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A Survey on UWB and Reconfigurable Antennas for Cognitive Radio Application

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ABSTRACT: In this paper, a survey on ultrawide band and reconfigurable antennas for cognitive radio application is presented. Cognitive radio is an intelligent wireless communication system that is aware of its surrounding environment (i.e., outside world), and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters (e.g. transmit-power, carrier-frequency, and modulation strategy) in real-time. For the realization of a CR system, wideband and a narrow band antennas are required. A UWB antenna is considered for the wide band operation and they are those systems which covers a large spectrum in the range of 3.1GHz to 10.6GHz and is used for sensing vacant slots in the spectrum. Reconfigurable antennas usually frequency reconfigurable are considered as narrow band antenna which is used for transmission of data through the vacant slots sensed by the wide band antenna.

Keywords: Cognitive Radio, Wideband Antennas, UWB Antennas, Reconfigurable Antennas, Narrow band Antennas.

I. INTRODUCTION

During the last few decades, the severe shortage of radio spectrum has been the main motivation always used by researchers in the field of wireless communications. It has been believed that this shortage is mainly due to the physical scarcity of radio spectrum and due to the rapid spread of diverse devices with wireless-interaction capability, such as mobile phones, laptop computers, home appliances, wireless tags, etc. Traditional and common approaches to solve this problem have been to increase the number of bits that can be transmitted per unit time and frequency, resulting in high capacity within a given frequency bandwidth. To this end, considerable research effort and fund have been spent to develop advanced wireless access technologies, and a lot of research is still ongoing all over the world. However, a recent report published by the federal communication commission (FCC) in US has shown a surprising finding, which highlights a different cause of the shortage of frequency resource: “In many bands, spectrum access is a more significant problem than physical scarcity of spectrum, in large part due to legacy command-and-control regulation that limits the ability of potential spectrum users to obtain such access”. Thus, the large part of the licensed spectrum is not utilized most of the time and space, and the frequency spectrum is actually abundant. We have been trying to put more signals into congested frequency bands even if there are almost free frequency bands next to them. This paradoxical fact has resulted from the complicated and old regulations, which prevent us from utilizing more flexible and open access to these abundant bands. Apparently, in order to increase the efficiency of our natural spectrum resource utilization, more flexible spectrum management techniques and regulations are required. The emerging feature-rich and high-data-rate wireless applications have put this increasing demand on radio spectrum. The scarcity of spectrum and the inefficiency in its usage, as caused by the current radio spectrum regulations, necessitate the development of new dynamic spectrum allocation policies to better exploit the existing spectrum.

The current spectrum allocation regulations assign specific bands to particular services, and grant licensed band access to licensed users only. Cognitive Radio (CR) will revolutionize the way spectrum is allocated. In a CR network, the intelligent radio part allows unlicensed users (secondary users) to access spectrum bands licensed to primary users, while avoiding interference with them. In this scheme, a secondary user can use spectrum sensing hardware/software to

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locate spectrum portions with reduced primary user activity or idle spectrum slots, select the best available channel, coordinate access to this channel with other secondary users, and vacate the channel when a primary user needs it.

Cognitive radio is an intelligent wireless communication system that is aware of its surrounding environment (i.e., outside world), and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters (e.g. transmit-power, carrier-frequency, and modulation strategy) in real-time, with two primary objectives in mind:

- Highly reliable communications whenever and wherever needed;
- Efficient utilization of the radio spectrum.

The antenna system for a cognitive radio is an integral part for its implementation. Two antennas are required for a CR system, first a wide band antenna which is usually a UWB antenna and the other is a narrow band antenna which have the frequency reconfiguration property. A UWB antenna is used to sense the spectrum in the range of 3.1GHz to 10.6GHz in order to find a vacant slot. The moment a vacant slot is obtained, the secondary user uses the narrow band antenna for transmitting data through that vacant slot. If the primary user needs that slot back for its use, then the frequency reconfiguration property which is integrated with the narrow band antenna helps to continue the data transmission through another vacant slot in the specified spectrum. Now we will have an overview about the UWB and reconfigurable antennas for the cognitive radio application[1][2].

II. UWB ANTENNAS

The band allocated to communications is a staggering 7.5 GHz, by far the largest allocation of bandwidth to any commercial terrestrial system. UWB is defined for a frequency range of 3.1GHz to 10.6GHz. The FCC UWB rulings allocated 1500-times the spectrum allocation of a single UMTS (universal mobile telecommunication system) license, and, worse, the band is free to use. The effort to bring UWB into mainstream was greeted with greater hostility because of two reasons, a) the enormous bandwidth of the system meant that UWB could potentially offer data rates of the order of Gbps and b) the bandwidth sat on top of many existing allocations causing concern from those groups with the primary allocations. One of the enormous potentials of UWB, however, is the ability to move between the very high data rate, short link distance and the very low data rate, longer link distance applications.

Antenna plays an essential task in UWB system, which is different from narrowband system. UWB systems transmit extremely narrow pulses on the order of 1 ns or less resulting in bandwidths in excess of 1 GHz or more. However, the design and fabrication of high-performance transmitting/receiving antennas often present significant challenges in the implementation of these systems. The challenge lies in the development of an antenna, capable of handling these high-speed pulse trains. The design of a UWB antenna is very difficult, because the fractional bandwidth is actually big, and antenna must cover multiple-octave bandwidths in order to transmit pulses that are of the order of a nanosecond in duration. Since data may be contained in the shape of the UWB pulse, antenna pulse distortion must be kept to a minimum. From a system design perspective, the impulse response of the antenna is of particular interest, because it has the ability to alter or shape the transmitted or received pulses. In practice, attempt must be made to limit the amplitude and group delay distortion below certain threshold that will ensure reliable system performance[3].

To comply with all of these requirements the microstrip antenna has been nominated. However, due to its narrow bandwidth, many solutions have been introduced, such as using different shapes of the patch that can accommodate multimode surface current waves, which in turn lead to resonating at multiband frequencies and finally widen the impedance bandwidth across the entire UWB range. Among the proposed broadband antenna shapes are; a triangular monopole [4], circular and elliptical disc monopoles [5][6]. Another technique was through applying the self-complementary principle to the circular disk and ring monopole antennas [7][8], respectively.

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The bandwidth can be enhanced by the use of a triple feed configuration connected to the lower edge of planar square monopole antenna. This method help to excite more uniform surface current on the planar monopole antenna. When such feeding structure is directly applied to the circular and elliptical monopoles then the feeding points won't coincide with the surface current distribution of various resonant modes. Therefore, before attempting any IM modification on the patch itself, one should be more aware of the modes formed inside the patch shape. Two IM techniques, first is the use of a quarter wave transformer and the second one is by using a meandered microstrip feed line, which is more efficient because it adds an excess shunt capacitance to the front end of the antenna equivalent circuit can be applied. By meandering the required capacitive reactance is achieved by with two right angle turns, because bending the microstrip line enables adding an excess shunt capacitance at the front end of its equivalent circuit[9].

When attempts are made to increase bandwidth it will also cause increase of the cross polarization. However, a pure linear polarization is imperative in many applications, especially those seeking circular polarizations. There is interest in two-port circularly polarized microstrip patch antennas for circular polarizations. One of the most common approach to increase the bandwidth of a microstrip patch antenna and avoid cross polarization is to increase the substrate thickness. It has been shown that the bandwidth of a microstrip patch antenna is a linear function of its dielectric thickness. Increasing the bandwidth of the patch antenna with a thicker dielectric substrate also increases the series inductance. This series inductance can be decreased with the help of a thick feeding probe. Unfortunately, this technique usually has practical problems. Specifically, using a thick probe in the structure of a patch antenna, on a ceramic substrate, imposes mechanical challenges to the design. Adding a thick probe increases the price of the antenna as well. Avoiding the need for a thick probe has advantages. This communication presents a feeding structure which allows the use of a thicker substrate and thus increased bandwidth without added cross polarization, and does not use a thick probe.[10]

Four techniques are applied for good impedance matching over the UWB range: 1) the specially designed patch shape, 2) the tapered connection between the patch and the feed line, 3) the optimized partial ground plane, and 4) the slots whose design is based on the knowledge of fractal shapes. Besides achieving wide bandwidth there are many issues involved in designing of UWB systems, such as antenna design, channel model, and interference. UWB antennas must cover an extremely wideband of 3.1-10.6 GHz (lower band 3.1-5.1 GHz, upper band 5.85-10.6 GHz) for the indoor and handheld applications, have electrically small size, and high efficiency. In addition, they are required to have a non-dispersive characteristic in time and frequency domain, providing narrow pulse duration to enhance a high data throughput. Antennas in the frequency domain are typically characterized by radiation pattern, directivity, impedance matching, and bandwidth. However, there are certain requirements for the antennas in the wireless system regardless of ultra-wideband or narrowband same as regulatory issues, antenna gain, antenna efficiency, and group delay of antenna.

Planar monopole antennas are widely used as ultra wide band antennas because of small size and simple structure. This type of antenna can be easily matched over 3.1 to 10.6GHz. But the main issue is the radiation pattern degradation of this antenna at higher frequencies. This degradation causes error in many applications such as high-accuracy positioning systems, portable devices, and cognitive radio systems, which require stable omnidirectional radiation pattern over the whole UWB frequency band. This can be improved with the help of using a circular shaped ground[11].

Another method to improve the impedance matching is to use notched ground. The notched ground can adjust the electromagnetic coupling effects between the disk monopole and the ground plane and thus the impedance matching is improved without any cost of size and expense[12]. By proper designing UWB antennas having the required results can be obtained.

III. RECONFIGURABLE ANTENNAS

Due to the rapid development of of electronics and wireless communications, the demand for mobile devices operating at different standards or for different applications is extending. On the other hand, wireless systems are evolving toward multifunctionality. A reconfigurable antenna that has tunable fundamental characteristics, including

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operating frequency, impedance bandwidth, radiation pattern, and polarization, is a well-suited candidate for providing multifunctionality. Moreover, cognitive radio (CR), which is considered as the future of communications, needs a sensing antenna with the capability to monitor the spectrum, and a communicating antenna that can be reconfigured to communicate over a chosen frequency band. This has led to an elevated interest in the development of frequency reconfigurable antennas to utilize the spectrum efficiently.

To increase the functionality of current wireless platforms and to improve their quality of service, frequency-reconfigurable antennas are used as an alternative for multiband antennas. Our study included various reconfigurable switches such as radio-frequency microelectromechanical systems (RF MEMS), p-i-n diodes and varactor diodes, which can be directly incorporated onto antenna structures to successfully form frequency reconfigurable antennas.

Frequency-reconfigurable antennas, have inherent bandpass characteristics and generally have excellent out-of-band rejection without of filters. While reconfigurable antennas can have higher-order resonances, typically they are far away from the operating band and therefore can be removed with much less selective filters at a lower cost. It is essential that a fair cost comparison of these two alternatives include the cost of the filters required for both antennas. Here we discuss frequency-reconfigurable antenna structures that are suitable for implementation on consumer-type mobile multiradio platforms. Such antennas are usually equipped with switches that are controlled by dc bias signals. Upon toggling the switch between on and off states, the antenna can be reconfigured to support a discrete set of operating frequencies[14].

There are three types of frequency-reconfigurable antenna structures that are major candidates for multiradio wireless platforms: patch antennas, wire antennas, and PIFAs. Each employs a distinct mechanism in order to achieve the required frequency reconfigurability. First, for the patches, a variety of slots are usually introduced to detour the current path on the patch antennas to control their resonances. The length of these slots can be controlled by switches to reconfigure the patch antenna’s operating frequency. Second, for the wire antennas, the resonant frequency is primarily defined by its length or perimeter, which also can be controlled for reconfigurability. For example, a monopole antenna has its first resonance when its length is about a quarter-wavelength, while a loop antenna resonates at a frequency where its perimeter is approximately one wavelength. Subsequently, various switches can be implemented to alter the length or perimeter of these wire antennas to allow operation over different frequency bands. Third, a PIFA structure can be considered as a half-sized slot, where its feed and ground location determines the input impedance of the antenna. By changing the PIFA’s feed or ground location, its mode of operation can be reconfigured, allowing its resonant frequency to be controlled.

Multiple MEMS switches are used to connect the small conductive pads to form patch antennas of different sizes, having different resonant frequencies. Although this approach provides great flexibility in reconfiguring the patch antenna’s operating frequency and polarization, the number of switches required can easily become so prohibitively high that the cost and loss of the switches and the corresponding complex biasing circuitry make the implementation of such a structure very challenging.

Another method is that a vertical slot is cut in the patch antenna with a diode switch placed across the slot in the middle. When the switch is on, the horizontal main current of the patch’s first resonance is only slightly disturbed as compared to the case with no slots. Hence, this introduced slot has limited effect on the patch antenna’s resonant frequency. But when the switch is turned off, the horizontal current is forced to detour around the slot and travels a longer path; as a result, the patch antenna resonates at a lower frequency. More recently, switchable slots have been implemented on the ground plane as well to enable frequency reconfigurability of the patch antenna design[15].

One of the main challenges of reconfigurable antenna development is the integration of switches. Commonly, three major types of switches, RF-MEMS p-i-n diodes and varactor diodes, are used in developing frequency-reconfigurable antennas for wireless applications. The advantages of p-i-n diodes include a very low driving voltage, a relatively high power handling capability, and extremely low cost. Since there are no moving parts in p-i-n diode switches, they also exhibit very high reliability. However, such diodes require a dc bias current in their on state, which consumes a significant amount of dc power. RF-MEMS switches, on the contrary, are biased by high dc voltages and actuated by built-up static charges, and hence no current is drawn and they consume almost no power. Since RF-MEMS switches

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rely on physical metallic connections, they offer exceptionally low insertion loss, relatively high isolation, extremely high linearity, and very wide bandwidth. However, the mechanical movement within RF-MEMS switches still requires prohibitively high actuating voltage (greater than 60 V in most cases) and yields comparatively low speeds. Currently, the high cost of RF-MEMS switches is another factor that hinders their proliferation in commercial products[16].

Integrating varactor diodes in an antenna structure is a common way for achieving frequency agility. The resonating microstrip radiator consists of several smaller patches which can be interconnected by varactors. These varactors are independently biased to change the electrical lengths of the corresponding patches. and thereby change the resonant frequency of the corresponding modes. In addition, unbalanced biasing of varactor sets electrically shifts the feed point out of the antenna center. In this way, the real part of the feed-point impedance has been modified to obtain the desired optimal impedance matching. The angular position of the feed point defines the antenna polarization state. So, the whole microstrip structure can be adjusted in terms of electrical size, shape, and feed-point location, while maintaining its well-known characteristics.

TABLE I
COMPARISON OF TUNABLE COMPONENTS

Tunable Component	Advantages	Disadvantages
MEMS	Reduced insertion loss, good isolation, extremely high linearity, low power losses, consumes little or almost no DC power, wide bandwidth	Need high-control voltage (50–100 V), poor reliability due to mechanical movement within the switch (0.2–100 µs), slow switching speed, discrete tuning, limited lifecycle
PIN Diode	Needs very low driving voltage, high tuning speed (1–100 ns), high power handling capability, very reliable since there are no moving part, extremely low cost	Needs high DC bias current in their on state which consumes a significant amount of DC power, nonlinear behavior, poor quality factor, discrete tuning
Varactor Diode	The current flow through the varactor is small compared to PIN diode or MEMS, continuous tuning	Varactors are nonlinear and have low dynamic range, and complex bias circuitry are required

There are two other major obstacles that are currently still limiting their widespread implementation on multiradio mobile platforms. On the antenna side, the power consumption of p-i-n diode switches is still relatively high for mobile platforms, where the battery life is one of the most important aspects. RF-MEMS switches offer almost ideal power and RF performance, but their cost today is still too high for the consumer market. Also the antenna is capable of operating over a bandwidth of more than one octave while improving the performance in terms of specific absorption rate.

On the wireless module side, the stand-alone diversity logic circuitry introduces an additional loss to the wireless link. This insertion loss can be significantly alleviated when more radios are integrated into one module. Fortunately, the trend of merging more radios is gradually taking place, as the initial successes of merging GPS with 3G and Bluetooth with UWB have recently shown. So, we believe practical reconfigurable antenna implementation is much closer to the market today.

IV. CONCLUSION

Both UWB and frequency reconfigurable antennas are promising and lot of works are undergoing in this area. UWB antennas should be designed with specification of flat amplitude and linear face response over the desired bandwidth. For UWB system antenna is the significant part of the system. Its characteristics have an effect on the overall system performance. Frequency-reconfigurable antennas have great potential for reducing production cost and offer better out-of-band noise rejection. However, the required added switches could complicate the design and could add more dc power consumption if RF-MEMS switches are not used. Better performance can be expected from these reconfigurable antennas, but currently, the RF-MEMS production cost is a deterrent to their widespread use. Choosing the optimum approach necessitates considering the cost of all components-filters and switches-in cost estimates. In general, in designing these reconfigurable antennas, we found it imperative to reduce the number of the required switches and place them properly. However, locating the switches very close to a common ground could eliminate many of these problems.

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With the fusion of more and more radios into a single wireless module and the commercialization of low-cost, low-driving-voltage RF-MEMS switches, we believe, reconfigurable multiband antennas will proliferate in multiradio wireless platforms in the near future.

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