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A Study of a Ferrite Phase Shifter

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ABSTRACT

A study of a DOFL-type phase shifter was conducted at S-band. This phase shifter was capable of operation at power levels above 10 kw peak power. Phase shift and loss were determined as a function of several parameters: ferrite width and height, waveguide height, and presence or absence of dielectric. The dielectric was used to permit use of this geometry at high power levels, where it served as a heat transfer medium between the axially located ferrite slab and the top and bottom waveguide walls. High power measurements consisted of measuring loss as a function of power level.

At low power levels, for a given width of ferrite, much more phase shift can be obtained if the ferrite only partially fills the waveguide in height, but when the height gap is filled with dielectric as required at high power levels, at most a 20% improvement can be obtained over ferrite filling the entire height. In the range of values studied, if the waveguide height is ferrite filled, increasing the ferrite width or waveguide height increases the maximum phase shift while having little effect on loss, this improvement also occurring at high power levels.

PROBLEM STATUS

This is an interim report; work continues on other phases of the problem.

AUTHORIZATION

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A STUDY OF A FERRITE PHASE SHIFTER

INTRODUCTION

The original DOFL (or Reggia-Spencer) phase shifter consisted of a rectangular waveguide containing a ferrite rod of circular or square cross section located along the waveguide axis and magnetized by means of a solenoid. Hughes Aircraft has designed a modified version of this phase shifter in which the ferrite element is a rectangular slab located along the waveguide axis and having both the top and bottom faces in contact with waveguide walls.

Some studies were made in this Laboratory of some other variations of the DOFL phase shifter. In one version two distinct slabs of ferrite were used, each in contact with the top and bottom waveguide walls. In another version, a single rectangular slab was centered along the waveguide axis but without contacting the waveguide walls. It was found that contact by two slabs with the top and bottom walls produced a phase delay while noncontact by a single slab gave rise to a phase advance. Moreover the single slab of ferrite gave a phase advance of considerably greater magnitude than the phase delay obtained by a pair of slabs fastened to the top and bottom waveguide walls.

Intuitively it appeared that if the single rectangular slab of ferrite filled the waveguide height, then both effects might be present simultaneously; that is, the part of the ferrite in contact with the top and bottom waveguide walls would tend to delay the phase while the rest would tend to advance it.

Thus it would appear that a greater phase shift could be achieved with a slab that did not fill the waveguide rather than one that did. As will be seen, this indeed turned out to be the case. However, for high power applications, a design wherein the ferrite does not have contact with the waveguide walls is clearly undesirable from the point of view of heat dissipation. One possible solution to this problem which suggested itself was to fill the space between the waveguide and ferrite with a dielectric material which is a good heat conductor (such as boron nitride). However, there still remained the possibility that even if dielectric were placed between the ferrite and walls of the waveguide, the rf field might be redistributed and the phase shift reduced. For this reason an experimental study was undertaken to see how the phase shift depended on the relative heights of ferrite and dielectric used. At the same time, the study was broadened to include the dependence of the phase shift, loss, and nonlinear effects on other parameters, namely, the width of ferrite slab and the height of waveguide.

The principal investigations were conducted at 2.84 Gc in waveguide having the "a" dimension of standard S-band waveguide (RG-48/U). Figure 1 is a sketch of the geometry studied, together with the nomenclature used. The ferrite used in these studies was TT 414. To lighten the machine work load, most sample bodies were composed of several small pieces which could be reassembled to form several samples of different dimensions. A small number of ferrite tapers were used for matching. The dielectric used in this study was Stycast HiK (ϵ = 5). Although this material is not a good conductor of heat, it has approximately the same dielectric constant as boron nitride, which has high thermal conductivity. From the point of view of electrical performance it could be expected that the Stycast would simulate the boron nitride. When Stycast was not used, polyfoam was used to support the ferrite because the dielectric constant of polyfoam (1.04) is close to that of free space. This geometry, ferrite supported by polyfoam, will

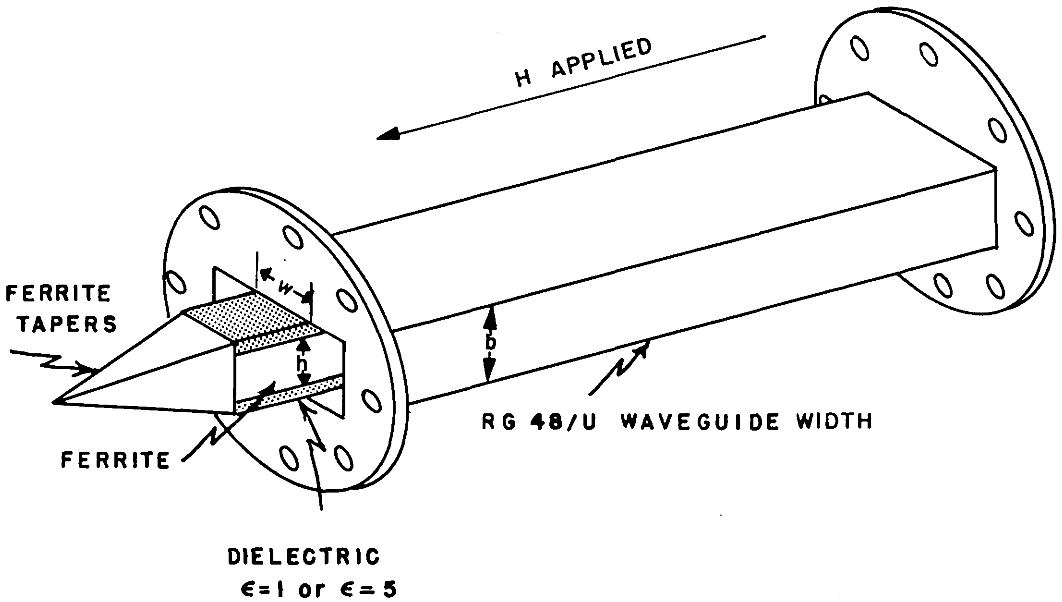

Fig. 1 - Configuration of the ferrite phase shifter

be referred to as "ferrite alone," while the geometry where the ferrite is supported by dielectric will be termed the "ferrite-dielectric combination."

Ferrite heights h were varied in steps from 0.590 inch to the full waveguide height. Three values of waveguide height b (b = 0.750, 0.970, and 1.340 inches) plus three values of ferrite width w (w = 0.750, 0.970, and 1.150 inches) were studied. These samples, all of the same ferrite slab length (approximately 6 inches), were considered sufficient to obtain a general picture of the propagation characteristics of this ferrite geometry.

Propagation characteristics were determined at both high and low power levels, because ferrite devices usually show nonlinear effects at high peak power levels. Since there appears to be little or no change in phase shift with peak power level, the phase shift measurements were made at low power levels, while the loss measurements were made at both low and high power levels. The nonlinear effects studied include threshold level,* incremental loss,† and rate of increase of percent loss with power level. One problem encountered in obtaining the required data is separation of the nonlinear effects from the heating effects. This separation is obtained by rapidly varying the peak power level from a low level to a high level and back again while recording the data photographically. Thus the average power and thereby the heating effects are kept small. The frequency (2.840 Gc) at which the data was obtained was determined by the magnetron available for this high power instrumentation.

Typical curves obtained from the low power studies are shown in Fig. 2, where relative phase shift and loss are shown as a function of applied magnetic field for a case where the ferrite slab fills the waveguide in height. The relative phase shift (i.e., the phase difference between the demagnetized state and a state with a given value of magnetic field) reaches a maximum value, then decreases. In comparing the different

*Threshold level refers to the peak power level at which the loss in db begins to vary with increasing peak power level.

†Incremental loss refers to the difference (in db) of the loss at low power levels and the loss at the power level under consideration.

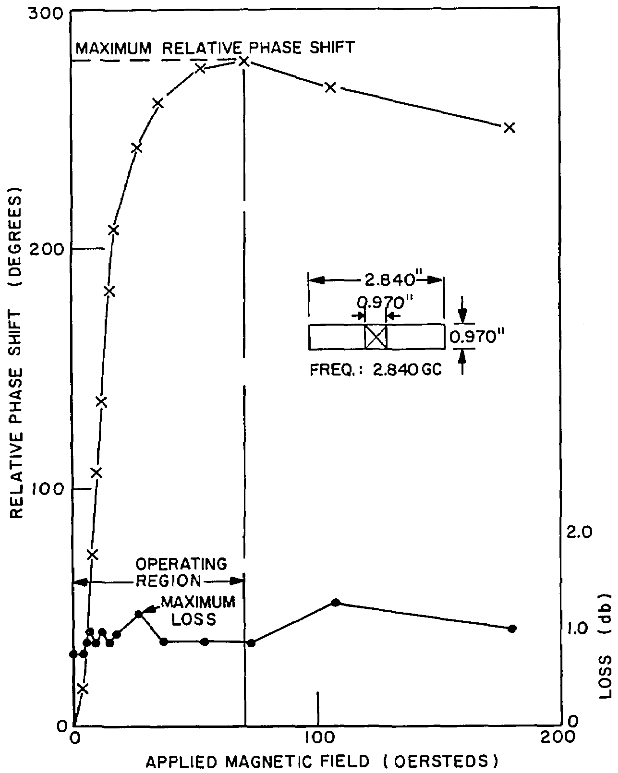

Fig. 2 - Typical low power data on the relative phase shift and the loss as a function of the applied magnetic field

geometries, the basis of comparison will be: (a) the maximum insertion loss obtained for the applied magnetic field values less than or equal to that required for the maximum relative phase shift, and (b) the maximum relative phase shift produced by each geometry.

EFFECT OF VARYING THE WAVEGUIDE HEIGHT

One series of measurements consisted of varying the relative amounts of ferrite and dielectric while keeping both ferrite width and length constant. For each of three given values of waveguide height b, the maximum relative phase shift was found as a function of the ratio of the ferrite height to the waveguide height h/b.

Figure 3 shows the results of these measurements. Note that for each waveguide height, one curve is shown for phase shift obtained by using ferrite alone and a second by using ferrite-dielectric combinations which fill the waveguide height. In certain ranges, filling the gap between the ferrite and broad waveguide walls with dielectric reduces the maximum relative phase shift, while in others it increases the phase shift. These ranges are strongly influenced by the waveguide height, as can be seen by comparison of the curves for $b = 0.750$, 0.970, and 1.340 inches. Although a combination of ferrite and dielectric can yield at most 15% more phase shift than the ferrite filled case ($h/b = 1$), practical considerations (e.g., dielectric to ferrite bonds) would tend to offset this advantage.

Now consider the special case where $h/b = 1$. In Fig. 4 both maximum phase shift and maximum loss are plotted as a function of waveguide height. As the waveguide height

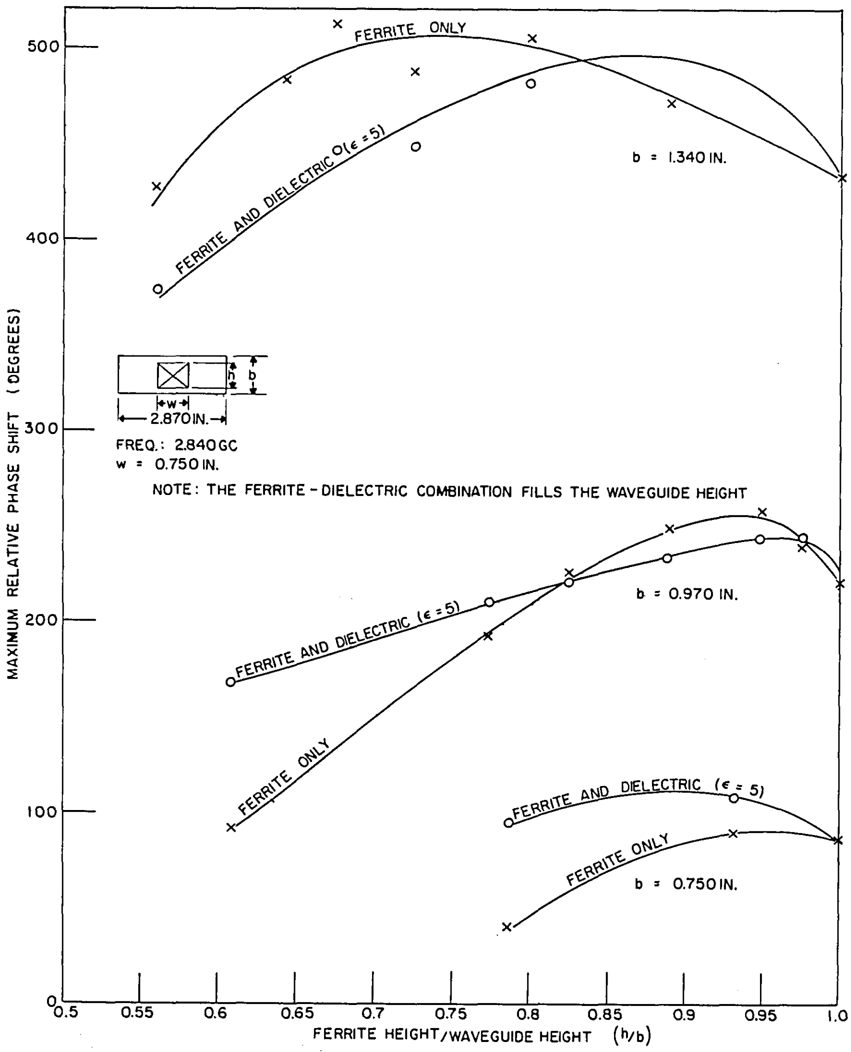

Fig. 3 - Low power data on the maximum relative phase shift as a function of the ratio of the ferrite height h to the waveguide height b for three values of b and the ferrite width w fixed at 0.750 inch

is increased to 1.340 inches (largest value of b studied), the maximum relative phase shift increases rapidly while there is but a small variation in the low power loss. It would thus appear more advantageous, from low power considerations, to use the waveguide having the larger height.

The high power characteristics will now be considered for this case in which the waveguide height is filled with ferrite. The insertion loss is shown as a function of power level in Fig. 5. It can readily be seen that, over the range of b studied, the larger values of waveguide height provided superior performance. The degree of improvement is more pronounced when the greater amount of phase shift provided by the larger waveguide is considered. This improved performance is noted in both the unmagnetized state and in the magnetized state producing the maximum phase shift. In general the threshold levels are lower, the incremental losses smaller, and the rates of change of loss less for the larger values of b.

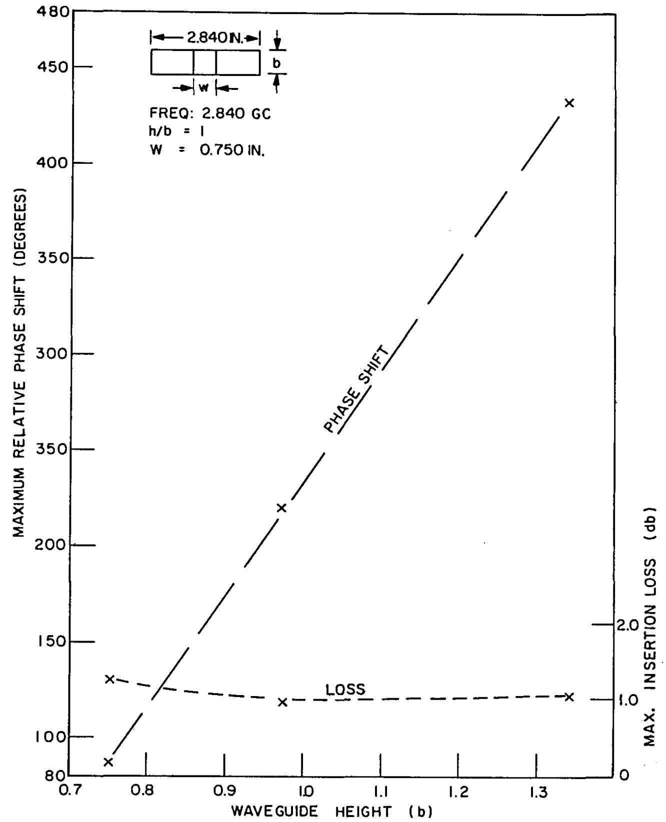

Fig. 4 - Low power data on the maximum relative phase shift and maximum loss as a function of waveguide height b (with ferrite height h = b) for a ferrite width w of 0.750 inch

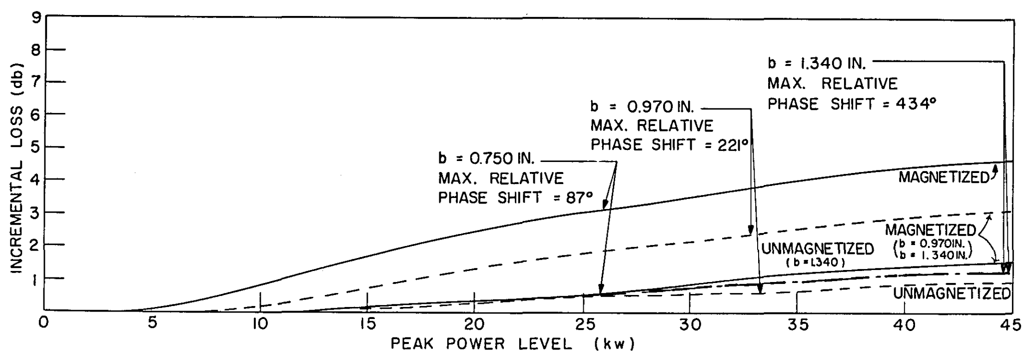

Fig. 5 - High power data on the incremental loss as a function of peak power level for three values of waveguide height b (ferrite height h = b) and a ferrite width w of 0.750 inch

EFFECT OF VARYING THE FERRITE ROD WIDTH

A study was conducted in which the maximum relative phase shift was again measured as a function of h/b, but with the ferrite width w as a parameter instead of the waveguide height b. Both waveguide height b and ferrite length were kept fixed.

Figure 6 shows the results of these measurements for each of the three ferrite widths investigated (w = 0.750, 0.970, and 1.150 inches). For each waveguide width, one curve is shown for phase shift obtained by using ferrite alone and a second by using ferrite-dielectric combinations. Again, in certain ranges, filling the gap with dielectric reduces the maximum relative phase shift, while in other regions, adding the dielectric increases it. Transitions between these ranges can be seen except in the case of the curves for w = 1.150 inches. For this case, extrapolation of the curves for the ferrite and the ferrite-dielectric combination indicates the transition range would be for values of h/b below 0.5.

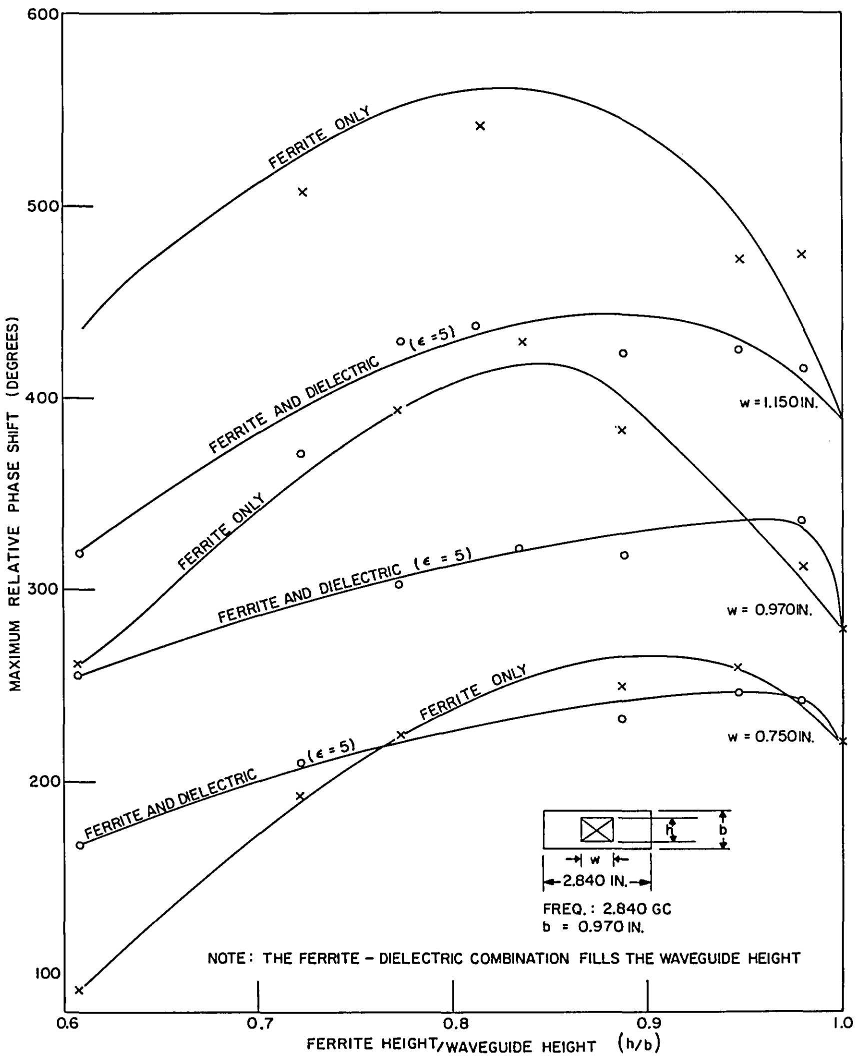

Fig. 6 - Low power data on the maximum relative phase shift as a function of the ratio of ferrite height h to waveguide height b for three values of ferrite width and a waveguide width of 2.840 inches

The ferrite alone can produce a greater maximum phase shift for the 0.970-inch waveguide height than can the ferrite-dielectric combination. However, in consideration that ferrite alone is undesirable for high power applications, comparison of the phase shift produced by the ferrite-dielectric combination and the ferrite-filled waveguide (h/b = 1) shows that the maximum phase shift of the combination is at most less than 20% greater than that of the ferrite-filled waveguide. Again practical considerations might diminish this advantage over the ferrite-filled waveguide.

Consider the filled waveguide case (h/b = 1). In Fig. 7 maximum relative phase shift and maximum loss are presented as a function of ferrite width (w). The phase shift increased rapidly with increasing ferrite width, while the insertion loss remains essentially constant. Thus it can be seen that the propagation characteristics improve as the width increases; however, once the width exceeds a critical value, the mismatch becomes quite large.

Next the loss measurements were repeated at high power levels. The results are shown in Fig. 8. For the three widths studied, increasing the width improves the high power performance by increasing the phase shift, by increasing the threshold level, and by decreasing both the incremental loss and rate of increase of loss.

When the high power characteristics of the ferrite alone ($h/b < 1$) and ferrite dielectric combinations are considered, there appear to be several trends. In general, the performance of each sample is improved as b or w is increased. When b and w are fixed, the higher values of relative phase shift tend to accompany the lower threshold levels.

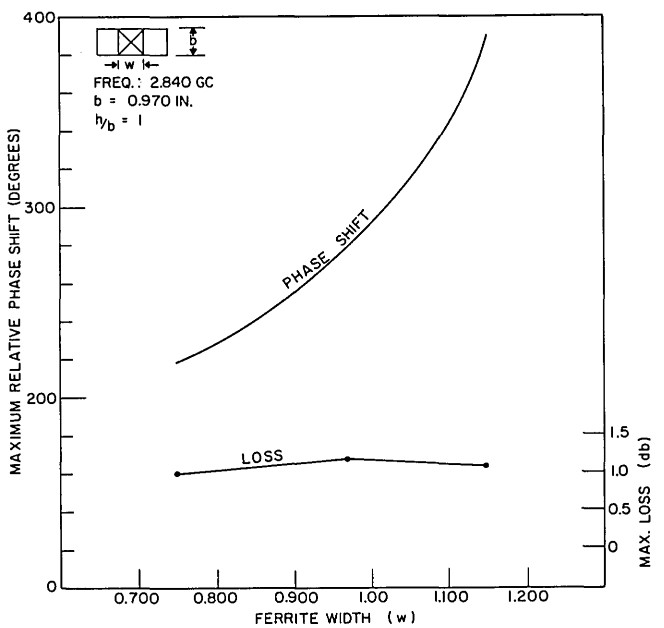

Fig. 7 - Low power data on the maximum relative phase shift and the maximum loss as a function of ferrite width w for a waveguide height and ferrite height of 0.970 inch

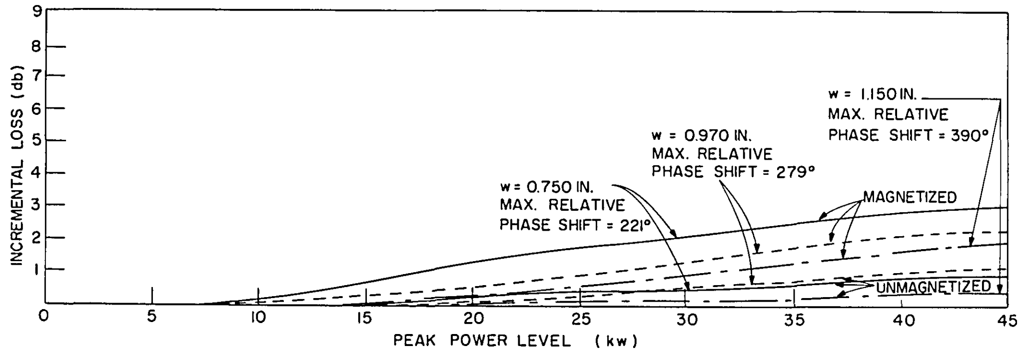

Fig. 8 - High power data on the incremental loss as a function of peak power level for three ferrite widths and a ferrite height and waveguide height of 0.970 inch

CONCLUSION

At low power levels, much more phase shift can be obtained if the ferrite only partially fills the waveguide in height. If the gap between the ferrite and broad waveguide walls are filled with a good heat conducting dielectric as required for high power operation, at most a 20% improvement can be obtained over the case where the ferrite completely fills the waveguide in height.

If the waveguide height is ferrite filled and is within the range of values studied, increasing the ferrite width or waveguide height increases the maximum phase shift while having little effect on loss. The high power performance is also improved by increasing the ferrite width or waveguide height.

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