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Bandwidth Enhancement for Microstrip Antenna in Wireless Applications

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Abstract

Antenna is a vital component in wireless application systems. The microstrip antenna can be used for wireless applications as it has features such as light weight, easily mounted and it is easy to mass produce. Although there are many features that suits well for microstrip antenna to be deployed for wireless applications, there is a very serious limitation where it has a very narrow bandwidth. The typical bandwidth of the microstrip antennas is between 1 - 3%. If this limitation is eliminated, the microstrip antenna can be used to its full potential. An alternative bandwidth enhancement technique is studied and then proposed in order to broaden the bandwidth of the microstrip antenna. The wireless application that is selected to be studied is the Wireless Local Area Network (WLAN) based on the IEEE 802.11b standard. In Malaysia, this WLAN band spans from 2.4GHz to 2.48GHz. The bandwidth enhancement technique which is selected is the Identical Dual-Patch Microstrip Antenna with Air-Gap (IDMA). By using this technique, a bandwidth enhancement of about 11% has been achieved. This bandwidth very well covers the required WLAN band with an operating frequency of 2.45GHz.

Keywords: Wireless Local Area Network (WLAN), Identical Dual Patch Microstrip Antenna with Air-Gap (IDMA)

1. Introduction

In recent years, the popularity of wireless applications is ever increasing in the industry as well as in our very own society. There is a very large demand for wireless applications because of its mobility. This is evident as the usage of mobile telephones which is integrated with wireless data services is very common these days. Portable devices which support data and telephony are being used in a mobile computing environment. There is a large investment that has been put into wireless communication by the major companies in the telecommunication industry. This shows that wireless applications are gaining an increase in its usage in our society. One particular wireless application that has experienced this trend is the Wireless Local Area Network (WLAN). According to the guideline by Malaysian Communications and Multimedia Commission (MCMC) on the provision of WLAN service, the unlicensed spread spectrum band in Malaysia for WLAN technologies are from 2.4GHz to 2.48GHz, 5.250 GHz to 5.350GHz and from 5.725GHz to 5.875GHz [1]. In this design, the wireless application that is selected to be studied is the 2.4GHz to 2.48GHz frequency band which is based on the 802.11b WLAN standard. This frequency band is very popular due to its low cost.

The role of antenna for wireless applications has become more vital because the antenna will ensure the efficient connectivity in a WLAN system. WLAN antennas required being low profile, light weight and broad bandwidth. The microstrip antenna suits the features very well except for its narrow bandwidth [2]. The WLAN antenna should have a minimum bandwidth of 100 MHz to fully utilize the WLAN band based on the 802.11b standard. The conventional microstrip antenna could not fulfill this requirement as its bandwidth usually ranges between 1 – 3%. Although the required operating frequency range is from 2.4 GHz to 2.48 GHz, at least double the bandwidth is required to avoid expensive tuning operations and to cause uncritical manufacturing [3]. Therefore, there is a need to enhance the bandwidth of the microstrip antenna for WLAN applications.

This paper investigates a technique which can enhance the bandwidth of the microstrip antenna without increasing the lateral size and the complexity of the microstrip antenna too much. The Identical Dual Patch Microstrip Antenna with Air-Gap (IDMA) bandwidth enhancement technique takes the advantage of using the air gap to increase the total thickness of the microstrip antenna which is essential for bandwidth enhancement. This bandwidth enhanced microstrip antenna can be deployed for the WLAN application operating at a frequency of 2.45GHz.

2. Design of the single-layer microstrip antenna.

The dimensions of the basic single-layer microstrip antenna are calculated using the equations (1) to (7). The shape for the patch which is selected is rectangular for ease of analysis and it is commonly used [4]. The dielectric substrate of low permittivity is selected for the microstrip antenna which is RT/Duroid 5880. The type of copper cladding used for this substrate is the 35µm thick rolled copper. The feeding method for this antenna is coaxial probe method. The 50 Ohms-SMA connector is used as the feed. The simulation was carried out using the full wave analysis simulation tool by Ansoft. The effective permittivity, width, extension of the length and effective length of the patch, the bandwidth as well as the location of the coaxial probe are shown below [5 – 8]:

For w/h>1

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-1/2} \tag{1}$$

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

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

$$L_{eff} = L + 2\Delta L \tag{4}$$

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \tag{5}$$

$$\mathrm{Y_f}\text{ (along the width)} = \frac{W}{2} \tag{6}$$

$$\mathrm{X_f}\text{ (along the length)} = \frac{L}{2\sqrt{\xi_{re}(l)}} \tag{7}$$

where

$$\xi_{re}(l) = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{L}\right)^{-1/2}$$

$$BW(\%) = \left(3.77\left(\frac{\varepsilon_r - 1}{\varepsilon_r^2}\right)\frac{W}{L}\frac{h}{\lambda}\right) \times 100 \tag{8}$$

These calculated dimensions are just approximations but they serve as the starting parameters for the simulation process. After numerous iterative processes to obtain the desired operating frequency and input impedance, the optimum dimensions are obtained and the relative bandwidth is recorded. Figure 1 and Table 1 show the simulated and measured results of the single-layer microstrip antenna.

3. Design of identical dual patch microstrip antenna with air-gap (IDMA).

Initially, the basic single-layer microstrip antenna is designed and fabricated to serve as a benchmark for the design of the bandwidth enhanced microstrip antenna. The rectangular probe-fed patch was selected for both the microstrip antennas due to its ease of analysis and it is commonly used. These microstrip antennas are fed using the 50 Ohms-SMA connector. A low permittivity dielectric substrate was used, namely the 1.575mm thick RT/Duroid 5880. The copper cladding for this substrate is the 35μm thick rolled copper. A full-wave analysis simulation tool by Ansoft was used. The fabricated microstrip antennas were measured with the Agilent E8362B Network Analyzer.

The Identical Dual-Patch Microstrip Antenna with Air-Gap (IDMA) takes the advantage of the air gap which increases the total thickness of the microstrip antenna which is an essential factor for bandwidth enhancement. Another advantage of this design is that the operating frequency of the fabricated microstrip antenna can easily be tuned without the need of a new design by just varying the size of the air gap. Therefore, this makes the design very cost effective. The structure of this bandwidth enhanced microstrip antenna is shown in Figure 2. It uses the same substrate, feeding method and patch shape as the single-layer microstrip antenna.

The following are the Equations (9) and (10) that are used to calculate the bandwidth of the IDMA [4 – 8]:

$$\varepsilon_{av} = \left(\frac{\left(\varepsilon_r h_{d1} + \varepsilon_r h_a + \varepsilon_r h_{d2} \right)}{\left(\frac{h_t}{3} \right)} \right) \tag{9}$$

Where $h_t = h_{d1}+h_a+h_{d2}$

$$BW = \frac{\sqrt{2}p}{45\pi}\left(1 - \frac{1}{\varepsilon_{av}} + \frac{2}{5\varepsilon_{av}^2}\right)\left(\frac{1}{\varepsilon_{av}}\right)\left(\frac{h_t}{\lambda}\right)\left(\frac{W}{L}\right)$$

where

$$p = 1 + \frac{a_2}{20}(k_0 w)^2 + a_4\left(\frac{3}{560}\right)(k_0 w)^4 +$$

$$b_2\left(\frac{1}{10}\right)(k_0 L)^2$$

where $a_2 = -0.16605$, $a_4 = 0.00761$, $b_2 = -0.09142$, $k_0 = 2\pi/\lambda$

The dimensions are calculated from [6-8]. These calculated results are approximated values. It is used to begin with the simulation work. Numerous iterative simulations were done to obtain the optimum configuration of the microstrip antenna. Once the desired operating frequency and input impedance are obtained, the bandwidth is taken at VSWR ≤ 2.

The simulated bandwidth was plotted together with the calculated bandwidth to determine the size of the air gap. When the maximum simulated bandwidth is achieved, the size of the air gap is determined. Once the size of the air gap is determined, the calculated bandwidth can easily be obtained. The reason this is done is because the calculated bandwidth is a straight line equation. This means that the size of the air gap is directly proportional with the bandwidth. However, this is true only up to a certain threshold. Therefore, the calculated and simulated bandwidths are compared to determine this threshold. The calculated and the simulated results are compared in order to determine the exact size of the air gap. The results of these comparisons are shown in Figure 3.

Once the optimum bandwidth is obtained which is 250 MHz, the spacing between the probe-fed patch and the stacked patch can be determined. To further increase the accuracy of the simulated results, fine-tuning is done. After fine-tuning, the maximum achievable simulated bandwidth is 270 MHz. The final configuration of the microstrip antenna is shown in Table 2 and the simulated results are shown in Figure 4.

Using the optimized configuration of the microstrip antenna in the simulation results, this design is fabricated. The measured results of this bandwidth enhanced microstrip antenna are shown in Table 2, Figure 5.

4. Discussion

Based on the results from the simulations and measurements, it is found that the single-layer microstrip antenna has a very narrow bandwidth that is less than 2% which is not sufficient to fully cover the WLAN band based on the 802.11b standard. There is a need to use a bandwidth enhancement technique in this microstrip antenna and the IDMA is deployed. Using this technique, both the simulated and measured results give a bandwidth enhancement at more than 11%. Furthermore, there is a very good agreement between the simulated and measured results of this design. The comparison between the simulated and measured bandwidths of IDMA is shown in Figure 6.

The comparison between the simulated bandwidth of the single-layer microstrip antenna and the IDMA is shown in Figure 7. As for the comparison of the measured bandwidth between those microstrip antennas, this is shown in Figure 8. Figure 9 shows the simulated radiation pattern of IDMA. Figure 10 shows the fabricated microstrip antennas.

5. Conclusion

The summary of the results obtained are shown in Table 3. It is shown clearly that the simulated and measured results are very similar. This bandwidth enhanced microstrip antenna is suitable for the required WLAN application. As mentioned, this technique has its advantages such as it does not increase the lateral size of the microstrip antenna and disadvantages such as it increases the height of the microstrip antenna. Therefore, in microstrip antenna design, it is very important to determine which feature to be prioritized as trade-off issues will always be present.

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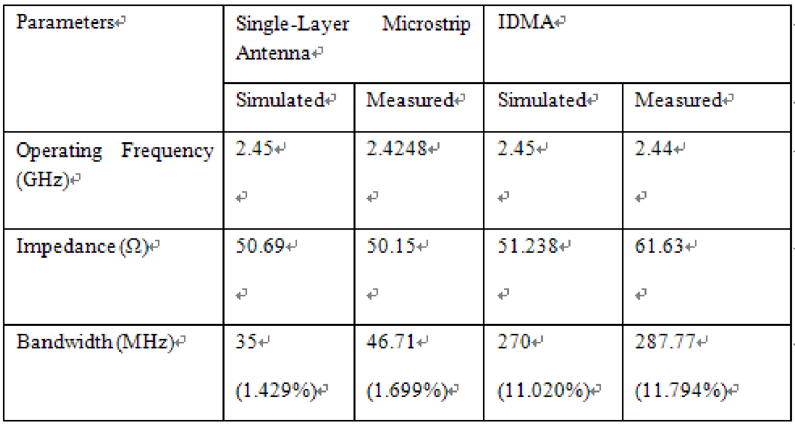
Table 1. Simulated and Measured results of the Single-Layer MSA

Dimensions	**Simulated**	**Measured results**
Width	51mm	51mm
Length	41mm	41mm
Location of the Probe (from the edge)	3.5mm	3.5mm
Spacing (air-gap)	9mm	9mm
Operating frequency	2.45GHz	*2.44GHz*
Input Impedance	50.15 Ω	*61.63 Ω*
Bandwidth	**270MHz (11.020%)**	**287.77MHz (11.794%)**

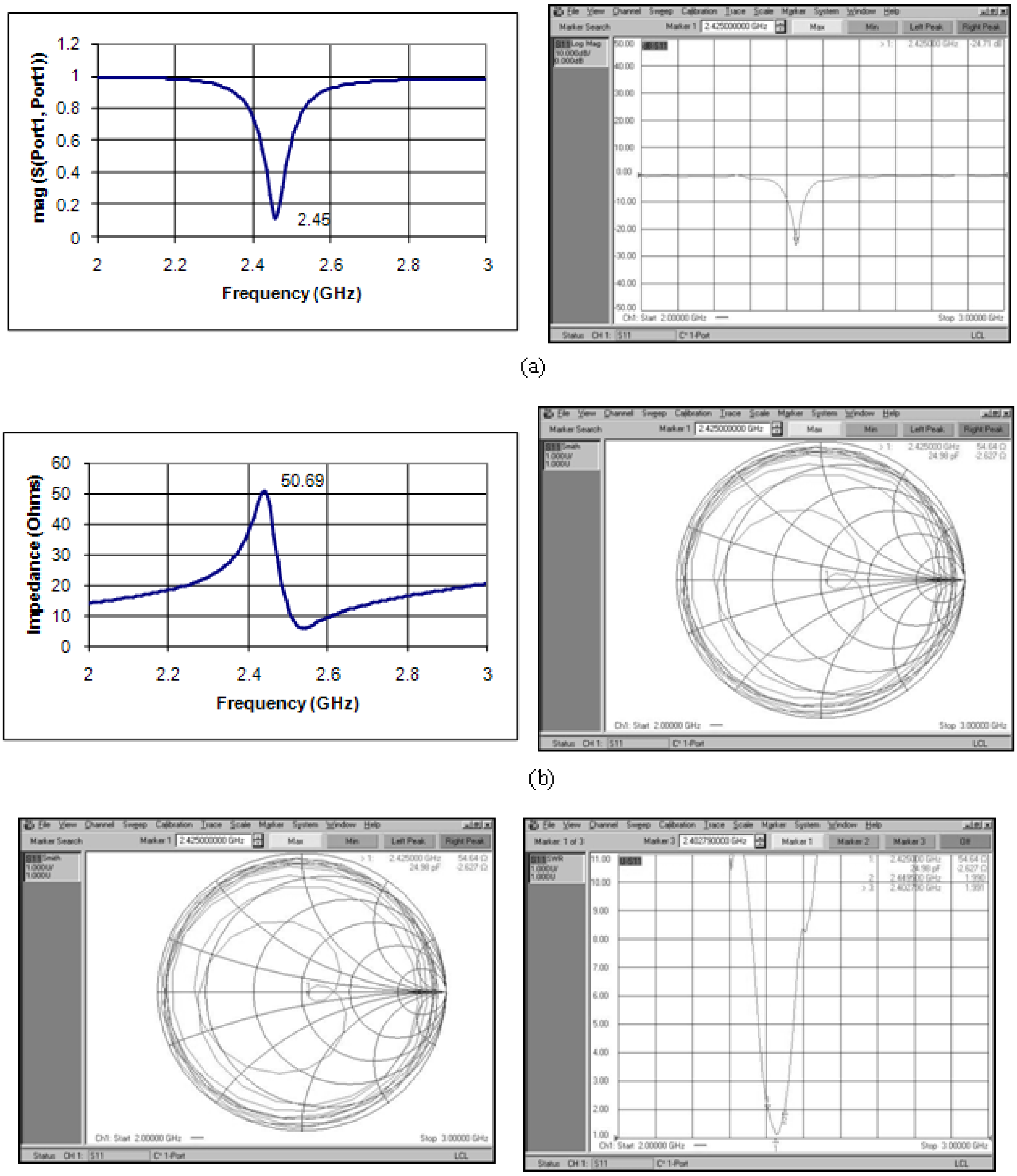
Table 2. Simulated and Measured Results of IDMA



Parameters	Single-Layer Microstrip Antenna		IDMA	
	Simulated	Measured	Simulated	Measured
Operating Frequency (GHz)	2.45	2.4248	2.45	2.44
Impedance (Ω)	50.69	50.15	51.238	61.63
Bandwidth (MHz)	35 (1.429%)	46.71 (1.699%)	270 (11.020%)	287.77 (11.794%)

Table 3. Comparison between the Simulated and Measured Results of the Single-Layer Microstrip Antenna and IDMA

Dimensions	**Simulated**	**Measured**
Width	50mm	same
Length	39.5mm	same
Location of the Probe	13.25mm	same
Operating frequency	2.45GHz	2.425GHz
Input Impedance	50.69 Ohms	54.64 Ohms
Bandwidth	**36MHz (1.469%)**	**46.71MHz (1.699%)**



(a)

(b)

(c)

Figure 1. Simulated and Measured of the Single-Layer Microstrip Antenna for (a) Operating Frequency, (b) Input Impedance and (c) Bandwidth

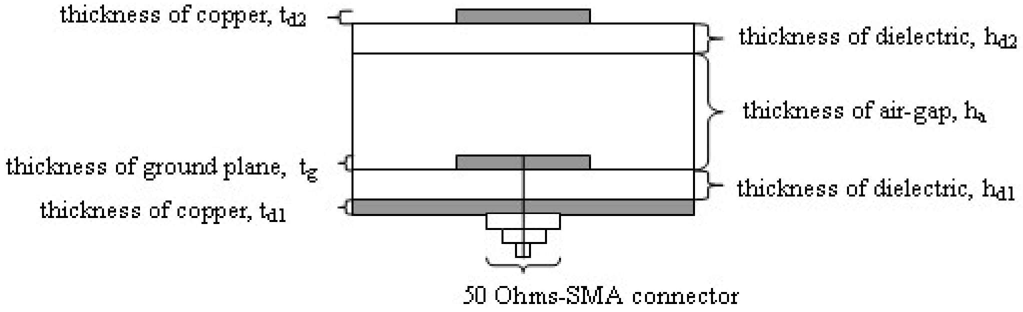


Figure 2. Structure of the IDMA Bandwidth Enhancement Technique

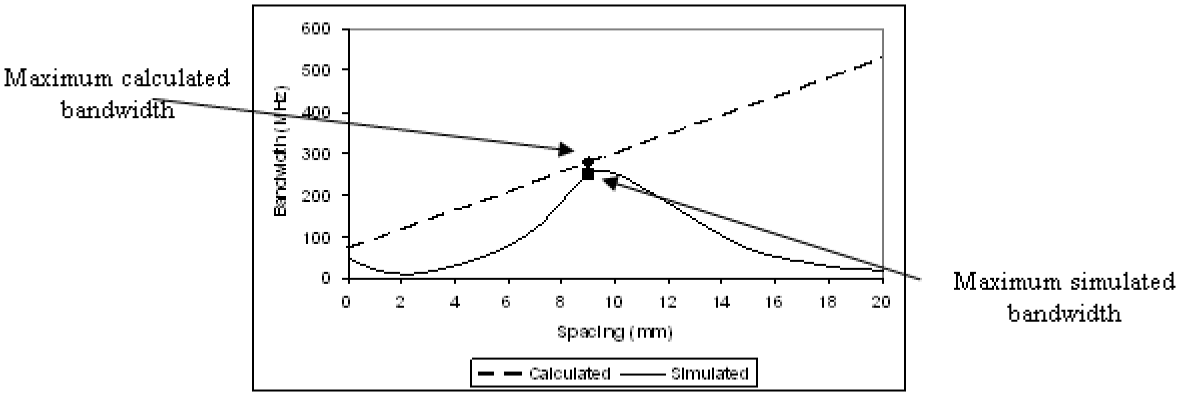
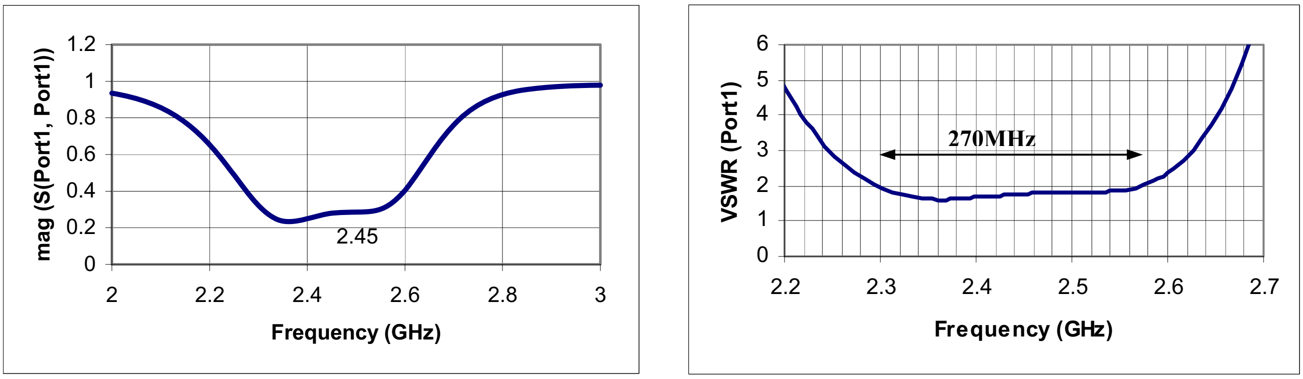
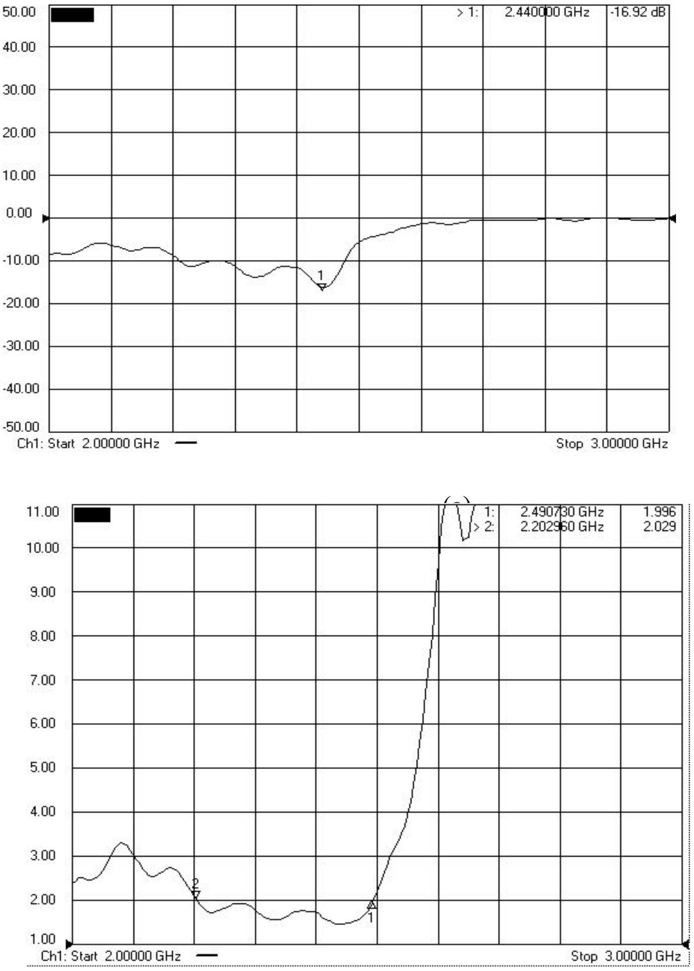


Figure 3. Comparison between the Calculated and Simulated Bandwidth of IDMA



(a) (b)

Figure 4. Simulated (a) Operating Frequency and (b) Bandwidth of IDMA



(b)

Figure 5. Measured (a) Operating Frequency and (b) Bandwidth of IDMA

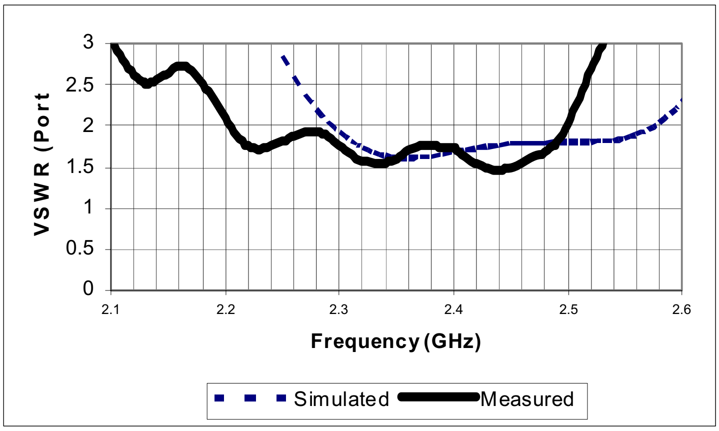


Figure 6. Comparison between the Simulated and Measured Bandwidth of IDMA

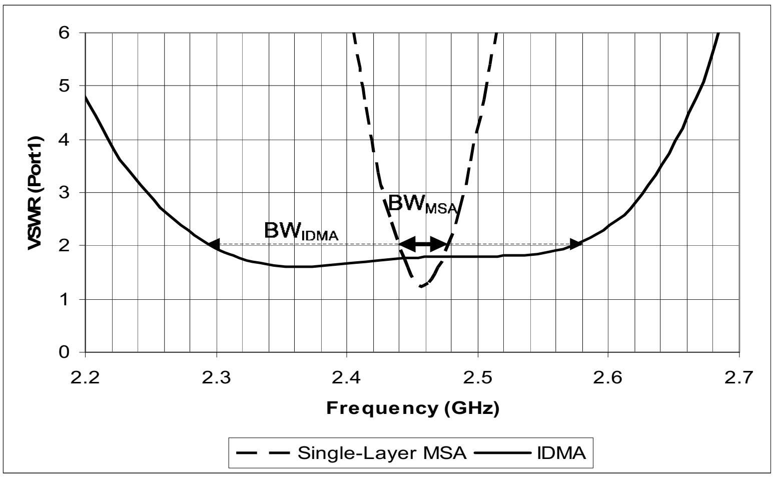


Figure 7. Comparison of the Simulated Bandwidth between the Single-Layer Microstrip Antenna and IDMA

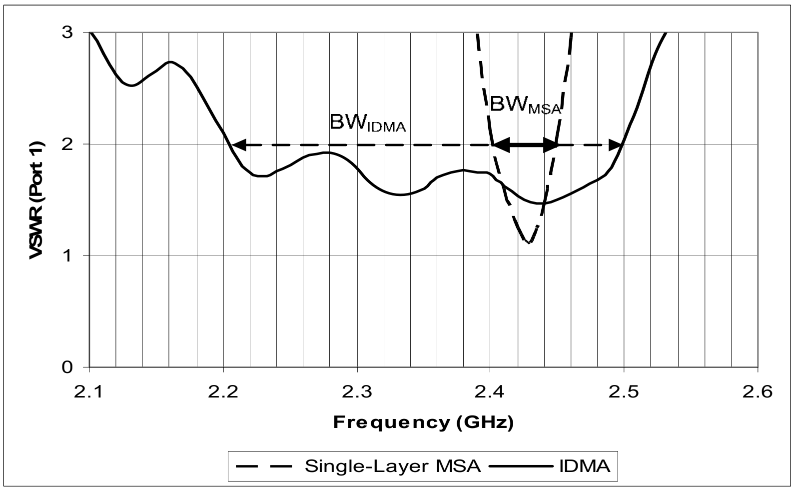


Figure 8. Comparison of the Measured Bandwidth between the Single-Layer Microstrip Antenna and IDMA

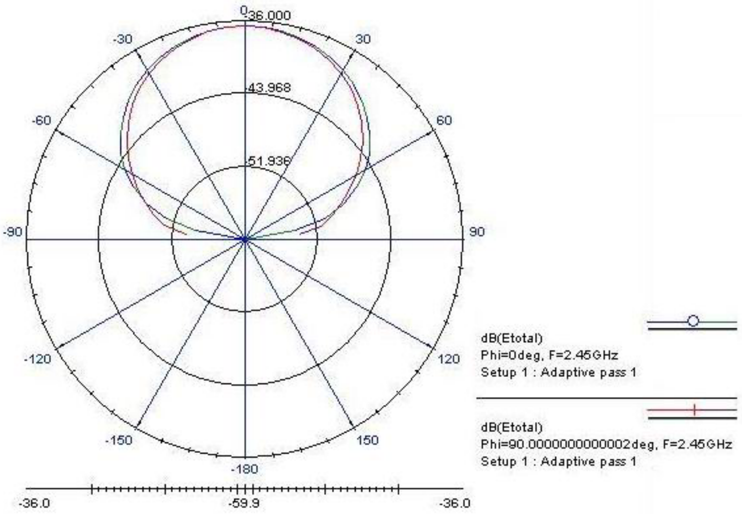
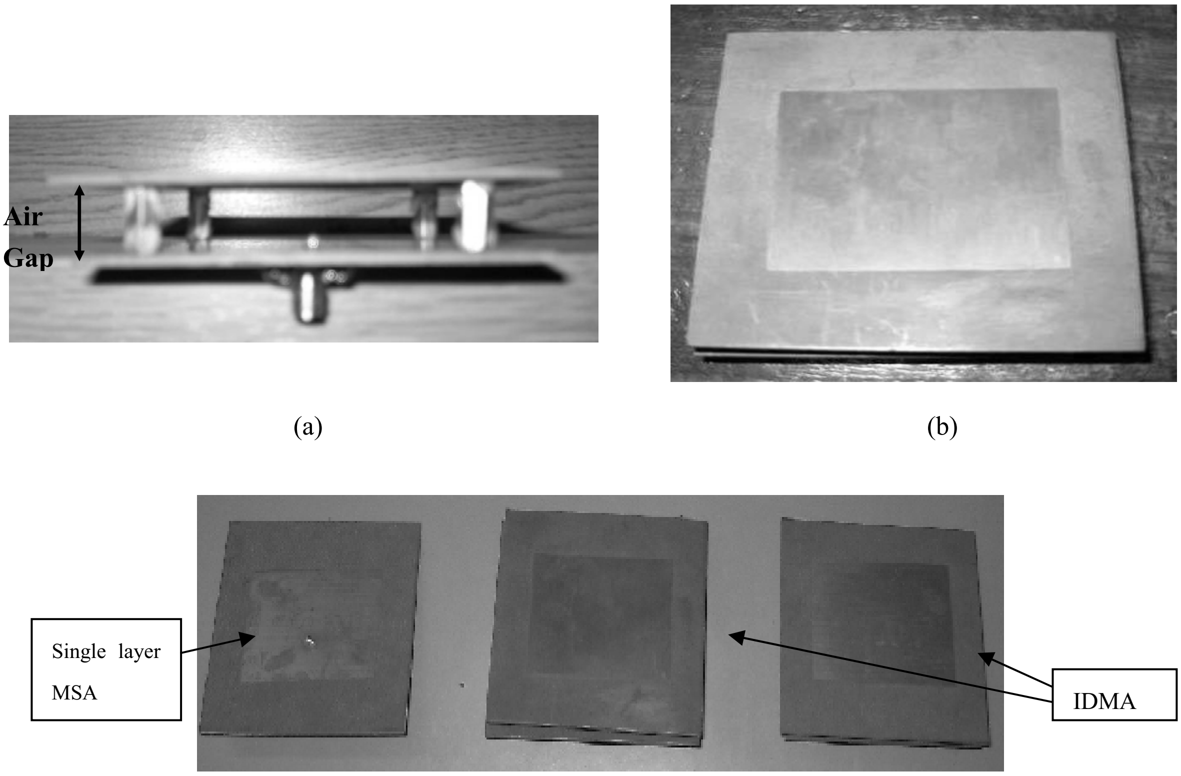


Figure 9. Simulated radiation pattern of IDMA



(a) (b)

(c)

Figure 10. The fabricated microstrip antenna (a) Side View of IDMA,
(b) Top view of IDMA and (c) Single-layer Microstrip Antenna and IDMA