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Circularly Polarized Equalizer Networks

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***Abstract*—Characteristics of the cross slot coupling aperture applicable to circularly polarized equalizer networks is presented. This coupling mechanism is analyzed and experimental results indicate good agreement between theory and practice. Extension of the single-cavity unit to multiple direct-coupled dual-mode equalizer networks is also discussed.**

Introduction

In recent years as microwave communications system requirements have become more sophisticated, the design of multiplexing bandpass networks together with the necessary equalization circuitry has attracted an increasing amount of attention. The choice of applicable equalizer networks has usually relied upon either single-mode cavities [1]–[4], using circulators or hybrids, or dual orthogonal mode [5] circularly polarized cavity networks. In general, the single dominant mode equalizer networks exhibit more dissipation loss, and the achievable isolation is limited due to the inherent circuit characteristics of the circulator or hybrid. Furthermore, with circulators or hybrids the weight will increase and most likely will be more expensive, especially if temperature compensation of the ferromagnetic material of circulators is required. In all cases the theory of reflection-type commensurate transmission-line all-pass networks has been utilized to analytically describe the behavior of these networks [6], [7].

This short paper describes an improved approach for realizing circularly polarized equalizer networks whereby use of the cross is employed instead of the more conventional circle or square-shaped iris as the coupling mechanism between the main transmission line and the appropriate cavity circuitry. The primary advantage of cross aperture coupling is that the return loss or match is much better than that exhibited by either the circle or square iris given identical coupling. The VSWR for the circular or square aperture can be significantly improved through the use of screw tuning in the main line. However, this matching will restrict the allowable number of cascaded equalizer units that can be tandem connected due to the frequency sensitivity of the spacing between each tuning screw, i.e., the reactive interaction effects. The inherent superior scattering characteristic of the cross will additionally prove valuable when utilized in multiple cascaded directional channel circular waveguide filter networks.

In this short paper, application of existing theory for circularly polarized single-cavity resonators is made with emphasis on the use of cross slot coupling for realizing microwave equalizer networks. Various properties of the cross are quantitatively defined. In addition, direct-coupled multiple-cavity equalizers are also discussed.

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Cross Aperture Coupling

A. General

If a pair of crossed slots couples energy into a cylindrical waveguide cavity, configured such that the dominant $TE_{11}{}^{0}$ mode can be orthogonally doubly degenerate, then the cavity supporting a resonant circularly polarized wave can be coupled to the rectangular waveguide $TE_{10}{}^{\square}$ mode in such a manner that an all-pass single-resonator equalizer circuit is realized. Fig. 1 denotes this circularly polarized equalizer network with the appropriate dimensional parameters.

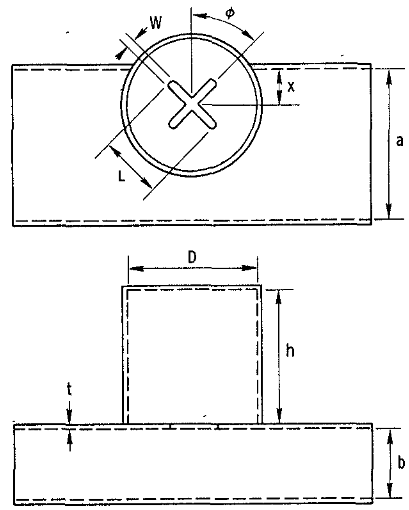

Fig. 1. CP equalizer using cross slot coupling.

The transverse location x is unique to the operation of circularly polarized equalizers in that only one location exists which provides circular polarization (CP). In fact, a proper x position allows the simultaneous achievement of minimum scattering with good CP. The amount of coupling is controlled by both the length and the width of the slots. The design of such circularly polarized cavity structures has been considered for directional filters [8] with circular hole coupling irises. Both the peak magnitude of the time delay and the time delay response as a function of frequency are determined by a single parameter, the external Q of the resonant cavity, which for singly loaded equalizer cavities is twice that of doubly terminated single-cavity filters [9].

B. Cross Location

The time delay response of the equalizer is completely specified by the power coupling factor and the resonant frequency of the cavity. As denoted in [10, p. 239], the power coupling coefficient is related to the square of the magnitude of the transfer scattering coefficient. Circular polarization will exist when the coupling to each orthogonal mode is equal from which the cross location is defined as

$$x = \frac{a}{\pi} \tan^{-1} \left[\frac{\lambda g}{2a} \tan^2 \phi \right]. \tag{1}$$

In general, the cross angle ϕ is set to about 45° with respect to the transverse axis of the rectangular waveguide. However, this angle is not critical and can be easily compensated for by a slight adjustment of the x position of the slots. In addition, it should be noted that as the angle ϕ is allowed to increase slightly above 45°, the optimum cross position will move a small distance toward the center of the rectangular waveguide which, in turn, will permit larger coupling values to exist by virtue of longer slots possible before the proximity of the side wall interferes.

It is necessary to determine a proper x position to achieve a match into the CP equalizer network. Fig. 2 shows the sensitivity of the match to the x position for an equalizer with a center frequency of

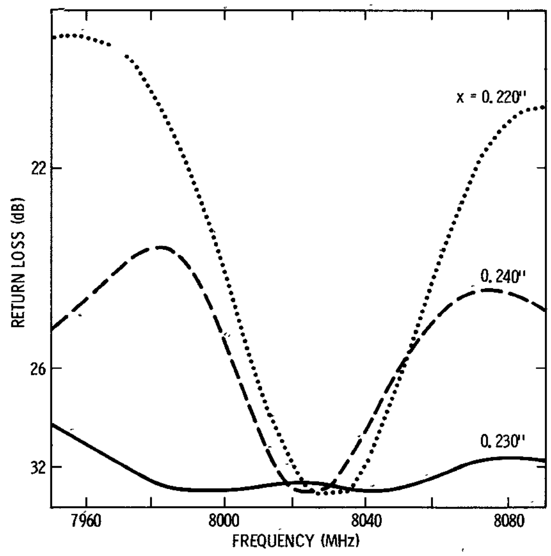

Fig. 2. Effects of cross position on match; cross geometry: $L = 0.694$ in, $W = 0.075$ in, $t = 0.020$ in, $\phi = 45°$.

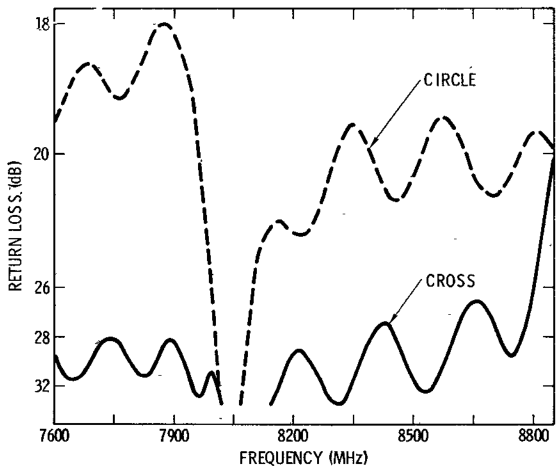

Fig. 3. Scatter comparison of cross and circular hole apertures with same external Q ($Qe \cong 78$) and cavity resonance ($\cong$8040 MHz), but with no manifold guide tuning screws.

8030 MHz and an external Q of 78. The discrepancy between the calculated x position as given by (1) and experiment is only 11 percent.

However, it should be noted that once the x position is determined, the center cavity resonance can be varied across at least a 5-percent bandwidth and the match will still be maintained without adjusting the x position. Small variations in the dominant mode cavity tuning screw depth will suffice to make the required adjustments in the axial ratio of the two degenerate modes. This fixed x position across a broad frequency region considerably simplifies the design task for time delay equalization.

C. Cross Versus Circular Hole

When small coupling values are required or conversely, when relatively large peak time delay responses are specified, coupling with circular or square holes is probably the best approach because of the ease of manufacture. However, as the hole size increases the match deteriorates; thus the cross becomes more attractive from the scattering viewpoint. Fig. 3 emphasizes this point where both a cross and circular hole were tested, each possessing the same degree of coupling or peak time delay at approximately the same cavity resonance.

In the limit as longer slots become necessary for realizing relatively small peak time delay responses, the window resonance will eventually become troublesome because of the proximity of the window resonance on the cavity match response near its fundamental resonance. For example, note the relative degradation in the scatter characteristic of the cross in Fig. 3 as the frequency is increased above 8.5 GHz toward the slot resonance, which in this case is about 9 GHz. This problem can be alleviated to some extent by using a fatter cross (larger W/L ratio) so as to move the slot resonance up the frequency spectrum. Unfortunately, as W/L increases the match achievable without tuning must be sacrificed somewhat. An alternate solution when relatively large coupling is required is to reduce the height (b) of the rectangular guide, thereby decreasing the external Q. Consequently, smaller slot lengths (with correspondingly higher window resonances) are thus required for a given amount of coupling.

Direct-Coupled Cavities

In system applications where the time delay edge slope network characteristics are more severe than can be compensated for with a single-resonator equalizer, multiple direct-coupled cavity equalizers may provide, in some cases, an adequate complementary response shape without resorting to the use of an excessive number of cascaded single-resonator networks. Thus the theory of circularly polarized single-cavity equalizer networks can be extended to multiple direct-coupled cavity networks by applying either all-pass com-

TABLE I
EXPERIMENTAL EQUALIZER CHARACTERISTICS

PARAMETER	SINGLET	DOUBLET	TRIPLET	DIMENSION
Resonant Frequency	8010.	7980.	7991.	MHz
Rectangular Waveguide	WR-112	WR-112	WR-112	----
Cavity Diameter	1.000	1.000	1.000	in.
Slot Length	0.694	0.694	0.694	in.
Slot Width	0.075	0.075	0.075	in.
Cross x Position	0.230	0.230	0.230	in.
Cross Angle	45.	45.	45.	Deg.
1st Circular Hole Diameter	----	0.420	0.420	in.
2nd Circular Hole Diameter	----	----	0.385	in.
Iris Wall Thickness	0.020	0.020	0.020	in.
External Q_e				
Input Cross	82.	93.	90.	----
1st Circular Hole	----	1400.	1350.	----
2nd Circular Hole	----	----	2300.	----
Measured Unloaded Q_u				
Input Cavity*	3100.	3000.	2800.	----
2nd Cavity	----	8200.	6200.	----
3rd Cavity	----	----	8200.	----

* Loss associated with adjustable mechanical joint of circular guide to top wall of rectangular guide.

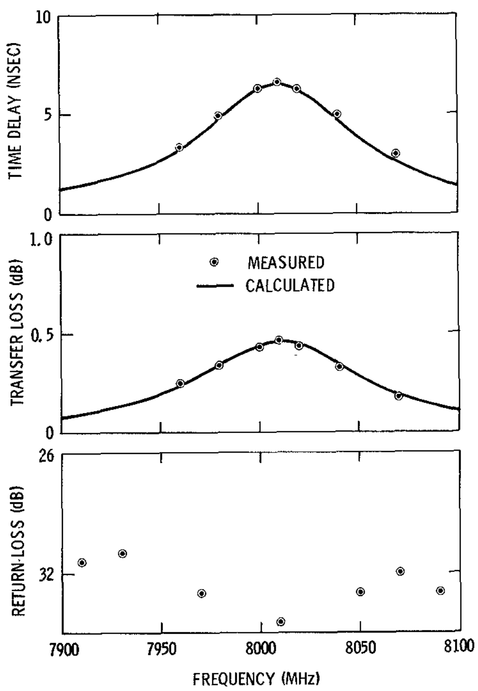

Fig. 4. Singlet CP equalizer response characteristics.

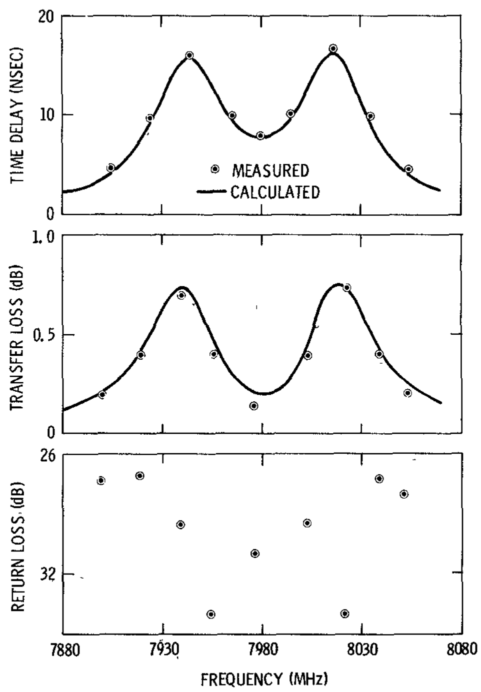

Fig. 5. Doublet CP equalizer response characteristics.

mensurate transmission-line network theory [3], [4], [6], [7] or the scattering matrix formulation [2]. In either approach, all the power coupling factors between the ith and $i+1$ cavities must be determined in order that the appropriate equalizer response be realized. Thus the technique is quite similar to that developed for circularly polarized waveguide directional filters [10, pp. 847–864] in that the coupling irises between all the cavities connected together by circular waveguide will normally be small circular holes.

To determine the feasibility of realizing such networks, two and three cavity direct-coupled equalizers, to be called doublets and triplets, were developed. Table I summarizes some of the pertinent characteristics of each experimental network. All units tested were configured in a tightly clamped fixture so that coupling hole diameters could be easily changed by replacing the thin iris plate. Hence the apparent unloaded Q values that each unit exhibited can probably be improved somewhat if the devices were fabricated as one solid fixture, for example either by brazing or electroforming. Figs. 4–6 indicate good correlation of the measured data with theory for both the time delay and the insertion loss or transfer loss responses. (The match was taken without any manifold tuning; however, a small amount of this tuning improves the match to about 45 dB across the 5-percent measured frequency band.) The theoretical

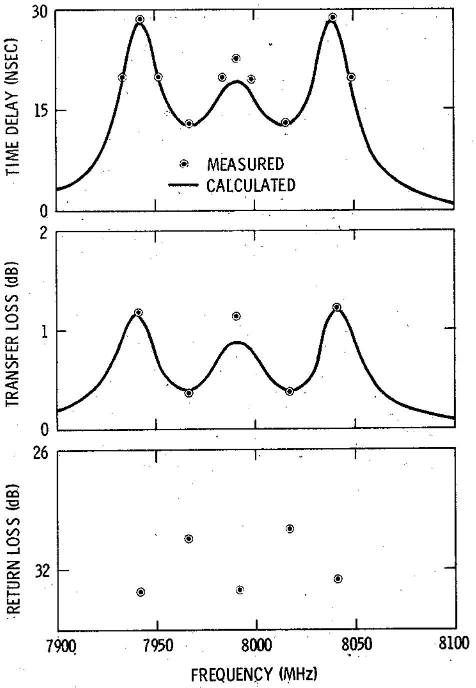

Fig. 6. Triplet CP equalizer response characteristics.

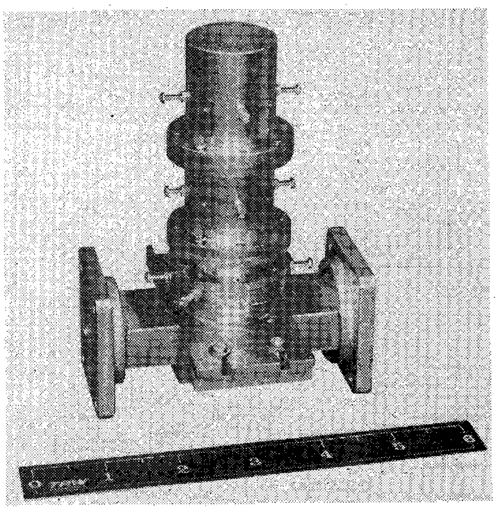

Fig. 7. Experimental triplet CP equalizer.

data here were computed through use of the scattering matrix approach [2] whereby different unloaded cavity Q values can be appropriately handled for each individual cavity without resorting to assuming an "average" value for all the resonators. When tuning the orthogonal modes in the doublet or triplet configurations it was observed that a mode coupling screw located 45° between each orthogonal E-field mode orientation was usually required in the first cavity (input resonator connected to the top wall of the waveguide). However, in the other cavities only mode resonance tuning screws were necessary, although symmetrical location of the screws was required to yield appropriate time delay and amplitude response simultaneously. The experimental triplet equalizer is shown in Fig. 7.

Conclusions

Use of the cross coupling aperture in circularly polarized equalizer networks has been shown to be valuable because of its superior scatter characteristics without the need of manifold tuning. Thus, because of the all-pass nature of this network, many equalizer sections can be cascaded directly for wider bandwidth equalization. In addition, it has been shown that the design of single-cavity circularly polarized networks can be easily extended to the concept of direct-coupled cavity equalizers. Furthermore, this unique characteristic of the cross should prove extremely useful when applied to cascaded directional channel filters in manifold system configurations.

In summary, the use of dual orthogonal mode circularly polarized equalizer networks are generally superior to that of conventional single-mode all-pass waveguide circuits in that the relative size, loss, isolation, and complexity are improved in view of the fact that circulators or hybrids are not required.

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Mode Compensation Applied to Parallel-Coupled Microstrip Directional Filter Design

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***Abstract*—A simple mode-compensation technique is introduced into the design of a pair of parallel-coupled microstrip lines and applied to a microstrip traveling-wave loop-directional filter. The compensated design of the filter shows a substantial improvement in its performance.**

Introduction

The unequal propagation velocities of the TEM even and odd modes in a microstrip parallel-coupled line [1], [2] introduce deterioration in the performance of the bandwidth and isolation characteristics of microstrip directional couplers, quadrature hybrids, and bandpass filters. Techniques [3], [4] to equalize the mode velocities on microstrip coupler characteristics have been reported, but these techniques have led to complicated design procedures. For example, the technique described in [3] requires special graphs based on numerical field analysis. These graphs are difficult to compute, and not widely available. The compensating overlay structure is also larger and more complicated than necessary. Similarly, the wiggly line technique of [4] involves a special strip design which can be obtained only by using a complicated experimental procedure. Further, this design does not work well for loose coupling.

On the other hand, the present mode compensation technique allows the coupled strips to be designed by using widely available information for TEM couplers [5] and microstrip parameters [1]. This technique involves placing an additional coupling dielectric bar along the gap between the parallel-coupled conducting strips

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