V-2. CERAMIC MICROSTRIP FOR MICROWAVE HYBRID INTEGRATED CIRCUITRY

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INTRODUCTION

The basic microstrip, or non-symmetrical stripline geometry, has been investigated as a transmission line medium,[1-4] and a number of types of transmission line components have been built utilizing microstrip construction.[5-9] Microstrip has found only sporadic applications, however, as designers generally chose the more shielded and lower loss stripline, coaxial or waveguide modes of propagation. With the availability of microwave transistors and other semiconductor devices usable well into the microwave frequency range, the microstrip transmission line was re-evaluated because of its compatibility with the fabrication and installation of passive components and active devices on the same substrate with the transmission line. Some of the ceramic materials appear particularly attractive as a substrate from performance and economic standpoints. This paper covers some of the characteristics of microstrip transmission lines on homogeneous ceramic dielectric substrates and on the two dielectric substrate as is the case in glazed ceramics. Some of the considerations in component and circuit design utilizing this medium will be discussed along with some examples of incorporating semiconductor devices with ceramic microstrip components to accomplish high performance microwave hybrid integrated circuitry.

CHARACTERIZATION OF MICROSTRIP TRANSMISSION LINES

The cross-section of a typical microstrip geometry is shown in Figure 1, along with a very approximate indication of electric field distribution. A two layer dielectric substrate is indicated with different dielectric constants and loss tangents as would be the case with glazed ceramics. Due to the non-symmetry of the basic microstrip geometry, an exact theoretical analysis to determine the characteristic impedance and propagation velocity has proved to be quite difficult.

An experimental approach was therefore taken to suitably characterize the microstrip transmission lines on various dielectric substrates. Characteristic impedance was investigated by preparing straight line segments of microstrip transmission line of various widths and measuring the characteristic impedance of these lines by the use of the slotted line and time domain reflectometer techniques. These lines were prepared on the desired substrates by evaporation and plating of the desired metal system and by photoresist etching techniques to define the line geometries desired. Gold, silver and aluminum were among the metals which were investigated. The characteristic impedance vs the width to height ratio for microstriplines on glazed and unglazed aluminum oxide is given in Figure 2. The thickness of the substrates utilized here was 20 to 25 mils. We see that a 50 Ω line on unglazed substrate corresponds to a width to height ratio of approximately 1. A given width line on the glazed ceramic has a higher impedance than it would on unglazed substrate of the same thickness due to the presence of the glazed layer which has a lower dielectric constant than that of the ceramic. Loss was measured as a function of frequency for these lines, a typical value being 0.08 dB/cm at 3 GHz. In order to perform most circuit functions it is also necessary to know the wavelengths in the transmission medium at the frequency range of operation. These measurements were made for various impedance microstriplines by operating a straight section of the microstripline as a very loosely coupled multiple of $\frac{\lambda}{2}$ filter. When the coupling is very loose, a transmission maximum will occur at an integral multiple of $\frac{\lambda}{2}$.

Results of these measurements are given in Figure 3. Here we see that the ratio of λ_0, the free space wavelength, to λ_g, the wavelength in the microstripline is nearly invariant with frequency up to at least 10 GHz. It does vary somewhat, however, with the impedance of the transmission line as well as the thickness and dielectric properties of the substrate. The characteristic impedance, loss and guide wavelength have also been investigated for microstrip transmission lines on beryllium oxide substrates which is of particular interest because of this material's combination of good dielectric properties and high thermal conductivity.

CIRCUIT DESIGN CONSIDERATIONS WITH MICROSTRIP

As seen in Figure 2, transmission lines with characteristic impedance between 100 Ω and 30 Ω represent a desirable range of impedance levels which can be readily fabricated and handled in microstrip circuitry on ceramic. Transmission line circuitry such as filters, directional couplers, and impedance matching and transformation networks can be designed in microstrip circuitry utilizing the transmission line network techniques which have been well developed and applied to a considerable extent in coaxial and stripline geometries. Branch-line hybrids were investigated for applications requiring 3 dB quadrature couplers, as 3 dB directional couplers of the coupled line type are difficult to realize with the lines in the same plane due to the extremely close spacing between lines required. An example of one 3 dB branch coupler design is shown in Figure 4. Overall size of this circuit is 25 x 550 x 880 mils. Figure 5 shows the "two-way" VSWR and insertion loss vs frequency for this coupler as measured with input as port 1, ports 2 and 3 open (i.e., total reflection with equal phase) and the output taken into a matched load at port 4. Measurements made with all ports terminated indicated a typical isolation of 20 dB and forward coupling of approximately -3.3 dB in each arm. Similar performance was obtained with two branch coupler designs except with less bandwidth as would be predicted.

SIMPLE BALANCED MIXER DESIGN

Utilizing the 3 dB branch-line coupler, balanced mixers were designed at S and X-band utilizing gallium arsenide Schottky barrier diodes[10] which were alloyed and bonded into a circuit on ceramic substrate. A photograph of an X-band mixer circuit and the test fixture which transforms from coaxial to the microstrip is shown in Figure 6. The circuit consists of a three branch 3 dB coupler with a length of high impedance line between each arm of the coupler and the point of bonding the diodes which was claculated to provide the desired source impedance for optimum mixer performance. The open stub on the output is a quarter wavelength of approximately 36 Ω characteristic impedance which serves as a filter to the X-band energy and adds little capacity on the I-F output. This mixer gave a typical average noise figure of 6.8 dB over the frequency range of 8.5 to 9.5 GHz. Designing the mixer so that the gallium arsenide diodes could be individually DC biased to an optimum point could further improve the noise figure by approximately 1 1/2 to 2 dB based on measurements made with the diodes in a single-ended mixer circuit. A similar mixer was designed at S-band utilizing the three branch coupler shown in Figure 4.

CONCLUSION

Although exact theoretical analysis of the microstrip mode is lacking, this medium can be accurately characterized by suitable measurement techniques. The characteristic impedance, Z_0, wavelength in the medium, λ_g, and loss per wavelength was determined as a function of frequency and other pertinent parameters for microstriplines on glazed and unglazed Al_2O_3 and unglazed BeO.

Results indicate that most transmission line circuitry such as couplers, filters, and various networks not requiring extremely low loss lines can be fabricated with microstrip on ceramic substrates. This type of circuit fabrication has the advantages of batch processing by high precision photoresist techniques on a substrate compatible for fabrication of thin film resistors and capacitors and installation of semiconductor devices.

An X-band balanced mixer with a noise figure less than 7 dB and occupying less than 0.01 cubic inch was described as an example of microwave hybrid integrated circuitry utilizing microstrip techniques on a ceramic substrate.

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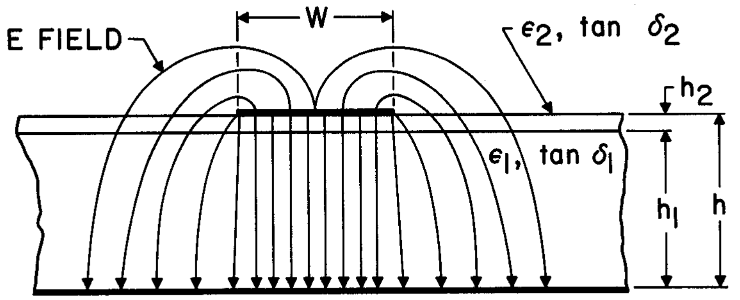

Figure 1. Cross-section of Microstrip Transmission Line

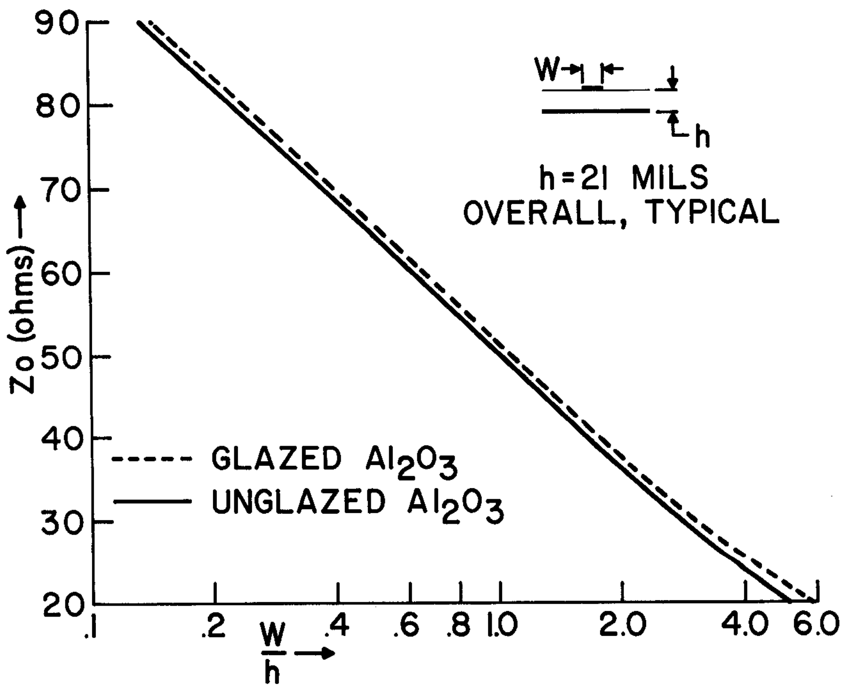

Figure 2. Characteristic Impedance for Microstrip Lines on Aluminum Oxide

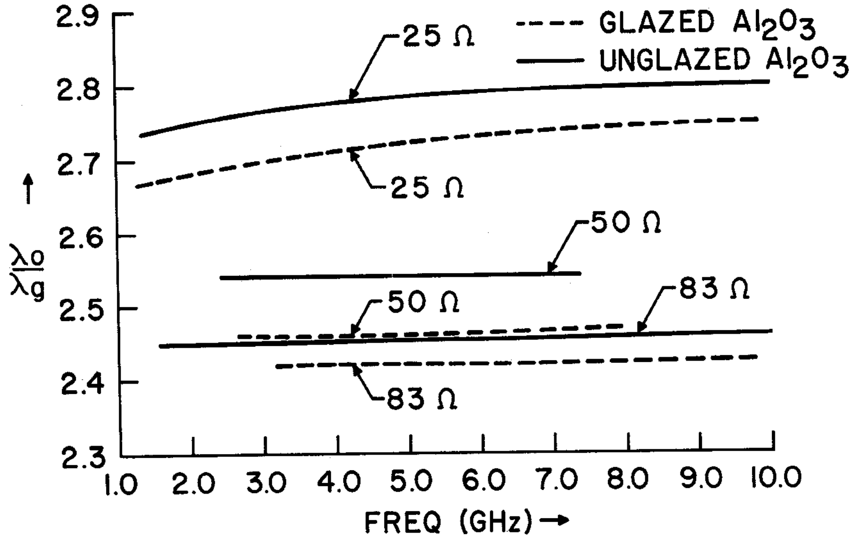

Figure 3. Free Space to Microstrip Wavelength Ratio ($\lambda O/\lambda g$) vs. Frequency for Microstrip on Aluminum Oxide Substrates

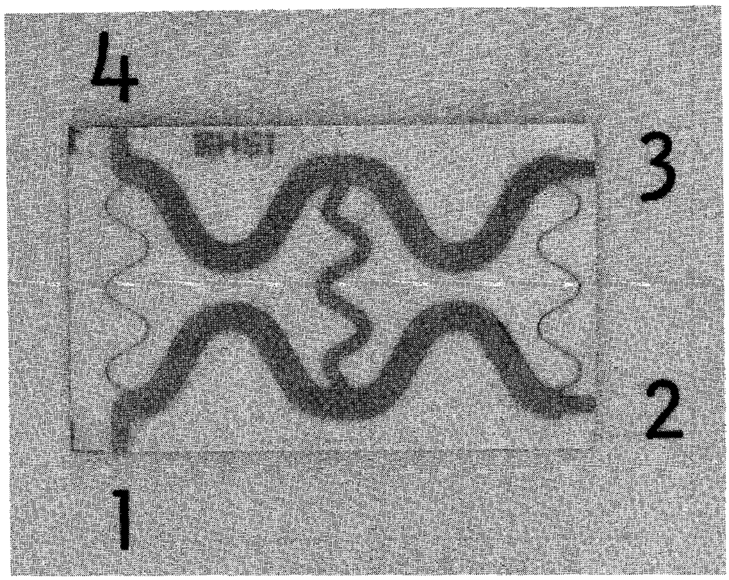

Figure 4. One 3 dB Branch Coupler Design

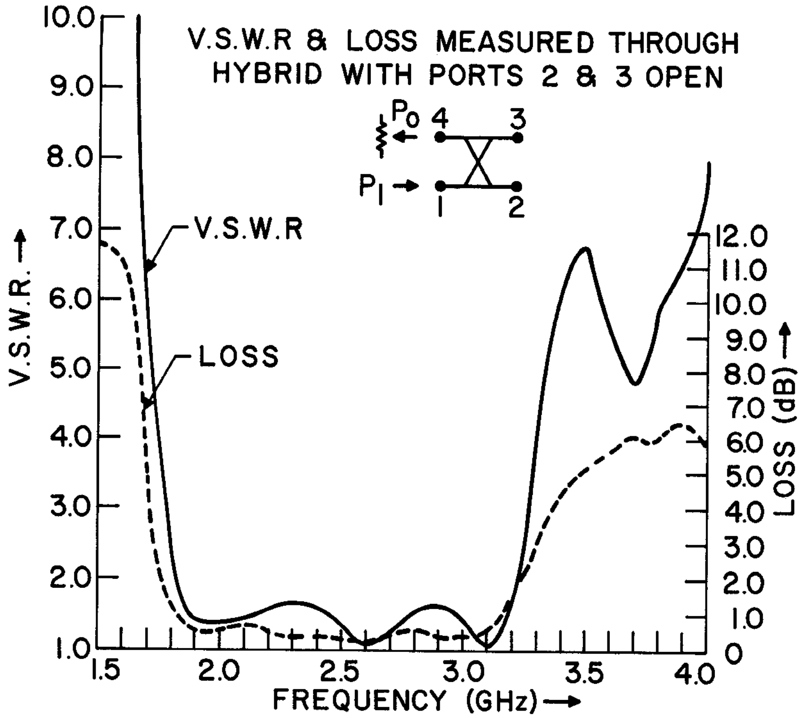

Figure 5. V.S.W.R. and Loss vs. Frequency for 3 Branch "S" Band Hybrid BHS-1

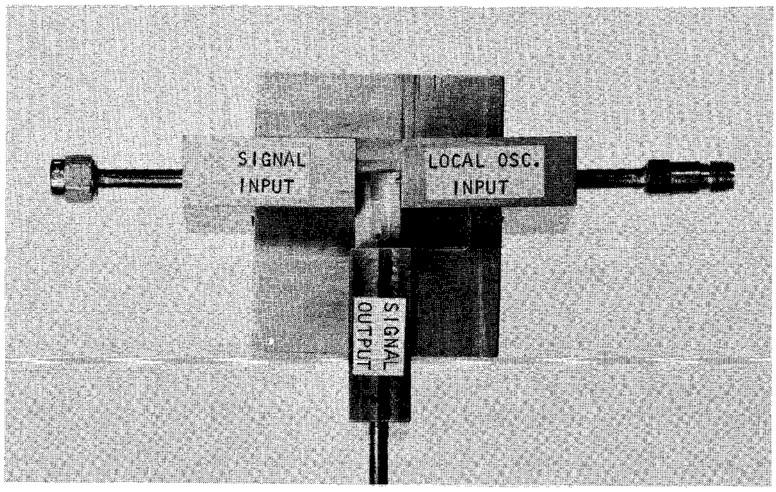

Figure 6. X-band Mixer Circuit and Test Circuit