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2014 J. Phys.: Conf. Ser. 495 012028

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10 GHz Microstrip Spanar Antennas: An Experimental Analysis

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Abstract. This paper presents Spanar Antenna designed using CST Microwave Studio Simulation 2011. The proposed antenna was designed to operate at 10 GHz, which suggested return loss, S_{11} must be less than -10 dB and voltage standing wave ratio (VSWR) must be less than 2. The best performance of simulation of Spanar Antenna was obtained at a small size of 24.8 mm x 8.0 mm with dimension board of FR4 substrate 31.7 mm x 18.5 mm. The thickness (h) and dielectric constant (ϵ_r) of substrate were 1.6 mm and 4.7. An analysis between simulation result and measurement result has been compared in order to see the antenna performance.

1. Introduction

Antenna is a one of useful component in communication era in different communication bands [1]. 10 GHz frequency spectrum in Malaysia mainly is used for fixed wireless access with two spectrum band; lower (10.15 – 10.30 GHz) and upper (10.50 – 10.65 GHz) band [2]. The fixed wireless access is mainly used for point-to-point communication usually between two base stations as a backhaul as an option to replace wired connectivity. Besides that, antenna is being proposed at 10 GHz for bio-detecting system to detect heart and respiration rates of human within far away [3]. It is due wireless bio-signal detection is the recent tendencies in the medical industry, and research for sensing bio-signal continues to rise.

A novel spanar printed antenna design aiming for X-Band frequency spectrum at 10 GHz radar applications that has advantages such as simple structure, compact size and easy fabrication is proposed in this work. By introducing a slit to the antenna, frequency operation for the radar

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application can be achieved [4]. Details of the antenna design are described, and both simulated and measured results such as return loss and radiation patterns are presented and discussed.

In this paper, the Spanar antenna design has referred from micro strip element. This antenna will use high dielectric constants such as FR4 with relative permittivity of $\epsilon_r = 4.7$ and thickness, h of 1.6 mm in order to get a smaller antenna size. An analysis between simulation and measurement results are conducted to investigate the effect of parameter for length by feed line on antenna performance. The thickness of copper of the patch is 0.035 mm with antenna feed by 50 Ω .

2. Antenna Design and Architecture

The dimension of patch is treated a circular patch element by the actual radius, a_e is given in [5] [6]. f_r is the resonant frequency, v_o is the free space speed of light, h is the thickness of substrate and ϵ_r is the dielectric constant of substrate.

The Effective radius of patch was starting with:

$$= \frac{8.791 \times 10^9}{f_r \sqrt{\epsilon_r}}$$

Actual/physical radius of patch, a :

$$a = \frac{1}{\left[1 + \frac{2h}{\pi\epsilon_r} \left(\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right)\right]^{\frac{1}{2}}}$$

Effective radius of patch, a_e :

$$a_e = a \left[1 + \frac{2h}{\pi\epsilon_r a} \left(\ln\left(\frac{\pi a}{2h}\right) + 1.7726\right)\right]^{\frac{1}{2}}$$

The dimension of rectangular patch is using equation as follows in [7] [8] where f_r is the resonant frequency, ϵ_r is the dielectric constant of substrate and c is the space speed of light.

Width of patch, W_r :

$$W_r = \frac{c}{2f_r} \sqrt{\frac{2}{\epsilon_r + 1}}$$

Length of patch, L_r :

$$L_r = \frac{0.49 \frac{c}{f_r}}{\sqrt{\epsilon_r}}$$

Effective of dielectric constant, ϵ_{reff} :

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[1 + 12 \frac{h}{W}\right]^{-\frac{1}{2}}$$

Changes of length of patch, ΔL :

$$\Delta L = 0.412h \frac{(\epsilon_{reff} + 0.3) \left(\frac{W}{h} + 0.264\right)}{(\epsilon_{reff} - 0.258) \left(\frac{W}{h} + 0.8\right)}$$

Actual/physical length of patch, L :

$$L = \frac{1}{2f_r \sqrt{\epsilon_{reff}} \sqrt{\mu_o \epsilon_o}}$$

Effective length of patch, L_{eff} :

$$L_{eff} = L + 2\Delta L$$

The length of triangular patch element can be determined in [9]. f_r is the resonant frequency, a be the side length of the triangular and c is the space speed of light.

Length of side of patch, a :

$$a = \frac{2c}{3f_r\sqrt{\epsilon_r}}$$

$$f_r = \frac{2c}{3a\sqrt{\epsilon_r}}$$

The dimension of width and length of feed line are determined in [10]. d is the thickness of substrate, Z_o is the impedance 50Ω , ϵ_r is the dielectric constant of substrate, ϕ is the loss tangent for dielectric constant, f is the frequency and c is the space speed of light.

Width of feed line of patch, W_f :

$$A = \frac{Z_o}{60} \sqrt{\frac{\epsilon_r + 1}{2}} + \frac{\epsilon_r - 1}{\epsilon_r + 1} \left(0.23 + \frac{0.11}{\epsilon_r} \right)$$

$$B = \frac{377\pi}{2Z_o\sqrt{\epsilon_r}}$$

$$W_f = \frac{8e^A}{e^{2A} - 2} \times d \text{ if } \frac{W}{d} < 2$$

$$W_f = \frac{2}{\pi} \left[B - 1 - \ln(2B - 1) + \frac{\epsilon_r}{2\epsilon_r} + 0.39 - \left(\frac{0.61}{\epsilon_r} \right) \right] \times d \text{ if } \frac{W}{d} > 2$$

Length of feed line of patch, L_f :

$$L_f = \frac{\phi c}{2\pi f \sqrt{\epsilon_{reff}}}$$

The calculation value is used in the CST Microwave Studio Simulation Software. The parameter design adjusted by the parametric method is used to achieve 10 GHz operating frequency. **Figure 1** and **Figure 2** show the geometry of the Spanar antenna that has been designed to cover operating frequency of 10 GHz.

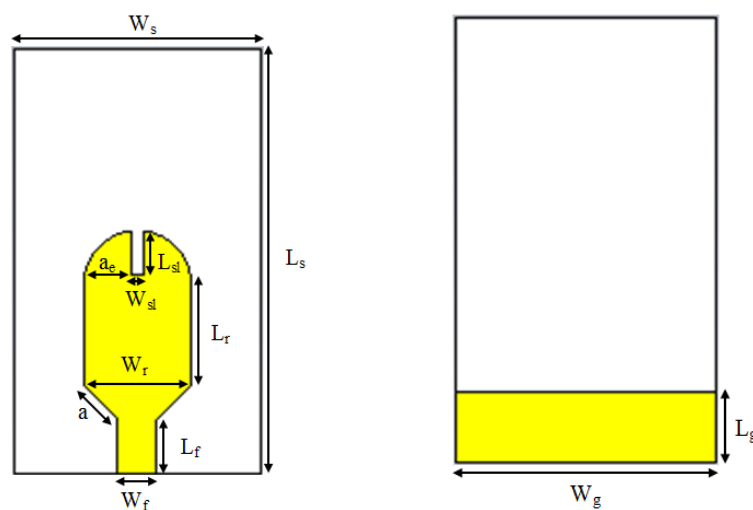


Figure 1. Front view of

Figure 2. Back view of

geometry of the proposed antenna.

geometry of the proposed antenna.

The antenna is fabricated on a thin FR4 substrate of thickness of 1.6 mm with a relative permittivity, ϵ_r is equal 4.7. The thickness of copper of the patch is 0.035 mm with antenna plate fed by 50 Ω . **Figure 3** shows front view of Spanar antenna and **Figure 4** shows back view of Spanar antenna. **Table 1** is shown the parameter and dimensions of the proposed Spanar antenna.

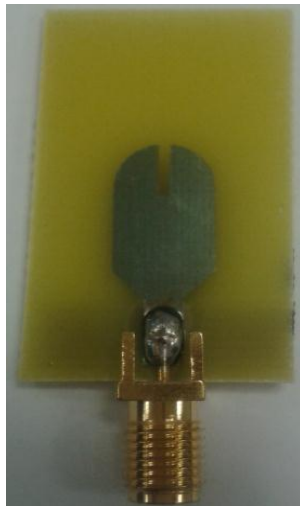


Figure 3. Front view of Spanar antenna.



Figure 4. Back view of Spanar antenna.

Table 1. Proposed Spanar antenna parameter.

Parameter	Value (mm)
$L_s \times W_s$	31.7 x 18.5
a_e	4.0
W_r	8.9
L_r	7.6
a	9.0
W_f	2.9
L_f	5.235
W_g	5.0
L_g	18.5
W_{sl}	1.0
L_{sl}	3.95

3. Results and Discussion

Figure 5 shows the simulation and measurement of Return Loss, S_{11} in dB of Spanar antenna. From graph, the antenna achieves the target of operating frequency at 10 GHz. The designs are simulated by using the CST Microwave Studio Simulation. The best Return Loss, S_{11} of simulation for this antenna is obtained -30.5 dB when it reaches the length of feed line antenna, which is at 5.235 mm. The measurement is obtained -17.07 dB using the Vector Network Analyzer. The good antenna must have return loss below than -10dB where is return loss is that portion of a signal that cannot be absorbed by

the end of line termination, or cannot cross an impedance change at some point in the transmission system. It also show that the antenna has less loss and able to transmit 90% from the maximum power. In this return loss the good efficiency antenna is less than 90%. In this simulation the efficiency is below than 90%. This measurement result is due to the soldering the connector to at the antenna feed lines.

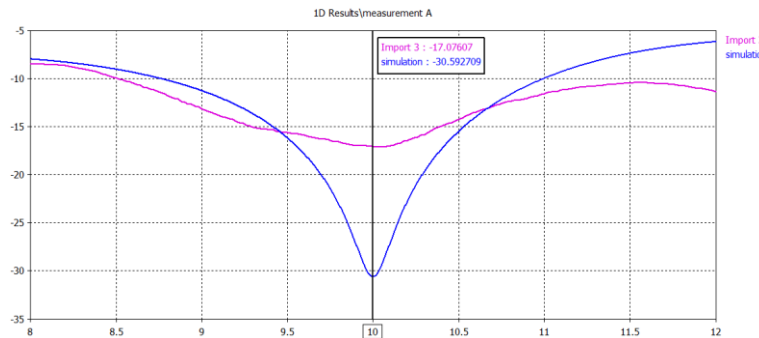


Figure 5. Return Loss, S11 in dB of Spanar antenna.

In the process of achieving this particular configuration for Spanar antenna to perform efficiently there is always a reflection of the power, which leads to the standing waves, which is characterized by the Voltage Standing Wave Ratio, VSWR. VSWR at the respective operating frequency is determined 1.06 from simulation and 1.29 from measurement that means the reflection coefficient is 0.09, which is less than 10% and plot in **Figure 6**.

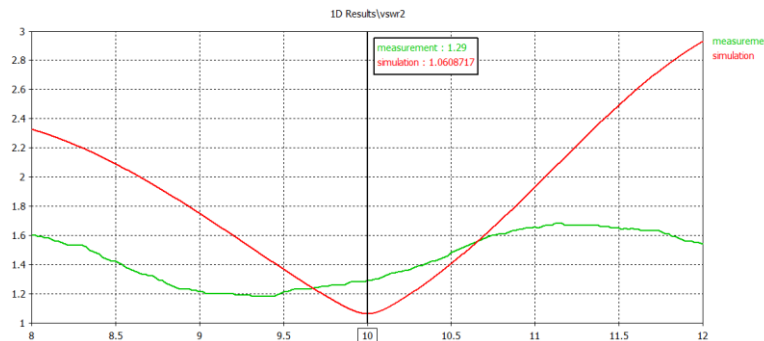


Figure 6. Voltage Standing Wave Ratio, VSWR of Spanar antenna.

The Directivity and the Gain are probably the most important parameters of an antenna. In this simulated Spanar antenna having the gain value is 4.123 dB as shown in **Figure 7** and directivity value its similar same with the value of parameter gain which is 5.587 dB as shown in **Figure 8**. Directivity is the ability of an antenna to focus energy in a particular direction when transmitting or to receive energy better from a particular direction when receiving. The relationship between gain and directivity: $Gain = efficiency/Directivity$. The Gain of antenna is an actual which is less than the directivity due to ohmic losses in the antenna or its radome [11]. From both the efficiency is -1.4 dB which is respectively less than -3 dB and nearly 0 dB.

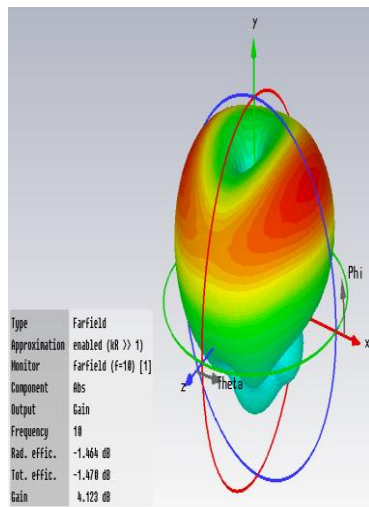


Figure 7. Gain of the proposed antenna.

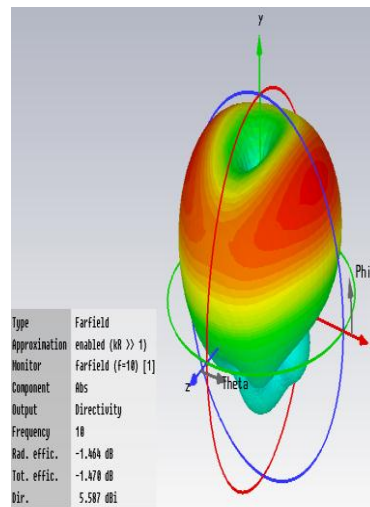


Figure 8. Directivity of the proposed antenna.

From the radiation pattern, parameter of HPBW and FNBW is obtained. **Figure 9** shows E plane radiation pattern the HPBW is 54.3° and FNBW is 108.6° . **Figure 10** shows H plane radiation pattern HPBW is 131.4° and FNBW is 262.8° . The HPBW are obtained by the angular width (3dB). HPBW is the angular separation in which the magnitude of the radiation pattern increases 50% from the peak of the main beam. The FNBW value usually twice the value of HPBW and for this design, the FNBW of both plane is about twice the HPBW and it is fulfil the characteristic which is the FNBW is larger than the HPBW.

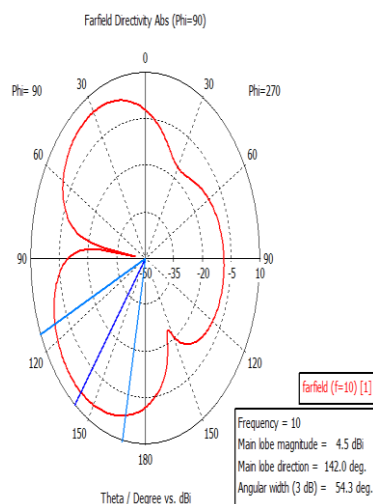


Figure 9. Radiation Pattern in Elevation (E) plane of proposed antenna.

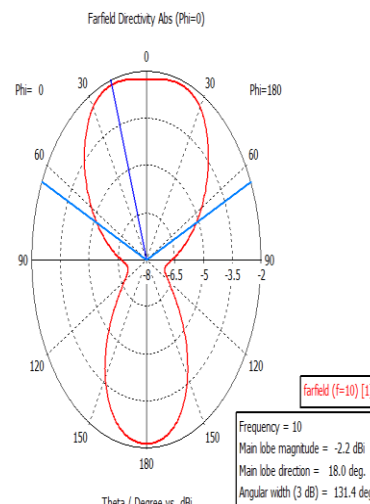


Figure 10. Radiation Pattern in Azimuth (H) plane of proposed antenna.

The parametric study has been done to see the effect by varying the lengths of the element length feed line, L_f . **Figure 11** shows the S-parameter simulations while **Figure 12** shows VSWR of the Spanar for different length, L_f by feed line is simulated by using the CST Microwave Studio Simulation. The most effective response for the antenna is at length feed line at 5.235 mm. The most challenging task in designing the antenna is to sufficiently match to its input transmission line that is

approximately 10 % or less of the incident signal which is lost due to the reflection. VSWR range at the respective operating frequency is determined which is less than 2.

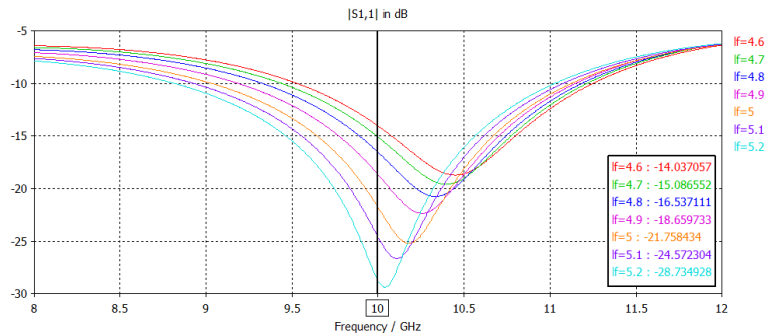


Figure 11. Return loss of the proposed antenna for various lengths of feed line.

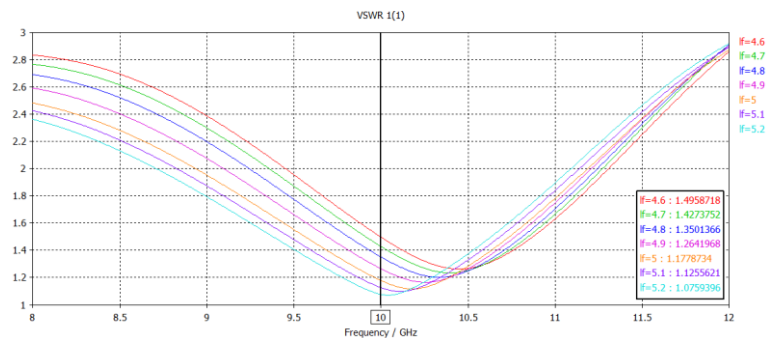


Figure 12. VSWR of the proposed antenna for various lengths of feed line.

Table 2 shows the simulated Return loss and VSWR for different length by feed line. It is obvious that the length of feed line has a lot of effect on the frequency resonance and the return loss also increases. It also displays the VSWR decrease with increases in length by feed line.

Table 2. Comparison different length of feed line, L_f at frequency 10 GHz.

L_f	S_{11}	VSWR
4.6 mm	-14.03 dB	1.49
4.7 mm	-15.08 dB	1.42
4.8 mm	-16.53 dB	1.35
4.9 mm	-18.65 dB	1.26
5.0 mm	-21.75 dB	1.17
5.1 mm	-24.57 dB	1.12
5.2 mm	-28.73 dB	1.07

Conclusion

A 10 GHz Spanar antenna design and concept was successfully discussed and presented. Parametric study of length of feed line that is affected a return loss and VSWR are done. The good antenna must have return loss below than -10dB and VSWR range at the respective operating frequency is determined which are less than 2. Antenna design gain is 4.123 dB and Directivity is 5.587 dB respectively. Also, the radiation patterns in E-plane and H-plane at 10 GHz frequency are obtained which are reported in the paper. The simulated and measurement results are compared and obtained the better result in desired operating frequency. With these features, this antenna is suitable for wireless communication systems operating at X-band.

Acknowledgment

First and foremost, the author would like to thank Universiti Teknikal Malaysia Melaka, Malaysia (UTeM) for financial assistance under project grant PJP/2012/FTMK (43C) S1047 and Zamalah cooperative support. Special dedication to kind-hearted project coordinating supervises lectures, student, parents, public and those involved directly and indirectly for their moral supports, contribution and cooperation in completing this paper.

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