Circularly Polarized Linear Array Antenna Using a Dielectric Image Line

TOSHIKAZU HORI AND TAKAO ITANAMI

Abstract—A new circularly polarized antenna using a dielectric image line is proposed. This antenna is composed of a slotted conductive plane and a rectangular dielectric rod.

This paper describes the design of and experimental results achieved with the circularly polarized array antenna fed by a dielectric image line. The fundamental characteristics of the image line are also presented. Since this line's losses are far lower than the microstrip line losses in the millimeter wavebands, antenna feed line losses expect to be also very low. Bandwidth within the 2-dB axial ratio was more than 7 percent, and the angle range within the same ratio was more than ±7.8 degrees at 29.5 GHz.

This antenna is far superior to the microstrip line feed array antenna in the millimeter wavebands.

I. INTRODUCTION

A MICROSTRIP array antenna fed by a microstrip line has advantages of low profile, low weight, compactness, simplicity, and ease of installation. This type of antenna has been investigated for many applications, and some experimental results have been reported [1]–[4]

The microstrip line feed array antenna is generally used below the X-band, where it shows good properties. However, since losses of the microstrip line increase due to the conductor losses in the higher frequencies (i.e., millimeter waveband), feed losses of the antenna become high.

Because of the above-mentioned characteristics, a low loss feed line is needed for an array antenna in the millimeter wavebands. Some of the low loss transmission lines in the millimeter waveband are a dielectric line, a dielectric image line and an H guide.[5] These lines are effective as feed lines to the array antenna.

This paper describes the fundamental characteristics of the dielectric image line, the design of the circularly polarized slot array antenna fed by the image line, and its experimental results.

II. ANTENNA STRUCTURE AND DESIGN CONCEPTS

Fig. 1 shows the structure of a circularly polarized slot array antenna fed by a rectangular dielectric image line. This antenna is composed of a slotted conductive plane and a rectangular dielectric rod with width a and height b.

The slots, which have the length a_s and the width b_s, are placed at the angle ϕ with the center line and at the distance δ, as shown in Fig. 1. The space between slots 1 is d_2, and the space between slot 1 and slot 2 is d_1.

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The authors are with the Yokosuka Electrical Communication Laboratory, Nippon Telegraph and Telephone Public Corporation, Yokosuka-shi, 238-03, Japan.

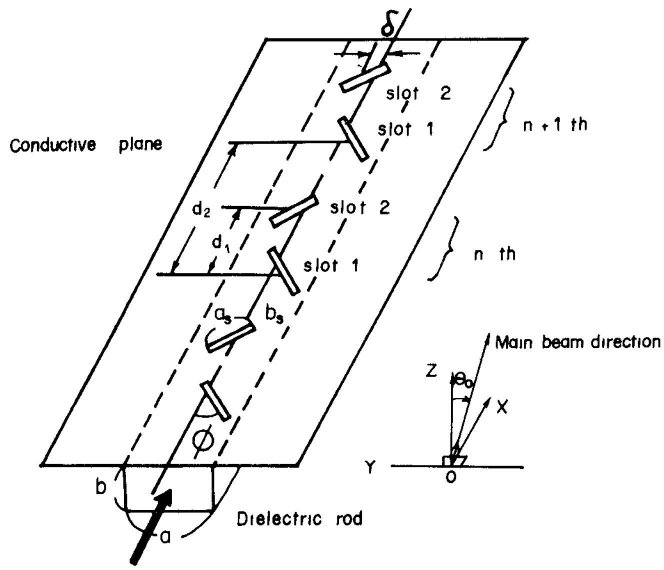

Fig. 1. Antenna configuration.

These slots radiate the electromagnetic wave fed by the image line. The main beam is in the XZ plane and is determined by the following equation:

$$\theta_0 = \sin^{-1}\left[\frac{\lambda_0}{\lambda_g}\left(1-\frac{\lambda_g}{d_2}\right)\right] \tag{1}$$

where λ_0 is the free-space wavelength, and λ_g is the guided wavelength in the image line, which is given by the equation in Section III-A. If the space d_2 equals λ_g, the main beam is radiated to broadside ($\theta_0 = 0$).

The axial ratio is determined by the slot space d_1 and the angle ϕ. In obtaining circular polarization in the main beam direction, the relationship between d_1 and ϕ is given by the following equation:

$$\tan\phi = -\cos\theta_0 \cot\left[\frac{k_0 d_1}{2}\left(\sin\theta_0 - \frac{\lambda_0}{\lambda_g}\right)\right] \tag{2}$$

where k_0 is the free-space propagation constant. If d_1 is $\lambda_g/4$ and ϕ is $\pi/4$, slot 1 and slot 2 are fed at the phase difference of $\pi/2$, and circular polarization is obtained at broadside.

III. FEED LINE

A. Dielectric Image Line

A dielectric image line, which is used for a feed line, is one of the surface wave transmission lines, and has low loss

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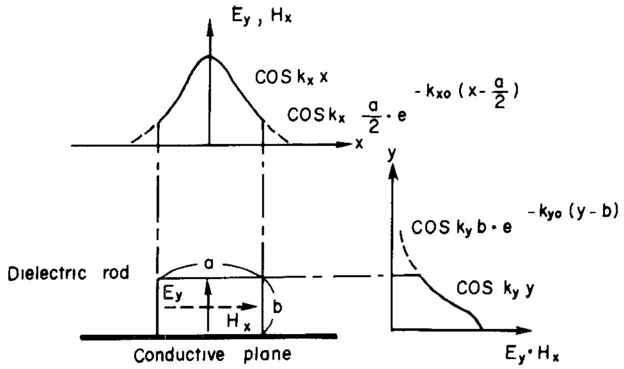

Fig. 2. Image line configuration and field distribution of E_{11}^{y} mode.

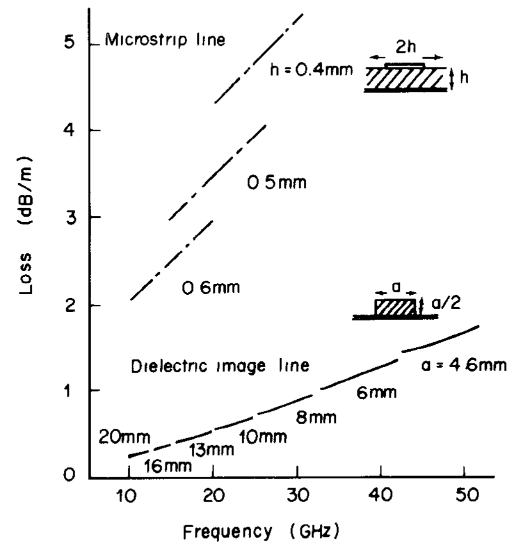

Fig. 3. Calculated transmission losses of dielectric image line and microstrip line.

properties in the millimeter wavebands. The dominant mode of this line is the E_{11}^{y} mode. The image line configuration and field distribution of E_{11}^{y} mode are shown in Fig. 2. The dimensions of the image line used here are determined so as to support only the E_{11}^{y} mode.

The propagation constant for the E_{11}^{y} mode is derived by the Toulios and Knox analysis [6], the guided wavelength λ_g in the image line is given as follows:

$$\frac{\lambda_0}{\lambda_g}=\left[\epsilon_r-\left(\frac{k_x}{k_0}\right)^2-\left(\frac{k_y}{k_0}\right)^2\right]^{1/2} \tag{3}$$

where ϵ_r is the relative dielectric constant, and k_x and k_y are the transverse propagation constants in the guide.

B. Comparison with Microstrip Transmission Line Losses

Transmission losses in the image line are the dielectric and conductor losses.

The attenuation constant α_d and α_c, due to dielectric losses and conductor losses, respectively, are given in [6].

Fig. 3 shows the frequency dependence of the image line losses calculated from equations in [6], in comparison with the microstrip line losses. The image line's dielectric is

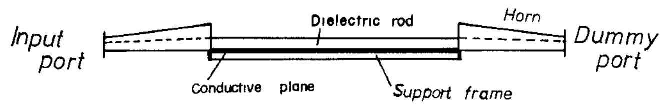

Fig. 4. Experimental setup

Poly-Tetra-Fluoro-Ethylene (PTFE) and the conductor is silver (Ag). The dimensions of this line are determined so as to support only the E_{11}^{y} mode. The microstrip line losses are calculated on the basis of the Pucel *et al.* analysis [7]. This line is made of a quartz dielectric and a silver conductor, so as to approximate to TEM mode, on the condition of 50-Ω line.

In Fig. 3, the image line losses are about one fifth the microstrip line decibel losses in the millimeter wavebands. Therefore, it is found that the image line has very good low loss properties and is therefore superior to the microstrip line when used as a feed line for an array antenna in the millimeter wavebands.

C. Image Line Loss Experimental Results

The image line used for this measurement is that employed in the construction of the antenna shown in the following section. This line is composed of a PTFE dielectric and a phosphor bronze conductor. The guide selected is 9.0 mm wide and 4.5 mm high, so as to support only the dominant mode. The size of the conductive plane is 60 mm wide and 200 mm long.

This line losses were measured by using the rectangular horns as a launcher. The experimental setup is shown in Fig. 4.

Measured losses are from 1.5 to 2.5 dB/m in the 27.0- to 31.0-GHz frequency band. However, calculated losses are from 1.23 to 1.41 dB/m in the same frequency bands, when the conductivity σ of phosphor bronze is 1.67×10^{7} mho/m, the relative dielectric constant ϵ_r of PTFE is 2.06 and $\tan\delta$ is 1.5×10^{-4}. The measured losses are greater than calculated at the higher frequency. This is because of the appearance of the higher mode. At the lower frequency, considering the difference between the practical values of σ, ϵ_r, and $\tan\delta$ and the nominal values, the measured values coincide with the calculated values.

IV. Antenna Design

The slot array antenna fed by the image line was designed to operate at 29.5 GHz. The number of slots is 2×10.

The image line shown in Section III-C is used for this antenna. The transverse propagation constants k_x and k_y in this line are 2.49×10^{2} rad/m and 2.97×10^{2} rad/m, respectively. Therefore, the wavelength λ_g in this line is calculated as 7.9 mm from (3), and the wavelength shortened ratio η_g is 0.774.

The slot spacings d_1 and d_2 and the angle ϕ are selected as 2.0 mm and 7.9 mm, and $\pi/4$ radians, respectively, so as to obtain a circularly polarized main beam at broadside, without considering the mutual coupling. The slot length a_s and width b_s are 4.5 and 0.3 mm, respectively, so as to operate at 29.5 GHz. Slots are placed at the distance $\delta = 1.0$ mm from the center line, and are not crossing each other.

V. Experimental Results

A. Measurement Conditions

The antenna electrical characteristics are measured in the radio anechoic chamber at frequencies from 27.0 to 31.0 GHz.

A conical horn antenna was used as a transmitting antenna for the measurements of the gain and the radiation patterns, and a pyramidal horn antenna was used for the measurements of the axial ratio. The transmitting antenna was placed 18.3 m away from the antenna positioner. This distance is a far-field region for antenna measurements.

The slot array antenna was measured by using the rectangular horns as a launcher, as shown in Section III-C.

B. Gain

Antenna gain was measured at the output port by comparing it with a standard gain conical horn. The measured gain is 10.7 dB at 29.5 GHz. The gain reduction factors are mainly (i) image line loss, (ii) launching loss to image line, and, (iii) power loss to dummy load. Image line loss, launching loss and power loss to dummy load are 0.4, 0.2, and 0.1 dB, respectively.

C. Directivity

Fig. 5 shows the radiation patterns in the XZ plane at 29.0 and 29.5 GHz. Half power beam width (HPBW) is 8.8° at 29.5 GHz.

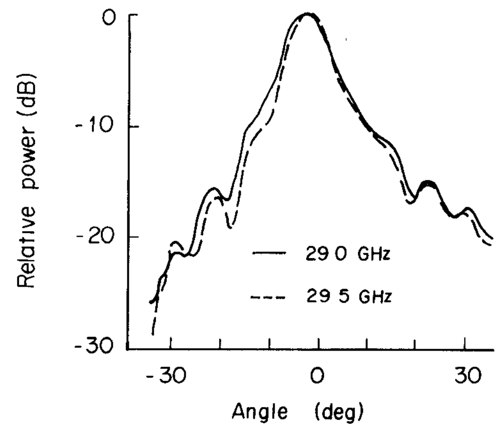

Fig. 5. Measured radiation patterns in the XZ plane.

Fig. 6 shows the measured direction of the main beam and the calculated value from (1). The measured direction of the main beam is tilted to the output port at 2.5 degrees from broadside.

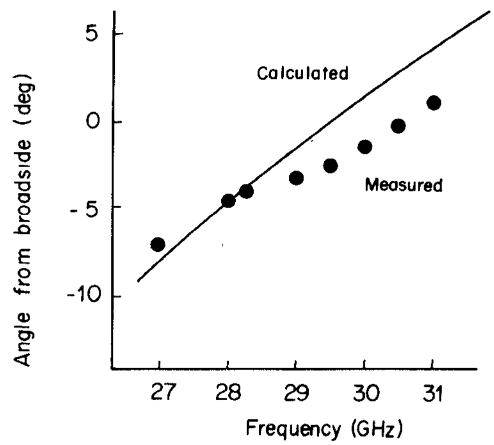

Fig. 6. Main beam direction.

The estimated wavelength shortened ratio η derived from each measured value of Fig. 6 by (1) is shown in Fig. 7. In this figure, the calculated shortened ratio η_g from (3) is also shown. At 29.5 GHz, η equals 0.804 and η_g equals 0.774. The wavelength shortened ratio η varies a little from the ratio η_g in the image line because of the arrangement of the slots, and is greater than the ratio η_g.

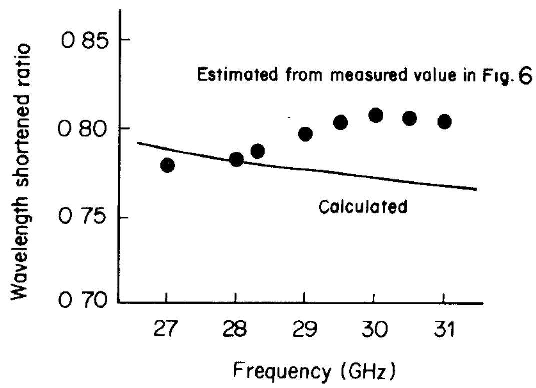

Fig. 7. Wavelength shortened ratio.

D. Axial Ratio

The axial ratio is defined as the ratio of the maximum power to the minimum power.

Fig. 8 shows the frequency dependence of the axial ratio. The solid line indicates the measured axial ratio in broadside and the broken line indicates the measured one in the direction of the main beam. This antenna has good polarization characteristics in the 29.0- to 29.5-GHz frequency range. The frequency band within the 1-dB axial ratio is more than 1.2 GHz (4 percent), and is more than 2.0 GHz (7 percent) within the 2-dB axial ratio.

Fig. 9 shows the angle dependence of the axial ratio. These values are measured at 29.0 and 29.5 GHz. The angle range within the 1-dB axial ratio is more than ±5.6 degrees from broadside, and is more then ±7.8 degrees within the 2-dB axial ratio.

This antenna has wide-band characteristics in the axial ratio and better circular polarization characteristics over wide angles than microstrip line array antennas [3], [4].

E. VSWR

Fig. 10 shows the measured VSWR characteristics. At frequencies from 27.0 to 31.0 GHz, VSWR is less than 1.4.

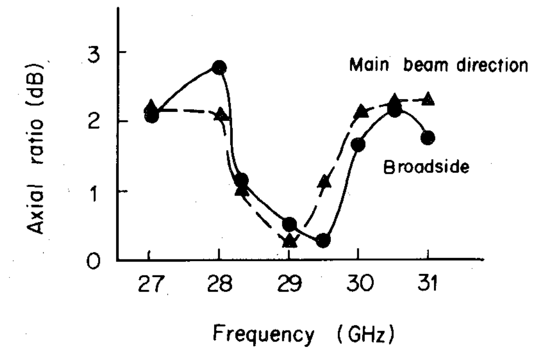

Fig. 8. Frequency dependence of measured axial ratio.

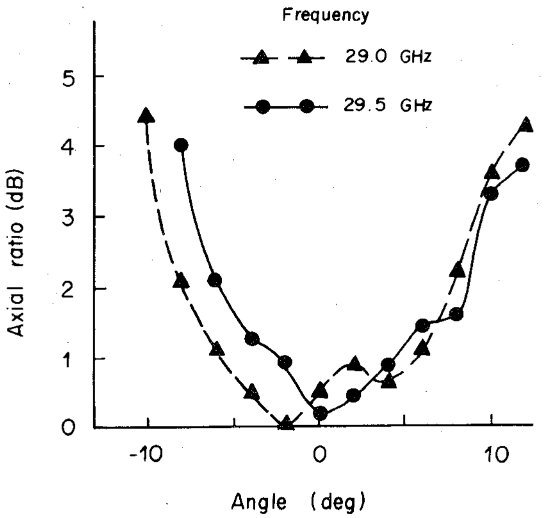

Fig. 9. Angle dependence of measured axial ratio.

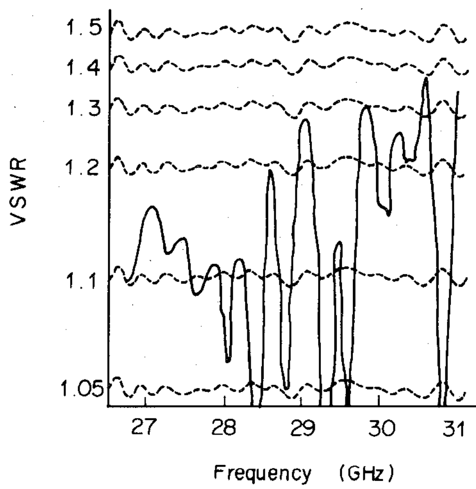

Fig. 10. Measured VSWR.

The periodicity in the data is caused by multiple reflection between the launchers of the input and dummy ports.

VI. Conclusion

A circularly polarized slot array antenna fed by a dielectric image line has been designed, and its measured characteristics have been examined.

The image line losses are about one fifth the microstrip line decibel losses in the millimeter wavebands, and a low loss feed system can be realized by the image line in the millimeter wave bands.

Antenna measurements showed that the bandwidth within the 2-dB axial ratio was more than 7 percent, and the angle range within the same ratio was more than ± 7.8 degrees at 29.5 GHz.

This slot array antenna is far superior to the microstrip line feed array antenna in the millimeter wavebands.

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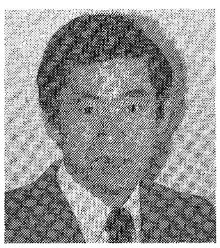
Takao Itanami, for a photograph and biography please see page 978 of this issue.



Toshikazu Hori was born in Hikone, Shiga, Japan, on December 8, 1950. He received the B.S. and M.S. degrees in electrical engineering from Kanazawa University, Japan, in 1974 and 1976, respectively.

From 1974 to 1976 he was engaged in the research of the electromagnetic wave theory in the Ionosphere. Since joining Yokosuka Electrical Communication Laboratory, Nippon Telegraph and Telephone Public Corporation, Yokosuka-shi, Japan, in 1976, he has been engaged in the development of the 30/20 GHz band Cassegrain and offset Cassegrain earth station antennas for the Japanese domestic satellite communication system. His current research interests are the development of scanning antennas and array antennas.

He is a member of the Institute of Electronics and Communication Engineers of Japan.