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Research Article

Antennas for Ultra-Wideband Applications: Design and Performance Study Using Printed and Dielectric Resonators

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Abstract: Ultra-wideband (UWB) communication systems may make use of a miniature dielectric resonator antenna. A 50 ohm microstrip line is included into the modified T-shaped feed network to produce strong coupling and some bandwidth augmentation; the antenna element itself is a rectangular low permittivity ceramic block with a dielectric constant of 9.4. Simulations and measurements of the antenna's performance in a range of 3100–5500 MHz reveal an impedance bandwidth of 55.8% and a Voltage Standing Wave Ratio (VSWR) of 2, making it well-suited for ultra-wideband (UWB) uses.

Keywords: Dielectric resonator ultra-wideband (UWB), Microstrip line, Voltage Standing Wave Ratio (VSWR)

Introduction

Due to the rapid development of wireless technology that enables high transmission speeds for a range of applications, there is a rising need for "ultra-wideband" (UWB) antennas to accommodate these technologies. Since the late 1960s, work has been done to develop UWB technology, which has been used almost exclusively in radio and radar systems, as well as in some government and military applications. However, the use of UWB technology to assist commercial sectors has started in earnest since 2002, when the United States Federal Communications Commission (FCC) authorised unlicensed spectrum from 3.1 to 10.6 GHz to obtain better flexibility in academic and industrial organisations [2]. Since the year 2002, ultra-wideband (UWB) communication systems have been the subject of a significant amount of attention in this sector. On the other hand, some implementations of well-known wireless protocols are permitted to make use of the licenced spectrum. This spectrum cannot be used for any other purpose. However, there is a substantial amount of variance in the spectrum occupancy across the various service providers. The Federal Communications Commission (FCC) has drawn attention to an issue that involves the inefficient use of spectrum in its entirety [3]. The Cognitive Radio (CR) system is one solution that might be considered for this effective utilisation of the radio spectrum. By boosting the effectiveness with which spectrum is used, it hopes to lessen the congestion that currently exists in the spectrum. It is essential to provide each radio technology with its own separate piece of the electromagnetic spectrum if one wishes to prevent that technology from interfering with another [1]. As a direct consequence of this, there is now a greater degree of rivalry for open channels inside the radio frequency (RF) spectrum. This is due to the proliferation of new radio services. Therefore, ultra-wideband (UWB) technology offers a remarkable solution to this problem by making it possible for previously established radio networks and newly developed radio services to coexist with little to negligible levels of interference [1-2]. This cohabitation reduces the possibility of interference occurring between users who already have licences by giving all of the services that are theoretically feasible. Ultra-wideband (UWB) radio and radar systems operate in the time domain, have a huge relative bandwidth, a quick impulse response, no carrier, and operate in the baseband [4]. UWB systems, which make use of impulse signals, have the potential to make use of a far wider bandwidth than traditional radio systems. [4].

Development of UWB antennas

An essential part of every wireless communication system is the antenna, which acts as a go-between for the guided wave and the free-space wave. According to the requirements set out by the IEEE, a device is considered to be an antenna if it either sends out or receives radio waves. An ultra-wideband antenna, often known as a

UWB antenna, is an example of broad-band antenna. There are two unique interpretations of the term "bandwidth," namely "impedance bandwidth" and "pattern bandwidth." The impedance bandwidth is connected to the relationships between input impedance, voltage standing wave ratio (VSWR), and return loss. On the other hand, the pattern bandwidth is related to the relationships between radiation pattern, gain, and polarisation. There are five primary categories of ultra-wideband (UWB) antennas, and they include helical antennas, frequency-independent antennas, log periodic antennas, horn antennas, and resonant antennas [3]. The first four categories are based on conventional wideband antenna designs [1-3], in contrast to the relatively recent introduction and widespread use of resonant antennas. The vast majority of these antenna types may also be laid out in a flat or three-dimensional configuration. It is not difficult to include planar resonant UWB antennas into the remainder of the communication system. Broadband and ultra-wideband (UWB) antennas have been used in the past, but these antennas either have a frequency-dependent phase centre or cumbersome designs, ranging such as frequency-independent antennas, smaller electric antennas, small magnetic antennas, which are log-periodic antennas, spiral antennas, Vivaldi antennas, bi-conical antennas, which are disk-cone antennas, horn antennas, which are and reflector antennas and ascend antennas, etc. [4]. Planar resonating antennas have been a well-liked option for many years due to the fact that they are available at a low cost, take up a very little amount of space, and have a large bandwidth [5-8]. Due to the fact that they frequently rise above the surface of the ground or circuit board, wideband planar directional antennas have a high profile. This prevents them from being used in consumer products that can be held in the hand or that can be worn. Printed UWB antennas are the most popular choice because of their ease as well as their low profile. Also, these antennas are easy to produce and integrate into an already established UWB communication system [8-11].

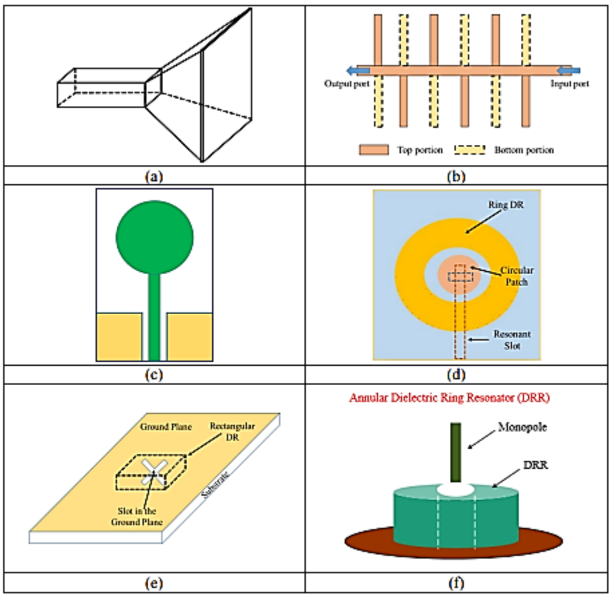


Figure 1: (a) Conventional Pyramidal Horn Antenna, (b) Conventional Log-periodic Antenna, (c) Conventional CPW-fed Monopole Antenna, (d) DR-Patch Hybrid Antenna , (e) DR-Slot Hybrid Antenna , and (f) DRMonopole Hybrid Antenna

It lowers the total cost of assembly while simultaneously improving the system as a whole. As a direct consequence of this, UWB antenna design has garnered a great deal of attention from antenna specialists throughout the course of time. The non-metallic radiating element known as a "dielectric resonator antenna (DRA)" has proven to be an essential component in the development of compact, low-volume, high-efficiency planar antennas that can operate at microwave and higher frequencies. It has a number of characteristics with its more distant ancestor, the micro-strip antenna (MSA), to which it is closely related. They behave in a manner that is similar to that of open resonators [12]. In addition to not having any conduction loss or surface-wave loss, the DRA offers a large impedance bandwidth, a straightforward design, and a lot of wiggle space in terms of how the geometry may be adjusted. Additionally, you are able to get various radiation patterns simply moving between the different modes. However, despite having a weak dielectric, DRA only experiences a little amount of loss throughout its operations. As a result of this, DRA is an attractive candidate for use in high-frequency wireless networks. However, the production process for DRA is more complicated and costly because to the high cost and difficulty of dealing with dielectric material. This is because working with dielectric material requires special care and attention. On the other hand, the low profile, compatibility with MIC, and mechanical toughness of MSA/printed antennas have considerably contributed to the widespread adoption of these types of antennas. In addition, Microstrip Array Antennas (MSAs) and Printed Antennas may be manufactured at a low cost by using contemporary techniques for printed circuitry, and they can be moulded to fit a wide range of surfaces, both planar and non-planar. The creation of hybrid antennas that take use of the benefits offered by both metallic patch antennas and dielectric resonator antennas has been one of the more challenging aspects of antenna research over the course of the last few decades. DRA has emerged as one of the most promising choices in the category of wide band miniaturised antenna domain in the recent decades due to its high power handling capability and outstanding radiation efficiency. This development took place in recent years. Therefore, the development of miniaturised antennas that may be used in a wide variety of broadband applications is an exciting direction of study in the area of antennas. In the past, there have been investigations into a wide variety of alternative methods for the design of such antennas. One of the many ways that broadband antennas may be created is by using a hybrid structure that consists of a Feed-Dielectric Resonator (DR). This is only one of many possible approaches. These antennas have a feed that functions not only as a DR feed but also as a self-radiator, therefore the feed has a dual purpose. The following are the typical configurations for these hybrid antennas: (i) DR-microstrip, (ii) DR-slot, or (iii) DR-monopole.

Frequency Selective Surface loaded UWB antenna

Another difficulty in building UWB antennas is increasing the gain characteristic of UWB antennas over the operational bandwidth, in addition to making them small and low-profile. Frequency selective surface (FSS) is a useful tool for dealing with this problem. Spatial filters, antenna reflectors, hybrid radome absorbers, high impedance surfaces, and electromagnetic shields are just some of the many places where FSS has found use in recent decades. Transmission, reflection, and absorption of electromagnetic (EM) waves across a certain frequency range is the main purpose of these periodic structures[16-18]. These FSSs are built by repeatedly printing various metallic shapes on one or both sides of a dielectric substrate in a regular pattern. While FSSs might in principle include an endless variety of structures, in practise they are restricted to a small set of periodic ones. As a result, these FSSs need to be small enough to fit a high density of unit cells into the available volume. Additionally, there is less variation in frequency response with respect to incidence angle of EM wave in FSSs that use miniaturised elements. As a result, there has been a lot of work done to reduce the size of the FSSs' individual cells in the hopes of achieving more reliable results. Miniaturised unit cells have been obtained in recent years by the use of geometries such convoluted rings, slots, dipoles, and fractals.

Literature Survey

Abolfazl Falahati et.al (2012) We introduce a nonparasitic grounded reflector for use in a wideband linear array antenna with minimal sidelobe fan beams. Using a standard planar monopole array antenna with six elements, this fan-beam antenna achieves side lobes at -26 dB. To meet the favourable input impedance bandwidth requirements between 1.7 and 2.2 GHz, a Dolph-Tschebyscheff distribution is used and a broadband array feed network is created. Therefore, the use cases for GSM-DCS2, DECT, and 3G are all covered by this set of components. An advantageous fan beam pattern may be formed by combining a planar monopole antenna array with a nonparasitic grounded reflector. The grounded reflector height may be used to adjust the beam width by 3 dB in the H-plane. The outcomes are compared across scenarios with and without a reflector array antenna.

Risang Arono et.al (2015) This study proposes the design and implementation of a compact antipodal Vivaldi printed antenna for ultra-wideband (UWB) applications. The antenna is constructed on a FR4 Epoxy dielectric substrate that is 1.6 mm thick and is designed for frequencies of 1.5 to 3.5 GHz. Small antipodal Vivaldi printed antennas are designed using the reflection coefficient as the key performance measure by prioritising the antenna's physical size. We present and construct two different antenna designs, one using a single antenna and the other using an array of two. A -10dB operating bandwidth of 800MHz is shown by the single antenna between 1.6-2.4GHz. The achieved array antenna operates between 1.6 and 3.5 GHz with a -10dB bandwidth of 1900 MHz.

Chun-Cheng Lin et.al (2016) This research presents a self-complementary antenna for UWB communications. The suggested antenna has a small form factor of 25 mm 15 mm and meets the requirements for ultra-wideband (UWB) operation in the frequency range of 3.1-10.6 GHz. The suggested small antenna has been shown to produce ultra-wideband (UWB) radiation with respectable radiating qualities.

This study focuses on the design of miniaturised antennas for use in broadband networks. Among the dielectric resonator (DR) family, the commitment of cylindrical shaped dielectric resonators (CDRs) [1] is the most promising option owing to the DRs' adaptability in terms of both geometry and excitation. Over the last several decades, research on dielectric resonator antennas (DRAs) has focused heavily on increasing impedance bandwidth (S11 -10 dB) to support many wireless bands. Miniaturised antennas that maintain their efficiency and impedance bandwidth (IBW) have also been the subject of much research. The DRA's IBW may be increased in a number of ways. The first involves a decrease in quality factor [2, 3], the second involves a matching of the input impedance [4, 5], and the third involves the introduction of numerous resonances [6, 7]. By merging the resonances of two resonant structures—a (i) modified slot geometry and a (ii) cylindrical dielectric resonator—option (iii) has been used in the current design. Each structure is activated by an optimal feeding mechanism designed to maximise IBW. Exciting higher order modes in CDRA has received a lot of interest from DRA researchers in recent years. Although evidences for further hybrid modes beyond the HEM11 mode are confirmed theoretically in [11], these modes have not yet been empirically investigated. Experimental studies in [12-14] have shown the special properties of hybrid modes like HEM12 and HEM21. One tiny hybrid radiator for X-band uses is the focus of this effort. The goals of the proposed study are twofold: (i) to explore the modal features of the CDR and (ii) to develop a hybrid antenna by merging various resonances of slot and CDR, stimulated by employing U-shaped microstrip feedline. The suggested hybrid antenna is excited by a U-shaped microstrip feed line through aperture coupling, which also reduces feedline-induced spurious radiation [15–20]. The physical justification for achieving such a large matching bandwidth has been elucidated using modelling [21] and experimental findings.

The design begins with a standard half-wavelength slot at the X-band centre frequency (as illustrated in Fig. 2). (a)). As can be seen in Fig. 2, it is further converted into a slot in the form of a dumbbell. (b). As may be seen in Fig. 2, an opening is made with a length of l2. (c). Composite aperture1 (CA1) refers to the T-shaped slot with two circular ends on opposing sides. Composite Aperture 2 (CA2), depicted in Fig. 2, consists of two additional symmetrical L-shaped and rectangular openings added to CA1. (d). Aperture is gradually adjusted over time, as seen in Fig. 2.1. Figure 2 displays the simulated S11 characteristics at each aperture. The dumbbell-shaped hole clearly offers superior IBW.

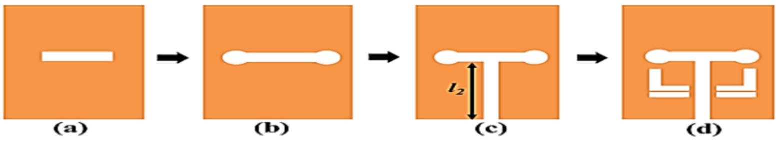


Figure 2.: Timeline of suggested aperture modifications, from left to right: (a) standard slot; (b) dumbbell-shaped slot; (c) T-shaped slot with two opposed circular ends; (d) composite aperture 1 with L-shaped and rectangular slits, carved out of the ground plane (CA2).

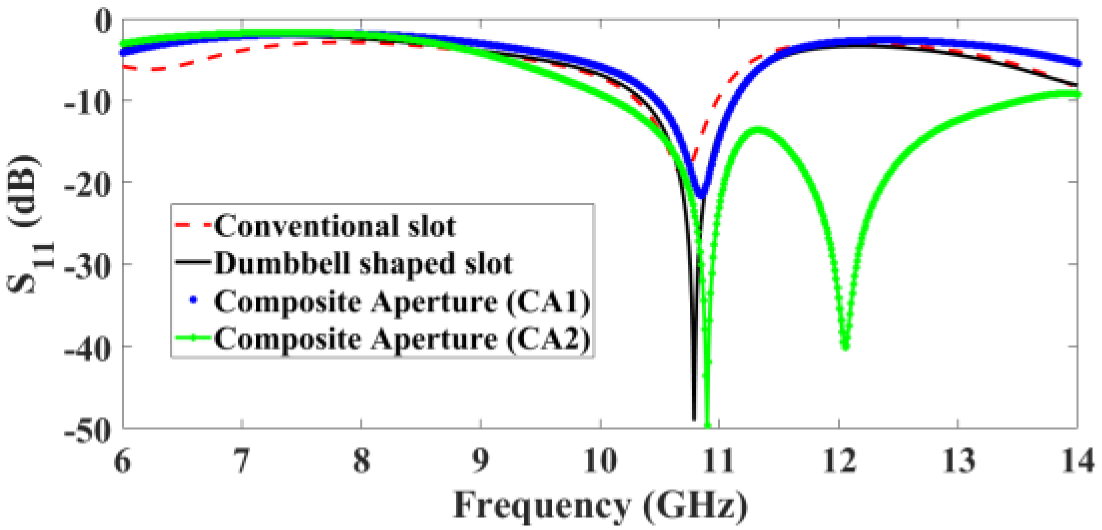
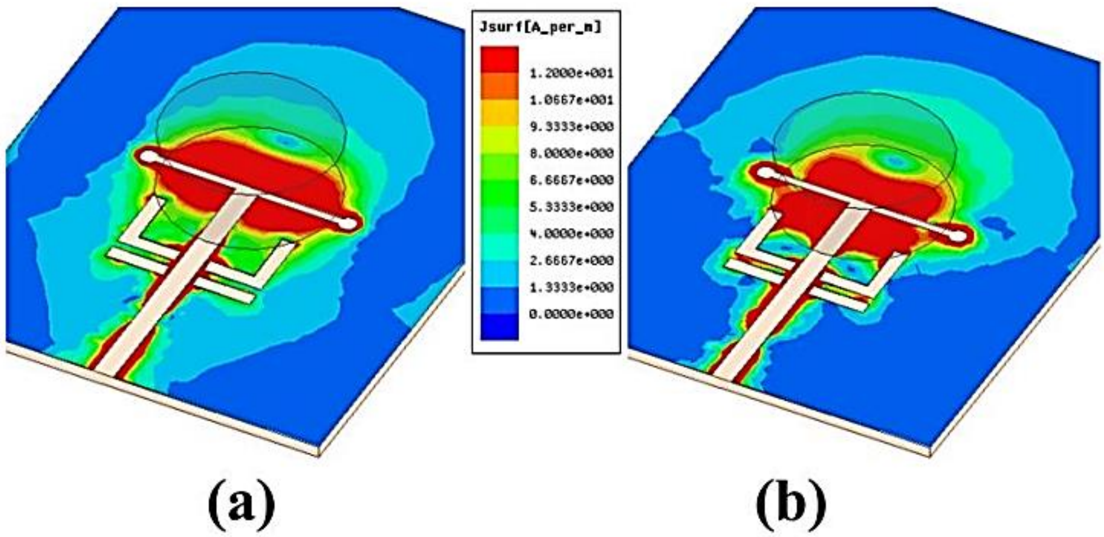


Figure 3. The conventional slot, the dumbbell-shaped slot, the composite aperture 1 (CA1), and the composite aperture 2 (CA2) each have their own simulated S11 (dB) characteristic curves.

(~7.5%) as compared to the conventional slot. Furthermore, adding a vertical slot (l2) does not significantly enhance the simulated S11 feature, but it does play important roles in exciting new L-shaped and rectangular slots. It is clear in Fig. 3 that the inclusion of slots (both rectangular and L-shaped) results in an extra resonance at 12.08 GHz in the S11 characteristic curve. Since CA2 increases slot impedance bandwidth by 22% (simulated) compared to CA1, it is an appropriate option.

Figure 4 depicts the distribution of surface currents at various resonance frequencies. As can be seen in Fig. 4, the vertical slot acts as a driver to stimulate L-shaped and rectangular parasitic slots. The CDRA is being excited at 8.19 GHz, 9.48 GHz, and 10.69 GHz by the electromagnetic field coupled via the dumbbell-shaped slot in the U-shaped microstrip feedline. According to the aforementioned research, the radiation during the first two minima is exclusive to CDRA alone.



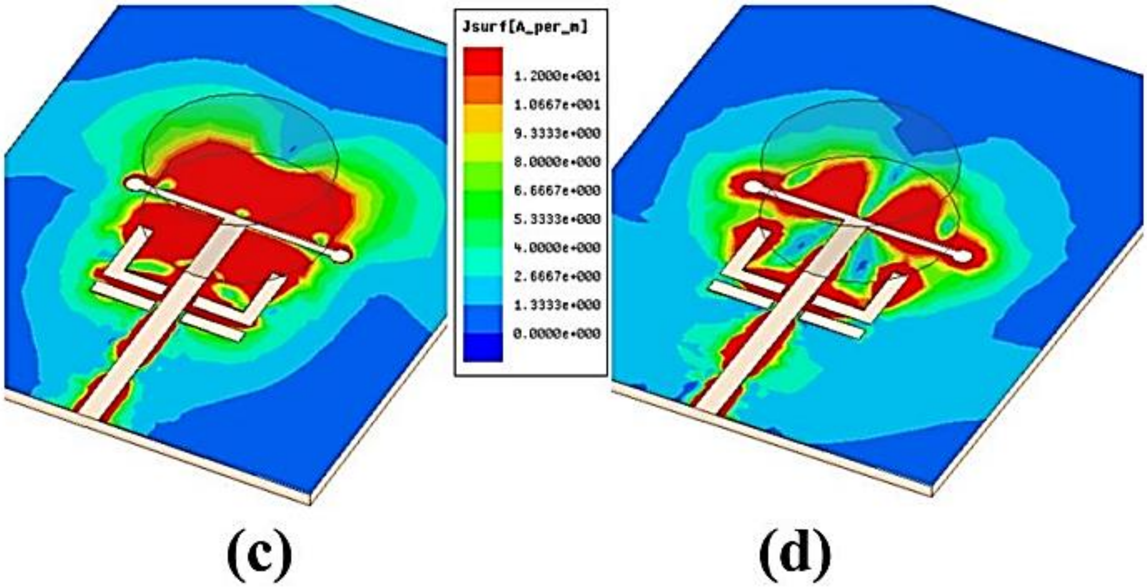


Figure 3: Surface current distribution at (a) 8.19 GHz, (b) 9.48 GHz, (c) 10.69 GHz, and (d) 11.88 GHz as simulated by the suggested design.

Conclusion

This research presents a compact hybrid X band radiator by integrating the resonances of two different resonator and emission structures. These structures are (i) a cylindrical dielectric resonator (CDR), and (ii) a one-of-a-kind slot geometry. The whole device is fed by a U-shaped microstrip feedline. We address the excitation of the several higher order modes found in the CDR structure that have been stimulated. The extra advantage of the suggested slot design is that it may be manufactured using the same technologies that are already in use for printed circuits, which will reduce the costs of production. In the category of hybrid antennas that cover a wide frequency range, and more especially in the category of Slot-DR hybrid antennas, this is a whole new choice. In order to help set the scene for the DRA's work, a series of proposals for the development of the same antenna has been offered. It has been found that the antenna in question has an impedance bandwidth of 46.3% (S11 -10 dB and VSWR 2), and it constantly radiates in a broadside pattern across the whole of the X-band, with a peak gain of around 4.5 dBi. The design that has been presented has the ability to perform the function of an electromagnetic (EM) sensor in the X-band.

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