A-4-1 THEORY AND EXPERIMENT ON MICROSTRIP ANTENNAS

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INTRODUCTION - Microstrip devices have widely been used as microwave circuit elements, such as transmission lines, filters, resonators, etc. The successful operation of, for example, the microstrip resonators seems to suggest that basically they are poor radiators. Despite this weakness, microstrip antennas have received much attention in recent years [1]-[6] because of their many unique and attractive properties - low in profile, light in weight, compact and comformable in structure, and easy to fabricate and to be integrated with solid state devices. They are superior to the conventional flushmount antennas in that they are truly "thin" antennas, requiring no cavity backing. There seems to be little doubt that they will find many applications in practice in much the same manner as in the modern hi-fi systems where the inefficiency of small speaker systems is tolerated whenever the compactness is of major concern. Likewise, the shortcomings can perhaps be compensated for as more new compact efficient solid-state devices are developed.

A few short papers, appearing in recent years, are concerned mainly with the experiments to demonstrate many design possibilities of the microstrip antennas. A general rigorous theory for this new family of antennas appeared to be very involved [7]. In view of the success in treating these type of structures as cavities in microstrip circuits, a simple theory based on the cavity model was advanced [7]. With this theory, almost all the properties of microstrip antennas of various geometries can be explained and predicted.

MODEL THEORY - A theoretical model for the microstrip antennas is based on the following observations:

(a) The close proximity between the microstrip antenna and the ground plane (see Figure 1) suggests that $\underset{\sim}{E}$ has only the z-component and $\underset{\sim}{H}$ has only the xy-components in the region bound by the microstrip and the ground plane.

(b) The field in the aforementioned region is independent of the z-coordinate for all frequencies of interest.

(c) The electric current in the microstrip must have no component normal to the edge at any point on the edge, implying a negligible tangential component of $\underset{\sim}{H}$ along the edge.

The region between the microstrip and the ground plane can, therefore, be treated as a cavity bounded by a magnetic wall along the edge and by electric walls from above and below. Obviously, such a closed cavity would radiate no power and have purely reactive input impedance of either zero or infinite value at resonance. However, one may assume that the field structure in the microstrip antenna is essentially the same as that in the cavity.

From this, one can compute the radiation pattern, the total radiated power, and the input admittance at any feed point.

For the cavity model stated above

$$\underline{E}_m = \psi_m \hat{z}, \; \underline{H}_m = \hat{z} \times \nabla_t \psi_m / j\omega\mu \qquad (1)$$

$$(\nabla_t^2 + k_m^2)\psi_m = 0 \qquad \text{with } \frac{\partial \psi_m}{\partial n} = 0 \text{ on the magnetic wall C.} \qquad (2)$$

where ∇_t is transverse part with respect to the z-axis of the del-operator. This problem is identical to a cylindric waveguide at cut-off frequency. In fact, the field solution is exactly the dual of TE modal fields of an ordinary guide (i.e., one with electric wall) at cut-off.

EXCITATION AND RESULTS - When a microstrip antenna is fed with a strip line or cable at any frequency, in general, many modal waves are excited. There are several possible representations for the field in terms of the modal fields [7]. In this paper, only two convenient ones will be discussed: by modal matching and by resonant mode expansion.

Measurements and theoretical computations were made for numerous microstrip antennas of various geometries, dimensions, and with various methods of feeding. All the antennas were made of copper-clad 1/16" thick Rexolite 2200 with relative permittivity 2.62 and loss tangent approximately 0.001. A few typical results are given in Figures 1-5. In general, the impedance characteristics follow closely a circle in the Smith Chart plot, except for the nearly degenerate case. It can be shown that the center of the circle lies off the real axis in the inductive side. For nearly degenerate case, the impedance behavior near resonance differs drastically from a circle. Other interesting results will also be discussed.

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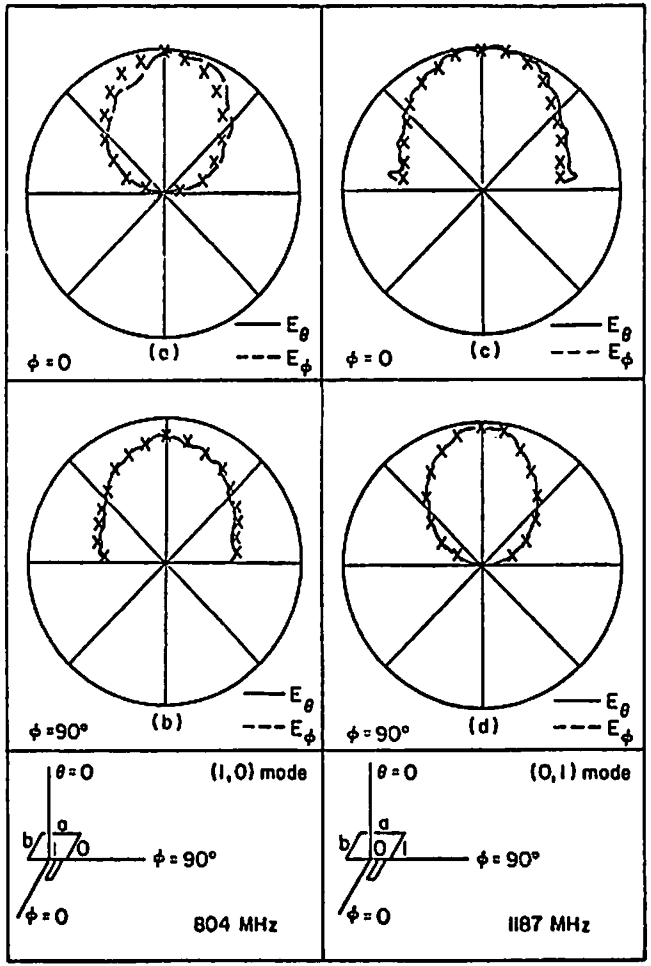
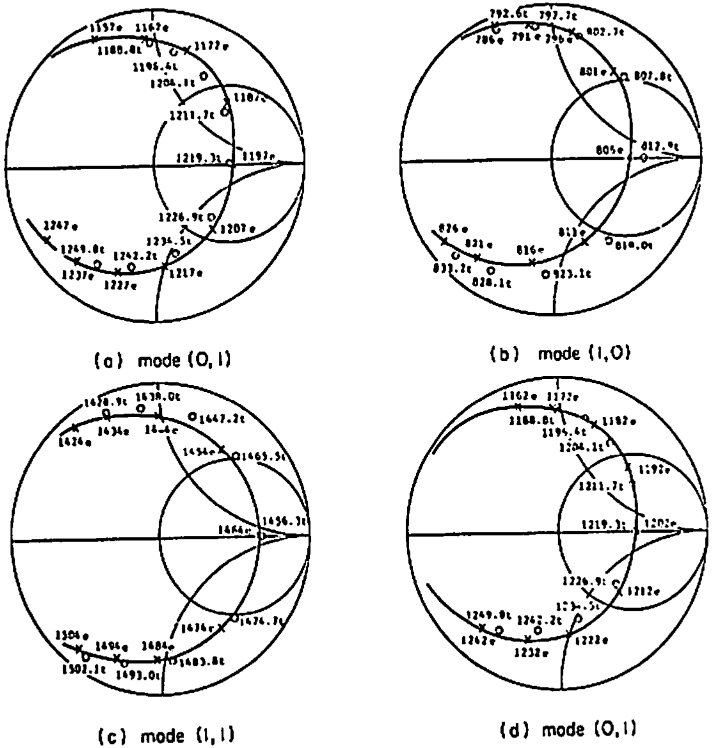


Fig. 1. Radiation patterns in $\phi=0^{\circ}$ and 90° planes of a rectangular microstrip antenna with a=11.43 cm, b=7.62 cm, fed off-center (---) Exp. (xxx) Theory.



(a) mode (0,1)

(b) mode (1,0)

(c) mode (1,1)

(d) mode (0,1)

Fig. 2. Impedance loci of the antenna shown in Fig. 1, except for (d) which is center-fed.
(e, xxx) Exp. (t, ooo) Theory.

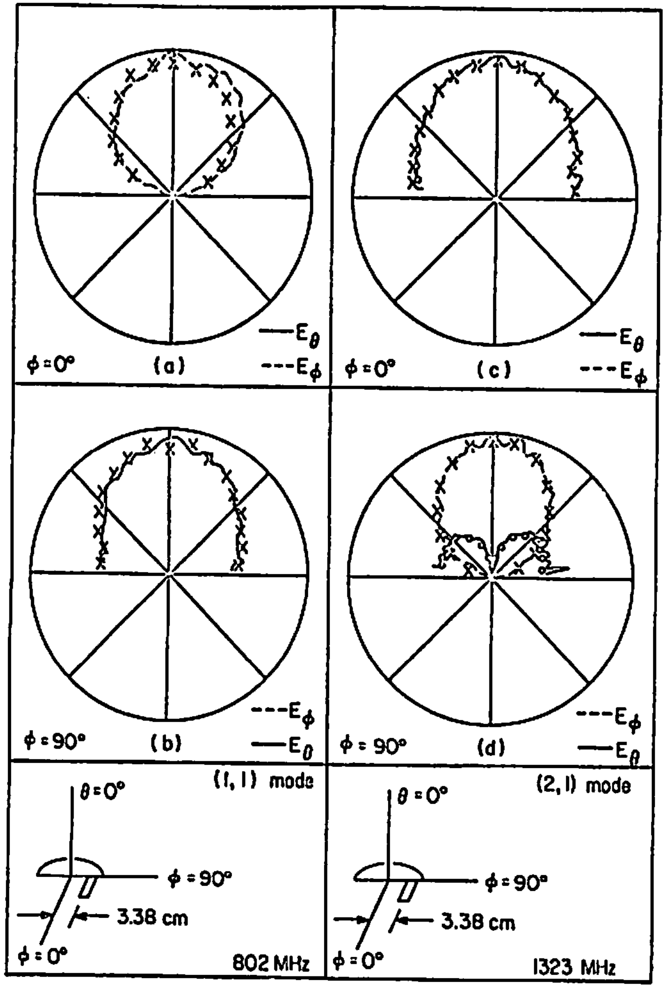
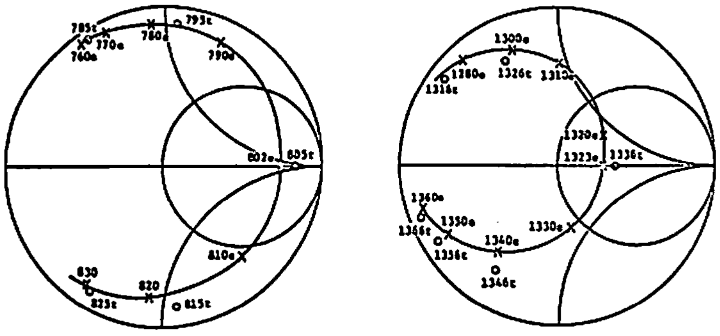


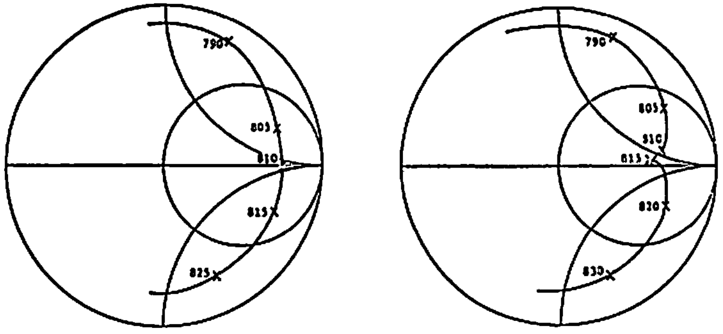
Fig. 3. Radiation patterns in ϕ=0° and 90° planes of a semi-circular microstrip antenna with radius 6.75 cm. ($\frac{\text{———}}{\text{- - -}}$) Exp. ($\frac{\text{xxx}}{\text{ooo}}$) Theory.



(a) mode (1,1)

(b) mode (2,1)

Fig. 4. Impedance loci of antenna shown in Fig. 3 (e,xxx) Exp. (t, ooo) Theory.



a=11.30 cm b=11.30 cm

(a)

a=11.30 cm b=11.20 cm

(b)

modes (1,0) and (0,1)

Fig. 5. Impedance loci of two corner-fed square microstrip antennas (a) degenerate case, a=b=11.30 cm; (b) slightly degenerate case, a=11.30 cm; b=11.20 cm.