$$\bar{S}' = \begin{Bmatrix} ae^{j\epsilon'} & j\sqrt{1-a^2}\, e^{(j/2)(\epsilon''+\epsilon')} \\ j\sqrt{1-a^2}\, e^{(j/2)(\epsilon''+\epsilon')} & ae^{j\epsilon''} \end{Bmatrix}. \tag{21}$$

If the reference planes are shifted to I and II, the scattering matrix becomes

$$\bar{S} = \begin{Bmatrix} a & j\sqrt{1-a^2}\, e^{j[(\epsilon''/2)-\beta' l]}L^{-1} \\ j\sqrt{1-a^2}\, e^{j[(\epsilon''/2)-\beta' l]}L^{-1} & ae^{j(\epsilon''-2\beta' l)}L^{-2} \end{Bmatrix} \tag{22}$$

where $L = e^{\alpha' \cdot l}$ is the attenuation of the transmission line.

From (22) the relevant parameters can be deduced:

$$\begin{aligned} \eta = \phi &= \epsilon'' - 2\beta' l \\ \Delta &= L^{-2} \\ c &= aL^{-2} \end{aligned} \tag{23}$$

and the correction parameter is found to be

$$\zeta = \frac{L^4 - a^2}{L^4 + 2L^2 a \cos\phi + a^2} - \frac{1 - L^4 a^2}{1 + 2L^2 a \cos\phi + L^4 a^2}. \tag{24}$$

Fig. 2 shows a plot of ζ. The negative value of ζ for ϕ values near π can be understood qualitatively from the fact that the cavity can have a small coupling factor r, but the apparent coupling factor measured at the input of the two-port is larger. The bandwidth is determined by the cavity and the small coupling factor. Calculation of Q_0 from the bandwidth and the large coupling factor therefore gives too high a value of Q.

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A Microstripline Slot Antenna

YOSHIKAZU YOSHIMURA

***Abstract*—A microstripline slot antenna is treated experimentally at X-band frequency. First, the input impedances of the slots for various geometries and the radiation patterns for the matched slots are measured. Second, the dependence of input impedances and radiation patterns on the slot-to-reflector spacing is tested. Finally, a two-dimensional X-band Dolph–Chebyshev slot-array antenna is designed and fabricated as an application of this type of slot.**

I. Introduction

Microstripline slot antennas appear to be quite useful in various fields of application because of their savings in cost, size, and weight. Concerning an antenna utilizing microstriplines, printed antennas, such that several types of array patterns are printed on the substrates of microstriplines, have been reported by several authors [1], [2], and slot antennas utilizing triplate striplines have also been reported by Oliner [3], Sommers [4], and Breithaupt [5]. Slot antennas utilizing microstriplines have also been investigated by the author [6].

II. Slot Configuration

A microstripline slot antenna shown in Fig. 1 is fabricated by simple and conventional photoetching techniques from copper-clad PTFE Fiberglas laminate. The width of the strip conductor is so determined that the characteristic impedance of the microstripline is 50 Ω. The slot is so made that its longer sides are perpendicular to the strip conductor. The method of the feeding is as follows: the strip

Manuscript received March 27, 1972; revised May 30, 1972.

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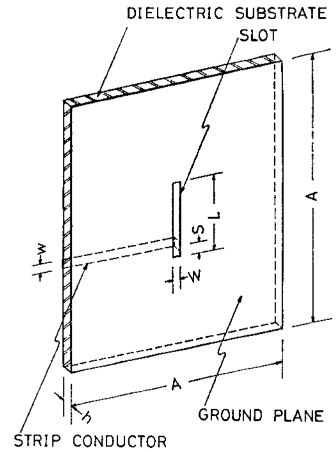


Fig. 1. Configuration of microstripline slot antenna.

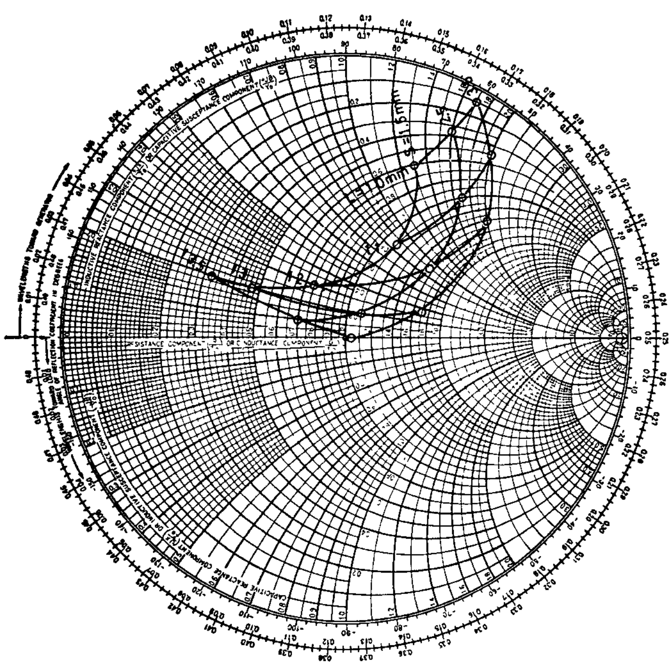
conductor is short-circuited through the dielectric substrate with the slot longer side, which is located farther from the feed input. No matching element is used because such an element decreases the bandwidth. It can be predicted that the radiation patterns of the slot are disturbed, with a certain amount due to the influence of the strip conductor near the feed point and the dielectric substrate on one side of the slot surface. The feed point on the slot can be divided into two cases; one, the feed point dislocated from the center of the longer side (which is called the offset-fed slot), and two, the feed point located on the center (which is called the center-fed slot).

III. Input Impedances and Radiation Patterns

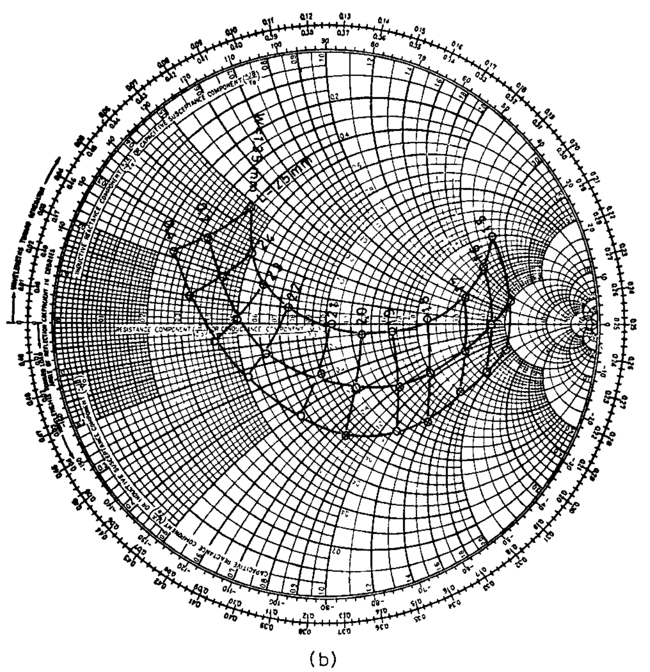
The microstripline slot antenna is measured after transforming a 50-Ω microstripline to a 50-Ω coaxial line. The thickness of the dielectric substrate, the width of the strip conductor, and the size of the ground plane are 0.6 mm, 1.55 mm, and 64 mm by 64 mm, respectively, and the relative dielectric constant of the dielectric substrate is nominally 2.7 at the frequency of 10 GHz. The measurement frequency is 10.525 GHz, which corresponds to the free-space wavelength of 28.5 mm.

The impedances of the slots are measured as functions of the lengths, widths, and feed points of the slots. Fig. 2(a) illustrates the measured data of input impedances of the offset-fed slots as functions of the lengths and the feed points with the slot widths kept constant. The input impedances indicate the impedances at the feed point where the strip turns 90° to go through the substrate. It is found that in the case of the offset-fed slot, the slot with a size of $L = 13.5$ mm, $W = 0.7$ mm, and $S = 3.5$ mm is matched to the feed line of the 50-Ω microstripline. Measurement data for the center-fed slot are shown in Fig. 2(b). It is found from the comparison of the sizes of the matched slots for both cases that the length from the feed point to the farther edge for the offset-fed slot is almost the same as the length from the feed point to one edge for the center-fed slot. From this fact, it could be predicted that the field distributions for these two parts would be similar [6].

The measurement results of the radiation patterns of the matched slots are shown in Fig. 3 for the offset-fed slot. The H-plane radiation patterns for both cases are quite similar to the E-plane patterns for dipole antennas, and no distortions of the H-plane patterns can be noticed. The beamwidth in the H plane is about 68° for the offset-fed case. Concerning the E-plane pattern, the wave-like radiation pattern illustrated in the figure is considered to have come from the interference of the radiations from the slot and the edges of the ground planes [7]. If an infinite ground plane could be used in essence, the E-plane radiation pattern should be uniform. Thus this type of slot can be regarded as an antenna complementary to a dipole antenna, except for the effect of the finiteness of the ground plane. The distortions of the radiation patterns due to the strip conductor and the dielectric substrate are hardly noticed contrary to the prediction previously stated. This can be explained by the fact that the effective thickness of the dielectric substrate is very small compared with the free-space wavelength; therefore, the far field is hardly influenced by the existence of the dielectric substrate. Furthermore, since the width



(a)



(b)

Fig. 2. (a) Input impedance of offset-fed slot as functions of length and feed point. (b) Input impedance of center-fed slot as functions of length and width.

of the strip conductor which corresponds to the characteristic impedance of 50 Ω is also very small compared with the length of the slot, the field disturbances due to the existence of the strip conductor near the feed point can hardly cause the far-field distortions.

In order to obtain the unidirectional radiation, a plane reflector sheet is placed on the side of the dielectric substrate parallel to the slot surface. The size of the reflector is confined to the same size as the ground plane of the slot to save space (see Fig. 4). Fig. 5(a) and (b) shows the variations of the input impedances as functions of the slot-to-reflector spacing for the offset-fed and the center-fed slots, respectively. It can be observed from Fig. 5 that the slot with the reflector is far from matching when the slot-to-reflector spacing is near one-half free-space wavelength, but it is close to matching when

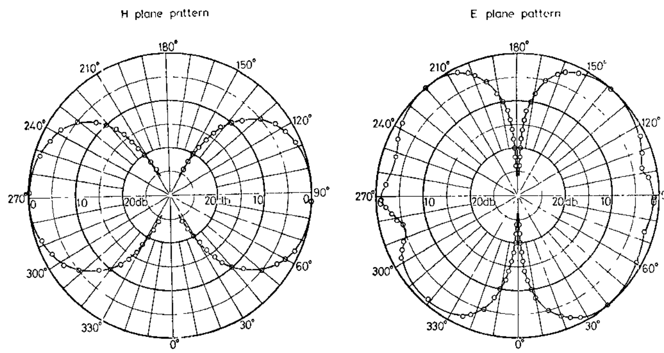


Fig. 3. Radiation patterns of matched slots for offset-fed case.

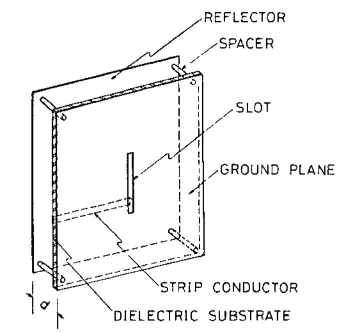


Fig. 4. Configuration of microstripline slot antenna with reflector.

it is near one- or three-quarter free-space wavelengths. In the case of one- or three-quarter wavelengths, the slot with the reflector can be matched again rather easily by a small alternation of the size of the slot. From the H-plane pattern measurements as a function of slot-to-reflector spacing, it is found that the optimum spacing between the slot and the reflector is nearly one-quarter free-space wavelength with respect to the beamwidth of the main beam, the maximum sidelobe level, and the front-to-back ratio (see Fig. 6).

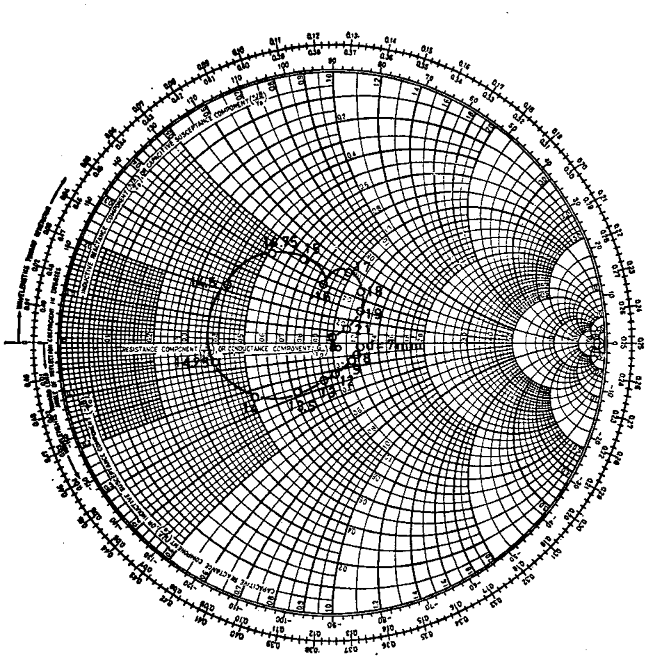
IV. Slot Array

As an application of the slot treated here to an array antenna, an X-band Dolph–Chebyshev slot array with 4 by 4 elements is designed and fabricated. The offset-fed type of slot is adopted because the array spacing of one-half wavelength can be realized in this case. The array spacings are uniform and one-half free-space wavelength in both directions. The array is constructed in the area of 64 by 64 mm.

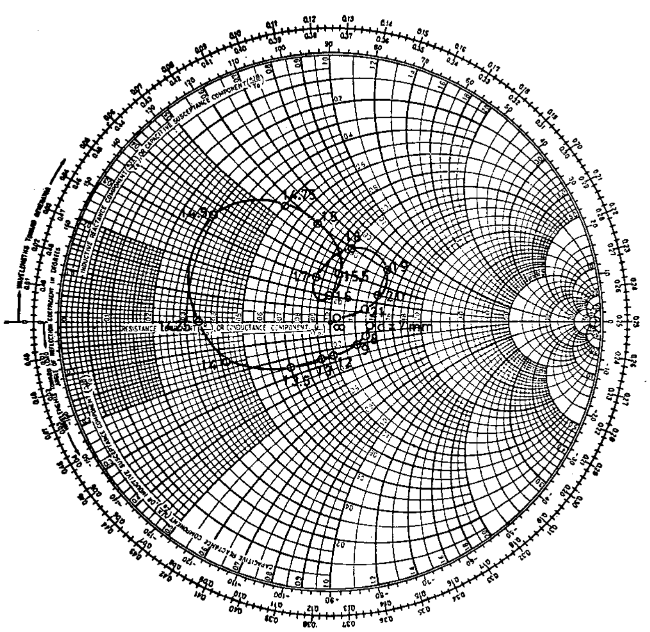
Fig. 7(a) shows the overall view of this slot array. In this figure, 16 slots and a plane reflector can be seen. The soldered parts, at which the strip conductors are short-circuited with the longer side of the slots, can also be seen. The feed circuit pattern of the microstriplines is shown in Fig. 7(b), which consists of the combinations of the power dividers with a division ratio such that the Dolph–Chebyshev distribution for the maximum sidelobe level of 26 dB is realized. The measured radiation patterns are shown in Fig. 7(c). The beamwidths of the main beam on H plane and E plane are 25° and 27°, respectively, and the maximum sidelobe levels on H plane and E plane are 24 and 22 dB, respectively. The maximum sidelobe on the E plane is 4 dB larger than predicted. It is thought that the difference is due to the exitation errors and the small sizes of the ground plane and the reflector. These beamwidths are comparable to those of a usual pyramidal horn with the same aperture area as the area of the array.

V. Conclusion

The slots can be matched to the microstripline by a choice of suitable lengths, widths, and feed points, and the matched slots are almost complementary to usual dipole antennas. In order to obtain a unidirectional radiation, the effect of a plane reflector placed parallel to the ground plane of the slot is tested, and a two-dimensional Dolph–Chebyshev slot array is designed and fabricated as an application. PTFE Fiberglas laminate is relatively easy to cut for the short-



(a)



(b)

Fig. 5. Input impedance of slot as function of slot-to-reflector spacing. (a) For offset-fed slot. (b) For center-fed slot.

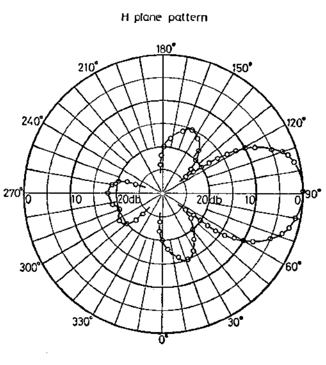
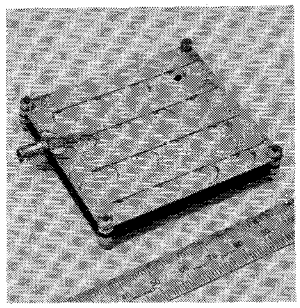
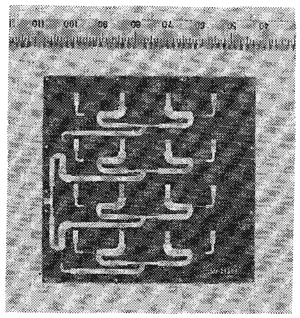


Fig. 6. Radiation patterns of offset-fed slot for slot-to-reflector spacings of 7 mm.



(a)



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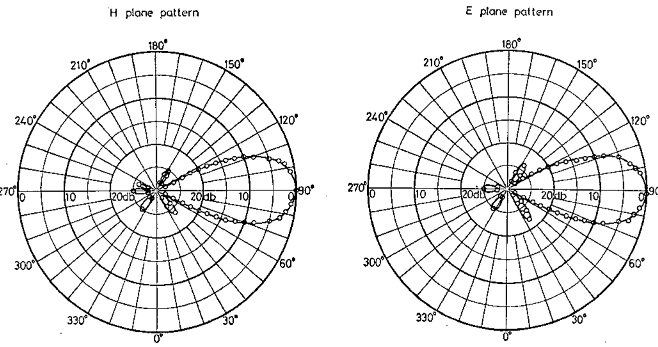

(c)

Fig. 7. 16-element microstripline slot array. (a) Overall view. (b) Printed feed circuit pattern. (c) Radiation patterns.

circuiting of the strip conductor, but when other substrates such as aluminum are used, it might be desirable to adopt another method of the feeding [8]–[10].

Acknowledgment

The author wishes to thank Dr. Y. Nakanishi of Osaka University and Dr. N. Okamoto of Kinki University for many helpful discussions and suggestions. The author also wishes to thank F. Valster and A. Meijer of Philips Research Laboratories for their helpful comments, A. Nishiyama, Manager, and T. Kamogawa, Chief Research Engineer, of Product Development Laboratories for their continued interest and encouragement.

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