URSI AP-RASC 2019, New Delhi, India, 09 - 15 March 2019

Multifunctional Antennas for Cognitive Radio Applications

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Abstract

Evolution, design concept and practical realization of multifunctional antennas (MFA) are systematically reported in this paper. MFAs, traditionally evolved as an intelligent solution to mitigate lower spectrum-utilization using the opportunistic spectrum allocation-policy, are key component for modern wireless applications, such as multi-standard radios, cognitive radios (CR) of software defined radio (SDR) environment. Traditional realizations of MFAs use multiple radiating elements on a common substrate which enhances design constrains in terms of mitigating/reducing parasitic coupling and spurious impacts of the rotary arrangements required for actuating various radiating elements. In this paper, recent research contribution of designing MFAs employing a single UWB radiating element is reported. Improvised feed design with combinatorial loading of SRRs and PIN diodes on a printed monopole antenna, along with controlling their position in the feed region, results into multifunctional operation. Design strategy, techniques, and theoretical ideas for realizing MFAs along with simulated and experimental results are presented in this paper.

1. Introduction

Unprecedented expansion of wireless market and industry, mainly driven by demands for high-speed high data-rate wireless services, acts as a continuous motivation to the electromagnetic and wireless engineers to explore the next generation technology and upgrade the ultrawide band (UWB) system in a more efficient manner. One of the key approaches that has been attempted over last few years to enhance the potential of UWB system further is the efficient utilization of the UWB spectrum in an opportunistic manner. This concept of efficient utilization of the UWB spectrum is evolved due to the observation that, i) many frequency bands in the spectrum are largely unoccupied most of the time, and ii) some frequency bands are partially occupied [1]. Cognitive radio (CR) technology which scans for availability of the unused spectrum from the primary user and allocate it to the secondary user, is an excellent solution towards efficient utilization of the UWB spectrum. Such spectrum search and then allocation of the idle spectrum in a dynamic manner to the secondary user, requires compatible antenna systems. The antenna design for such applications is quite complicated as it requires multiple antennas to be housed in a common platform. The antenna/antennas here should be capable of wideband 'scanning' to check the idle spectrum (this is known as 'white' space) and simultaneously communicating over a limited bandwidth in a reconfigurable fashion. Thus, for cognitive radio applications, the antenna modules need to be multi-functional.

This paper deals with the design and development of MFAs capable of multiple antenna functionalities, namely i) identifying the unused spectrum of the primary user, known as, 'spectrum sensing' and ii) allocating the idle spectrum (white space) to the secondary user [2].

2. CR Overview and Antenna Requirements

Utilization of radio spectrum can be significantly improved over conventionally used fixed spectrum access (FSA) policy, in which a portion of available spectrum is assigned to one/multiple users in a predefined manner. As indicated in the typical plot of power against combined time and frequency scale of Figure 1, in FSA scheme, there exist various unused spectrum which may change against time. Opportunistic and intelligent utilization of these unused spectrums of the licensed users, known as spectrum holes/white space, to the secondary users can significantly help in mitigating the challenges related to the wireless traffic management. CR technology works on this opportunistic uses of the unused spectrum and results in better spectrum utilization by allowing the unlicensed users to access the frequency bands dedicated to the licensed users. CR technology, first proposed by Mitola [3]-[5], employs three different strategies/models to support transmission from secondary/cognitive users and at the same time ensuring priority of the primary users. These are named as, i) overlay model, ii) underlay model and iii) interweave model. Different models of cognitive radio technology requires different types of

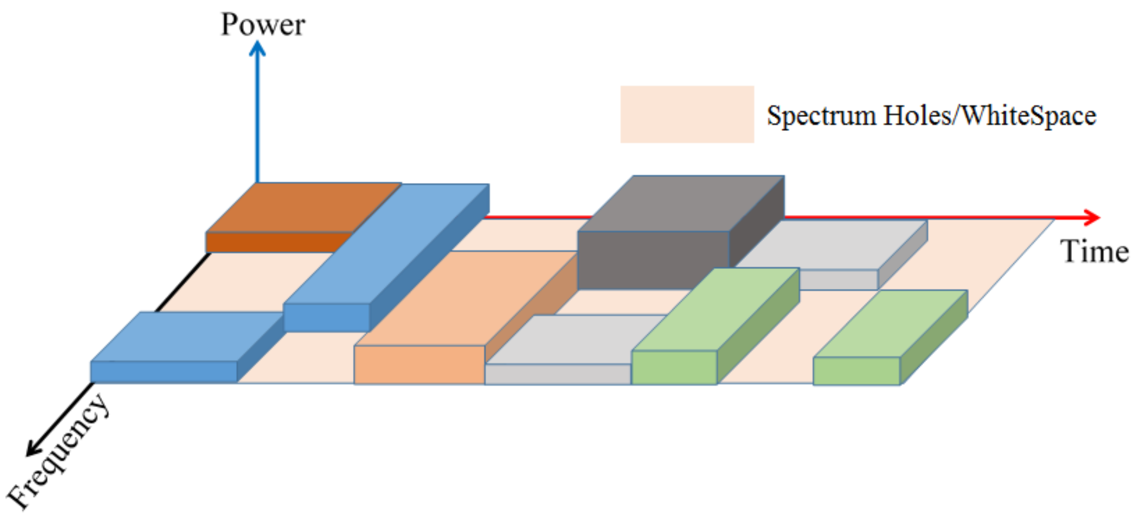

Figure 1.Spectrum holes/white space in a combined time-frequency diagram

antennas to be housed within the cognitive radio wireless device. Figure 2 shows a basic block diagram of the antenna module in a CR system. In general a CR system comprises a sensing UWB antenna and a reconfigurable antenna. The UWB antenna, called 'sensing antenna', continuously scans over the ultra-wide band to search the idle spectrum not currently in use by the 'primary user' and allocates it to the 'secondary user' which immediately starts communicating at this frequency, using the reconfigurable antenna, also known as 'communicating antenna'. Thus efficient utilization of the idle spectrum dedicated to the primary user and distributing it dynamically to the secondary user, is the key in CR technology in achieving higher spectrum utilization.

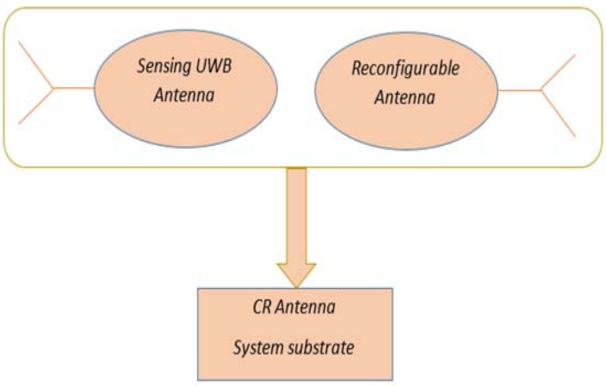

Figure 2.General antenna modules in a cognitive radio system

3. Multifunctional Antenna Design

MFAs, requiring UWB, narrow band and or notched UWB response in a common platform, can be designed by i) employing multiple radiating elements on a common substrate [6]-[10] and ii) improvised design of the radiator/feed-line and combinatorial loading of switches and parasitic elements, on a single radiator [11]-[13].

3.1 MFAs with Multiple Radiating Elements

In MFA realization with multiple radiators, one of the radiators is designed as UWB antenna for spectrum sensing while other radiator/radiators act as the 'communicating antenna' with frequency reconfigurable features. Rotation mechanism of a portion of the substrate sequentially brings the radiating elements in contact with the feeding line and thereby excites different narrowband configurations. Another useful technique of designing communicating antenna stage of the CR antenna system is to employ reconfigurable filtennas [14]. In this technique, a tunable bandpass or band stop section loaded in the feed line of the communicating antenna along with an UWB antenna together forms an excellent CR antenna for spectrum underlay and spectrum interweave models [8]. While designing MFA system comprising multiple radiating elements on a common substrate, ensuring minimal mutual-coupling is an important design criteria along impedance and radiation characteristics of the antenna.

3.1 MFAs with Single Radiating Elements

Since here the same antenna contributes to multiple antenna functionalities (UWB, notched UWB and/or narrow band) response, this technique employs an UWB radiator as the basic element. Figure 3 shows conceptual block diagram of a MFA, realized with a single radiating UWB antenna. When the Feed section of this basic UWB radiator is loaded with band-notch and or band-pass filter sections, the same antenna contributes to multiple antenna responses. Mechanical or electrical switching of the feed section to toggle around all-pass, band-notched and band-pass response with a sufficient speed is the key in practical realization of such multiple antenna response. In addition, sufficient care should be taken to ensure minimal impact of the switching and tuning elements on the radiator. Key advantages of this technique of MFA design is:

a) minimum antenna foot-print as only one radiator is enough to achieve multiple antenna response
b) no isolation enhancing elements are needed like the MFA design with multiple radiators.

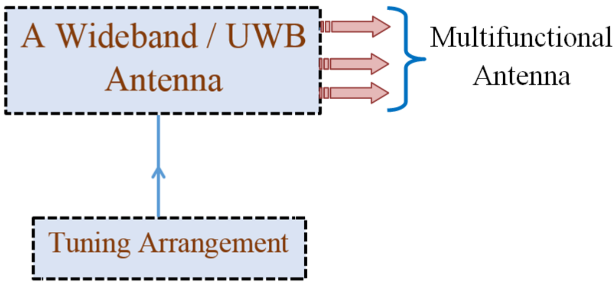

Figure 3.Conceptual block diagram of a MFA

Combinatorial loading of split ring resonators (SRR) and/or switches on the feed section of a CPW fed printed monopole antenna invokes various antenna performance and yields UWB, notched-UWB and narrow band antenna functionalities. Split ring resonators in such antennas are excited by the propagating electromagnetic waves which results into induced oscillating current at its magnetic resonance frequency [15]-[17]. At this frequency the propagation of the EM signal is inhibited due to the strong magnetic resonance phenomenon. When such SRR loaded antennas are further augmented with switches, the band-reject performance of the SRR is changed to band-pass response. Thus, SRR and switch loaded UWB antenna effectively acts as a narrow-band antenna. Tuning of the notch-frequency and narrowband response of the antenna can be achieved using varactor tuning or mechanical tuning. Thus, a single UWB radiator, based on the combinatorial loading of the parasitic resonators and switches on the feed line, can provide multifunctional antenna response.

4. Conclusion

A comprehensive summary on different multifunctional antennas for cognitive radio applications is reported in this paper. Application scenarios of MFAs and various schemes to realize these antennas are discussed. Research and development on MFA are yet not matured. Focused attention of antenna researchers is needed to realize such antennas with better efficiency and performance.

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