

A Silicon-Based Ferrite Loaded Miniaturized On-Chip Antenna with Enhanced Gain for Implantable Bio-Telemetry Applications

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Abstract—To make a truly compact size system on-chip (SoC) device for wireless bio-telemetry application, the design of a miniaturized on-chip antenna (OCA) with enhanced gain becomes a prime challenge in recent time. Unsuitable Si (Silicon) substrate and relatively larger antenna size at lower microwave frequencies make it even more challenging for the researchers. In this work, an OCA is designed on a low resistive ($\rho = 10 \text{ ohm}\cdot\text{cm}$) Si substrate by using standard CMOS technology process. The top metal layer of CMOS layout has been used for designing the antenna to reduce fabrication complexity. By using slot miniaturization technique, the proposed antenna size of $\lambda_0/22 \times \lambda_0/21.4 \text{ mm}^2$ is achieved and operable at ISM 915 MHz band for biotelemetry applications. A gain enhancement technique for OCA is proposed by introducing a $0.2 \mu\text{m}$ thin film of Cobalt Zirconium Oxide (CoZrO) ferrite material, and the gain is enhanced by +12.28 dB with the bandwidth and fractional bandwidth (FBW) of 1.14 GHz and 124%, respectively. The simulation results of the proposed antenna with coating of bio-compatible material show its potential applicability for implantable bio-telemetry applications. An equivalent circuit of the proposed OCA is presented and verified by ADS circuit simulator.

1. INTRODUCTION

In the last ten years, there have been many new emerging diseases which have no treatment, vaccine, possible prevention or control [1]. Some of these diseases, such as Brain disorders, Heart dysfunction, Pulmonary heart diseases, may be controllable in the initial stage but due to non-continuous monitoring, become incurable and threat to human lives. Bio-telemetry devices such as implantable medical devices (IMDs) are one of the effective solutions which provide continuous monitoring of health conditions not only for patients but also for normal persons to avoid any health hazards. IMDs are implanted inside the body by any surgical method for monitoring the health in a continuous manner. Presently, IMDs become effective for biotelemetry application due to continuous monitoring, precise drug delivery, and health care in some critical diseases like respiratory diseases, nervous system diseases, cardiac diseases, cancer, and in many others [2, 3].

Figure 1 shows the typical block diagram of communication between an IMD and monitoring device placed outside of the host body. In Fig. 1(a), the bio-signal, i.e., information of the host body, is sensed by sensor placed inside the IMD. This bio-signal is processed and transmitted through a wired link to the monitoring device which is placed outside the body. The inherent problems associated with wired communication are attenuation, latency, and propagation delay. Thus the wired communication with IMDs makes the device not only bigger and complex but also inefficient and less reliable. Incorporation of OCA (on-chip antenna) into the IMD makes the device compact in size, provides a wireless connectivity between IMDs and monitoring devices (as shown in Fig. 1(b)), and offers reliable and faster communication than wired one. The implementation of OCA in IMDs not only makes the system compact by removing complex wired network but also provides easy implantation to the host

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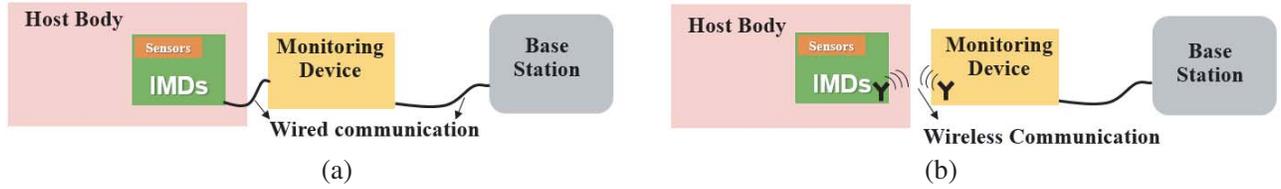


Figure 1. An implantable bio-telemetry monitoring system (a) IMD with wired connection (b) with wireless connection using OCA.

body. However, demand of compact IMDs needs miniaturized antenna to fabricate within the small area of the integrated chip and easy implantation. Thus, many antenna miniaturization techniques like slotting, shorting, meandering, loading, etc. have been successfully incorporated [2]. Another challenge for an on-chip antenna designer is the losses due to Si substrate. The IC industries mostly prefer Si substrate for fabrication of ICs. However, due to low resistivity and high permittivity, Si ($\rho = 10 \Omega\text{-cm}$, $\epsilon_r = 11.9$) produces huge substrate loss which drastically reduces the performance of OCAs in terms of gain and efficiency. To enhance the gain and efficiency of the OCA different techniques such as Si lens [4], electronics band gap (EBG) structure [5], dielectric resonators [6, 7], artificial magnetic conductors (AMCs) [8], partially shield layer (PSL) [9], high impedance layers [10], un-doped Si [11], and micro-machining [12, 13], have been successfully introduced. Most of these gain enhancement methods have been presented at higher microwave and THz frequency where wavelength is quite small, and thus the required antenna size comes down to smaller values. However, at the lower microwave frequency, the size of antenna becomes so large that it may not fit into the integrated chip of system and larger reduction of antenna size leads to reduction in gain and efficiency drastically. It is found from the literature that ferrite material is useful to enhance the performances of miniaturized antenna. In [14], it is investigated that the gain of an 80% miniaturized water quenched Co_2Z hexaferrite antenna is enhanced by 15.60 dB compared with a dielectric antenna operating at 200 MHz. In this regard, the thin layer of CoZrO (Cobalt Zirconium Oxide) ferrite material is introduced as an alternative to improve the gain characteristics of compact miniaturized OCA.

This paper proposes a miniaturized OCA with improved gain at ISM 915 MHz band for wireless biotelemetry applications. To enhance gain of the proposed antenna, the thin ferrite material layer of CoZrO is sand-witched in between top metal patch and SiO_2 . The proposed antenna with ferrite layer shows improved gain and efficient radiation characteristics with wide bandwidth for high speed communication. The Si_3N_4 layer is coated over the OCA to make it bio-compatible for implant devices. The design consideration and structure of the proposed OCA have been discussed in Section 2. Stepwise equivalent circuit analysis with the current distributions on OCA is also explained in Section 2. Along with that, parametric analysis of some of the important design parameters is shown later in this section. All the results and explanations are discussed in Section 3. Finally, a comparative analysis is demonstrated in Section 4, and then conclusion has been drawn in Section 5.

2. ANTENNA DESIGN

2.1. On-Chip Antenna Layout Consideration

The standard layout diagram of CMOS technology as in [9] is shown in Fig. 2(a). Initially, this standard layout is considered as the reference layout for designing the proposed OCA. The antenna is designed on the top metal layer of the CMOS layout stack. Generally, in CMOS technology, a thin silicon dioxide (SiO_2) layer is grown/deposited over a Si substrate to provide isolation between metal and substrate. Still, due to the lossy electrical properties ($\rho = 10 \Omega\text{-cm}$, $\epsilon_r = 11.9$) of Si, it causes large amount of substrate loss and reduces the gain and efficiency of an OCA. Further to mention that the idea of integrating antenna on the same IC wafer is relatively new, and there is no such design rules in foundries to realize the antenna with optimum radiation characteristics. In this regard, the major objective is to design a on-chip antenna with improved gain and reduced substrate loss. Thus, in the proposed OCA, as shown in Fig. 2(b), a high resistive Cobalt Zirconium Oxide (CoZrO) ferrite material layer

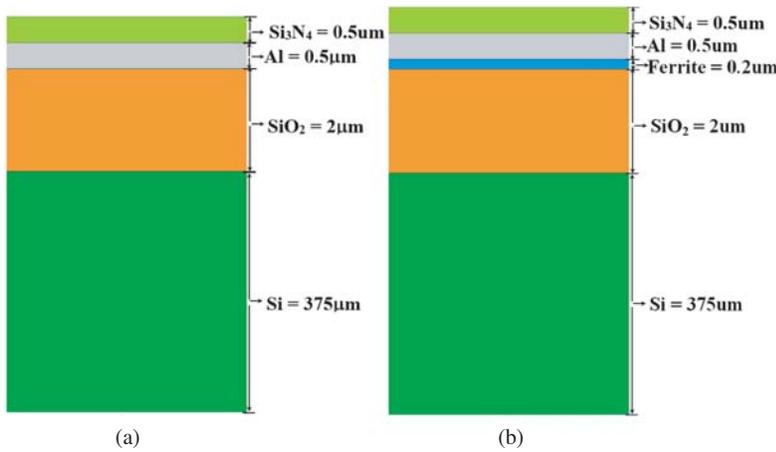


Figure 2. The process layout diagram of standard CMOS technology and the layout proposed for the antenna. (a) Standard CMOS layout. (b) Proposed layout for OCA.

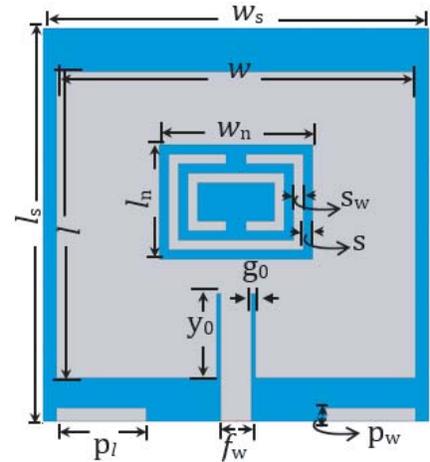


Figure 3. Top view of the proposed OCA (Removing Silicon nitride layer).

is introduced over SiO_2 . The selection of a proper ferrite material is also very important as the high quality factor (Q) with high permittivity (ϵ_r) ferrite works as a resonator, and it does not allow to radiate itself efficiently. Also a low ϵ_r and low Q ferrite will produce losses like eddy currents, which again reduces OCA efficiency [15]. The selection of CoZrO ferrite is an ideal choice here as it has $\epsilon_r = 4$, $\mu_r = 4.5$ with $Q = 10\text{--}15$ (frequency dependent), which is a good compromise between the high and low values of quality factor and permittivity. Insertion of CoZrO restricts EM waves toward the substrate and hence reduces the substrate loss that leads to improving the antenna gain. The placement of a ferrite layer is made such that it does not affect the resonant frequency of the proposed antenna [16]. Generally, a thin layer works perfectly as an insulator and isolates the metal and substrate effectively. As ferrite is not a bio-compatible material, a bio-compatible layer of Silicon Nitride (Si_3N_4) is coated over the metal layer to make the OCA more suitable for the bio-telemetry application (e.g., implantable devices) and thus reduces harmful effects on implantee’s tissues. The Si_3N_4 layer will also work as a passivation layer to protect the metal radiator from environmental hazards.

2.2. Design Structure

The top view of the proposed antenna is shown in Fig. 3. The OCA comprises a simple patch fed with co-planar waveguide (CPW) feed having two ground pads. The CPW feed is an obvious choice of a small OCA as it provides a planar feed structure which can be easily aligned and fed by suitable GSG probe. A 1.2 mm CPW with two $0.5 \times 2.9 \text{ mm}^2$ size ground pads is used to feed the antenna. A Si wafer of $375 \mu\text{m}$ thickness has been used as the substrate over which a SiO_2 layer of thickness of $2 \mu\text{m}$ has been deposited. A $0.2 \mu\text{m}$ thin film of ferrite material is included in modified CMOS stack over which $0.5 \mu\text{m}$ thin metal layer of the antenna is designed as depicted in Fig. 2(b). A Si_3N_4 layer is optimized to $0.5 \mu\text{m}$ thickness for 915 MHz band. Ideally, the antenna size for 915 MHz band would be $\lambda_0/2 = 32 \text{ cm}$, but such a large size antenna is not suitable for the on-chip application. Hence, a slotting technique of microstrip patch miniaturization has been used to reduce the size of the chip antenna. For this, two rectangular ‘C’ shaped rings have been used in the center of the rectangular slot of the patch as shown in Fig. 3. The optimized ring strip width and gap between the two rings is 0.375 mm for desired center frequency. These slots increase the electrical length of the patch without disturbing the physical length and hence decrease the frequency significantly. It gives a reduction of size up to $\lambda_0/21.2$, and the optimized dimension of the whole on-chip antenna is $15 \times 15.4 \times 0.306 \text{ mm}^3$, which is miniaturized and compatible with chip dimensions. The proposed OCA structure has been designed and simulated on ANSYS HFSS.15 platform.

Table 1. Parametrically Optimized parameters of proposed OCA.

Parameters	l_s	R_1	w_s	L_1	l	C_1	w_n	g_0	h
Optimized Value	15.4 mm	10 m Ω	15 mm	0.45 nH	12 mm	8.08 pF	6 mm	0.15 mm	0.377 mm
Parameters	w	ΔL	ϵ_r	ΔC	l_n	R_0	p_l	Q	y_0
Optimized Value	14 mm	26 nH	11.9	0.0047 pF	4.5 mm	50 Ω	3.5 mm	1.4	3.3 mm
Parameters	L_0	s	C_0	s_w	L'_0	f_w	C'_0	p_w	
Optimized Value	3 nH	0.375 mm	6 pF	0.375 mm	3.5 nH	1.2 mm	7.5 pF	0.5 mm	

2.3. Design Parameters

All the parametrically optimized parameters of the miniaturized antenna for the center frequency 915 MHz are shown in Table 1. The representations of parameters are as follow: l_s = Substrate length, w_s = Substrate width, l = Patch length, w = Patch width, l_n = Slot length, w_n = Slot width, s_w = Strip width, s = Strip (slot)gap, p_w = Ground pad width, p_l = Ground pad length, f_w = Feed width, h = Substrate height, Q = Patch antenna quality factor, and y_0 = Inset feed length. In the design of OCA, some of the parameters are limited by IC design foundry process like CMOS, GaAs, SiGe, etc. In different technologies, there are different numbers of metal layers with fixed thickness [17]. So some important parameters like substrate thickness (used to reduce resonant frequency), metal layer thickness (causes gain improvement), choice of substrate material, etc. are in limited control of an antenna designer. With these foundry level limitations, suitable miniaturization technique and a proper feed selection (here CPW feed) play an important role to control the characteristics of the antenna with improved radiation performance.

2.4. Equivalent Circuit analysis

Analytically, the equivalent circuit model of the ferrite loaded OCA is presented in this section. Fig. 4(a) shows the current distribution on the surface of a simple patch antenna. The maximum current density on a patch is near feed line, and along the length it gets lesser and at the end almost zero. The design of patch is optimized to resonate at 1.2 GHz. As shown in Fig. 4(b) in the equivalent circuit of the top layer on-chip patch can be represented as parallel R_1 , L_1 and C_1 , and the value of these parameters can be calculated as [18]

$$C_1 = \frac{\epsilon_e \epsilon_0 l_e w}{2h} \cos^{-2} \left(\frac{\pi y_0}{l} \right) \quad (1)$$

$$L_1 = \frac{1}{C_1 \omega^2 r} \quad (2)$$

$$R_1 = \frac{Q}{C_1 \omega r} \quad (3)$$

Here, l_e is the effective length, and ϵ_e denotes the effective permittivity. These parameters can be calculated as [19]

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(1 + \frac{10h}{w} \right)^{-1/2} \quad (4)$$

$$l_e = l - 2\Delta l \quad (5)$$

where,

$$\Delta l = 0.412h \left(\frac{(\epsilon_e + 0.3) \left(\frac{w}{h} + 0.262 \right)}{(\epsilon_e - 0.258) \left(\frac{w}{h} + 0.813 \right)} \right)$$

The current distribution in the proposed ferrite loaded miniaturized OCA is shown in Fig. 4(c). The principle of miniaturization of a patch antenna is to increase the travelling time of the current

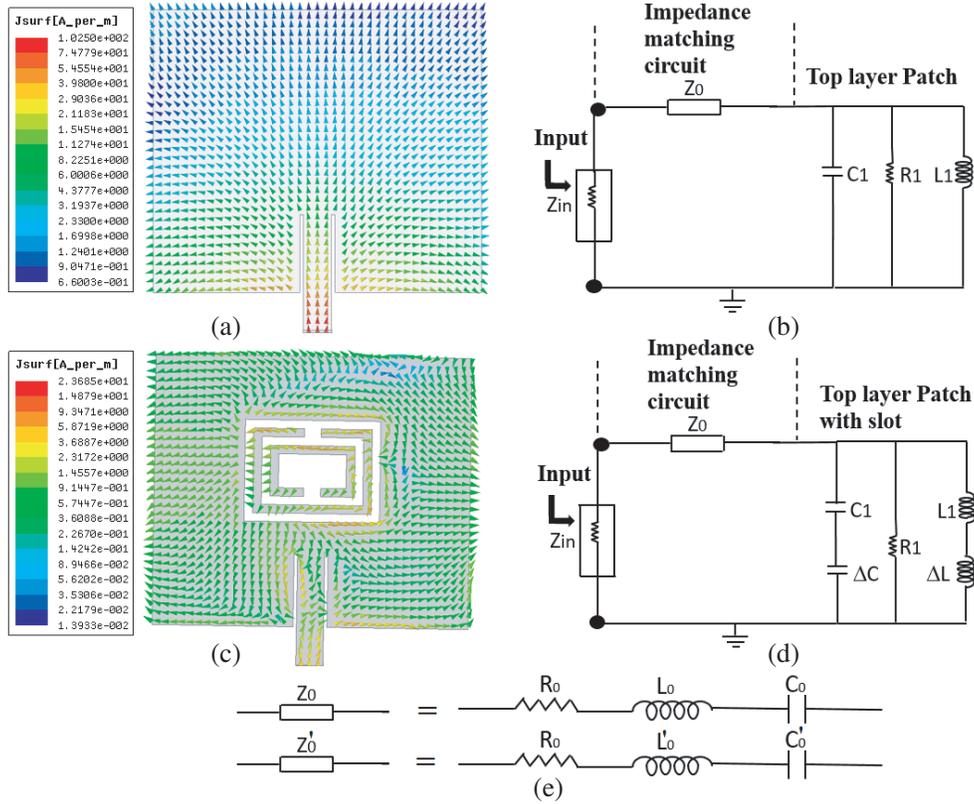


Figure 4. Current Distribution and Equivalent circuit with Impedance matching circuit. (a) Current distribution; (b) Equivalent Circuit; of rectangular patch; (c) Current distribution; (b) Equivalent Circuit; of proposed slotted OCA; (e) Impedance matching circuit.

stream along the length. Thus, to have miniaturization, two ‘C’-shaped rings are introduced into the rectangular slot of the patch. The reason of selecting two ‘C’-shaped rings is that together they form a slow wave structure which provides maximum delay for the travelling current stream. As can be seen from the figure, the current density is now maximum in the slots. It also depicts that the current travelling time from feed toward the other end of patch is more than that of a simple patch. As this travelling time of current is increased, due to inverse relation, the resonant frequency comes down to 0.915 GHz from 1.2 GHz. This miniaturization can also be analysed from the equivalent circuit of OCA as shown in Fig. 4(d), where ΔL and ΔC show the changes due to the slots and cause the frequency shift. These changes in parameters can be calculated as

$$\Delta L = \frac{h\mu_0\pi}{8} \left(\frac{l_n}{l}\right)^2 \tag{6}$$

$$\Delta C = C_s \left(\frac{l_n}{l}\right) \tag{7}$$

where C_s = Slot gap capacitance and can be calculated as

$$C_s = 0.5hQe^{(-1.86\frac{s}{h})} \left[1 + 4.09 \left\{ 1 - \left(0.785\sqrt{\frac{h}{w}} \right) \right\} \right]$$

and

$$Q = 0.04598 \left\{ 0.03 + \left(\frac{w}{h}\right)^{1.23} \right\} (0.272 + 0.07\epsilon_r)$$

Here, it is important to mention that the similar equivalent circuits of the antenna with and without ferrite layer are observed. It is because the highly resistive ferrite layer implementation provides isolation

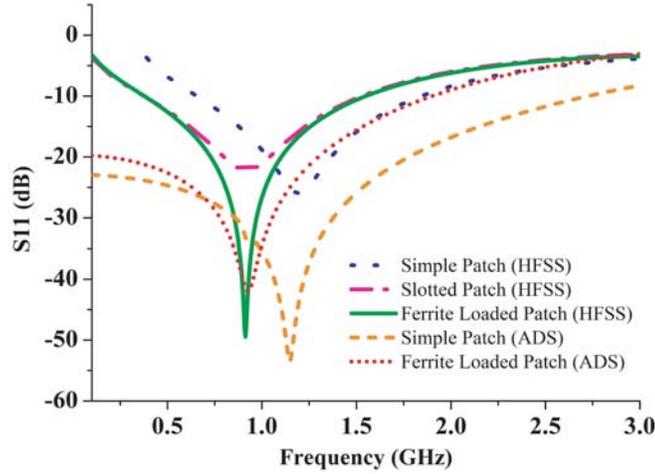


Figure 5. Comparison of the S_{11} characteristics of the equivalent circuit simulated in ADS and that for the antenna designed in HFSS.

between metallic patch and lossy Si substrate to enhance the antenna gain. This can also be understood from the return loss characteristics of the OCA under the two cases as presented in Fig. 5. The figure shows that there is some variation in the impedance whereas the resonance frequency remains same under both the cases.

The calculated values of these parameters for the optimized antenna are given in Table 1. Parameters R_1 , L_1 , C_1 , ΔL , and ΔC are corresponding to the equivalent circuit of the patch, which are calculated by utilizing Eqs. (1) to (7). However, Z_0 and Z'_0 (as shown in Fig. 4(e)) represent the equivalent impedance due to antenna static impedance and probes self-impedance and obtained by iterative tuning using ADS circuit simulator for matching with input $50\ \Omega$ impedance [20].

2.5. Parametric Analysis

The OCAs are so small that their characteristics are very sensitive to even slight variations of any design parameters. The values of all the parameters are parametrically optimized. The effect of dimensions of the patch and slot can be understood from the concept of the conventional microstrip patch antenna. However, during the fabrication process, there may be some variation in the metal and dielectric layer thickness due to the imperfection in the fabrication process. This variation depends on the foundry based data corresponding to the PDK of the manufacturing company. The typical range of such variation is about $\pm 5\text{--}10\%$ when the design layout is developed by considering 180 nm standard CMOS technology. Here, the effects of the thickness of the ferrite and top metal patch layers on the antenna performance have been observed by considering the process design kit (PDK) of the manufacturing firm. The variations of S_{11} and gain characteristics of the antenna with the thickness of the ferrite layer are plotted in Figs. 6(a) and (b), respectively. It shows that the ferrite layer thickness plays an important role in the antenna gain characteristics. When the layer thickness increases from $0.1\ \mu\text{m}$ to $0.3\ \mu\text{m}$, the gain is increased to its maximum, and then it decreases when thickness moves toward the higher values. At $0.5\ \mu\text{m}$ the gain, as well as the return loss, is comparably low. Though slightly higher value of maximum gain is obtained for the ferrite layer thickness of $0.3\ \mu\text{m}$, the gain variation over the entire range of theta is better for the thickness of $0.2\ \mu\text{m}$. Thus the optimum value of the thin film ferrite layer thickness is chosen as $0.2\ \mu\text{m}$. Similarly, Figs. 7(a) and (b) depict S_{11} and gain of the antenna against the changes in patch thickness. In these plots, it can be clearly seen that the return loss and gain performances of the antenna are affected by the patch thickness. For a lower value of patch thickness, slightly less gain is observed due to the skin effect of the RF signal. However, the optimum patch thickness is obtained as $0.5\ \mu\text{m}$. In both the cases, the analysis shows that the little ($\pm 0.1\ \mu\text{m}$) variation in parameters significantly changes antenna performance. Hence, choice of optimum thickness of the ferrite layers and patch becomes crucial for achieving optimum antenna performance.

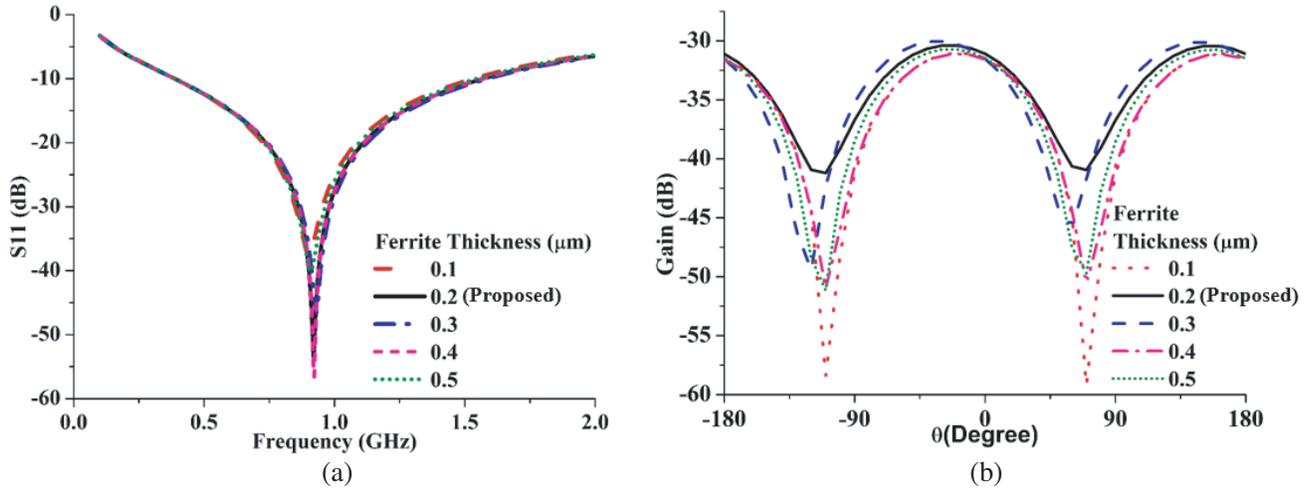


Figure 6. The variation of the S_{11} and gain characteristics with the variation of ferrite layer thickness. (a) Return loss characteristics, (b) Gain characteristics.

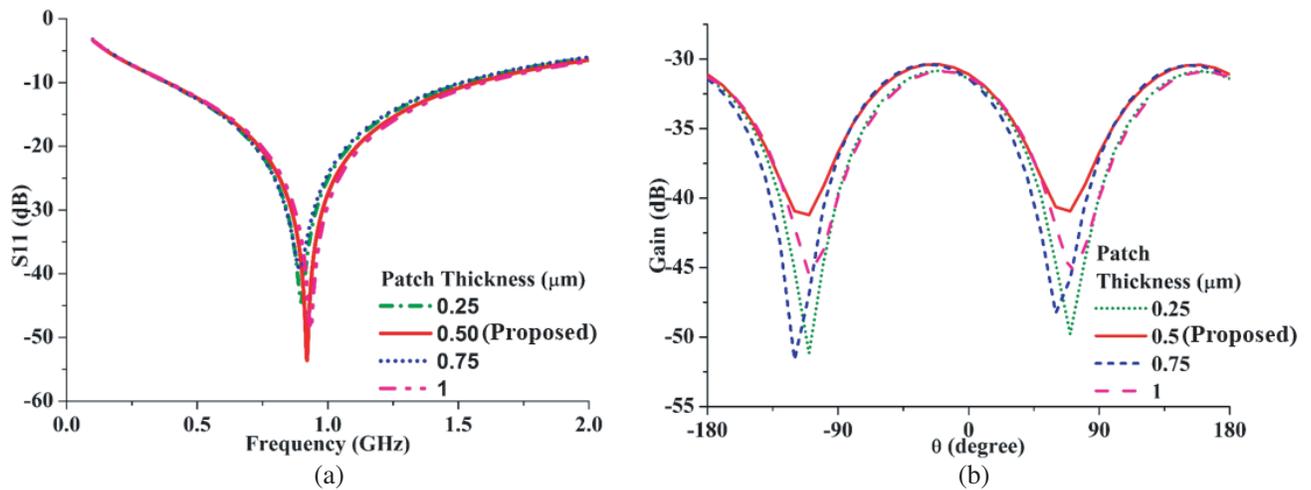


Figure 7. The variation of the S_{11} and gain characteristics with the variation of patch thickness. (a) Return loss characteristics. (b) Gain characteristics.

Keeping in mind about the deviation in fabrication, the antenna performance is checked with 5–10% variation of the optimum patch and ferrite layer thickness. It is observed that within the tolerance limit of fabrication error of the patch and ferrite layer thicknesses, the antenna gain is changed only by ± 0.07 dB and ± 0.127 dB, respectively. Thus, after fabrication, the antenna prototype is useful for the desired application without degradation of its performance.

3. RESULTS AND DISCUSSION

The proposed antenna with a thin film of CoZrO ferrite layer over SiO_2 provides excellent gain enhancement of +12.28 dB with 1.14 GHz bandwidth. Fig. 5 shows the comparison of return loss characteristics of the on-chip simple patch, slotted patch with CoZrO ferrite layer as obtained by EM simulation, as well as equivalent circuit analysis. The figure also shows the simulated return loss characteristics of slotted patch without ferrite resonating at 0.915 GHz. It is ascertained that insertion of the ferrite layer does not affect the resonant frequency. It is also observed from Fig. 5 that there is no effect on bandwidth due to the introduction of ferrite layer, as the bandwidths are almost same in

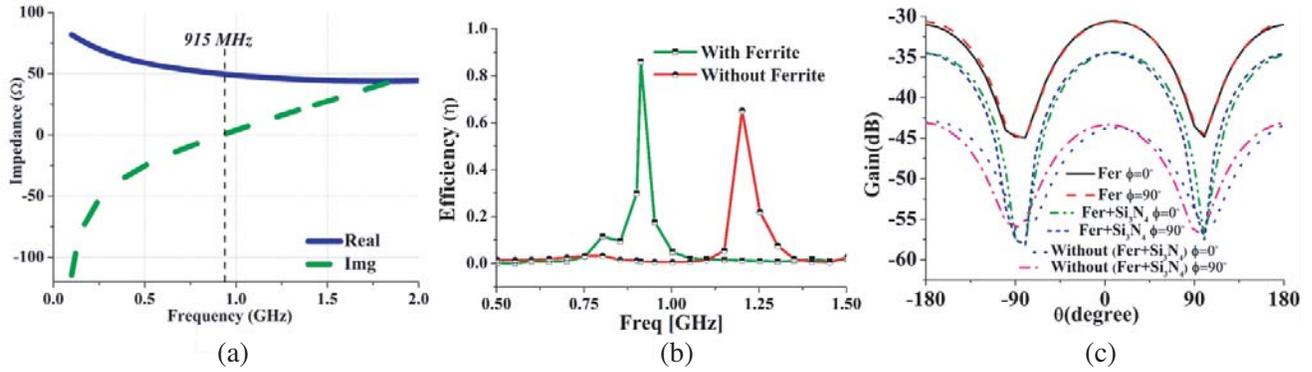


Figure 8. Characteristics of the proposed Ferrite loaded OCA (a) Plot of real and imaginary part of impedance; (b) Efficiency comparison with and without Ferrite layer; (c) Gain performances of the antenna with and without Ferrite and Si_3N_4 layer.

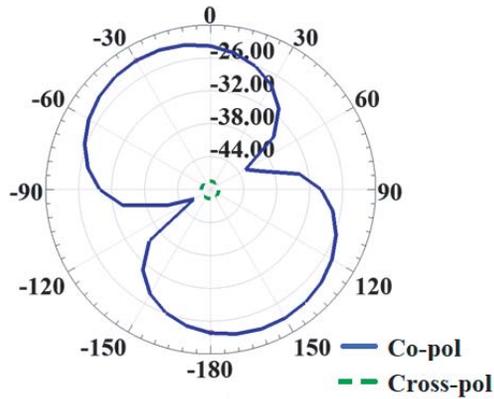


Figure 9. Co & Cross polarization component in XZ plane ($\phi = 0^\circ$).

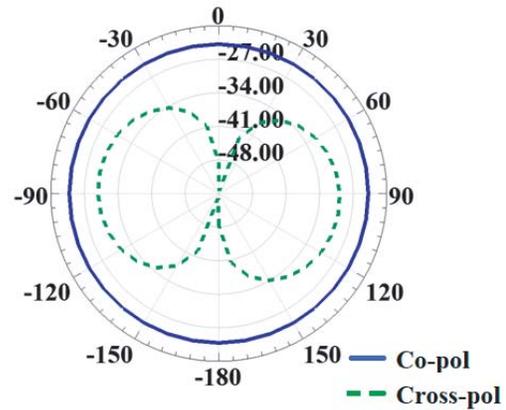


Figure 10. Co & Cross polarization component in YZ plane ($\phi = 90^\circ$).

both the cases. It is because the bandwidth depends mainly upon the substrate thickness and dielectric constant of the substrate used in the design of antenna [21]. In all the cases, simulated return loss curve shows excellent matching with 50Ω input impedance as they are well below the 10 dB line. This impedance matching can also be observed in Fig. 8(a), where the real part (resistive part) of impedance is 49.84Ω while the imaginary part (reactive part) is close to zero (0.04Ω). One of the main reasons of this matching is adequately tuned feed width as matching mainly depends on the width of feed line. Fig. 8(b) shows the efficiency plot for desired range of frequency band. The efficiency of ferrite loaded OCA also increases from 65% to 87% when it is compared with respect to the simple patch. It is because the ferrite layer inclusion allows EM wave propagation towards air instead of inside substrate. This effect is visible in the plot of gain pattern of the proposed antenna in Fig. 8(c). Here initially the gain obtained for the simple patch is -43 dB . One of the main reasons for low gain is substrate loss as most of the EM wave energy absorbed by Si substrate is due to high permittivity. The addition of thin ferrite in the structure provides the isolation to antenna from substrate without affecting resonance condition. The high resistivity of ferrite layer ($\sim 10^4 \Omega\text{-cm}$) does not allow the EM energy to move toward the Si (which has very high permittivity as compared to CoZrO) [14, 16]. To make the proposed antenna effective for IMDs, the complete OCA is coated by silicon nitride (Si_3N_4) bio-compatible material. The coating is very thin and does not affect the antenna characteristics significantly. This effect can be seen in the gain pattern of OCA in Fig. 8(c), where the gain with ferrite and bio-compatible layer is just reduced by 3 dB. The reduction of gain is due to the higher radiation loss in Si_3N_4 ($\epsilon_r = 7$) than in air. Also for implantable application, specific absorption ratio (SAR) should be maintained below 1.6 W/kg

for 1 gm of volume of tissues, to avoid the harmful effect of radiation on implanted body. This SAR can be easily controllable by input power to the system. Also, the fractional bandwidth (FBW) in this proposed OCA has been achieved as 124%. Because of the higher FBW, this OCA is applicable to high speed biotelemetry communication at 915 MHz ISM band.

As SoC devices work with very low input power, effective utilization of the power is required. Thus waste of power radiation to or received from the undesired direction should be as low as possible. In this regard, to observe the co-pol and cross-pol characteristics of the antenna, it is placed in XY plane and facing toward $+Z$ direction. Fig. 9 and Fig. 10 show the co-pol and cross-pol characteristics of OCA in two principal planes, XZ -plane ($\phi = 0^\circ$) and YZ -plane ($\phi = 90^\circ$), respectively. The co-pol and cross-pol components are well-isolated by 10 dB (null side) and 25 dB (broadside) in XZ -plane while 6 dB (null side) and 25 dB (broadside) are in YZ -plane respectively. This indicates significant reduction of unwanted interferences from or radiation to the cross-pole plane.

4. COMPARATIVE ANALYSIS

Gain enhancement with miniaturization is one of the major challenges in OCA due to its small size and substrate loss. Table 2 provides a comparison between the gain enhancement techniques for miniaturized OCAs as reported in different published research works. In [22], a dielectric resonating antenna (DRA) made with a high resistive silicon material fed by patch provides a gain enhancement of 6.7 dB. DR material can also be used to enhance the gain and directivity of patch antenna [23]. However, the main drawback with DR material is the non-planar structure of the antenna whereas in the SoC applications all the structures including antenna are preferably planar. Also, the process of preparing a high resistive DR material makes design costly and complex. Another interesting and popular technique to enhancement of gain is electromagnetic band gap (EBG) structure. EBG periodic structure stops EM waves to move towards substrate at resonant frequency and helps to increase gain. In [24], a patch array shows the gain enhancement of 4 dB using an EBG structure at 60 GHz center frequency. A circular cavity is used to provide air as the substrate and becomes comparably less lossy than Si, hence increases the gain by reducing substrate loss [25]. These gain enhancement techniques are either costly or the design structure gets complex. One of the most noticeable things is that the reported antennas are mostly designed for higher frequencies. At higher frequencies the wavelengths are so small that even $\lambda_o/2$ antenna size is sufficient for the chip size. In the proposed OCA, the slotted patch achieves miniaturization of $\lambda_o/21.2$. A simple planar thin film of ferrite layer has been used to enhance the gain up to +12.28 dB in 915 MHz.

Table 2. Parametrically optimized parameters of proposed OCA.

Reference	Max. Dimension	Antenna type	Frequency (GHz)	Gain enhancement (dB)	Enhancement technique
[22]	$\lambda_o/1.76$	DRA	340	6.7	High ϵ_r DR material
[23]	$\lambda_o/0.48$	Patch array	60	4	EBG technique
[24]	$\lambda_o/0.77$	Log-periodic	216	7.7	Printed circular cavity
[25]	$\lambda_o/1.77$	Slot Antenna	130	13.2	DR material
This work	$\lambda_o/21.2$	Slot antenna	0.915	12	Ferrite layer

5. CONCLUSION

In this paper, the proposed antenna provides a gain enhancement using a CoZrO ferrite layer thin film in between radiator and SiO₂ layer. The gain enhancement of +12.28 dB is obtained as compared to that without using ferrite layer. By employing two rectangular ‘C’ shaped slots, the OCA miniaturization up to $\lambda_o/21.2$ has been achieved successfully. An equivalent circuit of the OCA is presented, and the circuit simulation results are well matched with the simulation results of antenna. It is observed that proper selections of metal thickness and ferrite thickness are crucial to realization of the antenna

with optimum characteristics. Proposed antenna shows excellent isolation between co- and cross-pol components, which shows its applicability to low power handling devices. Proposed antenna with a biocompatible layer of Si_3N_4 material not only provides the gain enhancement but also offers the excellent fractional bandwidth of 124%. Thus, the proposed antenna becomes an ideal choice for high speed ISM band telemetry devices applications.

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