A T-Shaped Wide-Slot Harmonic Suppression Antenna

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***Abstract*—This paper proposes a T-shaped wide-slot harmonic suppression antenna at 4 GHz. Harmonic suppression is achieved by using a narrow microstrip-line-fed and a grounded T-shaped conductor line. The return losses and radiation patterns of the antenna at the fundamental and harmonic frequencies are measured and compared to those of the conventional T-shaped slot antenna. Equivalent circuit models are also presented to give physical insight into harmonic suppression mechanism.**

***Index Terms*—Equivalent model, harmonic suppression, T-shaped slot antenna, wideband.**

I. INTRODUCTION

ACTIVE integrated antennas (AIAs) in which the active devices are integrated directly into antenna structure have been developed by the interest in the potential for sensor applications and spatial power combiner applications [1]. With the advantages of no-feed line losses especially at the high-frequency, low-power consumption, size and weight reduction, reliability enhancement, AIAs are getting much attention in the today's wireless communication system [1], [2].

In AIAs, the active nonlinear device can generate high level of harmonic radiations. Electromagnetic interference which is caused by harmonic radiations degrades the system performance. To overcome this problem, a band stop filter between active device and antenna can be used. But this technique increases the total size, insertion loss, and fabrication cost. A better way to solve this problem is to make a harmonic suppression antenna which can suppress harmonic radiations. A kind of this technique uses conductor lines connected with ground plane inserted in the slot antennas [2]. But these conductor lines are only applied for narrow band antenna. For wideband application, a T-shaped wideband slot antenna is used, and a U shaped conductor line connected with ground in the rectangular slot to make an *L–C* resonator for filtering out harmonic frequency [3]. Although the comparison results between the simulation and measurement are shown, those papers did not include results from their equivalent circuit model.

This paper proposes a novel T-shaped wide-slot harmonic suppression antenna. Its return losses and radiation patterns are compared to those of the conventional T-shaped slot antenna. The proposed antenna is validated to suppress the second and the third harmonics. Harmonic suppression mechanism is exposed by equivalent circuit model, so it can be easily applied to other wide-slot antennas.

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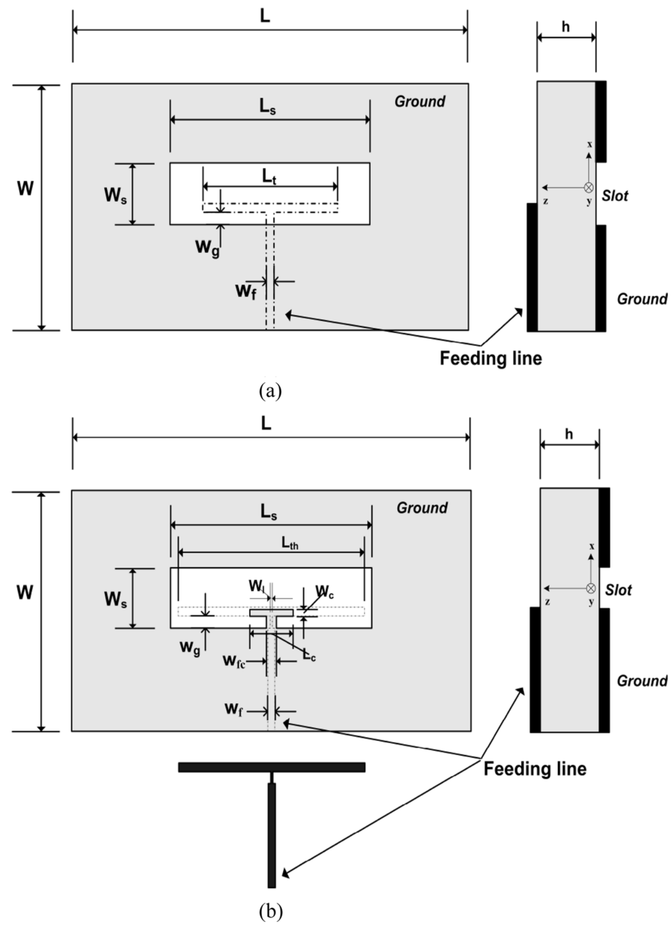

Fig. 1. (a) The conventional T-shaped slot antenna. (b) The proposed T-shaped harmonic suppression antenna.

TABLE I
PHYSICAL PARAMETERS OF THE PROPOSED ANTENNAS

Parameters	Values (mm)	Parameters	Values (mm)	Parameters	Values (mm)
h	0.508	W_g	2.2	W_l	0.4
L_s	40	W_f	1.56	L_c	8.6
W_s	11	L	100	W_c	1.2
L_t	27	W	91.14		
L_{th}	37	W_{fc}	2		

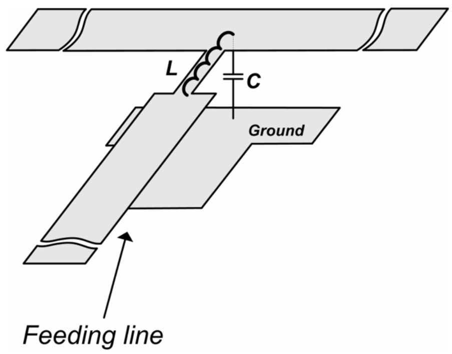

Fig. 2. Harmonic suppression structure of input feedline region.

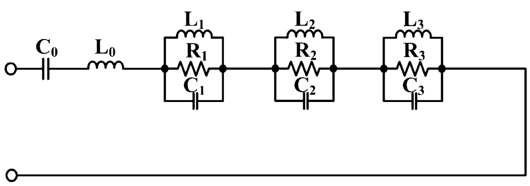

Fig. 3. Parallel resonant circuit model of the conventional antenna with $C_0 = 2.85$ pF, $L_0 = -0.22$ nH, $L_1 = 431$ pH, $C_1 = 7.75$ pF, $R_1 = 39\ \Omega, L_2 = 775$ pH, $C_2 = 1.715$ pF, $R_2 = 39\ \Omega, L_2 = 134$ pH, $C_2 = 1.075$ pF, $R_2 = 48.25\ \Omega$.

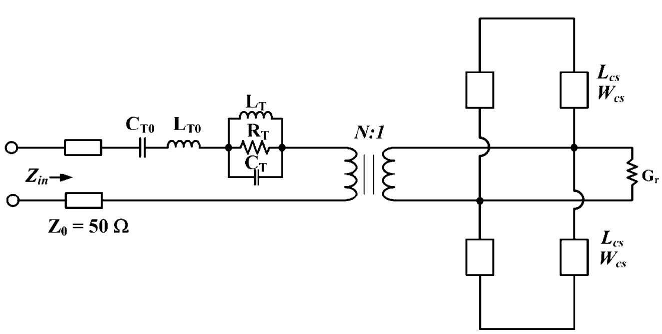

Fig. 4. Transmission line model of the conventional antenna with $C_{T0} = 2.85$ pF, $L_{T0} = -0.22$ nH, $L_T = 775$ pH, $C_2 = 1.715$ pF, $R_2 = 39\ \Omega, L_2 = 775$ pH, $N = 0.446, G_r = 1/195\ \Omega, W_{cs} = 0.35$ mm. $L_{cs} = 20$ mm, $\varepsilon_r = 2.2$.

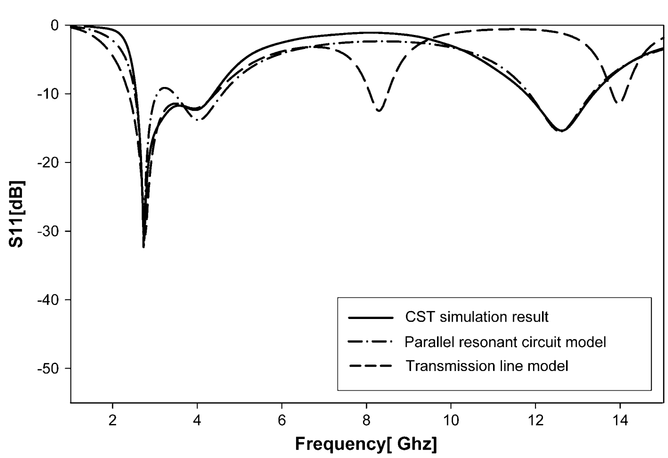

Fig. 5. Return losses of equivalent circuit models of the conventional antenna.

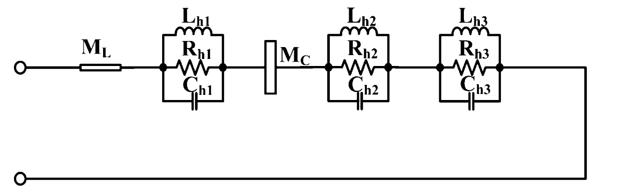

Fig. 6. Equivalent circuit of the harmonic suppression antenna with $L_{h1} = 620$ pH, $C_{h1} = 6.5$ pF, $R_{h1} = 40\ \Omega, L_{h2} = 830$ pH, $C_{h2} = 1.5$ pF, $R_{h2} = 37\ \Omega, L_{h3} = 134$ pH, $C_{h3} = 1.075$ pF, $R_{h3} = 4\ \Omega, \varepsilon_r = 2.2$.

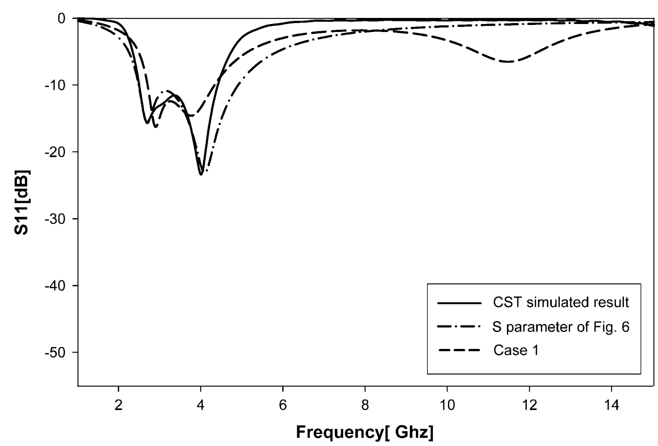

Fig. 7. Return losses of equivalent circuit model of the harmonic suppression antenna.

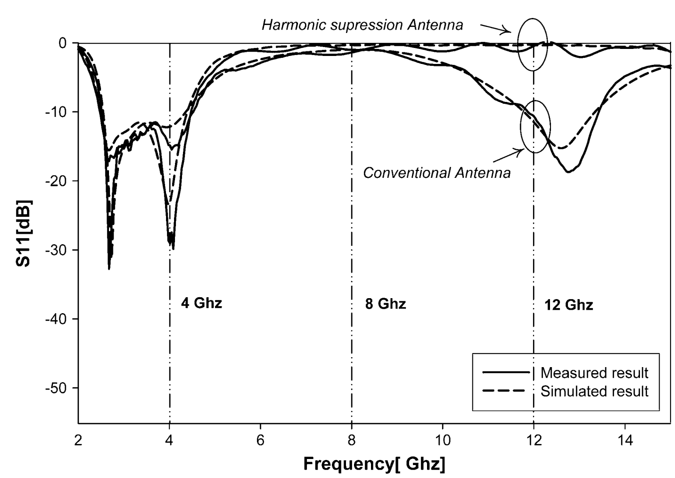

Fig. 8. The simulated and measured return losses of the proposed antennas.

II. Antenna Designs

Fig. 1 shows the layouts of the conventional T-shaped slot antenna and the proposed T-shaped slot harmonic suppression antenna. These antennas are fabricated on the high frequency substrate D5880 with 0.5-oz copper, 0.508 mm height, and dielectric constant (ε_r) of 2.2. The physical parameters of both the proposed antennas shown in Fig. 1 (a) and (b) are listed in Table I.

In order to get wider bandwidth compared to the conventional microstrip-line-fed slot antenna, a T-shaped microstrip-line-fed slot antenna is employed [4]. The width of the T-shaped microstrip-line-fed is 1.56 mm which is the same as the width of a 50 Ω microstrip feed line. To obtain harmonic

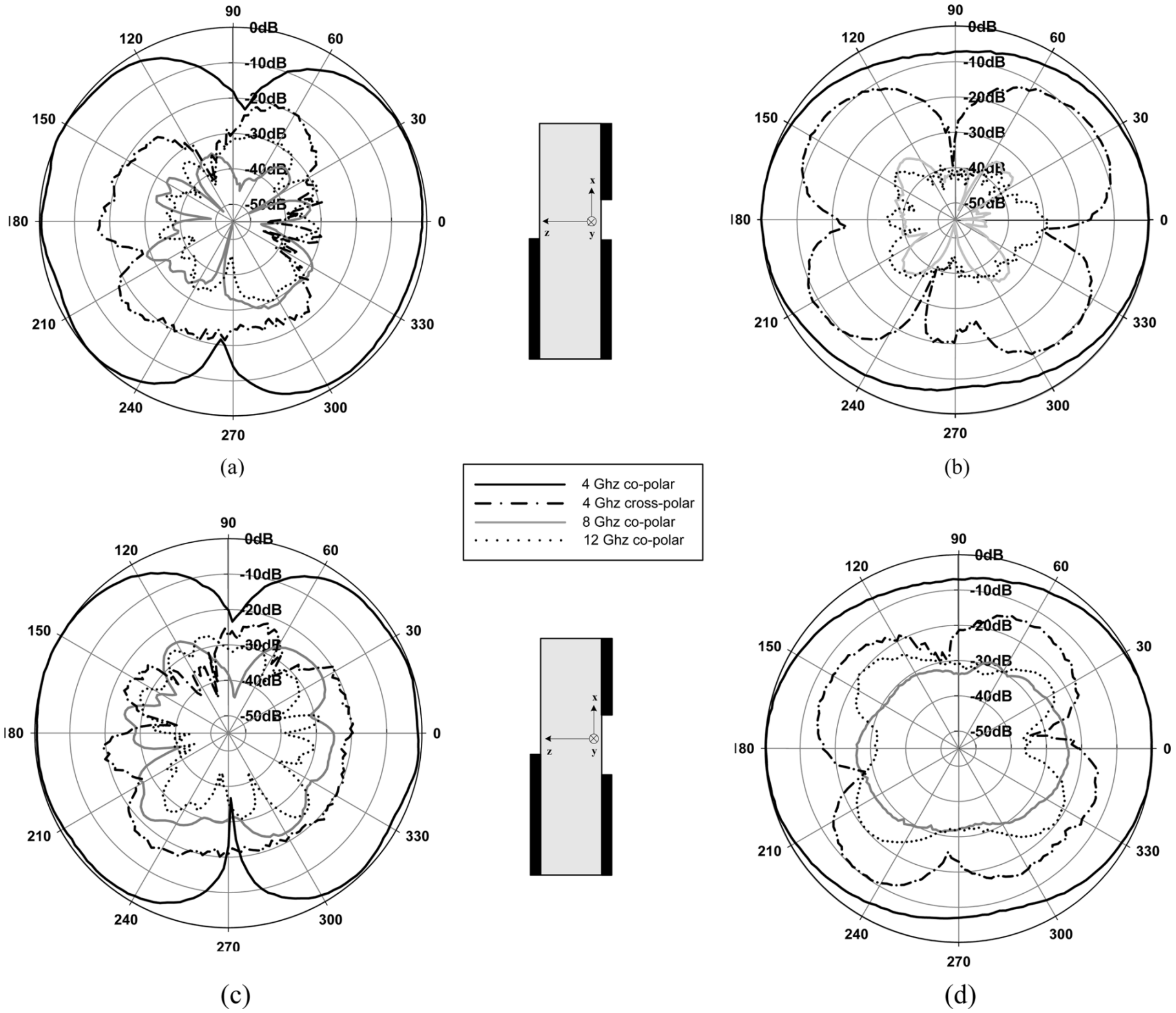

Fig. 9. Measured radiation patterns of the proposed antennas. (a) xz-plane of the harmonic suppression antenna, (b) yz-plane of the harmonic suppression antenna, (c) xz-plane of the conventional antenna, and (d) yz-plane of the conventional antenna.

suppression, a narrow microstrip-line-fed W_1 and T-shaped conductor line which is connected with ground is used. The narrow microstrip-line-fed W_1 is modeled as inductance L and the gap between T-shaped conductor line and T-shaped microstrip-line-fed is modeled as a metal-insulator-metal capacitor C as shown in Fig. 2. The narrow microstrip-line-fed W_1 is also used to adjust input impedance of the antenna to get wide bandwidth. The T-shaped microstrip-line-fed length L_{th} of the harmonic suppression antenna is approximately equal to the T-shaped microstrip-line-fed length L_t plus capacitor length L_c. It means that the physical length of T-shaped microstrip-line-fed L_{th} is shorted by coupling with the ground to make capacitor.

III. EQUIVALENT MODEL

The equivalent circuit of the T-shaped wide-slot harmonic suppression antenna can be modeled based on the transmission line model [5] or parallel resonant circuit model [6]. The former seems can provide better physical insight of the antenna behavior but only in a short frequency range, while the latter can be used to model the proposed antenna in any frequency range. As seen in Figs. 3 and 4, this paper proposes two equivalent circuits for modeling the conventional T-shaped slot antenna shown in Fig. 1(a).

The T-shaped microstrip-line-fed acts like a monopole antenna that contributes the second resonant frequency at 4 GHz. Thus, it can be modeled like a parallel resonant circuit, which is represented as the parallel R_2, L_2, C_2 model in Fig. 3 and as the parallel R_T, L_T, C_T model in Fig. 4. The rectangular slot contributes the first resonant frequency at 2.7 GHz so it can be model as a parallel resonant circuit R_1, L_1, C_1 in Fig. 3, or it can be modeled in Fig. 4 as two short circuit microstrip lines with the length $L_{cs} = 20$ mm which is equal to the half length L_s of the rectangular slot. The width of the two short circuit microstrip line is optimized to achieve good agreement with CST simulation result. The series inductor L_{T0}, L_0 (same values) and serias capacitor C_{T0}, C_0 (same values) are used to model the discontinuity from microstrip line to T junction monopole antenna. In transmission line model, the magnetic coupling between the T-shaped microstrip-line-fed and rentangular slot can be envisaged as a transformer with turn ratio $N : 1$. The ADS simulated results of the two equivalent models of Fig. 1(a) are also shown in Fig. 5.

In order to model the equivalent circuit of the harmonic suppression antenna for the case of Fig. 1(b) covering a large frequency range from 1 to 15 GHz, the parallel resonant circuit model is used [6]. Fig. 6 shows the proposed equivalent circuit model. The $\mathrm{M_L}$ and $\mathrm{M_C}$ are microstrip lines having the width and the length $\mathrm{W_1 \times W_g}$ and $\mathrm{L_c \times W_c}$, respectively, which are used to model the inductor L and capacitor C in Fig. 2. As seen in Fig. 7, the line Case 1 is the simulated result of equivalent circuit model of Fig. 6 topology when three resonant circuits have the same value with those of Fig. 3. It means that the microstrip filter $\mathrm{M_L}$ and $\mathrm{M_C}$ does not provide enough suppression at the third harmonic frequency. In order to model the third harmonic resonance suppressed completely, the resistance $\mathrm{R_{h3}}$ must be reduced near to zero while the $\mathrm{L_{h3}}$ and $\mathrm{C_{h3}}$ are keep constant compared to $\mathrm{L_3}$ and $\mathrm{C_3}$ of Fig. 3. Furthermore, to get better agreement with the CST result, $\mathrm{R_{h1}, L_{h1}, C_{h1}, R_{h2}, L_{h2}, C_{h2}}$ must be changed compared to $\mathrm{R_1, L_1, C_1, R_2, L_2, C_2}$. We can see that the harmonic suppression structure changes the radiation resistance of the slot antenna at the third harmonic frequency dramatically.

IV. Results

Both the conventional T-shaped slot antenna and harmonic suppression antenna have bandwidth about 2 GHz with -10 dB return loss, which is 50% bandwidth at the center frequency of 4 GHz. The return losses of both antennas which are simulated by CST Microwave Studio and measured by Network Analyzer Anritsu 37377C are shown in Fig. 8. The bandwidth does not change when the harmonic suppression structure is attached into the slot. The size of the harmonic suppression antenna is the same as that of the conventional slot antenna.

Next the radiation patterns of both antennas at the fundamental, second and third harmonic frequencies are measured. They are shown in Fig. 9. The copolarization radiation patterns of both antennas at the fundamental frequency are similar to each other and comparable to a simple slot antenna. The cross polarization level in H plane pattern at the fundamental frequency of harmonic suppression antenna increases because some of the unwanted higher order modes excite when the harmonic suppression structure was inserted into the slot. The second and third harmonic radiations of harmonic suppression antenna are less than -30 dB. It means that the radiation patterns at the harmonic frequencies are almost suppressed.

The measured and simulated maximum gains of the harmonic suppression antenna are 4.5 dBi and 4.56 dBi, respectively. Those of the conventional antenna are 4.8 dBi and 4.72 dBi, respectively. The measured maximum gains of the harmonic suppression antenna at the second and the third harmonic frequencies are -23.9 and -24.5 dBi, while those of the conventional antenna are -16.8 and -15.4 dBi, respectively.

V. Conclusion

In this work, a T-shaped slot antenna with harmonic suppression characteristic over the second and third harmonic frequencies has been proposed. The return losses were very high at the second- and third-harmonic frequencies compared to those of the conventional slot antenna. Since the principal of suppressing harmonic radiations here is analyzed by equivalent circuit model, it will be easy to apply to other wide band slot antennas while retaining the basic size and bandwidth.

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