Microstrip Antennas with Frequency Agility and Polarization Diversity

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Abstract—**A technique is investigated for controlling the operating frequency and polarization of microstrip antennas. The control is achieved by placing shorting posts at appropriate locations within the antenna's boundaries. By changing the number and locations of the posts, the operating frequency can be tuned over a 1.5-to-1 range, and the polarization can be changed from horizontal to vertical, right-hand circular, or left-hand circular. All of these changes are obtained without significantly altering the input impedance or radiation patterns of the antena and without increasing the complexity of the external microwave feed network. The frequency and polarization can be electronically controlled by using microwave switching diodes for the shorting posts. Antennas that have two feeds and operate simultaneously in two orthogonal polarizations have been constructed with the capability to switch between linear and circular polarization. Also, a thin frequency-scanned array has been built with the frequency-agile microstrip elements.**

I. INTRODUCTION

THE MICROSTRIP antenna has been shown to be an excellent radiator for many applications that require only a narrow bandwidth [1]-[5]. It is rugged and can be fabricated by using standard printed-circuit techniques. A single microstrip radiator has a moderately broad radiation pattern, but high-gain arrays suitable for space applications have been built [6].

In its simplest form, the microstrip antenna radiates linearly polarized signals over a bandwidth of one or two percent. However, by modifying the geometry of the basic antenna it is possible to obtain circularly polarized radiation [7], [8] or a shift in the operating frequency [9]. Since these techniques require permanent physical changes to the antenna they cannot be used to electronically modify or control the antenna's performance. Electronic control of the antenna's performance can be accomplished by means of varactors [10] or variable-length transmission lines [11]. However, varactors require a precise dc bias voltage, and switched-length transmission lines require space outside the basic microstrip antenna's boundaries. Both of these disadvantages can be overcome by using shorting posts (e.g., switching diodes) at appropriate points within the antenna's boundaries. By changing the number and locations of the shorting posts both the operating frequency and polarization of the microstrip antenna can be controlled. Also, Malagisi has shown that a phase-shifting reflector can be built by using circular microstrip elements with shorting posts [12]. Of course, all of the modifications that use diodes, capacitors, inductors, or shorting posts sacrifice the monolithic construction of the basic microstrip antenna. However, the additional capabilities of these modified antennas should offset the increased complexity of their fabrication.

The post-loading technique has been experimentally investigated by using machine screws as removable shorting posts. A single microstrip element has been made to radiate fields that are polarized horizontal linear, vertical linear, right-hand circular, or left-hand circular. Also, single elements and an eight-element array have been tuned to operate over a 1.5-to-1 range of frequencies. This frequency tuning is accomplished without the serious degradation of input impedance that was observed by Kernweis and McIlvenna [13]. A simple analytical model has been developed and used to generate useful design data for the post-loaded microstrip antennas.

II. FREQUENCY-AGILE ANTENNA

The operating characteristics of a typical rectangular-patch microstrip antenna are determined by the antenna's size and feed location and by the substrate permittivity. The antenna in Fig. 1, without the shorting posts, is a typical configuration designed for x-oriented linearly polarized radiation. The antenna operates at a fundamental frequency f_0,

$$f_0 \approx \frac{c}{2a\sqrt{\epsilon_r}}, \tag{1}$$

where the patch length a is approximately one-half wavelength in the dielectric. At this frequency the voltage and current distributions on the patch resemble those of an open-circuited microstrip transmission line with propagation in the $\pm x$ directions. The input impedance of the antenna is determined primarily by the patch width b and the feed location f [1], [14].

The addition of shorting posts along the centerline $y = b/2$ increases the operating frequency of the antenna. This frequency increase may be explained by considering the transmission-line model for the microstrip antenna [1], [15]. This model is depicted in Fig. 2, where Z_0 is the characteristic impedance of a microstrip line of width b on the substrate material. The length extensions Δl account for fringe-field reactance at the open-circuit ends, and the conductance G accounts for radiation from the ends. The formulas of Hammerstad [16] were used to calculate Z_0 and Δl, and Harrington's formula [17] for slot conductance was used for G:

$$Z_0 = \frac{377}{\sqrt{\epsilon_e}} \{b/t + 1.393 + 0.667 \ln (b/t + 1.444)\}^{-1} \tag{2}$$

$$\Delta l = 0.412t \, \frac{(\epsilon_e + 0.3)(b/t + 0.262)}{(\epsilon_e - 0.258)(b/t + 0.813)} \tag{3}$$

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2(1 + 10t/b)^{1/2}} \tag{4}$$

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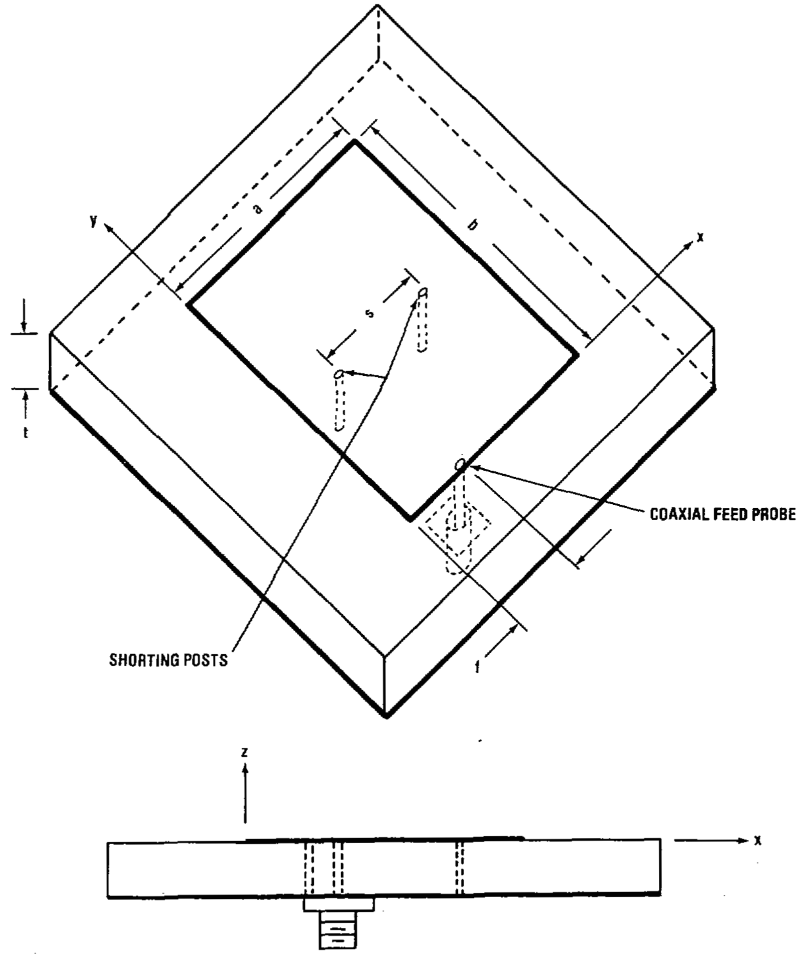


Fig. 1. Typical microstrip antenna with shorting posts for changing operating frequency.

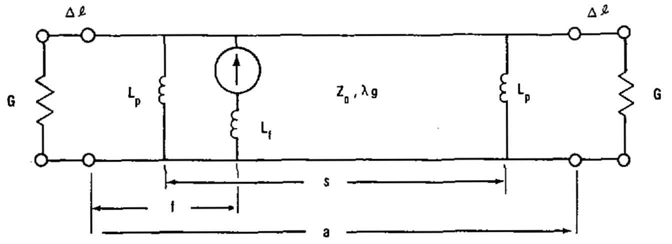


Fig. 2. Transmission-line model for calculating operating frequency and input impedance of frequency-tuned antenna.

$$G = \frac{\pi b}{377\lambda_0}\left[1 - \frac{(kt)^2}{24}\right] \tag{5}$$

$$\approx 0.0083\, b/\lambda_0, \qquad t/\lambda_0 \ll 1.$$

The RF feed is represented by a current source with a series inductor to represent the feed probe inductance [18]. The shorting posts are represented as shunt inductances at the locations of the posts. The inductive reactance of the posts and the feed probe are calculated from the formula

$$X_L = \frac{377}{\sqrt{\epsilon_r}} \tan \frac{2\pi t}{\lambda_0}. \tag{6}$$

The input impedance and radiation loss are calculated from this model. Plots of the operating frequency and voltage standing-wave ratio (VSWR) of a 6.2 × 9.0-cm antenna on 1.6-mm (1/16 in) Teflon fiberglass are shown in Fig. 3. The agreement between the calculated and measured frequencies is quite good (within five percent) and demonstrates that this simple transmission-line model is useful for predicting the performance of the post-tuned microstrip antenna.

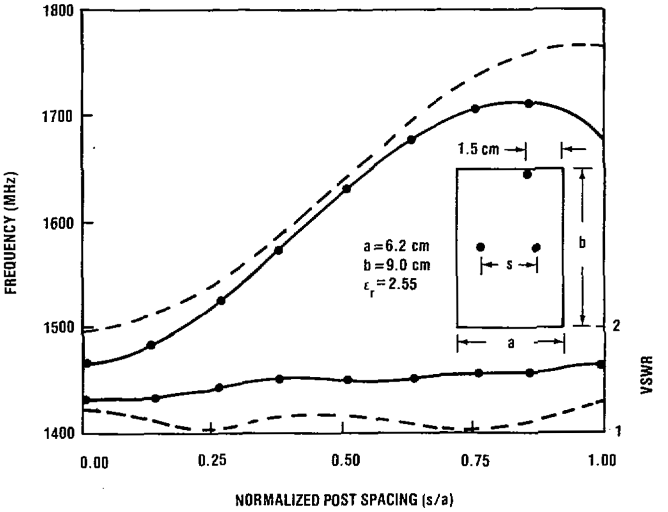


Fig. 3. Operating frequency (upper curves) and VSWR (lower curves) of frequency-tuned antenna. 1.6-mm Teflon fiberglass substrate. --- Calculated. —— Measured.

The range of frequency tuning achieved by a pair of posts along the center line is about 20 percent, but tuning ranges in excess of 50 percent have been achieved by adding more posts. These additional posts may be placed along the centerline $y = b/2$ (Fig. 1) or offset from the centerline along $y = b/2 \pm c$. (When placing posts away from the centerline it is preferred that they be added in pairs symmetric about the centerline. This avoids introducing cross-polarized signals.) The radiation patterns of the antenna are not significantly changed by the shorting posts. The bandwidth (VSWR < 2) is approximately one percent at each operating frequency.

The simple transmission-line model is not adequate to describe the antenna when several pairs of posts are used. In that case, a more detailed model (e.g., a leaky cavity with posts) will be required to obtain accurate performance predictions.

The major disadvantage of using many diodes to actively control the antenna's operating frequency appears to be the need to individually bias the diodes on or off. The bias circuit may require many components to properly distribute the dc bias signals while isolating the RF. However, this requirement is no more complicated than that already performed by solid-state RF switches, and it is not expected to greatly limit the usefulness of the post-tuned antenna.

The use of post tuning does not prevent the use of other antenna-tuning techniques. In particular, the inductive shorting posts may be combined with capacitive varactors to obtain a very wide tuning range extending above and below f_0. This combination will possess the benefits and problems of both techniques.

III. POLARIZATION DIVERSITY

The polarization of the microstrip antenna also can be selectively altered by proper location of the shorting posts [19]. A case of particular interest is the square patch fed along a diagonal with shorting posts located along the centerlines (Fig. 4). This antenna will radiate x- or y-oriented linear polarization, or right-hand or left-hand circular polarization, depending upon the locations of the posts. Typical radiation patterns obtained by using a spinning linearly polarized receive antenna are shown in Fig. 5. The pattern shapes of the two linearly polarized antennas are different because Fig. 5(a) is an E-plane pattern cut and Fig. 5(b) is an H-plane pattern cut. In Fig. 5(c) and (d) the antenna is configured for circular polarization. The axial ratios of the circularly polarized antennas are less than 3 dB over a wide sector around the zenith. (The axial ratio does not become infinite at the horizon because the ground plane is relatively small.)

The polarization changes can be explained by considering the frequency-tuning effects described above. The square patch without shorting posts supports both x-oriented and y-oriented modes, which have the same resonant frequency. Since the feed probe is located on the diagonal of the patch, both the x- and y-oriented modes are excited with equal amplitude and phase. By adding shorting posts along the centerline $x = a/2$ (Fig. 4), the resonant frequency of the y-oriented mode can be raised without affecting the x-oriented mode. Similarly, by adding posts along $y = a/2$, the resonant frequenty of the x-oriented mode can be raised without affecting the y-oriented mode. Therefore a single mode (x or y oriented) may be selected by shifting the resonant frequency of the undesired mode far above that of the desired mode. This large frequency shift is obtained by placing shorting posts at or near the edges of the patch. The result is linear polarization.

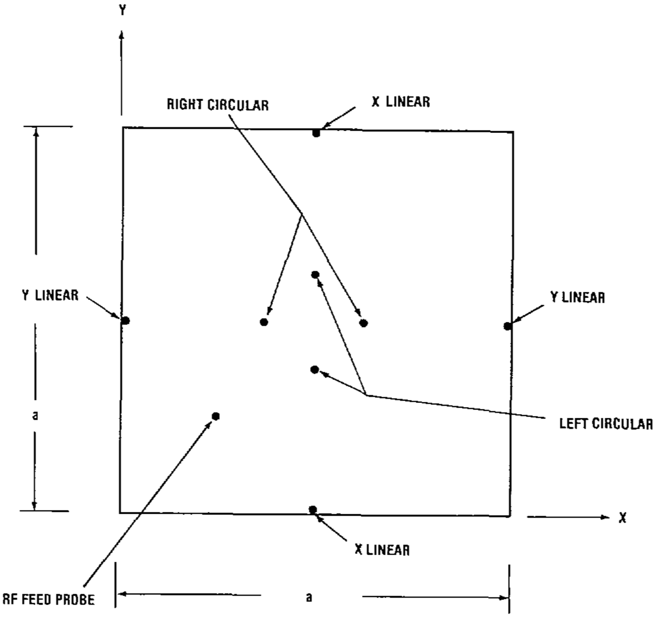


Fig. 4. Square patch antenna with four pairs of posts for obtaining four different polarizations.

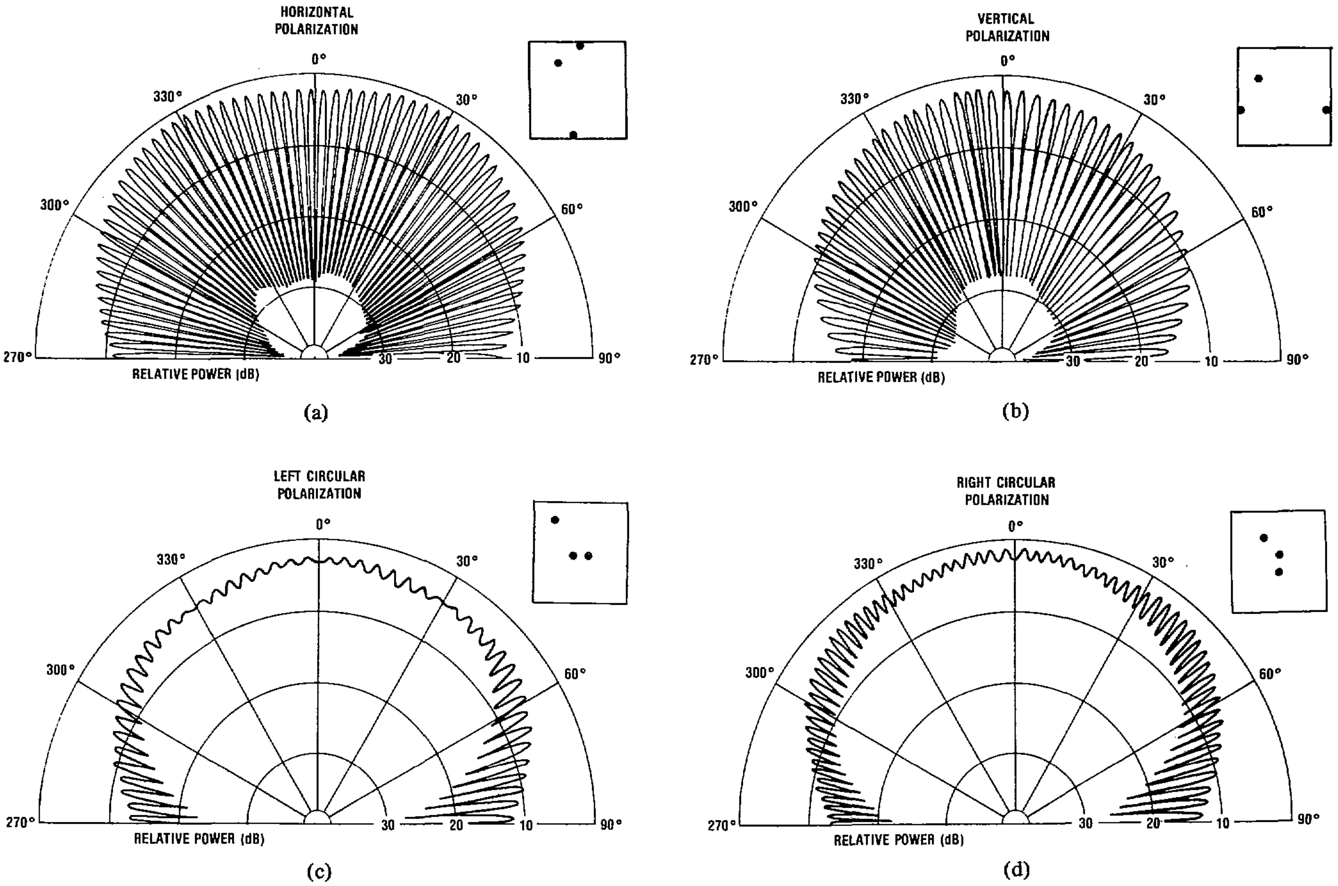
Circular polarization may be obtained by exciting both the x- and y-oriented modes with equal amplitudes, but with 90° phase difference. This can be accomplished by raising the resonant frequency of one mode slightly above the other and operating at a frequency between the two resonances. Then the input impedance of one mode is inductive and the other mode is capacitive. By adjusting the difference between the resonant frequencies, both modes can be excited with equal amplitudes and 90° phase difference.

Fig. 6 shows the measured axial ratio of a typical antenna as the separation between a pair of shorting posts is changed. When $s/a = 0$, the posts are at the center and they do not affect either mode. In this case the antenna is linearly polarized along the diagonal with the feed. When $s/a = 0.09$, the resonant frequencies of the two modes are offset enough to obtain a phase difference of approximately 90° and the antenna is circularly polarized. As the posts are moved further apart, the resonant frequency of the vertical mode is further increased and the antenna's polarization becomes horizontal linear (see the drawing in Fig. 6). The input impedance of the antenna changes as the posts are moved, but the VSWR remains very good for all senses of polarization. (Although the best circular polarization occurs over a narrow band of frequencies slightly above the resonance for the linear polarization, the bandwidth of the linearly polarized antenna is adequate to permit it to operate at the same frequency as the circularly polarized antenna.)

Experimental versions of the circularly polarized antenna have been built by using microwave switching diodes instead of machine screws for shorting posts. These antennas verified that diode tuning can be used for precise control of the frequency and polarization. However, it may be necessary to slightly adjust the diode locations to account for the parasitic effects inherent in the diodes.

IV. APPLICATIONS AND OTHER CONFIGURATIONS

The frequency-agile microstrip antenna has many potential applications. By using microwave switching diodes for shorting



(a) (b)

(c) (d)

Fig. 5. Typical spin-linear radiation patterns of 6.2-cm square patch antenna at 1470 MHz. Substrate and ground plane are 22-cm square.

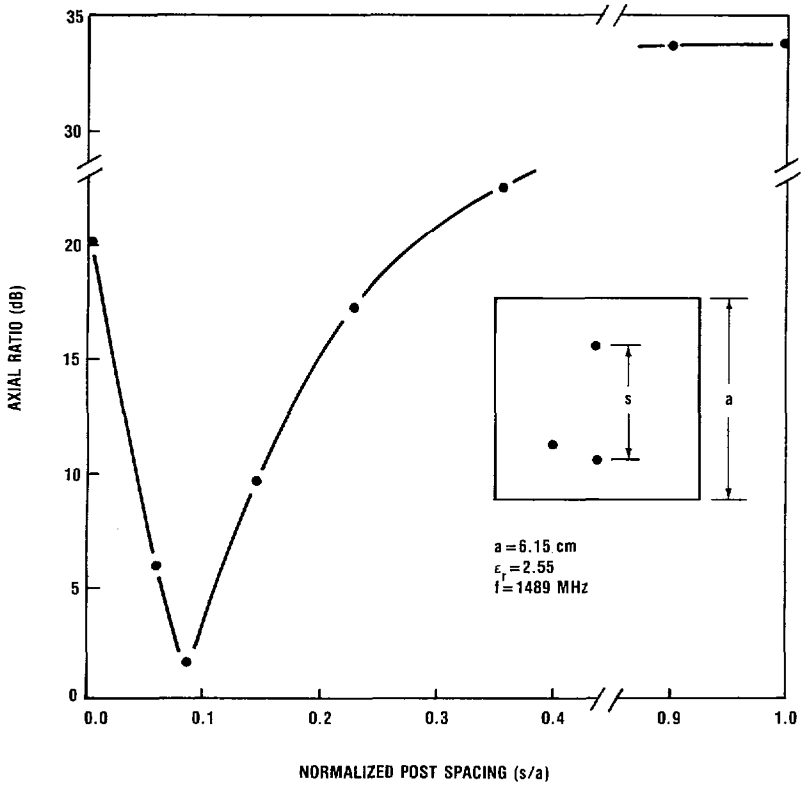


Fig. 6. Measured axial ratio of 6.15-cm square patch antenna with a pair of symmetrically located posts. 1.6-mm Teflon fiberglass substrate.

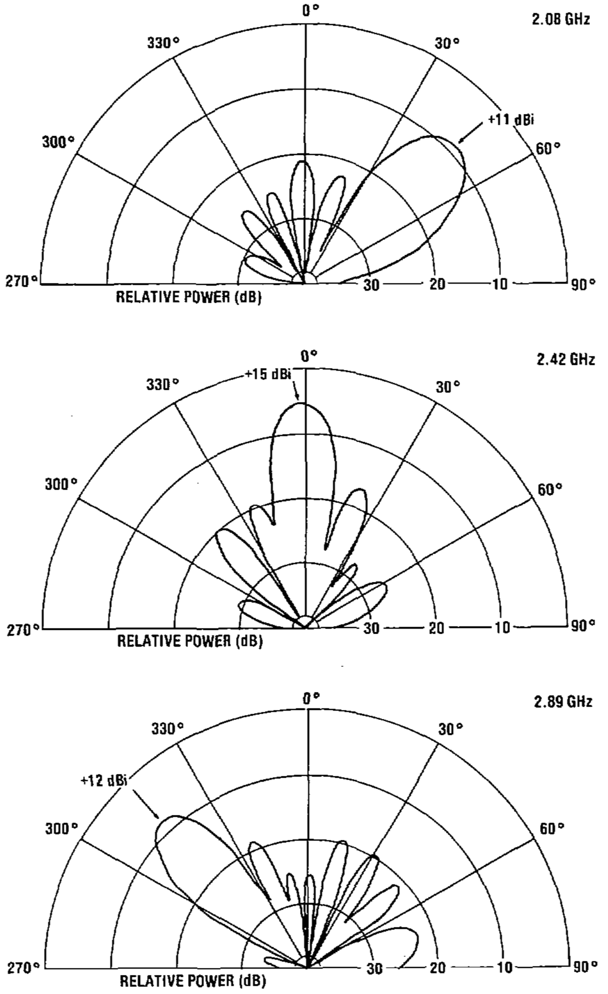


Fig. 7. Typical *E*-plane radiation patterns of linear eight-element frequency-scanned array with uniform amplitude distribution. Array gain is 11 dBi at 2.08 GHz, 15 dBi at 2.42 GHz, and 12 dBi at 2.89 GHz.

posts, a thin conformal communication or radar antenna can be fabricated with the ability to track the tuning of the transmitter or receiver. The antenna remains well-matched at each operating frequency and provides bandpass filtering of the transmitted and received signals. This type of frequency agility provides added flexibility in avoiding interfering signals.

Thin conformal frequency-scanned arrays can also be built with the frequency-agile microstrip antenna. An eight-element linear array consisting of 4.32 × 6.27-cm patches has been fabricated on a 1.6-mm (1/16-in) thick Teflon fiberglass substrate. This experimental array was tuned with small machine screws inserted into holes in the antennas. A corporate feed network that provides progressive phase shift was used to create an antenna that scans ±45° from broadside as the frequency varies from 2.08 to 2.89 GHz (Fig. 7). This type of array with diode tuning posts would perform well in a computer-controlled system that simultaneously increments the operating frequency of the antenna and the transmitter/receiver.

Simple low-power polarization-diverse antennas have been fabricated as shown in Fig. 8(a). A positive or negative bias voltage may be inserted through the RF feed line to select one of the two polarizations.

Other configurations of the microstrip antenna that provide polarization diversity include circular patches and square patches fed along a center line. The centerline-fed square patches (Fig. 8(b)) provide one linear polarization (no posts) and both circular polarizations by means of shorting posts located along the diagonals of the patch. The addition of a second feed (Fig. 8(c)) permits simultaneous operation in two polarizations. The isolation between the two linear polarizations is greater than 30 dB, and the isolation between the two circular polarizations is greater than 20 dB.

V. CONCLUSION

The operating frequency and polarization of microstrip antennas can be conveniently controlled by inserting shorting posts at appropriate locations within the antenna's boundary. By using microwave switching diodes, an electronically controlled frequency-agile or polarization-diverse antenna can be obtained.

The operating frequency of a rectangular microstrip antenna can be tuned over a 1.5-to-1 range without changing its size or the feed location. The tuning is accomplished by varying the number and locations of the shorting posts. The radiation patterns of the microstrip elements do not change significantly as the operating frequency is varied.

Most of the temperature drift and bias control problems that are encountered when varactors are used to electronically tune the antennas are eliminated by using the microwave switching diodes. Also, since the frequency depends on post locations and not on variable reactances, it should be easier to insure that all elements of an array are resonant at the same frequency. The switching diodes are also capable of operating in the high-power environment encountered in transmitting antennas.

The polarization of square and circular microstrip antennas can be varied by changing the locations of shorting posts. Very narrow bandwidth circular polarization of either sense can be obtained, as well as horizontal or vertical linear polarization. The axial ratio of the circularly polarized antenna is less than 3 dB over a wide portion of the beam.

In addition to providing active control of the frequency and polarization of a microstrip antenna, these post-tuning techniques can ease the burdens on designing and manufacturing the antennas. In order to obtain the desired performance, the antenna's precise operating frequency and polarization can be altered by inserting shorting posts during manufacturing or prior to use.

The frequency agility and polarization diversity provide added versatility to the microstrip antenna. Furthermore, these features are obtained without sacrificing the thin conformal structure of the microstrip antenna and without increasing the complexity of the external microwave feed network.

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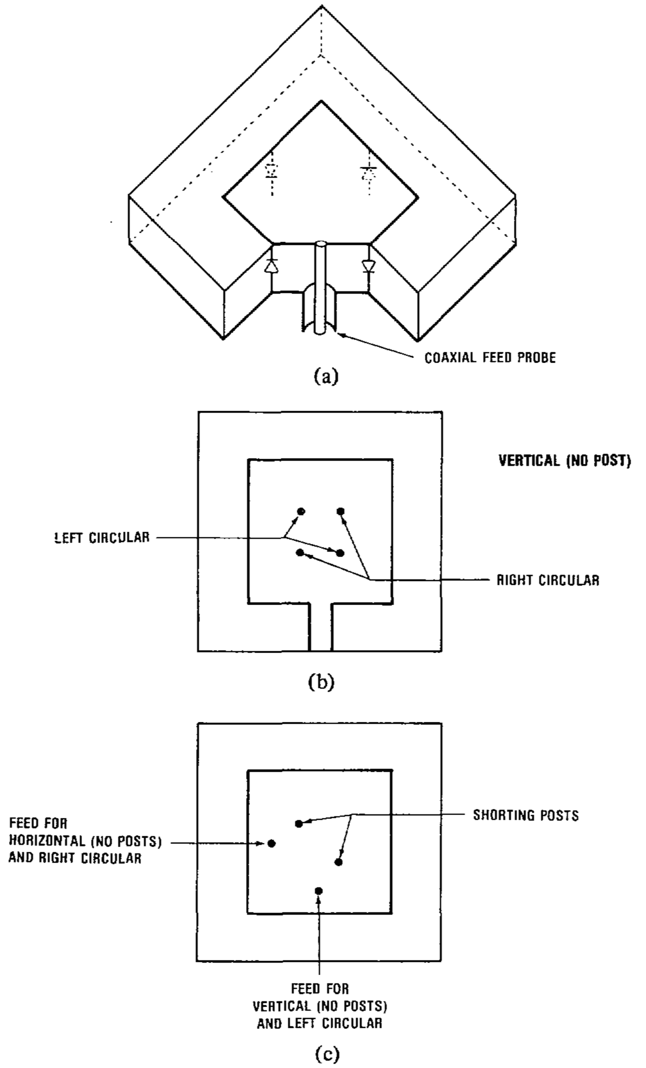

Fig. 8. Some configurations for polarization diversity. (a) Diagonal-fed two-polarization antenna with bias voltage inserted through RF feed. (b) Centerline-fed patch for three polarizations. (c) Dual-feed antenna for horizontal and vertical or left and right circular polarizations.

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