

# Square Shaped Dual Band Active Integrated Antenna and Passive Antenna

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## Abstract

Wireless local area network (WLAN) applications nowadays has become more popular especially those operating in the 2.4 GHz ISM band. Nowadays, there are a lot of efforts on combining the WLAN, a/b/g bands together. Research on dual band and multiband antennas has gone tremendous development throughout the century. This paper describes the design of the dual band microstrip antenna using scaling factor technique and inset feed with the integration of active devices. The antennas were designed to operate in the indoor WLAN ISM band at 2.4 GHz and 5.2 GHz. The dimensions of each single element of the microstrip antenna, at these operating frequencies were calculated using transmission line model and their individual S-parameter data. The scaling factor of 1.05 has been chosen for the design. The antennas have been fabricated on the FR4 microstrip board with  $\epsilon_r = 4.7$ , substrate thickness of 1.6 mm and  $\tan \delta = 0.019$  and proved to be operating with adequate bandwidth and radiation characteristics.

## 1. INTRODUCTION

Antenna is one of the important elements in the RF system for receiving or transmitting the radio wave signals from and into the air as the medium. Without proper design of the antenna, the signal generated by the RF system will not be transmitted and no signal can be detected for processing. Antenna engineering is a vibrant field which is bursting with activity and is likely to remain so in the foreseeable future [1]. Many types of antenna have been designed to cater with variable application and suitable for their needs. One of the types of antenna is the microstrip antenna. The microstrip antenna has been said to be the most innovative area in the antenna engineering because of its low material cost and its easiness of fabrication which the process can be made inside universities or research institutes.

Active antenna can be defined as an active devices employed in the passive antenna elements to improve the antenna performance [2]. The active integrated antenna (AIA) means that the active device is being incorporated on the same substrate with the passive antenna elements. The implementation of active devices with passive antenna shows

some advantages such as increasing the effective length of short antenna, bandwidth increment and noise factor improvement.

The power amplifier is the most power-hungry component in a transmitter designs, so high-efficiency power amplifier is an important aspect for designing the amplifying type active integrated antenna [3]. The implementation of the amplifier in a passive antenna may increase the antenna gain and bandwidth and will improve the noise performance [2].

## 2. ANTENNA DESIGN

The design of the AIA cannot be done in EM simulation because it involves active elements that cannot be simulated in the EM simulation. The AIA is simulated in the circuit simulation that incorporates the active elements and the passive elements using the Momentum results obtained for each single element.

### A. Square Patch Design Calculations

The design of the square shape patch follows the equation for designing the rectangular shape patch. The same length and width of the patch of the antenna was made to ease the design steps. Inset feed is being introduced into the design to offset the feeding location to the point where matched impedance can be achieved.

The basic parameters of the microstrip has to be determined such the width and length and the feeding technique that is being used. The width of patch can be determined using the equation 1.

$$W = \frac{1}{2f(\sqrt{\epsilon_o\mu_o})} \sqrt{\frac{2}{\epsilon_r + 1}} \quad (1)$$

The  $\epsilon_o$  and the  $\mu_o$  are the permittivity and the permeability in free space respectively. The equation  $\frac{1}{\sqrt{\epsilon_o\mu_o}}$  can also be

interpreted as the speed of light,  $c$  which is  $3 \times 10^8$  m/s. The symbol  $f$  is the resonant frequency that the antenna intended to be operating and  $\epsilon_r$  is the permittivity of the dielectric. The width of the antenna is used for the calculation of the antenna's length.

The patch's length can be calculated using the equations 2. The length's extension,  $\Delta L$  and the effective permittivity,  $\epsilon_{\text{reff}}$  have to be calculated before calculating the length of the microstrip patch as shown in figure 1. The  $h$  is the height of the substrate while the  $W$  is the width of the patch as calculated before.

$$L = \left( \frac{1}{2f \sqrt{\epsilon_{\text{reff}}} \sqrt{\epsilon_0 \mu_0}} \right) - 2\Delta L \quad (2)$$

$$\Delta L = 0.412h \frac{(\epsilon_{\text{reff}} + 0.3) \left( \frac{W}{h} + 0.264 \right)}{(\epsilon_{\text{reff}} - 0.258) \left( \frac{W}{h} + 0.8 \right)} \quad (3)$$

$$\epsilon_{\text{reff}} = \left( \frac{\epsilon_r + 1}{2} \right) + \left[ \left( \frac{\epsilon_r - 1}{2} \right) \left[ 1 + 12 \frac{h}{W} \right]^{-0.5} \right] \quad (4)$$

where:

- $f$  = Operating frequency
- $\epsilon_r$  = Permittivity of the dielectric
- $\epsilon_{\text{reff}}$  = Effective permittivity of the dielectric
- $\epsilon_0$  = Permittivity in free space
- $\mu_0$  = Permeability in free space
- $W$  = Patch's width
- $H$  = Thickness of the dielectric

The width of the patch is made to be in the same value with the length to ease the design process, so the patch will be a square patch. Actually, the determination of the patch's width is important because it affects the efficiency of the antenna. A small value of width compared to the calculated width will lead to low antenna efficiency while high value of width will lead to higher order modes [4].

The type of feeding technique that is being used is the inset feed technique. It is one of the easiest feeding techniques and it is also easy to control the input impedance of the antenna. From figure 1, the input impedance level of the patch can be controlled by adjusting the length of the inset. The calculation of the inset fed is shown in the equations 5 which show the resonant input resistance for the microstrip patch [5].

$$\ell = 10^{-4} \left( \frac{0.001699\epsilon_r^7 + 0.13761\epsilon_r^6 - 6.1783\epsilon_r^5 + 93.187\epsilon_r^4 - 682.69\epsilon_r^3 + 2561.9\epsilon_r^2 - 4043\epsilon_r + 6697}{2} \right) \frac{L}{2} \quad (5)$$

### B. Single Element Design

The design calculation for the square patch has been discussed earlier. The parameters that needed to be calculated are the length of the patch, the inset feed and the feed line's length as shown in figure 1.

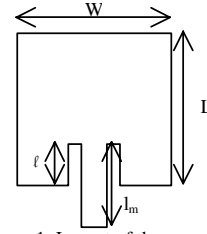


Figure 1: Layout of the square patch.

The calculated parameters of the patch is shown in Table 1. The resonant frequency of the antenna has been designed to be much lower than the expected frequency which at 2.4 GHz and 5.2 GHz as reported in reference [4]. The feed line is made to be a quarter wavelength of the operating frequency. The simulation and modification were done so that the operating frequency will be at the desired frequency with acceptable bandwidth and return loss. The new dimensions of the square microstrip antenna are shown in table 2.

Table 1: Calculated dimensions of the square patch.

Element	Frequency (GHz)	L and W (mm)	Inset, $\ell$ (mm)
1	2.27	30.16	9.47
2	2.38	28.74	9.02
3	4.95	13.46	4.22
4	5.20	12.77	4.01

Table 2: Modified dimensions of the square patch.

Element	Frequency (GHz)	L and W (mm)	Inset, $\ell$ (mm)	$l_m$ (mm)
1	2.27	30.70	10.00	18.36
2	2.38	29.30	9.50	17.47
3	4.95	14.30	4.90	8.40
4	5.20	13.60	4.70	8.00

### C. Dual Band Passive Antenna Design

After the design of the single elements, the elements were combined to form the dual band feature antenna. The width of the transmission line is made to be 3 mm, an approximately 50  $\Omega$  (48 – 49  $\Omega$ ) feed line. The scaling factor design involves in determining the operating frequencies of the single element of the antenna and the length of the transmission lines connecting each elements. The design of the dual band patch antenna needs four elements because a single element cannot cover the whole frequency band of the WLAN. So, with two elements for each frequency band and with proper matching between the elements, it will help to achieve the dual band feature.

Usually, the length of the  $d_m$  is made to be the half wave length of the operating frequency of the element as shown in equation 6. But, to be more precise, in this project, the length  $d_m$  is determined to make sure that the input impedance from the subsequent element (m+1) will be open circuit (high impedance) [6].

$$d_m = \lambda_0/2 \quad (6)$$

The scaling factor technique is the same technique as the log periodic technique which involves the scaling of the dimensions period by period which will make the performance of the antenna periodic to the logarithm of the frequency [6], [7].

The scaling factor technique The dimensions such as the length,  $L$  the width,  $W$  and the inset feed,  $\ell$  of the antenna can be related to the scaling factor,  $\tau$  as shown in the equation 7.

$$\tau = \frac{L_{m+1}}{L_m} = \frac{W_{m+1}}{W_m} = \frac{\ell_{m+1}}{\ell_m} \quad (7)$$

As shown in figure 2, the arrangement of the patch in the scaling method can be related to the factor  $\tau$ . The dimension of the array will be multiplied by the scaling factor  $\tau$  to the elements itself starting from element  $m$  which will then generate the element  $m+1$ ,  $m+2$  and so on.

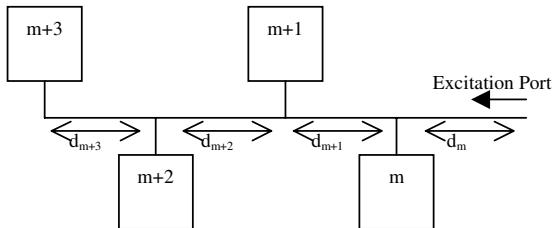


Figure 2: The model of the combination of the elements.

From this technique, the operating frequency will also be scaled to the factor  $\tau$ . The relation of the scaled frequency be viewed as shown below, thus it is called log periodic.

$$\ln \frac{f_2}{f_1} = \ln \tau, \quad \ln \frac{f_3}{f_1} = 2 \ln \tau, \quad \ln \frac{f_4}{f_1} = 3 \ln \tau \quad (3.19)$$

The log periodic technique has been modified to serve the purpose of frequency selective antenna. For example, the indoor wireless LAN system uses the ISM and UNII frequency band at 2.4 GHz and 5.2 GHz. If the log periodic technique is used, the bandwidth of the antenna will go along from the 2.4 GHz band up to 5.2 GHz band as shown in figure 3. But by modifying the log periodic technique, the selective band can be achieved as shown in figure 4. This method uses the scaling method rules, but with frequency selection technique. The operating frequency that will be used is selected to cover both frequency bands.

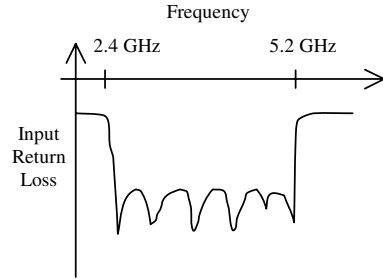


Figure 3: Input return loss example from a log periodic antenna.

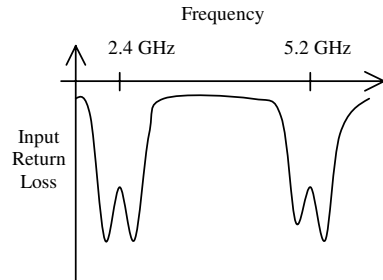


Figure 4: Input return loss from the scaling factor technique.

#### D. Active Integrated Antenna Design

The dual band AIA design uses the same layout of the passive antenna but with the addition of the active element. The active element is placed at the centre between the 2.4 GHz elements and the 5.2 GHz elements as shown in figure 5.

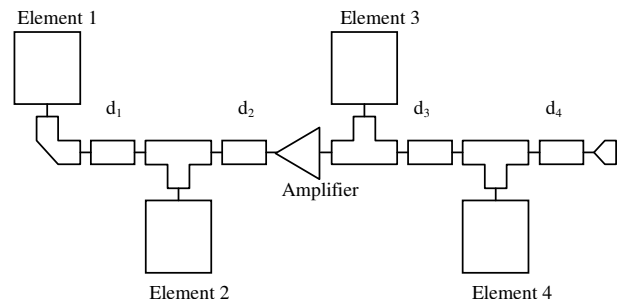


Figure 5: Data block layout of the AIA.

Figure 6 shows the typical biasing configuration for the amplifier. The 2.44 GHz elements will be at the output port of the amplifier while the 5.2 GHz elements will be at the input port of the amplifier. The resistor that has been used is  $150 \Omega$ , so the voltage,  $V_{cc}$  should be at around 9.8 V. The value for the  $C_{block}$  is 100 pF. The typical operating current for the amplifier is 40 mA. So, the voltage is slowly increased from 0 V until the current passing  $R_{bias}$  should be 40 mA.

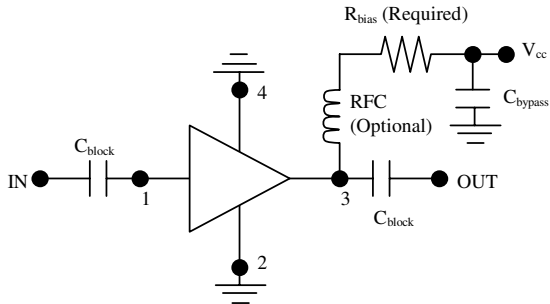


Figure 6: Typical biasing configuration of the amplifier.

The basic layout of the square patch passive antenna and AIA are as shown in figure 7 and 8 respectively.

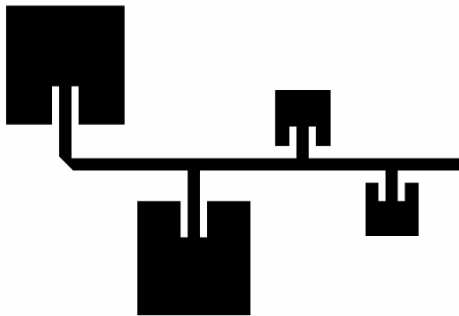


Figure 7: Layout mask of the square passive antenna.

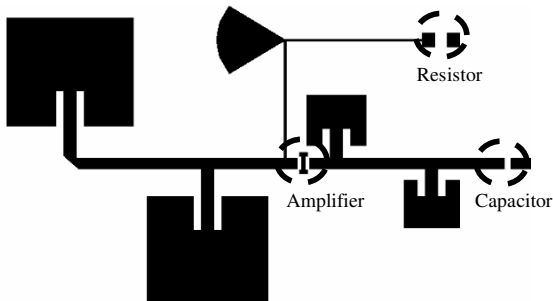


Figure 8: Layout mask of the square AIA.

### 3. RESULT AND DISCUSSION

#### A. Return Loss

The dual band feature on the square patch shows a good return loss at both frequency bands. As shown in the figure 9, at the 2.4 GHz band, the bandwidth percentage for the simulation result is about 8.34% and for the measured result is about 7.78%. For the 5.2 GHz band, the percentage bandwidth for the simulation is about 15.53% and for the measured result is about 17.08%.

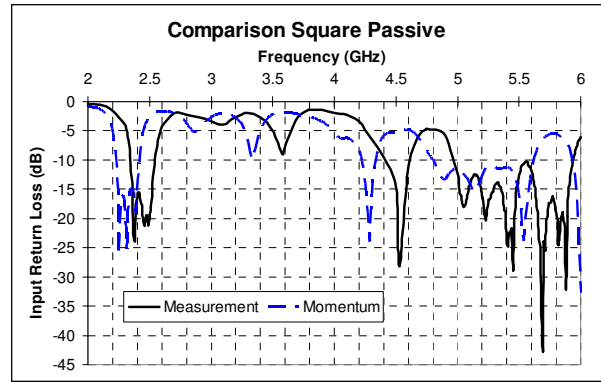


Figure 9: Input return loss for the square patch passive antenna.

The input return loss of the AIA improved much from the same passive structure when the active component was introduced as can be seen in figure 10. After adding the amplifiers to the transmission line, the bandwidth of the square patch antenna increase to 17.39% for the 2.4 GHz band, while at 5.2 GHz band, the bandwidth is much bigger at about 38.31%. Simulation results show a much lesser bandwidth of 8.34% for the 2.4 GHz band, while for the 5.2 GHz band at about 15.39%.

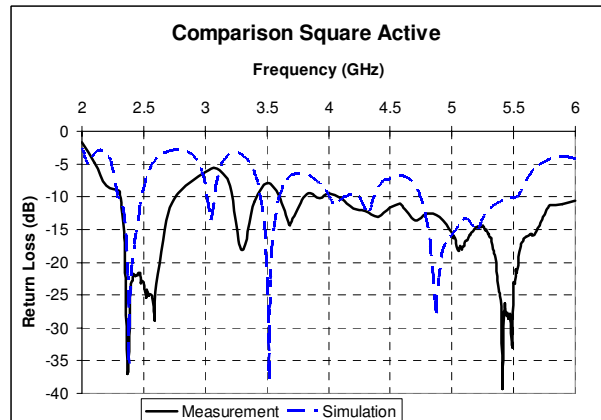


Figure 10: Input return loss for the square patch AIA.

#### B. Radiation Pattern

As shown in figure 11, the half power beamwidth (HPBW) at 2.44 GHz for the square patch at E plane at about  $64^\circ$  with cross isolation at  $0^\circ$  is about 17 dB. In H plane, the HPBW is about  $72^\circ$  with cross isolation of 15 dB.

At 5.2 GHz, the HPBW in E plane is about  $110^\circ$  with cross isolation of 12 dB. The radiation pattern in H plane, the HPBW is about  $68^\circ$  with cross isolation of 18 dB.

Compared to the horn antenna, it is found that the square patch passive antenna at 2.44 GHz has a gain of 8 dB, while at 5.2 GHz, it is -6 dB.

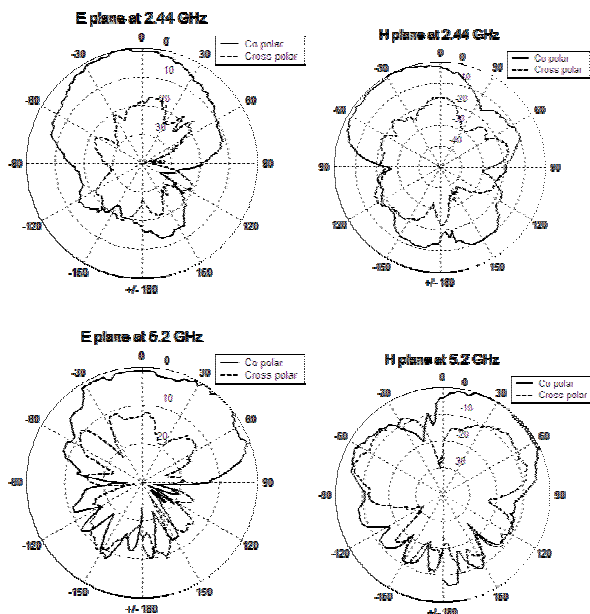


Figure 11: Radiation pattern for square patch passive antenna.

Figure 12 shows the radiation patterns of the square patch AIA. The cross isolation for the active antenna has decreased. The cross isolation at 2.44 GHz for E plane is about 7 dB only, while at H plane is about 4 dB. The HPBW achieved for the E plane and the H plane is about  $54^\circ$  and  $82^\circ$  respectively.

At 5.2 GHz, the cross isolation in E plane is about 19 dB while in H plane, the cross isolation is about 9 dB. The HPBW for the E plane is about  $58^\circ$  and for the H plane is about  $94^\circ$ .

The gains of the AIA are slightly greater than the passive antenna. Compared to the horn antenna, it is found that the square patch passive antenna at 2.44 GHz and 5.2 GHz has a gain of 10 dB and -3 dB respectively.

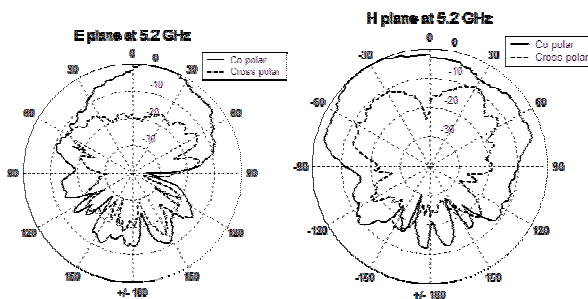
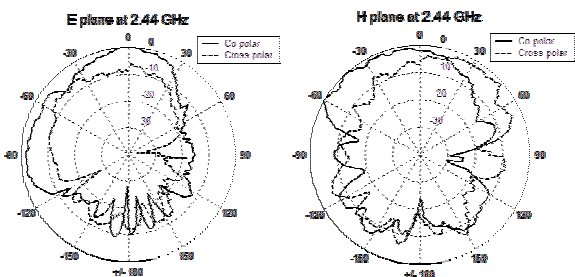


Figure 12: Radiation pattern for square patch AIA.

In terms of bandwidth the passive antennas offer an adequate bandwidth that can be used in the WLAN system, but by using the active element, the bandwidth of the AIA increases as shown in table 3. The square shape AIA shows a greater bandwidth than the passive antenna for both frequency bands.

Table 3: Comparison of the bandwidth percentage between the passive antenna and the AIA.

2 GHz band		5.2 GHz band	
Passive	AIA	Passive	AIA
7.78%	17.39%	17.08%	38.31%

The comparison of HPBW between the passive and the active antenna as shown in table 4, shows an almost similar result, but does give minor improvement to the antenna's beamwidth. The square patch AIA gives a greater HPBW only at the H plane, but in the E plane the passive antenna gives a greater beamwidth.

Table 4: HPBW comparison between the passive antenna and the AIA.

2.44 GHz				5.2 GHz			
E plane		H plane		E plane		H plane	
Passive	AIA	Passive	AIA	Passive	AIA	Passive	AIA
$64^\circ$	$54^\circ$	$72^\circ$	$82^\circ$	$110^\circ$	$58^\circ$	$68^\circ$	$94^\circ$

The cross isolations of the passive antenna as shown in table 5 give better results than AIA. It happens because the active device also increases the cross polarization of the AIAs.

Table 5: Cross isolation comparison between the passive antenna and the AIA.

2.44 GHz				5.2 GHz			
E plane		H plane		E plane		H plane	
Passive	AIA	Passive	AIA	Passive	AIA	Passive	AIA
17 dB	7 dB	15 dB	4 dB	12 dB	19 dB	18 dB	9 dB

The gain of the antennas can be viewed in table 6. From the table, it shows that the integration of an active device does improve the gain of the antenna compared to the passive antenna. Further improvements on the placement of the active device on the transmission line may help to increase the gain of the antenna even further.

Table 6: Gain comparison of the different shapes between the passive antenna and the AIA.

2.44 GHz		5.2 GHz	
Passive	AIA	Passive	AIA
8 dB	10 dB	-6 dB	-3 dB

#### 4. CONCLUSION

The design of the dual band microstrip antenna for WLAN application has been presented. The utilization of the softwares involve in the production process help to minimize the processing time for the calculation and the simulation of the design. Two antennas have been developed and manually fabricated in the facility in Wireless Communication Centre, Universiti Teknologi Malaysia.

The integration of the active device onto the same surface structure of the passive elements, improve the bandwidth of the microstrip antenna. The antennas that have been tested are proven to be operational, operating with sufficient return loss and radiation characteristics.

The performance of the dual band microstrip antenna, that incorporates the 3 basic shapes, has been investigated. The easiest shape to be analyzed and characterized is the square shaped patch, which in overall, shows a good result compared to the other two shapes.

By implementing the log periodic technique, the author was bounded to the rules of the log periodic technique where the design of the elements should be from the lowest frequency to the highest frequency, periodically. Using the scaling technique, some elements were cut-off from the design, and it becomes a frequency selective antenna or in this case a dual band antenna. This improves the physical size of the antenna as only a selected frequency element is needed to be designed.

#### ACKNOWLEDGEMENT

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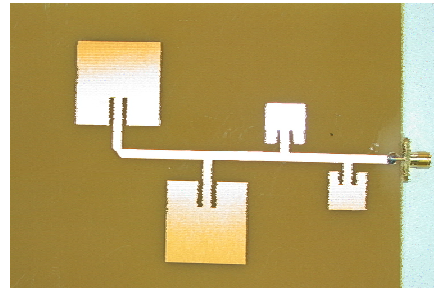


Figure 13: Photograph of the passive circular dual band antenna.

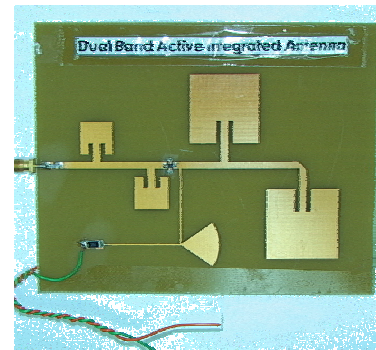


Figure 14: Photograph of the active integrated circular dual band antenna.

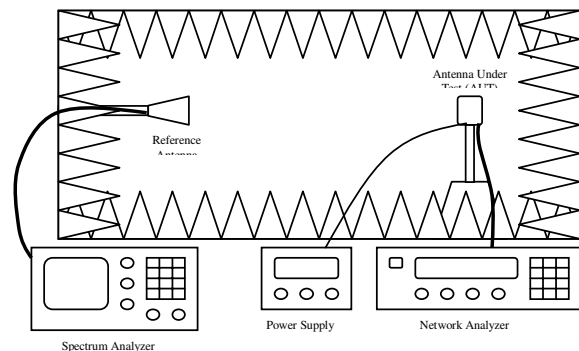


Figure 15: Radiation pattern measurement setup inside the anechoic chamber.