Antenna Design for Ultra Wideband Application Using a New Multilayer Structure

Yashar Zehforoosh, Changiz Ghobadi, and Javad Nourinia
Department of Electrical Engineering, Urmia University, Iran

Abstract— As wireless communication applications require more and more bandwidth, the demand for wideband antennas increases as well. For instance, the ultra wideband radio (UWB) utilizes the frequency band of 3.1–10.6 GHz.This paper presents a work carried out within ULTRAWAVES in the area of antenna design and analysis. A new multilayer microstrip antenna is introduced using Stacked Multiresonator patches. In order to achieve suitable bandwidth, the antenna size is fine for mobile applications. The antenna is designed, optimized and simulated using Ansoft designer. In addition results and conclusions are presented.

DOI: 10.2529/PIERS060531145356

1. INTRODUCTION

Ultra Wideband Radio (UWB) is a potentially revolutionary approach to wireless communication in that it transmits and receives pulse based waveforms compressed in time rather than sinusoidal waveforms compressed in frequency [1]. This is contrary to the traditional convention of transmitting over a very narrow bandwidth of frequency, typical of standard narrowband systems such as 802.11a, b, and Bluetooth. This enables transmission over a wide swath of frequencies such that a very low power spectral density can be successfully received [2]. The recent allocation of the 3.1–10.6 GHz frequency spectrum by the Federal Communications Commission (FCC) for Ultra Wideband radio applications has presented a myriad of exciting opportunities and challenges for antenna designers [3]. Pulsed UWB, by definition, refers to any radio or wireless device that uses narrow pulses (on the order of a few nanoseconds or less) for sensing and communication. This requires sufficient impedance matching, proper return loss and VSWR<2 throughout the entire bandwidth. In this paper a new low profile, small stacked multiresonator microstrip antenna is presented for UWB application. The bandwidth of a microstrip antenna increases with an increase in substrate thickness and decreases in the dielectric constant also, the bandwidth of the antenna increases when multiresonators are coupled in planar or stacked configurations. In this paper we use three patches placed in the bottom layer, and multiresonators taken on the top layers. One of the bottom patches is excited by a coaxial-fed. Ease of construction, suitable radiation pattern and better characteristics are advantages of this antenna over the previously presented antennas.

2. ULTRA WIDEBAND COMMUNICATION

Ultra-Wideband (UWB) technology has been around since the 1980s, but it has been mainly used for radarbased applications until now, because of the wideband nature of the signal that results in very accurate timing information. However, due to recent developments in high-speed switching technology, UWB is becoming more attractive for lowcost consumer communications applications. ULTRA-WIDEBAND communications involves the transmission of short pulses with a relatively large fractional bandwidth [4] and [5]. More specifically, these pulses possess a −10 dB bandwidth which exceeds 500 MHz or 20% of their center frequency [6] and is typically on the order of one to several gigahertz. The Federal Communications Commission's Report and Order (R&O), issued on Feb. 2002, defines UWB as any signal that occupies more than 500 MHz in the 3.1–10.6 GHz band and that it meets the spectrum mask shown in Figure 1. A comparison with the other unlicensed bands currently available in the US is shown in Table 1.

This definition, which replaces the previous one that expressed UWB in terms of fractional bandwidth, opened up a new way of thinking for several leaders in the UWB community.

Given the recent spectral allocation and the new definition of UWB adopted by the FCC, UWB is not considered a technology anymore, but available spectrum for unlicensed use. This means that any transmission signal that meets the FCC requirements for UWB spectrum can be considered UWB technology. This, of course, is not just restricted to impulse radios or high speed spread spectrum radios pioneered by companies so far, but to any technology that utilizes more than 500 MHz spectrum in the allowed spectral mask and with the current emission limit's restrictions.

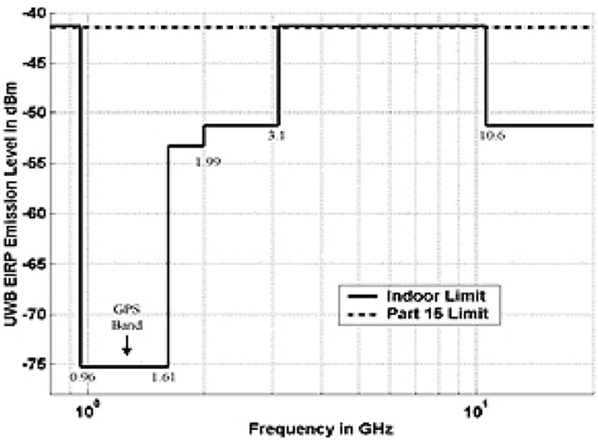

Figure 1: UWB spectral mask for indoor communication systems [1].

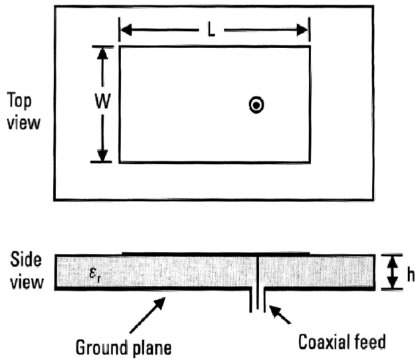

Figure 2: Top and side views of RMSA.

Table 1: Comparison between bands.

Unlicensed bands	Frequency of operation	Bandwidth
ISM at 2.4 GHz	2.4000-2.4835	83.5 MHz
U-NII at 5 GHz	5.15-5.35 GHz 5.75-5.85 GHz	300 MHz
UWB	3.1-10.6 GHz	7,500 MHz

3. MICROSTRIP ANTENNAS

3.1. History of MSAs

Deschamps first proposed the concept of microstrip antenna (MSA) in 1953 [8]. However practical antennas were developed by Munson [9, 10] and Howel [11] in 1970. The numerous advantages of MSA, such as its low weight, small volume, and ease of fabrication using printed circuit technology, led to the design of several configurations for various applications [12–15]. With increasing requirements for personal and mobile communications, the demand for smaller and low-profile antennas has brought the MSA on the forefront. An MSA in its simplest form consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other side. The top and side views of a rectangular MSA (RMSA) are shown in Figure 2. However, other shapes such as the square, circular, triangular, semicircular, sectoral, and annular ring shapes are also used.

3.2. Characteristics of MSAs

The MSA has proved to be an excellent radiator for many applications because of its several advantages, but it also has some disadvantages.

The main advantages of MSAs are listed as follows:

- They are lightweight and have a small volume and low profile planar configuration.
- They can be made conformal to the host surface.
- Their ease of mass production using printed-circuit technology leads to a low fabrication cost.
- They are easier to integrate with other MICs on the same substrate.
- They allow both linear polarization and circular polarization.
- They can be made compact for use in personal mobile communication.
- They allow for dual-band and triple frequency operations.

MSAs suffer from some disadvantages as compared to conventional microwave antennas. They are the following:

- Narrow BW.
- Lower gain.
- Low power-handling capacity.

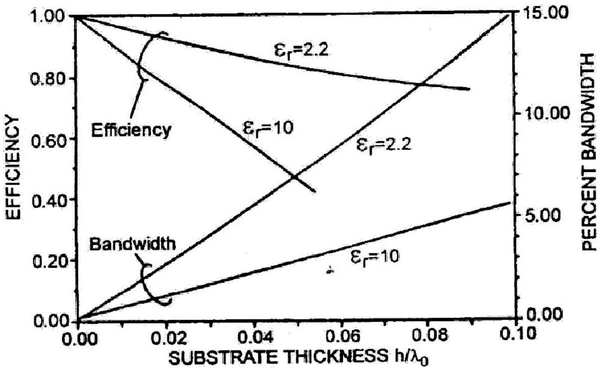

Figure 3: Effect of substrate thickness and dielectric constant on the impedance BW (VSWR<2) and radiation efficiency[12].

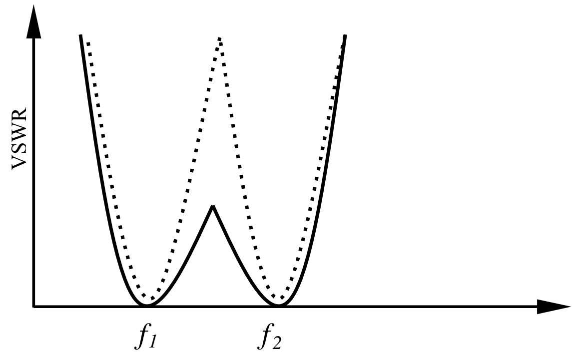

Figure 4: VSWR plot of two coupled resonators having narrow bandwidth(...) individual resonators and(—).

MSAs have narrow BW, typically 1–5%, which is the major limiting factor for the widespread application of these antennas. Increasing the bandwidth of MSAs has been the major thrust of research in this field.

3.2.1. Definition of BW

The VSWR or impedance BW of the MSA is defined as the frequency range over which it is matched with that of the feed line within specified limits. The BW of the MSA is inversely proportional to its quality factor Q and is given by [16].

$$\mathrm{BW} = \frac{\mathrm{VSWR} - 1}{Q\sqrt{\mathrm{VSWR}}}$$

where VSWR is defined in terms of the input reflection coefficient Γ as:

$$\mathrm{VSWR} = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

The Γ is a measure of reflected signal at the feed point of the antenna. It is defined in terms of input impedance Z_{in} of the antenna and the characteristic impedance Z_0 of the feed line as given below:

$$\Gamma = \frac{Z_{in} - Z_0}{Z_{in} + Z_0}$$

The BW is usually specified as frequency range over which VSWR is less than 2 (which corresponds to a return loss of 9.5 dB or 11% reflected power). Some times for stringent applications, the VSWR requirement is specified to be less than 1.5 (which corresponds to a return loss of 14 dB or 4% reflected power). In this paper we use VSWR<2.

3.2.2. Effects of Substrate Parameters on BW

Impedance BW of a patch antenna varies inversely as quality factor Q of the patch antenna. Therefore substrate parameters such as dielectric constant and thickness can be varied to obtain different Q, and ultimately the increase in impedance BW. Q of a resonator is defined as

$$Q = \frac{\text{energy stored}}{\text{power lost}}$$

Figure 3 shows the effect of substrate thickness on impedance BW and efficiency for two values of dielectric constants. Note that the BW increases monotonically with thickness. Also, a decrease ε_r in value increases the BW. This behavior can be explained from the change in Q value.

In conclusion, we can say that the increase in h and decrease in ε_r can be used to increase the impedance BW of the antenna. However, this approach is helpful up to $h \leq 0.02\lambda$ only. The disadvantages of using thick and high dielectric constant substrates are many, including these:

- Surface wave power increases, resulting in poor radiation efficiency.

- The radiation from surface waves may lead to pattern degradation near end-fire.
- Thick substrates with microstrip edge feed will give rise to increased spurious radiation from the microstrip step-in-width and other discontinuities. Radiation from the probe feed will also increase.
- Substrates thicker than 0.11λ for $\varepsilon_r = 2.2$ makes the impedance locus of the probe fed patch antenna increasingly inductive in nature, resulting in impedance matching problems.
- Higher order modes along the thickness may develop, giving rise to distortions in the radiation patterns and impedance characteristics. This is a limiting factor in achieving an octave BW.

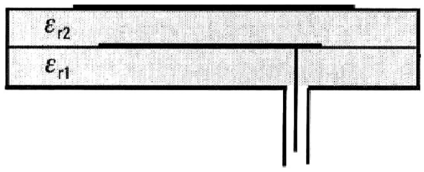

Figure 5: Multilayer MSA.

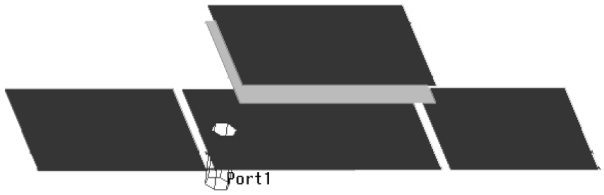

Figure 6: The geometry of the antenna.

Table 2: Dimensions of the antenna.

L	L_1	L_2	L_3	W	h_1	h_2	h_3	ε_{r1}	ε_{r2}	ε_{r3}	x
18 mm	15.4 mm	13.4 mm	11.7 mm	10.8 mm	1.2 mm	5 mm	4 mm	2.1 mm	2.1 mm	2.1 mm	7 mm

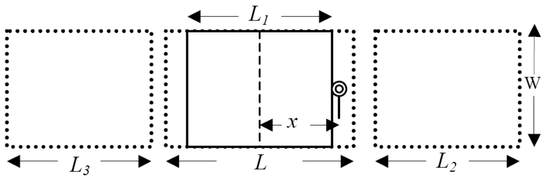

Figure 7: Top view of the antenna.

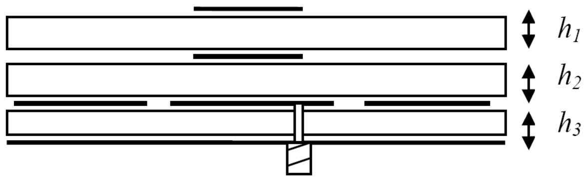

Figure 8: Side view of the antenna.

4. EFFECT OF PARASITIC PATCHES

A patch placed close to the fed patch gets excited through the coupling between the patches [4]. Such a patch is known as a parasitic patch. If the resonance frequencies f_1 and f_2 of these two patches are close to each other, then broad bandwidth is obtained as shown in Figure 4. The overall input VSWR will be the superposition of the responses of the two resonators resulting in a wide bandwidth [7, 8]. If the bandwidth is narrow for the individual patch, then the difference between f_1 and f_2 should be small and If the bandwidth of the individual patch is large, then the difference in the two frequencies should be large to yield an overall wide bandwidth.

5. MULTILAYER CONFIGURATIONS

In the multilayer configuration, two or more patches on different layers of the dielectric substrate are stacked on each other. Based on the coupling mechanism, these configurations are categorized as electromagnetically coupled or aperture coupled MSA.

In the electromagnetically coupled MSA, one or more patches at the different dielectric layers are electromagnetically coupled to the feed line located at the bottom dielectric layer as shown in Figure 5. Alternatively, one of the patches is fed by a coaxial probe and the other patch is electromagnetically coupled. The patches can be fabricated on different substrates, and accordingly the patch dimensions are to be optimized so that the resonance frequencies of the patches are close to each other to yield broad BW. These two layers may be separated by either air gap or foam [8].

The multilayer broadband MSAs, unlike single layer configurations, show a very small degradation in radiation pattern over the complete VSWR BW. The drawback of these structures is the increased height; which is not desirable for conformal applications and increased back radiation. Planar and stacked multiresonators techniques are combined to yield a wide bandwidth with a higher gain. In this paper we use two different configurations for this type of antennas.

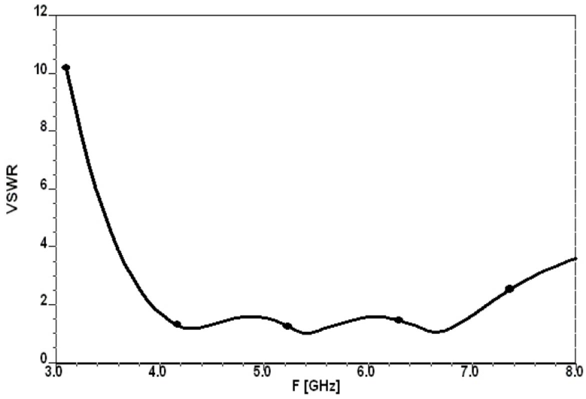

Figure 9: VSWR plot of antenna.

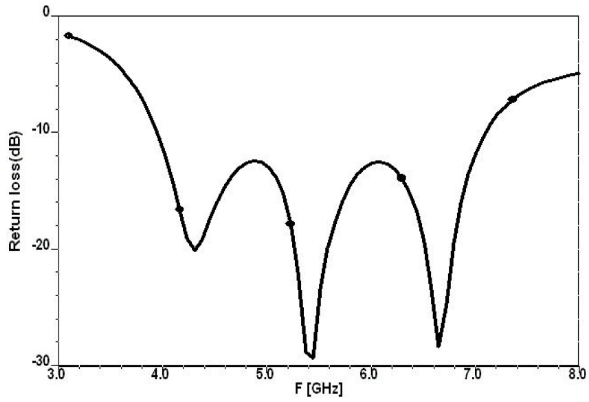

Figure 10: Return loss plot of antenna.

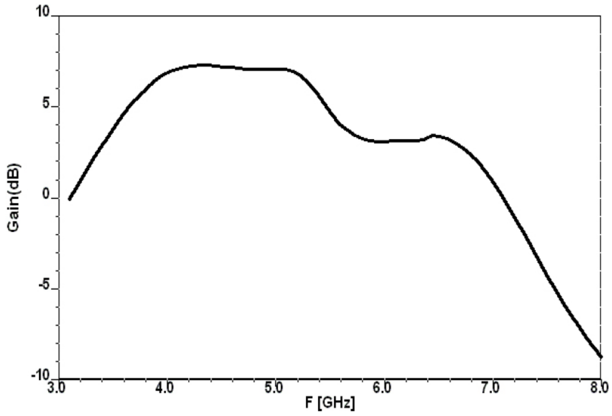

Figure 11: Gain plot of antenna.

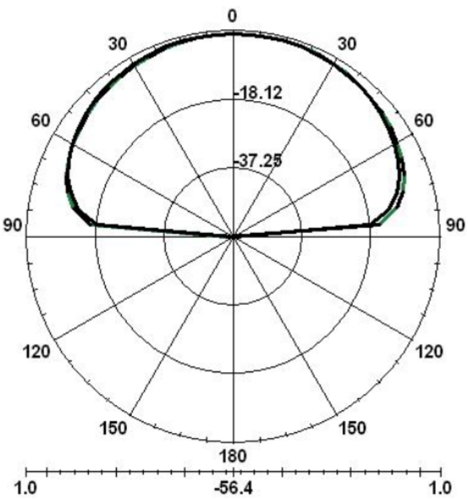

Figure 12: Radiation pattern of antenna.

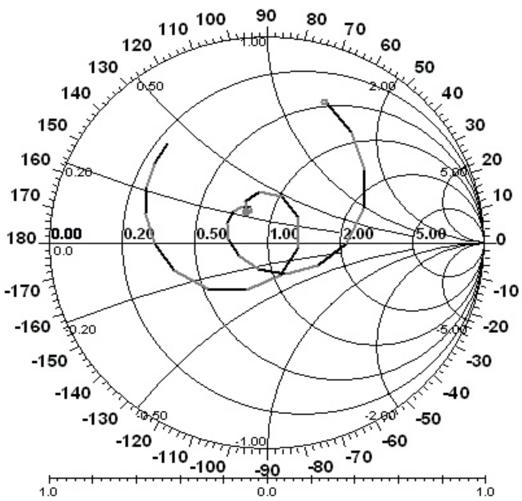

Figure 13: Smith chart of antenna.

6. ANTENNA DESIGN

As it is shown in Figure 6 planar and stacked multiresonators techniques are combined to yield a wide bandwidth with a higher gain.

The antenna has three rectangular patches at the bottom and two patches on the top layers exciting the bottom patch by coaxial feed. The two top patches are the same in size but the two patches beside the exited patch are different in size.

Only the bottom patch is fed and the other patches electromagnetically coupled as shown in Figure 6.

In Figure 7 the top view and in Figure 8 the side view of the antenna are shown. The patch on the bottom layer is shown in dotted lines and the patches on the top layer are shown in solid lines. Because of the multilayer configuration of the antenna and its especial structure the number of parameters that are to be optimized is increased. Referring to the antenna geometry from Figures 7 and 8, the dimensions of the antenna are presented in Table 2.

The antenna is designed, optimized and simulated using Ansoft designer software. The bandwidth obtained for the antenna is 3.25 GHz. The radiation is in the broad side direction, and the variation in the pattern is very small over the entire bandwidth. At 4.3 GHz, the gain is 7.5 dB. As shown in figures 9-13 the bandwidth and return loss are proper for ultra wideband applications and antenna dimensions are suitable for mobile devices.

7. CONCLUSIONS

In this paper, a new small microstrip antenna for ultra wideband applications is designed, optimized simulated. There was a great success in finding a suitable structure for mobile applications. Also obtaining bandwidth about 50% and maximum gain about 7.5 dB shows that this structure can be mentioned as a useful design for ultra wideband products. However acquired results show that the antenna design and structure need more refinement in order to achieve the ultimate design with a smaller physical profile and better performance.

ACKNOWLEDGMENT

The authors would like to thanks Iran Telecom Research Center (ITRC) for its financial support.

REFERENCES

1. First Report and Order (FCC 02-48), Action by the Commission February 14, 2002, "New public safety applications and broadband internet access among uses envisioned by FCC authorization of ultra-wideband technology".
2. James, J. R. and P. S. Hall, *Handbook of Microstrip Antennas*, Vol. 1, Peter Peregrinus Ltd., London, 1989.
3. Derneyd, A. G. and A. G. Lind, "Extended analysis of rectangular microstrip resonator antennas," *IEEE Trans. Antennas Propagation*, Vol. AP-27, 846–849, November 1979.
4. James, J. R., P. S. Hall, and C. Wood, *Microstrip Antennas Theory and Design*, Peter Peregrinus, London, 1981.
5. Taylor, J. D., *Introduction to Ultra-Wideband Systems*, CRC Press, Ann Arbor, MI, 1995.
6. Astanin, L. Y. and A. A. Kostylev, *Ultrawideband Radar Measurements Analysis and Processing*, IEE, London, U.K., 1997.
7. Kumar, G. and K. P. Ray, "Stacked gap-coupled multiresonator rectangular microstrip antennas," *IEEE AP-S Int. Symp. Digest*, Bostan, MA, 514–517, July 2001,
8. Deschamps, G. A., "Microstrip microwave antennas," *Proc. 3rd USAF Symposium on Antennas*, 1953.
9. Munson, R. E., "Single slot cavity antennas assembly," U.S. Patent No. 3713462, January 23, 1973.
10. Munson, R. E., "Conformal microstrip antennas and microstrip phased arrays," *IEEE Trans. Antennas Propagate*, Vol. AP-22, 74–78, 1974.
11. Howell, Q. E., "Microstrip antennas," *IEEE Trans. Antennas Propagat.*, Vol. ap-23, 90-93, January 1975.
12. Bahl, R. E. and P. Bhartia, *Microstrip Antennas*, Artech House, Dedham, MA, 1980.
13. Pozar, D. M., "Microstrip antennas," *Proc. IEEE*, Vol. 80, 79–91, 1992.
14. Carver, K. R. and J. W. Mink, "Microstrip antennas technology," *IEEE Trans. Antennas Propagate.*, Vol. AP-29, January 2–24, 1981.
15. Mailloux, R. J., et al., "Microstrip array technology," *IEEE Trans. Antennas Propagate.*, Vol. AP-29, 25–37, January 1981.
16. Pozar, D. M. and D. H. Schaubert, *Microstrip Antennas: The Analysis and Design of Microstrip Antennas and Arrays*, IEEE Press, New York, 1995.
17. Luk, K. M. and K. F. Lee, "Circular U-slot patch with dielectric superstrate," *Electronics Letters*, Vol. 33, No. 12, 1001–1002, 1997.
18. Sabban, A., "A new broadband stacked two-layer microstrip antenna," *IEEE AP-S Int. Symp. Digest*, 63–66, June 1983.
19. Chen, A. H., A. Tulintseff, and R. M. Sorbello, "Broadband two layer microstrip antenna," *IEEE AP-S Int. Symp. Digest*, Vol. 2, 251–254, June 1984.