ADAPTIVE PATTERN CONTROL OF A REACTIVELY LOADED, DUAL-MODE MICROSTRIP ANTENNA

William F. Richards and Stuart A. Long
Department of Electrical Engineering
University of Houston-University Park
Houston, Texas 77004

ABSTRACT

A dual mode microstrip antenna element has been investigated which has two independently excitable modes resonant at the same frequency. This element has been shown to be capable of producing a broadside maximum, a broadside null, or an end-fire type pattern by suitable choice of its reactive loads and suitable excitation of its degenerate modes. Appropriately located loads can be used to resonate modes normally resonant at quite different frequencies, at a single, common frequency. The results indicate that the nodal lines of the loaded element are accurately predicted by the generalized theory of loaded microstrip antennas, and that two modes can be excited independently of each other by feeding each mode along the nodal line of the other. To verify the theoretical predictions an actual dual mode microstrip element was fabricated and tested. The results of this experiment correlate well with the theoretical model with respect to the overall characteristics of the radiator.

INTRODUCTION

In recent years, microstrip antennas have found an increasing number of applications as the radiating element in a wide variety of systems. Their inherently attractive characteristics such as conformability, low cost, ruggedness, and limited profile, have produced the desire to use these elements in circumstances where radiation patterns other than a simple broadside one is required. In widely scanning arrays it would be further advantageous if the pattern could be adoptively controlled in some fashion. With these goals in mind, a dual-mode microstrip antenna has been designed which can provide a variety of different radiation patterns by appropriately positioning reactive loads and appropriately exciting degenerate modes the degenerate modes that result. A common limitation with the use of standard microstrip elements in phased arrays is the inability to scan toward angles near the plane of the radiator. One reason for this limitation is that the basic radiator has a broadside pattern with most of the power being radiated normal to this plane. The modified element proposed here could be used for large scan angles and could therefore be quite valuable.

THEORY

The pattern of a microstrip radiator can basically be controlled by modifying the patch-edge magnetic current (voltage distribution) by synthesizing a cavity mode that gives the desired current distribution. Unfortunately, the only degrees of freedom that are available with a typical patch design are the shape of the patch and the mode that is chosen to be excited. Furthermore, the resonant cavity mode is always real and so its phase cannot be controlled. Non-real magnetic current distributions can only be realized in cases where there are two or more degenerate modes.

Several circumstances can lead to a degeneracy of modes. First, symmetry in the shape of the patch can result in modes which are essentially identical except for a physical rotation about the broadside axis. This type of degeneracy has been used previously for polarization control[1,2,3]. Widespread examples include the nearly square and slightly elliptical patches used to produce circular polarization. Degeneracies can also arise between pairs of higher order modes, but practical applications of this type have not been reported. This present work is concerned instead with the use of two lower order modes. The resonant frequency of the so-called DC mode (which consists simply of a constant electric field between the patch and the ground plane) was forced upward to coincide with that of the commonly used (0,1) mode of a rectangular patch antenna. This DC mode produces maximum fields in the plane of the radiator much like that of a monopole above a ground plane since its effective magnetic current is simply a constant value around the rectangular boundary of the patch. (Note that the latter comment is based on the assumption that the ground plane is infinite, and that the dielectric is truncated abruptly at the edge of of the patch element.) These two patterns can then be combined to theoretically produce a composite end-fire pattern or be used individually to provide major coverage either in the plane of the radiator or perpendicular to it.

The problem that must first be addressed is how to force the DC mode to resonate at the same frequency as the (0,1) mode. This can be accomplished by the addition of a capacitive load with a properly chosen position and value. Resonance will occur when the series sum of the resonant reactance of the cavity, the feed reactance, and the chosen load reactance is zero ($X_r + X_f + X_L = 0$)[4] . The behavior of each of these reactances as a function of frequency is shown in Fig. 1. The point where the curve of $-X_f - X_L$ crosses that of X_r gives the new value of resonant frequency for the (former) DC mode.

There are several other effects of this loading in addition to the increase in the resonant frequency. The magnetic current distribution is modified slightly, but for a load near the center of the patch the currents simply have a small oscillatory behavior about a mean value near that of the unloaded patch, the overall result of which is little change in the far field radiation pattern. This loading also creates a new nodal curve along which the electric field is zero. For the case of a centered load this locus is a circle centered about the position of the load. This curve can be quite useful in the isolation of the two modes in that the feed of the (0,1) mode can then be located there without exciting the DC mode.

DESIGN

These characteristics point toward the design of the radiator depicted in Fig. 2 which shows a square patch antenna reactively loaded at its center. The nodal curve for the loaded DC mode is shown by the dashed circle as well as the nodal lines for the (0,1) and (1,0) modes. The feed for the (0,1) mode is located on the nodal curve for the loaded DC mode as well as on the nodal line for the (1,0) mode. Similarily, the feed for the loaded DC mode is placed on the nodal line of the (0,1) mode. In addition, it must be fed in phase on both sides of the patch to avoid excitation of the (1,0) mode as well.

To illustrate the resulting isolation of the two modes, measurements of the input impedance at the (0,1) feed were made both with DC mode port open-circuited and short-circuited. A Smith chart representation of these data is shown in Fig. 3 as well as the reverse case for measurements made at the DC feed with the (0,1) port open- and short-circuited in Fig. 4.

The antenna shown in Fig. 2 was fabricated and its radiation patterns measured for various feed configurations. The pattern for the element just fed at the loaded DC port in the H-plane of the (0,1) mode is shown in Fig. 5. The characteristic features of a monopole over a finite ground plane are evident with a minimum field normal to the plane of the radiator and maxima at angles near the plane. Patterns taken with the element fed at the (0,1) node port exhibit typical microstrip antenna characteristics with a broad beam normal to the plane.

CONCLUSIONS

Both theoretical analysis and experimental measurements have confirmed the possibility of raising the usual DC mode of a microstrip patch radiator to the resonant frequency of the (0,1) dominant mode. Use of these two degenerate modes can then result in control of the radiation pattern in an adaptive fashion.

REFERENCES

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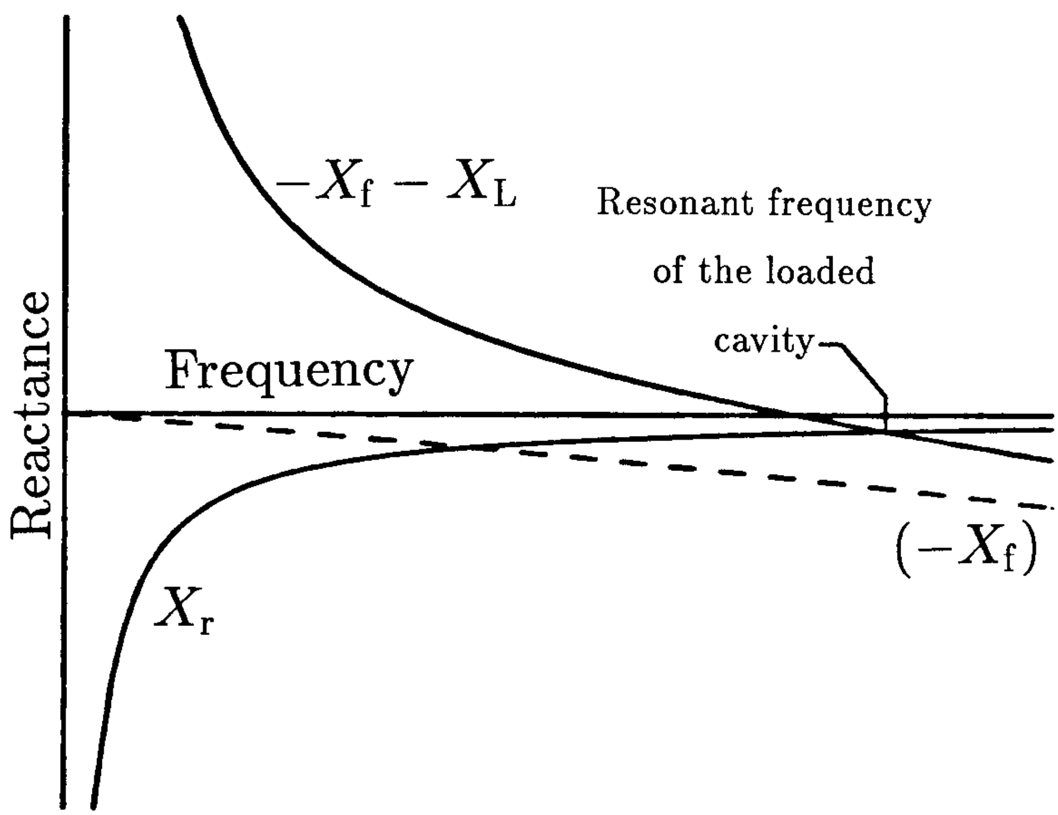

Fig. 1. Reactance components *versus* frequency for determining the resonant frequency of a loaded microstrip antenna.

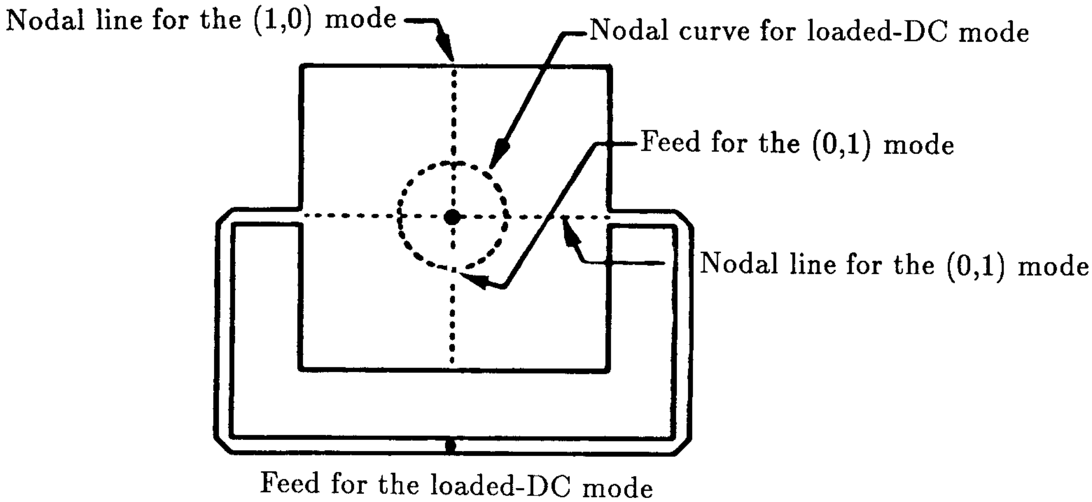

Fig. 2. Geometry of reactively loaded dual mode microstrip antenna.

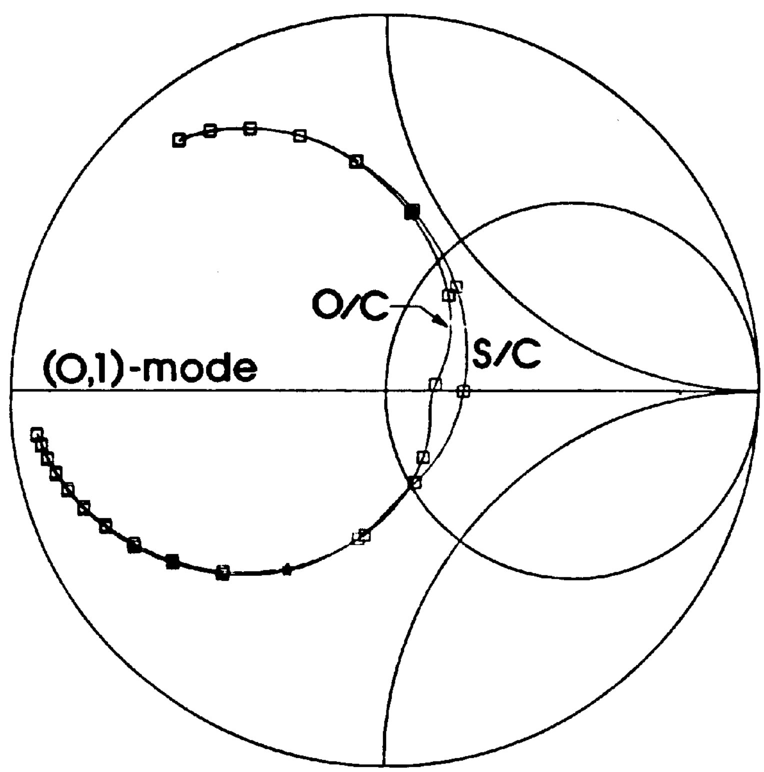

Fig. 3. Input impedance at the (0,1) port with the loaded DC port open and short circuited.

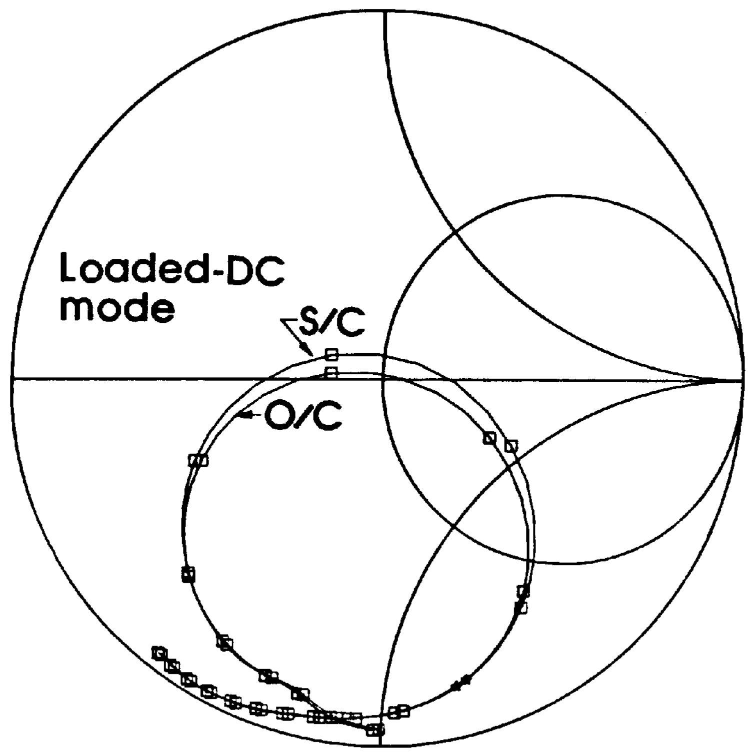

Fig. 4. Input impedance of the loaded DC port with the (0,1) mode port open and short circuited.

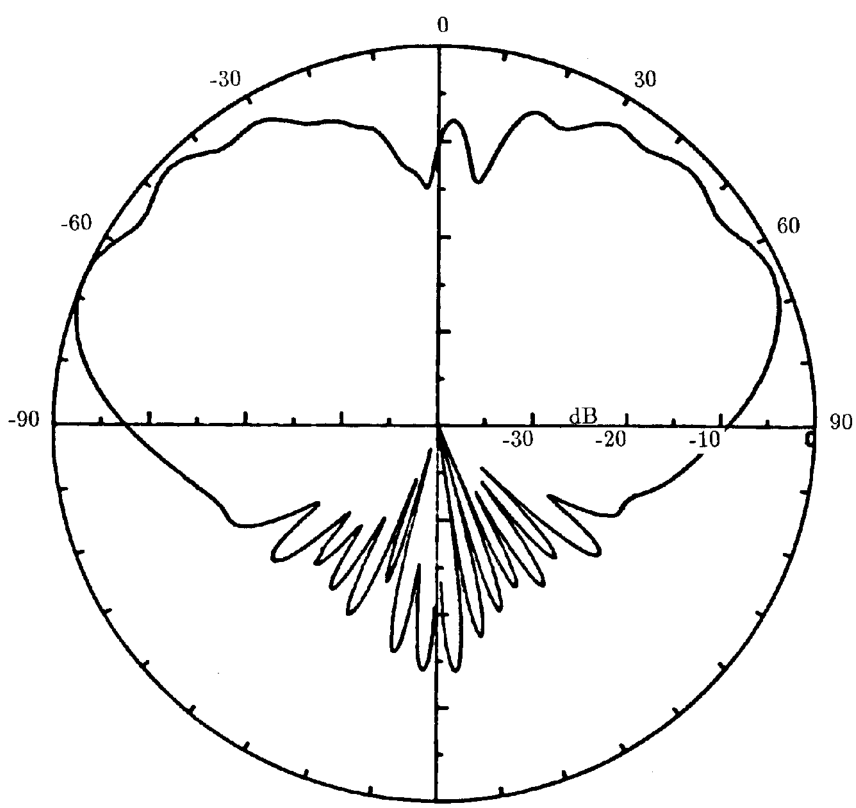

Fig. 5. E_θ radiation pattern for the loaded DC mode in the H-plane of the (0,1) mode.