the feed components were designed to achieve both flat gain and phase across the operating band. Measured amplitude response of the final feed showed a gain ripple of less than 0.3 dB and a phase ripple of less than ±2° across the entire 9.5- to 10.5-GHz operating band.

ACKNOWLEDGMENT

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A Mode Transducing Antenna

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***Abstract*—At power levels above those readily handled by standard waveguide, and for long waveguide runs, the TE_{01} mode in circular guide is a preferred transmission line approach. At the antenna, this mode is generally unsuited to radiation since it forms a conical, instead of a pencil beam. Phase and polarization shifting techniques at a reflecting surface cause the illumination to be transduced to form a pencil beam. The techniques have been demonstrated in a 33-GHz model.**

I. INTRODUCTION

AN ANTENNA radiating a pencil beam when fed from a circular waveguide operating in the TE_{01} mode is a desirable component for extremely high power systems. Such an antenna has been demonstrated.

The TE_{01} mode in circular waveguide has several desirable features. It is a low-loss mode. It has a large cross section which permits it to guide high total power at moderate power densities. Wall currents are circumferential; longitudinal contact is not required in waveguide section joints. As a result, rotary joints are simple. Mode conversion tends to be low for the usual discontinuities associated with tolerances in the guide and in the assembly. All modes except the TE_{0n} are readily absorbed, thus avoiding coherent energy transfer into other modes by repeated discontinuities. A new class of extremely high power generators, the "gyrotron" or "cyclotron-master" [1], operates in the TE_{01} mode, increasing the interest in this mode.

In the antenna, a circular TE_{01} mode has a fundamental limitation; it is circularly symmetrical and radiates a conical beam with a null on axis rather than a pencil beam [2]. The fields must be converted to those which produce an acceptable pencil beam, either before the antenna or in the antenna. This is accomplished in the mode transducing antenna, in any of its several configurations; an input TE_{01} mode is transformed to radiate a pencil beam with either a circular or a linear polarization. Monopulse operation is feasible with a mode-separating feed assembly. Applications of the mode-transducing antenna all feature low-loss lines to handle extreme power levels. Examples are millimeter wave radars (search or track), satellite communications earth stations, and millimeter wave point-to-point communications.

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II. THE MODE TRANSDUCING ANTENNA

The basis of the mode transducing antenna is the adjustment of the phase and polarization of the wave in the aperture by a modified reflecting surface in the antenna. The approach could also be implemented in transmission through a lens. If a TE_{01} mode were radiated from a circular aperture and the far zone field were probed with a linearly polarized receiver, the three and 6-dB contours for one linear component of the field would appear as shown in Fig. 1. The orthogonal linear polarization contours are identical to those shown, but rotated 90° mechanically about the center of the aperture. These components are in phase. Circular polarization is available by phase correction only, while linear polarization requires a twist-reflector [3] for efficient implementation. The reflection surfaces can be at the folds in folded circular horns, the main reflector in a single-reflector antenna, or the subreflector in a Cassegrain-type or other multiple reflector antenna.

III. MODEL TESTS

Three practical configurations of mode transducing antenna were demonstrated at 33.5 GHz in a folded conical horn antenna as shown in Fig. 2. The basic folded horn was described in 1963 [4] and a different application of

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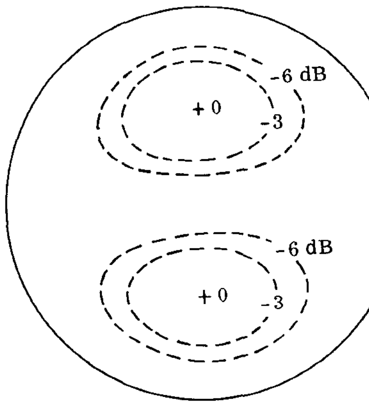

Fig. 1. Horizontally polarized component of TE_{01} mode illumination.

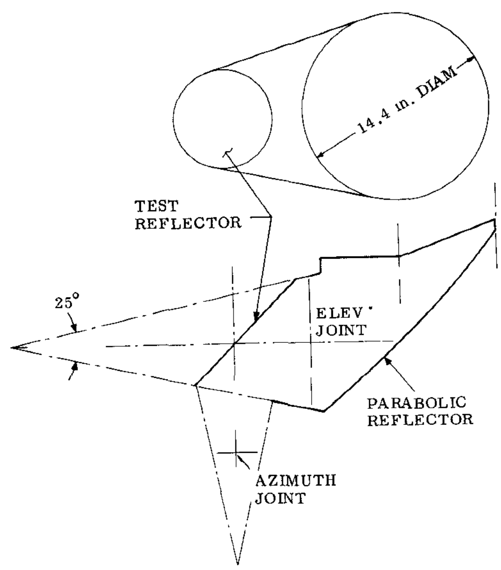

Fig. 2. Test antenna configuration.

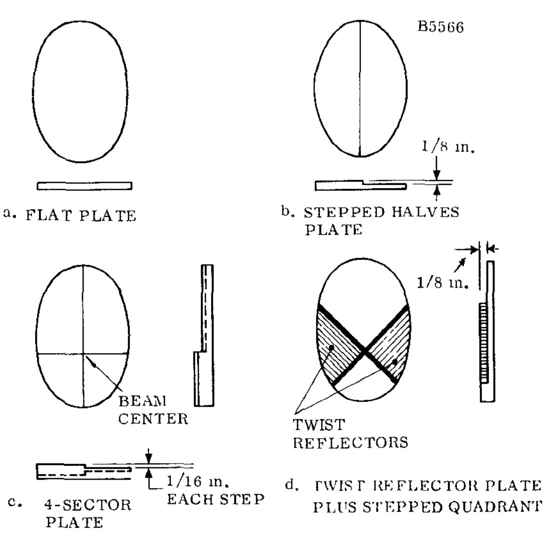

Fig. 3. Test reflector configurations.

folding appeared recently [5]. The reflector plates appear in Fig. 3. The plates are elliptical since they were installed as the test reflector in the fold of the folded horn. The plate was 21.7×31.3 cm or 24×35 wavelengths on its active minor and major axes. The flat plate was the reference case, providing a pencil beam from a TE_{11}

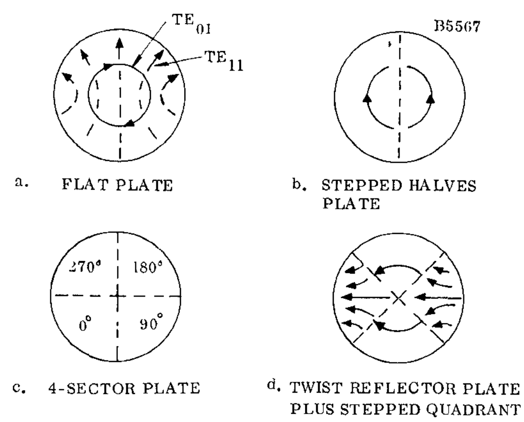

Fig. 4. Field configurations.

TABLE I
RESULTS

CASE	TE_{11} flat plate	TE_{01} four sector	TE_{01} twist reflector
Polarization	linear	circular	linear
Measured gain (dBi)	40.8	37.8 est each polarization	39.2
3-dB Beamwidth			
E-plane	1.6°	2.27	1.8°
H-plane	1.9°	1.43	1.6°
1st Sidelobe (dB)			
E-plane	-17.5	very low	-21
H-plane	-26	-9	-14.6
Cross polarization (dB)			
on-axis	low	-	below -26
max	-25	-	-13

mode, or a conical beam with a TE_{01} mode feed. The first conversion is provided by the stepped-halves plate. The field component parallel to the step is converted; the cross component cancels on axis. This introduces an inherent 3-dB gain loss, but provides linear polarization on-axis. Next, the four-sector plate produces a circularly polarized beam on axis by shifting the fields in each quadrant successively by one-quarter wavelength. Finally, the twist-reflector plate converts the polarization of the side sectors to match that of the top and bottom, reducing the loss of the cross-polarized component. Fig. 4 shows the resulting field configurations viewed along the propagation axis.

Samples of the patterns taken to verify the validity of the concept of a mode transducing antenna appear in Fig. 5, and the results are summarized in Table I. Since the objective was only validation of the concept, simple plates were assembled in the lab and a transition from WR26 waveguide to circular waveguide was scaled from a lower frequency. The mode purity was not measured except to the extent that the pattern with a flat plate (Fig. 5(a)) gave expected results. Plate steps utilized stock thicknesses which were close to the calculated values. Thus the results represent a less-than-finished design check, and must be interpreted with recognition of the test-part limitations.

The mode transducing antenna was tested in a folded horn model residual from a prior program where the fold

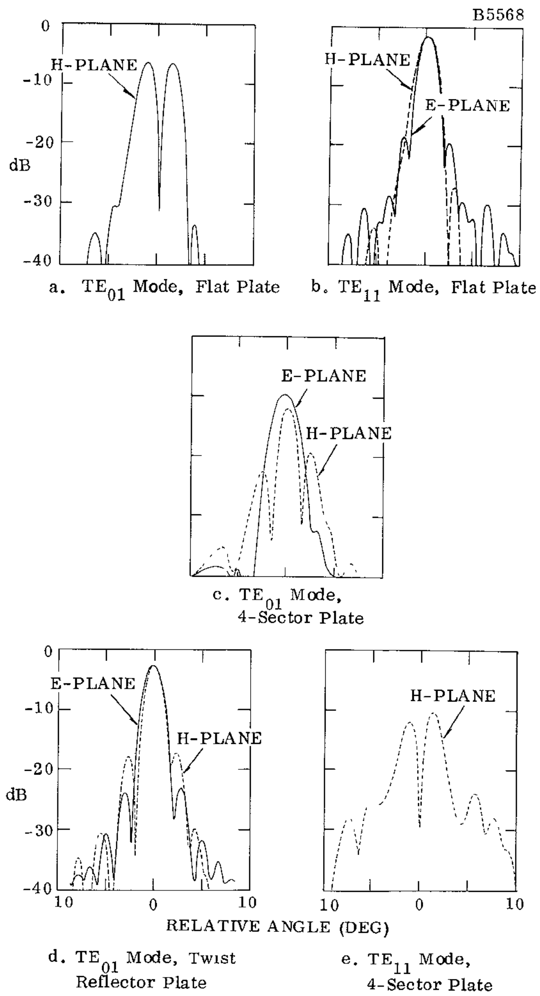

Fig. 5. Measured patterns.

was a flat plate. This was fed by a simple transition from TE_{10} rectangular waveguide formed by the intersection of the WR26 waveguide and the 25° cone of the antenna. The TE_{11} mode pattern is shown in Fig. 5(b) and the numerical results are tabulated for reference.

The four-sector plate in Fig. 3(c), and the fields of Fig. 4(c), phase both the horizontal and vertical components of an incident TE_{01} mode into pencil beams in time quadrature. One of these is shown in Fig. 5(c), E- and H-plane. The two polarizations together form a "circularly" polarized beam. The known errors in the step size precluded accurate ellipticity measurements.

A twist reflector was fabricated by milling a grating with quarter-wavelength-deep grooves between lands as narrow as the machinist felt practical. Two sectors of the reflector were made from this, the remaining two from flat plate as in Fig. 3(d). The fields which result from an incident TE_{01} mode are indicated in Fig. 4(d) and the patterns in Fig. 5(d). A pencil beam was formed. The design accuracy of the twist reflector was not checked except by the antenna patterns. Somewhat better performance should be possible with more effort on the reflector design.

The ability to generate difference signals by these techniques is indicated by the results in Fig. 5(e). The antenna with the four-sector plate was fed by the rectangular guide-to-cone transition which establishes a TE_{11} mode in the circular cross section of the conical guide. As expected, the result is a double-lobed pattern suitable for monopulse operation. The separation of two orthogonal TE_{11} modes from the TE_{01} mode is not a trivial task, but several approaches, all promising, have been identified.

The work described was very preliminary, intended only to demonstrate the concept. The four-sector reflector is a coarse approximation to a spiral reflector. Excellent on-axis circularity should be attained either with a smooth spiral or with optimized, multisector stepped plates. The fabrication of a high-quality twist reflector in the millimeter-wavelength region requires great care, and probably should be done by techniques other than utilizing mill saws. There is every expectation that approaches where the mode transducing is at the parabolic surface or at a subreflector in the conventional Cassegrainian antenna should be successful.

Checks of performance were made of the same antenna fed in the TM_{01} mode, where the electric fields are perpendicular to those of the TE_{01} mode. This mode was of interest only because it provides the orthogonal polarization in space to that of the TE_{01} mode. It is characterized by strong E-fields at the aperture edge. The natural field taper is the reverse of that desired in a low sidelobe antenna. The results were as anticipated, very high sidelobes.

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