

TUNABLE CIRCULAR PATCH ANTENNAS

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Abstract

A method to control the operating frequencies of circular patch antennas has been investigated experimentally and theoretically. It consists of the placement of passive metallic posts at approximate locations within the input region of the antenna. Comparison of measured and analytical results seems to establish the validity of a theoretical model proposed to determine the input performance of such circular patch antennas.

It has been reported¹ that the resonant or operating frequency of a rectangular patch antenna can be varied by placing passive metallic or tuning posts at suitable locations within the antenna's boundary. Uniform transmission line concepts have been utilized^{1,2} to develop an analytical model for such tunable antennas. Our measurements performed on circular patch antennas indicated that their operating frequencies can also be controlled by similar means. The present communication proposes a theoretical model based on non-uniform transmission line concepts for analysis of the input performance of tunable circular patch antennas.

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Although cavity models^{3,4} are generally used to analyze the performance of circular patch antennas, it is difficult to apply them to tunable circular patch antennas which contain an arbitrary number of internal discontinuities. In the proposed model the antenna is considered as an asymmetrically excited radial waveguide loaded internally with the tuning posts and terminated by an equivalent admittance appropriate for the radiating aperture. Figure 1 shows an untuned circular patch antenna of radius a , thickness d and excited from the back by a coaxial probe located at $\rho = \rho_0$, $\phi = 0$ degrees. It can be shown^{5,6} that the normalized m th mode admittances ($m = 0,1,2,\dots$) in the two regions (Fig. 1) are given by the following non-uniform transmission line equations:

$$y_{m_1}(\rho) = j \frac{J'_m(x)}{J_m(x)}, \quad 0 \leq \rho \leq \rho_0, \quad (1)$$

$$y_{m_2}(\rho) = \frac{j + y_{t_m}(y) \text{ct}_r(x,y) k_r(x,y)}{\text{ct}_r(x,y) + j y_{t_m}(y) k_r(x,y)}, \quad \rho_0 \leq \rho \leq a, \quad (2)$$

where y_{t_m} is the normalized boundary admittance appropriate for the radiating aperture and

$$\text{ct}_r(x,y) = \frac{N'_m(x)J_m(y) - J'_m(x)N_m(y)}{J_m(x)N'_m(y) - N_m(x)J'_m(y)}, \quad (3)$$

$$\text{ct}_r(x,y) = \frac{J_m(x)N'_m(y) - N_m(x)J'_m(y)}{J'_m(x)N'_m(y) - N'_m(x)J'_m(y)}, \quad (4)$$

$$k_r(x,y) = \frac{J_m(x)N_m(y) - N_m(x)J_m(y)}{J'_m(x)N'_m(y) - N'_m(x)J'_m(y)} \quad (5)$$

with $x = k\rho$, $y = ka$,

$$k = k_0 \sqrt{\epsilon_r} (1 - j \tan \delta)^{1/2}, \quad j = \sqrt{-1}, \quad (6)$$

k_0 being the free space propagation constant and ϵ_r , $\tan \delta$ are the relative permittivity and loss tangent of the substrate material; J_m, N_m are the m th order Bessel and Neumann functions, respectively, and the prime represents differentiation with respect to the total argument. The normalized boundary admittance y_{t_m} can be formally expressed as

$$y_{t_m} = g_m + jb_m. \quad (7)$$

Explicit expressions for g_m and b_m are obtained^{6,7} from the considerations of total power loss (i.e., radiation, conductor and dielectric losses) and the reactive power stored in the fringing fields at the aperture.

The input impedance of the antenna, in the absence of the exciting probe effects, can now be written as

$$Z_{in}(\rho_0) = \sum_{m=0}^{\infty} Z_m(\rho_0) \frac{1}{y_{m_2}(\rho_0) - y_{m_1}(\rho_0)}, \quad (8)$$

where

$$Z_m(\rho) = \frac{\eta d}{(1 + \delta_m) \pi \rho} \quad (9)$$

$$\eta = \sqrt{\frac{\mu_0}{\epsilon}}, \quad \mu_0, \epsilon \text{ being the permeability and permittivity of the substrate material,}$$

$$\delta_m = \begin{cases} 1 & m = 0 \\ 0 & m \neq 0 \end{cases} .$$

The resonant or operating frequency of the antenna is determined from the resonant propagation constant obtained numerically from the following:

$$\text{Im } Z_{in}(\rho_0) = 0 , \quad (10)$$

where $Z_{in}(\rho_0)$ is given by Eq. (8).

For a tuned circular patch antenna, the above non-uniform transmission line model is modified by inserting equivalent post impedances (admittances) at the locations of the tuning posts. Equivalent impedances of metallic posts in a radial waveguide have been discussed elsewhere.⁸ It can be shown^{5,8} that in the present case the effective inductive impedance of a tuning post of radius r_0 located at $\rho = \rho_1$, $\phi = 0$ degrees, may be approximated by

$$Z_p(\rho_1) = j \frac{\eta kd}{2\pi} \left[\ln \left(\frac{2}{\gamma k r_0} \right) + \frac{\pi}{2} J_0(k\rho_1) N_0(k\rho_1) \right] , \quad (11)$$

where $\gamma = 1.78107$. For a tunable circular patch antenna, it is now clear that multiple application of Eq. (2) would be required to obtain $y_m(\rho_0)$ before Eq. (10) can be solved to determine the required propagation constant.

Measurements and theoretical computations were performed for a 3.8 cm radius circular patch antenna. The antenna was fabricated on a 1/16 inch, double-clad Rexolite 1422 printed circuit board; the dielectric constant and loss tangent in the frequency range considered

(1.0 - 2.0 GHz) was approximately 2.54 and 0.001, respectively. Figure 2 shows the measured impedance locus (solid line) for the lowest resonant mode of an untuned antenna. The calculated input impedances obtained with $m = 1$ and $m = 10 \approx \infty$ are also shown in Fig. 2 for comparison.

The same antenna configuration was then tuned. This was done by first drilling a small hole through the substrate, then inserting a metallic pin of radius $r_0 = 0.045$ cm in the hole, and soldering the pin to the patch and the ground plane. Theoretical and experimental resonant frequency vs post location for antennas with one, and two diametrically opposed similar tuning posts are shown in Fig. 3.

The above results indicate that the proposed non-uniform transmission line model can be used to determine the resonant frequency and input impedance of circular patch antennas. With slight modification the same model is capable of providing similar information about the tunable circular patch antennas. Further study indicates that to maintain the polarization similar to that of the untuned configuration, the tuning posts must be placed along the lines $\phi = 0$ degrees or 180 degrees; and to minimize the cross-polarized fields the posts be used in pairs and disposed symmetrically in a diametrically opposed fashion.⁵ Detailed discussion of tunable circular patch antennas will be reported in a future paper.

References

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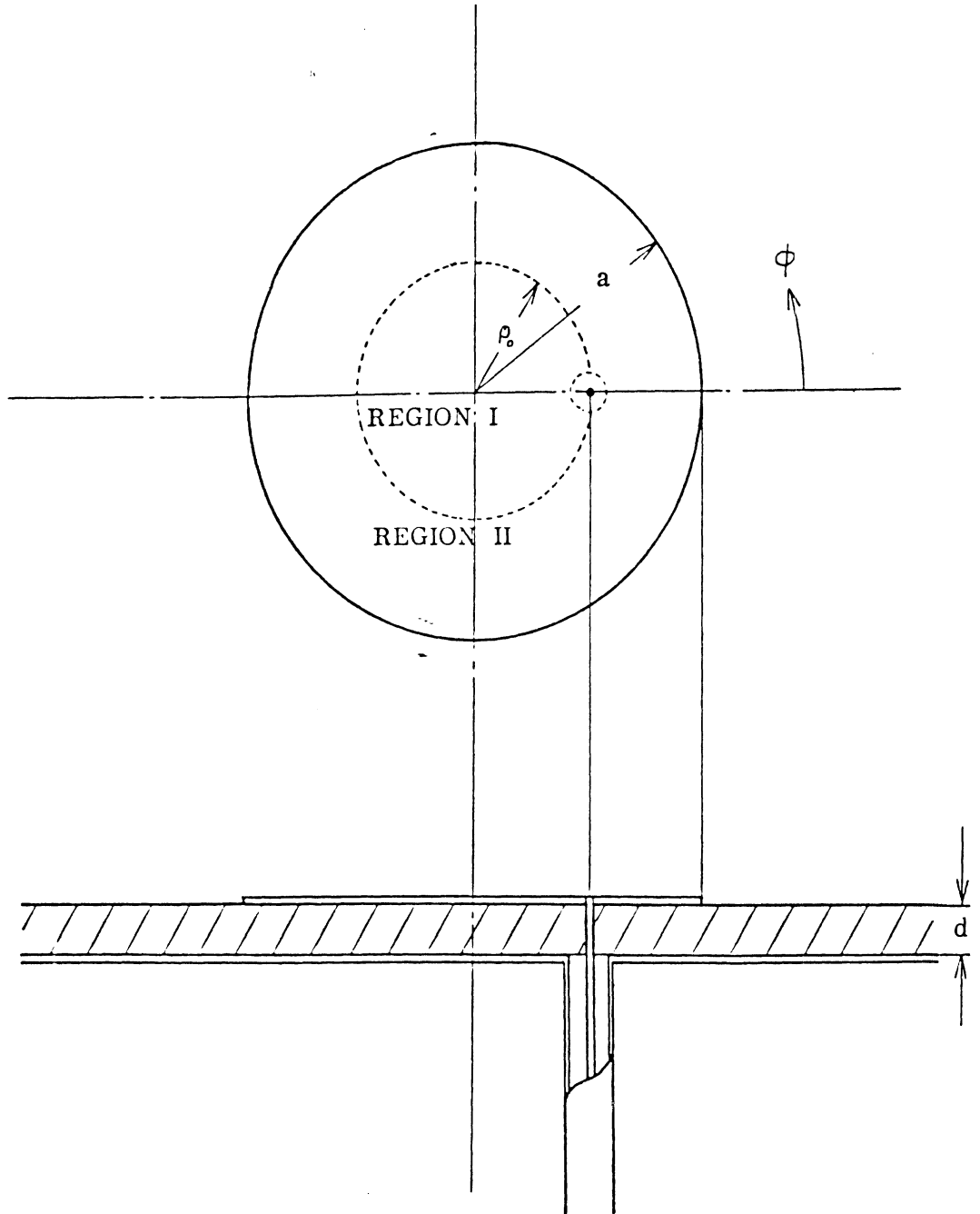


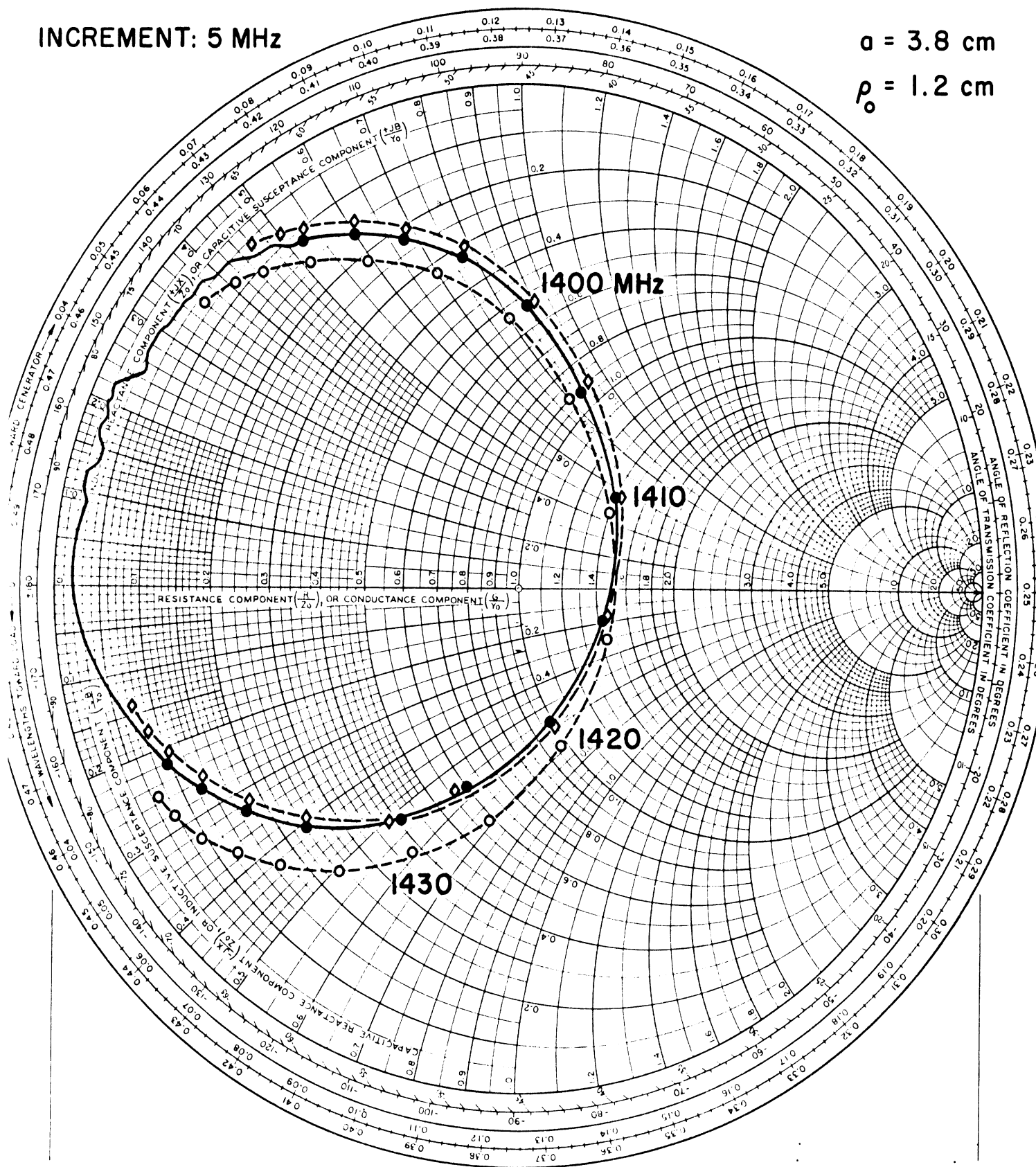
Fig. 1: A circular patch antenna showing the coaxial feed location and two source-free regions.

IMPEDANCE OR ADMITTANCE COORDINATES

INCREMENT: 5 MHz

$a = 3.8 \text{ cm}$

$\rho_0 = 1.2 \text{ cm}$



- MEASURED
- CALCULATED (RESONANT MODE, $m=1$)
- ◇---◇ CALCULATED (INFINITE MODES)

Fig. 2: First-mode input impedance of a circular patch antenna (without tuning posts).

CIRCULAR PATCH ANTENNA WITH ONE OR TWO POSTS

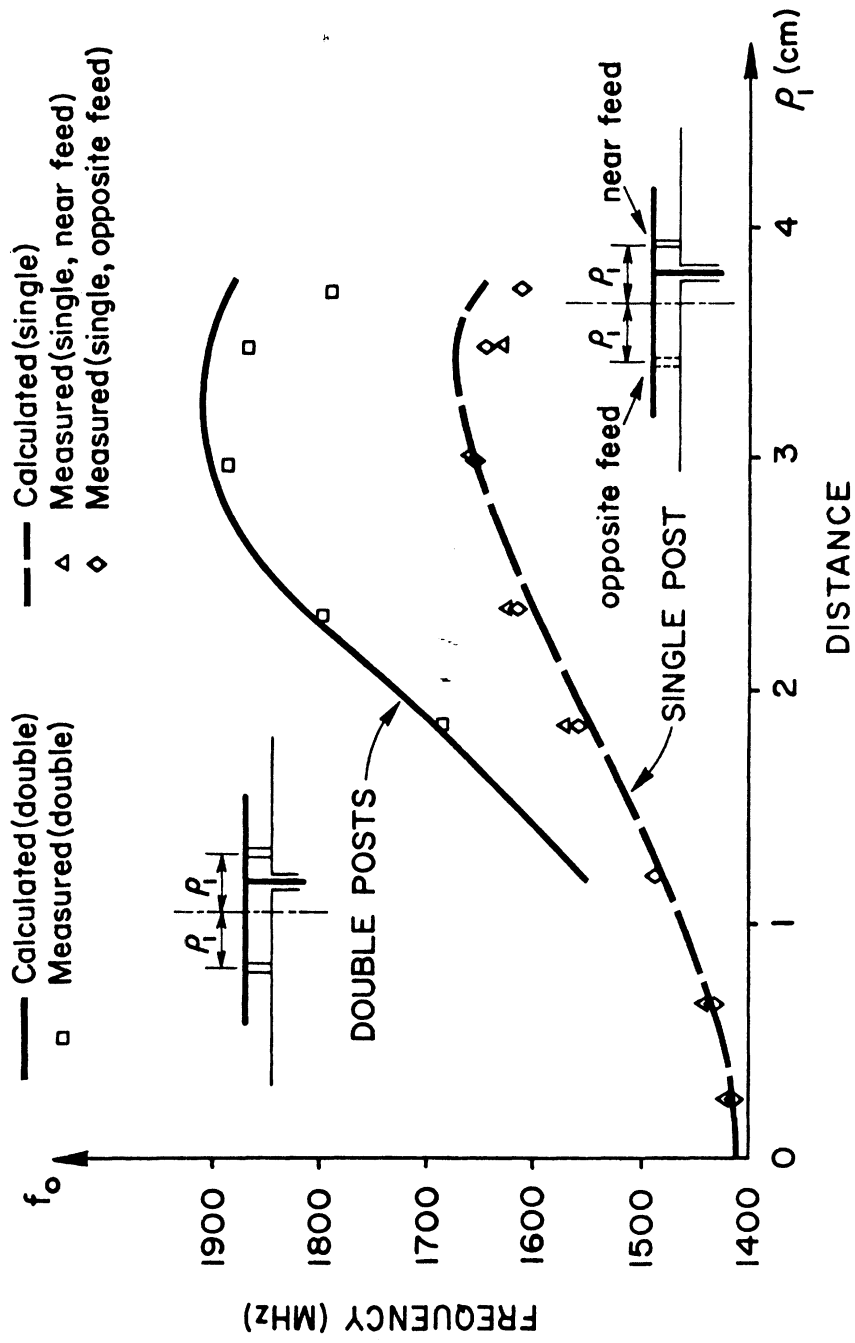


Fig. 3: The variation of resonant frequency with distance ρ_1 . (ρ_1 is the distance between the post and the center line.)