Quasi-Optical Components Using Total Reflection in Dielectrics

Abstract—**Two quasi-optical components operating at 90 GHz which use the effects of a metal plate on total reflection are described. A circular polarizer and, with the addition of a metal plate grating, a device having properties similar to a tuned turnstile junction were constructed. Experimental results showed better than 99 percent polarization conversion for the polarizer.**

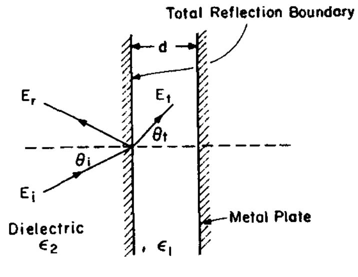

Fig. 1. Coordinate system for metal plate and totally reflecting boundary.

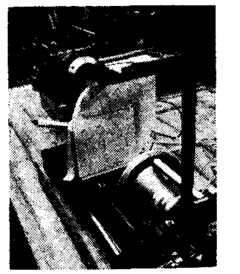

Fig. 2. Dielectric parallelepiped between two horn antennas.

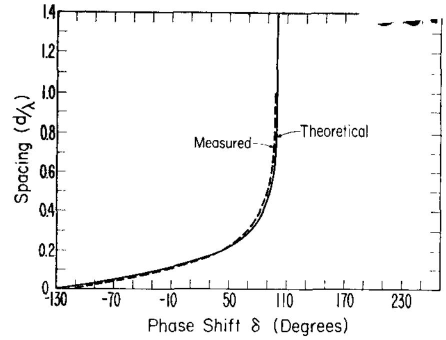

Fig. 3. Relative phase shift δ through the parallelepiped.

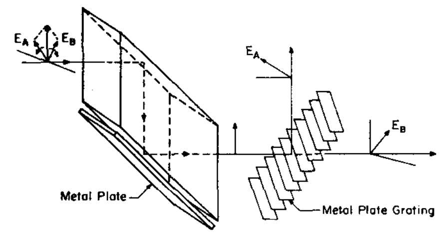

Fig. 4. Quasi-optical "turnstile junction."

As shown by Culshaw and Jones [1], the phase shift of a totally reflected plane wave can be controlled by a conducting boundary parallel and in close proximity to the totally reflecting boundary as shown in Fig. 1. The relation between the dielectric constants ϵ are $\epsilon_2 > \epsilon_1$. The relative phase shift between the reflected wave and the incident wave is a function of the separation d. When the electric field lies in the plane of incidence and $\epsilon_1 = \epsilon_0$ (air), the phase shift $\delta_{\parallel}$ is given by

$$\tan \frac{\delta_{\parallel}}{2} = \frac{\epsilon_2^{1/2} \alpha \tanh \alpha d}{k \cos \theta_i} \tag{1}$$

where $\alpha = k(\epsilon_2 \sin^2 \theta_i - 1)^{1/2}$. When the electric field is perpendicular to the plane of incidence, the relative phase shift $\delta_{\perp}$ is given by

$$\tan \frac{\delta_{\perp}}{2} = \frac{\alpha}{k(\epsilon_2^{1/2} \tanh \alpha d \cos \theta_i)} \cdot \tag{2}$$

The difference in phase shift between the two polarizations δ is given by

$$\tan \frac{\delta}{2} = \frac{k \cos \theta_i \, (\epsilon_2 \tanh \alpha d - \coth \alpha d) \alpha}{\epsilon_2^{1/2}(\alpha^2 + k^2 \cos^2 \theta_i)} \tag{3}$$

where $\delta = \delta_{\perp} - \delta_{\parallel}$.

The ability to control phase shift upon reflection was used by the author in the design of two components for operation at 90 GHz. A circular polarizer was constructed by cutting a parallelepiped out of polystyrene with the angles at 45°. The dimensions of the faces by which the energy entered and left the dielectric parallelepiped were 4¾ by 4¼ inches. These faces of the dielectric were matched to free space by a quarter-wave impedance transformer which consisted of rectangular slots cut into the dielectric in orthogonal directions. The slots were designed from information given in [2]. The parallelepiped is shown in Fig. 2 between two horn antennas with a metal disk mounted on the end of a micrometer. The transmitting horn, which is in the foreground, was oriented so that the polarization of the incident linearly polarized wave was 45° to the plane of incidence, thus providing equal fields perpendicular to and lying in the plane of incidence The receiving horn was mounted so it could be rotated about its axis and determine the ellipticity of the transmitted wave. The transmitting and receiving horns had 3-inch diameter circular apertures with phase correcting lenses. Their Rayleigh distances $D^2/2\lambda$ at 90 GHz were about 35 inches. The separation between the transmitting horn and the receiving horn was 20 inches or approximately 0.6 Rayleigh distances.

The relative phase shift between the waves with the electric field perpendicular to and lying in the plane of incidence is shown in Fig. 3 as a function of the plate spacing normalized to the wavelength. As can be seen in Fig. 3 two positions of the metal plate yielded circular polarization but of opposite senses. The sense of polarization could be reversed by rotation of the polarization of the incident wave by $\pm 90°$. More than 99 percent of the energy emerging from the polarizer was circularly polarized for either of these two positions.

Circular polarization can be achieved on only one reflection using the metal plate but for only very close plate spacings. Two reflections, one reflection not influenced by a conducting boundary, as used by the author produced circular polarization at larger plate spacings where reduced alignment requirements and greater bandwidths were available.

A second device was constructed by adding a metal plate grating to the device just described as shown in Fig. 4. The parallelepiped and metal plate were again adjusted to produce circular polarization. A plane linearly polarized wave was incident on the parallelepiped from the left. Because this incident wave was composed of a left and right circularly polarized wave, two linearly polarized waves, orthogonal to each other, emerged from the parallelepiped. The metal plate

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grating transmitted the wave polarized perpendicularly to the plane of the plates and reflected the other. This function is identical to that performed by a properly tuned turnstile junction [3]. Gratings which separate orthogonal linearly polarized waves have been explained by Fellers [4].

In summary, the use of two total reflections and a metal plate for producing circular polarization at 90 GHz was successful and agreed with the theoretically predicted results quite well. The use of the adjustable spacing metal plate has the obvious advantages of not having to know the dielectric constant of the material accurately and of obviating the need for cutting precise angles. Double reflection has the advantage of operation at a point where greater bandwidth and reduced tolerances are obtainable.

D. W. Hanson
Radio Standards Engrg. Div.
National Bureau of Standards
Boulder, Colo.

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