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Design of SIW based Millimeter wave Chipless Identification Tag for Low Cost Application

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Abstract

In this paper, a novel concept to implement millimeterwave substrate integrated waveguide-based circuits for chipless identification application has been demonstrated. The proposed design utilizes a pair of compact half mode SIW cavity to encode the interrogating signal and resend the signal through the open-end aperture of the cavity. Thus, the encoding resonator itself has been utilized as radiator of the interrogating signal which helps to improve the compactness of the design. The complete design has been realized in K band making physical size of the circuit very small which makes it attractive for practical application.

1. Introduction

With the recent advancement of Internet of Everything (IoE), there is a lot of attention to develop radio frequency Identification (RFID) Technology among the researchers [1]. The currently available commercial ID tag uses application specific integrated circuits (ASIC) along with RF circuit and antenna. The RF energy received by the antenna is used by the IC to encode data into the signal and resend the signal back to the transmitter for detection. However, the chip based tags are not cost effective and hence are not suitable for tracking of cheap products with large quantity. Recently, chipless RFID technique has grown much interest among the researchers as an attractive solution for low cost tracking application [2]. The chipless tag depends on designing RF circuits to generate unique signature in the interrogation signal which can replace the IC circuit. The replacement of IC reduces the power consumption criteria of the tag and also drastically reduces the cost. Also, it exhibits inherent advantages such as long reading range, non-line of sight detection etc. Several chipless RFID design working in microwave frequency range has been proposed in recent years. [3]. However, all these circuits have inherent drawback of comparatively large size, less capacity etc.

In recent years, a new approach to design chipless tag at millimeterwave (mmwave) frequency range has been reported. The design has its own advantage such that wideband unlicensed spectrum ensuring low interference, smaller size of tag, higher data encoding capacity etc. [4].

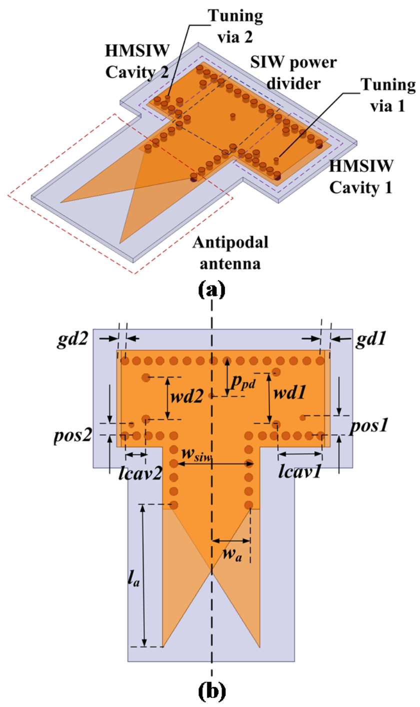

Figure 1. (a) Side view; (b) top view of the proposed chipless tag.
(l_a = 10 mm, w_a= 2.7 mm, w_{siw}= 5.4 mm, p_{pd} = 2.8 mm, *wd1* = 3.8 mm, *pos1* = 0.3 mm, *gd1* = 0.4 mm, *lcav1*= 3.2 mm, *lcav2* = 1.52 mm, *wd2* = 3 mm, *pos2* = 1 mm, *gd2*= 0.3 mm)

However, all these designs rely on microstrip based technique which suffers high radiation loss, surface wave loss at mmwave frequency ranges.

The substrate integrated waveguide (SIW) technology has been studied among the researchers as an attractive alternative for mmwave circuits [5]. Several SIW based mmwave antennas and circuits has been reported in recent years. A SIW based chipless tag with single encoding bit is reported in [6]. Recently, chipless millimeterwave ID (MMID) using HMSIW is reported in [7].

In this paper, a novel approach to design compact, chipless ID at mmwave frequency range using SIW circuits has been presented. The proposed design utilizes two distinctive HMSIW cavities to introduce a pair of encoding bit in the interrogating signal while maintaining a compact size of the tag.

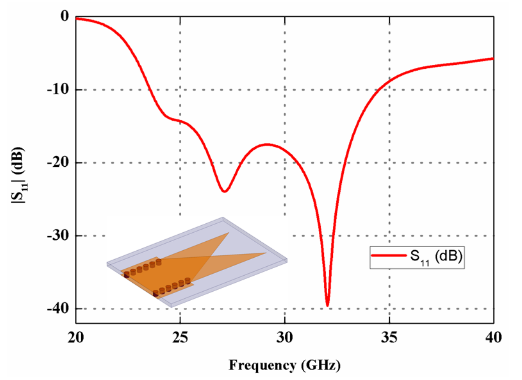

Figure 2. Performance of SIW fed antipodal antenna

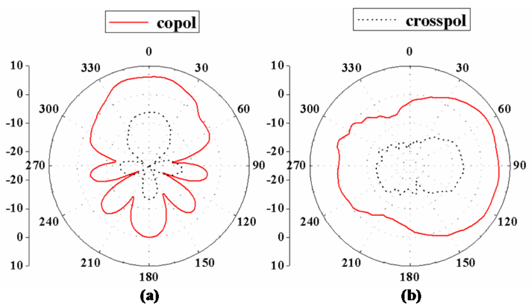

Figure 3. Radiation pattern of SIW fed antipodal antenna (a) E plane; (b) H Plane

2. Working Principle

The proposed design of chipless ID tag is shown in Figure 1. The tag consists of four major section as shown in Figure 1(a), an antipodal antenna followed by SIW line section, SIW equal power divider, Half-mode SIW (HMSIW) cavity 1 and HMSIW cavity 2 with tuning post. The details of each section are described below:

2.1 Design of SIW fed Antipodal Antenna

The chipless tag needs to receive the transmitted signal through antenna and resend the encoded signal back to the reader antenna. In the proposed design, a SIW fed antipodal antennas has been implemented to receive the interrogating signal. The antenna is designed by creating tapered section at the open end of SIW which helps to excite slot line mode in the flared section. The length and width of the flared section is optimized to achieve proper impedance matching of the antenna. The details of the design dimension of the antenna is shown in Figure 1. The performance of the antenna is shown in Figure 2 and 3. As shown in Figure 2, the proposed antipodal antenna exhibits a wide bandwidth from 23.57 GHz to 34.59 GHz operating in K band. The radiation pattern of the antenna shows end fire radiation with a high gain of 6.62 dBi. As a result, the antenna can be used as a suitable candidate to catch the interrogating signal from the interrogator antenna. The antipodal antenna is followed by a small section of SIW line and finally the received power is equally divided by the SIW equal power divider.

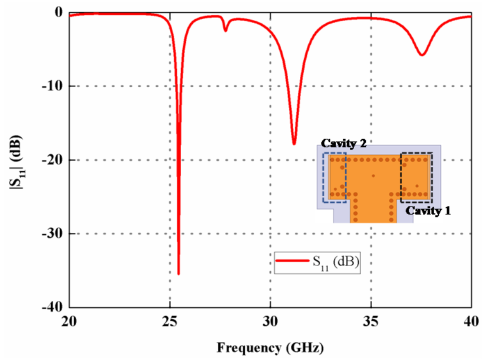

Figure 4. Performance of SIW fed HMSIW cavity pair

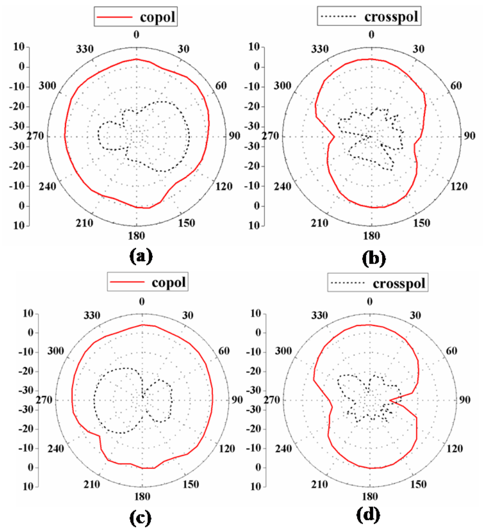

Figure 5. Radiation pattern of the HMSIW cavity-based antenna; (a) E Plane (cavity 1); (b) H Plane (cavity 1); (c) E Plane (cavity 2); (d) H Plane (cavity 2)

The diameter and pitch of the via in the SIW is 0.6 mm and 1 mm [5]. The design of equal Tee type power divider is realized by using the impedance matching post whose position and diameter contribute a major role to achieve proper matching of the proposed power divider [8]. Finally, the two output of the power divider is fed to two HMSIW cavity-based antenna.

2.2 Design of Tunable HMSIW Cavity-based Antenna

The proposed tag uses a pair of HMSIW cavity to encode the received signal and resend the signal to the reader antenna. The output of the SIW power divider section is connected to the pair of HMSIW cavity through a coupling window *wd1* and *wd2* at each side as shown in Figure 1(b). The coupling windows are placed at the center of the cavity to excite the dominant TE^{HM}_{110} mode in the cavity. The dimension of HMSIW cavity can be determined from (1) [7].

$$f_{mnp} = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m\pi}{2L_{eff}^{HMSIW}}\right)^2 + \left(\frac{n\pi}{W_{eff}^{SIW}}\right)^2 + \left(\frac{p\pi}{h}\right)^2} \quad (1)$$

$$L_{eff}^{HMSIW} = \frac{L_{eff}^{SIW}}{2} + \Delta l \quad (2)$$

$$\Delta l = h(0.05 + \frac{0.3}{\varepsilon_r}) \times \quad (3)$$

$$\ln(0.79\frac{W_{eff}^{SIW}}{4h^3} + \frac{52W_{eff}^{SIW} - 261}{h^2} + \frac{38}{h} + 2.77)$$

$$L_{eff}^{SIW} = 2L - 1.08\frac{d^2}{p} + 0.1\frac{d^2}{2L} \quad (4)$$

$$W_{eff}^{SIW} = W - 1.08\frac{d^2}{p} + 0.1\frac{d^2}{W} \quad (5)$$

Where $L^{SIW}{}_{eff}$ and $W^{SIW}{}_{eff}$ are effective length and width of the cavity. The open end of the HMSIW functions as a dielectric filled aperture. To radiate fields from the aperture, the ground plane of the HMSIW cavity 1 and 2 is extended by *gd1* and *gd2* respectively. The extended dielectric substrate section along with the extended ground plane helps the open-ended aperture to achieve impedance matching and as a result, the electromagnetic wave radiates through the aperture into free space. Due to the presence of the extended ground plane, the radiation pattern of the aperture is unidirectional with maximum radiation along broadside direction with orthogonal polarization to that of the antipodal antenna. The performance of the HMSIW cavity-based antenna fed by SIW power divider is shown in Figure 4. The two cavities exhibit corresponding resonant frequencies at 25.4 GHz and 31.17 GHz. The open-ended aperture of the cavities radiates at these frequencies with good radiation pattern as shown in Figure 5. However, the HMSIW cavity 1 and 2 are loaded with tuning via 1 and 2 respectively which can be used to change the resonance frequency of the antenna. The diameter of both the tuning via 1 and 2 is 0.4 mm. The position of the tuning via is kept along the half of the length of the cavity and its position can be varied along the width of the cavity. As a result, the dominant mode $TE^{HM}{}_{110}$ field is perturbed due to the conducting via and it shifts the dominant mode resonance of the cavity to higher frequency. The tuning capability of the via 1 and 2 is shown in Figure 6. It can be seen that the resonant frequency of both the cavities can be changed independently which is advantageous for the design.

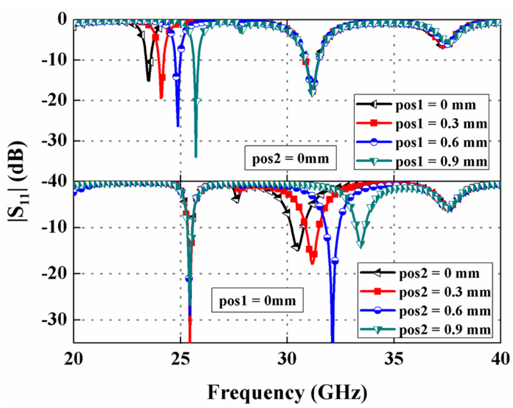

Figure 6. Variation of resonant frequency of HMSIW cavity with change in position of tuning via

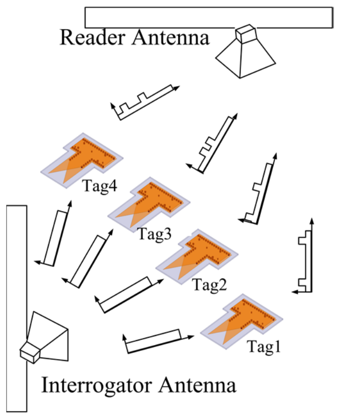

Figure 7. Proposed proof-of-concept schematic model for the proposed tag (**Tag1**: pos1 = 0 mm pos2 = 0.5 mm; **Tag2**: pos1 = 0 mm pos2 = 0.2 mm; **Tag3**: pos1 = 0.5 mm pos2 = 0 mm; **Tag4**: pos1 = 0.8 mm pos2 = 0.3 mm)

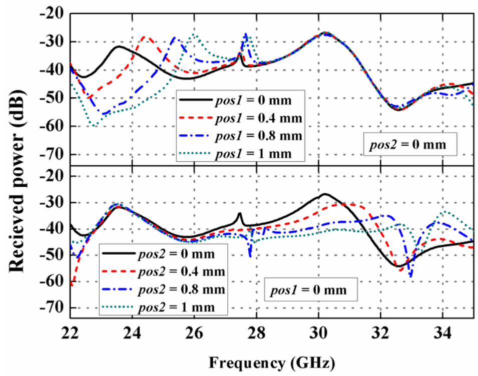

Figure 8. Received power at the reader antenna with change in tuning via position in tag

2.3 Design of Compact Mmwave ID Tag

As shown in Figure 1, the antipodal antenna and SIW power divider fed HMSIW cavity pair is combined together to implement the proposed compact tag. The design efficiently employs the tuning facility of the HMSIW cavity to facilitate the desired encoding of the interrogating signal which can be retransmitted by the open-ended aperture of the HMSIW cavity. A broadband signal transmitted by the interrogator can be received by the broadband antipodal antenna which then sends power to the HMSIW cavity 1 and 2 through SIW power divider. The cavity resonates at the dominant mode resonant frequency and as a result, we get a broadside radiation from the open end of the HMSIW cavity only at the resonant frequency. Thus, the retransmitted signal will exhibit magnitude peaks according to the resonant frequency of the HMSIW cavity over the full spectrum of the interrogating signal which can be received by the reader antenna. A proof of concept set up of the proposed tag is shown in Figure 7. The interrogating antenna can be fixed at the sidewall whereas the reader antenna can be fixed at ceiling. The resonant frequency of the cavity in each tag can be changed by changing the location of the tuning post.

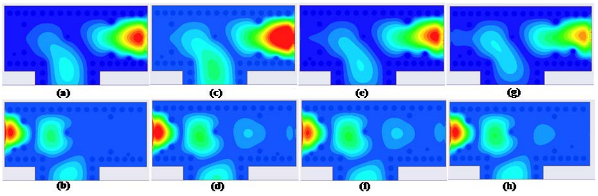

Figure 9. Magnitude of Electric field plot in different tag **Tag1:** (a) 23.52 GHz; (b) 31.8 GHz; **Tag2:** (c) 23.52 GHz; (d) 30.92 GHz; **Tag3:** (e) 24.96 GHz; (f) 30.52 GHz; **Tag4:** (g) 25.44 GHz; (h) 31.2 GHz

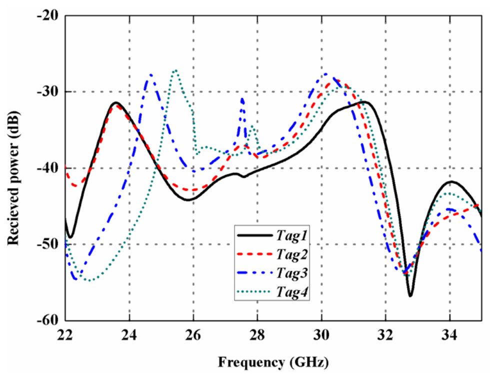

Figure 10. Performance of the four tags

As a result, different tag will resend different encoded signal with corresponding resonant peaks to the reader antenna. As shown in Figure 8, by changing position of tuning post, the resonant peaks of the two cavity antennas can be changed within a wide range of 3.52 GHz and 2.74 GHz respectively. Thus, by employing the proposed scheme, several number of combinations of the pair of resonant frequency is possible which can be employed to design different tag.

3. Result

The complete setup of the identification of several tag is simulated using Ansoft HFSS to analyze the performance of the tag. However, the interrogator and reader antenna used in the model is of low gain and the distance between tag and antenna is 16 cm which can be considered as a proof of concept only. To test the real-world scenario, further modification of broadband high gain interrogator and reader antenna is required. Four distinctive tag along with four different combination of tuning via position in the cavities has been used in the model to test the validity of the proposed design. The details of the position of the tuning via is shown in Figure 7. The perturbation of cavity field distribution due to the tuning via can be seen in Figure 9. As shown in the figure, as the via shifts towards the center of the cavity, it perturbs more field resulting in higher resonant frequency of the cavity. As a result, the received power peaks also shift according to the corresponding position of the tuning via in the cavities. As shown in Figure 10, the shift in peaks are easily distinguishable due to high selectivity of the response which is achieved due to inherent high Q nature of the HMSIW cavity. As a result, multiple combination of resonant peaks can be easily detected in the proposed configuration.

4. Conclusion

A novel design concept to design SIW based chipless tag has been discussed. The design utilizes HMSIW cavity with tuning post to encode the interrogating signal with distinctive resonant frequency. The wide range of tunable resonance opens up the possibility to use the proposed design for detection of large number of products. The complete design is compact and small size making it suitable for practical identification application in K band.

5. References

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