LOSSES IN GaAs MICROSTRIP

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ABSTRACT

This paper presents newly measured data for the loss of microstrip on 4 mil GaAs from DC-40 GHz. This data was taken from transmission measurements of lightly coupled, multiple half-wavelength, resonators. A comparison of the loss data with the predicted losses from three popular CAE tools is provided.

INTRODUCTION

Microstrip loss, and the models currently provided by microwave CAE tool vendors, is an issue of some debate between microwave engineers. This is especially true at frequencies through 40 GHz. Improper measurement of microstrip structures often leads to erroneous conclusions about the validity of microstrip models. It was decided that a series of end coupled, half wave resonators would be fabricated over a wide range of resonant frequencies and characteristic impedances to extract the loss of GaAs microstrip.

The Experiment

The objective of this experiment was to determine the losses associated with microstrip transmission lines with impedances from approximately 20 Ω to 90 Ω, at frequencies up to 40 GHz for structures fabricated on 100 µm (4 mil) GaAs. The circuits used in this experiment were fabricated as part of a process control monitor mask and dropped into another mask set. This step was taken to insure that the resulting data would accurately reflect the losses of microstrip lines employed in MMIC circuits.

The series of end coupled, half-wavelength resonators were designed to resonate at frequencies from 7.5 to 40 GHz. The resonators were coupled to the measurement system by 5 µm gaps. This provided sufficiently light coupling to measure the resonator without significantly loading it.

Since the most important requirement of this experiment is frequency accuracy, the resonators were first measured using a broad frequency sweep to determine the location of resonant peaks and then a set of narrow band sweeps was performed around each peak to determine the bandwidth.

Derivation of Loss Equations

From the 3 dB insertion loss frequencies (f_l, f_h), the loaded-Q of the resonator was determined at each resonance as follows:

$$Q_L = \frac{fo}{BW}$$

where $fo = \dfrac{f_l + f_h}{2}$

and: $BW = f_h - f_l$

The loaded-Q is a combination of the resonator-Q (Qo) and external effects such as loading (Qcc) and radiation (Qrad) and is expressed by:

$$\frac{1}{Q_L} = \frac{1}{Q_o} + \frac{2}{Q_{cc}} + \frac{2}{Q_{rad}}$$

This assumes that Q_{cc} and Q_{rad} are the same at both ends of the resonator.

Radiation is a significant contributor of loss in thick substrates and at high frequencies. Using the full-wave analysis method of Jackson [1] and checking by the method of Denlinger [2], the radiation Q for even the lowest impedance structures was > 2000 at all frequencies. This value has a negligible effect on the unloaded-Q of all but the lowest impedance resonator. The loss curve of the 350 µm resonator was adjusted for radiation using the method discussed in the references.

The effects of radiation on the loss of higher impedance structures were negligible. The unloaded-Q for these structures is:

$$\frac{1}{Q_o} = \frac{1}{Q_L} - \frac{2}{Q_{cc}}$$

The insertion loss (L_A) through the resonator is provided from filter theory [3] and relates internal Q and external Q by:

$$L_A = 10 \log \frac{Qcc^2}{4Q_L^2} \quad \text{[dB]}$$

After a straight forward substitution, the unloaded-Q then becomes:

$$Q_o = \frac{Q_L}{1-10^{(-L_A/20)}}$$

The loss of the microstrip is then provided by the method of Pucel, Masse' and Hartwig [4].

$$\alpha o = \frac{8.68\beta n}{Qo} \quad \text{[dB/mm]}$$

where:

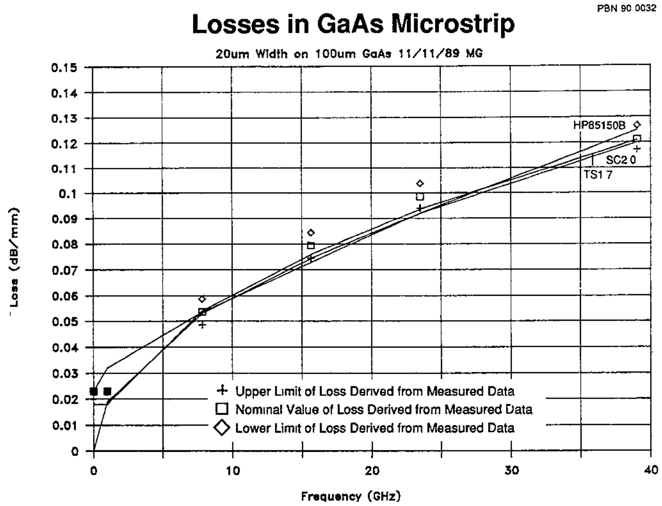
n = the number of half wavelengths

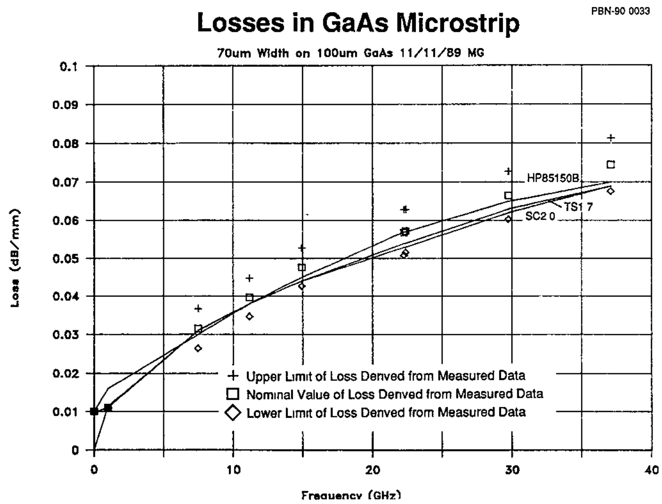
$\beta = \frac{2\Pi}{\lambda g}$

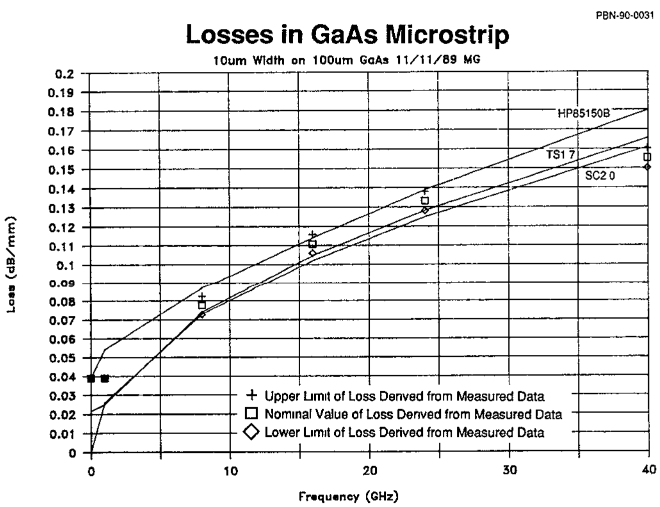
λg = guide wavelength in mm

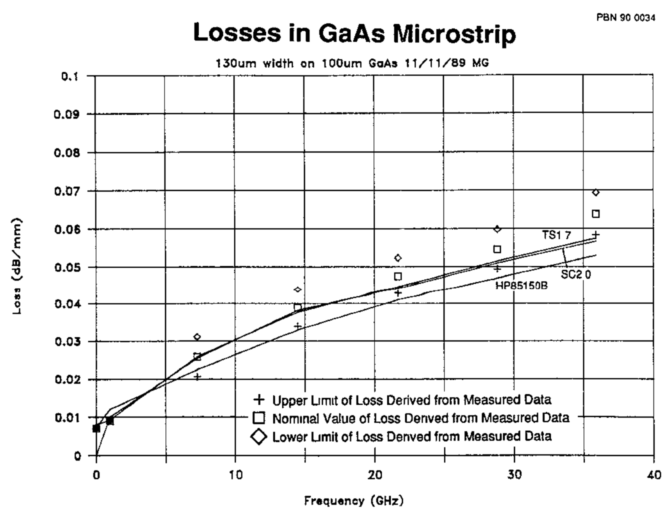
Results and Comparisons To Predictions of CAE Tools

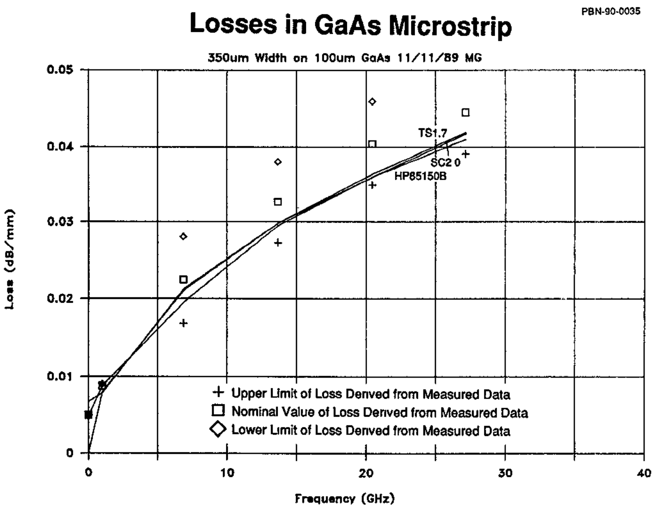
The results of the loss experiment are given for five different line widths: 10 µm, 20 µm, 70 µm, 130 µm and 350 µm which provided an impedance range of 90 to 20 Ω respectively (see Figures). Each line is plotted with a set of error bars calculated from the formulas which include the accuracy of the insertion loss and frequency measurement accuracy.











The values of loss given above 1 GHz are all extracted from resonator measurements. The DC value is derived from the bulk resistivity of the conductor. An additional data point at 1 GHz has been extrapolated downward from higher frequency measurements, as fitting the data from DC to the first resonance would be misleading.

Also plotted in Figs. 1-5 is the predicted loss for a 1 mm length of microstrip using TOUCHSTONE® Ver. 1.7 (EEsof, Westlake Village, CA), SUPERCOMPACT® 1.95 (Compact Software, Patterson, NJ) and MDS (HP85150B, Ver 2.0, HP, Santa Rosa, CA). In each case, the parameters used to obtain the data were:

> ER = 12.9, H = 100 μm, T = 3 μm,
> Resistivity = 2.44 μΩcm (4.1 x 10^{-7} sie/m)
> tan δ = 0, Roughness factor = 0

It should be noted that these resonators were viewed optically at 500 X and surface roughness was negligible.

Bulk resistivity of the substrate was measured after implantation and also after nitride deposition. The values achieved would result in a loss tangent of less than 1 x 10^{-4} [5]. The loss tangent of GaAs has been reported as high as 0.0004 [6] for somewhat different processing techniques. This would result in a maximum error of 0.003 dB/mm at 40 GHz and has been ignored.

The results of all three of the CAE simulators is within or very near the measurement limits of error for all line impedances.

The loss model in Version 2.0 of SUPERCOMPACT® approaches the correct assymptotic value of loss for low impedance lines as frequency approaches zero, however, it slightly underestimates the DC loss for high impedance lines. It is interesting to note that the loss model in SUPER COMPACT® Version 1.95 and TOUCHSTONE® 1.7 does not approach an assymptotic value as frequency approaches DC. MDS does approach the correct loss assymptotically. It should be noted that this is a new release of the HP simulation tool (HP85150B, Ver 2.00, November 1989). The previous version (HP85150A, Ver 2.00) was entirely too pessimistic at all frequencies equivalent to a factor of two in conductor resistivity.

Conclusions

The loss models provided by the three software vendors agree fairly well with measured data through 40 GHz. Since the measured loss roughly follows a square-law frequency relationship through 20 GHz, it should be possible to adjust the loss below this frequency and above 1 GHz by modifying the resistivity of the conductor in the simulator.

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