Antenna-Multiplexer for IoMT Wireless Connectivity

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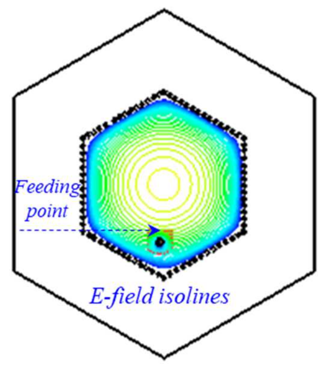
***Abstract*—A compact design of antenna-multiplexer is designed and analyzed, specifically to meet the requirement imposed by subsystems operating at 5.2, 5.5, and 5.8 GHz frequency bands for Internet of Medical Things (IoMT) applications. The proposed design includes a hexagonal shaped substrate integrated waveguide (HSIW) cavity, tripole-shaped radiating slot, tuning vias, and three inset microstrip feedlines. A tripole-shaped slot is imprinted on the top of the SIW. This slot subdivides the cavity into trio-radiating segments and each segment offers single frequency band. Further, the frequency bands are tuned at 5.2/5.5/5.8 GHz. The design maintains mutual port isolation better than 23.9 dB.**

Keywords*— Antenna-multiplexing, Port-Isolation, Specific Absorption Rate (SAR), Substrate Integrated Waveguide (SIW)

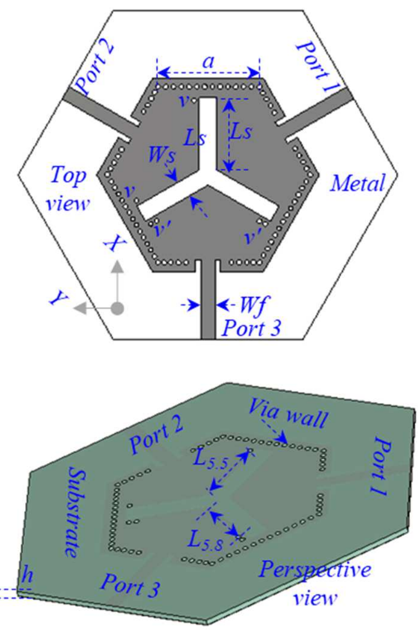
I. Introduction

Developing 5G mobile network may not be the only step to a fully functioning Internet of Medical Things (IoMT), but it is an important one and it comes with substantial performance requirements. In last decade, the cutting-edge technology, substrate-integrated waveguide (SIW) is considered as a capable entrant for high-density integrated circuits due to its inherent advantages of low-loss, low-cost, high-quality factor, and easy realization with other planar circuits [1-10]. In general, RF front-end circuits, the filter is cascaded right after the antenna for spurious signal suppression. Typically, these two components are designed disjointedly and associated with the standard transmission line. This would not only worsen system performance but also increase the circuit complexity due to the extra interconnections. Further, to improve the performance of self-multiplexing antennas, distinct cavity resonators and multi dielectric cavity-based architecture were implemented [11-12]. These designs display outstanding radiation characteristics.

However, such designs possess design complexity and increased R&D cost. Furthermore, issues like layer alignment and air-gap may affect the performance. Therefore, these are not preferable in compact and delicate wireless systems, particularly applications like implantable antenna for Internet of Medical Things (IoMT) Connectivity. Also, Specific Absorption Rate (SAR) is a parameter to be considered while designing antennas for biomedical applications. Mainly, SIW based antenna diplexers, that offer a variety of enhancements in their performances are to be tested for substantial SAR value.

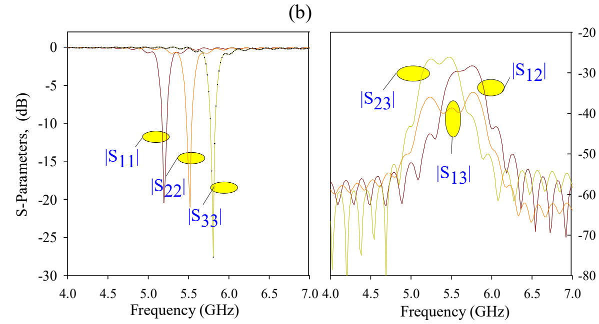


(a)



(Ls = 12.38, Ws = 3.0, Wf = 2.4, a = 17.42, L5.5 = 11.0, L5.8 = 10.4, h = 0.79).
UNIT: in mm.

(b)



(c)

Fig. 1. (a) TM_{010} mode E-field of HSIW cavity resonator, (b) Proposed design

and (c) *S*-parameters [16].

Recent studies in [13-15], modern communication appliances demand a high- have calculated SAR values for their suggested designs. performance, compact antenna multiplexer with acceptable SAR values. Here, we work describes the design aspects of a low-profile antenna multiplexer recently appeared in [16]. Due to page limitations, we could not able to reveal all results, wide explanation and comparative study. The low SAR values make this antenna more suitable for IoMT/ implantable devices.

II. Design Configuration and Simulation Study

Fig. 1(a, b) shows the unique architecture of a hexagonal SIW (HSIW) cavity, which is fashioned by inscribing metallic vertical posts along the substrate. They electrically short the upper and bottom copper laminates. The dimensions of the metallic posts, diameter (*d),* and pitch distance (s) are chosen in the manner, that it delivers very less energy leak from discrete gaps. Moreover, it must satisfy the empirical relation: $d/s \geq 0.5$ and $d/\lambda_o \leq 0.1$ (λ_o is the free space wavelength) [15, 16]. The side dimension of a regular hexagonal-shaped SIW cavity resonator, operating in the dominant (TM_{010}) mode is predicted by using (1) at the frequency around 5 GHz. The electric field distribution of the TM_{010} mode HSIW cavity resonator is displayed in Fig. 1(a).

$$a \approx \frac{2.404c}{2\pi f\sqrt{\varepsilon_r}} \tag{1}$$

Here, a, c and ε_r denotes the side length of the HSIW cavity, the speed of light, and relative permittivity, respectively. The dimension a has been optimized by considering the effect of lateral via-wall of the HSIW cavity. To realize the radiation properties, a tripole-shaped slot has been imprinted on the upper metal plate of the HSIW cavity, as shown in Fig. 1(b) which splits it into three sub-cavities. The length of the tripole leg (Ls) can be approximated by using (2) as per the lowest operating frequency band, *i.e.,* $f =$ 5.2 GHz.

$$Ls \approx \frac{c}{4\pi f}\sqrt{\frac{2}{1+\varepsilon_r}} \tag{2}$$

Furthermore, each sub-cavity is excited by the inset microstrip line so that the planar outline of the configuration can be preserved. The tripole slot induced cavity is excited by three distinct feeds, namely, *Port1, Port2,* and *Port3*, (shown in Fig. 1(a)). It exhibits a resonance around 5.2 GHz when *Port1* is excited. To realize resonances around 5.5 and 5.8 GHz corresponding to *Port2* and *Port3* excitations, additional shorted vias are embedded at the end of the open aperture. These vias control the effective radiation aperture. Therefore, by optimizing the location of these vias, the antenna shows the resonance frequency around 5.5 and 5.8 GHz while *Port2* and *Port3* are excited, individually. The frequency bands around 5.5 and 5.8 GHz are tuned with help of these additionally loaded vias while the dimension of the slot remains unchanged. To minimize the common coupling of the input ports, the radiating slot width is maintained quite broad [9]. By appropriately adjusting and optimizing the antenna parameters, all input ports are mutually isolated by -25 dB from each other. This property helps to realize the antenna multiplexing functionality. The response of the proposed design is summarized in Fig. 1(c). This design was analyzed and improved with the assistance of commercially available *CST MWS 2019* version.

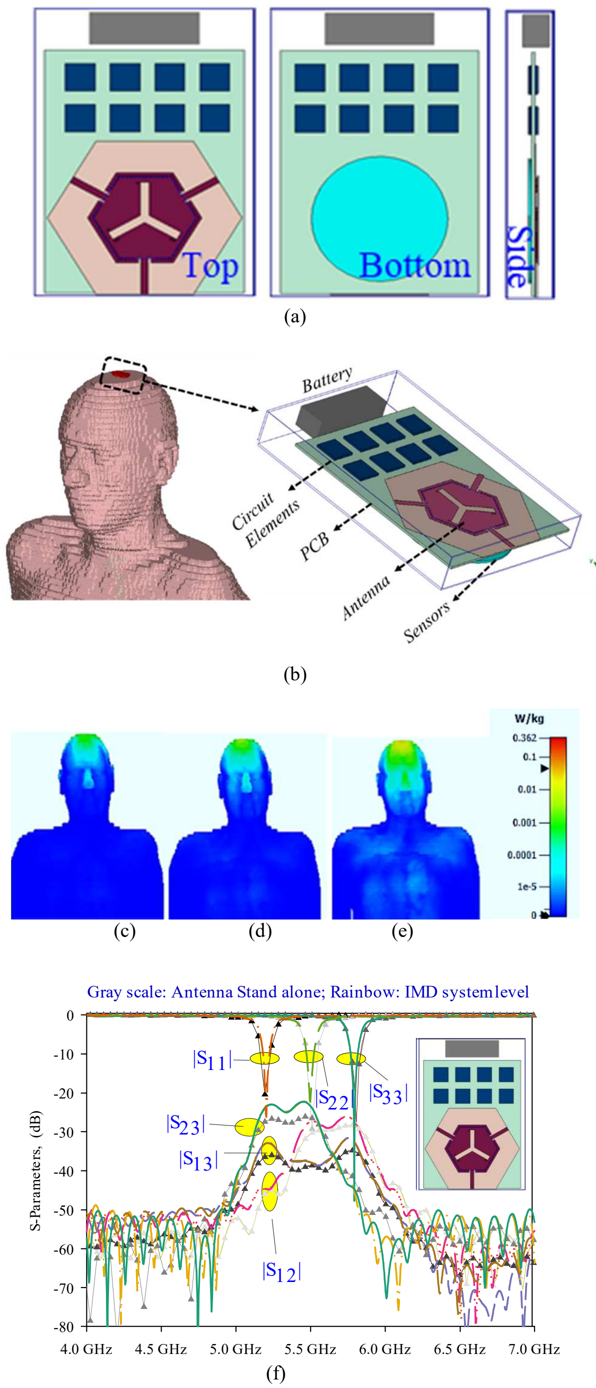


Fig. 2. (a) Geometry of the proposed IMD architecture (b) Simulation environment for SAR measurement. Simulated SAR distribution of the proposed antenna with the device set-up implanted on the human head model

at a depth of 3 mm around the frequency bands of (c) 5.2, (d) 5.5 (e) 5.8 GHz. and (f) *S*-parameters, with and without IMD level.

TABLE I
PERFORMANCE COMPARISON OF PROPOSED TRIPLEXER WITH OTHER SIW BASED TRIPLEXER DESIGNS

Component Name	Materials Used	Dielectric Constant	Loss Tangent
Bio-compatible Encapsulation	Ceramic Alumina	9.5	1.1×10^{-4}
Battery	Lithium	6.7	4.7×10^{-4}
Sensor	Graphene Oxide	11.2	2.5×10^{-4}
Circuit Elements	Metal pads with very high permittivity		

Specific Absorption Rate (SAR) analysis of proposed design component at the device level:

The proposed antenna is integrated along with a few other electronic components and is encapsulated in a cubical IMD of dimensions $73 \times 131 \times 15\, mm^3$. Since the IMD is intended for implantable IoMT applications, it is made up of a 0.25 mm thick bio-compatible ceramic alumina to avoid direct contact with the human tissues [16]. A few surface-mounted devices like mixers, modulators matching networks are mimicked by square metal pads on the PCB board. A battery and a sensor are also included for the simulation. This completes the entire system level set-up of the IMD for biological implantation as shown in Fig. 2(a) and (b). The antenna's standalone performance is compared with that of the IMD in terms of S-parameters before implanting in the human head model, which is shown in Fig.2(f). It is inferred that the resonance characteristics remain unaltered in both the cases, covering the required frequency ranges of (5.2, 5.5, and 5.8) GHz. As the antenna is proposed for implantable applications, it is very important to check the fulfillment of safety requirements in the terms of SAR. The IMD is then placed inside the skull of the realistic human head model at a depth of 3 mm for SAR analysis as shown in Fig. 2(b-e). The ICNIRP guidelines limit the SAR averaged over 1 g of tissue to 1.6W/Kg or lesser and over 10g tissue to 2 W/Kg or lesser. The input power to the antenna is one of the significant parameters that control the SAR achieved. The simulated SAR of this design implanted in a human head at a depth of 3 mm with an input power of 1mW is 0.105, 0.223, 0.362 W/Kg at 5.2, 5.5, and 5.8 GHz respectively, which satisfies the SAR requirement. Table I summarizes the values of dielectric constant and loss tangent used in the head model.

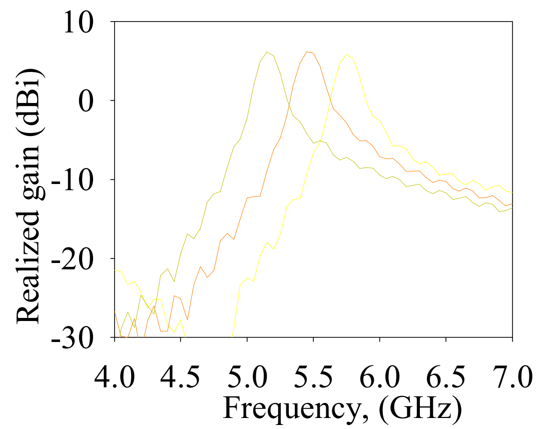
Gain, Antenna efficiency and Radiation Patterns:

As the component was modelled using *Rogers_RT_Duroid_5880* ($\varepsilon_r = 2.2$ & $tan\delta = 0.0009$). The result shows that the antenna maintains a reasonable isolation among the input ports. Fig. 3(a) shows the simulated gain performance of the proposed design. The peak gain values at the resonant frequencies around 5.2, 5.5, and 5.8 GHz are 5.4, 5.4, and 5.6 dBi, respectively. The normalized radiation patterns (*Co-pol* and *cross-pol*) in different planes are shown in Fig. 4.

To benchmark the performance of this design, a comparative study with a few SIW designs is summarized in Table-II. Any traditional higher-order diplex networks can be replaced with this proposed design which offers the advantage of a uniplanar layout to cover three-frequency bands.

TABLE II
PERFORMANCE COMPARISON OF PROPOSED TRIPLEXER WITH OTHER SIW BASED TRIPLEXER DESIGNS

Properties		Here/ [16]	[13]	[14]
Thickness(h)		0.78 mm	1.57 mm	0.78 mm
Freq. (GHz) f_1, f_2, f_3		5.21, 5.5, 5.8	5.57, 7.17, 7.65	7.81, 9.42, 9.80
Gain (dBi)	f_1	5.2	4.10	3.68
	f_2	5.2	3.95	4.76
	f_3	5.3	3.54	4.54
Isolation (dB)	f_1	>24	>26	>21.3
	f_2	>27	>21.3	>18.1
	f_3	>32	>25	>24.1
Size		$0.9\lambda_o \times 0.9\lambda_o$	$0.7\lambda_o \times 0.65\lambda_o$	$0.9\lambda_o \times 0.8\lambda_o$
SAR Analysis		Yes	No	No
Device-level study		Yes	No	No
Rad. Pattern		Unidirectional		
No. of Layers		Single		
(λ_o : wavelength @ lowest resonant frequency)				



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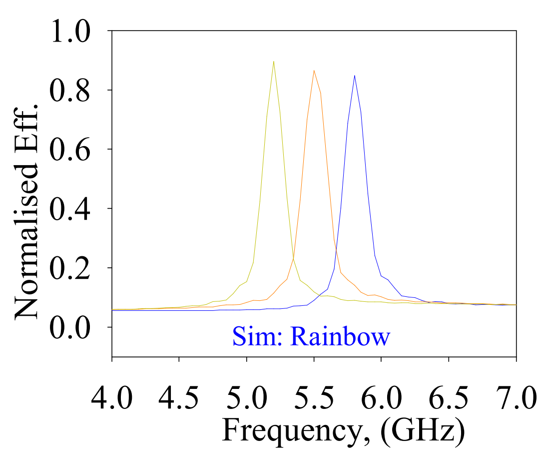
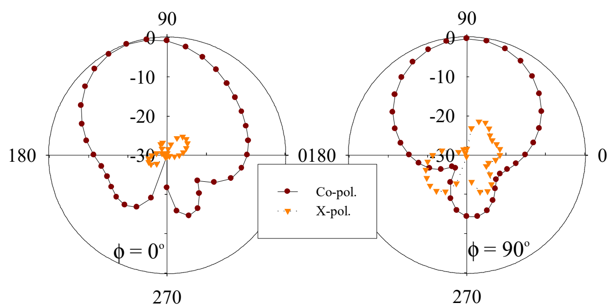


(b)

Fig. 3. (a) Realized gain characteristics and (b) Overall radiation efficiency.

Essentially, a similar performance is expected from the transceivers of any practical communication system. Thus, the design proposed in this paper meets such necessity by maintaining a thinness of $0.02\lambda_o$. The proposed idea could be an unfailing solution for light-weighted implantable wireless transceivers, connecting IoMT devices simultaneously for multiple wireless system integrations. The SAR is simulated which is much lower (<0.362 W/Kg) than standard limits.



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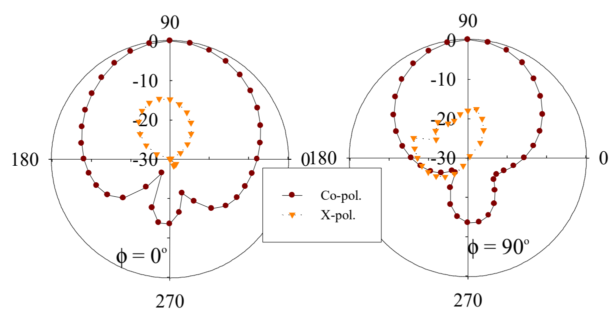

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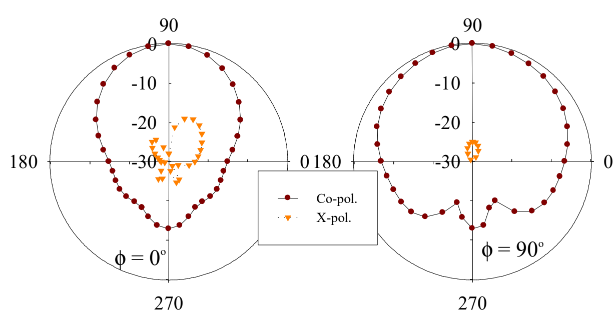

(c)

Fig. 4. Normalized simulated radiation patterns: (a) 5.2, (b) 5.5 and (c) 5.8 GHz.

III. Conclusion

Here, a study of HSIW backed-cavity tripole-shaped slot triplexer for modern is presented. As it performs simultaneous transmission and reception without multiplexing circuitry for On-Body IoMT Connectivity. The design integration and compatibility along with a few other electronic components and the system level set-up analysis for biological implantation is studied.

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