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# A DUAL-MODE FEED HORN FOR X-BAND

The DUAL-MODE or IMU feed horn which was developed in the 1960s is still a very efficient feed for a circularly symmetric parabolic reflector antenna. This feed has been widely used at 1296 mc/s and higher because of its excellent radiation characteristics with a single beam pattern having essentially no sidelobes in the side or rear directions.

At 10.368 GHz (X-band) the DUAL-MODE feed is relatively small and easier to fabricate. The troublesome part is the conical flare section which joins the two circular waveguides, feed line and aperture. By a stroke of good fortune, there is a copper water pipe plumbing fitting which is very close to the correct flare angle of 30 degrees. This fitting is called a FITTING REDUCER which has a part designation of FXC, in the U.S.A. It has a nominal flare angle of 40 degrees and the small end will accept a standard 3/4 inch copper water pipe inside, while the large diameter end is the same nominal size as a 1-1/2 inch copper water pipe.

A 3/4 inch Type-M copper water pipe which is generally available from many sources including hardware and building supply houses, Rickel's, Channel Lumber, etc., makes an excellent single mode circular waveguide (CWG) at the amateur radio X-band frequencies. The pipe is not precision round and some difficulty will be encountered when using a long CWG feedline. The slightly elliptic cross section can cause differential phase shift resulting in elliptic polarization unless precautions are taken to align the linear polarization with one of the major axes of the ellipse. Even then, twisting of the elliptic cross section will make it difficult or impossible to maintain linear polarization over long line sections. Even 3 feet is a long line at X-band.
Some experience with standard 3/4 inch copper pipe indicates that though the cross section may be out-of-round by as much as 0.010 inches, or more, the process of manufacture and handling results in a uniform ellipticity along the pipe. Still, a given long section must be evaluated by direct measurement to determine its characteristics.

## Fabrication

This *modified* DUAL-MODE small aperture horn is constructed entirely of standard copper pipe fittings, requiring no more than a file, hacksaw and a propane torch for sweating the parts together. Figure 1 shows a complete cross sectional drawing with all important dimensions and details.
The aperture diameter is the inside diameter of a 1-1/2 inch copper COUPLING, nominally 1.65 inches, which fits easily over the FITTING REDUCER larger diameter.

The 1/8 inch diameter soft copper tubing sweated into the large end corner of the flare should be formed (wound) around a round mandrel of appropriate size such that the ring is a snug fit inside the REDUCER. Make the gap in the ring snug so that solder will flow into the gap and form a continuous conductive ring. This ring should be sweated into the REDUCER first.

The purpose of the ring is to increase excitation of the TM11 mode so that the E and H plane radiation patterns are nearly matched.

Note that the 3/4 inch copper pipe is inserted only 1/4 inch into the small end of the REDUCER. This was found to be the nominal insertion position to make the discontinuities act as an impedance tuner with resulting very low VSWR. When the feed is constructed as shown the return loss will be better than - 25 dB at the design frequency of 10.368 GHz, and is not critical or narrow band for amateur radio purposes.
Because of this small overlap (pipe to coupling) it will be necessary to position the parts in good center line alinement with a simple prop jig when sweating the parts together in a horizontal position.

At the large end of the FITTING REDUCER, a standard pipe COUPLING is used as part of the differential phase section. This section along with the large REDUCER diameter form a dual mode CWG which is adjusted in length to provide 270 degrees of differential phase shift between the TE11 and TM11 modes. Since the conical flare and ring excite the TM11 mode in quadrature with the driving TE11 mode, it is necessary to shift their differential phase by 270 degrees so that the modes sum at the center of the aperture. The resulting aperture field distribution around the rim of the aperture is very low which results in the very low side and rear radiation characteristics.

Sweat all the remaining parts together with solder paste and a minimum of solder. Once solder has gotten inside the pipe wall it is difficult to remove. If this happens disassemble the parts, clean and remove all trace of solder from the inside exposed surfaces. Then reassemble and use less solder.

A standard 3/4 copper pipe coupling is used as a simple connector to another 3/4 inch copper pipe, or what ever means of exciting the CWG that you have on hand. This coupling is slotted at the open end with six equi-space slots approximately half way along the part. A simple hose clamp is then used to lock the coupled joint.

## Radiation Characteristics

This modified version of the IMU DUAL-MODE feed antenna can be used to front feed a parabolic reflector with an f/d = 1. However, it was specifically designed to illuminate a hyperbolic subreflector in a Cassegrainian reflector antenna system.

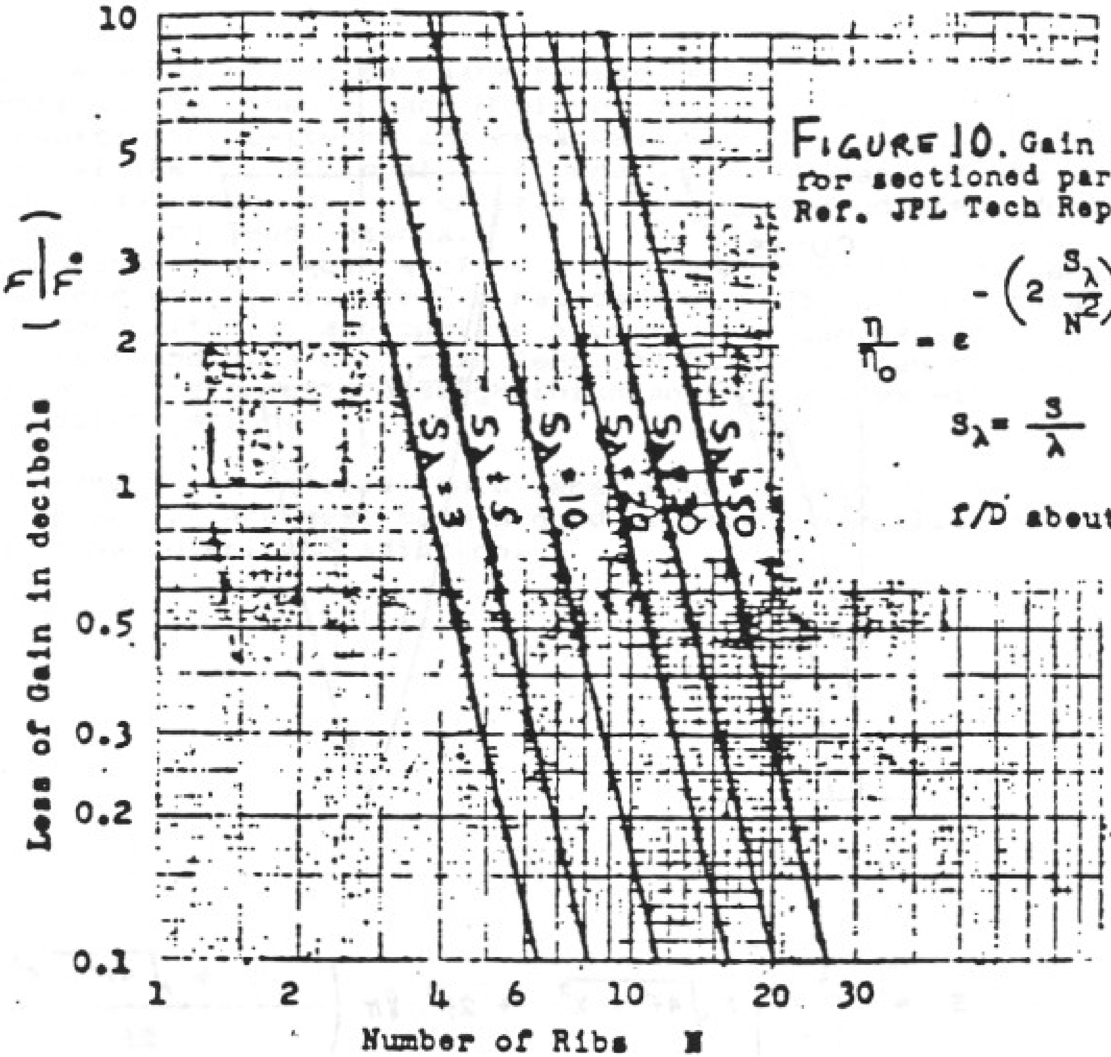
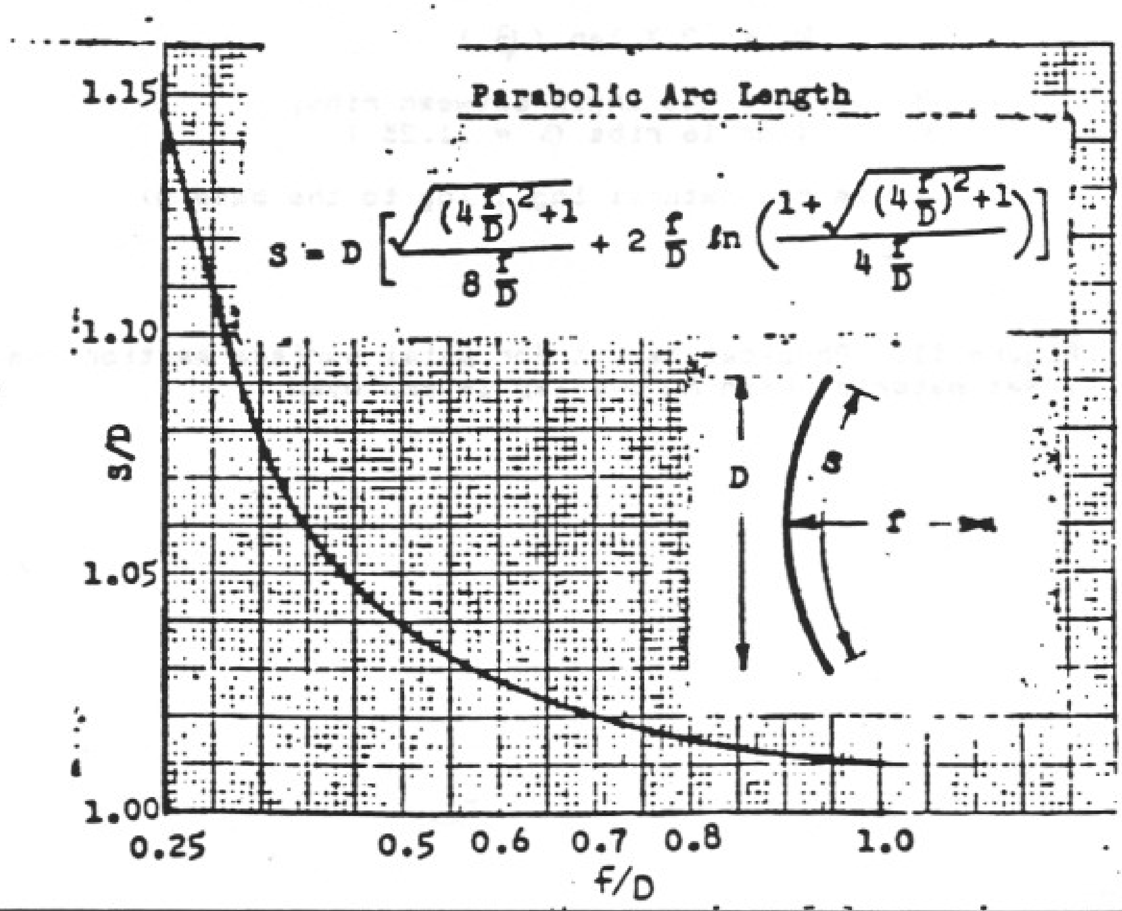



FIGURE 10. Gain degradation for sectioned paraboloid
Ref. JPL Tech Rept 32-1352

$$\frac{\eta}{\eta_0} = e^{-\left(2\frac{S_\lambda}{N^2}\right)^2}$$

$$S_\lambda = \frac{S}{\lambda}$$

f/D about 0.45




$$S = D\left[\frac{\sqrt{(4\frac{f}{D})^2+1}}{8\frac{f}{D}} + 2\frac{f}{D}\ln\left(\frac{1+\sqrt{(4\frac{f}{D})^2+1}}{4\frac{f}{D}}\right)\right]$$

The measured radiation characteristics at 10.368 GHz are almost identical in the E and H planes down to the -10 dB level. Thereafter the patterns are remarkably similar in characteristics even at the -35 dB level. Figure 3 is a average of the E and H plane radiation characteristics for this modified dual-mode circular horn feed antenna.
For parabolic reflectors of 48 inch diameter or larger, and with more commonly available f/d ratios from 0.35 to 0.5, this feed together with an appropriate subreflector can result in a very efficient and high gain rear feedline Cassegrainian antenna.
Figure 2 indicates a Cassegrainian antenna system with circular feed polarization.

As a *tand-alone antenna* this version has a gain of 14.3 dBi at 10.368 mc/s, and will make a good Gaussian beam illuminator with low cross polarized radiation.

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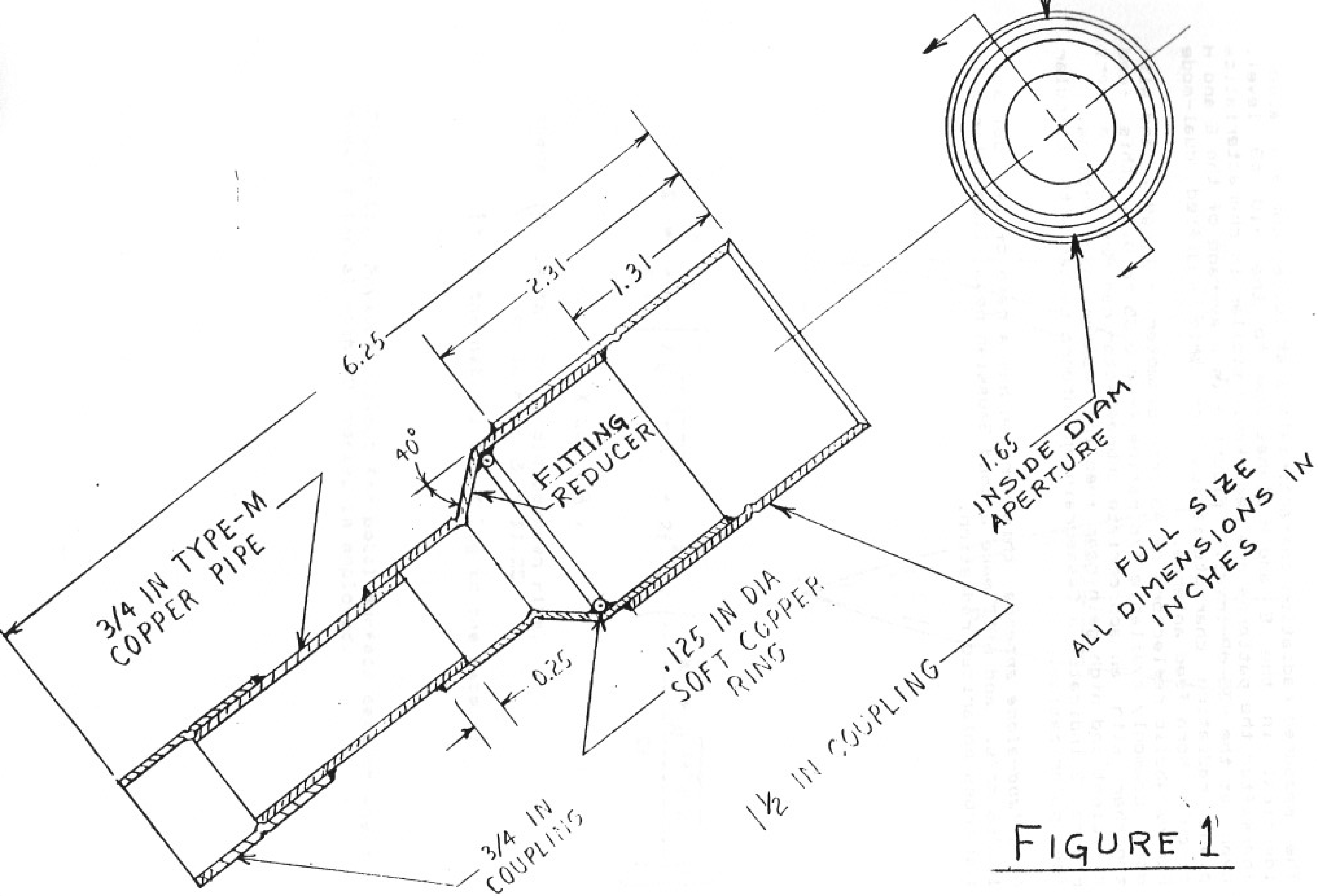


FIGURE 1

DUAL-MODE MODIFIED DESIGN
SIMPLIFIED CONSTRUCTION

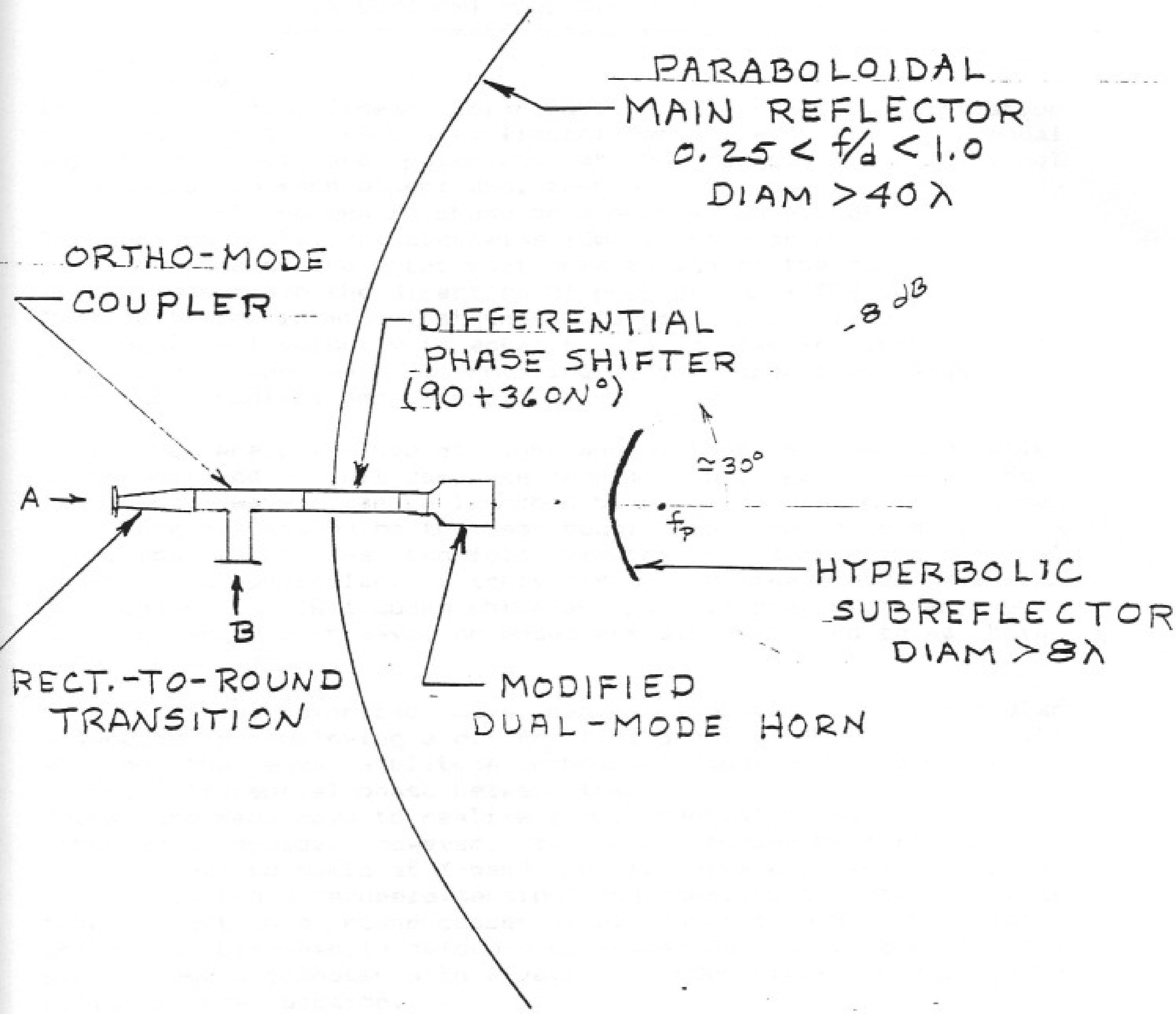


FIGURE 2

CIRCULARLY POLARIZED
CASSEGRAINIAN ANTENNA SYSTEM

A & B ARE RECT. W.G. PORTS OF OPPOSITE
CIRCULAR POLARIZATION

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# A DIFFERENTIAL PHASE SHIFTER FOR X-BAND IN DOMINANT MODE CIRCULAR WAVEGUIDE

## Introduction

Conversion from linear polarization to circular polarization involves first having two linearly polarized waves of equal amplitude that are polarized at 90 degrees in rotational orientation to each other; and, then delaying one of the waves by 90 electrical degrees in phase or a quarter wavelength in space. The sense of rotation, clockwise (CW) or counter clockwise (CCW), is determined by the rotational orientation of the composite wave as it proceeds in the direction of propagation (IEEE definition). One must keep in mind that the above description is one in which the rotational velocity is equal to the angular frequency $\omega = 2\pi f$, i.e., the wave is rotating at the operating angular frequency, radians per second.

Waves that are polarized at right angles to each other are called orthogonal and exhibit complete anonimity with each other. Such orthogonal waves can be launched by means of a pair of crossed yagi antennas nested on the same boom; and, can also exist in a waveguide which has two-fold symmetry to support orthogonal modes. In particular, a truly circular dominant mode waveguide can support two TE11 modes which are polarized at right angles to each other. Such waves or modes are also referred to as being cross polarized.

A circularly polarized wave can be generated in a circular waveguide by employing a differential phase shifter which will act on the equal amplitude orthogonal modes and produce a 90 degree differential phase between them.
There are many ways to realize a differential phase shifter in circular waveguide, however, the method chosen here is probably the easiest to build at X-band and will give excellent results. It is called a "squeeze section" and consists of nothing more than a section of round copper pipe, about 6 to 8 inches long, which is permanently deformed by squeezing the mid area of the pipe across a diameter with a pair of wooden blocks into slightly elliptic cross section.

Surprisingly little deformation is required to obtain the desired 90 degree differential phase. The squeezing should be done in a smooth even taper and be as symmetric as possible so that the cross section of the deformed pipe is round at each end and gradually transformed to elliptic at the center.

When the pipe is deformed into an elliptic cross section, the notion of differential phase shift can be easily shown. Figure 1A shows an exagerated view of an elliptic cross section

with TE11 modes polarized along the major (a) axis; and, Figure 1B polarized along the minor (b) axis of the ellipse. These exagerated views are presented to show that the cross sections resemble rectangular waveguide sections with heavily rounded corners.
With this analogy it follows that the height of the "rectangular" guide determines its charcteristic impedance while the width determines the cut-off wavelength. That is, the lower the guide height, the lower the impedance while the wider the guide width the longer the cut-off wavelength (lower cut-off frequency).

Unlike familiar TEM mode transmission lines like coax or open wire lines where the wave propagation velocity is the same over a vast r-f frequency range, waveguides behave like low-pass filters and have a definite cut-off frequency where they will cease to carry r-f energy. But more importantly, for any given propagating mode, its velocity is not constant with frequency. This last property is called dispersion and is crucial to, and makes possible the "squeeze section" differential phase shifter.

For any mode in any waveguide the wavelength of the r-f energy inside the guide is :

$$\lambda_{guide} = \frac{\lambda_o}{\sqrt{1 - \left(\frac{\lambda_o}{\lambda_{co}}\right)^2}}$$

where $\lambda_o$ is the "free space" wavelength and $\lambda_{co}$ is the cut-off wavelength, always longer than the operating wavelength.
Each guide wavelength represents 360 degrees of phase along the axial dimension of the guide.

It should now be evident that for the slightly deformed "squeeze section" the cut-off wavelengths for the TE11 modes polarized along the ellipse major and minor axis will have slightly different cut-off wavelengths.
A slightly shorter cut-off wavelength for the narrow (b) width ellipse, Figure 1A, and slightly longer cut-off wavelength for the wider (a) width ellipse, Figure 1B. It then follows from the above equation for the guide wavelength that the shorter cut-off wavelength will result in a longer guide wavelength; and the longer cut-off wavelength will result in a shorter guide wavelength. And that these guide wavelengths will be slightly longer and shorter than the circular guide wavelength. Here then is the notion of differential phase shift.

As the two equal amplitude orthogonal modes propagate through the "squeeze section" they will be sped up in the narrow width case and slowed down in the wide width case when compared with the circular guide velocity. The length of the "squeeze section" and its deformation will determine how much the difference in wave velocities will be as they pass through. Here we are interested