram

                    ********************************

0000F14D 00B10166   INTOF      FDB        SCALOF,SCALOF
0000F151 021A0238                         +181,SCALOF+3
0000F155 02ED03A1                         61,SCALOF+391
0000F159 00000000                         ,SCALOF+572,S
0000F15D                                  CALOF+752,0,0

                    ********************************

0000F15D 00000016   BCDTAB1    FDB        $0000,$0016,$
0000F161 00320048                         0032,$0048,$0
0000F165 00640080                         064,$0080,$00
0000F169 00960112                         96,$0112,$012
0000F16D 01280144                         8,$0144,$0160
0000F171 01600176                         ,$0176,$0192,
0000F175 01920208                         $0208,$0224,$
0000F179 02240240                         0240
0000F17D 00000256   BCDTAB2    FDB        $0000,$0256,$
0000F181 05120768                         0512,$0768,$1
0000F185 10241280                         024,$1280,$15
0000F189 15361792                         36,$1792,$204
0000F18D 20482304                         8,$2304,$2560
0000F191 25602816                         ,$2816,$3072,
0000F195 30723328                         $3328,$3584,$
0000F199 35843840                         3840
0000F19D 00004096   BCDTAB3    FDB        $0000,$4096,$
0000F1A1 81922288                         8192,$2288,$6
0000F1A5 63840480                         384,$0480,$45
0000F1A9 45768672                         76,$8672,$276
0000F1AD 27686864                         8,$6864,$0960
0000F1B1 09605056                         ,$5056,$9152,
0000F1B5 91523248                         $3248,$7344,$
0000F1B9 73441440                         1440
0000F1BD 00000001   BCDTAB4    FCB        $00,$00,$00,$
0000F1C1 01020202                         01,$01,$02,$0
0000F1C5 03030404                         2,$02,$03,$03
0000F1C9 04050506                         ,$04,$04,$04,
0000F1CD                                  $05,$05,$06

                    ********************************

0000F1CD 01010000   HLOOK      FDB        $0101,$0000,$
0000F1D1 00000000                         0000,$0000,$0
0000F1D5 00000000                         000,$0000,$00
0000F1D9 00000000                         00,$0000,$001
0000F1DD 00100000                         0,$0000,$0000
0000F1E1 00000001                         ,$0001,$0100,
0000F1E5 01000000                         $0000,$0000,$
0000F1E9 00000302                         0302
                    ********************************

0000F1ED            LOGTAB1    LOAD       A.ADDLOG

0000F5ED            LOGTAB2    LOAD       A.TIMLOG
```

```
0000F6ED 010F012D  ROTOFF     FDB       $010F,$012D,$
0000F6F1 014B0169                       014B,$0169,$0
0000F6F5 018701A5                       187,$01A5,$01
0000F6F9 01C401E2                       C4,$01E2
0000F6FD 00F100D3             FDB       $00F1,$00D3,$
0000F701 00B50097                       00B5,$0097,$0
0000F705 0078005A                       078,$005A,$00
0000F709 003C001E                       3C,$001E,$000
0000F70D 0000FFE2                       0,$FFE2,$FFC4
0000F711 FFC4FFA6                       ,$FFA6,$FF88,
0000F715 FF88FF69                       $FF69,$FF4B,$
0000F719 FF4BFF2D                       FF2D

                   *******************************

0000F71D                      MEND
```

```
0000F71D                       A.STRING
```

```
                      A.STRING   MODULE
0000F71D                         IF        CIRRUS=1
0000F71D              INSTYPE    ALIAS     "CRL 2.36  "
0000F71D                         ELSE
                      INSTYPE    ALIAS     "SA 11.40  "
0000F71D                         ENDIF

0000F71D 1A           ESCSTR     EQUB      26
0000F71E 43524C20                EQUS      "CRL 2.36  "
0000F722 322E3336
0000F726 2020
0000F728 30303030                EQUS      "000001"
0000F72C 3031
0000F72E 0D0A0D0A                EQUB      13,10,13,10
0000F732 39363030                EQUS      "9600"
0000F736 0D0A                    EQUB      13,10

0000F738 14           WELCOME    EQUB      20
0000F739 43524C20                EQUS      "CRL 2.36  "
0000F73D 322E3336
0000F741 2020
0000F743 30303030                EQUS      "000001"
0000F747 3031
0000F749 0D0A0D0A                EQUB      13,10,13,10

0000F74D 2C           IDMESS     EQUB      44
0000F74E 43524C20                EQUS      "CRL 2.36  "
0000F752 322E3336
0000F756 2020
0000F758 73657220                EQUS      "ser #"
0000F75C 23
0000F75D 30303030                EQUS      "000001"
0000F761 3031
0000F763 20524F4D                EQUS      " ROM ver 1.0
0000F767 20766572                          0 rev 0"
0000F76B 20312E30
0000F76F 30207265
0000F773 762030
0000F776 0D0A0D0A                EQUB      13,10,13,10

0000F77A 1C           ITMESS     EQUB      28
0000F77B 43524C20                EQUS      "CRL 2.36  "
0000F77F 322E3336
0000F783 2020
0000F785 30303030                EQUS      "000001"
0000F789 3031
0000F78B 0D0A0D0A                EQUB      13,10,13,10
0000F78F 30303031                EQUS      "000100"
0000F793 3030
0000F795 0D0A                    EQUB      13,10

0000F797 14           ERMESS     EQUB      20
0000F798 43524C20                EQUS      "CRL 2.36  "
0000F79C 322E3336
0000F7A0 2020
0000F7A2 30303030                EQUS      "000001"
0000F7A6 3031
0000F7A8 2424                    EQUS      "$$"
0000F7AA 0D0A                    EQUB      13,10
```

```
0000F7AC 00000000  HEXTBL   FDB   $0000,$0000,   ;00000000
0000F7B0 96800098           FDB   $9680,$0098,   ;10000000
0000F7B4 2D000131           FDB   $2D00,$0131,   ;20000000
0000F7B8 C38001C9           FDB   $C380,$01C9,   ;30000000
0000F7BC 5A000262           FDB   $5A00,$0262,   ;40000000
0000F7C0 F08002FA           FDB   $F080,$02FA,   ;50000000
0000F7C4 87000393           FDB   $8700,$0393,   ;60000000
0000F7C8 1D80042C           FDB   $1D80,$042C,   ;70000000
0000F7CC B40004C4           FDB   $B400,$04C4,   ;80000000
0000F7D0 4A80055D           FDB   $4A80,$055D,   ;90000000
0000F7D4 00000000           FDB   $0000,$0000,   ;00000000
0000F7D8 4240000F           FDB   $4240,$000F,   ;01000000
0000F7DC 8480001E           FDB   $8480,$001E,   ;02000000
0000F7E0 C6C0002D           FDB   $C6C0,$002D,   ;03000000
0000F7E4 0090003D           FDB   $0090,$003D,   ;04000000
0000F7E8 4640004C           FDB   $4640,$004C,   ;05000000
0000F7EC 8D80005B           FDB   $8D80,$005B,   ;06000000
0000F7F0 CFC0006A           FDB   $CFC0,$006A,   ;07000000
0000F7F4 1200007A           FDB   $1200,$007A,   ;08000000
0000F7F8 54400089           FDB   $5440,$0089,   ;09000000
0000F7FC 00000000           FDB   $0000,$0000,   ;00000000
0000F800 86A00001           FDB   $86A0,$0001,   ;00100000
0000F804 0D400003           FDB   $0D40,$0003,   ;00200000
0000F808 93E00004           FDB   $93E0,$0004,   ;00300000
0000F80C 1A800006           FDB   $1A80,$0006,   ;00400000
0000F810 A1200007           FDB   $A120,$0007,   ;00500000
0000F814 27C00009           FDB   $27C0,$0009,   ;00600000
0000F818 AE60000A           FDB   $AE60,$000A,   ;00700000
0000F81C 3500000C           FDB   $3500,$000C,   ;00800000
0000F820 BBA0000D           FDB   $BBA0,$000D,   ;00900000
0000F824 00000000           FDB   $0000,$0000,   ;00000000
0000F828 27100000           FDB   $2710,$0000,   ;00010000
0000F82C 4E200000           FDB   $4E20,$0000,   ;00020000
0000F830 75300000           FDB   $7530,$0000,   ;00030000
0000F834 9C400000           FDB   $9C40,$0000,   ;00040000
0000F838 C3500000           FDB   $C350,$0000,   ;00050000
0000F83C EA600000           FDB   $EA60,$0000,   ;00060000
0000F840 11700001           FDB   $1170,$0001,   ;00070000
0000F844 38800001           FDB   $3880,$0001,   ;00080000
0000F848 5F900001           FDB   $5F90,$0001,   ;00090000
0000F84C 00000000           FDB   $0000,$0000,   ;00000000
0000F850 03E80000           FDB   $03E8,$0000,   ;00001000
0000F854 07D00000           FDB   $07D0,$0000,   ;00002000
0000F858 0BB80000           FDB   $0BB8,$0000,   ;00003000
0000F85C 0FA00000           FDB   $0FA0,$0000,   ;00004000
0000F860 13880000           FDB   $1388,$0000,   ;00005000
0000F864 17700000           FDB   $1770,$0000,   ;00006000
0000F868 1B580000           FDB   $1B58,$0000,   ;00007000
0000F86C 1F400000           FDB   $1F40,$0000,   ;00008000
0000F870 23280000           FDB   $2328,$0000,   ;00009000
0000F874 00000000           FDB   $0000,$0000,   ;00000000
0000F878 00640000           FDB   $0064,$0000,   ;00000100
0000F87C 00C80000           FDB   $00C8,$0000,   ;00000200
0000F880 012C0000           FDB   $012C,$0000,   ;00000300
0000F884 01900000           FDB   $0190,$0000,   ;00000400
0000F888 01F40000           FDB   $01F4,$0000,   ;00000500
0000F88C 02580000           FDB   $0258,$0000,   ;00000600
0000F890 02BC0000           FDB   $02BC,$0000,   ;00000700
```

```
0000F894 03200000          FDB     $0320,$0000,   ;00000800
0000F898 03840000          FDB     $0384,$0000,   ;00000900
0000F89C 00000000          FDB     $0000,$0000,   ;00000000
0000F8A0 000A0000          FDB     $000A,$0000,   ;00000010
0000F8A4 00140000          FDB     $0014,$0000,   ;00000020
0000F8A8 001E0000          FDB     $001E,$0000,   ;00000030
0000F8AC 00280000          FDB     $0028,$0000,   ;00000040
0000F8B0 00320000          FDB     $0032,$0000,   ;00000050
0000F8B4 003C0000          FDB     $003C,$0000,   ;00000060
0000F8B8 00460000          FDB     $0046,$0000,   ;00000070
0000F8BC 00500000          FDB     $0050,$0000,   ;00000080
0000F8C0 005A0000          FDB     $005A,$0000,   ;00000090
0000F8C4 00000000          FDB     $0000,$0000,   ;00000000
0000F8C8 00010000          FDB     $0001,$0000,   ;00000001
0000F8CC 00020000          FDB     $0002,$0000,   ;00000002
0000F8D0 00030000          FDB     $0003,$0000,   ;00000003
0000F8D4 00040000          FDB     $0004,$0000,   ;00000004
0000F8D8 00050000          FDB     $0005,$0000,   ;00000005
0000F8DC 00060000          FDB     $0006,$0000,   ;00000006
0000F8E0 00070000          FDB     $0007,$0000,   ;00000007
0000F8E4 00080000          FDB     $0008,$0000,   ;00000008
0000F8E8 00090000          FDB     $0009,$0000,   ;00000009

0000F8EC                   MEND
```

0000F8EC A.MONITOR

```
                    A.MONITOR  MODULE

                    ;this module provides a way to "look into" a 68XX target
                     system from the "Serial Communicator" part of META.  It
                    's almost entirely LOCAL since it may need to be include
                    d in any 68XX program.

                    ;the routines CSEND and CGET are specialised to this par
                    ticular 6303 system:    they send and await Chars on the
                     RS232 link with the BBC, vis through the DP-37 connecto
                    r.

                    ;MONITOR program assembled at current ORG

0000F8EC                      LOCAL     100

                    ********************************

0000F8EC            OTEMP     EQU       *           make a copy of current O
0000F8EC                                            RG

00000100                      ORG       $0100       define constants/storage
00000100                                             area in RAM

00000100            .DMPSTRT  DS.W
00000102            ACCA      DS.B                  storage for accumilator
00000102                                            A
00000103            ACCB      DS.B                  storage for accumilator
00000103                                            B
00000104            XREG      DS.W                  storage for X index
00000106            PC        DS.W                  storage for Program Coun
00000106                                            ter
00000108            CCR       DS.B                  storage for Condition Co
00000108                                            de Register
00000109            CUR       DS.W                  "cursor" position
0000010B            COUNT     DS.B
0000010C            XTEMP     DS.W                  temporary storage
0000010E            TEMPW     DS.W                  temporary storage
00000110            STACK     DS.W                  storage for stack pointe
00000110                                            r

0000F8EC                      ORG       OTEMP       back to where we left of
0000F8EC                                            f..

                    ********************************

                    CSEND
                    ;send the character in ACCA down RS232 port: preserve A,
                    B,X
0000F8EC 37                   PSHB
0000F8ED 3C                   PSHX
0000F8EE D611       TXWAIT1   LDAB      TRCSR1
0000F8F0 C420                 ANDB      #%00100000
0000F8F2 27FA                 BEQ       TXWAIT1
0000F8F4                      IF        HD6303Y=1
0000F8F4                      ELSE
                              OIM       %01000000,RMC
                                        R
```

```
0000F8F4                      ENDIF
0000F8F4 9713                 STAA     TDR
0000F8F6 D611       TXWAIT2   LDAB     TRCSR1
0000F8F8 C420                 ANDB     #%00100000
0000F8FA 27FA                 BEQ      TXWAIT2
0000F8FC 38                   PULX
0000F8FD 33                   PULB
0000F8FE 39                   RTS


                    CGET
                    ;"get" a character routine; loops until character receiv
                    ed.  Exit with character in Acc A, X preserved.
0000F8FF 3C                   PSHX
0000F900 D611       RXWAIT1   LDAB     #%10000000
0000F904 27FA                 BEQ      RXWAIT1
0000F906 9612                 LDAA     RDR
0000F908 38                   PULX
0000F909 39                   RTS

                    *******************************


                    ;RESET entry point
                    .MONITA
0000F90A 71EF11               AIM      %11101111,TRC
0000F90D                               SR1
0000F90D BF0110               STS      STACK
0000F910 CEF91C               LDX      #SSTRING
0000F913 BDFB86               JSR      MSG
0000F916 BDFA24               JSR      REGDISP
0000F919 7EFA7E               JMP      PROMPT

                    *******************************


                    ;start-up string

0000F91C 0C         SSTRING   EQUB     12
0000F91D 2D2D2D2D             EQUS     "----- 6303 MO
0000F921 20363330                      NITOR ----"
0000F925 33204D4F
0000F929 4E49544F
0000F92D 52202D2D
0000F931 2D2D
0000F933 0D0A                 EQUB     13,10
0000F935 28432920             EQUS     "(C) JOHN HOL
0000F939 4A4F484E                      DING 1986"
0000F93D 20484F4C
0000F941 44494E47
0000F945 20313938
0000F949 36
0000F94A 0D0A                 EQUB     13,10
0000F94C 00                   EQUB     0


                    ;"help" message string
```

```
0000F94D 0D0A      HSTRING   EQUB    13,10
0000F94F 3C52544E            EQUS    "<RTN>   Next
0000F953 3E202020                     Byte"
0000F957 4E657874
0000F95B 20427974
0000F95F 65
0000F960 0D0A                EQUB    13,10
0000F962 2D202020            EQUS    "-        Back
0000F966 20202020                     one byte"
0000F96A 4261636B
0000F96E 206F6E65
0000F972 20627974
0000F976 65
0000F977 0D0A                EQUB    13,10
0000F979 3C58583E            EQUS    "<XX>    Stor
0000F97D 20202020                    e XX into cur
0000F981 53746F72                    rent pos."
0000F985 65205858
0000F989 20696E74
0000F98D 6F206375
0000F991 7272656E
0000F995 7420706F
0000F999 732E
0000F99B 0D0A                EQUB    13,10
0000F99D 52202020            EQUS    "R       Redi
0000F9A1 20202020                    splay Regs"
0000F9A5 52656469
0000F9A9 73706C61
0000F9AD 79205265
0000F9B1 6773
0000F9B3 0D0A                EQUB    13,10
0000F9B5 473C5858            EQUS    "G<XXXX> Move
0000F9B9 58583E20                     pos to XXXX"
0000F9BD 4D6F7665
0000F9C1 20706F73
0000F9C5 20746F20
0000F9C9 58585858
0000F9CD 0D0A                EQUB    13,10
0000F9CF 58202020            EQUS    "X       Exec
0000F9D3 20202020                    ute from curr
0000F9D7 45786563                    ent pos"
0000F9DB 75746520
0000F9DF 66726F6D
0000F9E3 20637572
0000F9E7 72656E74
0000F9EB 20706F73
0000F9EF 0D0A00              EQUB    13,10,0

                   ;register headings

0000F9F2 0D0A      RSTRING   EQUB    13,10
0000F9F4 20504320            EQUS    " PC  ACCA AC
0000F9F8 20414343                    CB XREG CCR
0000F9FC 41204143                    SP"
0000FA00 43422058
0000FA04 52454720
0000FA08 43435220
```

```
0000FA0C 205350
0000FA0F 0D0A00                 EQUB      13,10,0


                    ;command keys list

0000FA12 0D         COMLIST     EQUB      13
0000FA13 47582D52               EQUS      "GX-RH"
0000FA17 48

                    ;jump table for each of the commands  above

0000FA18 FB29       COMVEC      FDB       INCPC          ;move on one byte
0000FA1A FB52                   FDB       GOTO           ;"GOTO" a new address
0000FA1C FB43                   FDB       EXEC           ;"EXECUTE" from current
0000FA1E                                                 address
0000FA1E FB33                   FDB       DECPC          ;move back a byte
0000FA20 FB3D                   FDB       REPREG         ;repeat register values
0000FA22                                                 from last SWI
0000FA22 FB20                   FDB       HELP           ;print up the "HELP" lis
0000FA24                                                 t

                    ********************************


                    ;display register values as recorded  on entry into mon
                    itor

0000FA24 CEF9F2     REGDISP     LDX       #RSTRING
0000FA27 BDFB86                 JSR       MSG
0000FA2A B60106                 LDAA      PC
0000FA2D BDFBAE                 JSR       HEX
0000FA30 B60107                 LDAA      PC+1
0000FA33 BDFBAE                 JSR       HEX
0000FA36 BDFBA8                 JSR       SPACE2
0000FA39 B60102                 LDAA      ACCA
0000FA3C BDFBAE                 JSR       HEX
0000FA3F BDFBA5                 JSR       SPACE3
0000FA42 B60103                 LDAA      ACCB
0000FA45 BDFBAE                 JSR       HEX
0000FA48 BDFBA8                 JSR       SPACE2
0000FA4B B60104                 LDAA      XREG
0000FA4E BDFBAE                 JSR       HEX
0000FA51 B60105                 LDAA      XREG+1
0000FA54 BDFBAE                 JSR       HEX
0000FA57 BDFBA8                 JSR       SPACE2
0000FA5A B60108                 LDAA      CCR
0000FA5D BDFBAE                 JSR       HEX
0000FA60 BDFBA0                 JSR       SPACE1
0000FA63 B60110                 LDAA      STACK
0000FA66 BDFBAE                 JSR       HEX
0000FA69 B60111                 LDAA      STACK+1
0000FA6C BDFBAE                 JSR       HEX
0000FA6F 860D                   LDAA      #13
0000FA71 BDF8EC                 JSR       CSEND
0000FA74 860A                   LDAA      #10
0000FA76 7EF8EC                 JMP       CSEND
0000FA79 860A                   LDA       #10
0000FA7B 7EF8EC                 JMP       CSEND
```

```
                        ;main prompt routine

0000FA7E 860D           PROMPT    LDAA      #13
0000FA80 BDF8EC                   JSR       CSEND
0000FA83 860A                     LDAA      #10
0000FA85 BDF8EC                   JSR       CSEND
0000FA88 B60109         PROMPT1   LDAA      CUR
0000FA8B BDFBAE                   JSR       HEX
0000FA8E B6010A                   LDAA      CUR+1
0000FA91 BDFBAE                   JSR       HEX
0000FA94 BDFBA0                   JSR       SPACE1
0000FA97 FE0109                   LDX       CUR
0000FA9A A600                     LDAA      0,X
0000FA9C 847F                     ANDA      #%01111111
0000FA9E 8120                     CMPA      #' '
0000FAA0 2F04                     BLE       DOT
0000FAA2 817F                     CMPA      #%01111111
0000FAA4 2602                     BNE       DOT1
0000FAA6 862E           DOT       LDAA      #'.'
0000FAA8 BDF8EC         DOT1      JSR       CSEND
0000FAAB BDFBA0                   JSR       SPACE1
0000FAAE FE0109                   LDX       CUR
0000FAB1 A600                     LDAA      0,X
0000FAB3 BDFBAE                   JSR       HEX
0000FAB6 863A                     LDAA      #':'
0000FAB8 BDF8EC                   JSR       CSEND
0000FABB BDF8FF         IGNORE    JSR       CGET                strip out line feeds
0000FABE 810A                     CMPA      #$0A
0000FAC0 27F9                     BEQ       IGNORE
0000FAC2 CEFA12                   LDX       #COMLIST
0000FAC5 C600                     LDAB      #0
0000FAC7 A100           PRO       CMPA      0,X
0000FAC9 272E                     BEQ       PR1
0000FACB 08                       INX
0000FACC 5C                       INCB
0000FACD 5C                       INCB
0000FACE C10C                     CMPB      #12
0000FAD0 26F5                     BNE       PRO
0000FAD2 8130                     CMPA      #'0'
0000FAD4 2D0C                     BLT       NOTHEX
0000FAD6 8146                     CMPA      #'F'
0000FAD8 2E08                     BGT       NOTHEX
0000FADA 8139                     CMPA      #'9'
0000FADC 2F07                     BLE       ISHEX
0000FADE 8141                     CMPA      #'A'
0000FAE0 2C03                     BGE       ISHEX
0000FAE2 7EFA7E         NOTHEX    JMP       PROMPT
0000FAE5 CE0000         ISHEX     LDX       #0
0000FAE8 FF010E                   STX       TEMPW
0000FAEB BDFBCE                   JSR       GH1A
0000FAEE B6010F                   LDAA      TEMPW+1
0000FAF1 FE0109                   LDX       CUR
0000FAF4 A700                     STAA      0,X
0000FAF6 7EFB29                   JMP       INCPC

0000FAF9 CEFA18         PR1       LDX       #COMVEC
0000FAFC FF010E                   STX       TEMPW
```

```
0000FAFF 0C                    CLC
0000FB00 F9010F                ADCB     TEMPW+1
0000FB03 F7010F                STAB     TEMPW+1
0000FB06 F6010E                LDAB     TEMPW
0000FB09 C900                  ADCB     #0
0000FB0B F7010E                STAB     TEMPW
0000FB0E FE010E                LDX      TEMPW
0000FB11 A600                  LDAA     0,X
0000FB13 B7010C                STAA     XTEMP
0000FB16 A601                  LDAA     1,X
0000FB18 B7010D                STAA     XTEMP+1
0000FB1B FE010C                LDX      XTEMP
0000FB1E 6E00                  JMP      0,X

                   ;display help list

0000FB20 CEF94D    HELP        LDX      #HSTRING
0000FB23 BDFB86                JSR      MSG
0000FB26 7EFA7E                JMP      PROMPT

                   ;move on a byte

0000FB29 FE0109    INCPC       LDX      CUR
0000FB2C 08                    INX
0000FB2D FF0109                STX      CUR
0000FB30 7EFA88                JMP      PROMPT1

                   ;move back a byte

0000FB33 FE0109    DECPC       LDX      CUR
0000FB36 09                    DEX
0000FB37 FF0109                STX      CUR
0000FB3A 7EFA7E                JMP      PROMPT

                   ;repeat list of registers

0000FB3D BDFA24    REPREG      JSR      REGDISP
0000FB40 7EFA7E                JMP      PROMPT

                   ;execute from current address

0000FB43 FE0109    EXEC        LDX      CUR
0000FB46 721011                OIM      %00010000,TRC ;RECEIVE INT NOT RE ENAB
0000FB49                                SR1              LED
0000FB49 0E                    CLI
0000FB4A AD00                  JSR      0,X
0000FB4C 71EF11                AIM      %11101111,TRC
0000FB4F                                SR1
0000FB4F 7EFB61                JMP      MONITB

                   ;GOTO new address

0000FB52 BDFBC5    GOTO        JSR      GETHEX
0000FB55 FE010E                LDX      TEMPW
0000FB58 FF0109                STX      CUR
0000FB5B 7EFA7E                JMP      PROMPT

                   ********************************
```

```
                    ;SWI entry point

                    .SWI

0000FB5E 71EF11                AIM      %11101111,TRC
0000FB61                                SR1
0000FB61 B70102     .MONITB    STAA     ACCA
0000FB64 32                    PULA
0000FB65 B70108                STAA     CCR
0000FB68 F70103                STAB     ACCB
0000FB6B FF0104                STX      XREG
0000FB6E 32                    PULA
0000FB6F 32                    PULA
0000FB70 32                    PULA
0000FB71 32                    PULA
0000FB72 32                    PULA
0000FB73 B70106                STAA     PC
0000FB76 B70109                STAA     CUR
0000FB79 32                    PULA
0000FB7A B70107                STAA     PC+1
0000FB7D B7010A                STAA     CUR+1
0000FB80 BF0110                STS      STACK

0000FB83 7EF90A                JMP

0000FBA0 8620       SPACE1     LDAA     #32
0000FBA2 7EF8EC                JMP      CSEND
0000FBA5 BDFBA0     SPACE3     JSR      SPACE1
0000FBA8 BDFBA0     SPACE2     JSR      SPACE1
0000FBAB 7EFBA0                JMP      SPACE1

                    ******************************
```

```
                          ;display binary value in Acc A as two  hex ASCII digits

0000FBAE 36         HEX         PSHA
0000FBAF 47                     ASRA
0000FBB0 47                     ASRA
0000FBB1 47                     ASRA
0000FBB2 47                     ASRA
0000FBB3 BDFBB7                 JSR         HEX1
0000FBB6 32                     PULA
0000FBB7 840F       HEX1        ANDA        #%00001111
0000FBB9 8A30                   ORAA        #'0'
0000FBBB 813A                   CMPA        #':'
0000FBBD 2D03                   BLT         HEX2
0000FBBF 0C                     CLC
0000FBC0 8907                   ADCA        #7
0000FBC2 7EF8EC     HEX2        JMP         CSEND

                    ********************************

                    ;await an incoming hex number terminated by CR ($D).  Ma
                    y be any number of digits, but only last four returned i
                    n the 2-byte result store "TEMPW".

0000FBC5 CE0000     GETHEX      LDX         #0
0000FBC8 FF010E                 STX         TEMPW
0000FBCB BDF8FF     GH1         JSR         CGET
0000FBCE 810D       GH1A        CMPA        #13
0000FBD0 2604                   BNE         GH2
0000FBD2 BDF8FF                 JSR         CGET
0000FBD5 39                     RTS
0000FBD6 8130       GH2         CMPA        #'0'
0000FBD8 2D0C                   BLT         GH3
0000FBDA 8146                   CMPA        #'F'
0000FBDC 2E08                   BGT         GH3
0000FBDE 8141                   CMPA        #'A'
0000FBE0 2C0C                   BGE         GH4
0000FBE2 8139                   CMPA        #'9'
0000FBE4 2F0B                   BLE         GH5
0000FBE6 8607       GH3         LDAA        #7
0000FBE8 BDF8EC                 JSR         CSEND
0000FBEB 7EFBCB                 JMP         GH1
0000FBEE 0D         GH4         SEC
0000FBEF 8206                   SBCA        #'A'-['0'+11]
0000FBF1 0D         GH5         SEC
0000FBF2 8230                   SBCA        #'0'
0000FBF4 4C                     INCA
0000FBF5 48                     ASLA
0000FBF6 48                     ASLA
0000FBF7 48                     ASLA
0000FBF8 48                     ASLA

0000FBF9 0C                     CLC
0000FBFA 48                     ASLA
0000FBFB 79010F                 ROL         TEMPW+1
0000FBFE 79010E                 ROL         TEMPW
0000FC01 0C                     CLC
```

```
0000FC02 48                 ASLA
0000FC03 79010F             ROL      TEMPW+1
0000FC06 79010E             ROL      TEMPW
0000FC09 0C                 CLC
0000FC0A 48                 ASLA
0000FC0B 79010F             ROL      TEMPW+1
0000FC0E 79010E             ROL      TEMPW
0000FC11 0C                 CLC
0000FC12 48                 ASLA
0000FC13 79010F             ROL      TEMPW+1
0000FC16 79010E             ROL      TEMPW
0000FC19 7EFBCB             JMP      GH1

                   ********************************

0000FC1C                    MEND
```

```
0000FC1C                SKIP     $FFEA-*,$FF  fill with FF for eprom p
0000FC1C                                      rogrammer

              ******************************

0000FFEA                ORG      $FFEA        interrupt vector label i
0000FFEA                                      nitialization

0000FFEA                A.INTVECT             initialize processor reg
0000FFEA                                      isters
```

```
                        A.INTVECT  MODULE
                        ;module to write interrupt vectoring   locations
                        ********************************

0000FFEA E983               FDB       IRQ2       interrupt request 2
0000FFEC E983               FDB       CMI        timer 2 counter match
0000FFEE E000               FDB       TRAP       undefined opcode/illegal
0000FFF0                                          address
0000FFF0 ED22               FDB       SIO        serial I/O (RDRF+ORFE+TD
0000FFF2                                         RE)
0000FFF2 E985               FDB       TOI        timer 1 overflow
0000FFF4 E983               FDB       OCI        timer 1 output compare 1
0000FFF6                                         ,2
0000FFF6 E983               FDB       ICI        timer 1 input capture
0000FFF8 E983               FDB       IRQ1       interrupt request 1
0000FFFA FB5E               FDB       SWI        software interrupt
0000FFFC E96D               FDB       NMI        non-maskable interrupt
0000FFFE E000               FDB       RES        reset program start vect
00010000                                         or

                        ********************************

00010000                    MEND
```

```
                          ********************************
00010000                        END
```

Symbol Table:

```
ADST.....GBL ......31       ADRD.....GBL ......30       ADLOAD...GBL ......37
ACTYPE...GBL ......47       ACMODE...GBL ......6A       ADPSU....GBL .......0
ADLINA...GBL .......1       ADLEQ....GBL .......2       ADWAIT2..GBL ....E620
ADWAIT3..GBL ....E668       ADWAIT4..GBL ....E6B0       ADSTRT...GBL ....E9B8
ADWAIT...GBL ....E9BE       ADMISS...GBL ....E9C4       ADWAIT1..GBL ....ECFA
ASCDN1...GBL ....F0DE       ASCDN2...GBL ....F0FA       ACCA.....100 .....102
ACCB.....100 .....103       BYTCTR...GBL ......B5       BCDOVF...GBL ......C3
BATTLOW..GBL ....E9AB       BIGDAT1..GBL ....EB07       BIGDAT2..GBL ....EBC5
BADMESS..GBL ....EF7C       BNKDONE..GBL ....EFF3       BCDTAB1..GBL ....F15D
BCDTAB2..GBL ....F17D       BCDTAB3..GBL ....F19D       BCDTAB4..GBL ....F1BD
CODE.....GBL ......48       CHDSTRT..GBL ......49       CUMBIN...GBL ......4C
CUMBCD...GBL ......4E       CODUSE...GBL ......C4       CALFLG...GBL ......C7
CUMDOSE..GBL ......CC       CUMTIME..GBL ......CF       CALOFF...GBL ......D5
CALDNF...GBL ......DA       CALVAL...GBL ......DC       CALKCNT..GBL ......E0
CIRRUS...GBL .......1       CAL......GBL ......11       CUMLEQ...GBL ......42
CODE1....GBL ......18       CODE2....GBL ......28       CODE3....GBL ......48
CODE4....GBL ......88       CALPH....GBL ....E248       CALMOD...GBL ....E253
CALOK....GBL ....E2ED       CALEND...GBL ....E30E       CONVCMP..GBL ....E3D2
CHDB1....GBL ....E464       CHDBDN...GBL ....E467       CMI......GBL ....E983
CUMCNEND.GBL ....EB2A       CCR......100 .....108       CUR......100 .....109
COUNT....100 .....10B       CSEND....100 ....F8EC       CGET.....100 ....F8FF
COMLIST..100 ....FA12       COMVEC...100 ....FA18       DATA.....GBL ......50
DATACNT..GBL ......52       DBLANKF..GBL ......6B       DSCRTCH..GBL ......74
DATADIF..GBL ......CA       DOCAL....GBL ....E303       DOPAUSE..GBL ....E3B8
DOWRT....GBL ....E423       DOLAST...GBL ....E445       DOLAST1..GBL ....E45B
DCALWRT..GBL ....E547       DONOUP...GBL ....E79D       DOMAXUP..GBL ....E7AF
DOCUMUP..GBL ....E84A       DOLEQUP..GBL ....E8E5       DOLCD....GBL ....E8E9
DOCONV...GBL ....E9B2       DTIMCMP..GBL ....EB96       DORX.....GBL ....ED2B
DOESC....GBL ....ED37       DONUM....GBL ....ED82       DODIGS...GBL ....ED94
DORTI....GBL ....EE95       DOMESS...GBL ....EEB0       DOTX.....GBL ....EFA3
DOTX1....GBL ....EFAC       DO16BIT..GBL ....EFE3       DOBNKO...GBL ....F046
DATADN...GBL ....F072       DOHDR....GBL ....F079       DMPSTRT..GBL .....100
DOT......100 ....FAA6       DOT1.....100 ....FAA8       DECPC....100 ....FB33
EPROM....GBL .......0       ERRFLAG..GBL ......55       ERRSTAT..GBL ......D7
ERRHOLD..GBL ......D8       EIGTH....GBL ......14       ENDPG....GBL ....EE95
ESCSTR...GBL ....F71D       ERMESS...GBL ....F797       EXEC.....100 ....FB43
FRC......GBL .......9       FULL.....GBL ....EC51       FIDLTST..GBL ....ECFA
FIDDLE...GBL ....ED14       GOTO.....100 ....FB52       GETHEX...100 ....FBC5
GH1......100 ....FBCB       GH1A.....100 ....FBCE       GH2......100 ....FBD6
GH3......100 ....FBE6       GH4......100 ....FBEE       GH5......100 ....FBF1
HDWCTR...GBL ......56       HLPTR....GBL ......57       HDRFLD...GBL ......6C
HI32VL1..GBL ......76       HI32VL2..GBL ......7A       HDRSTRT..GBL ......A6
HDRCTR...GBL ......A8       HSTRTPG..GBL ......B4       HD6303Y..GBL .......1
HIMIDST.. 4 ....E14B        HIST..... 4 ....E168        HIMIDST.. 11 ....E717
HIST..... 11 ....E734       HIMIDST.. 12 ....E7EE       HIST..... 12 ....E80B
HIMIDST.. 13 ....E889       HIST..... 13 ....E8A6       HIMIDST.. 16 ....EA78
HIST..... 16 ....EA95       HIMIDST.. 17 ....ECA4       HIST..... 17 ....ECC1
HDRBNK1..GBL ....F02A       HLOOK....GBL ....F1CD       HEXTBL...GBL ....F7AC
HSTRING..100 ....F94D       HELP.....100 ....FB20       HEX......100 ....FBAE
HEX1.....100 ....FBB7       HEX2.....100 ....FBC2       ICR......GBL .......D
INTRPRT..GBL ....E315       IRQ2.....GBL ....E983       ICI......GBL ....E983
IRQ1.....GBL ....E983       INTRES...GBL ....E9EC       INTOF....GBL ....F14D
IDMESS...GBL ....F74D       ITMESS...GBL ....F77A       IGNORE...100 ....FABB
ISHEX....100 ....FAE5       INCPC....100 ....FB29       KEYVAL...GBL ......41
KEYCNT...GBL ......42       KEYTEMP..GBL ......43       KENCNT...GBL ......BE
```

```
KENFLG...GBL ......C5     KEYLOOP.. 3 ....E020      KEYTST... 3 ....E04E
KEYCOMP.. 3 ....E05C      KEYOK.... 3 ....E064      KEYRET... 3 ....E069
KEYLOOP.. 6 ....E1F4      KEYTST... 6 ....E222      KEYCOMP.. 6 ....E230
KEYOK.... 6 ....E238      KEYRET... 6 ....E23D      LCDIG....GBL ......32
LEDS.....GBL ......36     LCDWORD..GBL ......44     LEDSREG..GBL ......59
LCDMAXUP.GBL ......6D     LCDCUMUP.GBL ......6E     LCDLEQUP.GBL ......6F
LCDNOUP..GBL ......71     LEDSONF..GBL ......72     LO32VL1..GBL ......78
LO32VL2..GBL ......7C     LINCTR...GBL ......B6     LOGTIME..GBL ......D2
LINASTR..GBL ......DB     LEDENABL.GBL ......21     LEQNO....GBL ......12
LOSTR.... 4 ....E127      LOMIDST.. 4 ....E130      LINPOS1..GBL ....E633
LINPOS2..GBL ....E67B     LINPOS3..GBL ....E6C3     LOSTR.... 11 ....E6F3
LOMIDST.. 11 ....E6FC     LOSTR.... 12 ....E7CA     LOMIDST.. 12 ....E7D3
LOSTR.... 13 ....E865     LOMIDST.. 13 ....E86E     LOGAIN...GBL ....EA2B
LOSTR.... 16 ....EA54     LOMIDST.. 16 ....EA5D     LOSTR.... 17 ....EC80
LOMIDST.. 17 ....EC89     LINPOS...GBL ....ED0E     LOGTAB1..GBL ....F1ED
LOGTAB2..GBL ....F5ED     MAXBIN...GBL ......5A     MAXBCD...GBL ......5C
MONFLG...GBL ......C0     MEMLBIN..GBL ......E1     MEMLBCD..GBL ......E3
MAXLEQ...GBL ......82     MLOOP....GBL ....E1BF     MAXOK....GBL ....EAD4
MESSOK0..GBL ....EEC2     MESSOK1..GBL ....EF00     MESSOK2..GBL ....EF34
MESSOK3..GBL ....EF68     MOREMES..GBL ....EFE2     MONITA...GBL ....F90A
MONITB...GBL ....FB61     MSG......100 ....FB86     MESSG....100 ....FB86
MSG3.....100 ....FB92     MSG1.....100 ....FB9F     NOBIN....GBL ......5E
NOTYPE...GBL ......70     NUMMODE..GBL ......7E     NOBCD....GBL ......C1
NRAMOK...GBL ....E0C2     NMON.....GBL ....E1CB     NKEYEN...GBL ....E1D8
NOKEY....GBL ....E240     NCALCLR..GBL ....E270     N94DB....GBL ....E27B
N104DB...GBL ....E286     N117DB...GBL ....E291     N124DB...GBL ....E29A
NUP1DB...GBL ....E2B3     NDN1DB...GBL ....E2C2     NUPPT1DB.GBL ....E2CD
NCALMOD..GBL ....E30E     NLEDKEY..GBL ....E32B     NSHRTLEQ.GBL ....E347
NMAXLEQ..GBL ....E363     NCUMLEQ..GBL ....E37F     NLEQNO...GBL ....E3A9
NXEMPTY..GBL ....E3EC     NFULL1...GBL ....E3F7     NHDOVF1..GBL ....E475
NHDOVF2..GBL ....E492     NHDOVF3..GBL ....E4A8     NPGCHNG..GBL ....E4B5
NNULL....GBL ....E4CE     NHDOVF4..GBL ....E4EB     NHDOVF5..GBL ....E501
NHDOVF6..GBL ....E514     NHDOVF7..GBL ....E520     N18......GBL ....E539
N1.......GBL ....E543     NHDOVF8..GBL ....E553     NEWHDST..GBL ....E561
NLASTEND.GBL ....E578     NPAUSE...GBL ....E58F     NRSTCUM..GBL ....E5A7
NRELMAX..GBL ....E5B4     NCODE....GBL ....E5C0     NRUNKEYS.GBL ....E5C3
NCAL.....GBL ....E5EC     NFULL2...GBL ....E5F4     NEIGTH...GBL ....E63A
NONESEC..GBL ....E682     NTENSEC..GBL ....E6C7     NSTRT....GBL ....E6C7
NINTRPRT.GBL ....E6CD     NLEDS....GBL ....E6D4     NOUP.....GBL ....E6DE
NPGCORR..GBL ....E782     NONOUP...GBL ....E7A7     NZMAX....GBL ....E7BC
NMAXUP...GBL ....E842     NZERCUM..GBL ....E857     NCUMUP...GBL ....E8DD
NLEQUP...GBL ....E8E9     NOVLERR.. 14 ....E903     NCALERR.. 14 ....E90E
NBATTLO.. 14 ....E919     NERRDET.. 14 ....E919     NERDISP.. 14 ....E935
NDBLANK.. 14 ....E947     NLEDZER.. 14 ....E955     NUPDATE.. 14 ....E969
NMI......GBL ....E96D     NOCHNGE..GBL ....E9D9     NOLOAD...GBL ....E9E9
NDATOVF..GBL ....EA08     NGCOMP...GBL ....EA12     NRUNING..GBL ....EA41
NRUNCLR..GBL ....EAE3     NXTROT1..GBL ....EB3F     NTHREEB..GBL ....EB67
NXTROT2..GBL ....EB6F     NTOGL....GBL ....EBF4     NDTAOVF..GBL ....EC3F
NFULL....GBL ....EC63     NRAMOVF..GBL ....EC6D     NSTORE...GBL ....ECFA
NFIDDLE..GBL ....ED1C     NOTESC...GBL ....ED5E     NCTRLS...GBL ....ED6C
NCTRLQ...GBL ....ED7A     NXTDIG1..GBL ....EDC2     NO32CR1..GBL ....EDEE
NXTDIG2..GBL ....EDFB     NO32CR2..GBL ....EE27     NO32CR3..GBL ....EE41
NPGJMP...GBL ....EE57     NOPAGE...GBL ....EE61     NOENDP1..GBL ....EE70
NOENDP2..GBL ....EE86     NOENDP3..GBL ....EE92     NOTNUM...GBL ....EE9E
NOTPR....GBL ....EEF3     NOTID....GBL ....EF27     NOTID1...GBL ....EF2D
NOTIT....GBL ....EF5B     NOTLG....GBL ....EF6D     NOPEND...GBL ....EFDC
NOBANK...GBL ....EFF0     NOPGE....GBL ....EFFC     NOT6.....GBL ....F020
NOT16....GBL ....F036     NOTHDR1..GBL ....F03E     NOFLIP...GBL ....F062
NXTHDR...GBL ....F083     NXTHDR1..GBL ....F09F     NXTLIN...GBL ....F0BB
```

```
NXTBYT...GBL ....F0BE      NOTASC1..GBL ....F0DC      NOTASC2..GBL ....F0F8
NOTHEX...100 ....FAE2      OCR1.....GBL .......B      OCR2.....GBL ......19
OFFSET4..GBL ......B0      OFFSET3..GBL ......B1      OFFSET2..GBL ......B2
OFFSET1..GBL ......B3      ONESEC...GBL ......24      OLDCAL...GBL ....E0B7
OTHRPG...GBL ....E40B      OCI......GBL ....E983      ONLY1....GBL ....EB96
OTEMP....100 ....F8EC      PORT2DDR.GBL .......1      PORT2....GBL .......3
PORT5....GBL ......15      PORT6DDR.GBL ......16      PORT6....GBL ......17
P2SAVE...GBL ......7F      PENDFLG..GBL ......B7      P2BACK...GBL ......D9
PARITY...GBL .......1      PAUSE....GBL ......84      PGCORR...GBL ....E76D
PAGEUP...GBL ....E791      PHASE2...GBL ....E998      PGDONE...GBL ....EFFF
PC.......100 .....106      PROMPT...100 ....FA7E      PROMPT1..100 ....FA88
PR0......100 ....FAC7      PR1......100 ....FAF9      RAMPORT5.GBL ......14
RMCR.....GBL ......10      RDR......GBL ......12      RAMPNTR..GBL ......60
RAMPNTB..GBL ......62      RAMPSTR..GBL ......63      RAMPBSTR.GBL ......65
RUNBIN...GBL ......66      RAMFULL..GBL ......73      RXBUF....GBL ......80
RXPTR....GBL ......A9      RAMFLAG..GBL ......AE      ROTCNT...GBL ......BF
RUNBCD...GBL ......C8      RAMSTRT..GBL .....140      RAMEND...GBL ....E000
RAMENDB..GBL .......1      RESETCUM.GBL ......41      RELMAX...GBL ......81
RES......GBL ....E000      RAMOK....GBL ....E00E      RAMCLR...GBL ....E0C9
ROW3OK...GBL ....E1E7      RUNKEYS..GBL ....E3B1      RUNTST...GBL ....EA33
RUNNING..GBL ....EACE      RUNCONV..GBL ....EBA1      RCONVEND.GBL ....EBE8
RAMDUMP..GBL ....F0B0      ROTOFF...GBL ....F6ED      RXWAIT1..100 ....F900
RSTRING..100 ....F9F2      REGDISP..100 ....FA24      REPREG...100 ....FB3D
SCRATCH..GBL ......AF      STAKPTR..GBL ......DE      SCALOF...GBL ......B1
SHORTLEQ.GBL ......22      START....GBL ....E1AF      SETP2....GBL ....E575
SELF1....GBL ....E97B      SELF2....GBL ....E97D      SMDATA1..GBL ....EAF4
SMCUM....GBL ....EB13      SMDATA2..GBL ....EBB2      SMRUN....GBL ....EBD1
STORE....GBL ....EBFC      SIO......GBL ....ED22      STACK....100 .....110
SSTRING..100 ....F91C      SWI......GBL ....FB5E      SPACE1...100 ....FBA0
SPACE3...100 ....FBA5      SPACE2...100 ....FBA8      TCSR1....GBL .......8
TCSR2....GBL .......F      T2CNT....GBL ......1D      TCONR....GBL ......1C
TCSR3....GBL ......1B      TRCSR1...GBL ......11      TDR......GBL ......13
TRCSR2...GBL ......1E      TLOOPCNT.GBL ......40      TFLAG....GBL ......46
TOTALCNT.GBL ......69      TXPTR....GBL ......A0      TXEND....GBL ......A2
TXFLAG...GBL ......A4      TXHFLG...GBL ......A5      TXBYTE...GBL ......AB
TXBANK...GBL ......AC      TXENDPG..GBL ......AD      TXPPEND..GBL ......B8
TXPBPEND.GBL ......BA      TXEPEND..GBL ......BB      TXEBPEND.GBL ......BD
TOGLCNT..GBL ......C6      TENSEC...GBL ......44      TRAP.....GBL ....E000
TRYREAD..GBL ....E1DF      TSTOFF...GBL ....E2D8      TOGL1....GBL ....E417
TOI......GBL ....E985      TDEL1....GBL ....E9D4      TSTAUTO..GBL ....EA1C
TENSCMP..GBL ....EC11      TCOMPDN..GBL ....EC18      TRWAIT...GBL ....EFAE
TESTPG...GBL ....F06B      TEST.....GBL ....F0B9      TXWT1....GBL ....F0C0
TXWT2....GBL ....F0E0      TXWT3....GBL ....F0FD      TXWT4....GBL ....F114
TXWT5....GBL ....F124      TXWT6....GBL ....F13B      TEMPW....100 .....10E
TXWAIT1..100 ....F8EE      TXWAIT2..100 ....F8F6      WELCOME..GBL ....F738
XREG.....100 .....104      XTEMP....100 .....10C      ZERMAX...GBL ....E7B8
ZERCUM...GBL ....E853
```

Labels used: 481

```
MODULE LIST

  1 A.LABELS
  2 R.RESET
  3 A.TEST
  4 A.MONITOR
  5 A.INTVECT
00000001                     LIST      ON
               ;LIST  ON ENABLES LISTING AND MAY BE USED BEFORE ONE MOD
               ULE TO PRINT THAT ONE ONLY. USE LIST    OFF TO DISABLE A
               FTER THE MODULE(S) TO BE LISTED.

               ;MODULE   ON SENDS ANY PRINT OUTPUT TO PRINTER INSTEAD O
               F THE SCREEN

00000000                     HEADER    "CRL 2.36 SHO
00000000                               RT Leq DATA A
00000000                               QUISITION UNI
00000000                               T, 6303Y PROC
00000000                               ESSOR"
00000000                     SYMTAB    OFF          symbol table enabled

00000000       EPROM         =         0

00000000                     IF        EPROM=1
                             OBSEND    1,0,0,"2360BJ send object code to disc
                                       "
                             OBFORM    1
               no load or exec address specified
               ;        OBSEND   6,2764,128,0,0
               ;        OBSEND   4,7
00000000                     ELSE

00000006                     OBSEND    6,2764,128,0,
00000006                               0
00000001                     OBFORM    1            straight binary (1,0,0,"
00000001                                            2360BJ")

00000000                     ENDIF

               ;FOR EPROM, STORE OBJECT CODE ON DISK  USING OBSEND 1,0,
               0,"2360BJ"/OBFORM 2   THEN WHEN THE EPROMER SOFTWARE PRO
               MPTS FOR FILENAME, GIVE "2360BJ".        FOR PORTAL U
               SE OBSEND   6,2764,128,0,0   AND OBSEND    1.

               *******************************

0000E000                     ORG       $E000        origin for program code
00000001                     LIST      ON

0000E000                     R.RESET                reset/restart module
```

```
                    R.RESET    MODULE
                    ;module to detect warm/cold start
                    ;and temporarily to set ports
                    IRQ2
                    IRQ1
                    ICI
                    OCI
                    TOI
                    CMI
                    NMI
                    SIO
                    RES
                    TRAP
0000E000 71E014               AIM      %11100000,RAM
0000E003                               PORT5
0000E003 724014               OIM      %01000000,RAM
0000E006                               PORT5
0000E006 8E00FF               LDS      #$00FF        set stack pointer
0000E009 CE0040               LDX      #$40
0000E00C 4F                   CLRA
0000E00D A700      RAMCLR     STAA     0,X
0000E00F 08                   INX
0000E010 8C0100               CPX      #$100
0000E013 26F8                 BNE      RAMCLR
0000E015 86A8                 LDAA     #%10101000    set dec pt and SIO rec'v
0000E017                                             e line
0000E017 9703                 STAA     PORT2
0000E019 86FF                 LDAA     #%11111111    set port 2 for output
0000E01B 9701                 STAA     PORT2DDR
0000E01D 8600                 LDAA     #%00000000
0000E01F 9717                 STAA     PORT6
0000E021 860F                 LDAA     #%00001111    set port 6 for input/out
0000E023                                             put
0000E023 9716                 STAA     PORT6DDR
0000E025 8602                 LDAA     #$2           set timer 2 baud rate
0000E027 971C                 STAA     TCONR         9600
0000E029                      IF       HD6303Y=1
0000E029 8624                 LDAA     #%00100100
0000E02B 9710                 STAA     RMCR
0000E02D 861A                 LDAA     #%00011010
0000E02F 9711                 STAA     TRCSR1
0000E031 8601                 LDAA     #%00000001
0000E033 971E                 STAA     TRCSR2
0000E035                      ELSE
                              LDAA     #%01110100
                              STAA     RMCR
                              LDAA     #%00011010
                              STAA     TRCSR1
0000E035                      ENDIF
0000E035 8610                 LDAA     #%00010000
0000E037 971B                 STAA     TCSR3
0000E039 0E                   CLI

0000E03A CE0140               LDX      #RAMSTRT
0000E03D FF0100               STX      DMPSTRT

0000E040 71FC03               AIM      %11111100,POR
0000E043                               T2
0000E043 FE0100    NEXT       LDX      DMPSTRT
```

```
0000E046 86FF     TSLP1    LDAA   #%11111111
0000E048 A700              STAA   0,X
0000E04A A100              CMPA   0,X
0000E04C 264B              BNE    WRNGRAM
0000E04E 08                INX
0000E04F 8CE000            CPX    #RAMEND
0000E052 26F2              BNE    TSLP1
0000E054 7C0003            INC    PORT2

0000E057 CE0140            LDX    #RAMSTRT
0000E05A 86FF     TSLP2    LDAA   #%11111111
0000E05C A700              STAA   0,X
0000E05E A100              CMPA   0,X
0000E060 2637              BNE    WRNGRAM
0000E062 08                INX
0000E063 8CE000            CPX    #RAMEND
0000E066 26F2              BNE    TSLP2
0000E068 7C0003            INC    PORT2

0000E06B CE0140            LDX    #RAMSTRT
0000E06E 86FF     TSLP3    LDAA   #%11111111
0000E070 A700              STAA   0,X
0000E072 A100              CMPA   0,X
0000E074 2623              BNE    WRNGRAM
0000E076 08                INX
0000E077 8CE000            CPX    #RAMEND
0000E07A 26F2              BNE    TSLP3
0000E07C 7C0003            INC    PORT2

0000E07F CE0140            LDX    #RAMSTRT
0000E082 86FF     TSLP4    LDAA   #%11111111
0000E084 A700              STAA   0,X
0000E086 A100              CMPA   0,X
0000E088 260F              BNE    WRNGRAM
0000E08A 08                INX
0000E08B 8CE000            CPX    #RAMEND
0000E08E 26F2              BNE    TSLP4
0000E090 7C0003            INC    PORT2

0000E093 CE0000            LDX    #0000
0000E096 8600              LDAA   #0
0000E098 3F                SWI

0000E099 9603     WRNGRAM  LDAA   PORT2
0000E09B 8403              ANDA   #3
0000E09D 3F                SWI
0000E09E                   MEND
```

```
L.
  10 REM: SAVE"L.LOGGEN"
  20 X=OPENOUT("A.ADDLOG")
  30 PRINT"Difference in levels        Add                hi_byte   lo_byte"
  40 FOR A= 0 TO 5.11 STEP 0.01
  50      B=10^A :REM A=10LOG(B)  0=10LOG(1)
  60      C=B+1
  70      D=LOG(C)
  80      E=10*D :REM E=10LOG(1+B)
  90      F=10*A :REM F=10LOG(B) ie dB's
 100      G=E-F  :REM G=10LOG(1+B)/B
 110      H=G*2560 :REM H IS IN 0.00039dB MULTIPLES
 120      I=INT(H/256)
 125      J=INT((H-(I*256))+0.5)
 130      PRINTTAB(9); F;TAB(24);G,~I,~J
 140      BPUT# X,I
 145      BPUT# X,J
 150 NEXT A
 160 CLOSE# X
 170 END
>
```

BBC BASIC PROGRAM LOGGEN:GENERATES LOOK-UP TABLE FOR LOG ADDITION OF DOSE

>RUN

Difference in levels	Add	hi_byte	lo_byte
0	3.01029996	1E	1A
0.1	2.96058778	1D	9B
0.2	2.91145115	1D	1D
0.3	2.86288985	1C	A1
0.4	2.8149035	1C	26
0.5	2.76749157	1B	AD
0.6	2.72065336	1B	35
0.7	2.67438805	1A	BE
0.8	2.62869465	1A	49
0.9	2.58357203	19	D6
1	2.53901891	19	64
1.1	2.49503386	18	F3
1.2	2.45161531	18	84
1.3	2.40876154	18	16
1.4	2.36647071	17	AA
1.5	2.32474081	17	3F
1.6	2.28356971	16	D6
1.7	2.24295515	16	6E
1.8	2.20289472	16	7
1.9	2.1633859	15	A2
2	2.12442603	15	3F
2.1	2.08601232	14	DC
2.2	2.04814186	14	7B
2.3	2.01081164	14	1C
2.4	1.9740185	13	BD
2.5	1.9377592	13	61
2.6	1.90203037	13	5
2.7	1.86682852	12	AB
2.8	1.83215008	12	52
2.9	1.79799137	11	FB
3	1.76434862	11	A5
3.1	1.73121796	11	50
3.2	1.69859541	10	FC
3.3	1.66647692	10	AA
3.4	1.63485838	10	59
3.5	1.60373556	10	A
3.6	1.57310417	F	BB
3.7	1.54295985	F	6E
3.8	1.51329816	F	22
3.9	1.48411461	E	D7
4	1.45540463	E	8E
4.1	1.42716361	E	46
4.2	1.39938687	D	FE
4.3	1.37206968	D	B8
4.4	1.34520726	D	74
4.5	1.3187948	D	30
4.6	1.29282744	C	EE
4.7	1.26730028	C	AC
4.8	1.24220837	C	6C
4.9	1.21754677	C	2D
5	1.19331048	B	EF
5.1	1.16949448	B	B2
5.2	1.14609374	B	76
5.3	1.1231032	B	3B
5.4	1.10051779	B	1
5.5	1.07833242	A	C9
5.6	1.05654201	A	91
5.7	1.03514145	A	5A
5.8	1.01412566	A	24
5.9	0.993489517	9	EF
6	0.973227937	9	BB
6.1	0.95333582	9	89
6.2	0.933808079	9	57
6.3	0.914639637	9	25

6.4	0.895825423	8	F5
6.5	0.877360394	8	C6
6.6	0.859239517	8	98
6.7	0.841457769	8	6A
6.8	0.82401016	8	3D
6.9	0.806891721	8	12
7	0.790097499	7	E7
7.1	0.773622578	7	BC
7.2	0.757462062	7	93
7.3	0.741611101	7	6B
7.4	0.726064855	7	43
7.5	0.710818527	7	1C
7.6	0.69586736	6	F5
7.7	0.681206627	6	D0
7.8	0.666831642	6	AB
7.9	0.65273775	6	87
8	0.638920344	6	64
8.1	0.625374854	6	41
8.2	0.612096757	6	1F
8.3	0.599081568	5	FE
8.4	0.586324845	5	DD
8.5	0.573822197	5	BD
8.6	0.561569266	5	9E
8.7	0.549561758	5	7F
8.8	0.537795413	5	61
8.9	0.52626602	5	43
9.0	0.51496942	5	26
9.1	0.503901504	5	A
9.2	0.493058205	4	EE
9.3	0.482435506	4	D3
9.4	0.472029448	4	B8
9.5	0.461836115	4	9E
9.6	0.451851644	4	85
9.7	0.44207222	4	6C
9.8	0.432494074	4	53
9.9	0.423113514	4	3B
10	0.413926855	4	24
10.1	0.404930498	4	D
10.2	0.396120884	3	F6
10.3	0.387494501	3	E0
10.4	0.379047893	3	CA
10.5	0.370777652	3	B5
10.6	0.362680417	3	A0
10.7	0.354752887	3	8C
10.8	0.346991803	3	78
10.9	0.339393966	3	65
11	0.331956204	3	52
11.1	0.32467543	3	3F
11.2	0.317548562	3	2D
11.3	0.310572609	3	1B
11.4	0.30374461	3	A
11.5	0.297061644	2	F8
11.6	0.290520847	2	E8
11.7	0.284119412	2	D7
11.8	0.277854558	2	C7
11.9	0.271723568	2	B8
12	0.265723761	2	A8
12.1	0.259852514	2	99
12.2	0.254107226	2	8B
12.3	0.248485368	2	7C
12.4	0.24298444	2	6E
12.5	0.237601984	2	60
12.6	0.232335597	2	53
12.7	0.227182914	2	46
12.8	0.222141605	2	39
12.9	0.217209384	2	2C

13.0	0.212384026	2	20
13.1	0.207663316	2	14
13.2	0.203045104	2	8
13.3	0.198527258	1	FC
13.4	0.194107715	1	F1
13.5	0.189784419	1	E6
13.6	0.185555376	1	DB
13.7	0.181418601	1	D0
13.8	0.177372191	1	C6
13.9	0.173414242	1	BC
14.0	0.169542897	1	B2
14.1	0.165756341	1	A8
14.2	0.162052784	1	9F
14.3	0.158430476	1	96
14.4	0.154887699	1	8D
14.5	0.151422773	1	84
14.6	0.148034044	1	7B
14.7	0.144719895	1	72
14.8	0.141478747	1	6A
14.9	0.138309028	1	62
15.0	0.135209225	1	5A
15.1	0.132177848	1	52
15.2	0.12921343	1	4B
15.3	0.126314532	1	43
15.4	0.12347975	1	3C
15.5	0.120707702	1	35
15.6	0.117997043	1	2E
15.7	0.115346454	1	27
15.8	0.112754639	1	21
15.9	0.110220321	1	1A
16.0	0.107742269	1	14
16.1	0.105319247	1	E
16.2	0.102950074	1	8
16.3	0.100633584	1	2
16.4	9.83686224E-2	0	FC
16.5	9.61540937E-2	0	F6
16.6	9.39888731E-2	0	F1
16.7	9.18718874E-2	0	EB
16.8	8.98021013E-2	0	E6
16.9	8.77784789E-2	0	E1
17.0	8.57999995E-2	0	DC
17.1	8.38656947E-2	0	D7
17.2	8.1974566E-2	0	D2
17.3	8.01257119E-2	0	CD
17.4	7.83181712E-2	0	C8
17.5	7.65510499E-2	0	C4
17.6	7.48234615E-2	0	C0
17.7	7.31345341E-2	0	BB
17.8	7.14834109E-2	0	B7
17.9	6.98692724E-2	0	B3
18.0	6.82912841E-2	0	AF
18.1	6.67486787E-2	0	AB
18.2	6.52406439E-2	0	A7
18.3	6.37664348E-2	0	A3
18.4	6.23252988E-2	0	A0
18.5	6.09165058E-2	0	9C
18.6	5.95393404E-2	0	98
18.7	5.8193095E-2	0	95
18.8	5.68770841E-2	0	92
18.9	5.55906668E-2	0	8E
19.0	5.43331429E-2	0	8B
19.1	5.31039089E-2	0	88
19.2	5.19023091E-2	0	85
19.3	5.07277399E-2	0	82
19.4	4.9579598E-2	0	7F
19.5	4.84573022E-2	0	7C

19.6	4.73602712E-2	0	79
19.7	4.62879539E-2	0	76
19.8	4.52397689E-2	0	74
19.9	4.42152172E-2	0	71
20.0	4.321374E-2	0	6F
20.1	4.22348529E-2	0	6C
20.2	4.1278027E-2	0	6A
20.3	4.03427705E-2	0	67
20.4	3.94286141E-2	0	65
20.5	3.85350734E-2	0	63
20.6	3.76617014E-2	0	60
20.7	3.68080437E-2	0	5E
20.8	3.59736532E-2	0	5C
20.9	3.51580903E-2	0	5A
21.0	3.43609527E-2	0	58
21.1	3.35818157E-2	0	56
21.2	3.28202918E-2	0	54
21.3	3.20759565E-2	0	52
21.4	3.1348452E-2	0	50
21.5	3.06373835E-2	0	4E
21.6	2.99423933E-2	0	4D
21.7	2.92631015E-2	0	4B
21.8	2.85991877E-2	0	49
21.9	2.79502869E-2	0	48
22.0	2.73160487E-2	0	46
22.1	2.66961679E-2	0	44
22.2	2.60903165E-2	0	43
22.3	2.54981667E-2	0	41
22.4	2.49194205E-2	0	40
22.5	2.4353765E-2	0	3E
22.6	2.38009319E-2	0	3D
22.7	2.32606009E-2	0	3C
22.8	2.27325037E-2	0	3A
22.9	2.22163722E-2	0	39
23.0	2.17119381E-2	0	38
23.1	2.12189108E-2	0	36
23.2	2.07370669E-2	0	35
23.3	2.02661231E-2	0	34
23.4	1.98058635E-2	0	33
23.5	1.93560272E-2	0	32
23.6	1.89163908E-2	0	30
23.7	1.84867233E-2	0	2F
23.8	1.80667862E-2	0	2E
23.9	1.76563635E-2	0	2D
24.0	1.72552615E-2	0	2C
24.1	1.68632418E-2	0	2B
24.2	1.6480118E-2	0	2A
24.3	1.61056742E-2	0	29
24.4	1.57397389E-2	0	28
24.5	1.53820887E-2	0	27
24.6	1.50325522E-2	0	26
24.7	1.46909505E-2	0	26
24.8	1.435709E-2	0	25
24.9	1.40308067E-2	0	24
25.0	1.37119368E-2	0	23
25.1	1.34002939E-2	0	22
25.2	1.30957291E-2	0	22
25.3	1.27980635E-2	0	21
25.4	1.25071779E-2	0	20
25.5	1.22228712E-2	0	1F
25.6	1.19450316E-2	0	1F
25.7	1.16734952E-2	0	1E
25.8	1.14081129E-2	0	1D
25.9	1.11487657E-2	0	1D
26.0	1.08953118E-2	0	1C
26.1	1.06476173E-2	0	1B

26.2	1.0405533E-2	0	1B
26.3	1.01689398E-2	0	1A
26.4	9.93774831E-3	0	19
26.5	9.71177965E-3	0	19
26.6	9.49095935E-3	0	18
26.7	9.27515328E-3	0	18
26.8	9.06424224E-3	0	17
26.9	8.85812193E-3	0	17
27.0	8.65668803E-3	0	16
27.1	8.45982134E-3	0	16
27.2	8.26744735E-3	0	15
27.3	8.0794245E-3	0	15
27.4	7.89568573E-3	0	14
27.5	7.71610439E-3	0	14
27.6	7.54062831E-3	0	13
27.7	7.3691383E-3	0	13
27.8	7.20153004E-3	0	12
27.9	7.03772902E-3	0	12
28.0	6.87766075E-3	0	12
28.1	6.72122091E-3	0	11
28.2	6.56835735E-3	0	11
28.3	6.41894341E-3	0	10
28.4	6.27294183E-3	0	10
28.5	6.13025576E-3	0	10
28.6	5.99081069E-3	0	F
28.7	5.85453212E-3	0	F
28.8	5.72134554E-3	0	F
28.9	5.59120625E-3	0	E
29.0	5.46401739E-3	0	E
29.1	5.3397119E-3	0	E
29.2	5.21823764E-3	0	D
29.3	5.09952754E-3	0	D
29.4	4.9835071E-3	0	D
29.5	4.87014651E-3	0	C
29.6	4.75934148E-3	0	C
29.7	4.65106219E-3	0	C
29.8	4.5452565E-3	0	C
29.9	4.44184244E-3	0	B
30.0	4.34078276E-3	0	B
30.1	4.24202532E-3	0	B
30.2	4.14550304E-3	0	B
30.3	4.05118614E-3	0	A
30.4	3.95901501E-3	0	A
30.5	3.86893749E-3	0	A
30.6	3.78090888E-3	0	A
30.7	3.69487703E-3	0	9
30.8	3.61081213E-3	0	9
30.9	3.52864712E-3	0	9
31.0	3.44835967E-3	0	9
31.1	3.3698976E-3	0	9
31.2	3.29322368E-3	0	8
31.3	3.21828574E-3	0	8
31.4	3.14506143E-3	0	8
31.5	3.07348371E-3	0	8
31.6	3.00355256E-3	0	8
31.7	2.93520093E-3	0	8
31.8	2.86842138E-3	0	7
31.9	2.80314684E-3	0	7
32.0	2.73936242E-3	0	7
32.1	2.67702341E-3	0	7
32.2	2.61610746E-3	0	7
32.3	2.55657732E-3	0	7
32.4	2.49838829E-3	0	6
32.5	2.44154036E-3	0	6
32.6	2.38597393E-3	0	6
32.7	2.331689E-3	0	6

32.8	2.27861106E-3	0	6
32.9	2.22675502E-3	0	6
33.0	2.17609107E-3	0	6
33.1	2.12657452E-3	0	5
33.2	2.07817554E-3	0	5
33.3	2.03087926E-3	0	5
33.4	1.98467076E-3	0	5
33.5	1.93950534E-3	0	5
33.6	1.8953532E-3	0	5
33.7	1.85222924E-3	0	5
33.8	1.81007385E-3	0	5
33.9	1.76888704E-3	0	5
34.0	1.72862411E-3	0	4
34.1	1.68928504E-3	0	4
34.2	1.65084004E-3	0	4
34.3	1.61327422E-3	0	4
34.4	1.57654285E-3	0	4
34.5	1.54066086E-3	0	4
34.6	1.50561333E-3	0	4
34.7	1.47134066E-3	0	4
34.8	1.43784285E-3	0	4
34.9	1.4051199E-3	0	4
35.0	1.373142E-3	0	4
35.1	1.34190917E-3	0	3
35.2	1.31134689E-3	0	3
35.3	1.28151476E-3	0	3
35.4	1.25233829E-3	0	3
35.5	1.22384727E-3	0	3
35.6	1.1959821E-3	0	3
35.7	1.16875768E-3	0	3
35.8	1.14217401E-3	0	3
35.9	1.11618638E-3	0	3
36.0	1.090765E-3	0	3
36.1	1.06593966E-3	0	3
36.2	1.04169548E-3	0	3
36.3	1.01798773E-3	0	3
36.4	9.94801521E-4	0	3
36.5	9.72151756E-4	0	2
36.6	9.50038433E-4	0	2
36.7	9.28416848E-4	0	2
36.8	9.07287002E-4	0	2
36.9	8.86633992E-4	0	2
37.0	8.6645782E-4	0	2
37.1	8.46728683E-4	0	2
37.2	8.27461481E-4	0	2
37.3	8.08641315E-4	0	2
37.4	7.90223479E-4	0	2
37.5	7.72252679E-4	0	2
37.6	7.54654408E-4	0	2
37.7	7.37473369E-4	0	2
37.8	7.20694661E-4	0	2
37.9	7.04288483E-4	0	2
38.0	6.88254833E-4	0	2
38.1	6.72593713E-4	0	2
38.2	6.5729022E-4	0	2
38.3	6.42329454E-4	0	2
38.4	6.27696514E-4	0	2
38.5	6.13406301E-4	0	2
38.6	5.99458814E-4	0	2
38.7	5.8580935E-4	0	1
38.8	5.72472811E-4	0	1
38.9	5.59449196E-4	0	1
39.0	5.46723604E-4	0	1
39.1	5.34266233E-4	0	1
39.2	5.22091985E-4	0	1
39.3	5.10215759E-4	0	1

39.4	4.98607755E-4	0	1
39.5	4.87267971E-4	0	1
39.6	4.76151705E-4	0	1
39.7	4.65318561E-4	0	1
39.8	4.54738736E-4	0	1
39.9	4.4439733E-4	0	1
40.0	4.34279442E-4	0	1
40.1	4.24385071E-4	0	1
40.2	4.14714217E-4	0	1
40.3	4.05296683E-4	0	1
40.4	3.96057963E-4	0	1
40.5	3.87042761E-4	0	1
40.6	3.78236175E-4	0	1
40.7	3.69638205E-4	0	1
40.8	3.61219048E-4	0	1
40.9	3.53008509E-4	0	1
41.0	3.44976783E-4	0	1
41.1	3.37123871E-4	0	1
41.2	3.29434872E-4	0	1
41.3	3.2196939E-4	0	1
41.4	3.14608216E-4	0	1
41.5	3.0747056E-4	0	1
41.6	3.00467014E-4	0	1
41.7	2.9361248E-4	0	1
41.8	2.8693676E-4	0	1
41.9	2.80410051E-4	0	1
42.0	2.74017453E-4	0	1
42.1	2.67773867E-4	0	1
42.2	2.61679292E-4	0	1
42.3	2.5574863E-4	0	1
42.4	2.49907374E-4	0	1
42.5	2.44230032E-4	0	1
42.6	2.38671899E-4	0	1
42.7	2.33232975E-4	0	1
42.8	2.2791326E-4	0	1
42.9	2.22742558E-4	0	1
43.0	2.17661262E-4	0	1
43.1	2.12714076E-4	0	1
43.2	2.07871199E-4	0	1
43.3	2.03132629E-4	0	1
43.4	1.98498368E-4	0	1
43.5	1.93998218E-4	0	0
43.6	1.89587474E-4	0	0
43.7	1.85281038E-4	0	0
43.8	1.8106401E-4	0	0
43.9	1.76936388E-4	0	0
44.0	1.72913074E-4	0	0
44.1	1.68979168E-4	0	0
44.2	1.65119767E-4	0	0
44.3	1.61364675E-4	0	0
44.4	1.57698989E-4	0	0
44.5	1.5412271E-4	0	0
44.6	1.50606036E-4	0	0
44.7	1.47163868E-4	0	0
44.8	1.43811107E-4	0	0
44.9	1.40532851E-4	0	0
45.0	1.37344003E-4	0	0
45.1	1.3422966E-4	0	0
45.2	1.31189823E-4	0	0
45.3	1.2819469E-4	0	0
45.4	1.25259161E-4	0	0
45.5	1.2242794E-4	0	0
45.6	1.19641423E-4	0	0
45.7	1.16884708E-4	0	0
45.8	1.14247203E-4	0	0
45.9	1.11669302E-4	0	0

46.0	1.09121203E-4	0	0
46.1	1.0663271E-4	0	0
46.2	1.04188919E-4	0	0
46.3	1.01834536E-4	0	0
46.4	9.95099545E-5	0	0
46.5	9.7244978E-5	0	0
46.6	9.50247049E-5	0	0
46.7	9.28491354E-5	0	0
46.8	9.07480717E-5	0	0
46.9	8.87066126E-5	0	0
47.0	8.66502523E-5	0	0
47.1	8.46982002E-5	0	0
47.2	8.27759504E-5	0	0
47.3	8.08686018E-5	0	0
47.4	7.90506601E-5	0	0
47.5	7.72476196E-5	0	0
47.6	7.54743814E-5	0	0
47.7	7.37905502E-5	0	0
47.8	7.20769167E-5	0	0
47.9	7.0437789E-5	0	0
48.0	6.88433647E-5	0	0
48.1	6.72638416E-5	0	0
48.2	6.5729022E-5	0	0
48.3	6.42389059E-5	0	0
48.4	6.27934933E-5	0	0
48.5	6.13629818E-5	0	0
48.6	5.99473715E-5	0	0
48.7	5.8606267E-5	0	0
48.8	5.72651625E-5	0	0
48.9	5.59389591E-5	0	0
49.0	5.46872616E-5	0	0
49.1	5.3435564E-5	0	0
49.2	5.222857E-5	0	0
49.3	5.10513783E-5	0	0
49.4	4.98592854E-5	0	0
49.5	4.87416983E-5	0	0
49.6	4.76390123E-5	0	0
49.7	4.65363264E-5	0	0
49.8	4.5478344E-5	0	0
49.9	4.44352627E-5	0	0
50.0	4.34368849E-5	0	0
50.1	4.24534082E-5	0	0
50.2	4.14699316E-5	0	0
50.3	4.05311584E-5	0	0
50.4	3.96072865E-5	0	0
50.5	3.86983156E-5	0	0
50.6	3.78191471E-5	0	0
50.7	3.69697809E-5	0	0
50.8	3.61353159E-5	0	0
50.9	3.53008509E-5	0	0
51.0	3.45110893E-5	0	0
51.1	3.37362289E-5	0	0

>

BBC BASIC PROGRAM TIMLGEN:GENERATES LOOK-UP TABLE TO CALCULATE LOG OF TIME

```
L.
   10 CLOSE#0
   20 REM SAVE"L.TIMLGEN"
   30 X=OPENOUT("A.TIMLOG")
   40 Y=1.0232929922:REM 10**(0.01)
   50 Z=LOG(Y)
   60 PRINT"   Difference  hi_byte   lo_byte"
   70 PRINT"    in levels"
   80 FOR A= 128 TO 255 STEP 1
   90     B=256*LOG(A)/Z
  100     I=INT(B/256)
  110     J=INT((B-(I*256))+0.5)
  120     BPUT# X,I
  130     BPUT# X,J
  140     PRINT A,~I,~J
  150 NEXT A
  160 CLOSE# X
  170 END
>
```

>RUN

Difference in levels	hi_byte	lo_byte
128	D2	B9
129	D3	F
130	D3	65
131	D3	BA
132	D4	F
133	D4	63
134	D4	B6
135	D5	9
136	D5	5B
137	D5	AC
138	D5	FD
139	D6	4D
140	D6	9D
141	D6	EC
142	D7	3B
143	D7	89
144	D7	D6
145	D8	23
146	D8	6F
147	D8	BB
148	D9	7
149	D9	52
150	D9	9C
151	D9	E6
152	DA	2F
153	DA	78
154	DA	C1
155	DB	8
156	DB	50
157	DB	97
158	DB	DE
159	DC	24
160	DC	69
161	DC	AF
162	DC	F4
163	DD	38
164	DD	7C
165	DD	C0
166	DE	3
167	DE	46
168	DE	88
169	DE	CA
170	DF	B
171	DF	4D
172	DF	8E
173	DF	CE
174	E0	E
175	E0	4E
176	E0	8D
177	E0	CC
178	E1	B
179	E1	49
180	E1	87
181	E1	C5
182	E2	2
183	E2	3F
184	E2	7B
185	E2	B8
186	E2	F4
187	E3	2F
188	E3	6A
189	E3	A5
190	E3	E0

191	E4	1A
192	E4	55
193	E4	8E
194	E4	C8
195	E5	1
196	E5	3A
197	E5	72
198	E5	AB
199	E5	E3
200	E6	1A
201	E6	52
202	E6	89
203	E6	C0
204	E6	F7
205	E7	2D
206	E7	63
207	E7	99
208	E7	CE
209	E8	4
210	E8	39
211	E8	6E
212	E8	A2
213	E8	D7
214	E9	B
215	E9	3E
216	E9	72
217	E9	A5
218	E9	D8
219	EA	B
220	EA	3E
221	EA	70
222	EA	A3
223	EA	D5
224	EB	6
225	EB	38
226	EB	69
227	EB	9A
228	EB	CB
229	EB	FC
230	EC	2C
231	EC	5C
232	EC	8C
233	EC	BC
234	EC	EC
235	ED	1B
236	ED	4B
237	ED	7A
238	ED	A8
239	ED	D7
240	EE	5
241	EE	34
242	EE	62
243	EE	90
244	EE	BD
245	EE	EB
246	EF	18
247	EF	45
248	EF	72
249	EF	9F
250	EF	CB
251	EF	F8
252	F0	24
253	F0	50
254	F0	7C
255	F0	A7

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Proceedings of The Institute of Acoustics

EVALUATION OF LOUDNESS EQUIVALENT METERS

G J McNULTY, J HOLDING, B PLUMB, D WALLIS

SHEFFIELD CITY POLYTECHNIC

Evaluation of L_{eq} Meters

Introduction

L_{eq} meters are almost exclusively calibrated using a continuous input signal. This calibration only confirms that the L_{eq} meter can measure sound pressure level, but tells nothing about the L_{eq} meters ability to measure impulsive signals. The Health & Safety Executive have produced a much needed draft standard for L_{eq} meters which, it is expected, will form the basis of an international standard. The work presented here describes the use of a tone-burst generator which has been developed in order to investigate certain aspects of the draft standard, with reference to specific L_{eq} measuring systems.

Tests

The type of input signal which most readily distinguishes between sound level meters and the different grades of L_{eq} meters proposed in the draft standard is that which consists of high amplitude impulses; the maximum amplitude and mark:space ratio of these impulses being different for each grade of instrument. The output of the tone-burst generator, which has been developed in order to produce such impulses, consists of integral cycles of 6KHz sinusoid with a variable, but pre-determined, mark:space ratio; each cycle starting and ending at a zero-crossing. The tone-burst generator also produces these impulses in the presence of a completely variable level of background signal of identical frequency which is phase-locked to the pulses.

A continuous sinusoidal signal at 6KHz is applied to the L_{eq} meter to be tested, and the level of the input is adjusted to give a reading of approximately 10 dB above the bottom of the indicator range. A series of tone-bursts is then substituted for the continuous signal and the level of the input is increased to give an identical L_{eq}, ie if the number of pulses in a given period is reduced by a factor of 10, the level of the pulses must be increased by 10dB to maintain the same L_{eq}. The permissible error for different combinations of mark:space ratio and signal amplitude is specified in the draft standard as the Exchange Rate Tolerance. Although such a test does measure the exchange rate, it is also a measure of the instruments ability to handle impulsive signals, however, this is of no serious consequence since the main reason for using an L_{eq} meter in place of a sound level meter is to accurately integrate high level transients.

A further test is specified in the draft standard which measures the maximum impulse which the L_{eq} meter can measure, to within a certain tolerance of the error allowed by linearity tests performed using a continuous signal. This impulse is presented to the meter in the presence of a continuous background signal which is set at a level corresponding the bottom end of the dynamic span. The result of this test is called the Peak Factor capability and is expressed as the ratio of the peak value of the impulse to the rms level of continuous background signal.

To have any confidence in the results in any of the above tests, there must be complete confidence in all of the testing equipment. An important part of this work was to conduct a thorough examination of the signal sources used and to consider any possible irregularities in measurements due to properties of the signal, or of the measuring equipment. A transient recorder was used to check that the tone-bursts started and stopped at zero and several spectrum analyzers were used to check the frequency content of the signal source.

Results

Instrument	Input Signal Mark:Space Ratio/Level			
	1:9/+10dB	1:99/+20dB	1:999/+30dB	1:9999/+40dB
1	0.4, 0.2	7.5, 5.8	∞, 9.8	∞, ∞
2	0.2, 0.3	0.9, 1.1	5.5, 3.5	∞, 3.8
3	0.0, 0.0	0.3, 0.3	3.4, 1.9	∞, 2.7
Reference Standard	0.2 (0.5)	0.4 (0.5)	0.6 (1.0)	1.0 (1.0)
4	0.0	0.0	0.0	0.3
5	0.0	0.0	0.0	<0.1

Fig.1 Exchange Rate Error for some of the meters which were tested.

The results of the exchange rate test are shown in Fig.1. The input signal levels shown are relative to the continuous signal which is applied to the meter as the reference level. The errors shown in the table are the difference between the reading with the reference level applied and the reading with the specified mark:space ratio and level, expressed in decibels.

Initially the test was carried out using only a single cycle in the tone-burst. Where an instrument failed to meet a certain standard, which is shown as in the table, the test was repeated using a series of ten cycles in each tone-burst and a correspondingly larger gap between bursts. This accounts for the readings where two errors are given for each input signal mark:space ratio and level; the first reading corresponding to the single cycle test, and the second, to the ten cycle test.

Discussion

The five instruments whose exchange rate errors appear in Fig.1 are all instruments which are described by their manufacturers as precision grade. Therefore, the reference standard included in the table corresponds to a Type 1 peak instrument as specified by the Health & Safety Executive in their draft standard which was supplied to instrument manufacturers for a competitive tender. Since that time the exchange rate tolerance has been increased, and the current proposed tolerances are shown in brackets for comparison. It can be seen, however, that this does not affect the ranking.

The draft standard allows for instruments with a reduced peak factor capability. This restricts the range of mark:space ratios over which the instrument must measure and also increases the permissible error. On the basis of the above results, instrument no.3 may be considered as a type 1 non-peak instrument under both the original and the relaxed specifications, and instrument no.2 may be considered as marginal for type 1 non-peak under the relaxed specification only.

It is interesting to note that instruments 1-3 calculate L_{eq} from a rectified signal, ie from sound pressure level, whereas instruments 4 and 5 calculate L_{eq} directly, ie from sound pressure. Instruments 1-4 have a digital display and presumably digital processing, whereas instrument 5 has an analogue display and analogue processing. This information suggests that optimum accuracy cannot be achieved by calculating L_{eq} from sound pressure level and contradicts a popularly held view that digital instruments are inherently more accurate.

Conclusion

The results of this work emphasize the great disparity between instruments which nominally measure the same parameter. The proposed standard is obviously much needed in order to help both the prospective customer and the instrument manufacturer.

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A METHOD OF GENERATING "SHORT LEQ"

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The concept of short Leq was originally developed by the LNE in France as a method of time compressing data without losing any of the basic energy information. In essence the object is to take a series of elemental Leqs one after the other with no break. The time of each elemental Leq can vary between 125mS which equates to the Fast time constant, up to an acquisition period of several minutes. In practical systems, where the number of elemental Leq are limited by storage space, the fastest acquisition rate is used consistent with the total measurement time. Table 1 shows the total measurement times for a 64K store (65536 words).

Table 1.

Acquisition time	64K storage time
125mS	2hr 16min
1sec	18.2hr
1min	45 days
10min	1yr 3mths

In any system of short Leq there are certain essential specification points to permit the system to operate to agreed international specifications such as IEC 651 and the proposed IEC Integrating Sound Level Meter standard. As, however the current proposals do not include short Leq, there are many points which need specially defining.

The first and most vital part of the specification is that each elemental Leq shall individually meet at least the full specification of normal Leq. The only exception to this would be that the normal 10sec or so to allow the reading to stabilise is too long and in the design specification we have required that at the end of the elemental Leq the reading shall be within 0,1dB of the nominal "final" reading over the prime range and 0,2dB over the whole dynamic span of the unit.

The second specification point is that the time between elemental Leq shall be small in relation to the Leq time. In the original concept 'lost' times of about half a millisecond were considered acceptable. However, in the current realisation lost time is down to about 20 microseconds, i.e. about 2 parts in 10^4 at the fastest acquisition rate. Thus the lost data is insignificant in any practical situation.

The third vital point concerns the total measuring range. If the unit is to be used over a 7 day period there are many situations where the instantaneous level will vary between the noise floor, which could be of the order of 20dBA, and levels in the low hundreds say 120dBA. A dynamic span of 100dB is to say the least difficult unless auto-ranging is employed. 100dB may not seem a vast range, but for a 50mV/Pa microphone it is a voltage range from 10 microvolts rms to 3V peak to peak. If auto-ranging is used there is the classic problem of how and when to switch ranges. Clearly, with a microcomputer unit the decision is eased, but the time over which range switching occurs must be of a similar order to the dead time. However, practical sound level meters in the recent past which incorporated auto-ranging have usually not been a success usually because of settling time or computation error. In the new concept of short Leq it has been pre-supposed that auto-ranging is not acceptable and thus the present realisation has no auto-ranging. Instead 3 manual ranges are fitted each of 100dB. While there must be many situations where this dynamic span is exceeded, there are fortunately many more where a 100dB span is adequate.

When the elemental Leq has been computed it is stored in a CMOS RAM. This is organised into 2 parts: the Leq itself and other data bits. The actual Leq which has a resolution of 0,1dB requires an 11 bit word to allow for longer dynamic spans than the current 100. Bits 12 through 16 gives a 5 bit code with 32 possibilities. The precise codes are in the main established although some of the 32 have been left undefined to allow for system extensions. At this time the 5 bit coding is not being published not only for reasons of software copywight but also for reasons of contractual agreement. However, the principles involved in the coding are of interest.

Firstly one code must indicate that the reading is indeed an Leq. This way seems redundant but in fact the system can acquire other data in the environmental analyser: For example, vehicle count, temperature, humidity, windspeed in non-acoustic terms and also the peak value or an octave band level in the acoustic domain.

Also, some of the 2048 possible levels far exceed the required coding for Leq alone. If we assume a maximum range of say 0dB to 164dB, that requires 1640 to give 0,1dB resolution leaving over 400 to be used in complex programming for other purposes. Some high Leq codes are used where the elemental Leq may be in error and thus is not recorded. Examples of this would be a routine microphone calibration, power drop out, operating of controls during an elemental Leq etc. At this time 7 error codes are fully defined all of these replacing an Leq.

Some of the other 400 non Leq values are assigned to test and data function which are stored while the current Leq is being calculated. For example, in one realisation of short Leq 10 parallel channels of 9 octaves plus dBA are measured at the same time. This requires special test and timing routines which are stored and coded in the 400 'false' Leq values.

One bit of the 16 is used as an overload flag. Thus if any elemental Leq exceeds the dynamic span the Leq is stored but the overload is flagged and thus the software can take account of this. Other vital data which must be recorded is generated at each use of 'Pause' or even switch-on. For example, the real time is first recorded followed by a test sequence. Thus, if a handheld unit such as the CRL 2.36 is in use, the operator merely has to record his physical position at each time pause or switch-on. The unit itself records the time and calibration data. This function which involves a real time clock is, like the memory, backed up by a separate battery which has a working life of over one year after the main battery is totally discharged. This back-up is automatically float charged from the main battery during normal use.

As turning the unit off does not destroy data some means have to be provided for resetting the memory. Normally this is never done in the field and thus it is a software function which occurs only after readout of memory. However, to enable the full store to be used at any time, a keyboard routine is built into the CRL 2.36 to enable reset to be achieved only by a multiple keystroke.

The first long term monitor unit having short Leq, the CRL 2.40, has instead a locked hard reset. We consider that a outdoor monitor is less likely to be put to 'pause' and thus does not usually make several measurements on one reset.

The next part of the chain after data acquisition is data readout and for this an interface is required. Clearly if this can be to some defined standard this will naturally increase the number of access units available.

In 1980 Cirrus Research proposed the DP15 analogue bus and the L3M microphone input interface. Now we propose a new digital interface the DP37. This like the DP15 and L3M is based on a connector available internationally from many sources.

The CRL 2.36 has the new DP37 digital bus which has already had over a years field trials. Included in the DP37 is a full RS432 type serial interface with all the standard commands together with the IEEE 488 Purpose Interface Bus (GP1B). This allows the acquisition unit to function both as a talker/listener "on line" to a micro but when not connected to a computer system, it takes over the function of bus controller, allowing control of intelligent peripherals. Extra connections are codified for filter drive and power supply so that plug-in units can be developed to modify the acquisition function of the units. For example, one of the first new units is a ⅓rd octave filter which operates via the DP15 analogue bus but can be software controlled via the DP37 digital bus in real time.

The provision of both parallel and serial interfaces may seem excessive but this is a system requirement. The RS432 is needed for MODEM use wich includes the use of the acquisition unit as a monitor at the end of a telephone line. If the CRL 2.40 is connected to a phone line it can be interrogated from anywhere in the world on a routine basis to output the data to a local computer and if required reset the memory for the next period's acquisition. Imagine a city with a series of units like the CRL 2.40. Each acquiring short Leq on a 1 sec basis. Twice a day the unit is automatically interrogated by the main computer and the data dumped onto disc. The noise foot-print of a small town can be mapped on a second by second basis using very little manpower. If telephone line installation is too expensive, as would be the case for short events such as a Pop Festival, the unit can be read back by dumping down to a standard cassette recorder. Naturally this needs a visit twice a day but that is a small price to pay for the amount of data that is acquired.

Software for the CRL 2.36 and CRL 2.40 is a vital part of the package and currently work is underway on using several microcomputers as the basic processor via an international operating system as well as in some machine codes.

SUMMARY

The concept of short Leq has allowed the realisation of a new generation of data acquiring sound level meters both handheld and as monitors. These units have a potential production cost far lower than current generation units together with storage capacities an order higher than current units. Raw data is time compressed into units which lose little basic information and in many cases obviate the need for tape recording noise data for subsequent analysis.

INDUSTRIAL NOISE ASSESSMENT VIA SHORT LEQ

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The value of Leq in assessing time varying and, particularly, impulsive noises lies in its extended integration period when compared with the conventional sound level meter responses. The integration period for an Leq meter is equal to the measurement duration. Equal weighting is given to all noises, independently of their position in the time history of the measurement. These properties make Leq a better indicator than SPL when assessing hearing damage risk and noise nuisance due to impulsive noises. Having identified a potentially hazardous environment, a more detailed analysis is required to ensure that effective noise control measures can be adopted.

The method chosen for this detailed analysis is dependent on the type of noise source encountered. If the noise is varying, but with a restricted pulse range and rise/fall time, a level recorder can be used to generate a permanent record of the time history for later analysis. This analysis could consist of identifying the major peaks by correlation with a tape recorder or by notes written on the trace during recording. The response speed of the level recorder would preclude any accurate prediction of the overall Leq if a major noise source were attenuated due to some proposed noise control measure. If the noise is highly impulsive, with a large pulse range, an integrating sound level meter with the capability of measuring sound exposure level (SEL) can be used. This allows comparison of the energy content of individual impulses, but loses the time history value of a level recorder and may not allow separation of sources whose energy contributions overlap in time. Short Leq, originally proposed by researchers at LNE in France, combines all the attributes of an Leq meter with the analytical capabilities of the SLM/level recorder and SEL techniques.

Short Leq is generated by taking individual or elemental Leqs over a constant, pre-determined period, and storing them for later analysis on a computer. The number of different integration periods, the number of elemental Leqs which can be stored and the storage medium would depend on the particular instrument in use. At present, two basic types have been produced: one with the integration period set by the instrument front panel controls and containing internal memory, the other having its integration period controlled by an external microcomputer and utilising the mass storage of the computer for retaining the elemental Leqs. Further instruments which can be configured as intelligent peripherals on a large data aquisition system are already proposed.

The choice of integration period for the elemental Leq depends on the resolution which is envisaged at the analysis stage. If the total memory capacity is not a limitation, then the shortest integration period should be chosen. For extended monitoring applications, the integration period need only be short enough to resolve the expected noise sources, e.g. the passing of an aeroplane, motor vehicle or train. If however, only one important noise source is expected, and the background noise is sufficiently low, the integration period need only be short enough to resolve the time between occurrences of the noise. With an integration period of 10 minutes and a fairly modest store of 64K words, data could be aquired for in excess of one year.

An integrating sound level meter is primarily intended for measuring impulsive noises. It is therefore essential that a short Leq aquisition unit should accurately integrate all incoming signals, and should not misrepresent large impulses which occur on an overlap between two successive elemental Leqs. The time lost between Leqs must be small enough such that an instantaneous impulse at the upper limit of the dynamic range, which overlapped two elemental periods, should not result in an error greater than the tolerance allowed for the elemental Leqs individually. The contiguous nature of the elemental Leqs is what transforms them from a simple sequence of values to a versatile representation of the raw data, from which many acoustic parameters can be derived.

If the elemental Leq period was correctly chosen, complete flexibility exists in the later treatment of the data. The elemental values can be recombined to form an overall or global Leq for any period within the total measurement. If a large period is to be represented when a very short elemental period was used during the aquisition, groups of short Leq can be combined to give a time history with any desired resolution in time. At the analysis stage, different noise events can be identified so that their contribution to the overall Leq, and the percentage of the measurement period for which each occurred, can be calculated.

Data from a number of aquisition units can be inserted into a common file, so that concurrent data from a number of measurement positions can be processed. Possible applications of an array of units include identifying and measuring transmission paths, quantifying the performance of sound barriers or simply to provide a convenient means of displaying multi-channel monitoring data.

The ability to recombine the elemental Leqs, identify and separate various noise sources and operate on multi-channel data are all new and powerful analysis tools; they are not, however, made available at the expense of more familiar acoustic measures.

A level recorder type trace can be produced which shows the time history of the measurement period. Such a graphic representation is often useful to demonstrate noise duration and repetition rate. Parameters which have historically, and empirically, been derived from level recorder traces can also be synthesized using short Leq, without the need for a dedicated measuring instrument. The most common of these are the Ln values, statistical parameters based on the level which was exceeded for n percent of the measurement time. A combination of at least two of these parameters is usually used to represent the variability of a particular noise environment. The flexibility of short Leq allows the choice of the appropriate percentage levels to be made at the analysis stage, rather than having to preset instrument controls.

The representation of the energy content of individual noise events by SEL is also supported by short Leq. Since all the raw data is recorded, the exact duration of an event can be defined with the aid of an examination of the time history. The definition of the time at which an event appears out of the background and returns back into it can be varied to determine precisely what uncertainty exists in the SEL. Performing this function at the analysis stage allows much greater flexibility than either relying on preset thresholds or on the mechanical pressing of buttons by an operator in real time.

Short Leq has shown itself to be a versatile tool for acoustic analysis. The existing software is being continually updated and expanded, to run on more powerful computers with more capable aquisition units, as more of the potential of short Leq is realized. An apparently conventional integrating sound level meter can now be interfaced with a popular home computer to provide a powerful analysis package at a much lower cost than existing dedicated hardware.

Summary

Short Leq provides a new measurement concept which draws together and enhances existing acoustic parameters rather than trying to replace them. Its principal value lies in the retention of the raw data to allow flexibility at the analysis stage. These facilities can be incorporated into a hand-held instrument which can be used for short Leq or as a stand-alone instrument, as required.

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DP37 - A DIGITAL ACOUSTIC INTERFACE

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INTRODUCTION

Advances in the availability of highly integrated computing power has led to a dilemma in the design of hand-held acoustic instrumentation. This arises from the designer being able to offer the instrument user a wide range of measurement options, including acquisition of large quantities of data, but at the same time not wishing to confuse the user with the presentation or volume of data. The simple solution is of course to leave the arduous analysis task to an office or home computer, where programming power and sophisticated, multi-colour graphics aid in presentation and interpretation. There are problems, however, in the transfer of data between the acquisition unit and the computer. This paper addresses these problems in an attempt to establish an internationally agreed hardware and software protocol for data transfer.

Interface Requirements

The functional requirements of the interface determine the best form of implementation. Care must therefore be exercised in the specification of the possible functions. Cirrus Research have gained much experience from the design and use, over a number of years, of both the L3M microphone input interface and the DP15 analogue interface which is used for external plug-in units. The value of investing time in making these interfaces as universal as possible has allowed expansion to applications which could not have been foreseen when the individual connector pins were assigned.

The original requirement was to transfer data from some acquisition unit to a microcomputer for subsequent analysis. For secure and controlled data transfer, some form of two-way communication is needed to allow a handshaking sequence to take place. The basic form of interface need consist of no more than a uni-directional data channel between the acquisition unit and the computer, together with a couple of control lines to conduct the handshaking sequence.

To limit the interface to this simple implementation is, however, unnecessarily restrictive. The principal impetus which encouraged Cirrus Research to investigate communication interfaces suitable for instrumentation systems was the advent of the acoustic parameter short L_{eq}, which is described more fully in an accompanying paper. In essence, the time history of an acoustic signal is described by a series of L_{eq} values, each taken with a short integration period, which are contiguous in time. The concept allows for versatile and powerful interpretation of these elemental L_{eq} to reveal much information about the acoustic signal, and possible relationships with other concurrent data. A consequence of this is that an acquisition unit will often contain many data, possibly taken at different times or from a number of different measuring positions. A very useful feature to be incorporated in the interface is therefore the possibility of sending data from the computer which the acquisition unit can interpret as commands to control the volume and format of the L_{eq} data in the opposite direction.

Having established that two-way communication is a desirable feature of the interface, it is necessary to decide whether the handshaking protocol should allow simultaneous or sequential exchange of data, in established computer jargon - full-duplex or half-duplex. The advantages of full-duplex being increased transfer rate when two-way exchange is required and easier interruption when an erroneous data stream is being transmitted. These are attained at the expense of having to provide two independent data channels. A valued judgement between these alternatives can best be made by consideration of specific hardware options.

Serial or Parallel?

Many issues are raised by consideration of whether the data transfer should be bit serial or bit parallel, however, by confining attention to the number of data channels, one seems to be suited to each of the possible alternatives. The use of a second channel with serial data exchange requires only one extra wire, whereas with bit parallel transfer the number of extra wires is equal to width of the byte, typically 8-bit. It is no accident, therefore, that these correspond to versions of the two most popular and commonly implemented interface standards: RS232C and IEEE488.

The RS232C interface standard defines a number of signal lines but no connector. By common use, the DP25 connector works as an effective standard. Most of the 25 pins are assigned, but few are usually used in practice. This arises from the origin of the RS232C system, which was developed to enable data transfer between devices via some communication equipment, typically a pair of modems together with a telephone line. RS232C defines how the device interfaces with the communication equipment, however direct connection is not envisaged. The often used direct connection must therefore gloss over this inconsistency with the standard. This is usually achieved by simply ignoring many of the available signal lines. Use of RS232C type interfaces do enable simple, reliable communication links over relatively long distance, including, of course, via modems and telephone lines.

The IEEE488, in contrast, is primarily designed for local communication within intelligent instrumentation systems. If the system is restricted to a controller, the computer, and one peripheral, the acquisition unit, then the maximum separation is 2 metres. The limitation on cable length and the specification of line drive capabilities ensures that IEEE488 system can be used for extremely high data rates, up to 1 Mbyte per second. The IEEE488 standard does specify a stackable, 24-pin connector, however, the situation has been confused by the issuing of an almost identical IEC standard which specifies a 25-pin D-type connector. The use of a 3-wire handshaking protocol controls whichever of the instruments is putting data onto the common 8-bit bus, each instrument having a unique address code to enable it to distinguish which of the data on the bus are intended for it. The system must contain a single controller which is usually programmable and often a microcomputer. In the context of acoustic instrumentation, a complete system might comprise several acquisition units transferring data periodically to a central computer. An alternate system could have the acquisition unit acting as system controller, supervising a number of peripherals which might include a microphone multiplexer, a filter unit or even other forms of environmental monitoring.

The major disadvantage of the IEEE488 system is that of the cable length restriction. A bus extender, which converts from parallel to serial and vice versa, can be used where long distance communication is essential. Such a solution is only viable where a heavy commitment to the IEEE488 system has already been made, and the added complexity of the bus extenders can be justified.

The DP37 Solution

The proposed DP37 digital interface aims to draw together the useful features of both the RS232C and IEEE488 systems. To ensure complete compatibility with all IEEE488 systems, all of the 24 defined pins need to be implemented. For the reasons outlined earlier, only a further 5 or 6 pins need to be reserved to ensure compatibility with a majority of RS232C type interfaces. This leaves sufficient pins free for duplication of the standard power supply voltages and other signals which have proved useful on the DP15 analogue interface.

The DP37 uses an internationally available, multi-sourced connector. Different cables can be used to adapt to whichever of two standard interfaces is most appropriate for the system in use. Although the DP37 interface is fully specified, it is not expected that every instrument which has a DP37 connector supports all the possible interface functions. For example, a basic instrument might be a hand-held acquisition unit. The basic unit size is little more than the width of the connector and the interface is only capable of serial transfer of its memory contents upon request. More sophisticated units can form part of a distributed instrumentation system whose task would currently be performed by an environmental noise analyser. The advantage of a distributed system is the design flexibility and ease of system extension and upgrade.

The data formats which have already been used with the DP37 interface are also intended to be flexible. The serial transfer is accomplished using the asynchronous serial protocol of 1 start bit, 8 data bits, 1 parity bit (even) and 1 stop bit. All the commands sent to the acquisition unit have so far been in ASCII code, an extensive list of commands already exist. The 8-bit data format allows response in ASCII, which eases the formatting task of the computer, or in binary. The binary option is used where large data blocks are to be transferred. The parallel transfer using the IEEE488 component of the interface is naturally 8-bit, which therefore can also be in ASCII or binary. Different commands are used to elicit the two formats of data. Although single byte parity checks are performed on the serial data no attempt has been made to perform parity checks across blocks of data, eg by checksums. This is because such a requirement would unnecessarily increase the computing requirement of the acquisition unit. We have not experienced any problems as a result of not including such a feature.

The Limits of Imagination

In summary, the purpose of the DP37 digital interface is to provide a versatile system for transferring data from the increasingly powerful acquisition units to microcomputer systems which operate sophisticated analysis packages. A major objective was to ensure that the specification of the interface did not limit its future use.

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CONSIDERATION OF ACOUSTIC ACCURACY OF COMPUTER METHODS

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Most scientists and engineers will be familiar with the use of specialist computer packages to process and analyze large volumes of data. This paper offers some observations about the use of conventional acoustic measuring hardware in conjunction with data processing software packages.

PROBLEMS OF COMPUTERS

A computer at the end of an acoustic signal processing chain replicates the function normally performed by the meter. The resolution of the display unit should be consistent with the tolerances on the data. Use of clever software should not detract from the acoustic accuracy. As an example, claims have been made for 0.1 dB resolution over a 60 dB span when employing an 8-bit analogue to digital converter. The differing presentations of analogue, digital and computer-based displays are all the same thing - man-machine interfaces. If the data present in the computer have a gaussian distribution, a combination of such data would statistically yield a result of greater accuracy than the basic data. After combining many Short L_{eq}, the apparent resolution is greater than that of each individual sample. The separate samples must therefore be to the full accuracy or the resolution is meaningless. This is evident since although such resolution improvement would be correctly gained for background noises, many industrial and environmental noise nuisances are impulsive, or at least intermittent.

DATA DISPLAY

The great value of analogue data presentation is that it can show important information about trends. Digital presentation is, however, much better for steady-state signals as the readings can be resolved better by humans. Computer displays can utilize the advantages of both, but software errors can easily devalue the display. For example, the use of monitors with different numbers of pixels can cause problems if the screen display is addressed directly. A good design goal is to have easily transportable software. Such software should either overcome these difficulties or indicate possible limitations. Even the very simplest computers can also recombine Short L_{eq} to give any acoustic index, within the limitation of the acquired data, and can easily cope with data from several sources. This makes it possible to calculate and display differences in space, time and frequency or, given three microphones, plot probable noise sources.

FREQUENCY ANALYSIS

Simple signal processing, together with a simple computer can simulate a digital filter in quasi real-time. Semi-conductor manufacturers offer specialized integrated circuits which allow the construction of a number of parallel channels. If the FAST rms time constant is applied, microsecond differences will occur which will lead to minimal errors. Upon logarithmic conversion of the rms signal, a 50 dB dynamic range can be achieved using a 9-bit converter to yield 0.1 dB resolution. The games port of a simple computer usually has an 8-bit conversion accuracy - this would give 0.2 dB resolution. Such developments enable the rapid generation and synthesis of new indices. A combination of the 63 Hz, 125 Hz and 250 Hz octave-bands can be used to assess noise nuisance from discos. The transmission characteristics of buildings can be simulated to worn system controllers or limit the level. Realistic assessment of the nuisance due to industrial noise or rock festivals is facilitated in a way which was not previously possible.

TIME HISTORY

Desk top and home computers are generally programmed in a high-level language. This often has the effect of complicating input/output processes. The net result of this is that the control of data acquisition through its input ports is at "arms length" and necessarily has poor resolution in time. Some computers have the ability to include machine code subroutines within high-level language programs, but for ease of software portability, reliance on external hardware for signal conditioning and data caputre is more profitable. Experience has shown that when the acquisition is controlled directly by the computer, a minimum resolution of about one second is consistent with amplitude resolution normally required.

The advent of instruments which can acquire Short L_{eq} data has provided an ideal complement for the modern desktop and home computer. Dedicated hardware can provide the optimum accuracy in both amplitude and time resolution. Standards are already in existence which specify the dynamic, time-averaging capabilities and the pre-set measurement time resolution required of such instruments. This highlights the major difficulty in making comparisons between results produced from different software packages; there is no standard for performance. There should be no degradation of the data during transfer into the computer. The software package should therefore recognize the resolution of the data presented to it, and not allow the user to ascribe unrealistic accuracy to any derived results. A sample output from a typical software package is shown in Figure 1.

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Serial Number	2985
L_{eq} period	1 sec
Range	30 dB
Date of readings	21 January 1986
Time of readings	10:50.08
Mode	L_{eq}

NOTES: Demonstration of Indices for Inter-Noise 86

L values

L1 = 77.1
L10 = 58.3
L50 = 53.6
L90 = 52.7
L99 = 50.8

Overall L_{eq} is: 55.2

FIGURE 1: Sample Output from Typical Software Package

The employment of the Short L_{eq} methodology, with its constant measurement interval, allows graphical and tabulated presentation of the time history with the data combined in any multiple of the elemental period. This allows the software user to concentrate on either extreme of time resolution. When the data are combined into large multiples of the elemental period, long-term trends can be observed without distraction from fine detail. Lower multiples, down to the elemental period itself, enable examination of this fine detail. This is extremely useful in attempting to identify which of a number of possible sources, each with a recognizable signature, is providing the major contribution to the overall measured level.

Earlier reference was made to the ease with which computers can combine and analyze data from a number of sources. The additional data which is afforded by a multi-channel system enhances the ability of software to identify sources, though there is a natural limit on the localization possible, determined by the elemental Short L_{eq} period. Utilization can also be made of the value of the multi-channel facility in readily assessing transmission loss from acoustic source to a number of observation locations. This is particularly useful where there is a restriction on the available time for acquisition. For instance, where the source being analyzed is of a transient nature, data obtained from a series of sequential tests may contain masking which arises from usual experimental variation. Simultaneous data capture overcomes this problem, there being the added advantage of alignment of measured data by the software through a synchronizing signal such as a starting pistol shot.

SUMMARY

A number of software packages have been evaluated. Attention has been drawn to the necessary precautions to be taken before placing reliance on processed data from computers. The available software packages are extremely powerful analysis tools, enabled varied presentation in terms of time history, the L_n values and L_{eq}. The calculated values can be determined from any subset within the total measurement period, and at least one package can calculate the above in the octave bands.

SINE BURST TESTING OF INTEGRATING SOUND LEVEL METERS

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INTRODUCTION

Over the past decade there has been a continuing discussion as to the performance characteristics required of integrating sound level meters. Discussion has centred on quantifying the limits and tolerances of important parameters, however, a significant portion of the debate has been concerned with testing methodology and its relevance to practical acoustics. The aim of this paper is to review the various procedures which have been proposed for evaluating the transient response of instruments, and to report on developments in instrumentation required for such evaluation.

TRANSIENT RESPONSE

The acceptable performance of acoustic instrumentation is often a compromise between practical requirements and technical feasibility. With integrating sound level meters, the current differences are small. There is fairly general agreement as to whether a specific instrument meets the acceptable standard, but divergence as to how the evaluation should be performed. For the steady-state testing, which is highly derived from conventional sound level meter standards, only the numbers are subject to debate. It is in the testing of dynamic behaviour or transient response where the divergence occurs.

Multi-cycle Testing

The use of tonebursts of integral cycles of sinewaves is accepted in IEC 804 as being an appropriate method of determining the linearity of the instrument outside the display range. The duty factor and tone burst duration are chosen to allow on scale readings to be taken without causing limitations due to the pulse range.

The pulse range, as defined in IEC 804, is determined by superimposing an in-phase tone burst on to a low level signal. The amplitude of the fixed frequency tone burst and its duration are varied in order to investigate the dynamic performance. A minimum pulse range is specified for each grade of instrument. This quantifies the ratio of the peak of the tone burst to the rms value of the low level background over which the instrument will integrate within given tolerances. The expectation is normally that the tolerance will only be approached at the higher peak levels, but the variation in tone burst amplitude allows investigation of mid-range non-linearities.

The use of the low level background performs a couple of useful functions. It provides a defined signal during the tone bursts "off" period, giving a minimum signal to noise ratio for the signal generator. Secondly, it provides what can arguably be described as a realistic representation of an acoustic signal, being an impulse rising out of a background level.

Single-cycle Testing

The use of single-cycle sine bursts of various frequencies to evaluate the "dynamic frequency weighting" was central to several drafts of the American National Standard for integrating sound level meters. As the frequency of the sinusoid is varied, the effective toneburst duration also varies. The instrument's response is most easily determined if it measures and displays sound exposure level. The reading on sound exposure level is stable after the single cycle has been applied. The actual meter reading is compared with a calculated value of sound exposure level which is based on both signal amplitude and frequency. If the instrument does not display sound exposure level, the calculation of theoretical meter reading is further complicated by having to compensate for the measurement duration. In addition, if the instrument has no provision for short term, fixed-period measurement, the meter reading will be falling constantly after the application of the impulse. The meter reading during the IEC 804 pulse factor test is also time variant, but as the input is repetitive the reading converges to a specific value.

The relevance of single-cycle sine bursts to the majority of acoustic signals is questionable. Low frequency single-cycles are reasonable simulations of shock waves, but a larger number of industrial noises are repetitive with considerable mid-frequency energy.

There is an argument that a single-cycle sine burst is a more efficient signal for stimulating the transient response than a multi-cycle tone burst. This could lead to the adoption of a dc step input as signal source, with the Impulse Response Function as the sole arbiter of acceptable dynamic performance. This may have interesting possibilities, but is even more difficult to relate to practical sound sources.

Independently, however, of any technical discussion as to the relative merits of these or any other evaluation methods, an international standard is now in existence. It is hoped that this can be universally accepted so as to remove the uncertainties about required performance which have existed since the construction of the first dedicated integrating sound level meter. Future debate on the testing of integrating sound level meters would most profitably centre on the tolerances of the various tests, with a view to the issuing of a future revised IEC 804.

PRACTICAL IMPLEMENTATION

The authors have had experience over the last eight years in the design and use of instrumentation specifically designed for evaluating the transient performance of integrating sound level meters. The equipment which has been used has always had capabilities in excess of the performance required of the instruments, but the precise effect of shortcomings in the signal source is not fully understood. For example, whilst conducting a multi-cycle tone burst test as per IEC 804, the signal source was intentionally adjusted so as to start and stop at other than zero crossing. The resulting spectrum was virtually indistinguishable from that of the correctly adjusted waveform, the extra steps adding little to the already broadband spectrum. The instrument under test gave identifical readings with both signals, within normal experimental uncertainty.

In a current exercise to further upgrade our existing testing facility, a number of commercial signal generators have been examined. Recognizing the role which computer assisted testing has to play, this included "intelligent" instrumentation designed for use via the IEEE 488 interface bus. One particular example, a programmable waveform generator, with the facility of remotely setting sinusoidal tone bursts with integral number of cycles, starting and stopping at zero crossing, with the ability to generate ISO preferred frequencies to 1 part in 10^6, could only manage a signal to noise ratio of 62 dB and produced a less than orderly completion of the tone burst sequence.

Attention has therefore focussed on the development of specialized signal sources "in house". An interface has been constructed which allows control over signal level and frequency, tone burst duration and level of in-phase background signal for IEC 804 tests. Additional provision includes the facility for automatic logging of instrument performance, particularly of the latest generation of instruments which have the DP37 - digital acoustic interface.

The necessary software development to accompany this programmable hardware has resulted in a pseudo-language which enables quick setting up of a particular test schedule. Some knowledge of structured programming is all that is needed to modify the parameters which are passed to the procedures.

SUMMARY

The two commonly used methods of determining the ability of an integrating sound level meter to measure accurately impulsive signals have been discussed. It is suggested that, as the two methods would not result in significantly different instrumentation, the duality of evaluation procedures is avoided and the existing IEC 804 is universally adopted.

Attention has been drawn to the lack of quantified specification for signal sources. This has led to the development of dedicated hardware and software to aid in instrument evaluation.