ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 3, March 2015

UWB Antenna with Configurable Notches for Cognitive Radio Applications

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ABSTRACT: In this paper, an UWB antenna with configurable notches for cognitive radio applications is proposed. The antenna can be operated as ultra wideband, and is configurable in terms of the ability to select notched bands in UWB spectrum. The configurable band notches are induced using structures called complementary split-ring resonators (CSRR), and are controlled using electronic switches mounted over the CSRRs.

KEYWORDS: Cognitive Radio, Ultra Wide Band Antenna, Split Ring Resonator

I.INTRODUCTION

Reflecting the ever-growing expectations and needs for smart spectrum management, on December 30, 2003, the FCC (Federal Communications Commission) of the USA released a Notice of Proposed Rulemaking (NPRM) covering various application scenarios for cognitive radio technologies. According to this, one of the possible application scenarios of cognitive radio [7] is stated as the following [1]:

Cognitive radio technologies can be used to enable non-voluntary third party access to spectrum, for instance as an unlicensed device operating at times or in locations where licensed spectrum is not in use.

Therefore, starting from this kind of application scenario and consider it as the most suitable approach for the CR concept to become a reality, an approach that is especially relevant to ultra-wideband (UWB) wireless technology and systems.

UWB technology is currently regarded as a key player for broadband wireless communications in multimedia-rich environments. The UWB signals by definition occupy a bandwidth in excess of 500 MHz, or are such that their fractional bandwidth is greater than 20%. UWB is a promising technology for future short- and medium-range high-data-rate wireless communication networks. The most appealing property of UWB is that it is an underlay system, meaning that it can coexist in the same temporal, spatial, and spectral domains with other licensed/unlicensed radios. Other interesting features of UWB include that it has a multi-dimensional flexibility involving adaptable pulse shape, bandwidth, data rate, and transmit power. On top of these, UWB has low power consumption, and it allows significantly low complexity transceivers leading to a limited system cost. Another very important feature of UWB is providing secure communications. The power spectrum of a UWB transmission is embedded into the noise floor, thus it is very hard to detect. Combined with other higher layer encryption techniques, this feature introduces very secure transmission. UWB systems are allowed to operate in the 3.1–10.6 GHz band without a license requirement (according to the current FCC regulations in the USA).There are two common technologies for implementing UWB: the Orthogonal Frequency Division Multiplexing based UWB (UWB-OFDM) and the impulse radio based UWB (IRUWB).

While UWB has generated a great deal of interest, it has also caused a number of controversies among industry, regulation, and standardization bodies. Since UWB signal waveforms are spread over very large bandwidth, they unavoidably overlap with existing and planned (licensed) narrow-band radio systems. In this respect, coexistence and compatibility have become critical issues demanding innovative solutions. In response to this, the FCC released the UWB radio emission mask for the realization of coexistence with traditional and protected wireless services. However, it has been widely recognized that UWB signal waveform design is quite a challenging subject, given the need for complying with various spectral masks while still achieving interference avoidance as well as efficient transmission.

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Taking these facts and requirements into account, our main objective and contribution for coexistence, interference avoidance, and compliance with any regulatory spectral mask is the provision of CR capabilities to UWB devices. Correspondingly, there exist a number of reasons why it makes sense to promote the use of the UWB technology in the context of cognitive radio and CR networks. The main technical reasons for endowing UWB devices with CR capabilities can be summarized as follows:

- UWB is by definition an underlay technology, so it will face severe interference from and cause interference to nearby narrow-band systems; therefore it will surely benefit from utilizing CR techniques implementing collaborative coexistence policies.
- UWB devices have inherent capabilities to observe large bandwidths, which is the prerequisite and technical basis for dynamic spectrum sensing.
- There is an intrinsic scalability in the UWB technology, which makes it an ideal candidate for realizing a versatile PHY layer, adaptable to various wireless environment conditions.

Starting from this background, a strategy of utilizing the advantages and features of the integration of cognitive radio with UWB technologies becomes relevant. This strategy exploits UWB radio as an enabling technology for implementing cognitive radio by virtue of the unique attributes of the UWB device endowed with CR-enhanced capabilities. Moreover, through intelligent spectrum planning and appropriate UWB waveform design, such a UWB radio with both spectrum agility and adaptation flexibility is anticipated to improve the prospects for both spectrum compatibility and interoperability among the ever-proliferating wireless communication devices and systems.

II.RELATED WORK

Mohammed Al-Husseini [Mohammed Al-Husseini, Karim Y. Kabalan, Ali El-Hajj and Christos G. Christodoulou 2010] [9] gives an overview about the current spectrum allocation/regulations. It also explains about dynamic spectrum access and cognitive radio. Several spectrum allocation models such as the dynamic exclusive use model, the open sharing model, and the hierarchical access model along with their related antenna design are also explained.

Sahin [Sahin,Mustafa E., Sadia Ahmed, and Hüseyin Arslan [2007][10] explains the attractiveness of UWB for cognitive radio networks is addressed from two main points. First UWB is considered as a direct means of practical cognitive radio realization. In this approach, the UWB features such as negligible interference, dynamically adjustable bandwidth and data rate, and adaptive transmit power and multiple access are discussed. The second approach considers UWB as a source of supplementary uses for cognitive radio networks. Numerous uses are addressed in the paper include sensing the spectrum with UWB-OFDM receiver, exchanging various supportive information via UWB, locating the nodes in a cognitive network by means of IR-UWB, and sensing the physical environment or the channel with IR pulses.

Akyildiz, Ian F., et al [2006][11] gives an overview about Dynamic Spectrum Access (DSA) and cognitive radio networks. More specifically, a brief overview of the cognitive radio technology is provided and the DSA network architecture is introduced. They also introduce the additional challenges to the choice of a spectrum unit/channel. The possible dimensions of the spectrum space are classified as power, frequency, time, space, and signal. Although not orthogonal, these dimensions can be used to distinguish signals.

Masri, Ahmed, et al [2012][12] addressed the problem of establishing a common control channel in cognitive radio networks, by exploiting the UWB technology. UWB let cognitive radio nodes discover each other and exchange control information for establishing a communication link. The UWB-based approach can significantly outperform an in-band signalling solution, in terms of both probability of success and latency in establishing a contact.

Granelli [2005][13] introduces the concept of cognitive UWB radio, a wireless system based on UWB transmission able to self adapts to the characteristics of the surrounding environment. First, salient features of UWB transmission arc reviewed, and then, application of UWB characteristics to the problem of cognitive radio systems are discussed.

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III.UWB COGNITIVE RADIO

Though usually associated with the underlay mode, UWB offers the possibility of also being implemented in the overlay mode [2]. The difference between the two modes is the amount of transmitted power. In the underlay mode, UWB has a considerably restricted power, which is spread over a wide frequency band. When a UWB system is operating in the underlay mode, it is quite unlikely that any coexisting licensed system is affected from it. On top of this, underlay UWB can employ various narrowband interference avoidance methods.

In the overlay mode, however, the transmitted power can be much higher. It actually can be increased to a level that is comparable to the power of licensed systems. But this mode is only applicable if two conditions are met: 1) if the UWB transmitter ensures that the targeted spectrum is completely free of signals of other systems, and 2) if the regulations are revised to allow this mode of operation. UWB can also operate in both underlay and overlay modes simultaneously. This can happen by shaping the transmitted signal so as to make part of the spectrum occupied in an underlay mode and some other parts occupied in an overlay mode. Apparently, in any mode of operation, UWB causes negligible interference to other communication systems. This special feature of UWB makes it very tempting for the realization of cognitive radio.

CR should have a high flexibility in determining the spectrum it occupies, because the bands that will be utilized for cognitive communication could vary after each periodic spectrum scan. Flexible spectrum shaping is a part of UWB's nature. In IR-UWB, the occupied spectrum can directly be altered by varying the duration or the form of the short transmitted pulses. In UWB-OFDM, on the other hand, spectrum shaping can be conveniently accomplished by turning some subcarriers on or off according to the spectral conditions. CR systems are should be able to adjust their data rates according to the available bandwidth, which varies according to the utilization of the bands by the licensed systems.

CR systems are also expected to provide a solution for the cases when the available bandwidth is so limited that the communication cannot be continued. UWB systems are able to make abrupt changes in their throughput. For example, an IRUWB system can respond to a decrease in available bandwidth by switching to a different wider pulse shape, and can do the opposite if there is more band to use. In UWB-OFDM, the adjustment of the occupied bandwidth is even simpler. The subcarriers that overlap with the newly occupied bands are turned off, and this way the data rate is decreased, or more subcarriers are used to occupy newly available bands, thus increasing the data rate.

Furthermore, UWB provides an exceptional solution regarding the dropped calls. If UWB is performed in overlay mode and in cases when it becomes impossible to continue the communication, UWB can switch to the underlay mode. Thus, UWB can maintain the communication link even though it is at a low quality since licensed systems are not affected by UWB operated in the underlay mode.

The spectral masks that are imposed by the regulatory agencies (such as the FCC in the USA) [5] are also determinative in spectrum usage in that they set a limit to the transmit power of wireless systems. UWB offers satisfactory solutions to the adaptable transmit power requirement of cognitive radio. Both UWB-OFDM and IR-UWB systems can comply with any set of spectral rules mandated upon the cognitive radio system by adapting their transmit power.

CR networks should be able to provide multi-user access since there will be a number of users willing to make use of the same spectrum opportunities at the same time. CR is also required to be able to modify its multiple access parameters to cope with the changes that may occur in the overall spectrum occupancy, or with the possible fluctuations in the signal quality observed by each user. From the point of adaptive multiple access, UWB is a proper candidate for CR applications and is very flexible in terms of multiple access. For example, in IR-UWB, the number of users can be determined by modifying the number of chips in a frame. In UWB-OFDM, on the other hand, more users can be allowed to communicate by decreasing the subcarriers assigned to each user.

UWB has information security in its nature. Hence, it can be considered a strong candidate for CR applications in terms of information security. Underlay UWB is a highly secure means of exchanging information. If a UWB system is working in the underlay mode, because of the very low power level, it is impossible for unwanted users to detect even the existence of the UWB signals. Overlay mode UWB, on the other hand, can also be considered a safe communication method. In overlay IR-UWB, multiple accessing is enabled either by time hopping or by direct sequencing. Therefore, receiving a user's information is only possible if the user's time hopping or spreading code is

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known. UWB-OFDM also provides security by assigning different subcarriers to different users. The level of security can be increased by periodically changing these subcarrier assignments. Apparently, UWB is a secure way of communicating in both its underlay and overlay modes.

UWB communication can be accomplished by employing very low cost transmitters and receivers. The transceiver circuitries required to generate and process UWB signals are inexpensive, and the RF front-end required to send and capture UWB signals are also quite uncomplicated and inexpensive. This property of UWB makes it very attractive for CR, which aims at limited infrastructure and transceiver costs.

IV.PROBLEM DEFINITION

When a CR network implements the dynamic spectrum access (DSA) approach, secondary users need to identify and use the white space in the spectrum. In this case, the transceiver of the CR device should be ended with an antenna system that can simultaneously sense the channel over a wide frequency range and communicate over a narrow band once the operating frequency is determined.

If UWB is used as the CR enabling technology, UWB antennas can be employed at the transceiver front-end. In the underlay mode, a UWB antenna can be used to transmit/receive the very-low-power pulse. In the overlay mode, the UWB higher-power pulse could be transmitted if the targeted spectrum is completely free of signals of other systems (time white space), or this pulse should be unique and adaptive with spectral notches to avoid strong interference to existing narrow-band wireless services. In both modes, UWB antennas could still be used, however in the overlay mode UWB antennas with controllable frequency notches are more robust.

V.ANTENNA CONFIGURATION

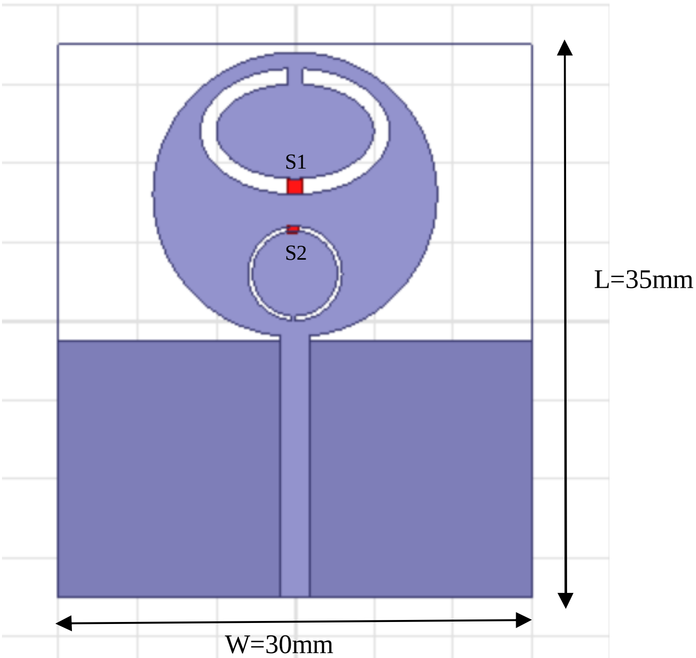

Fig.1. Antenna configuration

The antenna is circular disc monopole [6] and a 50Ω microstrip feed line are printed on the same side of the FR4 substrate (the substrate has thickness of 0.8 mm and a relative permittivity of 4.4). L=35mm and W=30mm denote the length and the width of the substrate, respectively. The width of the microstrip feed line fixed to achieve 50Ω impedance [4]. On the other side of the substrate, features a partial conducting ground plane only covers the section of the microstrip feed line. The dimensions of the different parts are optimized for an impedance bandwidth covering the 3.1–10.6 GHz range.

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To induce band notches, one circular and one elliptical split-ring slots are etched on the patch. Their sizes are optimized so that the elliptical split-ring slot causes a notch in the 3.5 GHz WiMax band,and the circular one in the 5.2 GHz U-NII radio band which part of the radio frequency spectrum used by IEEE-802.11a devices. To enable band notch configurability, two electronic switches (S1 and S2) are mounted across the slots, as detailed in Fig. 1.

Depending on the state of a switch, the corresponding split ring slot does or does not induce a band notch. When the Switch is OFF, the slot behaves as a single-ring complementary split-ring resonator (CSRR) [3] causing a notch in its design band, and notch disappears when the switch is turned ON. The different switching cases lead to different band notch combinations.

VI. RESULT AND DISCUSSION

The antenna was designed and simulated using Ansoft HFSS 15.0[8].

Fig. 2 Return loss when both S1 and S2 ON

Fig. 2 show the computed return loss plots of the switching case where both switches are OFF. Then, a UWB response is obtained, which is needed for underlay CR operation and for sensing in the overlay UWB scenario. In this case, none of the slots resonates, and as a result, no notch appears in the frequency response of the antenna.

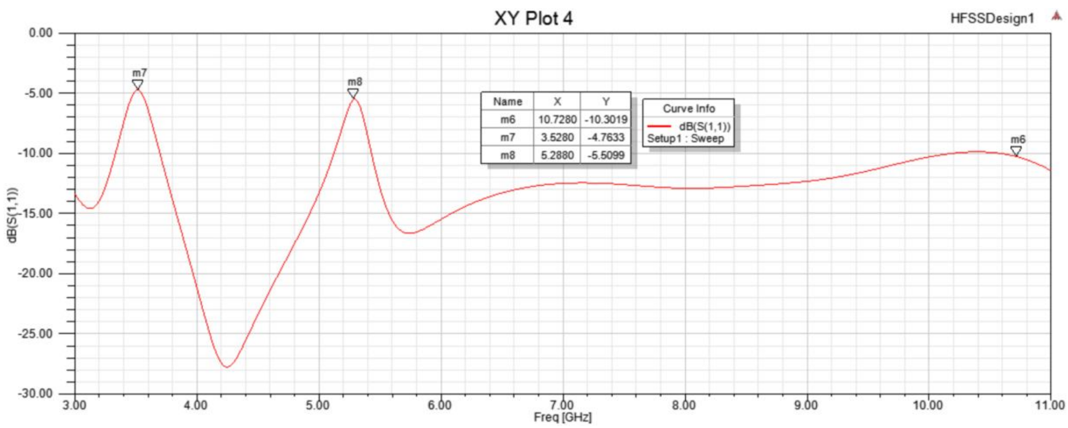

Fig. 3 Return loss when both S1 and S2 OFF

Fig. 3 show the computed return loss plots of the switching case where both switches are OFF, in which band notchs in the 3.5 GHz band and 5.2 GHz is appeared. A notch in a certain band helps to prevent interference to a primary user or the service operated in that band.

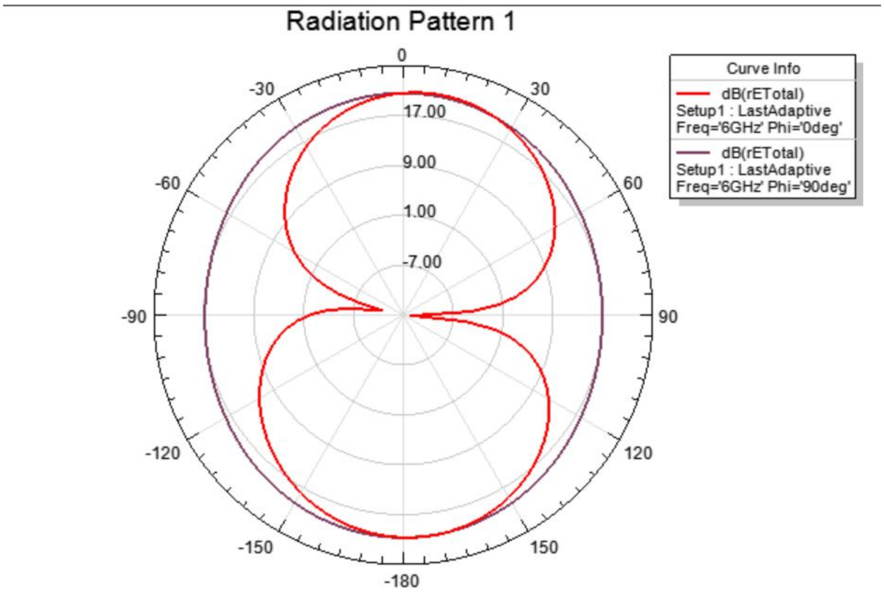

Fig .4 Radiation pattern at 6 GHz

Being a printed version of a monopole, the antenna has omnidirectional radiation patterns. It also has good gain values in its band(s) of operation. The computed radiation patterns, at 6GHz, are shown in Fig. 4. The omnidirectionality of the patterns is clear.

VII.CONCLUSION

In this paper, a cognitive radio antenna was proposed. The design is based on structures called Split ring resonator, which is integrated into a wideband monopole antenna. The antenna has a UWB response, and it has configurable band notches that are induced by CSRRs, and controlled by electronic switches mounted over the CSRRs. The simulated S parameter, radiation pattern of the proposed antenna is shown. The proposed antenna can be operated in UWB cognitive radio systems. In the future works, the antenna will be fabricated and tested.

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