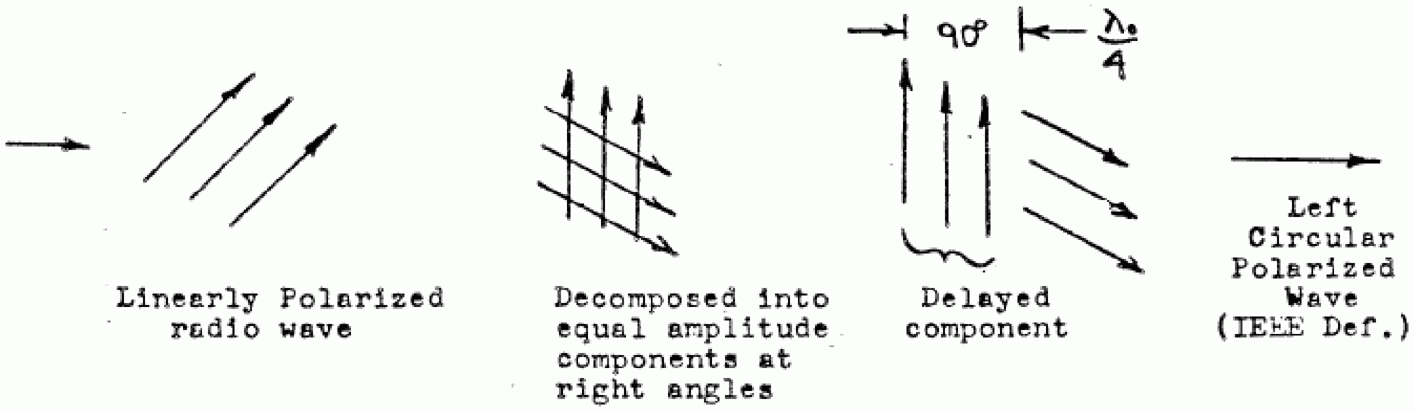
Technical/Report #9

From: The Crawford Hill VHF Club, W2NFA

Date: December 1971

Subject: **A CIRCULARLY POLARIZED FEED ANTENNA FOR 1296 mc/s.**

To convert a linearly polarized radio wave into a circularly polarized wave the process is to decompose the linear wave into two components which are equal in magnitude and phase and are at right angles to each other. Then cause one of the components to be advanced or delayed in phase by 90 degrees with respect to the other. This process is illustrated vectorially step-by-step below. The wave is propagating from left to right on the page.

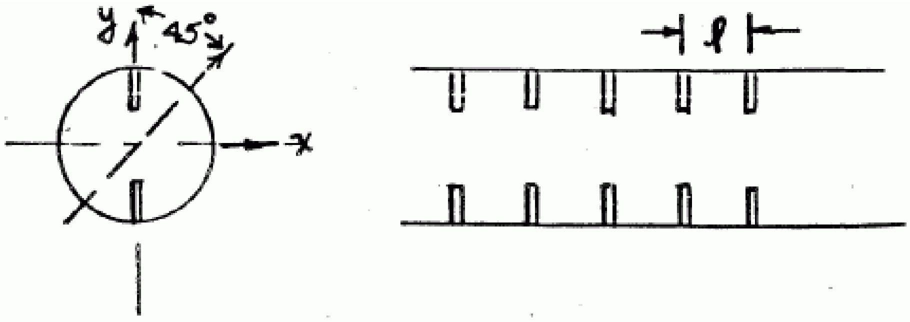


In Technical Report #2, it was suggested that a quadrature hybrid fbe employed to process the radio signal into the proper phase and amplitude components and then radiate the two components through linearly polarized orthogonal (at right angles to each other) antennas. In this report another method or processing the wave is described which can be applied to the high efficiency feed antenna described in Technical Report #5. The processing is done directly in the circular waveguide and no external hybrid is required. Both left and right circular polarizations are available through the original orthogonal coaxial ports on the feed.

A reminder that the sense of circularly polarized wave is reversed .upon reflection. Therefore, with a reflecting type antenna the sense of the feed polarization must be reversed from the desired radiated polarization. Using the convention suggested in Technical Report #1, transmit right circular and receive left circular, the feed antenna ports must be interchanged.

The Method

The method chosen here to °obtain the phase difference between linear components is by means of a periodically loaded circular waveguide, loaded in one plane by means of an array of diametrically symmetric posts.



By introducing a linearly polarized propagating wave in the guide at an angle of 45 degrees with respect to the plane of the posts, this wave IS decomposed into two equal amplitude in phase components linearly polarized in the x and y direction. This constitutes the basic power splitting action.

Now the two waves must be caused to differ in electrical phase by 90 degrees in order for the original linear wave to be transformed into a circularly polarized wave. The phase shift is brought about by the post loaded guide which slows the y polarized component down while the x polarized component is unaffected by the post loading. The reason that the x polarized component does not interact with the posts is that the electric field of the dominant waveguide mode is everywhere at right angles to the posts and so cannot couple. For the y polarized component the posts essentially represent small periodic capacitive loading. (Delay line)

By suitably positioning a number of posts along the guide and adjusting their penetration into the guide, the required 90 degrees of difference phase between the x and y components can be achieved as the wave proceeds down the loaded section of guide. No further phase difference occurs after the wave leaves the loaded section,
and since the guide is circularly symmetric the now circularly polarized wave will continue undist bed.

Polarizer Design

The design of this type of polarizer is uncritical and easy to adjust when certain guidelines are followed. The number of pairs of diametrically opposite posts should be an odd number, 3 pairs being the minimum number. A larger number of posts will result in a physically longer polarizer but less critical and wider in bandwidth. The choice of an odd number of post pair results in an even number of sections results polarizer which gives the minimum VSWR.

The design procedure will be illustrated here for the case shown by Figure 1. Five pairs of posts were selected resulting in **a** four section polarizer. The phase shift per section in this case is therefore 90°/4. = 22.5 degrees.

The differential phase shift between x and y polarized waves in the waveguide for a single section of length l is given by:

$$(1) \qquad \Delta\theta = \beta' l - \beta l$$

where β' is the y polarized wave propagation factor in the guide and

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And the relationship between β' and β in the loaded guide is given in terms of the capacitive suspectance loading (normalized to the guide admittance Y_0) by:

$$(2) \qquad \beta' l = \cos^{-1}\left(\cos \beta l - \frac{B}{Y_0} \sin \beta l\right)$$

$$\beta = \frac{2\pi}{\lambda_g}$$

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In general values of B/Y_o, the normalized capacitive susceptance, below 1.0 are desirable with values below 0.5 peferred.

Equations (1) and (2) have been reduced to *a* family of curves in Figure 2 from which the phase distance $\beta\ell$, between pairs of posts may be obtained for a practical range of $\Delta\theta$ and B/Y_o. Having determined $\beta\ell$, from the equations or Figure 2 for a selected $\Delta\theta$ phase shift per section, the value of ℓ the physical distance between pairs of posts may be evaluated by means of the equations at the bottom of Figure 2.

For the design shown by Figure 1, with $\Delta\theta$ =22.5° per section,

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from Figure 2 $\beta\ell$, = 45°, for B/ Y_o = 0.45. With the 6.5 inch diameter circular waveguide the guide wavelength, λ_g at 1296 mc/s is 16 inches and the separation between pairs of posts is 2.0 inches.

Although the value of B/Y_o, is now determined its actual value is of academic concern since it is quite satisfactory to simply adjust the penetration gradually inward (all posts the same penetration) and sample the emerging wave for circularity. (A method of doing this is suggested at the bottom of Figure 1.) The penetration depth will quickly converge to the proper value as the emerging wave goes from linear polarization through various degrees of elliptic polarization to near circular polarization. It is sufficient to stop adjusting when the max. to min. ratio of the ι elliptic polarized wave is less than 1 db, as this already means that the cross polarized wave (opposite sense polarized wave) i some 25 db below the level of the desired sense polarization.

At this point in the tuning procedure it is best to check the impedance match of the original linearly polarized launchers. In general this should be found to be satisfactory since the conditions ref the design equations have been met empirically. If the match is not good enough (20 db return loss or 1.2 VSWR) it may be improved by trimming the end screws of the polarizer, syminetrically.

A further extension of the design equations permits an exact impedance matched polarizer to be designed. The polarizer loaded waveguide sections now become resonant and exhibit a fixed phase shift per section at one frequency $\beta'\ell = 90^\circ$. The equations which specify this design are:

$$\Delta\theta_{\substack{\text{per}\\ \text{section}}} = 180^\circ - 2\beta\ell$$

and $$\cot\beta\ell = \frac{1}{2}\frac{B}{Y_o}$$

These design equations are from an article by A.J.Simmons, in the IRE Transactions on Microwave Theory and Techniques, December 1955.

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Construction Notes

This polarizer has been applied to the dual mode feed horn described in Technical Report #5 but may be applied to any feed in circular waveguide geometry. With suitable modifications in the design equations for the guide cut-off wavelength, this method may also be applied to square waveguide feeds or antennas.

The only precaution is to allow about a quarter of a guide wavelength or more space between the polarizer and any other obstacles in the guide.

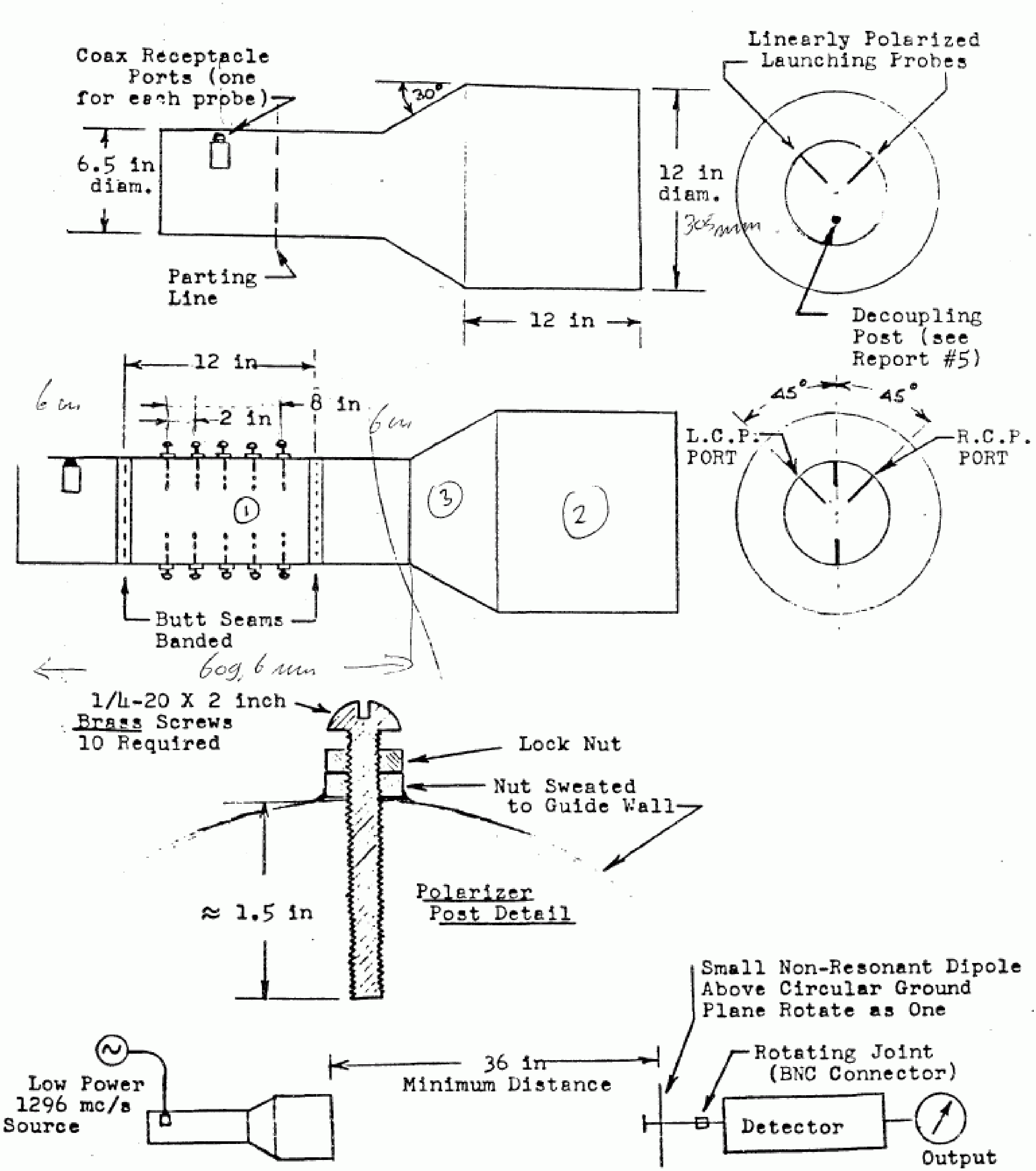
The modifications to the 1296 mc/s dual mode feed are shown by Figure 1 and consist of parting the small diameter section of circular waveguide about midway and splicing in the polarizer section. The choice of a 12 inch long polarizer section is purely from convenience of available sheet brass size. The splices are butt joined with external bands and completely soldered around the joint.

The posts in this design consists of 2 inch long 1/4 - 20 brass screws. A brass nut is first sweated to the sheet brass guide section at the appropriate locations determined from the design. The brass nut serves as a guide for drilling and tapping the sheet brass wall after the nut is soldered in place. A second brass nut is used as a lock to secure the screw adjustment electrically and mechanically.

Measurements of the completed feed as per Figure 1 showed the return loss at each port to be better than 25 db and the ellipticity of the circularly polarized wave for either sense to be about 1 db, with the post penetration as shown. Both the return loss and polarization ellipticity are preserved below 1296 mc/s but depart rapidly above. No attempt was made to optimize the bandwidth as operation over a narrow band ± 100 kc around 1296 mc/s is all that is contemplated.

The cross talk between coaxial ports on the feed was measured at -25 db with the "nulling" post unchanged from the original design.

Figure 1. Modified 1296 mc/s Dual Mode Feed for Circular Polarization.



Rotate sampling dipole slowly and determine ratio of maximum to minimum signal detected level. Be sure that the output indicator can display a 1 db change in level.

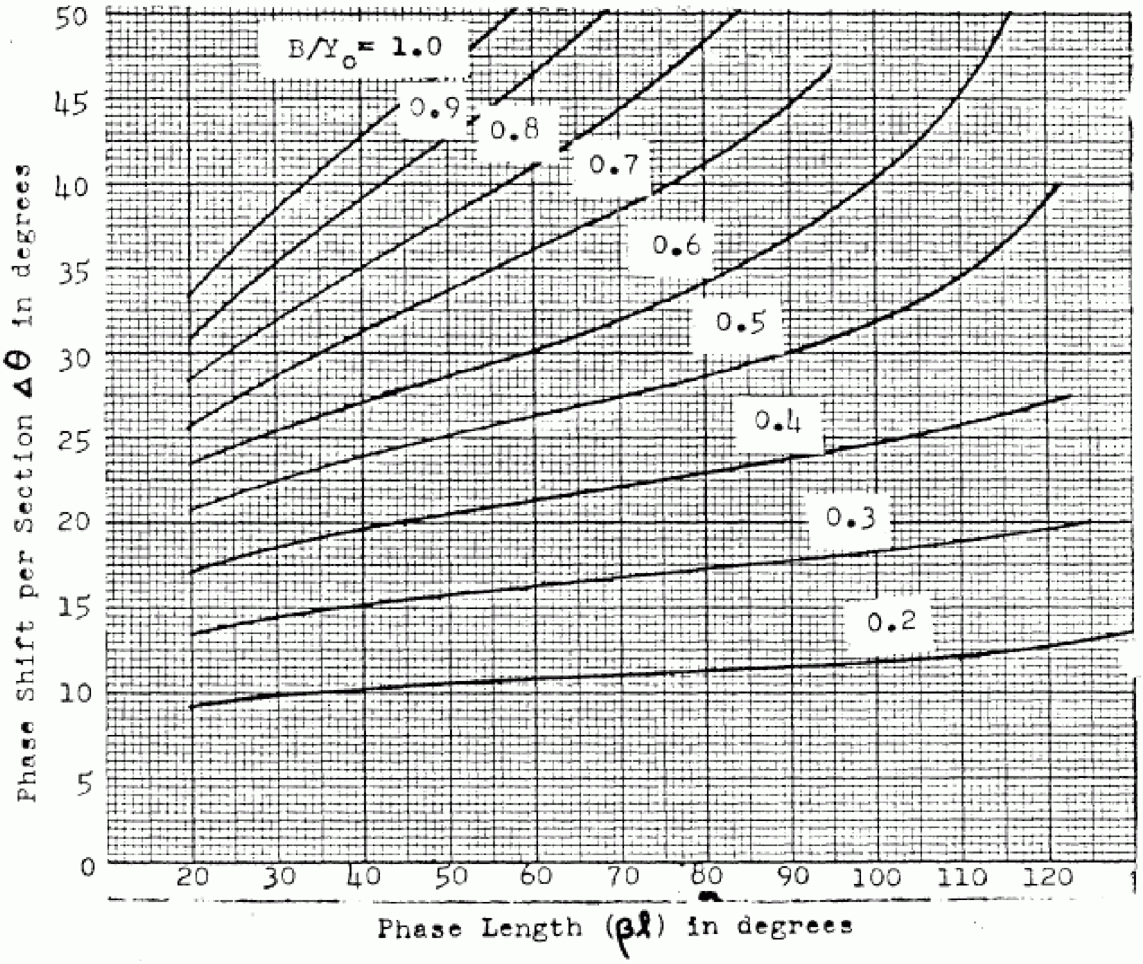


Figure 2. Phase shift per section, $\Delta\theta$ v.s. post separation, $\beta\ell$ in degrees for specific values of B/Y_o.

The length, ℓ can be determined from:

$$\ell = \frac{(\beta\ell)^\circ}{360^\circ}\lambda_g$$ where the guide wavelength

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

and the cut-off wavelength

$$\lambda_{co} = \frac{\pi d}{1.841}$$ for the TE_{11} mode

d = diameter of the circular waveguide
λ_o = 23.148cm or 9.113 inches at 1296 mc/s.
π = 3.1416