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Design and Development of 6 Elements Aperture Coupled Feed Planar Array Rectangular Microstrip Patch Antenna for CPE WiMAX Application at 3.3 GHz

Yusnita Rahayu[1], Mohamad Tarmizi Ali[2] and Tutut Herawan[3,4,5]

[1]Faculty of Engineering, Department of Electrical Engineering, Universitas Riau, Indonesia
[2]Antenna Research Center (ARC), Microwave Technology Centre (MTC) Faculty of Electrical Engineering, UiTM, Shah Alam, Malaysia
[3]Universitas Negeri Yogyakarta, Indonesia
[4]Universitas Teknologi Yogyakarta, Indonesia
[5]Politeknik Negeri Malang, Indonesia
yusnita.rahayu@lecturer.unri.ac.id

Abstract

In this paper, the 6 elements aperture coupled feed planar array rectangular microstrip patch antenna was designed and developed for CPE WiMAX application. This antenna uses aperture coupled feed to improve bandwidth. The proposed antenna is compared to similar design of antenna with microstrip line feed, to justify that the proposed antenna produces broader bandwidth. Both of antennas are designed and simulated by using HFSS simulation software and operated in WiMAX frequency range of 3.3 GHz. The 6 elements aperture coupled feed antenna gives an impedance bandwidth of 10.53 %, this is broader than the 6 elements microstrip line feed antenna which is only has impedance bandwidth of 6.23 %. The measured return loss shows 30 MHz frequency shifted from the simulated result at 3.35 GHz. Broad radiation pattern E-plane is achieved for both simulated and measured results.

Keywords: *CPE WiMAX; Aperture coupled antenna; Array antenna; Microstrip antenna*

1. Introduction

The Worldwide Interoperability for Microwave Access (WiMAX) is a Broadband Wireless Access (BWA) technology which has high data transfer speed (up to 70 Mbps) and large access range (up to 50 km) [1]. WiMAX is positioned as solution for outdoor and long-range last-mile solutions. It is intended to deliver high speed data communication, and it also has the ability to maintain dedicated links and Voice over IP (VoIP) services at a reliable and high quality speed [2]. WiMAX operates in both licensed and unlicensed spectrum. The WiMAX IEEE 802.16a standard was released in January 2003 with the frequency in use between 2 GHz to 11 GHz [3]. According to Indonesia regulation body, Ministry of Communication and Informatics, No.05/KEP/M.KOMINFO/01/2009, the frequency band used for Wireless Broadband technology is 3.3-3.4 GHz [4]. Antenna plays signifant role in wireless communication. An antenna is a transducer that converts guided electromagnetic energy in a transmission line to radiate electromagnetic energy in free space. Since WiMAX technology was introduced, many researchers have been investigated the antenna design for WiMAX applications. The comparison between WiMAX and WiFi technology has been performed

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in [2]. WiMAX supports mobile, nomadic and fixed wireless applications. To access mobile WiMAX network, it is required a Customer Premise Equipment (CPE) in the subscriber station. Research on microstrip antenna for WiMAX application can be found in literature review [5-15]. Microstrip antenna has numerous advantages that it has small size, low fabrication cost, light weight and it can be easily installed on the CPE. Microstrip antenna has very narrow bandwidth. The bandwidth can be improved by aperture coupled feeding technique [16]. Single layer microstrip line feed elements are typically limited to bandwidth of 2-5%. But aperture coupled antenna provides up to 10-15% of bandwidth with single layer [17]. Several research papers are found in literature that related to the design of microstrip antenna by using aperture coupled feeding technique. Suryakanth & Mulgi [18] has designed the rectangular microstrip antenna by using aperture coupled feeding technique for dual band operation. The antenna resonates for two resonant frequencies at 11.36 GHz and 14.26 GHz. The impedance bandwidths are found to be 23.87% and 21.68%, respectively. The similar study was conducted by Nwalozie, *et al*. [19], where in antenna configuration consisted of 16 array elements. They used aperture coupled feeding for exciting array elements and obtained nearly 11% of impedance bandwidth. Vishwakarma & S. Tiwari [20] presented aperture coupled stacked patch antenna using air gap variation, the measured return loss exhibit an impedance bandwidth of 35% in the frequency range of 2.9 GHz to 6.0 GHz. Lai, *et al* [21] has studied the aperture-coupled microstrip-line feed for circularly polarized patch antenna. The wide impedance and axial ratio bandwidths are achieved by the proposed feeding mechanism.

Other feeding techniques are also proposed by some researchers for WiMAX antenna. A dual-band design of a finite ground coplanar waveguide (CPW) fed antenna for WiMAX was presented by Chitra [8]. Sim & Lai [9] designed an inverted-F antenna for WLAN/WiMAX dual-network applications. To achieve broad bandwidth, the techniques of shorting the open–end of the microstrip feed line to the driven monopole and loading a C-shaped parasitic element with dissimilar arm lengths into the opposite side of the IFA were introduced. Nishamol *et al* [10] presented a broadband proximity coupled patch antenna for IEEE802.11a, WiMAX, HIPERLAN2 and HiSWaNa applications. The V-slots and corner notches are employed in a rectangular patch to achieve broadband operation. Other types of WiMAX antennas are listed in [11-13].

Therefore, this paper describes the design and development of rectangular microstrip patch antenna array for the CPE WiMAX which operates at 3.3 GHz band by using aperture coupled feeding technique. Our present work is an extension from our previous paper published in [14]. The simulation is developed in *Ansoft* HFSS. Comparison between the simulation and measurement results are discussed. Simulation antenna with similar design using microstrip line feed is also done to justify that this proposed feeding technique produced bandwidth is broader than that one.

2. Design Parameters

Figure 1 shows an overview of a microstrip patch antenna design with aperture coupled technique. There are two substrates; one for feed line and another for patch are formed. A slot is formed at center of ground and feed line is below the second substrate. These types of antennas are more popular, because of the patches and slots can be any shape and this gives the improvement in the performance of microstrip patch antennas.

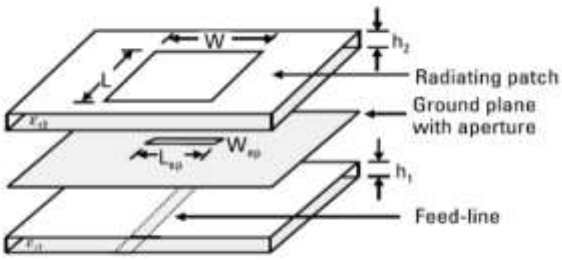


Figure 1. Technique of Aperture Coupled Feed

The simulation is developed in *Ansoft* HFSS with the specifications shown in the Table 1 below.

Table 1. Array Antenna Specification

Features	Specification
Center Frequency (f_0)	3.35 GHz
Array Antenna Configuration	6 Elements Planar Array
Microstrip Radiator used	Rectangular Patch Cooper
Antenna Gain	≥ 6 dB
Antenna Impedance BW	≥ 10 %
Input Impedance (Z_0)	Connector SMA 50 Ω
Substrate	FR4 (Epoxy), ε_r = 4.4

2.1. Patch Dimension

In this design, the patch used is rectangular form that has a width and a length. Equation (1)-(5) is used to calculate the width and length of patch [20].

$$W = \frac{c}{2 f_0 \sqrt{\frac{(\varepsilon_r + 1}{2}}} \tag{1}$$

Equation (1) is used to calculate the width of patch. To determine the length of the patch (L), parameter ΔL which is the length due to the fringing effect is required. Calculation ΔL is given by equation (2-3):

$$\Delta L = 0,412h \frac{\left(\varepsilon_{reff} + 0,3\right)\left(\frac{W}{h} + 0,264\right)}{\left(\varepsilon_{reff} - 0,258\right)\left(\frac{W}{h} + 0,8\right)} \tag{2}$$

The ε_{reff} is the effective dielectric constant is given by:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + 12\left(\frac{h}{W}\right)}}\right) \tag{3}$$

Thus the patch length (L) is given by (4-5):

$$L_{eff} = \frac{c}{2 f_0 ? \sqrt{\varepsilon_{reff}} ?} \tag{4}$$

Where L_{eff} is the effective length of the patch can be given by:

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

From the equation above, the width and length of patch obtained are 27.25 mm and 21 mm, respectively. Size optimization has been done for patch length of antenna design with microstrip line feed. The optimized length is 21.5 mm instead of 21 mm. the optimized is performed to get center frequency fixed at 3.35 GHz.

2.2. Feed Network

Feed network is the feed line configuration of array antenna. Feed network consists of 50 Ω feed line and T-junction. The T-junction used has an impedance of 70.71 Ω and 86.6 Ω.

2.2.1. Calculation of the 50 Ω Feed Line Width (Wf)

The width of the 50 Ω feed line is given by equation (6) and (7) [22]. From the equations, the feed line width is obtained 3.06 mm.

$$B = \frac{60 ? \varepsilon_r^2}{Z_0 \times \sqrt{\varepsilon_r}} \tag{6}$$

$$W = ?\frac{2h}{\pi}\left\{B - \ -\ln(2B-1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left[\ln(B-1) + 0,39 - \frac{0,61}{\varepsilon_r}\right]\right\} \tag{7}$$

2.2.3. Calculation of the T-Junction

This paper uses the T-junction as a power divider [23]. T-junction used has an impedance of 70.71 Ω and 86.6 Ω. The width of T junction 70.71 Ω is given by equation (6) and (7). From the equation, the feed line is 1.6 mm. To calculate the length of the feed line of T junction 70.71 Ω is calculated by the equations (8) to (10):

$$l = \frac{\lambda_o}{4\sqrt{\varepsilon_{eff}}} \tag{8}$$

Where ε_{eff} is an effective dielectric constant calculated by the equations:

$$\frac{W}{h} = ?\frac{2h}{\pi}\left\{B - \ -\ln(2B-1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left[\ln(B-1) + 0,39 - \frac{0,61}{\varepsilon_r}\right]\right\} \tag{9}$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + 12\left(\frac{1}{\mathrm{W/h}}\right)}}\right) \tag{10}$$

From the calculation, the length of the T junction 70.71 Ω feed is obtained 12.57 mm. In addition, *T*-Junction 86.6 Ω is also used for 3 branching points. By using the same equations, the width and length of *T* junction 86.6 Ω are obtained 0.98 mm and 12.77 mm, respectively.

2.3. Aperture Slot

Design of aperture slot is only used by antenna using aperture coupled feed. The width and length of the slot aperture determined by using equation (6) and (7) [15].

$$L_a = 0,2\lambda_0 = \ ,2\times 89,55 = 18\ \text{mm} \tag{11}$$

$$W_a = 0,1L_a = \ ,1\times 18 = 1,8\ \text{mm} \tag{12}$$

From the calculation obtained the slot width (W_a) and length (L_a) are 1.8 mm and 18 mm, respectively. Size optimization has been done for slot aperture length. The optimized length is 20.3 mm instead of 18 mm. the optimized is performed to get center frequency fixed at 3.35 GHz.

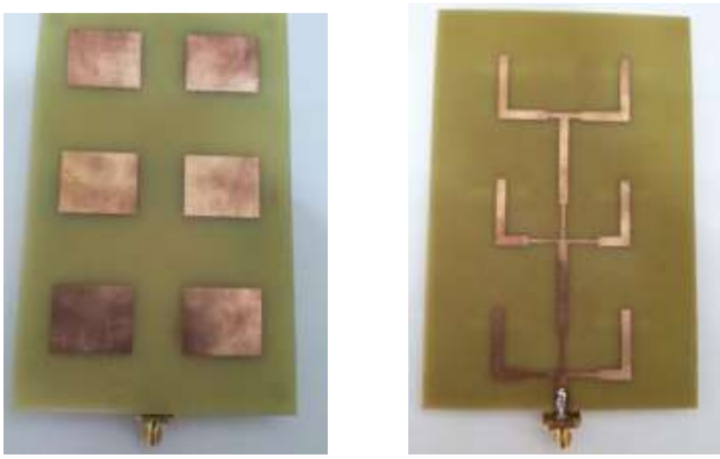
In this paper, two antennas design are simulated. One antenna uses aperture coupled feed and the other one uses microstrip line feed. Bandwidth of both antennas will be compared and analyzed. Table 2 is antenna dimensions after optimization.

Table 2. Antenna Dimensions after Optimization

Dimensions	**Values**		
	Parameters	**Aperture Coupled Feed**	**Microstrip Line Feed**
Substrate FR-4 (epoxy)	Length (L_s)	140.57 mm	140.57 mm
	Width (W_s)	96.02 mm	96.02 mm
Patch	Length (L_p)	21 mm	21.5 mm
	Width (W_p)	27.25 mm	27.25 mm
Ground Plane	Length (l_g)	140.57 mm	140.57 mm
	Width (w_g)	96.02 mm	96.02 mm
50 Ω Feed Line	Length (L_{50})	20 mm	5 mm
	Width (W_{50})	3.06 mm	3.06 mm
T-Junction (86.6 Ω)	Length ($L_{86.6}$)	12.77 mm	12.77 mm
	Width ($W_{86.6}$)	0.98 mm	0.98 mm
T-Junction (70.71 Ω)	Length($L_{70.71}$)	12.57 mm	12.57 mm
	Width ($W_{70.71}$)	1.6 mm	1.6 mm
Aperture Slot	Length (L_a)	20.3 mm	-
	Width (W_a)	1.8 mm	-

2.4. Antenna Geometry

Figure 2 shows the 6 elements aperture coupled feed planar array rectangular microstrip patch antenna prototype that has been developed. This antenna is designed using two FR-4 (epoxy) substrates having 1.6 mm thickness (h) and 4.4 dielectric constant (ε_r). The gap between the substrate-1 and substrate-2 is 3 mm. Radiating elements (patch) are etched on the top surface of the substrate-1. Usually in array configuration, spacing between two radiating elements is kept at a distance $\lambda_o/2$. The network feed is etched below the substrate-2 as shown in Figure 2(b) having thickness (h) and dielectric constant (ε_r) as that of substrate-1. The network feed consists of the 50 Ω feed line and T-Junction. The 50 Ω feed line has the length of 20 mm after it was optimized. The aperture slots are placed on the top surface, which is the ground plane of the substrate-2 exactly at the below center of the radiating elements. The aperture slot has 20.3 mm × 1.8 mm size after it was optimized. The substrate-2 is placed below the substrate-1 that forms aperture coupled feed. The radiating elements are placed on the top surface of substrate-1 shown in Figure 2(a) energizes through coupling slots. The SMA connector is used at the tip of 50 Ω feed line for feeding the microwave power.



(a) Top View of Substrate-1 (b) Bottom View of Substrate-2

Figure 2. Prototype of 6 Elements Aperture Coupled Feed Planar Array Rectangular Microstrip Patch Antenna

Figure 3 shows geometry of 6 elements microstrip line feed planar array rectangular microstrip patch antenna. This antenna was designed using one substrate. The radiating elements and network feed are etched on the top surface of the substrate. The ground plane is placed below of the substrate. The spacing between two radiating elements and network feed are used same with antenna using aperture coupled feed. But the 50 Ω feed line has the length of 5 mm and then length of radiating element is 21.5 mm after it was optimized.

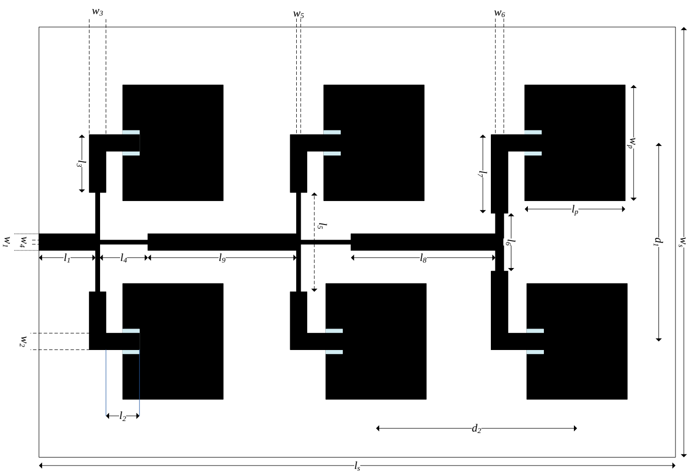


Figure 3. Geometry of both Microstrip Feed Line and Electromagnetically Coupling Feed

3. Results and Analysis

VSWR simulation results for both antennas design with different feeding techniques are shown in Figure 4. It shows that the antenna operates at 3.3-3.4 GHz. Both antennas provide well matched VSWR at the desired frequencies.

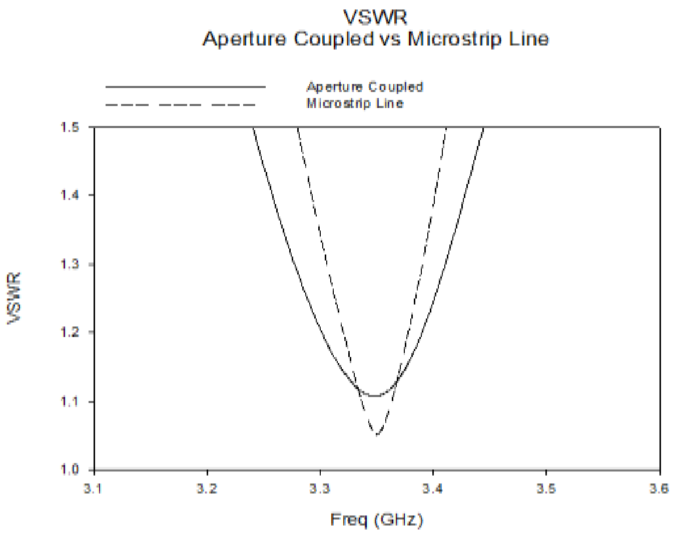


Figure 4. VSWR Simulation Results for Aperture Coupled and Microstrip Feed Line Techniques

The impedance bandwidth is calculated using the following formula [24]:

$$Bandwidth = \frac{f_2 - f_1}{f_c} \times 100\ \% \tag{13}$$

Where, f_2 and f_1 are higher and lower cut-off frequency of the band respectively, when its return loss reaches ≤ -10.16 dB (VSWR ≤ 1.9) and f_c is the center frequency of this band. Comparison of bandwidth for both antennas design, using aperture coupled feed and microstrip line feed, is given in Table 3.

Table 3. Comparison of Antenna Bandwidth

Antenna	Lower Frequency (GHz)	Higher Frequency (GHz)	Center Frequency (GHz)	Bandwidth	
				MHz	%
6 Elements microstrip line feed planar array rectangular microstrip patch antenna	3.236	3.444	3.34	208	6.23
6 Elements aperture coupled feed planar array rectangular microstrip patch antenna	3.18	3.5335	3.3568	353.5	10.53

Table 3 presents the 6 elements microstrip line feed planar array rectangular microstrip patch antenna having an impedance bandwidth of 208 MHz (6.23 %). And then the 6 elements aperture coupled feed planar array rectangular microstrip patch antenna gives wider impedance bandwidth (10.53%) when compared to antenna using microstrip line feed. The 6 elements aperture coupled feed planar array rectangular microstrip patch antenna achieves bandwidth of 10% which is usually bandwidth obtained single element antenna using aperture coupled feed. Figure 5 shows the gain of each antenna versus frequency. Gain of 6 elements aperture coupled feed planar array rectangular microstrip patch antenna at 3.4 GHz is 8.4327 dBi. This gain has achieved the required specification (≥ 6 dBi). This antenna gain is higher compared to the gain of 6 elements microstrip line feed antenna which is only 3.8805 dBi. Aperture coupled antenna is able to decrease surface wave thus improves the gain.

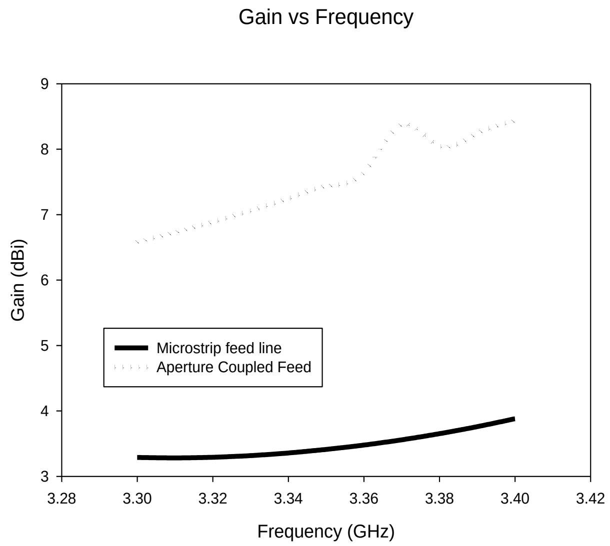


Figure 5. Gain of Antennas

Characteristics of various length of feed line and dimension of aperture slot that affect to the return loss is depicted in Figure 6 and Figure 7, respectively. The effect of various length of 50 Ω feed line to the 6 elements aperture coupled feed planar array rectangular microstrip patch antenna is shown in Figure 6. It shows that the feed length of 20 mm provides -44 dB of return loss. This is the best return loss compared to other feed line length.

Figure 6. Feed Line Length vs Return Loss

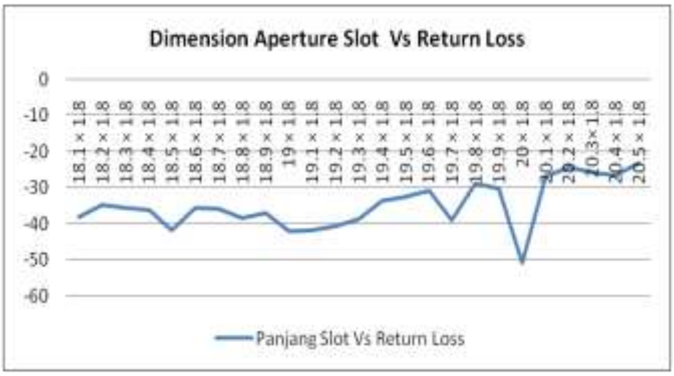


Figure 7. Dimension Aperture Slot vs Return Loss

Figure 7 shows the effect of dimension aperture slot to the return loss. The dimension aperture slot of 20.3 × 1.8 mm provides the return loss of -25.84 dB at 3.35 GHz. But, the dimension of 20 × 1.8 mm gives the return loss of -50.75 dB at 3.28 GHz. The antenna measurement setup in anechoic chamber is shown in Figure 8. Radiation pattern E-plane is measured for each 10^{o} phase shift at 3.3 GHz. Horn antenna is used as antenna reference.

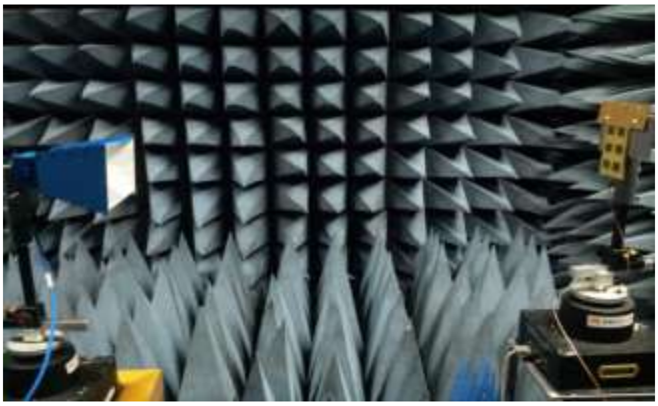


Figure 8. Antenna Measurement Setup in Anechoic Chamber

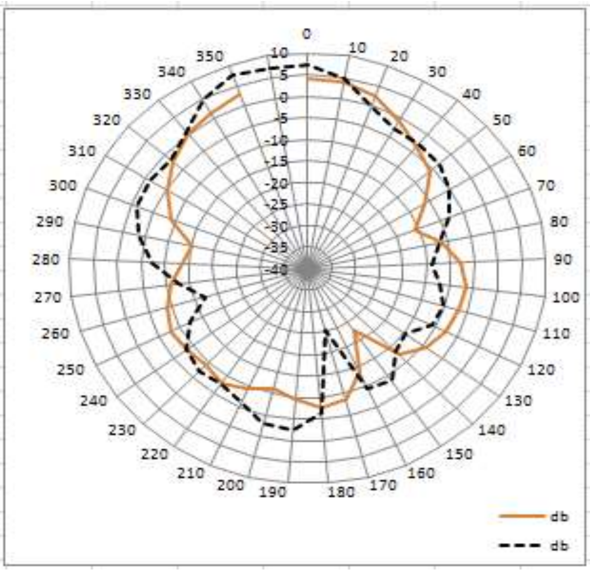


Figure 9 Simulated and Measured Radiation Patterns

The simulated and measured radiation pattern of 6 elements aperture coupled feed planar array rectangular microstrip patch antenna is shown in Figure 9. The measured radiation pattern is shown by solid line and the simulated radiation pattern is shown in dashed line. Both results are almost similar. Comparison return loss for both antennas design with different feeding techniques is performed in Figure 10.

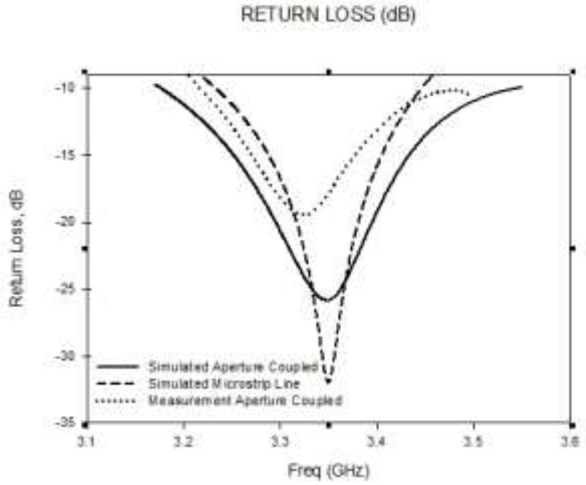


Figure 10. Simulated and Measured Return Loss

From Figure 10, the simulated and measured return loss for 6 element aperture coupled feed planar array rectangular microstrip patch antenna are also been done. It is shown that the maximum return loss for antenna with microstrip line feed is achieved at -32 dB of 3.35 GHz. The maximum return loss for antenna with aperture coupled feed is -25.8 dB at 3.35 GHz, while for measured return loss is -19.38 dB at 3.32 GHz and -17.77 dB at 3.35 GHz. There is frequency shifted such 30 MHz between simulated and measured result but both results are consider good.

4. Conclusions

Design and development of 6 elements aperture coupled feed planar array rectangular microstrip patch antenna operating at 3.3 to 3.4 GHz is successfully performed. Both simulated and measured results are almost similar. There is 30 MHz frequency shifted between simulated and measured return loss. Broad radiation pattern is achieved for both results. The antenna using microstrip line feed is simulated and analysed. It is shown that the microstrip antenna using aperture coupled feed has an impedance bandwidth of 353.5 MHz (10.53%). This antenna has broader bandwidth than antenna using microstrip line feed (6.23%). This antenna has compact in size of about 15 x 10 cm and suitable on the CPE WiMAX device.

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