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INDEPENDENTLY CONTROLLABLE HYBRID DRA FOR OFF-BODY WBAN APPLICATION

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Abstract: This study proposes, simulates, and experimentally validates a hybrid dual-band antenna made up of an L-shaped radiating slot and a cylindrical dielectric resonator antenna (CDRA). The fundamental mode (TM10) of the slot that produces the lower frequency resonant band (2.4 GHz) is excited by the microstrip transmission line, and the slot underneath the CDRA is excited by the HEM11 mode of the CDRA to produce the higher frequency band (5.8 GHz). Both the slot and CDRA modes have a resonance frequency that may be changed almost independently of one another. To demonstrate the true behaviour of the modes and overall system, an analogous circuit model of the hybrid system's separate modes is extracted. The antenna's on-body study demonstrates that it is appropriate for usage in wearable biomedical devices.

KEYWORDS On-Body antenna, slot antenna, hybrid antenna, dielectric resonator antenna, biomedical antenna, wearable antenna.

INTRODUCTION

There is a great demand for multi-standard, independently controlled, and small radio frequency (RF) components given the telecommunications industry's rapid expansion. Data transmission and reception are carried out via an antenna, a crucial RF circuit component. It is difficult to develop a small, multi-standard, and individually band-controllable antenna. The slot antenna is regarded as the finest option among planar antennas because to its straightforward shape. However, because to its many advantages over other antennas, dielectric resonator antennas have caught the attention of researchers.

Before creating a DRA, one must have a thorough grasp of the DRA modes and excitation process. DRAs may be excited using a variety of approaches, including microstrip feeding, slot feeding, and probe feeding. The slot excitation technique, in which the slot plays a function to connect DR with the feed line, is the common approach across all feeding systems. Recent times have seen a lot of interest in hybrid DRA because to its benefits of compactness and many bands or wideband properties. Typically, hybrid DRAs are a mix of two Mohsen Khalily served as the assistant editor who oversaw this submission's evaluation and gave final approval for publication. However, there is also research that discusses the employment of parasitic components to produce additional modes in the DRA in resonating structures with a shared feeding mechanism. The multi-mode DRA's independent band control is subject to several restrictions.

The lower and second resonant bands of a multiple band hybrid DRA are produced by an H-shaped monopole, while the upper resonant band is produced by combining an H-shaped monopole with a rectangular DRA. The hybrid DRA that the authors of developed serves as both a feeder and a resonator for the DRA. No band is independently controlled, despite the great gain and radiation efficiency of the antennas in the resonant regions.

Wireless body area networks (WBAN) have drawn a lot of interest recently due to their many uses across several industries. The development of implanted devices for several uses, including capsule endoscopy, lead pacemakers, intra-oral tongue drive systems, intracranial pressure monitoring, and glucose monitoring, has further raised the significance of WBAN. A crucial part of the WBAN receiver is an antenna. Although several wearable antennas have been researched thus far for WBAN applications, there is relatively little information on DRAs and hybrid DRAs.

DESIGN METHODOLOGY

The hybrid DRA's design approach may be summed up as follows:

• In the first phase, an L-shaped slot antenna for 2.4 GHz was created. The corresponding circuit model was extracted to display the circuit's actual behaviour.

• A 5.8 GHz slot-excited DRA was created in the second stage. For DRA, the corresponding circuit model was taken.

The final phase included designing and jointly optimising a hybrid slot-DRA structure. The radiating slot and DRA were positioned to minimise coupling. For a hybrid system, an analogous circuit model was also derived. The antenna was tested both in open air and close to a human body.

• The antenna was modelled within a container with various fake electronics components in the last phase to actualize it in a simulated environment.

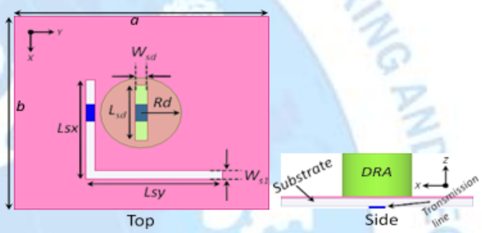
SLOT-DRA HYBRID ANTENNA DESIGN

Fig. 1a shows the proposed hybrid antenna, which is built on a slot and DRA. The hybrid antenna consists of a resonant DRA, a rectangular non-resonating slot for DRA excitation, and an L-shaped radiating slot. A 50 ohms single microstrip transmission line is used to excite the radiating L-shaped slot as well as the non-radiating rectangular slot. The FR-4 substrate used for the hybrid antenna is 1.6 mm thicker than standard FR-4 (r = 4.4, tan = 0.020).

The suggested model operates in dual bands using two modes. The fundamental mode (TM10) of the slot is used to generate the lower band, and the HEM11 mode of the DRA is used to generate the upper band. The hybrid antenna resonates at two frequencies, the lower of which is produced by the L-shaped radiating slot and the upper by the cylindrical DRA.

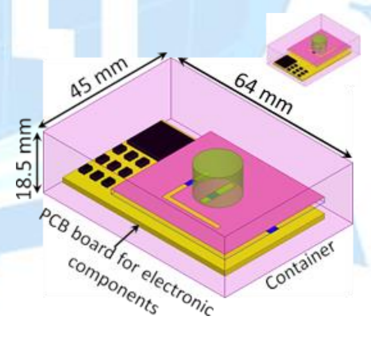
HYBRID SLOT-DRA DESIGN

The DRA and slot antenna were separately investigated and both resonators were packed in such a way that they can be integrated with each other in the later stage. In this stage, both the resonators were packed within the same substrate, having a common ground and a common source. The position of both resonators was selected so as to have a minimal coupling effect on each other. The optimized hybrid antenna along with the detailed parameter dimensions are portrayed in Fig. 1a. The equivalent circuit model of the hybrid system is derived so as to see the real behaviour of the system. The L-shaped resonating slot, DRA, and slot beneath the DRA was modelled as an RLC circuit. The undesirable coupling between radiating L-shaped slot and DRA was modelled as LC circuit. The equivalent circuit model was optimized in the Advanced Design System (ADS). The input impedance of the EM model and the circuit model is compared, which shows a reasonable agreement.



(a)

(a) Proposed slot-DRA based dual-band hybrid antenna [Lsy =21.5, Lsx =18, Ws1=1.5, Lsd =11, Wsd= 2, Rd 6.35, a 40, and b=35, H=d 8, and Hsub =1.6 (unit = mm)], and (b) detail architecture of the wearable device.



(b)

ELECTRIC FIELD DISTRIBUTION

Electric field distribution of the antenna inside the device at 2.4 GHz and 5.8 GHz. The E-fields are concentrated on an L-shaped slot at 2.4 GHz and on the DRA at 5.8 GHz, which further confirms the operating mode of each band. It is evident from the L-shaped slot is responsible for the lower resonant band. CDR is responsible for the higher resonant band. We

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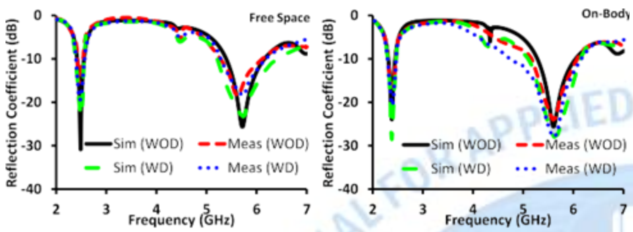
can also see from the Fig. 5 that the electronic packaging and 3-D container have negligible effects on the antenna. It is noticeable that a less amount of current is coupled with the electronic packaging. Hence, it is confirmed from the discussion that the 3-D device and electronic packaging is not offering any detuning effects.

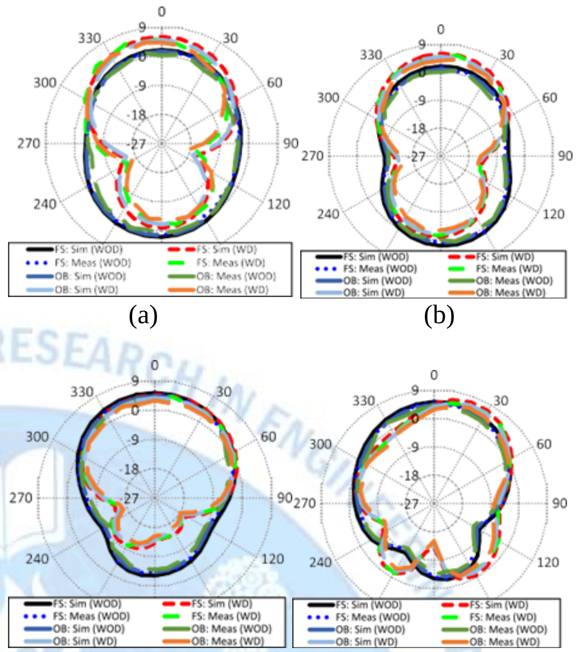


(a) (b)

Simulated and measured reflection coefficient of the antenna with the device (WD) and without the wearable device (WOD) (a) in free space (FS), and (b) in on-body (OB) case

SPECIFIC ABSORPTION RATE (SAR) ANALYSIS

The human body absorbs a portion of radiation when an antenna is placed in its nearby. These absorbed radiation increases temperature of the human body . The intensity of the absorbed radiation is measured by the specific absorption rate (SAR) value. The SAR value can be calculated using the Equation. SAR = $\sigma E\ 2\ \rho$ where σ represents conductivity, E represent the electric field intensity, and ρ shows the mass density. We selected portion of the body instead of the whole phantom to reduce the simulation time. In the first case (without the device), we kept the antenna 3 mm away from the human leg and simulated the SAR value. In the second case (with device), we kept the device 2 mm away from the human body. Fig. 8 shows the SAR distributions in two cases. We see that the SAR value in the second case is relatively lower than the first case. The reason behind the lower SAR value in the second case is attributed to the extra electronic packaging PCB board below the antenna, which acts as a quasi-reflector



(a) (b)

(c) (d)

Simulated and measured radiation pattern of the antenna with (WD) and without the wearable device (WOD) in free space (FS) and on-body (OB) (a) φ = 0◦ at 2.4 GHz, (b) φ = 90◦ at 2.4 GHz

CONCLUSION

A low-profile, dual-band hybrid antenna using an L-shaped slot and cylindrical DR as a resonator has been proposed in this paper. The parametric study confirms that the proposed antenna is independently controllable: the lower band is controllable using L-shaped slot's dimensions and higher resonant band is controllable using DR parameters (radius and height). A reliable equivalent circuit model has been presented for the individual resonators and hybrid antenna. The suitability of the antenna for biomedical devices is confirmed by embedding the antenna in a dummy biomedical receiver and by analyzing the SAR value in the device, and without the device. We found that the PCB board below the antenna acts as a reflector, results in increasing the gain, reducing the backward radiation, and reducing the SAR.

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