THE APPLICATION OF PERIODIC LOADING TO FERRITE PHASE SHIFTER DESIGN

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The use of periodic loading[1] to enhance the differential phase shift of a remanence ferrite phase shifter, while maintaining frequency compensation, has been reported previously. This paper reports on progress in the use of this technique, and the characteristics obtained versus the degree of periodic loading. The circuit has low cost potential and results in a reduction of the size and switching energy of the phase shifter; however, this is obtained at the expense of peak power handling capability.

Geometry and Periodic Structure. The cross-section of the waveguide and ferrite toroid is shown in the inset of Figure 1. The intersecting circular boundaries are machined in aluminum plates and provide captivation of a perfectly circular ferrite torroid. The dimensions of this cross-section were chosen to provide frequency compensation of the differential phase shift for a conventional phase shifter; e.g., one without periodic loading. The compensation of the cross-section is not necessary; however, it is a logical geometry to use as a starting point and reference in determining the merit of the periodic loading technique.

Periodic loading, as discussed here, refers to the use of two types of shunt susceptances placed at regular intervals down the guide in the direction of propagation. The first is an aperture consisting of a thin aluminum or copper sheet in a plane normal to the direction of propagation with a round hole concentric to the ferrite toroid. The other is a disk, also a thin conductor in a plane normal to the direction of propagation. It is of the same circular shape as the ferrite toroid, except that its outer diameter is less than the diameter of the toroid. The disk and the toroid are also concentric and have center holes of the same diameter. The disks are placed between segments of the toroids with the switching wire, used for the magnetization of the toroids, threaded through both. The apertures have diameters larger than the toroid and therefore segment the air filled guide outside the toroid.

A typical assembly is shown in Figure 2 where the waveguide was machined from plates of aluminum 0.125 inch thick that are stacked in a laminated fashion. The apertures are machined in thin sheets .005 inch thick and fit between the plates. The disks are die-cut from adhesive backed, .002 inch aluminum foil and are stuck to the torroids before assembly. The switching wire is brought out the side of the assembly through a groove in the end plates.

Transitions to coax allowed connection to a network analyzer for measurements centered around 5.5 GHz in C-band. Magnesium ferrite (Trans Tech TT1-105) and gadolinium doped yttrium garnet (Trans Tech G-1001 and Xtalonic X-1198) were utilized as toroid material.

The differential phase shift can be adjusted to be constant with frequency by the selection of disk and aperture diameters. The two types of obstacles are then used in alternation down the guide. The periodicity is adjusted to establish the passband frequency range. Figure 1, showing a plot of geometries that were experimentally adjusted for frequency compensation, indicates that the process is orderly enough to be described by the empirical equation shown. A similar log-log plot should yield an equation for other wave-guide boundaries.

To quantitatively describe the extent of periodic loading, a Loading Factor, γ, is defined in Figure I. Note that for no loading $\gamma = 0$ and a closed guide or maximum loading is represented by $\gamma = 1.0$. The range of practical values for γ is therefore between 0 and 1.0.

Effect of the Periodic Loading. The enhancement of phase shift per unit length of device is illustrated in Figure 3. The periodic structure reduces the passband of the phase shifter, however, the differential phase shift variation with frequency can be held to less than a few degrees over the entire passband.

The peak power threshold of nonlinear losses is reduced by periodic loading. This is illustrated for both ferrite and garnet materials in Figure 4 where the threshold power is plotted versus phase shift per inch for various loading factors.

An advantage of the periodic loading is the reduction obtained in the insertion phase length. A given absolute phase variation tolerance is easier to meet because the allowable variation is a larger percentage of the total. The insertion phase length per section is plotted versus frequency in Figure 5. This plot summarizes computed results from experimental data which was taken by the resonant line technique. It therefore represents a mean between the two sets of curves that would be obtained for the two states of remanent magnetization maxima. The figure of merit, differential phase shift divided by insertion phase length, is plotted in Figure 6.

The figure of merit, phase shift per db of loss, can be improved slightly with periodic loading as shown in Figure 6. (No transition losses are included here) This occurs because the increase in loss per unit length is offset by the increase in phase shift.

Application. The configuration represented by Figure 2 ($\gamma = .52$) is currently being used in the simultaneous assembly of a 64 element, laminated subarray. Each plate has the required holes to form the 64 periodic phase shifters and 64 cavities alongside for location of a hybrid IC driver. For applications where the peak power is not a severe criteria, this assembly technique, the simple geometry of the toroids, and the reduced volume of the ferrite appear to have low cost potential. In addition, the switching energy and driver costs are also reduced by the decrease in toroid volume.

These results are tabulated below for TT1-105 at 5.5 GHz.

Periodic Loading	γ	A in.	D in.	Δϕ °/in.	Loss db/in.	1/λg °/in.	Δϕ / Φ Total	Δϕ / db
None	0	–	–	100	.24	554	.18	416
Light	.19	.562	.158	170	.3	362	.47	570
Medium	.52	.422	.250	288	.5	362	.79	576
Heavy	.68	.388	.316	330	1.0	446	.75	330

1. W. G. Spaulding, "A Periodically Loaded, Latching, Non-reciprocal Ferrite Phase Shifter", Late News Item 1969 International Microwave Symposium, Dallas, Texas, May 5-7, 1969.

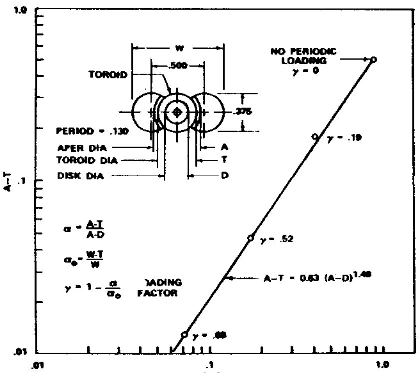

FIGURE 1. GEOMETRY OF PERIODIC LOADING REQUIRED FOR FREQUENCY COMPENSATION. LOADING FACTOR IS DEFINED AS SHOWN.

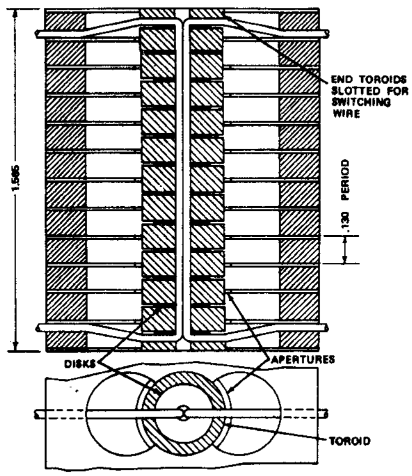

FIGURE 2. PERIODIC FERRITE PHASE SHIFTER ASSEMBLY. FOR SINGLE BIT, FLUX-DRIVE CONTROL.

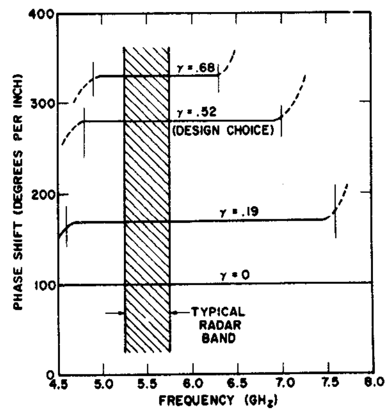

FIGURE 3. DIFFERENTIAL PHASE SHIFT VERSUS FREQUENCY FOR VARIOUS PERIODIC LOADING FACTORS. (TT1-105)

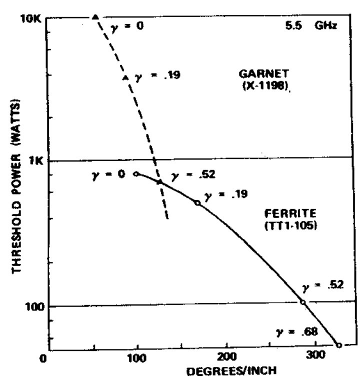

FIGURE 4.

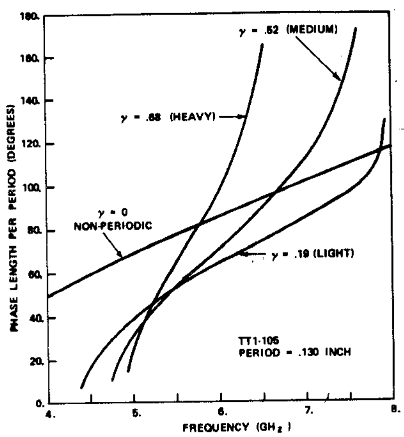

FIGURE 5. THE MEAN INSERTION PHASE LENGTH PER SECTION VS FREQUENCY.

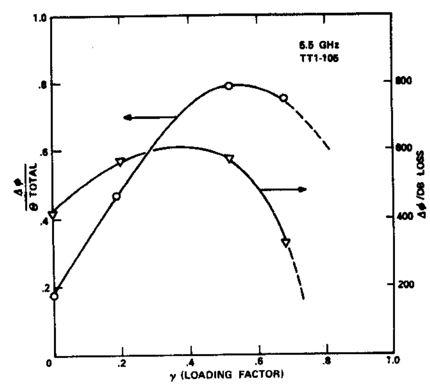

FIGURE 6. FIGURE OF MERITS PHASE SHIFT PER TOTAL INSERTION PHASE AND DB OF LOSS VS PERIODIC LOADING