Miniaturized CPW-fed Inductively Coupled Slot Antennas Using Stepped Impedance Resonator With Tuning Slot Stub Loading

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Abstract

Miniature CPW-fed inductively coupled slot antennas (CIC-SAs) using stepped impedance resonator (SIR) with tuning slot stub loading are designed and compared to the CPW-fed uniform impedance resonator (UIR). Reduction size of up to 50% in stepped impedance resonator with tuning slot stub loading length with respect to a traditional uniform impedance resonator (UIR) operating at the same frequency is obtained. The characteristics of the proposed antenna have been calculated using simulation software IE3D. Simulated results are verified with measurements.

1. Introduction

Wireless communications have progressed very rapidly in recent year and many mobile units are becoming smaller and smaller. To meet the miniaturization requirement, the antennas employed in mobile terminals must have their dimensions reduced accordingly. Planar antennas, such as microstrip and printed antennas, have the attractive features of low profile, small size, and conformability to mounting hosts. Several techniques for reducing its size have been presented in the literatures: first using a substrate with high dielectric constant, second incorporating a shorting pin in microstrip patch, third employing a dielectric resonator and forth inverted-F. Another importance candidate which may complete favorably with microstrip for the above applications is coplanar waveguide (CPW). CPW-fed slot antennas also have many attractive features including low radiation loss, less dispersion, easy integration for monolithic microwave integrated circuits and a simple configuration with a single metallic layer. Accordingly, many antenna elements suitable for a CPW-fed configuration have been proposed, the slot antenna being one of the most attractive solutions. One of the main issues with CPW-fed slot antennas is to provide an easy impedance matching to the CPW line. So far, several impedance tuning techniques based on a change of slot dimensions, coupling mechanism or both have been reported in the literatures [1]-[3]. The length of a conventional dipole slot antenna is about a half guided wavelength with a capacitive type feed, and about one guided wavelength for inductive type feed. These CPW-fed capacitive slot antennas are one-half guide wavelength center- and offset-fed slot antennas [4]-[5]. With this technique, the impedance matching with the CPW line is facilitated by the possible adjustment of several geometric parameters. However, the conventional CPW-fed slot antenna is still relatively large. Recently, size reduction technique for CPW-fed slot antenna using stepped impedance with capacitive type feed have been proposed [6].

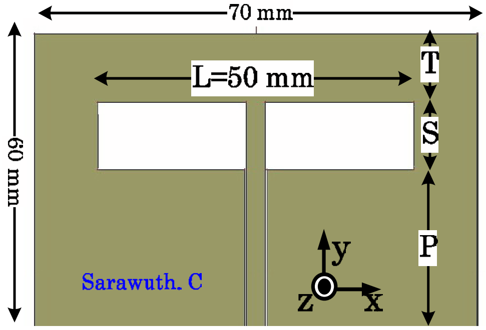


Fig. 1: Geometry of the conventional CPW-fed inductively coupled slot antenna.

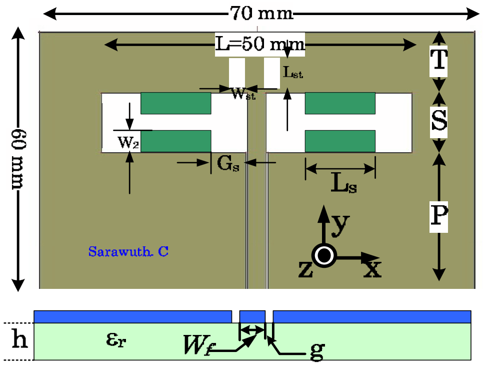


Fig. 2: Geometry of the proposed CPW-fed inductively coupled slot antenna using stepped impedance resonator (SIR) with open stub.

This paper presents a miniature CPW-fed inductively coupled slot antenna (CICSA) using stepped impedance resonator with tuning slot stub loading. To improve the characteristics impedance and radiation pattern of the one-wavelength center-fed slot antenna and to reduce its size, a stepped impedance resonator with tuning slot stub loading is proposed. Structure simulations are performed to investigate the variation of a center frequency depending on the slot length, width, and tuning slot length and width. It is expected that the resonant frequency of the proposed antenna is lower than that of the conventional antenna. A conventional CICSA will be fabricated for comparison. The conventional and proposed CICSAs are constructed by adding the same slot length and width including ground plane. The design considerations and simulated results are presented and discussed.

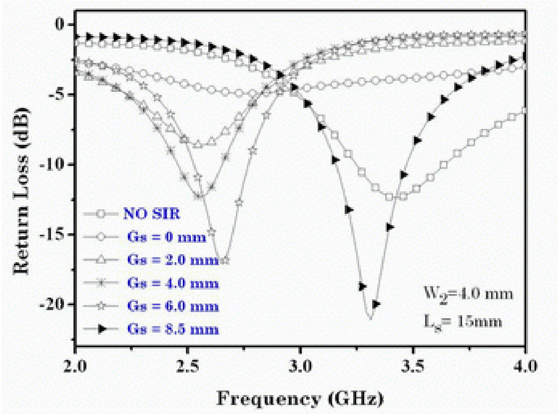
2. Antenna Design

The geometry of the conventional CPW-fed inductively coupled slot antenna is shown in Fig. 1. This antenna has a simple structure with only one layer of dielectric substrate and metallization. The antenna is center-fed inductively coupled slot where the slot has a length (L-W_f) and width S. The slot length (L) determines the resonant length, while the slot has a width (S) which may be adjusted to achieve a wider bandwidth. The length L is approximately one-guide wavelength (λ_g) at the slotline resonance. It is also noted that the wavelength in the slot, λ_g, is determined to be about (0.78 $\sqrt{(1+\epsilon_r)/2\epsilon_r}$) free-space wavelength. For this study, the dimensions are chosen to be L = 50 mm, T = 10 mm, S = 10 mm, P = 40 mm, and the ground size 60 mm $\times$70 mm.

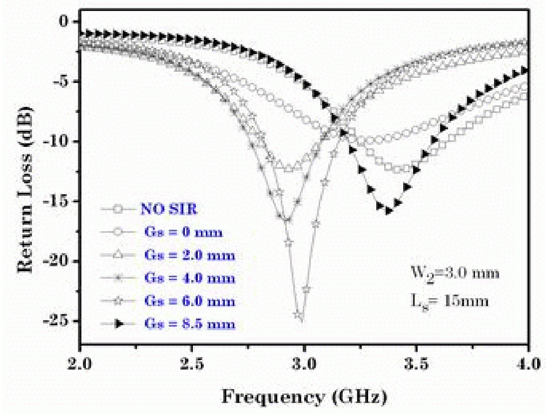
A size-reduction the conventional CPW-fed inductively coupled slot antenna by using SIR with slot stub is presented. The presented antenna geometry is shown in Fig. 2. In additional, the patches into the slot extrude by W_2 and L_s to create the slot SIR and a tuning slot stub of length L_{st} and width W_{st} terminates the CPW feed. The antenna is designed on a single-layer PCB substrate with dielectric constant ϵ_r), loss tangent tan δ and thickness h. All cases, the perimeters of slotline parameters, G_s, W_2, and L_s, respectively, are three key parameters for obtaining the resonant frequencies and an input impedance match. Many prototypes of the proposed antennas were demonstrated and studied.

3. Experimental Results and Discussion

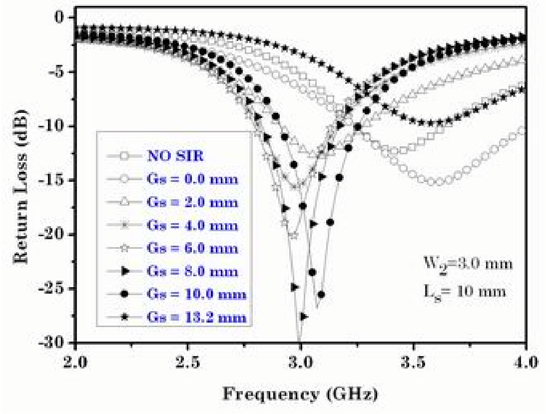
Several antennas with the geometrical configuration proposed in Fig. 1 and Fig. 2 have been implemented and studied both numerically and experimentally. The effect of the slot lengths, widths, and length of a tuning stub on the size reduction factor, impedance, and radiation characteristics of the antennas has been investigated. All antennas are fabricated on an inexpensive FR4 substrate with a dielectric constant of 4.4 and a substrate thickness of 1.6 mm. A CPW-fed, which consists of a signal strip width of 3.0 mm and a gap (g) of 0.3 mm for approximate 50-Ω characteristic impedance between the signal strip and the coplanar ground plane, is used for feeding the antenna. For conventional CICSA, the dimensions are chosen to be L = 50 mm, T = 10 mm and S = 10 mm can excite the resonant frequency (3.6 GHz for calculated) of this antenna. The return loss for L = 50 mm, T = 10 mm and S = 10 mm, denoted as reference antenna, and the calculated return loss has also been demonstrated for



(a)



(b)



(c)

Fig. 3: Simulated return losses for various gap between CPW-fed line (G_s). (a) W_2 = 4 mm, L_s = 15 mm (b) W_2 = 3 mm, L_s = 15 mm, and (c) W_2 = 3 mm, L_s = 10 mm.

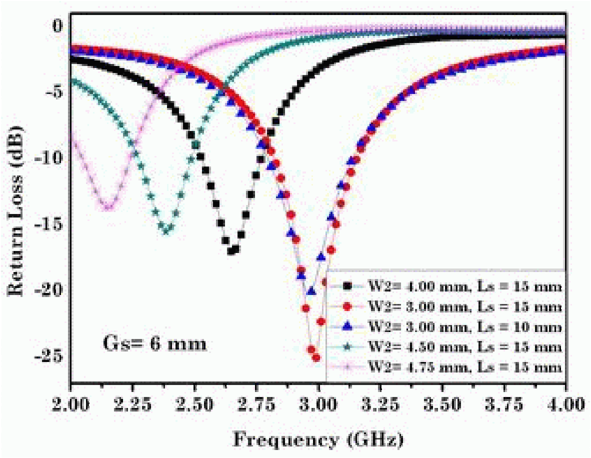


Fig. 4: Simulated return losses for various gap between CPW-fed line (G_s).

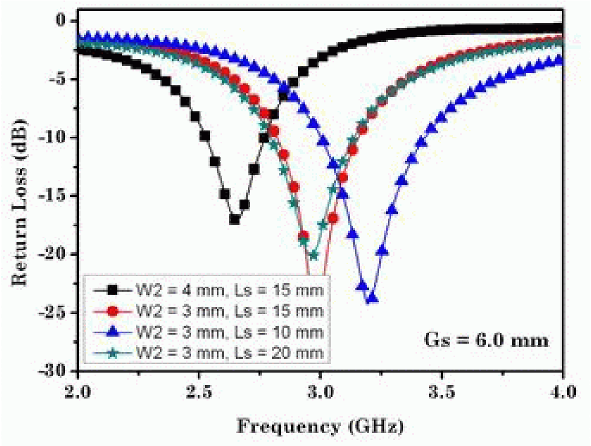


Fig. 5: Simulated return losses for various tuning stub length L_{st} when W_{st} = 1 mm.

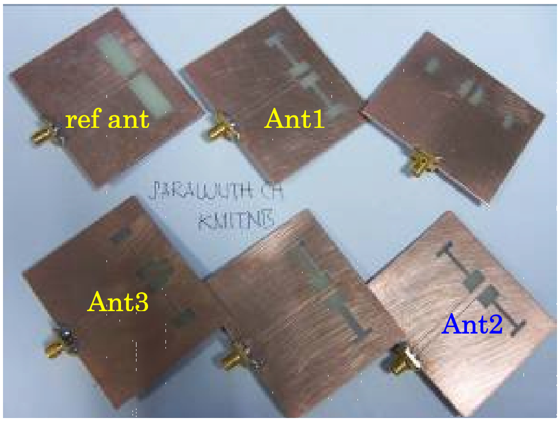


Fig. 6: The fabricated antennas.

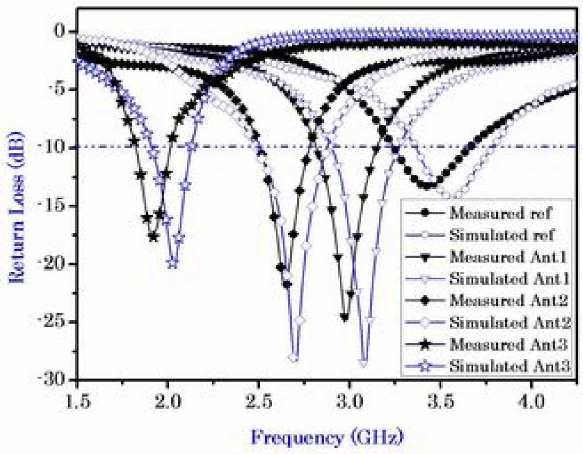
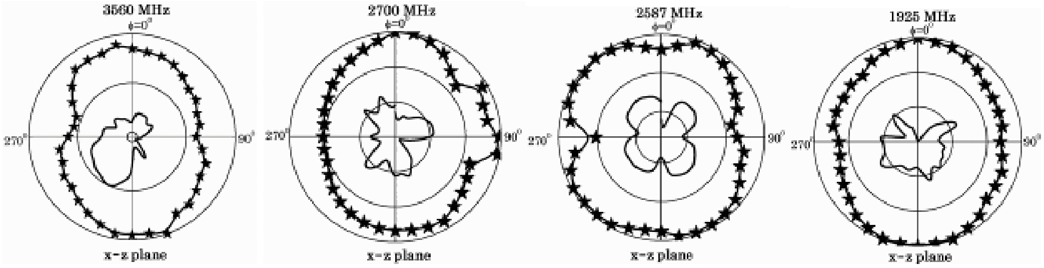


Fig. 7: Measured and simulated return losses for the reference antenna and the prototypes (Ant1,Ant2, Ant3).

comparison. Commercial software IE3D based on MOM has been used to simulate the antenna characteristics. Fig.3 shows the simulated effects on the antennas' frequency response by changing the gap between CPW-fed line (G_s) and slot stepped impedance resonator parameters W_2 and length L_3 which keeping slot circumference (L = 50 mm, S= 10 mm) and ground plane constant. When a smaller gap is chosen, the antenna's resonant frequency is decreased and it also becomes difficult to achieve good impedance matching for desired operating frequencies. It should also be noted that, although the slot length and ground plane size are the same, the obtained bandwidth of the proposed antennas have lower frequencies than the conventional design of reference antenna. Fig. 4 shows the simulated return loss versus frequency for different widths W_2 and length of patches L_s. The value of W_2 is varied from 3 to 4.75 mm, the fundamental resonance is shifted to a lower frequency. However, when W_2 increased beyond 4.75 mm, there was a poor response in the fundamental resonance. A large frequency shift occurred in the fundamental resonance when changing the parameter W_2.

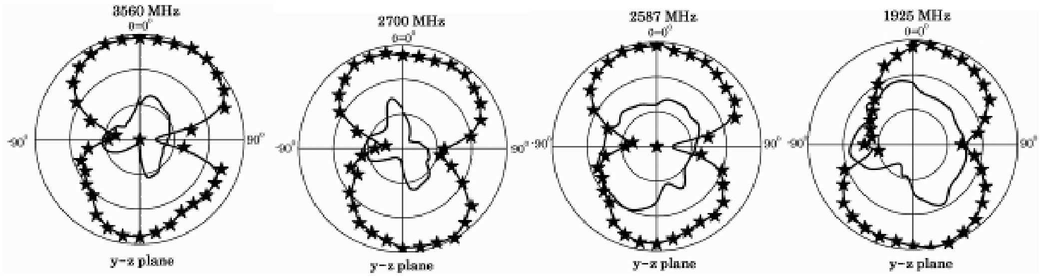
In addition, a tuning stub length L_{st} and width W_{st} terminates the end of CPW feed. To achieve shifting down resonant frequency, the tuning stub should be lengthened and that causes the horizontal slot section of the slot to be etched outwards with a length of L_{st}. By carefully adjusting the tuning stub, the simple CPW-fed slot antenna can operate in the different bands and good impedance matching for the operating frequency can easily be obtained. Fig. 5 shows the effect of varying the tuning stub length as L_{st} = 0, 3, 5 and 7 mm with W_{st} is 1 mm. It is observed that with a decrease in the length L_{st}, the resonant frequency shifts to a high frequency.

A total of three different CICSAs-SIR with tuning slot stub loading with difference parameters are designed, fabricated, and measured. The geometrical parameters of the antennas are given in Table I and Fig. 2. The input reflection coefficients of the all antennas are measured using a calibrated HP8710C vector network analyzer. Fig. 6 shows a photograph of the fabricated antennas. Fig. 7 shows a comparison between the



(a) (b) (c) (d)

Fig. 8: Measured radiation pattern in x-z plane of the conventional antenna and proposed antennas in Table 1.



(a) (b) (c) (d)

Fig. 9: Measured radiation pattern in y-z plane of the conventional antenna and proposed antennas in Table 1.

TABLE 1: DIMENSIONS OF THE FOUR ANTENNA PROTOTYPES (REF, ANT1, ANT2, ANT3) WITH T = 10 MM, AND P = 10 MM ON ϵ_r = 4.4, H = 1.6 MM.

Antennas	L(mm)	S(mm)	G_s(mm)	W_2(mm)	L_s(mm)	L_{st}(mm)	W_{st}(mm)
Ref	50	10	-	-	-	-	-
Ant1	50	10	4	4	15	-	-
Ant2	50	10	6	4	15	-	-
Ant3	50	10	4	4.7	15	5	2

simulated and measured return losses of the reference antenna and the constructed antenna prototypes (Ant .1-3). The simulated and measured data of the proposed and conventional antennas are approximately the same. Some errors in the resonant frequencies occurred due to tolerance in FR4 substrate and poor manufacturing in the laboratory. The radiation patterns of the proposed and conventional antennas measured at their corresponding resonant frequencies are shown in Fig. 8 and 9, respectively. The radiation patterns are bi-directional on the broadside.

4. CONCLUSION

The combination of stepped impedance and slot tuning stub structure is used to design a miniature CPW-fed inductively coupled slot antenna in this paper. In general for UIR, the slot length of slot antenna determines the resonant frequency and the slot width affects the bandwidth. The measured results show good agreement with simulations. It shows a 46 % length reduction compared with the conventional CPW-fed inductively coupled slot antenna.

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