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Ultra-Wideband Printed Antennas Design

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1. Introduction

On February 14, 2002, the Federal Communications Commission (FCC) of the United States adopted the First Report and Order that permitted the commercial operation of ultra wideband (UWB) technology (FCC, 2002). The FCC allocated a bandwidth of 7.5GHz, i.e. from 3.1GHz to 10.6GHz, to unlicensed use for UWB applications. Ultra Wideband is defined as any communication technology that occupies greater than 500 MHz of bandwidth, or greater than 25% of the operating center frequency. The UWB spectral mask was defined to allow a spectral density of -41.3 dBm / MHz throughout the UWB frequency band. UWB technology has several advantages that are the reasons that make it very attractive for consumer communications applications; it has been regarded as one of the most promising wireless technologies that have a capability of revolutionizing high data rate transmission and enables the personal area networking industry leading to new innovations and greater quality of services to the end users.

Ultra wideband systems present several advantages *i*) have potentially low complexity and low cost; *ii*) have noise-like signal which makes unintended detection quite difficult, because of their low average transmission power, UWB communications systems have an inherent immunity to detection and interception; and low power consumption; *iii*) are resistant to severe multipath and jamming; and *iiii*) have very good time domain resolution allowing for location and tracking applications. Also UWB systems can penetrate effectively through different materials. The low frequencies included in the broad range of the UWB frequency band have long wavelengths, which allow UWB signals to penetrate into a variety of materials, such as walls. This advantage makes UWB technology favourable for through the wall communications, ground penetrating radar, body implant wireless communications...

Since UWB has an ultra wide frequency bandwidth, it can achieve huge capacity as high as hundreds of Mbps or even several Gbps with distances of 1 to 10 meters (Oppermann, 2004).

UWB systems operate at extremely low power transmission levels, and hence UWB signals do not cause significant interference to other wireless systems. The UWB technology is one of the viable candidates for short-range indoor radio communication systems supporting very high bit rates services and applications.

In this chapter, different aspects and challenges of UWB antennas design are discussed. And compact printed disc monopole antenna (3.5 to 31.9 GHz) for current and future ultra wideband applications will be presented.

2. Antennas for ultra wideband systems

Unlike conventional narrowband communication systems, UWB occupies a bandwidth of several GHz. Consequently, the antennas in UWB systems play a more important role than in other systems since they actually act as a band pass filter to reshape the pulse spectra so they should be carefully designed to avoid unnecessary distortions. UWB systems design are much more challenging than for conventional narrowband systems.

The systems must produce broad operating bandwidths for impedance matching, high gain transmissions in the desired direction, stable transmission patterns and gains, consistent group delays, high transmission efficiency, and low profiles. Various studies have been devoted to evaluating the performance of UWB antennas (Agrawall et al., 1998; Amman & Chen, 2003; Hertel & Smith, 2003; Klemm et al., 2005; MaTG & Jeng, 2005).

2.1 Printed monopole antennas

The huge development in communication technology and the significant demands of wireless communication systems, lead to a fast evolution in the antennas design to take up the challenges in size and performances. Antennas are considered to be the largest components of integrated wireless systems; thus antenna miniaturization is a necessary task to achieve an optimal design for integrated wireless and mobile communication systems. The microstrip antennas present good solution and play an important role in the development of the new generation of wireless and mobile communication systems.

These antennas have several advantages compared to the conventional microwave antennas. The main advantages are: lightweight, small volume, low-profile, planar configuration, compact, can be made conformal to the host surface, easy integrated with printed-circuit technology and with other MICs on the same substrate, low cost, allow both linear polarization and circular polarisation. On the other hand, theses antennas suffer from some disadvantages as compared to conventional microwave antennas, due to the fact that they have narrow bandwidth, lower gain, and Low power handling capability (Kumar & Ray, 2003).

The printed monopole antennas give very large impedance bandwidth with reasonably good radiation pattern in azumuthal plane.

2.2 UWB antenna design

As already mentioned, ultra wideband wireless communication systems are defined as any radio system that has a -10dB bandwidth larger than 25 % with respect to the center frequency. UWB is a carrier-less short range communications technology which transmits the information in the form of very short pulses.

2.2.1 UWB antennas criteria

The antenna has a greater impact in UWB than in narrower band systems because of the very large bandwidth of an UWB signal.

In the literature, several antenna types have been presented for use in UWB systems. In addition to the fundamental parameters that must be considered in designing antennas for any radio application, there are additional challenges for Ultra Wideband antennas. Antennas play a critical role in the UWB communication systems, since they act as pulse-shaping filters (Chen et al., 2004).

Based on return loss (>-10dB) or voltage standing wave ratio (VSWR<2), the impedance bandwidth can be determined. The bandwidth ΔBW is a frequency span determined by the upper frequency band limit f_2 and the lower limit f_1:

$$\Delta BW = f_2 - f_1 ;$$

and the center frequency f_c is defined as:

$$f_c = \frac{f_1 + f_2}{2}$$

2.2.2 UWB antennas requirements

The UWB antenna must achieve almost a decade of impedance bandwidth, spanning 7.5 GHz. The portable UWB systems are the main promising issue of UWB applications. For this, antennas must be small size, conformal design, low cost, easily integrated into other RF circuits. UWB antennas should have stable response in terms of impedance matching, gain, radiation patterns, phase, and polarization within the operating band. Moreover, the requirements for broad bandwidths are associated with other crucial constraints such as small size and low cost because most promising UWB applications will be portable devices (Arslan et al., 2006).

In addition, two essential design considerations for UWB antennas should be emphasized: 1) the power density spectrum (PDS) shaping of the radiated signals should conform to the emission limit masks for avoiding possible interference with other existing systems, and 2) the source pulses and transmit-receive antennas should be evaluated in terms of the overall system performance (minimal BER). Other crucial criterion of the UWB antennas is associated with the performance of overall transmit–receive antenna systems, due to the fact that UWB systems maintain invariable performance across a wide range of a few gigahertz, which affects the waveforms and spectra of the radiated pulses.

The design considerations of the UWB antennas and source pulses are based on investigating S parameters, transfer functions, systems efficiency, group delay and fidelity. However, in a systems point of view, the key performance parameter for wireless communications is BER, which is formulated in terms of antenna system transmission efficiency, fidelity between the received pulse and the template pulse, and incident power (Arslan et al., 2006).

In impulse radio, transient characteristics of the system are very important. In other words, the transmitted signal must be received at the receiver with minimum distortion. So, the UWB antennas must be as distortion less as possible. Also, due to power limitations specified by FCC mask for indoor UWB communications, UWB antennas must provide a good matching between radiator part and feed section.

The group delay is another consideration that must be taken into account. It will be constant for the frequency range if the phase is linear throughout the frequency range. This indicate how well a UWB pulse will be transmitted and to what degree it may be distorted or dispersed.

A nearly omnidirectional radiation pattern is desirable; this enables freedom in the receiver and transmitter location. Also, high radiation efficiency is imperative for an UWB antenna because the transmit power spectral density is excessively low. Conductor and dielectric losses should be minimized in order to maximize radiation efficiency.

With the great development on UWB technology, there is a growing demand for small and low cost UWB antennas that can provide satisfactory performances in both frequency domain and time domain.

Both transmit and receive antennas can affect the faithful transmission of UWB signal waveforms because of the effects of impedance mismatch over the operating bandwidth, pulse distortion effects, and the dispersive effects of frequency dependent antenna gains and spreading factors (Sorgel et al., 2003).

For UWB communication systems, antennas requirements differ from base station antennas to portable antennas. The base station antenna may be designed for indoor or outdoor usage, and may be either directive or omnidirectional, depending on the application (e.g. directional antennas could be used for example in radio links, whereas omnidirectional antennas would be more favourable in mobile applications). On the other part, the portable UWB antenna must be small and highly desirable to be low cost and preferably constructed on a printed circuit board. The radiation efficiency is not as critical parameter as in base station antennas, which makes it possible to use resistive loading (Oppermann et al., 2004).

The choice of antenna type differs according to the applications. For example, for radar applications a highly directive antenna is preffered, while for point-to-multipoint communications an omnidirectional antenna is desired (Telzhensky & Leviatan, 2006).

It is relatively easy to design a UWB monopole antenna when considering only the impedance bandwidth. But it is difficult to achieve the same radiation pattern bandwidth, due to the significant changes in the antenna pattern at higher frequencies (Shih et al., 2004).

An ideal wideband antenna acts like a high-pass filter, which means that the pulse waveform is differentiated when passing through the antenna. UWB antennas should be linear in phase and should have a fixed phase centre. Typical impedance circuits may not be phase linear, and the antennas should be inherently impedance matched. The UWB antenna gain should be smooth across the frequency band in order to avoid dispersion of the transmitted pulse. On the other hand, the antenna gain appears different from different angles, which lead to different pulse shapes depending on the angle to the receiver (Opperman, 2004).

The performance of a UWB antenna is required to be consistent across the entire operational band: radiation patterns, gains and impedance matching should be stable over the operational band. Sometimes, it is also demanded that the UWB antenna provides the band-rejected characteristic to coexist with other narrowband devices and services occupying the same operational band.

In several context, due to the overlap of the currently allocated UWB frequency band with other existing technologies, such as WLAN2 (5.2GHz (5150–5350 MHz) and 5.8GHz (5725–5825 MHz)), WiMAX (3400–3690 MHz) and C-band (3.7–4.2 GHz), different ways have been used: cutting a proper slot, putting parasitic elements near or rear the printed monopole (Danesfahani et al., 2009; Soltani et al., 2009), C-shaped attachment element in patch (S. Chen et al., 2007), and thus various structures with band rejection characteristic are proposed, such as U-slot, inverted U-slot (Choi et al., 2005), small strip bar (Kim & Park, 2006), H-shaped conductor-backed plane (Zaker et al., 2008), rectangle-shaped plane (W.S. Chen & Yang, 2007), arc-shaped slot (Khan et al., 2008), para- sitic coplanar elliptical patch (H.J. Chen et al., 2008), fractal tuning stub (WenJun et al., 2005), U-slotted tuning stub (S.S. Wen et al., 2005) , or fractal-shape wide slot (WenJun et al., 2006).

2.2.3 Impedance bandwidth improvement

Printed monopole antennas are largely considered for use in UWB systems, due to theirs attractive features. Circular planar monopole antennas show basic characteristics of the planar UWB antennas.

The limited impedance bandwidth of planar monopole antennas should be improved to satisfy UWB applications. Several attempts have been made to increase their operation bandwidth (Behdad & Sarabandi, 2004; H.D. Chen, 2003; Lee et al., 2002; WenJun, 2005, 2006; Sze & Wong, 2001).

Different structures with a simple bevel (Amman et al., 2001, 2003), with shorting pins (Amman & Z.N. Chen, 2003), using smooth rounded elements (Agrawall et al., 1998; Wu et al., 2007a, 2007b) and using fractal elements (Ding et al., 2007; Gianviffwb & Rahmat-Sammi, 2002) have been designed for the bandwidth enhancement, and several techniques have been proposed, such as adding steps to the lower edge of the patch Kim & Park, 2006), the insertion of additional stub to the one side of circular patch (Choi et al., 2005) and adding of the slit on one side of the radiating element (Wang et al., 2004), the use of feedgap optimization (John, 2005), bevels (Amman, 2001), groundplane shaping (Zhang & Fathy, 2007) multiple feeds (Antonino et al., 2003), and offset feeding techniques (Amman & Z.N. Chen, 2004), and introducing slit into the groundplane (Bao, 2007).

3. Printed disc monopole antenna for future UWB applications

In the last few years, circular monopole antennas have been studied extensively for UWB communications systems because of some appealing features (easy fabrication, feedgap optimization alone gives wide impedance matching and omnidirectional radiation patterns).

One of the strongest contenders in terms of good impedance bandwidth, radiation efficiencies, and omnidirectional radiation patterns are the circular disc monopole (CDM) and elliptical antennas (Abbosh & Bialkowski, 2008; Allen et al., 2007; Antonino et al., 2003, Liang et al., 2004; Powell, 2004; schartz, 2005; Srifi et al., 2009).

There is great demand for UWB antennas that offer miniaturized planar structure, so the vertical disc monopole is still not suitable for integration with a PCB. This drawback limits its practical application. For this reason, a printed structure of the UWB disc monopole is well desired, which consist on printed radiator disc on substrate. Printed CDM antennas can be fed simple microstrip line, coplanar waveguide (CPW), or slloted structures.

3.1 Geometry of the proposed antenna

The increased development on wireless technologies demands small and compact systems with high transmission speeds. This requires higher operating bandwidths for the next generation ultra wideband systems. For this reason, antennas have to be capable to provide bandwidth much larger than the currently band defined by FCC.

The proposed UWB antenna (Srifi et al, 2009) consists of a circular disc with a radius of R=7.5mm, printed in the front of dielectric substrate of 30mm x 35mm x 0.83mm dimensions and a relative permittivity of 3.38, as shown in figure 1. On the other side of the substrate, the partial ground plane with a length of 15.6mm only covers the section of the microstrip feed line. The width of the ground plane is 30mm.

For this design, it was observed that operational bandwidth of the CDM antenna is from 3.3GHz to 10.6GHz.

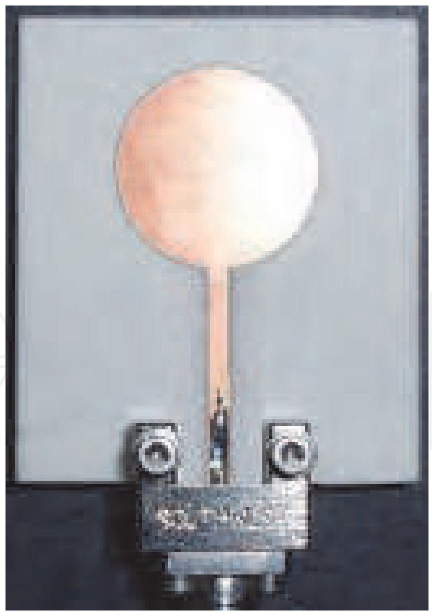

Fig. 1. The prototype of the proposed simple fed CDM antenna

As previously discussed, various techniques have been proposed to improve the matching over a broad bandwidth, such as: feed gap optimization, bevels, ground plane shaping, multiple feeds, and slit into the ground plane…

In this work, the bandwidth of a compact printed circular antenna is improved by introducing one and two microstrip lines between the feed line and the printed disc, which gives two design structures: antenna1 (single microstrip line transition) and antenna2 (dual microstrip line transition).

Antenna2 is modified by adding a second microstrip line between the feedline and the circular disc patch on the antenna.

Figures 2-3 show geometry of both antenna1 and antenna2.

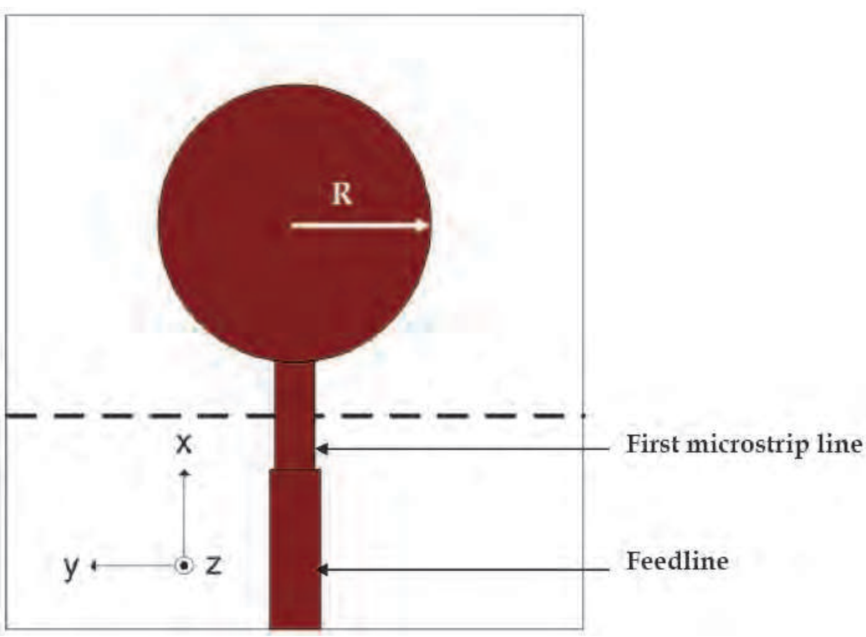

Fig. 2. Geometry fo antenna1 (single microstrip line transition)

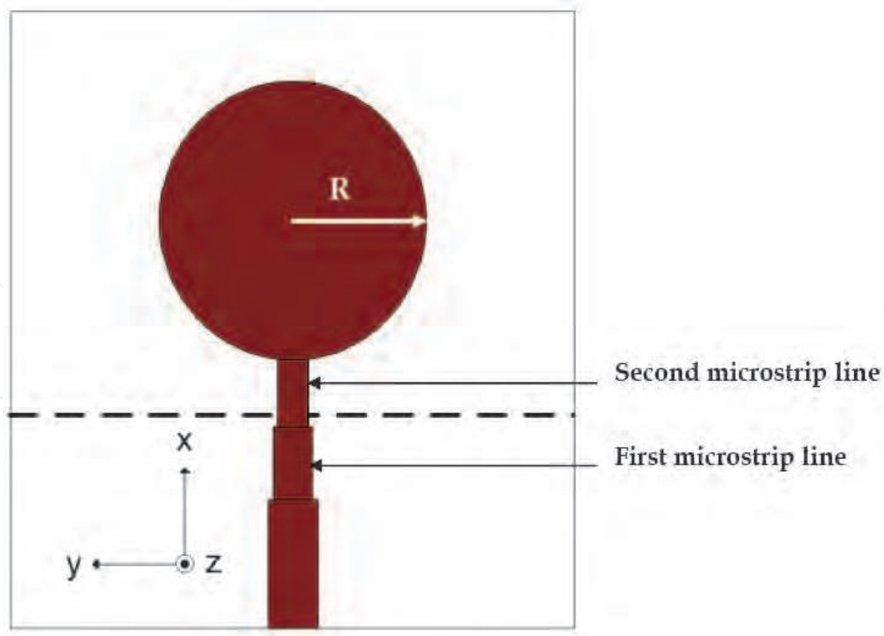

Fig. 3. Geometry fo antenna2 (dual microstrip line transition)

The following table resumes data corresponding to the proposed antenna

Width of the substrate	W	30 mm
Length of the substrate	L	35 mm
Width of the feed line	W_f	1.8 mm
Length of feed line	L_f	8 mm
Width of the first microstrip line	W_1	1.4 mm
Length of the first microstrip line	L_1	5 mm
Width of the second microstrip line	W_2	1 mm
Length of the second microstrip line	L_2	3 mm
Radius of the printed disc	R	7.5 mm
Length of the partial ground plane	L_g	15.6 mm
Dielectric permittivity	ε_r	3.38
Thickness of the substrate	H_{sub}	0.83 mm

Table 1. Dimensions of the proposed antenna

These microstrip lines, with different impedance characteristic, allow the control of the impedance bandwidth and return loss level by modifying the capacitance between the patch and the ground plane.

The proposed antennas are fabricated and tested in Royal Military College of Canada (RMC), Kingston, Ontario, Canada. Prototypes of antenna1 and antenna2 are illustrated on figure 4-5.

3.2 Experimental and simulated results

Initially reflection loss measurements of the two antennas were completed in an anechoic chamber, as shown in Figure 6.

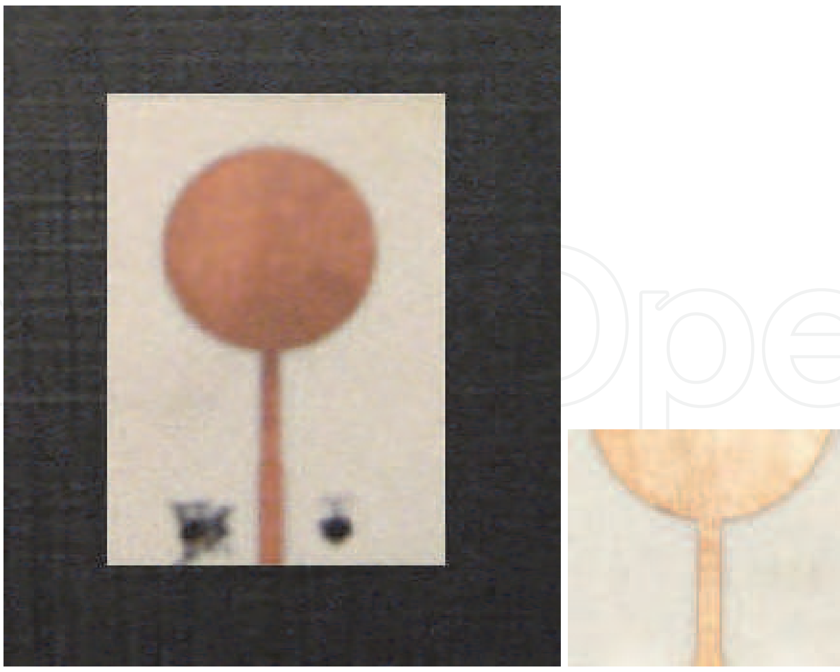

Fig. 4. Prototype of antenna1

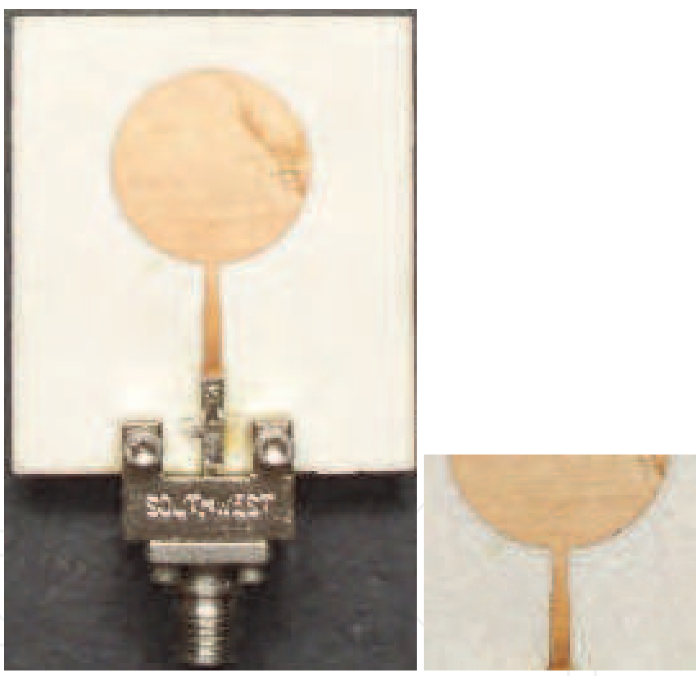

Fig. 5. Prototype of antenna2

A single S11 port calibration was completed on a Anritsu 37377C VNA from 0.2 GHz to 40 GHz with 1601 data points. The proposed antennas were connected to a SouthWest Microwave (SWM 1092-03A-5) K Connector. The end launch connector was only rated to 40 GHz (2.92 mm) and thus measurements above this frequency were not trusted.
The impedance bandwidth is improved by addition of a second microstrip line between the feed line and the printed disc (antenna2).
For the first antenna (Antenna1), return loss measurement results, as shown in Figure 7, illustrate |S11| is below -10 dB from 3.18 GHz to 11.74 GHz.

Reflection loss measurements of the second UWB antenna (Antenna2) were completed and results are shown in Figure 8. A performance increase is observed; i.e. |S11| is below -10 dB from 3.5 GHz to 31.94 GHz.

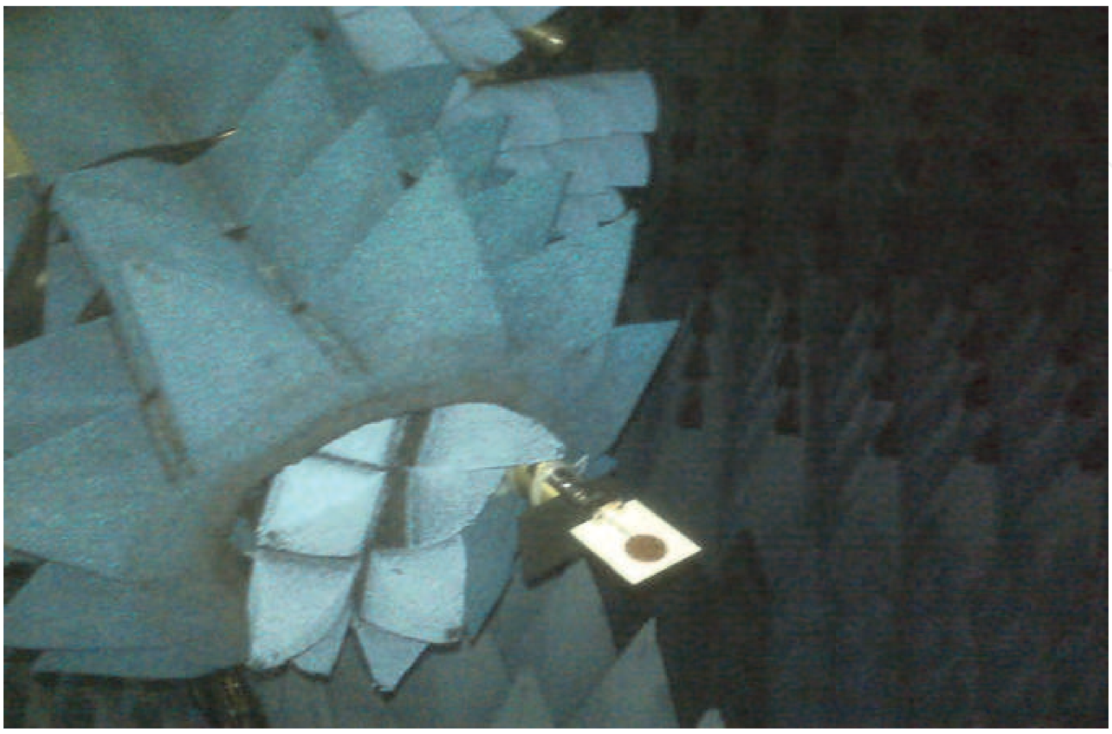

Fig. 6. Photograph of the proposed antenna in an anechoic chamber

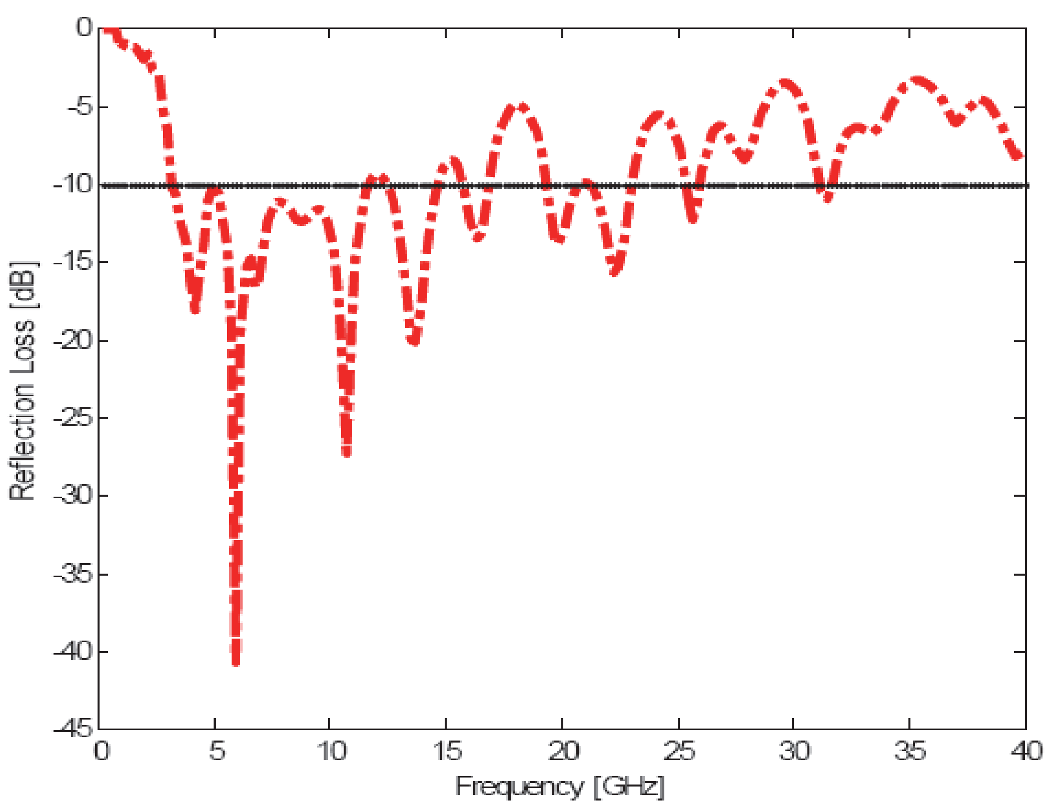

Fig. 7. Measured Return Loss of the first proposed antenna (Antenna1)

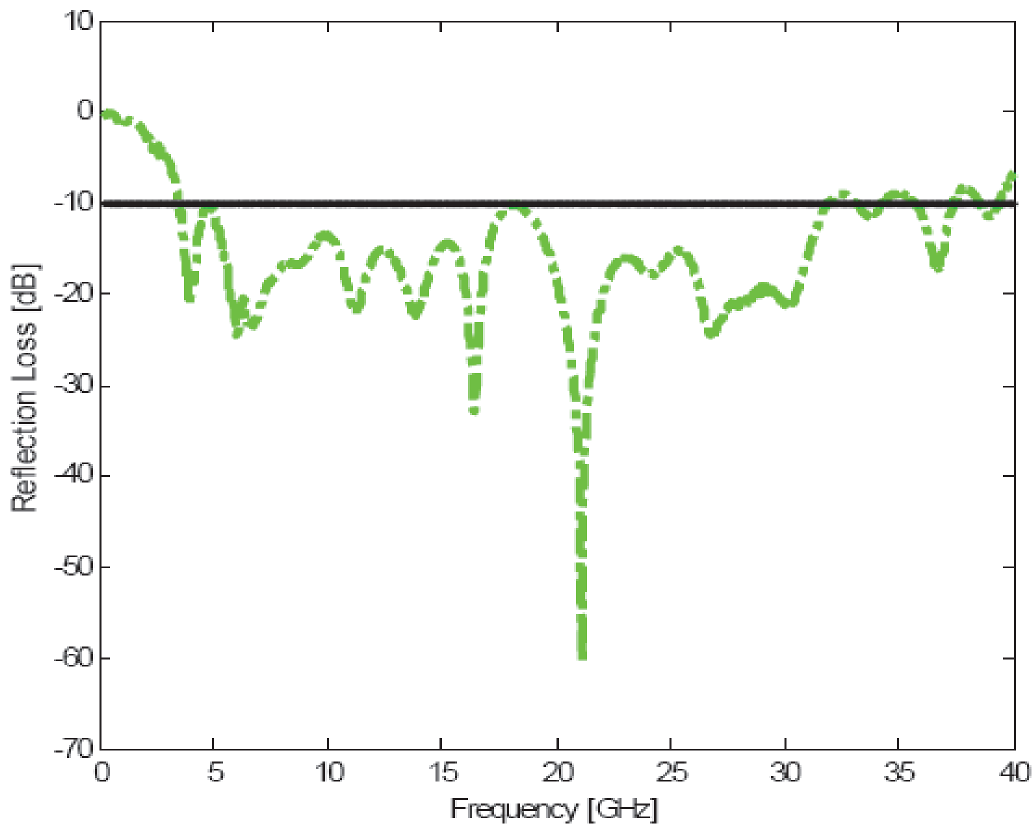

Fig. 8. Measured Return Loss of the modified antenna (Antenna2)

The measurements of Radiation pattern of the proposed antenna were completed in an anechoic chamber. Measured radiation patterns for antenna1 and antenna2, at 3.4GHz and 30.1GHz are illustrated in figures 9-10.

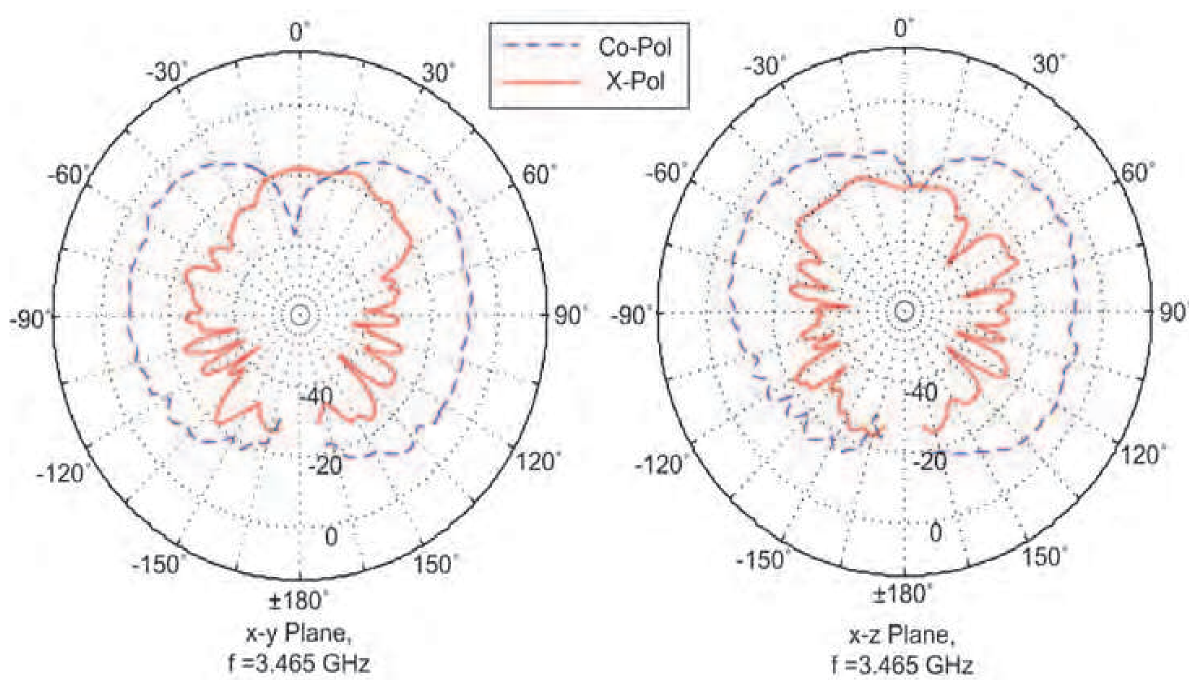

Fig. 9. Measured Return Loss of the antenna1 (single microstrip line transision)

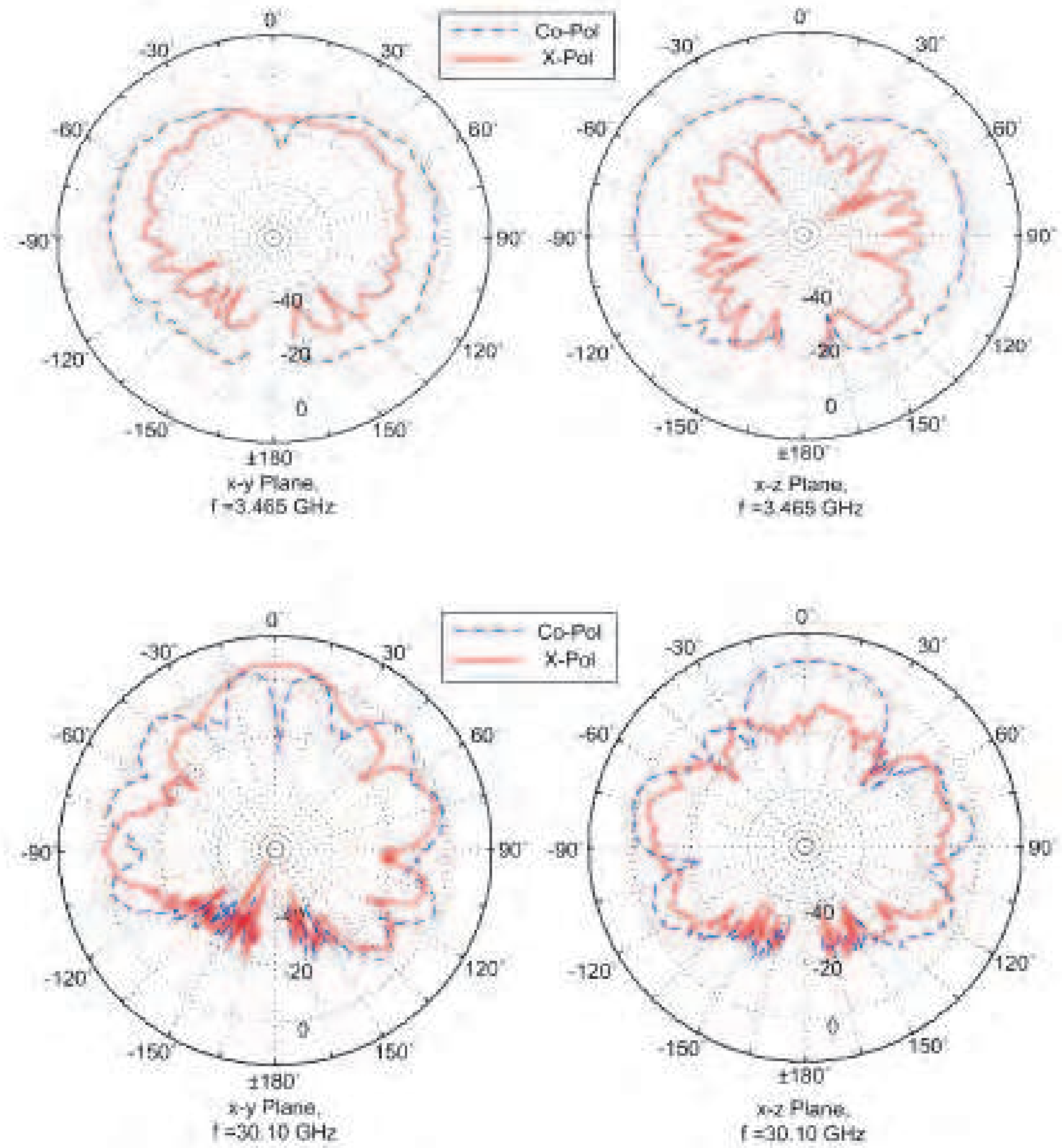

Fig. 10. Measured radiation pattern of the Antenna2 (dual microstrip line transision) at 3.4GHz and 30.10GHz

The simulated current field distributions on the antenna close to the measurement resonance frequencies (5.2GHz, 9.5GHz, and 23.5GHz) are plotted in figures 11-13.
It is observed that the current distribution is mostly concentrated near the edge of the ground plane in the closed region to the disc radiator element, while on top of the structure the current are primarily distributed along the contour of the disc (edge) and feed line on the top edge of ground plane, this leads to confirm that the performance of the antenna is almost independent of the length of the ground plane, but highly dependant to its width.

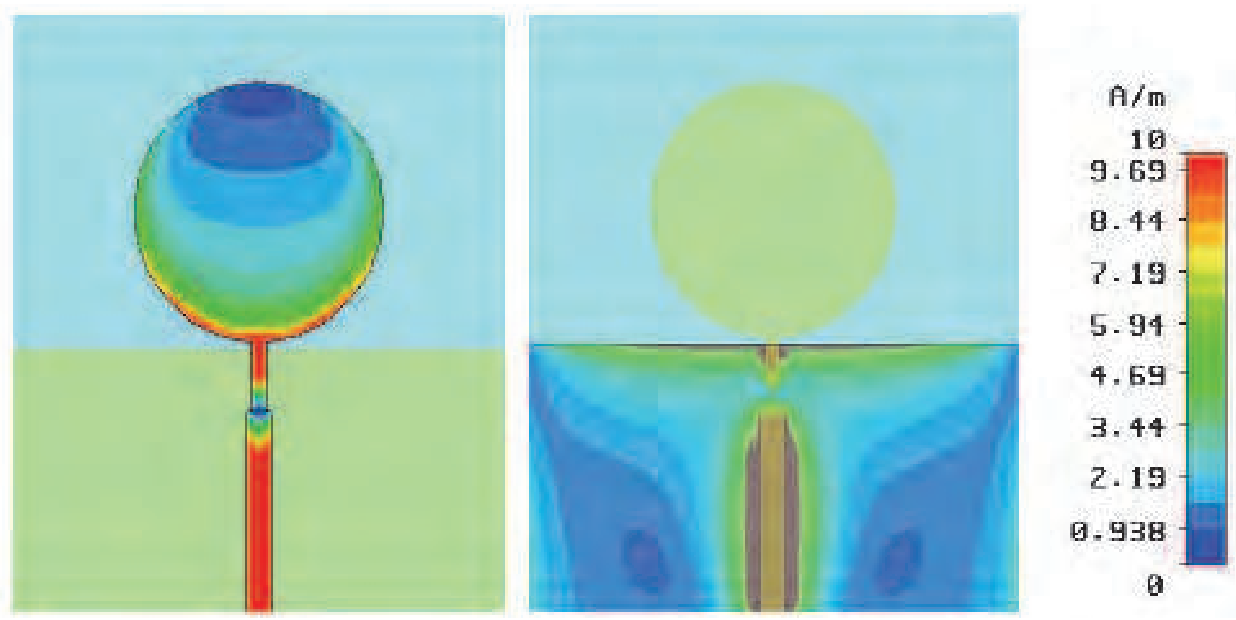

Fig. 11. Simulated current distribution on the disc monopole and ground plane at 5.2GHz

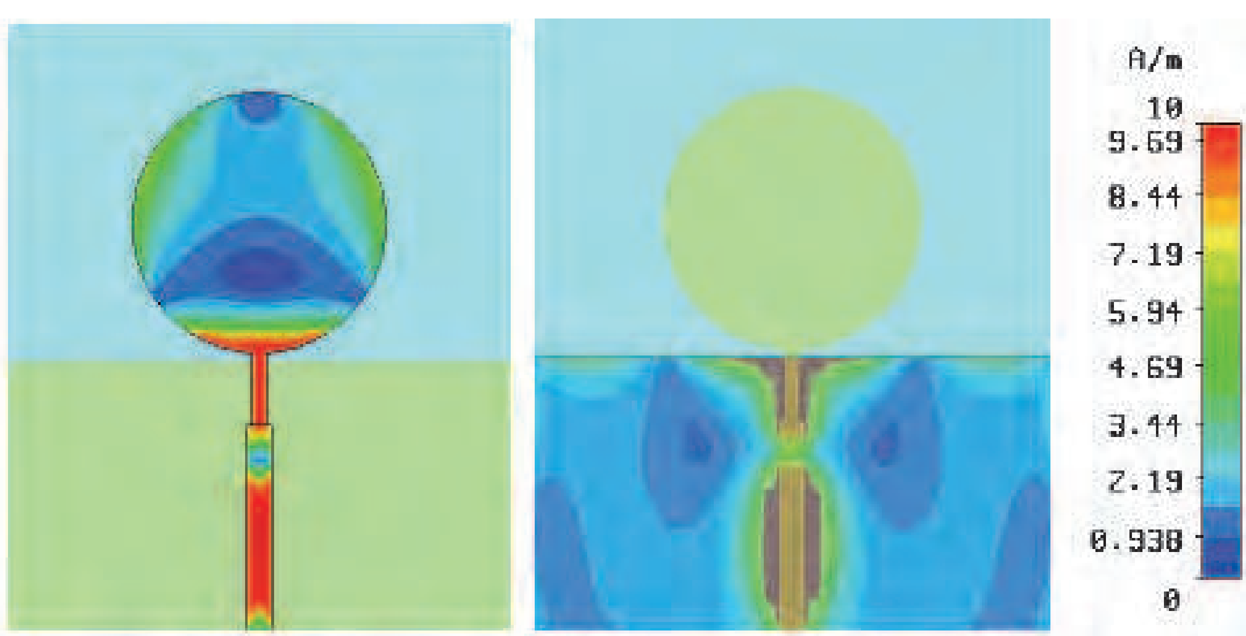

Fig. 12. Simulated current distribution on the disc monopole and ground plane at 9.5GHz

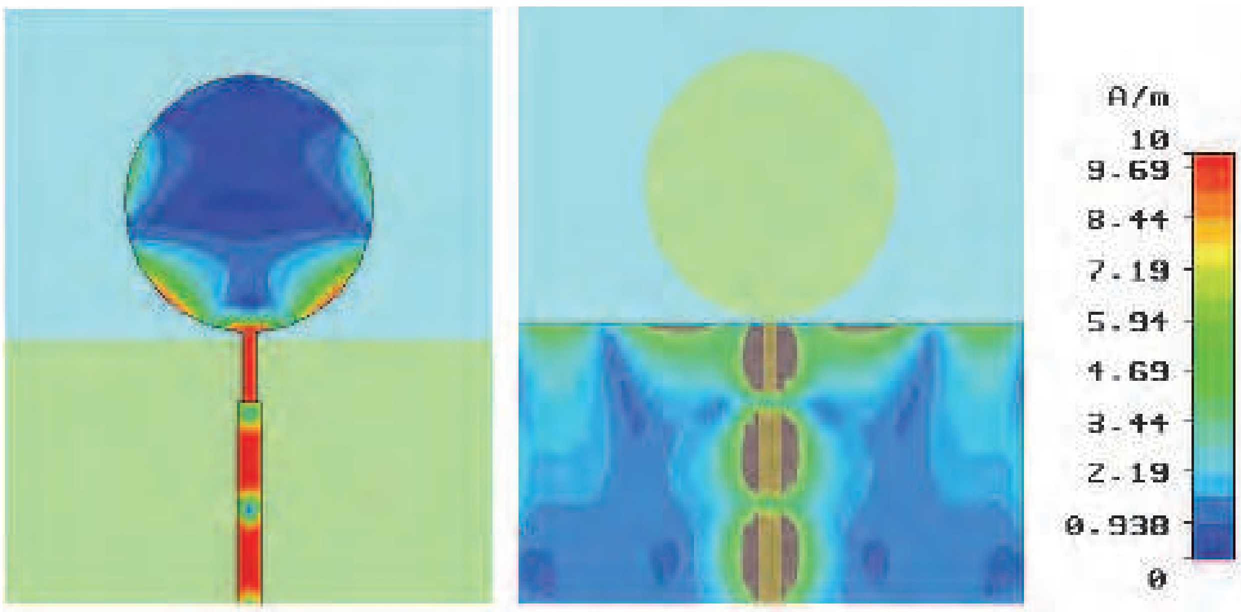

Fig. 13. Simulated current distribution on the disc monopole and ground plane at 23.5GHz

4. Printed arms monopole antenna

The design of antennas operating in multi-band (Guo et al., 2004, Lee et al., 2000, Llorens et al., 2003; Sindou et al., 1999) allows the wireless devices to be used with only a single antenna for multiple wireless applications, and thus permits to reduce the size of the space required for antenna on the wireless equipment.

In this section, we present dual band antenna designed for two promising technologies 3G and UWB wireless communication systems (srifi et al., 2009).

The geometrical configuration of this antenna, especially the size and position of the arms, and size of the slot on the partial ground plane, are the critical parameters that permit to obtain the desired operational bands, which cover several mobile and wireless communication technologies: IMT-2000, PCS (1850-1990 MHz), UMTS (1920-2170 MHz), IEEE 802.11j, a, the US-NIi, HIPERLAN2 (5.470 –5.725 GHz) frequency band, and the 5.8 GHz ISM band. The UWB frequency range for this antenna is from 5.15 to 8.22 GHz. A third frequency band, with a low level, is also observed around 3 GHz.

The antenna consists on six printed arms on the Rogers substrate (dielectric permittivity of 3.38, dielectric loss tangent of 0.0027). The substrate dimensions are of 16mm×36mm×0.83mm.

To improve the impedance matching, a rectangular slot with a size of 4mm×4mm is introduced on the partial ground plane. Figure 14 shows the prototype of the proposed antenna, a) top view, and b) bottom view.

Figure 15 plots measured return loss of the planar monopole antenna. Two frequency bands are observed: 1.8-2.3GHz, 5.16-8.12 GHz, and additionally a third band at 3.07-3.32 GHz with low reflection coefficient (-10.7 dB). The middle band is highly affected by the length of the feed line Lf, as shown in figure 5.5. By varying Lf values, the operational bands of this antenna can include other technologies such as WiMAX.

The measured radiation pattern of the proposed antenna at 2, 5.5, 5.8 and 7 GHz are illustrated in figure 16. These patterns show an omnidirectional radiation characteristic, with good gain values.

The proposed compact printed monopole antenna for ultra wideband and third generation mobile and wireless communication systems is easy to manufacture, low-cost, and can be easily integrated within the printed circuit boards (PCBs) of notebook computers, mobile terminals, and other wireless networking equipment.
By modifying antenna design parameters (mainly the size of the microstrip arms and the slot on the partial ground plane) the proposed antenna can be used also for other technologies such as WiMAX, and become thus triband antenna.

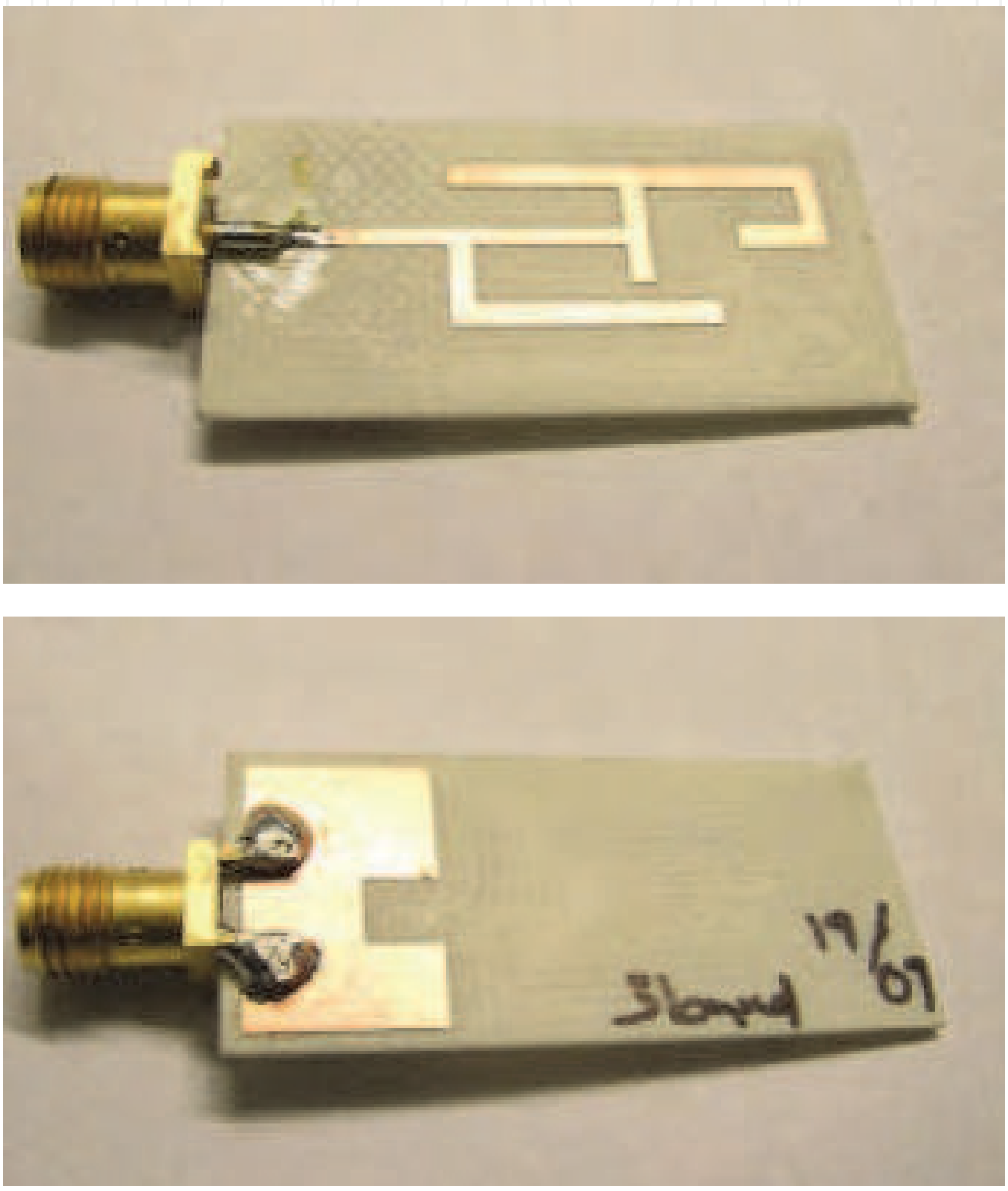

Fig. 14. Prototype of the planar monopole antenna

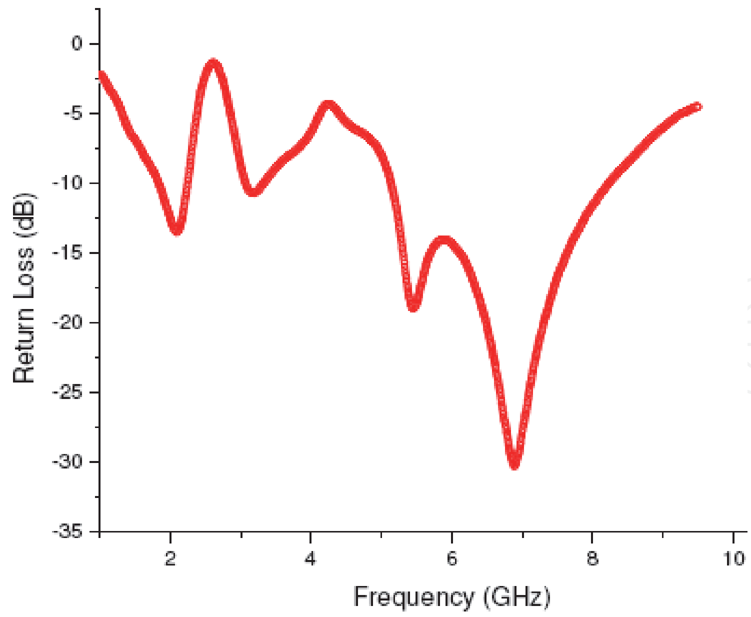

Fig. 15. Measured return loss of the proposed antenna

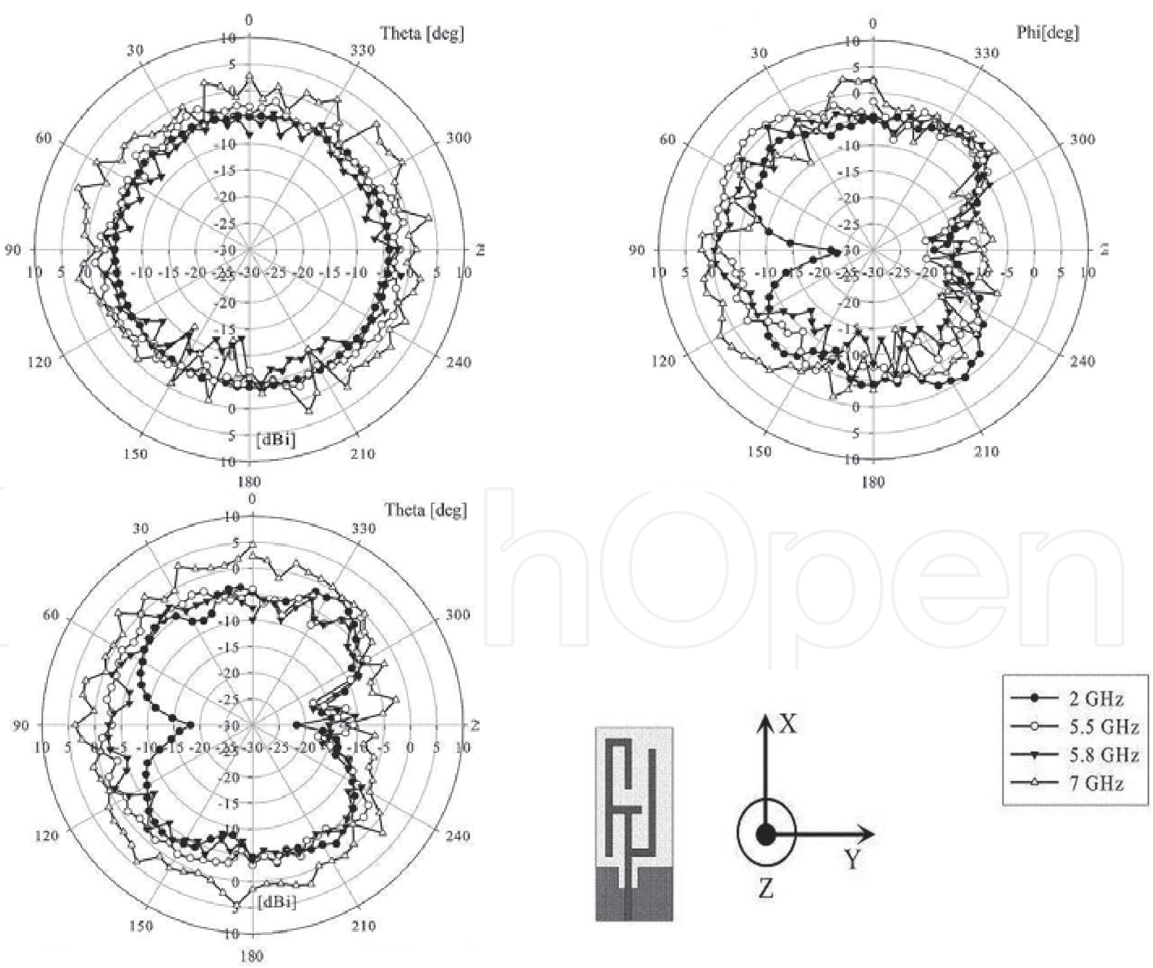

Fig. 16. Measured radiation pattern of the antenna in YZ plane, XY plane, and XZ plane, at 2, 5.5, 5.8 and 7GHz.

5. Conclusion

The UWB technology will be the key solution for the future wireless and mobile communication systems. This is due to its ability to achieve very high data rate which results from the large frequency spectrum occupied. UWB antenna is a crucial element in UWB system; it remains as a particular challenging topic because there are requirements for a suitable UWB antenna compared with a narrowband antenna.

The increasing demands for improved performances, and higher bit rate transmission speeds, gives place to the need for new and future UWB wireless schemes, in which, UWB antenna operation could be required to function beyond the 10.6 GHz upper frequency band limit currently defined by the FCC.

Therefore, it is essential to design a smooth transition between the feeding line and the radiator element for good impedance matching over the entire operational bandwidth. For this reason, a novel technique has been introduced to improve its performance, which consists on introducing two microstrip lines between the feedline and the radiator disc element. This proposed matching technique is very simple to introduce in practice and could be attractive for current and future UWB applications.

Measurements show that the operating bandwidth of the proposed antenna, after introducing the second microstrip line, increases from 3.18 GHz to 11.74 GHz (bandwidth of 8.56GHz) to 3.5 GHz to 31.94 GHz (bandwidth of 28.47GHz), so the bandwidth increase is of 232%. It's observed that the performances of the modified antenna are better compared to the first antenna.

Multiband printed arms monopole antenna is designed for 3G and UWB communications systems. Two main frequency bands 1.8-2.3GHz, 5.16-8.12 GHz are covered, and an additionally third band at 3.07-3.32 GHz is obtained and can be improved by slot size and feed line dimensions. This antenna has a good performance, thus it is more suitable for multiband systems including ultra wideband applications.

Proposed antennas in this chapter present good candidate for current and future ultra wideband applications, due to theirs attractive features (i.e. small size, low profile, low cost, impedance bandwidth, gain, nearly omnidirectional radiation).

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