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IMPACT OF DIELECTRIC LOSS TANGENT ON THE PERFORMANCE OF MILLIMETER WAVE FERRITE CIRCULATORS*

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ABSTRACT

A ferrite circulator can be modeled as a dielectric resonator whose unloaded Q is a function of dielectric loss. This model predicts that when loss tangents of ferrite materials are increased from 0.0002 to 0.002, circulator insertion loss increases by about 0.14 dB. Experimental measurements confirm that loss tangents significantly less than 0.001 are required to achieve low insertion loss, high performance, millimeter wave circulators.

INTRODUCTION

A junction circulator can be modeled as a dielectric resonator having an unloaded Q determined by magnetic, dielectric, and conductor losses and an external Q determined by coupling to the feed lines at the various ports. The theoretical work of Matthei, Young, and Jones (1) provides a base for studying the sensitivity of circulator performance to material parameters. Of particular interest here is the dependence of circulator insertion loss on ferrite dielectric loss.

At millimeter wave frequencies, high performance millimeter wave junction circulators (fixed bias and switchable junctions) require the use of high $4\pi Ms$ ferrite materials (Ni-Zn or Li-Zn ferrite compounds with 4π Ms values greater than 3000 gauss). For most applications very low insertion loss is required in these signal processing and control components. Typical values achieved over operational bandwidths of 2 to 4 GHz are 0.07 db insertion loss in the 20 GHz region to 0.2 db in the 90 GHz region.

ASTM standard techniques (2) for measuring dielectric loss tangents in the high 4π Ms materials are difficult to implement routinely due to contributions of magnetic loss at the X-band measurement frequency. Typically, loss tangents of these materials are not measured accurately by suppliers, and materials are cataloged as having loss tangents of 0.001 or less. Thus a compound possessing a dielectric loss tangent of 0.0002 would not be distinguished from one possessing a loss tangent of 0.001.

The study reported here indicates that significant precision and accuracy must be utilized in the measurement of dielectric loss tangents and that materials must be fabricated with loss tangents significantly below 0.001 to achieve low loss performance in millimeter wave components.

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THEORETICAL MODEL

The unloaded Q of the ferrite resonator is given by:

$$1/Q_u = 1/Q_c + \tan\delta_e + \tan\delta_m \qquad (1)$$

where Q_c accounts for ohmic losses in the conductor walls of the structure,

$\tan\delta_e$ is the dielectric loss tangent of the ferrite,

and

$\tan\delta_m$ is the magnetic loss tangent of the ferrite.

The loaded Q of the ferrite modeled as a two port resonator is:

$$1/Q_L = 1/Q_u + 1/Q_{e1} + 1/Q_{e2} \qquad (2)$$

where Q_{e1} and Q_{e2} are the external Q's at ports 1 and 2, as determined by RF transformers or coupling design. The basic theory of Matthaei, Young and Jones yields an insertion loss given by:

$$dB = 10 \log_{10}\left[Q_{e1} Q_{e2}/4Q_L^2\right] . \qquad (3)$$

The effect of dielectric loss on insertion loss can therefore be computed from equations (1) through (3).

The results of this treatment are plotted in Figure 1 which presents the predicted change in insertion loss as a function of change in dielectric loss tangent for various operating bandwidths. The sensitivity of insertion loss to $\tan\delta_e$ is dependent on the Q_L of the device. The smaller the loaded Q, or the broader the bandwidth, the less sensitive is loss to changes in $\tan\delta_e$.

From Matthaei, Young and Jones, the loaded Q is determined by the measurement of input VSWR (which in a circulator is closely related to isolation). At millimeter wave frequencies, most circulators studied are operating near the 10% bandwidth curve of Figure 1.

From Figure 1, it is noted that a change in $\tan\delta_e$ of 0.001 produces a change in insertion loss of about 0.1 db for a 10% bandwidth regardless of the contributions from magnetic and conductor loss. Loss tangents reported to be less than 0.001 can thus provide considerable difference in insertion loss performance in low loss circulators. For example, materials with loss tangents of 0.0003 and 0.0008 are both less than 0.001 but the insertion loss would vary by at least 0.05 db or from 0.15 to 0.2 db in low loss circulator applications. This treatment clearly indicates the value of properly characterizing loss tangents for millimeter wave materials, particularly if improvements are desired or necessary.

EXPERIMENTAL RESULTS

Experiments conducted on a variety of ferrite materials and at different frequencies confirm the predictions of the model. Table I shows results obtained near 20 GHz and near 95 GHz. All these ferrites are nominal low loss materials, but substantial differences in performance result from relatively small changes in dielectric loss tangent.

Good progress is being made regarding improved routine measurement techniques to accurately characterize the dielectric loss tangents of ferrites for millimeter wave applications. The precision and sensitivity of these measurements must be sufficient not only to correlate material characteristics with RF performance data but to also provide a basis for material quality control.

CONCLUSIONS

Dielectric loss leads to a direct increase in insertion loss of ferrite circulators. While it is intuitively obvious that such would be the case, the extent of the correlation is perhaps greater than might have been expected.

The control of dielectric loss tangents is more difficult than that of most other material parameters, and few industries actually measure it. A general perception is that once loss tangents are below ~0.0025, their effects on circulator loss are insignificant. However, the theoretical models and experimental data presented here show that dielectric loss is still significant down to loss tangents of 0.0005 or less. In microwave circuits containing multiple, series connected, circulators the effects of loss tangent variations, even at low loss tangent values, may be quite significant.

REFERENCES

1. G. Matthaei, L. Young, and E.M.T. Jones, Microwave Filters, Impedance-Matching Networks, and Coupling Structures, Artech House Books, Deham, MA., 1980, pp. 651-673.

2. ASTM Standard C525-63T.

TABLE I

Experimental Values of Insertion Loss as a Function of Dielectric Loss

fo = 95 GHz, Δf = 3 GHz		fo = 19.5 GHz, Δf = 3 GHz	
tanδe	Insertion Loss (dB)	tanδe	Insertion Loss (dB)
0.0004	0.550	0.0006	0.075
0.0005	0.600	0.0019	0.190
0.0006	0.650		
0.0030	0.900		
0.0035	0.850		

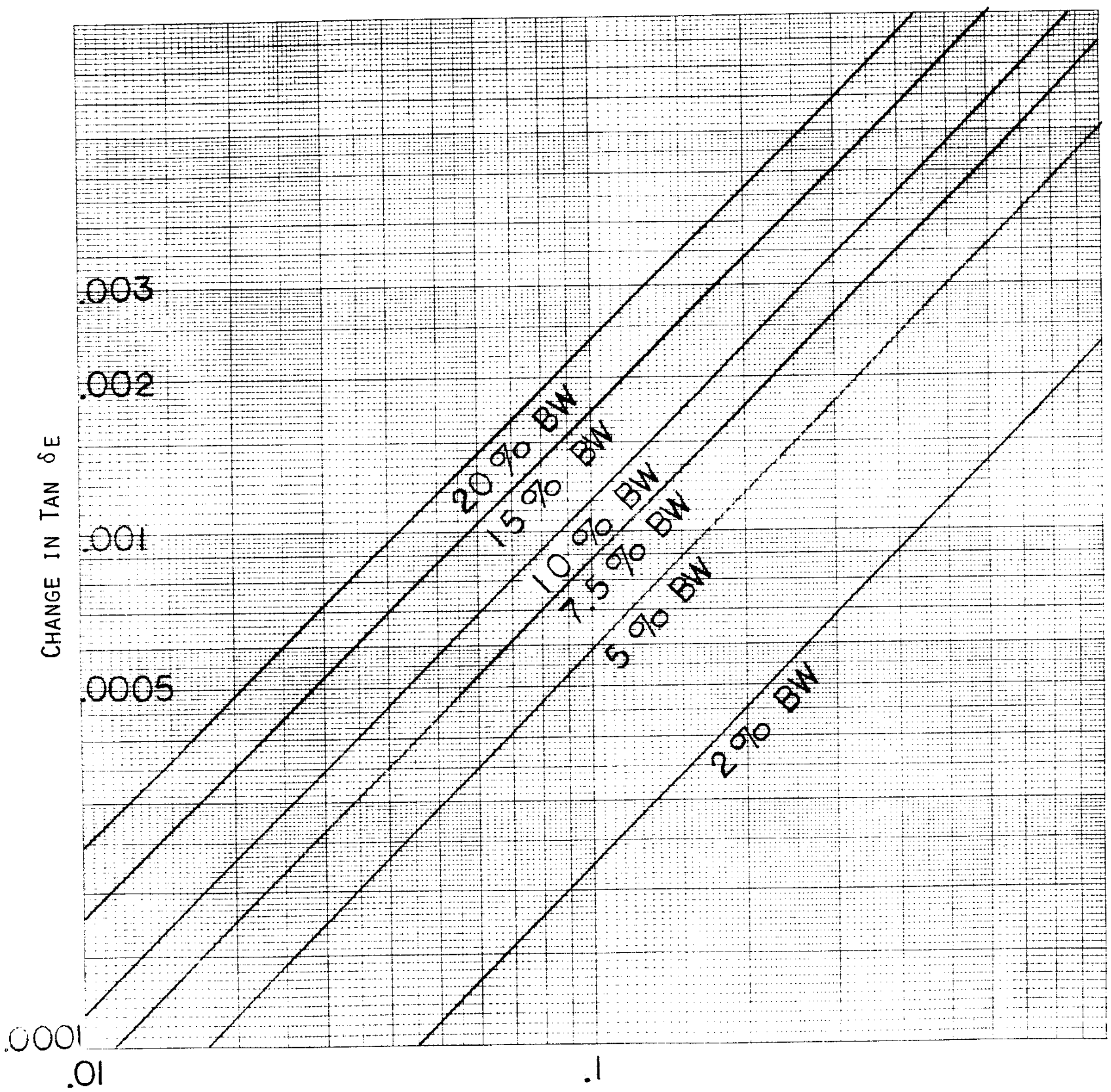

FIGURE 1: SENSITIVITY OF INSERTION LOSS TO CHANGES IN DIELECTRIC LOSS TANGENT AS A FUNCTION OF BANDWIDTH FOR Y-JUNCTION CIRCULATORS