V-2 MICROSTRIP TRANSMISSION LINES ON HIGH DIELECTRIC CONSTANT SUBSTRATES FOR HYBRID MICRO-WAVE INTEGRATED CIRCUITS

K.C. Wolters and P.L. Clar

Motorola, Inc.

Among the various approaches to the design of microwave integrated circuits, thick film hybrids combine a relative ease of manufacturing with excellent performance at the lower portion of the microwave frequency spectrum where high performance semiconductor devices are now available in a wide variety. When using conventional ceramic substrates for such circuitry, limitations exist in solving the problem of obtaining maximum degree of compactness at very low impedance levels required for optimum power handling capability of active semi-conductor devices. One approach to this problem discussed here is the utilization of microstrip transmission line circuits on substrates with very high dielectric constants ($\epsilon_r = 33$).

A theorectical analysis of the microstrip transmission line structure, when based on conformal mapping techniques with the usual simplifying assumption of homogeneity throughout the entire field region, is entirely inaccurate when applied to high dielectric constants as considered here. A solution of this problem is presented which applied well known finite difference approximations of Laplace's equation in combination with a successive over-relaxation program on a digital computer.[1, 2, 3, 4]

In this method, as illustrated in Figure 1, a fine net of rows and columns is superimposed upon the geometry to be analyzed. The electrostatic potential is calculated at each node point and by integrating the normal component of the E field over an enclosure around the conductor, capacitance is determined. Repeating this process once with the dielectric material in place and once with it removed, characteristic impedance and velocity of propagation is obtained. Figure 2 shows some of the computer results in comparison with experimental data. The analysis has been extended to specific components and transmission line circuit configurations. Data is presented on directional couplers, terminations, attenuators, right angle bends and meander lines. In conventional microstrip parallel line couplers such as shown in Figure 3A, two problems are restricting the range of application. First, the spacing required for tight coupling becomes so small, especially in high ϵ transmission lines, that prohibitively tight tolerances are needed. Secondly, the velocity of propagation in the odd mode is different from that in the even mode which leads to a severe restriction of bandwidth.

A new and different structure, the overlay coupler shown in Figure 3B avoids these problems by providing high ϵ material in the coupling gap and a separate coupling strip over both lines. Theoretical and experimental data are also presented on this directional coupler.

Using all the data obtained in the above study as design inputs, hybrid micro-wave integrated circuits have been developed. Actual performance has been evaluated in relation to the performance of comparable conventional stripline circuits. An example of an S-band rf front end section is shown in Figure 5. The circuit combines a Schottky barrier diode balanced mixer with a transistor amplifier - quadrupler to provide LO power at S-band from an externally available VHF signal.

The 1 x 1 inch chip on high ϵ ceramic contains one transistor, two diodes and two discrete coupling capacitors in combination with the microstrip transmission line rf circuitry. For optimum thermal connection to the aluminum base plate, the transistor chip was mounted on beryllia to allow heat sinking and at the same time provide electrical insulation of the collector. Electrical connections between active semiconductor devices and passive transmission line circuits are made with wire-bonding techniques.

Measured performance data of the mixer are presented in comparison with conventional stripline circuit. As exemplified in Figure 4, the higher loss of microminiaturized circuitry causes some increase in noise figure. All noise figure measurements are based upon a 2.3 dB noise figure of the i.f. preamplifier. The objective was a comparison rather than optimization of noise figure and bandwidth leaving considerable room for improvement.

In conclusion, it is shown that the use of these substrates of high dielectric constant materials for hybrid integrated circuits offer two basic advantages at microwave frequencies: greater compactness and low impedance levels. The former is particularly advantageous at UHF, L and S-Bands due to the larger physical wavelengths. The latter allows the use of semiconductors with higher power handling capability which make low impedance matching imperative.

References

1. Clarricoats, P.J.B., "Guided Wave Research in British Universities," 1966 G-MTT International Symposium, Palo Alto, California, Paper VI-1.
2. Green, H.E., "The Numerical Solution of Some Important Transmission Line Problems," IEEE Transactions on Microwave Theory and Techniques, Vol MTT-13, NO. 5, p. 676-692.
3. Ramo, Whinnery, Van Duzer, "Fields and Waves in Communications Electronics," John Wiley & Sons, New York, 1965.
4. Southwell, R.V., "Relaxation Methods in Theoretical Physics," The Claredon Press, Oxford, First Edition, 1946.

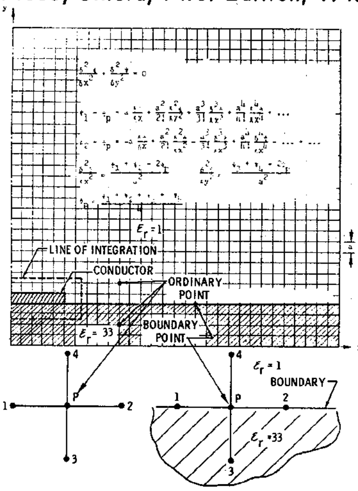

FIG. 1 - Finite Difference Approximation of a Field Problem

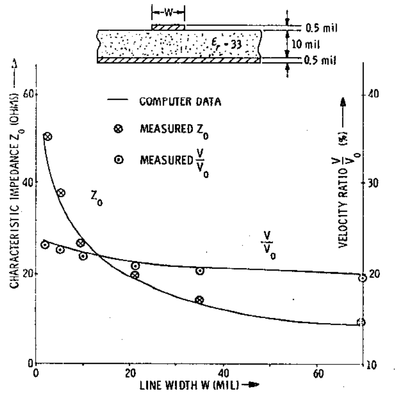

FIG. 2 - "High K" Microstrip Transmission Line

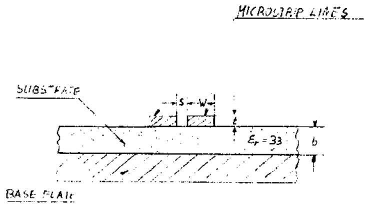

FIG. 3A - Conventional Microstrip Coupler

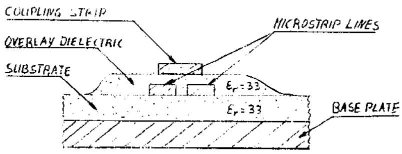

FIG. 3B - Overlay Parallel Line Coupler

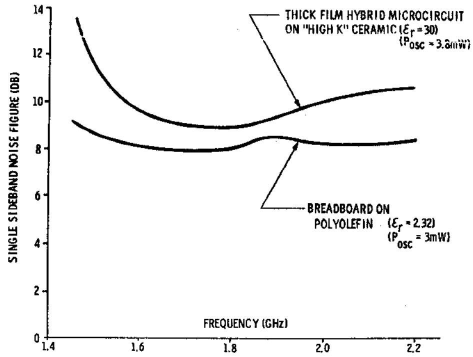

FIG. 4 - SSB Noise Figure of Hot Carrier Diode Mixer at Optimum Power Level

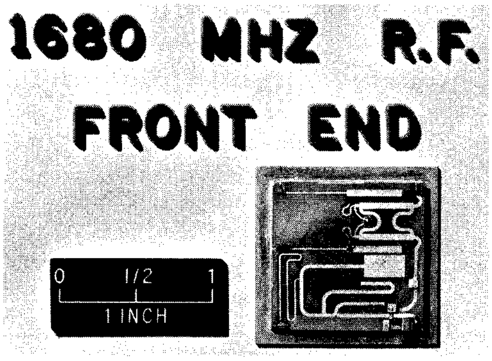

FIG. 5