# Software defined antenna testing

GAMBO, Dan Asabe, SIMMONS, Nadine, KAREEM, Murtadha and FAUST, Oliver <http://orcid.org/0000-0002-0352-6716>



**Citation:**

GAMBO, Dan Asabe, SIMMONS, Nadine, KAREEM, Murtadha and FAUST, Oliver (2017). Software defined antenna testing. ICTACT Journal on Communication Technology, 8 (4), 1664-1672. [Article]

DOI: 10.21917/ijct.2017.0244

# SOFTWARE DEFINED ANTENNA TESTING

**Dan Asabe Gambo[1], Nadine Simmons[2], Murtadha Kareem[3] and Oliver Faust[4]**
*Department of Telecommunication and Electronics Engineering, Sheffield Hallam University, United Kingdom*

***Abstract***
***Micro strip patch directional antennas are an attractive solution for modern wireless systems due to their high gain and directivity. Being an attractive solution creates the need to design such devices for various application scenarios. We have addressed that need by designing, simulating, and testing a rectangular microstrip patch directional antenna at 5GHz. Antenna patch and ground plane were designed with the well-known guided wavelength equation. The antenna performance, in terms of return loss at -10dB, gain, bandwidth, and the radiation pattern was analyzed with a simulation model. The proposed antenna achieved an impedance bandwidth of 77.8MHz (from 4.9662GHz to 5.0440GHz) and a gain of 6.26dBi at 5GHz. The antenna performance was verified with a software defined radio platform. We found that the software radio measurements confirmed the key simulation results. Furthermore, the extensive use of simulation enabled us to develop both antenna and digital baseband algorithms in parallel.***

***Keywords:***
***Antenna, CST-MS, Gain, Directivity, Return Loss, Software Radio***

## 1. INTRODUCTION

Wireless communication is an incredibly useful technology [1] [2]. The idea of using space as medium for information transmission yields flexible and cost-effective problem solutions [3]. Therefore, the need for wireless communications increases exponentially without any indication of slowing down [4].

Besides traditional broadcasting technology, such as television and radio, today, wireless communication systems exist for sending and receiving digital data between two or more stations. Wireless connectivity can only be achieved by incorporating antennas into both sender and receiver units. Antennas crate electromagnetic waves which can carry information in phase, amplitude and frequency changes [5].

As such, antennas are just one component in a communication chain [6]. In the past, new communication systems were created based on a divide and conquer approach [7]. That means, complex communication systems were developed by partitioning the functionality into individual parts [8]. The realization of the individual functional parts leads to components which can be developed independently from one another. Once all components are created, the communication system is assembled gradually. Such a design approach is inflexible and the development time is long. The inflexibility leads to underperforming systems, because development progress manifests itself in iterative prototypes where improvements are incremental from one revision to the next [9]. Software Defined Radio (SDR) offers a radical new approach to communication system design [10]. SDR technology moves the design of communication systems from the hardware into the software domain [11]. That shift opens up the opportunity to use software design methods for the creation of wireless communication systems. Rapid prototyping [12] becomes possible and more ambitious problem solutions can be realized. However, wireless systems must incorporate antennas and these devices cannot be replaced by software.

To address the problem of antenna design for SDR prototyping systems, we have used state of the art simulation models for rapid prototyping. We show that it is possible to integrate an analog RF frontend into the software based design of modern communication systems. That integrated approach was used to find the perfect antenna, not only for a given frequency range, but also for the required modulation scheme. Furthermore, having such an integrated design approach allows pre-correcting the communication signal before it goes through the analog processing.

To support our claim, for the integrated design approach, we have organized the remainder of the paper as follows. The next section details the materials used to design and test the microstrip patch antenna. Section 3 focuses on the implementation and section 4 presents measurement results. Conclusions and future works are covered in section 5.

## 2. MATERIALS

The flowchart, shown in Fig.1, depicts the design approach for the proposed communication system. We use modeling for both antenna and baseband design. Once these models have been tested the system is implemented and verified. The two subsequent sections introduce antenna and baseband models respectively.

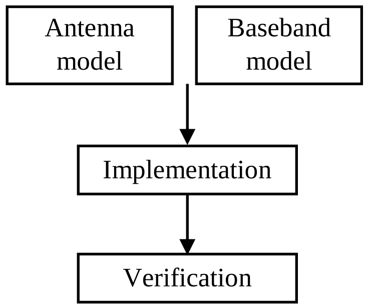


Fig.1. Software defined antenna testing flowchart

### 2.1 ANTENNA MODEL

This section discusses the design methodology of a directional antenna. Computer simulation technology was used to design and critically analyze the performance of the proposed antenna. To realize a high antenna gain, we optimized the physical geometry - until a value, that satisfies the project specification, was achieved. Finally, the simulated antenna was manufactured in order to analyze its characteristics.

### *2.1.1 Antennas:*

Antennas radiate or receive electromagnetic waves [13]. Typically, antennas are metallic structures, but dielectric materials are also used.

### *2.1.2 Microstrip Patch Antenna:*

Microstrip patch directional antennas have been used in many applications [14] - [16], because of their low profile, conformability, light weight, easy connectivity (feed), cheap realization and attractive radiation characteristics. A microstrip patch antenna is a wide-beam, narrowband antenna which is created by etching the antenna element (patch) in a metal trace material bonded to an isolating dielectric substrate [17]. Most physical realizations feature a Printed Circuit Board (PCB), with a continuous metal layer attached to the opposite side of the substrate which creates a ground plain. Common microstrip antenna shapes are square, rectangular, circular, elliptical, but any continuous shape is possible. The Fig.2 shows the mechanical drawing of a rectangular patch antenna.

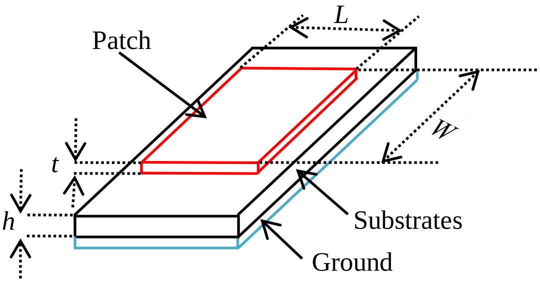


Fig.2. Rectangular patch antenna [18]

where,

*W* - width of the patch,

*L* - length of the patch,

*h* - height of the Dielectric substrate and

*t* - thickness of the patch and ground plane.

### *2.1.3 Material Specification:*

The microstrip antenna substrate provides mechanical rigidity and its dielectric properties allow surface waves to propagate through it. These penetrating waves will consume some part of the total power available for radiation. Hence, the dielectric properties influence the antenna performance.

The relative permeability, $E_r$ of substrates varies in the range from 1 to 10 [19]. We consider dielectric constant and dielectric loss tangent of the materials used to manufacture the antenna. Hence, the dielectric constant of a substrate is an important parameter for the design of passive devices, like microstrip filters. The relative permittivity $E_r$ of the substrate, together with the thickness $h$ of the microstrip antenna, has a considerable impact on the resonant frequency, gain, polarization, and matching of an antenna. There is a significant reduction in the microstrip antenna performance when $E_r$ increases, because the antenna size reduces with high performativity substrates at the expense of the matching bandwidth and antenna gain [20]. Furthermore, the loss tangent has a large impact on antenna gain and performance. The following holds for microstrip patch antennas: when the loss tangent increases the bandwidth also increases. Therefore, the antenna performance reduces when the loss tangent is increased [21].

In this project, FR-4 material was used as substrate. Although it is lossy, it has advantages in terms of availability and cost. The Table.1 gives the substrate specification for the proposed antenna.

Table.1. Material characteristics

| Characteristics | Values |
|---|---|
| Substrates material | FR-4 |
| Dielectric constant of the substrate ($E_r$) | 4.6 |
| Thickness of the substrate | 1.6mm |
| Tangential loss | 0.0019 |

### *2.1.4 Microstrip Patch Radiator Design Procedure:*

Most microstrip patch directional antennas consist of four parts: 1) ground plane, 2) patch, 3) feed and 4) substrate [22]. We designed a rectangular Microstrip patch radiator, utilizing RF-4 material as substrate. The Table.1 details the relevant parameters. The patch width ($W$) has a minor effect on the resonant frequency ($f_r$), it is calculated by using the following formula [23]:

$$W = \frac{c}{2f_r} + \sqrt{\frac{2}{E_r + 1}} \tag{1}$$

where, $c$ is the free space propagation speed of light and $E_r$ is the relative permittivity of the RF-4 substrate.

The microstrip patch lies between air and the substrate. The following equation models such a scenario. The model result is the effective permittivity ($E_{eff}$) [24]:

$$E_{eff} = \frac{E_r + 1}{2} + \frac{E_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-0.5} \tag{2}$$

where, $h$ is the height of the substrates.

The length of the patch determines the resonant frequency and is a critical parameter in design, because of the inherent narrow bandwidth of the patch. For the effective length $L_{eff}$ is calculated by [25]:

$$L_{eff} = \frac{c}{2f\sqrt{E_{eff}}} \tag{3}$$

The additional line length $\Delta L$ at both ends of the patch, is due to the fringing field effect:

$$\Delta L = \left[0.412h\frac{E_{eff} + 0.3}{E_{eff} - 0.258}\right]\left[\frac{\frac{W}{h} + 0.268}{\frac{W}{h} + 0.8}\right] \tag{4}$$

The effective patch length is given by [18]:

$$L = L_{eff} - 2\Delta L \tag{5}$$

A careful design of the patch geometry results in a good antenna that resonates at the specified frequency. The design process, discussed above, was executed before the design was simulated.

### *2.1.5 Simulation Procedure:*

We used the Computer Simulation Technology Microwave Studio (SCT MS) 2014 to model the microstrip patch antenna.

This software comes with a template that helped us to decide the feed parameters for numerous antenna types, such as dielectric, microstrip and coplanar waveguide. The software was used to estimate, and subsequently optimize, return loss, axial ration, gain, and radiation pattern for an SMA feed. The Table.2 provides the design specifications.

Table.2. Design specification

| Parameters | Specifications |
|---|---|
| Center Frequency | 5GHz |
| Return Loss $S_{11}$ | < -10dB |
| Gain | > 5dB |
| Shape of the Patch | Square |
| Feeding Techniques | Coaxial cable |
| Conductive Material | Copper |
| Copper thickness | 0.035mm |

### *2.1.6 Antenna Patch Geometry:*

By using the microstrip antenna Eq.(1) - Eq.(5), the square patch antenna dimensions were evaluated. Substituting $f_c$ = 5GHz and $E_r$ = 4.6 [26] the length $L$ and the width $W$ for the antenna square patch were obtained. Unfortunately, there is no equation to calculate the substrate area. There are two methods to determine the substrate area. The first method is to use a standard design as published by scientific literature. The second approach is based on optimization through trial and error, which was adopted for the purpose of this research. The Fig.3 and Fig.4 show the patch, on top of the substrates, and on the ground respectively.

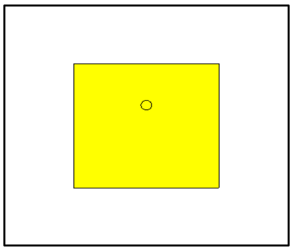

Fig.3. Antenna patch and substrate

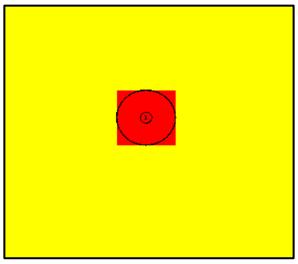

Fig.4. Antenna ground with feed point

The Fig.5 shows the side view of the patch antenna, which indicates the extrusion of the antenna coaxial feeding port and the substrate thickness of 1.6mm.

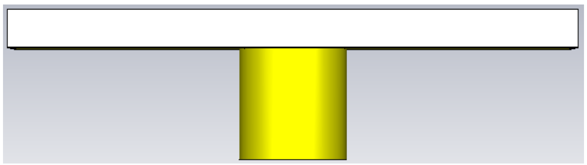

Fig.5. Antenna side-view

Table.3. Parameters and calculated values of the proposed antenna

| Parameters | Value (mm) |
|---|---|
| $W_P$ | 17.9 |
| $L_P$ | 13.6 |
| $W_S$ | 35.8 |
| $L_S$ | 27.2 |
| $t$ | 0.035 |
| $r_i$ | 0.50 |
| $r_o$ | 2.50 |

The Table.3 shows the length and width values that were calculated using Eq.(1) - Eq.(5).

The dimension of the antenna patch was calculated based on to the center frequency and found to be 13.6×17.9mm. The substrate dimension, which is assumed to be twice the size of the patch, is 27.2×35.8mm.

### *2.1.7 Antenna Feed:*

The Fig.6 shows the antenna feed point. The radius of the coaxial feed was designed, such that the impedance is equal to, 50Ω [27]. The coaxial port is made from three components: 1) Dielectric, 2) Pin, and 3) Shield (cover). The Pin and Shield are made of pure copper while the Dielectric is made of Teflon. The Fig.6 shows the designed coaxial port.

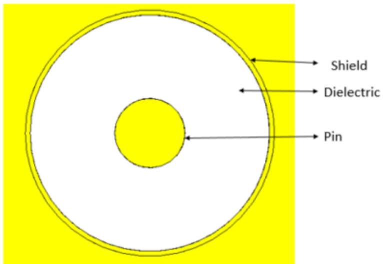


Fig.6. Coaxial feed point drawing

The Table.4 details the parameters that were used to design and simulate the coaxial port.

Table.4. Standard values of the proposed antenna design

| Parameters | Values (mm) |
|---|---|
| Pin radius | 0.5 |
| Dielectric | Teflon |
| Shield | 0.035 |
| Location | $l$ / 3 |

## 2.2 BASEBAND MODEL

The baseband model was developed with an SDR system. The flexibility and versatility of SDR structures makes it possible to use general-purpose hardware that can be operated or programmed and configured with software [28]. The Fig.7 shows a generic software-defined radio block diagram.

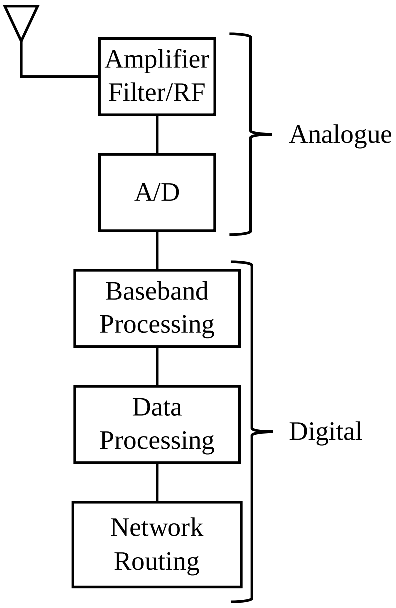


Fig.7. Generic SDR block diagram

For this project, we have used an Avnet Zynq 7000 system on chip as digital backend and an AD9361 as analogue frontend. The resulting SDR system can be used for evaluating and prototyping a wide range of standard as well as nonstandard communication methods [29]. The comprehensive application range comes from the fact that the system operates over a wide Radio Frequency (RF) range. To be specific, the system can operate from 70MHz-6GHz, with a tunable channel bandwidth that ranges from 200kHz - 56MHz [30]. The next sections describe the baseband model.

### 2.2.1 *Top Level Tranceiver Setup:*

The Quadrature Phase Shift Keying (QPSK) algorithm encodes two bits of information into a carrier phase change [31]. The Fig.8 shows the top level QPSK transceiver setup.

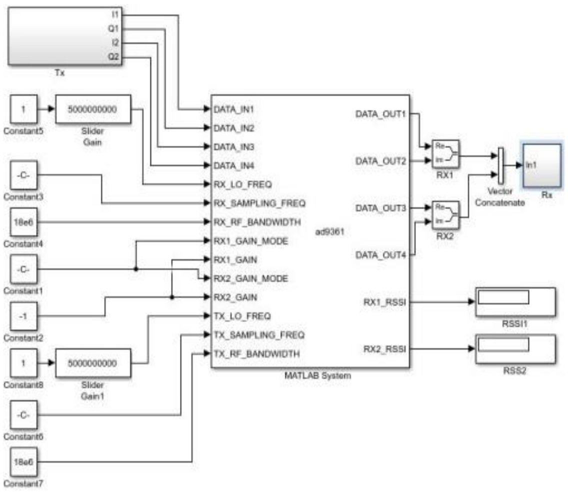


Fig.8. QPSK transmitter and receiver baseband processing

### 2.2.2 *Transmitter:*

The QPSK modulator converts the input bit stream into a digital signal which can be transmitted over the communication channel. The modulated symbols are up sampled by four and fed through a Raised Cosine Transmit Filter with a roll off factor 0.5 [32], as shown in Fig.9.

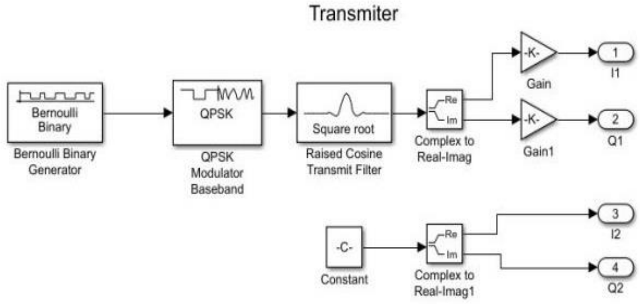


Fig.9. QPSK transmitter

### 2.2.3 *Receiver:*

The receiver section consists of Automatic Gain Control (AGC), coarse frequency compensation, fine frequency compensation and time recovery [32]. The Fig.10 shows the functional block diagram of the QPSK receiver. The following sections introduce the functionality of the individual blocks that make up the receiver.

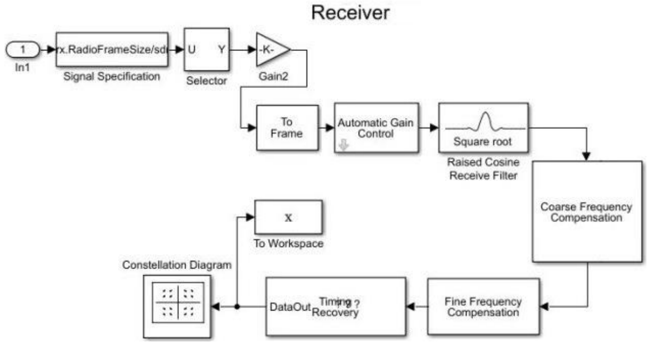


Fig.10. QPSK receiver

### 2.2.4 *Automatic Gain Control:*

The AGC [33] is placed before the raised cosine receive filter so that the signal amplitude can be measured with an oversampling factor of four. This process improves the accuracy of the estimate.

### 2.2.5 *Coarse Frequency Compensation:*

That step performs a fast Fourier transform on the modulation-independent signal to estimate the tone at four times to estimate the frequency offset. After dividing the estimate by four, the Phase/Frequency Offset System block corrects the frequency offset [34].

### 2.2.6 *Fine Frequency Compensation:*

The fine frequency compensation block implements a Phase-Locked Loop (PLL) to track both residual frequency offset and phase offset in the input signal [35].

#### *2.2.7 Timing Recovery:*

The timing recovery step uses closed-loop scalar processing to overcome the effects of delays introduced by the channel [36].

## 3. IMPLEMENTATION

The implementation process includes the physical creation of the antenna and the configuration of the software radio. As such, these process steps are quite different, because configuring the SDR involves setting up the software and the configurable hardware components. The learning curve is steep, but errors are largely inconsequential. In contrast, creating the physical microstrip patch antenna requires controlling the manufacturing process. With a PCB milling machine that is not difficult, but mistakes usually result in defective prototypes. Additional prototypes increase the development cost. The next section introduces the manufacturing process.

### 3.1 FABRICATION PROCESS

Fabrication turns the model into a physical problem solution. The RF-4 substrate has a thickness 1.6mm, copper conductor of thickness 0.035mm and tangential loss of 0.0019. During the first fabrication stage, the antenna is exported from CST into Gerber, a file format that is recognized by the PCB milling machine.

After milling, the antenna was cut into shape. Subsequently, a 50Ω SMA connector was carefully soldered to the antenna. The Fig.11 and Fig.12 show the manufactured antenna.

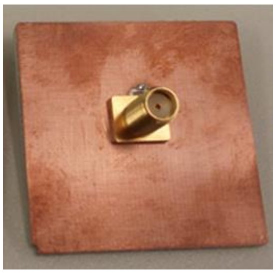

Fig.11. Fabricated antenna ground view

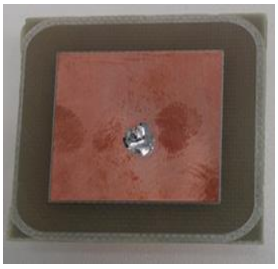

Fig.12. Fabricated antenna Patch view

#### *3.1.1 Test setup:*

The Fig.13 shows the test setup. That setup combines the fabricated antenna with the implemented baseband model such that the system functionality can be established. The software radio system generates a test signal, according to the transmitter model, discussed in Section 2.2.2. That test signal is transmitted with the TX Antenna. The RX Antenna receives the signal. The receiver model, discussed in Section 2.2.3 extracts the information from the received signal.

Both receiver and transmitter algorithms are executed in the digital backend. The analogue frontend modulates the 5.0GHz carrier. The two antennas are mounted on an optical bench. That allows us to adjust the distance between the antennas.

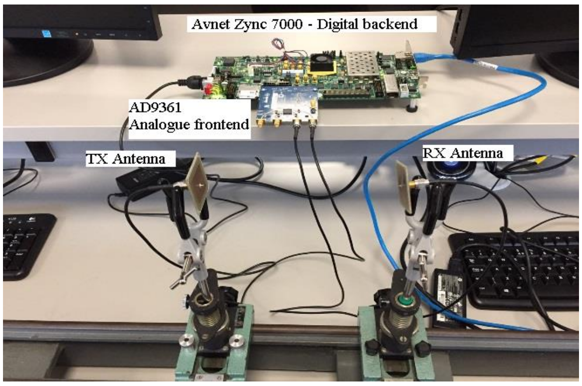


Fig.13. Test setup with transmitting and receiving antennas fixed on a variable prove

## 4. RESULTS

This section introduces the antenna design results. We discuss the optimization process with the CST Microwave Studio. The antenna simulation model is evaluated in terms of return loss, radiation pattern, directivity, voltage standing wave ration, and gain. Finally, we turn our attention to physical measurements by discussing the SDR test results.

### 4.1 ANTENNA GEOMETRY

The antenna specification was used for an initial design simulation. The Fig.14 documents that; the initial result did not meet the performance requirements. Therefore, we initiated a parameter sweep to optimize the design.

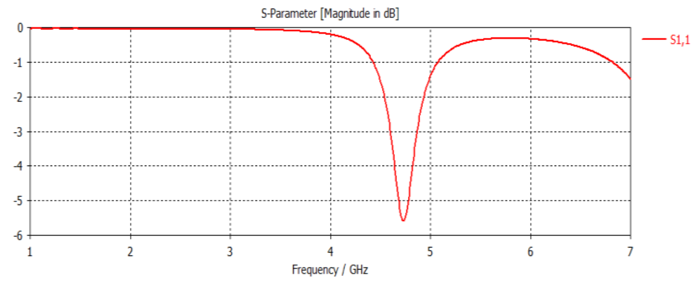


Fig.14. Return loss ($S_{11}$) result of first geometry

#### *4.1.1 Optimization:*

The area of the antenna's patch is inversely proportional to the operational frequency; hence the antenna's length and width should be optimized until the antenna resonates at nearly the designed operating frequency. The Table.5 shows the variation of length (*L*), width (*W*) and corresponding feed locations (*XL*). The first four values of *L* were kept constant and *W* changed. For the subsequent nine values, SN4 to SN13, *W* was kept constant and *L* was varied. For the last four values, SN14 to SN17 *W* was kept at 13.2mm and *L* was varied.

Table.5. Parameter optimization

| | Parameters (mm) | | |
|---|---|---|---|
| SN | L | W | XL |
| 1 | 12.7 | 11.98 | 4.23 |
| 2 | 12.7 | 12.20 | 4.23 |
| 3 | 12.7 | 12.30 | 4.23 |
| 4 | 12.7 | 13.0 | 4.23 |
| 5 | 12.7 | 13.0 | 4.23 |
| 6 | 10.0 | 13.0 | 3.33 |
| 7 | 10.7 | 13.0 | 3.33 |
| 8 | 11.4 | 13.0 | 3.33 |
| 9 | 12.1 | 13.0 | 4.00 |
| 10 | 13.0 | 13.0 | 4.33 |
| 11 | 13.5 | 13.0 | 4.50 |
| 12 | 13.2 | 13.0 | 4.40 |
| 13 | 13.3 | 13.0 | 4.43 |
| 14 | 13.3 | 13.2 | 4.43 |
| 15 | 13.4 | 13.2 | 4.46 |
| 16 | 13.0 | 13.2 | 4.33 |
| 17 | 13.1 | 13.2 | 4.37 |

Both length and width of the antenna's patch were optimized to obtain a good radiation pattern and gain at 5GHz. The Fig.15 shows the effect of varying length and width of the antenna patch and the corresponding effect to that of substrates.

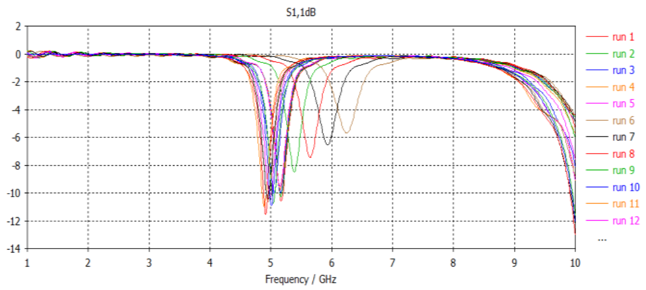


Fig.15. Effect of length and width parameters

### 4.1.2 *Second Antenna Geometry:*

By studying and observing the optimized result, as shown in Table.5, the values of length, width and their corresponding coaxial feed location of 12.7mm, 11.98mm and 4.23333mm respectively were chosen. With these parameters, we obtained the simulation result shown in Fig.16. The graph indicates that the antenna resonated at the desired frequency of 5GHz with a return loss of less than -10dB as specified in Table.2.

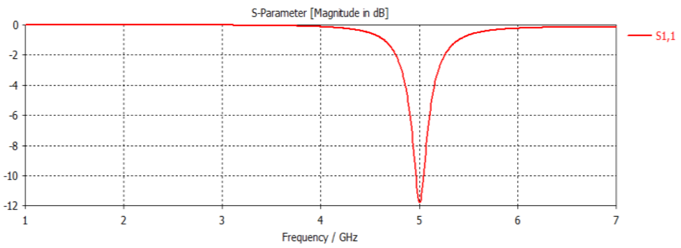


Fig.16. Return loss (S11) result with the optimized geometry

### 4.1.3 *Proposed Antenna Bandwidth:*

The antenna bandwidth is defined as the frequency range where the antenna exhibits a VSWR of less than 2:1 [35].

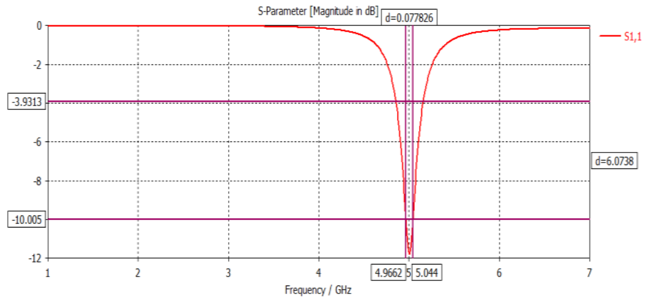


Fig.17. Higher and lower frequencies at -10dB

To calculate the bandwidth of the proposed antenna at -10dB, there is need to consider the higher as well as the lower frequencies at the same point, as indicated in Fig.17. Hence, the bandwidth of the designed proposed antenna can be obtained using the following relation:

$$BW = H_f - L_f$$
$$BW = 5.0440 - 4.9662 = 77.8MHz \quad (5)$$

The bandwidth of the proposed antenna is 77.8MHz which is an improvement on the proposed bandwidth of 1MHz. The Fig.17 shows the simulated antenna bandwidth.

### 4.1.4 *Percentage Bandwidth:*

Percentage bandwidth gives a normalized measure of how much frequency variation a system or component can withstand. As the frequency increases, the absolute bandwidth will also increase, while it percent bandwidth decreases.

$$\%BW = \frac{H_f - L_f}{H_f + L_f} \times 100$$
$$= \frac{5.0440 - 4.9662}{5.0440 + 4.9662} \times 100 \quad (6)$$
$$= 1.56\%$$

This bandwidth implies that our device is a narrowband antenna, because the %BW < 20%. That confirms the well-known fact that microstrip patch antennas have narrow band characteristic.

### 4.1.5 *Voltage Standing Wave Ratio:*

For high quality antennas, the impedance of the radio and that of transmission line must be well matched to the antenna's impedance. A mismatched antenna reflects some part of the incident power back to the transmission circuit. The reflected wave is moving in the reverse direction compared to that of the incident wave, there is a point, along the cable or transmission line, where the both waves are in phase and also other points in which the two waves are out of phase. Both voltages can be measured and their ratio is called: Voltage Standing Wave Ratio (VSWR) [37]. The VSWR is a measure that numerically describes how well the antenna impedance is matched to the transmission line it is connected to. The VSWR is a function of the reflection coefficient, which indicates the power reflected from the antenna. If the reflection coefficient is represented by (Γ), then, the VSWR is defined as:

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \quad (7)$$

The VSWR is a real and positive number when we deal with physical antennas. The lower the VSWR value is, the better the antenna is matched to the transmission line and this means more power is delivered to the antenna [38]. Likewise, the reflected power is basically the reflection coefficient square. The minimum value of VSWR is 1.0, which indicates that no power is reflected from the antenna - the ideal case. The Fig.18 shows the VSWR of the proposed antenna.

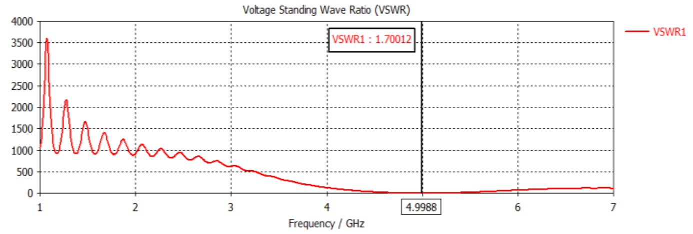


Fig.18. VSWR value over a frequency range from 1 to 7GHz

The simulation result, shown in Fig.18, indicates that the minimum VSWR value is 1.70012 at a frequency of 4.9988GHz. The value of the reflection coefficient at the input port ($\Gamma_{in}$) can be obtained with:

$$\Gamma_{in} = \frac{VSWR - 1}{VSWR + 1}$$
$$\Gamma_{in} = \frac{1.700 - 1}{1.700 + 1} = 0.26 \quad (8)$$

Hence, the proposed rectangular microstrip directional antenna is well matched to the input port. The optimal VSWR occurs when all power is transmitted to the antenna and there is no reflection. This scenario is expressed as,

$$|\Gamma_{in}| = 0 \; or \; VSWR = 1 .$$

Typically $\leq 2$ is acceptable at resonant frequency $f_r$ for perfect impedance matching [39]. The power reflected from the antenna is given by $|\Gamma|^2$ multiplied by the power available from the sources [40].

### 4.1.6 Return Loss:

Return Loss (*RL*) is the ration of the power send to that of reflected power in dB [39].

$$RL = -10 \log \Gamma^2 \quad (9)$$

The Fig.19 indicates the input output impulse response simulation result. RL is another way of expressing mismatch. It is a logarithmic ratio measured in dB that compares the power reflected by the antenna with the power that is fed into the antenna from the transmission line.

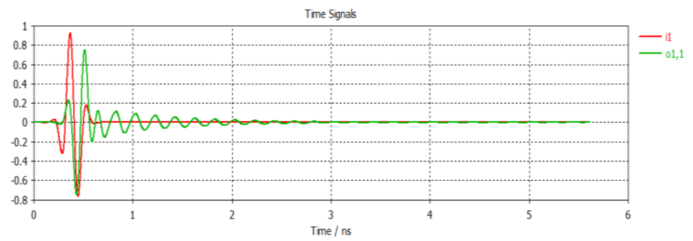


Fig.19. Input and output impulse response

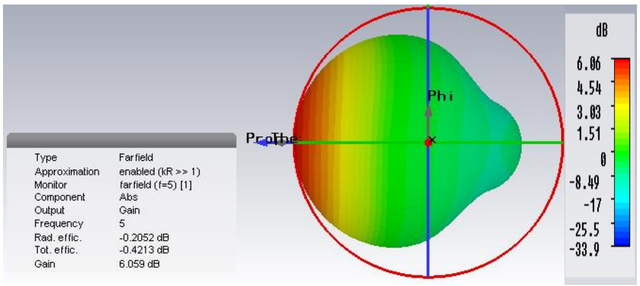


Fig.20. 3D Simulation radiation pattern of antenna gain

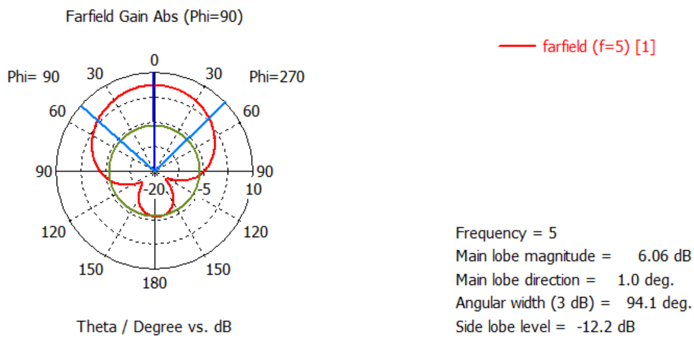


Fig.21. 2D Simulation radiation pattern

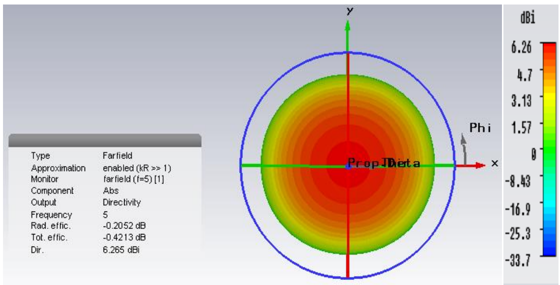


Fig.22. 3D Simulation result for directivity

The radiation pattern, shown in Fig.20 - Fig.22, indicates that the antenna is directional, with maximum gain along a particular bore sight.

### 4.1.7 SDR Measurement Results:

With the test setup, described in Section 3.1.1 we transmitted and received the physical communication signal. Based on the constellation diagram, shown in Fig.10, the Error Vector Magnitude (EMV) was extracted [41]. As such, the extraction was governed by the following formula:

$$EMV\,(dB) = 10log_{10}\left(\frac{P_{error}}{P_{ref}}\right) \quad (10)$$

where, $P_{error}$ is the variance of the received error vector. $P_{ref}$ is the amplitude of the reference signal, in our case, $P_{ref} = 1$. The Fig.23 shows the measured EMV dependent on the distance between the antennas. The EMV decreases as the distance between the antenna increases.

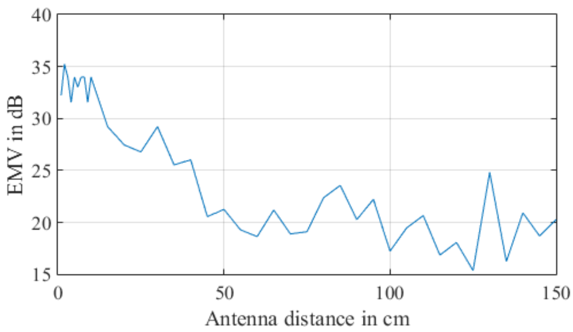


Fig.23. EMV over the distance between transmit and receive antenna

## 5. DISCUSSION AND FUTURE WORK

For this study, we developed the baseband models and the antenna in parallel. Both development processes dependent heavily on modeling and computer simulation. The SDR system was used to measure the EMV dependent on the distance between the antennas. These measurements were satisfactory, i.e. they were in line with the expectations. To be specific, the synchronization algorithms, described in Section 2.2 could recover the signal timing. That is a prerequisite for information transmission. The subsequent EMV measures establish that information transmission is possible with the test setup, even for a distance of 150 cm between the antennas. Therefore, the antenna functionality was established.

We predict that in future antennas will be tested with the actual RF system. Such antenna testing can establish whether there is a problem with the functionality. Only if a problem is found, antenna and baseband models need to be tested separately. In other words, there is no need to validate the model results, as long as the overall functionality of the communication system is established. Thus, there is a huge time saving potential.

## 6. CONCLUSION

The main aim of this research was to design, simulate and test a rectangular micro strip patch antenna that resonates at 5GHz. We investigated the general concept of a Gain, Directivity, Radiation Pattern, Efficiency, and Bandwidth of a directional antenna. The directional antenna was successfully designed and simulated using CST microwave studio. The physical antenna was created by milling the shape from a PCB. The device achieved a bandwidth of 77.8MHz and high gain of 6.27dBi with a directional radiation pattern having it main lobe in the boresight direction.

The main contribution of our work is that we established optimal parameters for the patch antenna. With these parameters, the antenna meets and for some performance measures exceeds the requirements. The antenna implementation was tested and verified with an SDR platform. We found that the simulated results matched the practical measurements.

### 6.1 RECOMMENDATIONS

The main advantage of a rectangular micro strip patch directional antenna is its high directivity. The directional antenna designed, in this research, can be modified such that it represents an omnidirectional antenna by introducing an inverted "z" slot asymmetrical structure at the center of the radiating element (patch), once incorporated onto the rectangular patch two orthogonal components of electric field will be excited by a $90^o$ phase difference. Hence, this will improve the antenna flexibility.

## REFERENCES

[1] K. Pahlavan and P. Krishnamurthy, "*Principles of Wireless Networks: A Unified Approach*", Prentice Hall, 2011.

[2] T.S. Rappaport, "*Wireless Communications: Principles and Practice*", Prentice Hall, 1996.

[3] R. Shorey, A. Ananda, M.C. Chan and W.T. Ooi, "*Mobile, Wireless, and Sensor Networks: Technology, Applications, and Future Directions*", John Wiley and Sons, 2006.

[4] Ser Wah Oh, Yugang Ma, Ming-Hung Tao and Edward Peh, "*The First Step towards better Utilization of Frequency Spectrum*", Wiley Online Library, 2016.

[5] Computer simulation technology, products applications, academic event support company, Available at: https://www.cst.com/products/CST, Accessed on 2016.

[6] B. Sklar, "*Digital Communications*", Prentice Hall, 2001.

[7] J. Torresen, "A Divide-and-Conquer Approach to Evolvable Hardware", *Proceedings of International Conference on Evolvable Systems*, pp. 57-65, 1998.

[8] M. Dillinger, K. Madani and N. Alonistioti, "*Software Defined Radio: Architectures, Systems and Functions*", John Wiley and Sons, 2005.

[9] C. Larman and V.R. Basili, "Iterative and Incremental Developments. A Brief History", *Computer*, Vol. 36, No. 6, pp. 47-56, 2003.

[10] Walter Tuttlebee, "*Software Defined Radio: Enabling Technologies*", John Wiley and Sons, 2002.

[11] Tuttlebee, W.H. ed., 2003. "*Software Defined Radio: Enabling Technologies*", John Wiley and Sons, 2003.

[12] C.K. Chua, K.F. Leong and C.S. Lim, "*Rapid Prototyping: Principles and Applications*", 2nd Edition, World Scientific Publishing, 2003.

[13] 145-2013-IEEE Standard for Definitions of Terms for Antennas, *IEEE*, 2014.

[14] K.F. Lee and K.M. Luk, "*Microstrip Patch Antennas*", Imperial College Press, 2011.

[15] R. Waterhouse, "Small Microstrip Patch Antenna", *Electronics Letters*, Vol. 31, No. 8, pp. 604-605, 1995.

[16] S. Dey and R. Mittra, "Compact Microstrip Patch Antenna", *Microwave and Optical Technology Letters*, Vol. 13, No. 1, pp. 12-14, 1996.

[17] A. Rani and R.K. Dawre, "Design and Analysis of Rectangular and U Slotted Patch for Satellite Communication", *International Journal of Computer Applications*, Vol. 17, No. 7, pp. 36-40, 2010.

[18] Umar U and Seman N, "Design and Simulation of Rectangular and Circular Microstrip Patch Antenna at 1.8GHz", University Technologi Malesiya (UTM), 2016.

[19] Muhammad Sani Yahya and S.K.A. Rahim, "15GHz Grid Array Antenna for 5G Mobile Communications System", *Microwave and Optical Technology Letters*, Vol. 58, No. 12, pp. 2977-2980, 2016.

[20] Y.T. Jean-Charles, V. Ungvichias and J.A. Barbosa, "Effects of Substrate Permittivity on Planner Inverted-F Antenna Performance", *Journal of Computers*, Vol. 4, No. 7, pp. 610-614, 2009.

[21] P. Puttaswamy, P.S.K. Murthy and B.A. Thomas, "Analysis of Loss Tangent Effect on Microstrip Antenna Gain", *International Journal of Applied Sciences and Engineering Research*, Vol. 3, No. 6, pp. 1102-1107, 2014.

[22] H. Werfelli, K. Tayari, M. Chaoui, M. Lahiani and H. Ghariani, "Design of Rectangular Microstrip Patch Antenna", *Proceedings of IEEE 2nd International Conference on Advanced Technologies for Signal and Image Processing*, pp. 798-803, 2016.

[23] Norhudah Seman, "Antenna Design of Rectangular and Circular Shape", Technical Report, Department of Wireless Communiation Centre, University Teknologi Malasiya, 2016.

[24] S. Sankaralingam and B. Gupta, "Determination of Dielectric Constant of Fabric Material and Their use as Substrates for Design and Development of Antenna for Wearable Application", *IEEE Transactions on Instrumentation and Measurement*, Vol. 59, No. 12, pp. 117-123, 2010.

[25] C.A. Balanis, "*Antenna Theory: Analysis and Design*", 2nd Edition, John Wiley and Sons, 1997.

[26] Fujun Xu, Lan Yang, Da Zhao, Muwen Jiang and Yiping Qiu, "Effect of a Surface Resing Layer Covering the Radiating Patch on Performance of a Three Dimentional Patch on Performance of a Three Dimentional Integrated Microstrip Patch Antenna", *Journal of Composite Materials*, Vol. 45, No. 15, pp. 1627-1635, 2010.

[27] D.M. Pozar, "*Microwave and RF Design of Wireless Systems*", John Wiley and Sons, 2001.

[28] Toney J. Rouphael, "*RF and Digital Signal Processing for Software-Defined Radio, A Multi-Standard Multi-Mode Approach for Software-Defined Radio*", Newnes, 2009.

[29] ZedBoard Product Briefs, Available at: http://zedboard.com/sites/default/files/Avnet%20ZedBoard%20Brochure%20English%20Version.pdf

[30] XILINX, Available at: http://www.xilinx.com/products/boards_kits/zynq-7000.htm, Accessed on 2014.

[31] Rice Michael, "*Digital Communications-Adiscrete-Time Approach*", 1st Edition, Prentice Hall, 2008.

[32] B.S. Junior, V.C. Olveira and B.J. Gunnar, "Software Define Radio Implementation of a QPSK Modulation/Demodulator in an Extensive Hardware Platform Based on FPGAs Xiling ZYNQ", *Journal of Computer Science*, Vol. 11, No. 5, pp. 598-611, 2015.

[33] J.P.A. Perez, S.C. Pueyo and B.C. Lopez, "*Automatic Gain Control*", Springer, 2011.

[34] Prachi Gupta and Brajlata Chauhan, "Performance analysis of Bandwidth and Gain Improvement of Predicted Wide Slot Antenna using Parasitic Patch", *Academic Journals Scientific Research and Essay*, Vol. 9, No. 15, pp. 661-666, 2014.

[35] A.M. Large and S.U. Bhandari, "QPSK System implementation on FPGA", *International Journal Emerging Trends Technology*, Vol. 1, No. 1, pp. 139-143, 2014.

[36] K. Mueller and M. Muller, "Timing Recovery in Digital Synchronous Data Receivers", *IEEE Transactions on Communications*, Vol. 24, No. 5, pp. 516-531, 1976.

[37] RF Microwave Knowledge Center, Available at: http://www.antennatheory.com/definitions/vswr.pp, Accessed on 2016.

[38] Chang Kai, "*RF and Microwave Wireless System*", John Wiley and Sons, 2000.

[39] S. Gurpreet and S.M. Ranjit, "Microstrip Patch Antenna with Defected Ground Structure for Bandwidth Enhancement", *International Journal of Computer Application*, Vol. 73, No. 9, pp. 78-83, 2013.

[40] Trevor S. Bird, "Definition and Misuse of Return Loss", *IEEE Antenna and Propagation Magazine*, Vol. 59, No. 2, pp. 166-167, 2009.

[41] R. Schmogrow et. al., "Error Vector Magnitude as A Performance Measure for Advanced Modulation Formats", *IEEE Photonics Technology Letters*, Vol. 24, No. 1, pp. 61-63, 2012.