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Design and Implementation of Compact Reconfigurable Antenna for UWB and WLAN Application

Dr.M.Maharajan
Department of Electronics and Communication Engineering,Shadan College of Engineering and Technology HYD,T.S,INDIA

Abstract:

Antenna has rapidly developed due to the introduction of wireless communication. A compact four band antenna is well suited for WLAN/WIMAX application as it covers 2.39-2.67, 3.42-3.61 GHZ and 4.90-7.01 GHZ. Acceptable` agreement is obtained between the stimulated and measured antenna for performance parameters. Various applications can be implemented in a multiband antenna. Hence, the antenna provides quasi-omnidirectional radiation pattern in X-Z plane. These characteristics illustrates that the proposed antenna is an impressive model for handheld mobile devices. Index terms-Composite right/left handed (CRLH), Envelope correlation coefficient (ECC), Multiple- input multiple- output (MIMO), UWB Antenna.

1. INTRODUCTION

The objective of this research is to realize compact and reconfigurable antennas for next generation Ultra Wide Band (UWB) and Wireless Local Area Network (WLAN) applications. The contributions of this research are, a methodology for designing compact UWB antennas, a compact WLAN prototype antenna with reconfigurable characteristics in both radiation pattern and frequency of operation, and compact UWB antennas with reconfigurable WLAN band rejection characteristics. For the completion of this dissertation, five research projects have been studied. First, a doubleexponentially tapered slot antenna with conformal shape, high gain, and consistent radiation patterns is implemented. The radiation pattern consistency results in minimum distortion for any transmitted pulse.

The second and third projects involve an elliptical slot with a tuning uneven U-shaped stub and two cactus-shaped monopoles. The elliptical slot demonstrates omni-directional radiation patterns and compact size. As an improved iteration of the elliptical slot antenna, two cactus-shaped monopoles are implemented. The two prototypes occupy only 60% and 40%, respectively, of the area that the original elliptical slot occupies resulting in a significant size reduction, while maintaining omni-directional radiation patterns. Through the cactus-shaped monopoles some general design methodologies for UWB antennas are introduced and successfully applied.The fourth research topic introduced, concerns the study of compact elliptical UWB monopoles. Several prototypes of different geometrical characteristics were designed and tested. Broadband matching techniques and the integration of reconfigurable features onthe elliptical radiator are investigated. For the reconfigurable UWB antenna, resonating elements are used to create a rejection band in the frequency range that is occupied by WLAN applications. Finally, a reconfigurable annular slot antenna operating at the wireless local area network (WLAN) band is implemented. The proposed antenna demonstrates reconfigurable characteristics in bothradiation pattern and return loss.

All of the UWB antennas are fabricated on liquid crystal polymer (LCP) and can be easily integrated with active components on the same module using system on package (SoP) technology. Currently there are several wireless systems applications in a multitude of areas such as mobile and personal communications, radio-frequency (RF) identification, wireless local area networks (WLAN), remote sensing, etc. Regardless of the application, most of those systems have similar demands for increased functionality, improved performance, compact size, and most importantly lower development cost. An objective that attracts a lot of effort is the integration of multiple functions on a single convergent system. Such a system requires a one-step integrated solution for all sensing, computing, andcommunicating functions. An example could be a device, which can function as a cell phone, monitor weather, store data, perform basic computations, connect to the internet and can be hand-worn like a simple watch. Such devices require an effective packaging technique and a versatile transceiver that would be able to operate in different frequencies. Ideally this versatile operation would be dynamic. For the operation versatility a cognitive radio is desired. Cognitive radio is a communications system which can change its transmission or receptionparameters to communicate efficiently without interfering with licensed users. An approach like that, requires reconfigurable modules and therefore reconfigurable antennas.
Although different packaging approaches have been investigated in order to create such convergent systems, like system-on-a-chip (SoC), multichip module (MCM), and system-in-a-package (SiP), the system-on-a-package (SoP) approach [1,3] has been identified as the best solution to implement multiple system functions into one compact, low-cost, high-performance packaged system. In a SoP-based system, the packageperforms the functions of powering, cooling and interconnecting these chips and additionally it houses passive functionality. Those passives are built on and/or embedded inside the package and therefore the package and the chip(s) have to be designed together in a SoP system[3]. Part of the SoP challenge is the identification of suitable material technology that supports such integration. For example, a viable 3-D SoP technology for wireless communication applications would require building blocks such as active components, embedded passives, integrated antennas, and a suitable platform to integrate the different parts. The material platform should provide excellent electrical properties, mechanical stability, chemical resistance, good barrier properties, multilayer lamination capabilities, and be cost competitive.

Microwave composites and ceramics are attractive candidates that have been identified as suitable platforms for a SoP system. Microwave composites such as variations of Rogers Duroid or Taconic RF [8] series materials use proprietary mixes of materials like polytetraflouroethylene (PTFE), glass weave, and ceramic fills. These materials are carefully engineered for excellent performance, but are expensive. Furthermore, because a mix of materials is used, the homogeneity is lost. Low-temperature co-fired ceramic (LTCC) is one of the very few substrates that satisfies nearly all the requirements [6, 7].However LTCC may not be ideal for all applications. For example, printed antennas on LTCC substrates suffer from reduced efficiency because of their relatively high dielectric constant (εr=5.4−9.1). Furthermore, LTCC is still expensive compared to conventional laminate materials. Another disadvantage with the LTCC process is that its process temperature (800◦C −1000◦C) may not be acceptable for some fully integrated solutions. As an example, micro-electro-mechanical system (MEMS) switches which are necessary for the design of smart reconfigurable systemscannot survive this high processing temperature. The comparatively high processing temperature of LTCC prevents the incorporation of MEMS-based reconfigurability into systems developed on an LTCC platform. Therefore to realize the full advantages of an integrated SoP system, especially for reconfigurable systems alternative material technologies need to be explored such as liquid crystal polymer (LCP). A reconfigurable antenna is a antenna capable of modifying dynamically its frequency and radiation properties in a controlled and reversible manner. In order to provide a dynamical response, reconfigurable antennas integrate an inner mechanism (such as RF switches, varactors, mechanical actuators or tunable materials) that enable the intentional redistribution of the RF currents over the antenna surface and produce reversible modifications over its properties. Reconfigurable antennas differ from smart antennasbecause the reconfiguration mechanism lies inside the antenna rather than in an external beam formingnetwork. The reconfiguration capability of reconfigurable antennas is used to maximize the antenna performance in a changing scenario or to satisfy changing operating requirements. Multi-user MIMO (MU-MIMO) is a set of multiple-input and multiple-output (MIMO) technologies for wirelesscommunication, in which a set of users or wireless terminals, each with one or more antennas, communicate with each other.[1] In contrast, single-user MIMO considers a single multi-antenna transmitter communicating with a single multi-antenna receiver. In a similar waythat OFDMA adds multiple access (multi-user) capabilities to OFDM, MU-MIMO adds multiple access (multi-user) capabilities to MIMO. MU-MIMO has been investigated since the beginning of research into multi-antenna communication. The Multiple –Input Multiple –Output (MIMO) technology has drawn the attention of researches, as by developing antennas. More researches about MIMO antennas were focused on WLAN (wireless local area network) and WIMAX (world wide interoperability for microwave access). MIMO antenna is very scant in the literature. MIMO technology has been introduced to miniaturized planar mobile antenna design for more applications of Bluetooth (2.4-2.484 GHZ).WIMAX for (3.4-3.69 GHZ) WLAN for (5.15-5.825 GHZ). MIMO antenna should have compact size, structure, high radiation efficiency, low envelope correlation and high isolation between the signal ports.MIMO antenna has a size of 45mm*25mm is presented .This elements are fed by 50ohm micro strip lines.

Contributions and Organization

The contributions of this research are, a methodology for designing compact UWB antennas, a compact WLAN prototype antenna with reconfigurable characteristics in both radiation pattern and frequency of operation, and compact UWB antennas with reconfigurable WLAN band rejection characteristics.A number of UWB antennas for both radar and personal mobile communications applications are presented in chapter 3 with major concern to achieve antennas with compact size and improved characteristics. The first proposed antenna is a double exponentially tapered slot antenna (DETSA), an endfire antenna with high gain, high directivity and relatively large size suitable for radar applications and wearable electronics. For UWB mobile, hand-held devices that require omni-directional pattern and compact size, four additional prototypes are proposed. An elliptical slot antenna tuned by a U-shaped stub, two iterations of a cactus-shaped monopole and lastly a CPW-fed elliptical monopole. A reconfigurable antenna in both frequency and radiation pattern is introduced and investigated. A bidirectional annular slot antenna (ASA) is used, fabricated on Duroid substrate. Two matching stubs are used to match the antenna under detection at 5.2, 5.8 and 6.4 GHz.

2. ANTENNA DESIGN

In recent time, many interesting and novel concepts have been developed to achieve adaptable antenna properties. Key aspects of some outstanding concepts will be addressed in the following sections. In our discussion, we mainly focus on antenna design with frequency

agility. Some examples of antenna structures with polarization, bandwidth, and pattern reconfigurable property will be addressed as well.
A quad-band circularly polarized (CP) antenna for 2.4/5.3/5.8 GHz WLAN and 3.5 GHz WIMAX applications is proposed to improve speed of data transmission.

ADVANTAGES

- Quad band frequencies for transmission.
- Less complexity in antenna design compared to existing antenna system.

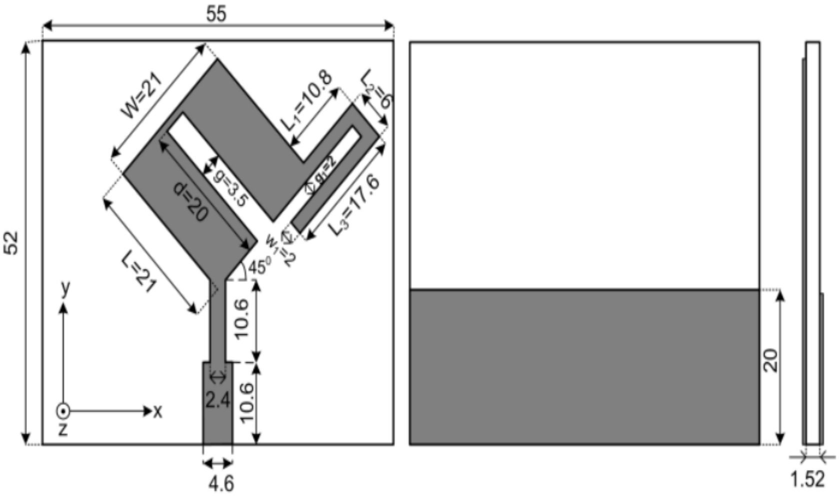

Fig 1 Proposed Antenna Structure

Comparison between Bluetooth, Wi-Fi and Gi-Fi

SPECIFICATION	BLUETOOTH	WI-FI	GI-FI
Frequency	2.4 GHz	2.4 GHz	57 – 64 GHz
Range	10 m	100 m	10 m
Data transfer rate	800 kbps	11 Mbps	5 Gbps
Power consumption	5 mW	10 mW	< 2 mW
Primary Devices	Mobiles phones, consumer Electronics etc.,	Notebook computers, Desktop Computers, Servers	Both areas
Primary Application	WPAN: cable replacement	WLAN: Ethernet replacement	Both
Usage location	Anywhere atleast two bluetooth device exist	Within range of WLAN infrastructure,usually inside a buildings	WPAN Networks
Development Start Date	1998	1990	2004 Under development

Fig 2: Proposed Antenna Structure

There are basically three design approaches for achieving antenna frequency agility which are as follows:

(a)Antennas integrated with electronic switches, mechanical actuators, tunable materials for reconfigurability in terms of circuital characteristics and/or radiation properties;
(b)Ultrawideband (UWB) or multiband antennas integrated with tunable filters;
(c)Reconfigurable/multiband arrays where the same aperture is utilized for different operational modes.

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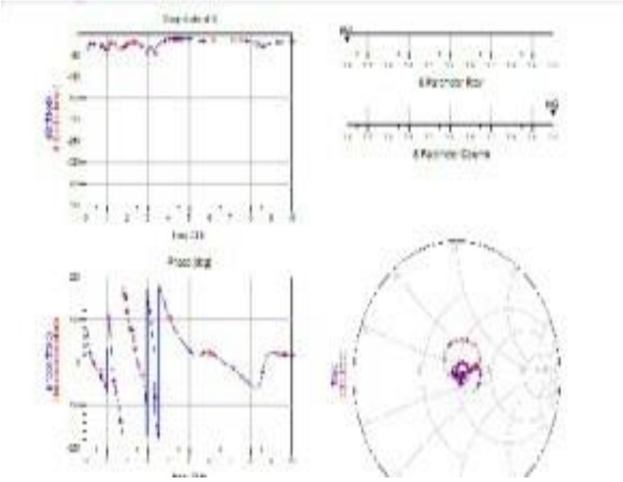
RADIATION PATTERN



The proposed antenna was fabricated on a 200 µm thick liquid crystal polymer (LCP) substrate with an 18 µm thick copper layer. The DETSA schematic is presented in Figure1. The length of the board is L=13.62 cm, the width is D=6.64cm and the slot gap at the feeding point is 100 µm wide. LCP was preferred because of a number of desirable features.

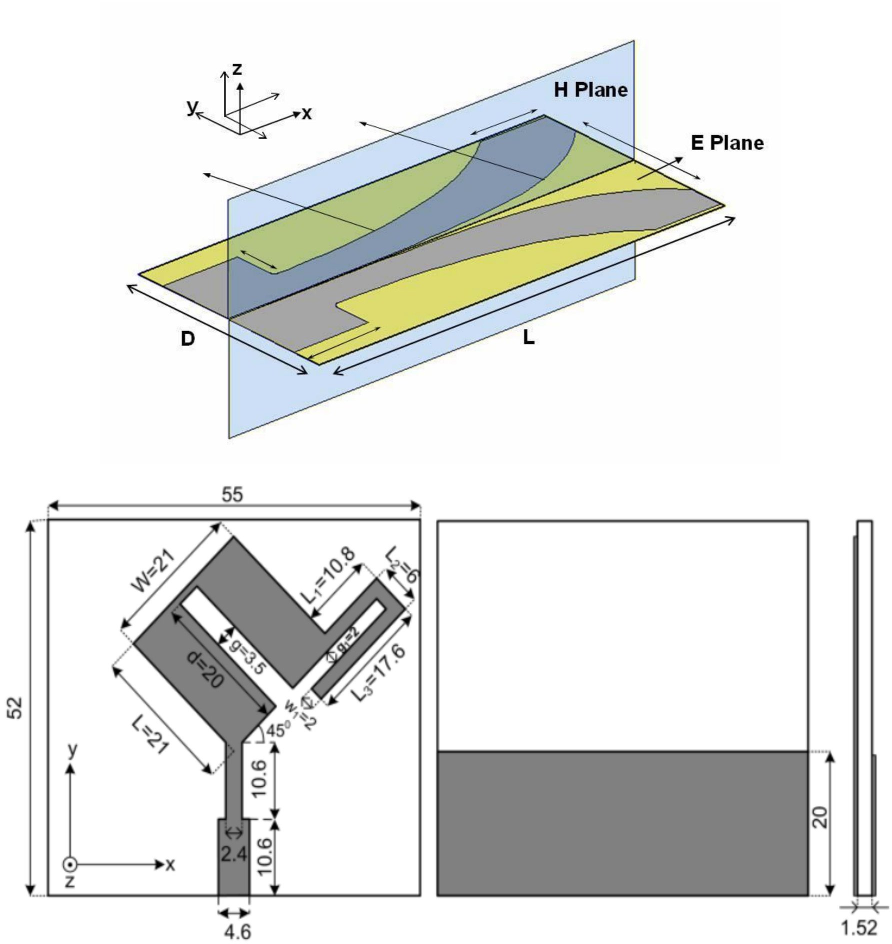


Fig 3: DETSA schematic E and H planes are defined.

The dielectric constant εr=3.0 is low enough to be used for an end-fire antenna, it has low loss (tanδ=0.002) while being conformal, and it is easy to fabricate with an engineered Coefficient of Thermal Expansion (CTE) [60]. Standard photolithography was used for the fabrication. The design dimensions have been optimized for the antenna to be matched over a frequency range of 3 GHz to 11 GHz. The design parameters are summarized in Table2. For contours C1 and C2, the y variable starts at distance L1 from the edge of the board and is measured in centimeters.

Table 1: Dimensions of DETSA.

C1	0.76exp(0.16y)
	0<y<8.53 cm
C2	0.012exp(0.48y
	0<y<10.67 cm
d1	12.00 mm
d2	42.92 mm
L1	24.00 mm
L2	21.40mm
D	66.40 mm
L	130.70 mm

3.1.2

Return Loss and Radiation Pattern Measurements

For return loss and radiation pattern measurements, an SMA connector was soldered directly on the slot with no tuning components. The antenna was folded in such a way that the end of the board forms an 18° angle with the y axis, as shown in Figure 3. The contour that describes the projection of the resulted folded antenna surface on the H plane where the y variable is measured in cm and starts at the origin.

$C(y) = -0.0126(y + 1.451y^2 + 0.074y^3)$

$0 \leq y \leq 10.67\ cm$

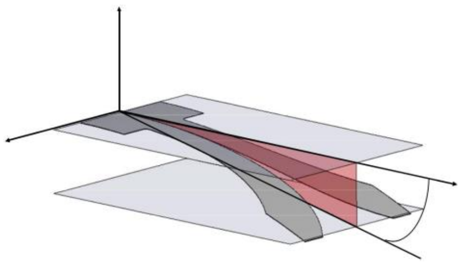


Fig4: Folded DETSA schematic.

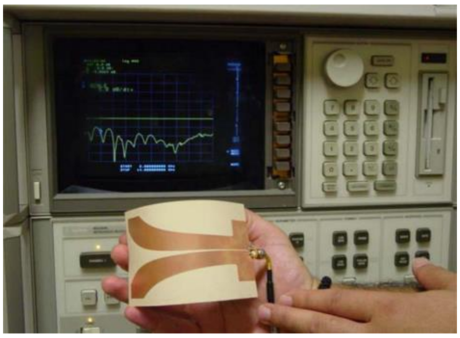


Fig 5: (a) Planar DETSA antenna connected to

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the HP 8530A Network Analyzer

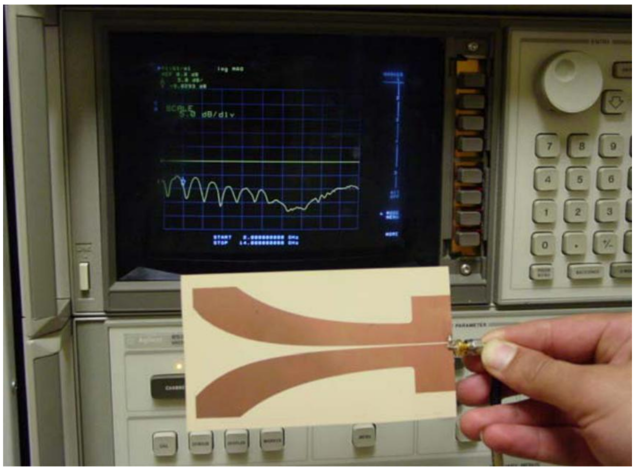

Fig (b) Folded DETSA antenna connected to the HP 8530A Network Analyzer.

Different techniques were documented to reduce the size of antennas at a given frequency for a compact design. One simple method was the use of a dielectric substrate with higher εr value Although using higher εr value results in a size decrease, it also affected the efficiency of the antenna and in many cases was avoided.

Another method used for resonant antennas was the use of meandered metal segments. The meandering was achieved by cutting slots in the non-radiating edges of the antenna [9]. This effectively elongated the surface current path on the antenna and increased the loading, which resulted in a decrease in the resonant frequency. This second technique could be used primarily for resonating antennas, like the antennas that are used for WLANs with the IEEE 802.11a protocol. However, for non-resonating antennas like the UWB antennas that radiate in a wide frequency, that technique could not be applied.

The earliest UWB antennas reported in the literature were pretty sizeable in order to radiate effectively at the lower frequencies. Because of the variety of UWB applications, the proposed designs demonstrated equally great variety. Clearly, the early designs could not meet the size and integration characteristics that were necessary for mobile devices.

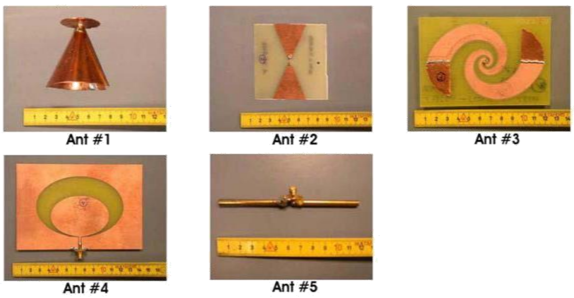

Fig 6: Early UWB antennas

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One of the main issues was the fact that many of those designs were not printed; therefore, their integration with the other radio components was difficult. One of the early printed wideband antennas that were considered for UWB applications was the Vivaldi antenna [10]. Soon after, an improved variation of the Vivaldi antenna, the Double Exponentially Tapered Slot Antenna was introduced and generated a lot of attention because of its easy matching and high gain. Although those antennas had appealing radiation and matching characteristics, they remained very large compared to the desired size for handheld devices. In addition they were directive antennas and therefore unsuitable for mobile devices that require omni-directional radiation patterns. A better approach than the end fire DETSA was the micro strip fed, or CPW fed slot antennas presented in. Those slot antennas were not directive and were considerably smaller since the elliptical slots could support multiple radiation modes.

CRLH UNIT CELL LOADED ANTENNA

Artificial transmission lines exhibiting left- and right-handed wave propagation [that is, composite right/left handed (CRLH) lines] can be implemented by loading a host line either with series capacitances and shunt inductances (CL-loaded approach) , or with complementary split ring resonators (CSRRs) combined with series gaps (resonant type approach) . Due to the greater degrees of freedom, the dispersion characteristics of these CRLH lines can be engineered, and they can be applied to the design of novel microwave components with superior performance (as compared to conventional implementations) or based on new functionalities.

In particular, CRLH lines can be applied to the design of dual-band microwave components. Such components exhibit certain functionality at two arbitrary different frequencies, which can not be easily implemented through traditional distributed approaches since conventional transmission lines have a certain phase only at the fundamental frequency and its odd harmonics. Dual-band operation requires that transmission lines and stubs exhibit identical characteristic impedance and equivalent phase shift at the operating frequencies, f1 and f2. As mentioned, this is not possible in conventional lines unless f2 (the higher frequency) is an odd harmonic of f1. However, by properly engineering the dispersion diagram of CRLH lines, it is possible to obtain the desired characteristics at the two operating frequencies, as has been demonstrated by Lin et al. [11] in the design of a dual-band branch line hybrid coupler. In [11], the two pairs of 90° impedance inverters of the conventional implementation are replaced with CL-loaded artificial lines able to provide −90∘ and −270∘ phase shifts at f1 and f2, respectively.

PROPOSED FOUR-ELEMENTS QUAD BAND MIMO ANTENNA

A novel four-element multiple-input-multiple-output (MIMO) antenna having quad-bandcharacteristics is proposed. A coplanar waveguide-fed monopole is loaded with a split-ring resonator and an inter-digital capacitor to achieve miniaturization and quad-band operation. These quad-band elements are arranged properly to implement a four-element MIMO configuration which provides both spatial and pattern diversities. The achieved isolation performance is better than 20 dB. The proposed antenna can be useful for MIMO applications in global system of mobile/Bluetooth/wireless local area network/worldwide interoperability for microwave access operating bands.

The most designs of multi-antenna system in mobile terminals are for WLAN operation [2] and applied in the PCMCIA card of a laptop. In [3], a dual-band diversity antenna in 2.4/5.2-GHz WLAN bands is proposed. The antenna consists of two orthogonal C-shaped monopoles. A protruding T-shaped stub at the ground plane is used to increase the isolation. Another design with dual-helical antenna on mobile handsets was provided in [12]. However, the relatively large antenna volume and the strong coupling between two elements restrict its application. At present, few of diversity antennas operate in the UMTS band (1920-2170 MHz). However, the demand for diversity antenna in the UMTS band is more and more great. The design faces the problems of working at lower frequency, wider bandwidth and more limited volume than one in the WLAN band does.

IMPROVEMENT ISOLATION

Quad Band Handset Antenna for LTE MIMO and WLAN Application

The proposed antenna comprises two symmetrical quarter wavelength radiating strips and a slotted ground plane. On the ground plane, a T-shaped slot is cut from the bottom. Two symmetrical P-shaped slots are etched at both sides of the ground plane. The radiating strips and slots generate a lower resonant at 780 MHz and an upper resonant at 2.350 GHz to cover LTE 700 Band 14, LTE 2300, 2.4 GHz WLAN, and LTE 2500. A novel isolation technique by placing a rectangular patch between the radiating strips is presented. The rectangular patch creates a dedicated current path for each radiating strip. The proposed antenna has high isolation of less than −18 dBi at LTE 2300, 2.4 GHz WLAN, and LTE 2500 band.

UWB Applications

Unlike WLAN applications, which are well known and defined as mobile or base station wireless network terminals, UWB applications have great variety [17]. Some of the current and potential applications are listed below.

- *Altimeter/Obstacle avoidance radars*
- *Collision avoidance sensors*
- *Tags*
- *Intrusion detection radars (through wall imaging)*
- *Industrial RF monitoring systems*
- *Wearable electronics for wireless body area network (WBAN)*
- *High speed WLANs and wireless personal area network (WPANs)*

Depending on the application, the required antenna characteristics may varysignificantly. For radar applications more directive antennas are needed; for WBAN applications conformal features may be necessary, while for mobile handheld devices Omni-directional pattern characteristics are highly desirable. Handheld devices are the terminals for WLANs and WPANs. The UWB radios for wireless networks have many advantages that make them very appealing. UWB signals are very difficult to intercept and they have multipath immunity because of the wide spectrum they use. The fact that UWB radios *require fewer components results in small size, low weight, and additionally, relatively low cost.*

MINIATURIZATION OF UWB ANTENNAS

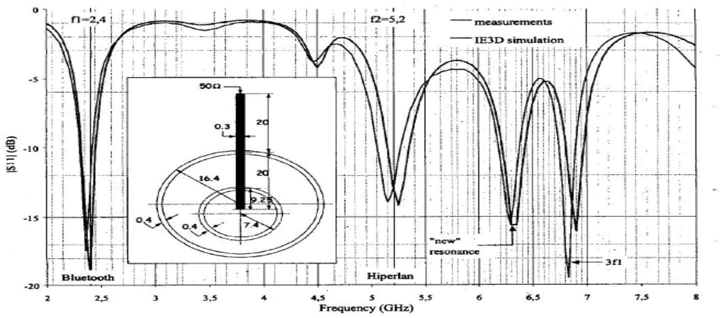
A number of requisite research tasks for developing compact antennas for UWB applications have been accomplished by the author. Those steps are:

Conformal Double Exponentially Tapered Slot Antenna (DETSA) on LCP

CPW-fed Elliptical Slot UWB Antenna with a Tuning Uneven U-shaped Stub on Liquid Crystal Polymer (LCP)

Cactus-shaped UWB Monopole Antenna

Compact UWB CPW-fed Elliptical Monopole on Liquid Crystal Polymer (LCP)



Return loss of the dualband antenna.

CONCLUSION

The design and implementation of compact reconfigurable antennas for UWB and WLAN applications has been investigated. UWB elliptical monopoles with reconfigurable band rejection in the WLAN frequency range have been implemented, using MEMS switches actuated without the need of DC bias lines. For WLAN applications, an annular slot antenna was implemented that demonstrates reconfigurable frequency operation and radiation pattern capabilities, using PIN diodes. These are the first such illustrations.

Reconfigurable antennas can be used for next generation cognitive radio systems. In the process and in addition to those prototypes several other UWB antenna designs were also investigated and led to a design methodology for designing compact broadband antennas. Taking advantage of LCP's flexibility the properties of UWB radiators in non-planar shapes were studied and demonstrated that their performance is very similar to the performance of their planar counterparts. Something that indicates that antennas for a number of conformal applications, like wearable electronics, can be designed and tested in planar shapes and still be trusted to operate equally well in non-planar shapes.

A double exponentially tapered slot antenna with high gain was implemented. The flexibility of the prototype and the directive radiation patterns make it a good candidate for portable or wearable personal radar devices. The need for more compact and omni-directional antennas for mobile and personal communication applications led to the design of the U-stub fed elliptical slot, and in an improved iteration, the design of the cactus-shaped monopoles that demonstrate remarkable size and radiation pattern characteristics that make them excellent candidates for such applications. The design of the cactus-shaped monopoles demonstrated a broadband matching technique. Good matching was achieved by modifying the equivalent load of the feed line. That was achieved by altering the geometrical features of the antenna.

In the attempt of designing compact omni-directional antennas, CPW fed elliptical monopoles were built. The matching difficulties were overcome with the implementation of a broadband transition from a CPW line to the elliptical radiator that reduced the high real part of the input impedance without changing the radiator and therefore degrading the radiation characteristics of the monopole.Several of the fabricated antennas were tested when they were mounted on non-planar surfaces. Return loss, radiation pattern and channel measurements, demonstrated the applicability of conformal UWB antennas.Two kind of resonating elements were integrated using MEMS switches with a version of the elliptical monopole to provide reconfigurable band rejection in the frequency range occupied by WLAN applications. A λ/2 long U-shaped slot was used in one case and two inverted L-shaped λ/4 long stubs were used in the second case. The presence of the band rejection protects a UWB radio from high noise levels coming from neighboring WLAN transmitters, while its elimination improves the available bandwidth when the noise level is low.Finally a reconfigurable annular slot antenna in both frequency and radiation pattern was presented. PIN diodes were used to connect and disconnect the matching stubs that control the frequency operation, and another type of PIN diodes is used to direct the null of the radiation part in a desired predefined direction.

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