Impedance Characteristics of Microstrip Antennas Excited by Coplanar Waveguides with Inductive or Capacitive Coupling Slots

Sheng-Ming Deng, Ming-Dong Wu, and Powen Hsu, *Member, IEEE*

***Abstract*—A rectangular microstrip antenna fed by a coplanar waveguide with an inductive or a capacitive coupling end slot is analyzed by using the moment method. Numerical calculations for the input impedances are shown to agree well with those of the measurements. For the purpose of design, a parameter study for the variations of input impedance with length and width of the coupling slot is presented. Differences in the input impedance characteristics between the inductive and capacitive coupling cases are also discussed.**

I. Introduction

COPLANAR waveguides have been suggested as an alternate to microstripline for feeding the microstrip antenna [1], [2], and they have been used increasingly in the design of millimeter-wave microstrip antennas. In a coplanar-waveguide-fed microstrip antenna, the antenna and the coplanar line are placed on the opposite sides of the same dielectric substrate and the coupling from the coplanar line to the microstrip antenna is accomplished via a slot in the ground plane connected directly to the end of the coplanar line. The coupling slot can be a simple open end [1], [2] or a slot with inductive or capacitive coupling [3]. For the simple open end slot, the slot length is fixed; whereas for the inductive or capacitive coupling slot, the slot length can be adjusted to achieve a good input match of the antenna, and hence it is more attractive to the antenna designers. Both experimental and theoretical investigations on the simple open end slot case have been presented [2], [4]. So far, however, there is only one experimental work [3] published for the inductive and/or capacitive coupling slot case. No information on the theoretical investigation of the impedance characteristics for this case has been presented. Thus, we show in this letter the analysis results for the input impedances of the coplanar-waveguide-fed microstrip antenna with inductive and/or capacitive coupling slot. Experimental results are also shown to agree well with our numerical calculations.

II. Method of Analysis

The antenna configurations under study are shown in Fig. 1. A rectangular microstrip patch is placed on one side of the substrate, while a slot fed by a coplanar line is arranged opposite to the patch in the ground plane on the other side of the substrate. For the inductive type of feeding [Fig. 1(a)], the inner conductor of the coplanar line is connected across

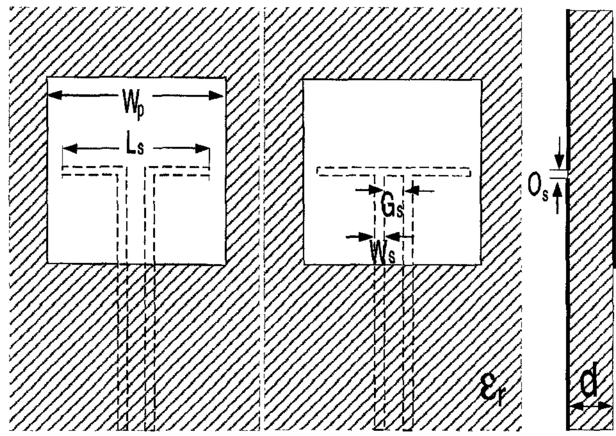

Fig. 1. Configuration of coplanar-waveguide-fed microstrip antenna with (a) inductive and (b) capacitive coupling slot.

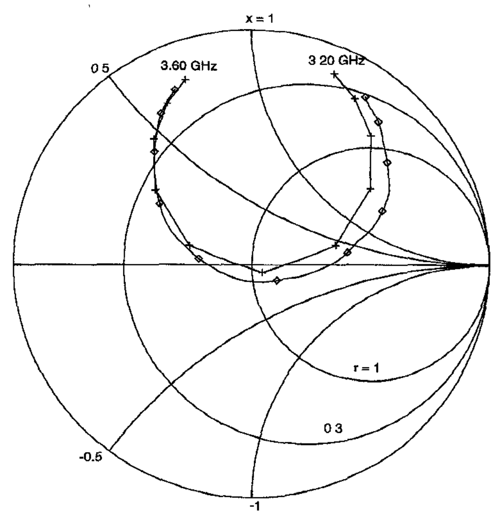

Fig. 2. Normalized input impedance of the microstrip antenna with inductive coupling slot. Frequency increases clockwise with step of 0.04 GHz. $L_p = 25$ mm, $W_p = 36$ mm, $G_s = 3$ mm, $W_s = 0.3$ mm, $\varepsilon_r = 2.5$, $d = 1.58$ mm, $L_s = 15.2$ mm, and $O_s = 2$ mm. —◇—: Experiment. —+—: Theory.

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The authors are with the Department of Electrical Engineering, National Taiwan University, Taipei, Taiwan 10617, R.O.C.

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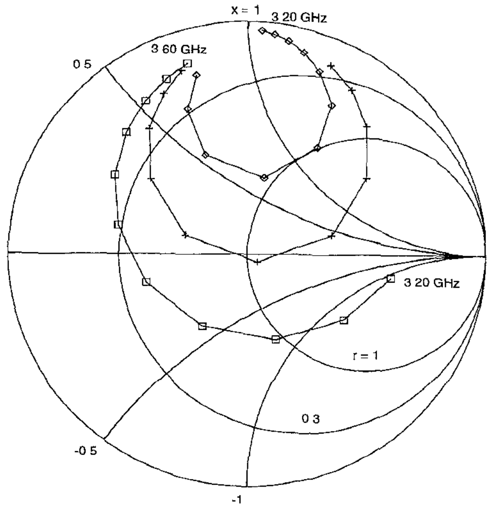

Fig. 3. Variaton of input impedance with length of coupling slot L_s for inductive coupling case. Frequency increases clockwise with step of 0.04 GHz. Parameters used are the same as those in Fig. 2 except L_s is varying. —◇—: $L_s = 12.0$ mm —+—: $L_s = 15.2$ mm —□—: $L_s = 18.0$ mm.

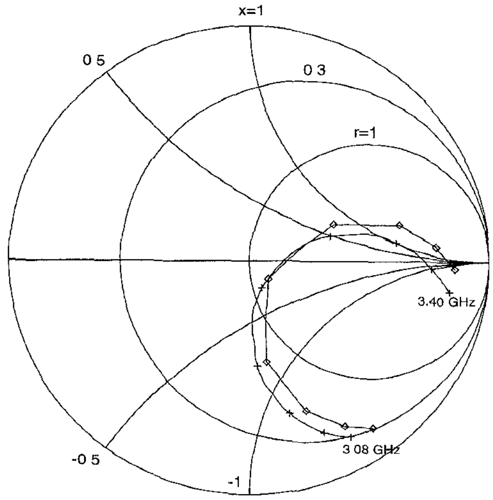

Fig. 5. Normalized input impedance of the microstrip antenna with capacitive coupling slot. Frequency increases clockwise with step of 0.04 GHz. Parameters used are the same as those in Fig. 2 except $L_s = 14.4$ mm —+—: Experiment. —◇—: Theory.

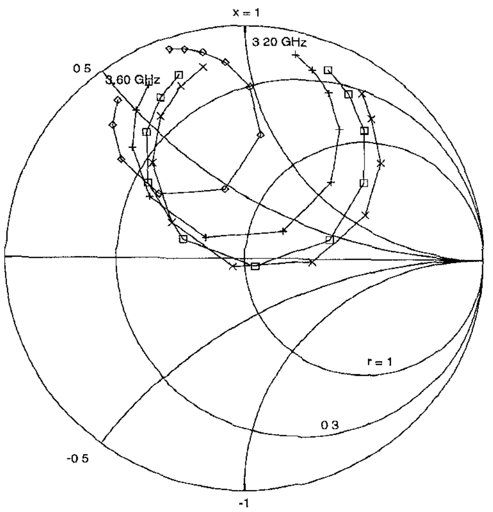

Fig. 4. Variaton of input impedance with width of coupling slot O_s for inductive coupling case. Frequency increases clockwise with step of 0.04 GHz. Parameters used are the same as those in Fig. 2 except O_s is varying. —◇— $O_s = 1.0$ mm. —+—: $O_s = 1.5$ mm. —□—; $O_s = 2.0$ mm. —x—: $O_s = 2.5$ mm.

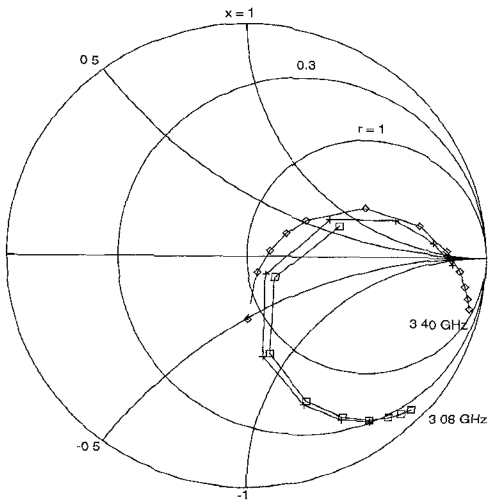

Fig. 6. Variaton of input impedance with length of coupling slot L_s for capacitive coupling case. Frequency increases clockwise with step of 0.04 GHz. Parameters used are the same as those in Fig 5 except L_s is varying. —□—: $L_s = 12.0$ mm. —+—: $L_s = 14.4$ mm. —◇—· $L_s = 16.8$ mm.

the slot, whereas for the capacitive type of feeding [Fig. 1(b)], the inner conductor is disconnected by the slot [3].

The theoretical analysis is based on the solution of integral equations solved in the spectral domain by the method of moments. Since this analysis is just a slight modification of the method proposed for the simple open end slot case [4], the details will not be included here. The modification is in the modeling of the slot magnetic current, which should be extended to cover the entire length of the slot. The magnetic current densities in the coupling slot and in the slots of the coplanar waveguide near the discontinuous end are expanded by the subsectional roof-top basis functions, while the electric current density on the microstrip patch is expanded in a set of entire domain basis functions. Only the fundamental mode is assumed propagating on the slots of the coplanar waveguide away from the coupling slot. Using the suitable Green's functions [2], [5], [6] and the numerical technique described in [4] for a fast and accurate solution, the Galerkin testing procedure is then employed on the patch and the slot to determine the reflection coefficient and hence the input impedance of the antenna.

III. Results and Discussions

In the following investigations, the antenna patch is placed centered about the center of the coupling slot, and the input impedances of the antenna are calculated and measured referenced to the end of the coplanar waveguide (or the input of the coupling slot). With the parameters defined in Fig. 1, we use $L_p = 25$ mm, $W_p = 36$ mm, $G_s = 3$ mm, $W_s =$

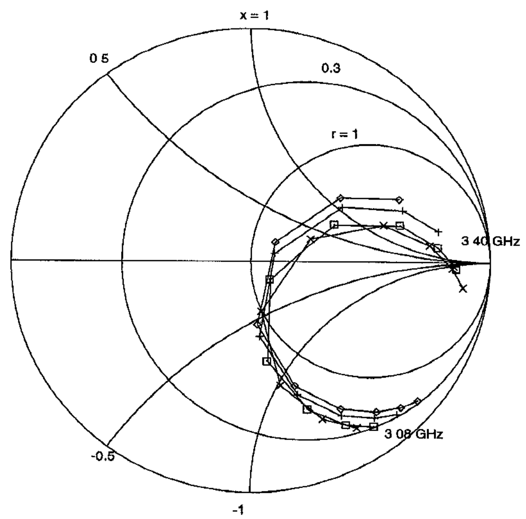

Fig. 7. Variaton of input impedance with width of coupling slot O_s for capacitive coupling case. Frequency increases clockwise with step of 0.04 GHz. Parameters used are the same as those in Fig. 5 except O_s is varying. —◇—: $O_s = 1.0$ mm. —+—: $O_s = 1.5$ mm. —□—: $O_s = 2.0$ mm. —×—: $O_s = 2.5$ mm.

0.3 mm, $\varepsilon_r = 2.5$, and $d = 1.58$ mm in all the numerical calculations. First, we investigate the inductive coupling case. The theoretical and experimental input impedances for $L_s = 15.2$ mm and $O_s = 2$ mm are plotted and compared in Fig. 2. The experiment is performed using HP8510B network analyzer with TRL (through-reflect-line) calibration technique. From the loci of the input impedances, Fig. 2 shows a good agreement between theory and experiment and reveals the inductive nature (positive reactance) of the coupling slot. The resonant frequencies defined at the minimum reflection for theory and experiment are 3.40 and 3.412 GHz, respectively, and the antenna bandwidths defined for VSWR ≤ 2 are 2.53 and 2.57% for theory and experiment, respectively.

For design purpose, it is important to discuss the input impedance characteristics of the antenna with different length L_s and width O_s of the coupling slot. The variations of the input impedance with L_s and O_s for the inductive coupling case are calculated and plotted in Figs. 3 and 4, respectively. It is found that the input impedance is very sensitive to the length and width of the coupling slot.

For the capacitive coupling case, the comparison between theoretical and experimental input impedances is presented in Fig. 5, and the variations of input impedances with L_s and O_s are shown in Figs. 6 and 7, respectively. Again, a good agreement between theory and experiment is obtained in Fig. 5, in which the capacitive nature (negative reactance) of the coupling slot is revealed. By comparing Fig. 6 to Fig. 3 and Fig. 7 to Fig. 4, it is interesting to find that the change with L_s and O_s for the capacitive coupling case is mainly in the shift of the resonant frequency (rotation of frequency point in the impedance locus circle), the values of the input impedances are less sensitive to L_s or O_s than those in the inductive coupling case. This means that, for a fixed design frequency, it is possible to find an L_s and an O_s for the input match of the antenna without changing the patch dimensions in the inductive coupling case, whereas in the capacitive coupling case, it is difficult to do so. Here, the patch dimensions are calculated beforehand from the moment method analysis for simple open end slot case [2], [4]. Notice that in an actual design, the widths of the strip (G_s) and slot (W_s) of the coplanar waveguide should also be considered, since they affect the input impedance calculations.

IV. Conclusion

Input impedance characteristics of the microstrip antennas fed by coplanar waveguides with inductive or capacitive coupling slots have been investigated by using the method of moments. The agreement between theory and experiment has been shown, and the differences in impedance characteristics between the inductive and capacitive coupling cases have been discussed. This should be helpful to the antenna designers.

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