GaAs SAMP DEVICE FOR Ku-BAND SWITCHING*

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ABSTRACT

Switchable attenuating medium propagation (SAMP) devices are coplanar transmission lines on an epitaxial semiconductor (GaAs) substrate. These transmission lines can be switched rapidly between states of high and low attenuation. Because they are uniform transmission lines they can easily be characterized for impedance matching purposes, and are well suited for use in microwave integrated circuits (MICs). Experimental performance data and theoretical background will be presented.

Introduction

This paper describes the development status of a new type of microwave device termed SAMP† (switchable attenuating medium propagation). This work has evolved from the active medium propagation (AMP) transmission line concept 1-3. The operation of SAMP depends on entirely different physics than that of AMP. The AMP device could also be used as a switch; however, for this application, its bilateral gain in the on-state presents impedance matching and stability problems. SAMP is stable, and matching for low VSWR can easily be achieved. SAMP devices also require much less power to maintain the on-state and have switching times less than or equal to 1 ns. They could be used, for example, instead of PIN diodes in a microwave "cross-bar" switch onboard a communications satellite.

Figure 1 shows the present SAMP design. The GaAs conducting layer is about 5 μm thick and has a carrier concentration of about 10^{15} cm^{-3}. The cross section is shown in Figure 2. The ground planes make ohmic contact to the GaAs and the center conductor is a Schottky barrier. In the on-state a negative bias is applied to the center conductor causing electrons to be depleted from the GaAs under the gaps, resulting in low-loss transmission. In the off-state, a small positive bias is applied to the center conductor, resulting in high attenuation due to the shunt conductivity across the gaps. GaAs is used because its high electron mobility allows high shunt conductivity and thus high off-state loss, and because of the availability of semi-insulating GaAs for substrates.

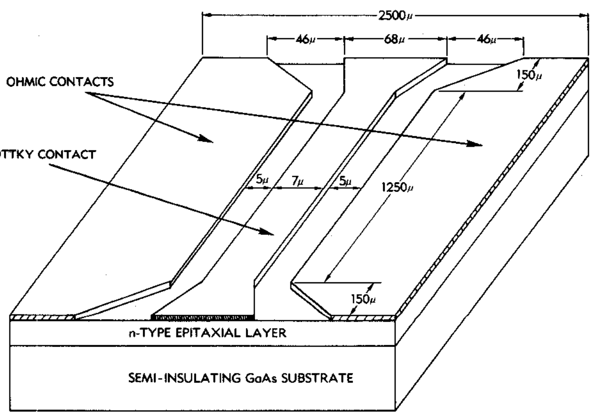


Figure 1. Geometry of SAMP Chip on GaAs Material (not to scale)

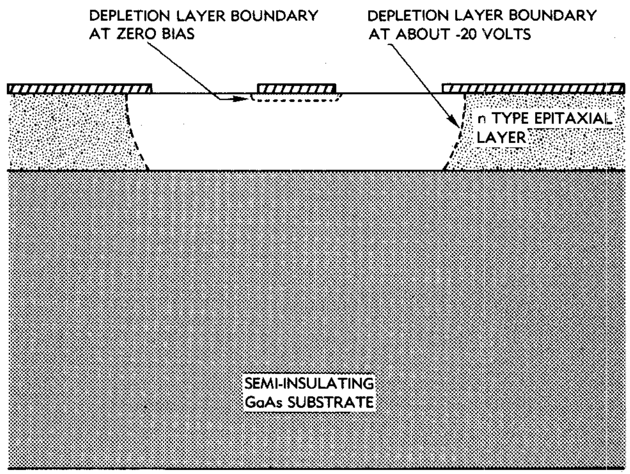


Figure 2. Cross Section of a SAMP Showing the Positions of the Depletion Layer Edge in the On-State and at Zero Bias

The typical on-state bias for SAMP devices is -20 to -30 V, center conductor to ground planes, and the on-state current is less than 1 μA. For maximum off-state loss, a center conductor bias of about +0.8 V is applied. The off-state current is then about 1 mA. If less off-state loss is acceptable, zero bias can be used.

Experimental Results

Measurements were performed with the SAMP devices mounted in an opening in an alumina microwave integrated circuit (MIC) board. The SAMP conductors are connected to the corresponding coplanar conductors on the MIC board. The MIC board coplanar lines are connected to standard 50-Ω SMA microstrip to coaxial connectors. All the measurement data quoted refer to these ports and are not corrected for any losses between the ports and the SAMP device.

Insertion loss was measured in the 13- to 18-GHz range. Early SAMP devices demonstrate losses from 7 to 10 dB for the on-state and 22 to 25 dB for the off-state. The fairly high on-state loss is mainly due to the series resistance of the center conductor. To reduce the series resistance, 3 μm of gold is electroplated onto the center conductor and ground planes. These devices, designated SAMP-P, exhibit on-state

†Patent pending.

*This paper is based upon work performed in COMSAT Laboratories under the sponsorship of the Communications Satellite Corporation.

insertion loss ranging from 1.5 to 3 dB and off-state loss from 17 to 20 dB. These data are shown in Figure 3.

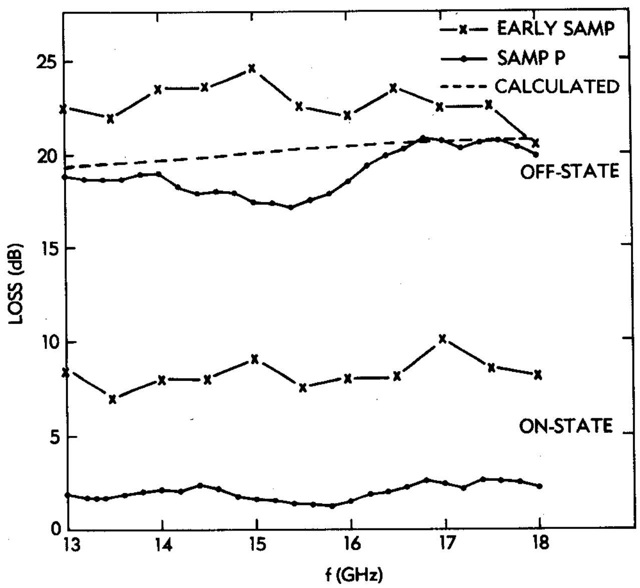


Figure 3. Insertion Loss vs Frequency for a Mounted Early SAMP and for SAMP-P in Both On- and Off-States

The VSWR measured in the input coaxial line to a SAMP-P device is 1.4:1 for the on-state and 2.6:1 for the off-state. The off-state VSWR increases with increasing shunt conductivity per unit length, and the on-state VSWR is attributed to mismatches at the various transitions. It was found that tuning discs on the MIC board could equalize the on-state and off-state VSWR values to 1.65:1 at 15 GHz. Figure 4 shows the effect of this tuning.

SAMP-P devices have switched up to 2-W input power when mounted with the type of heat sink previously described for Amp III devices.[1] The switching time of SAMP devices is estimated to equal the time required for a change in bias to propagate from one end of the line to the other. The phase velocity can be calculated from the transmission line parameters to yield a switching time of about 0.4 ns per millimeter of line length. Experimentally, the switching time of these 1.25-mm SAMP devices is less than or equal to 1 ns, which is the rise and fall time of the pulse generator. The on-state carrier to third-order intermodulation products ratio for two carriers in the 11-GHz satellite communications band, separated by 600 kHz, 1 W per carrier, has been measured at 45 dB.

Theoretical Considerations

Various design trade-offs exist for SAMP devices. For example, increasing the shunt conductivity increases both the loss per unit length and the off-state VSWR while decreasing the power handling capability. Increasing the line length increases both the on-off ratio and the on-state loss. Increasing the center conductor width decreases both the on-state loss and characteristic impedance. Suitable choices must be made to meet the requirements of each application.

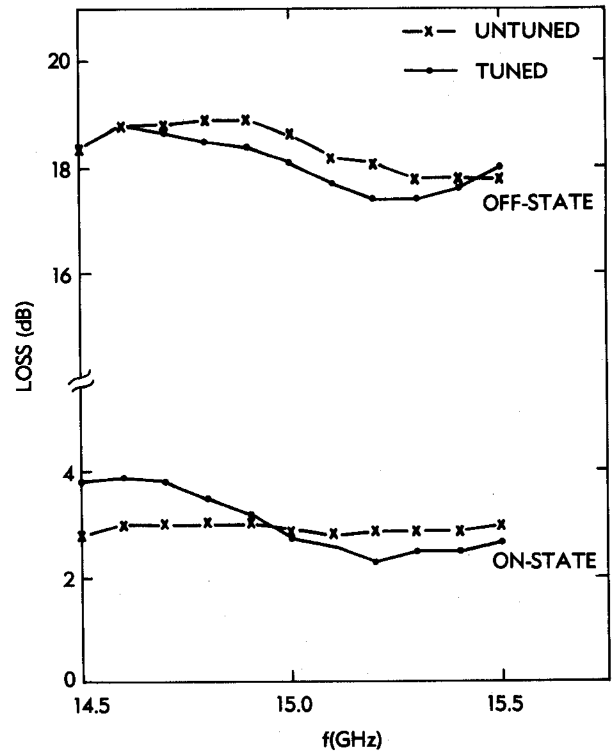


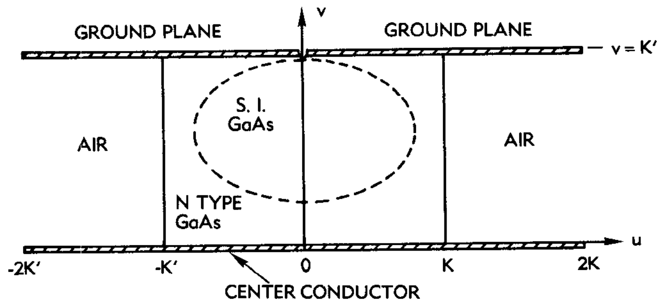
Figure 4. Effect on Insertion Loss of Tuning to Equalize On-State and Off-State VSWR at 15 GHz

The parameters of coplanar transmission lines may be calculated by using two Schwarz-Christophel conformal transformations. Figure 5 shows a transformation given by Wen,[4] which results in parallel plate strip line geometry. The conductor width of 4K and separation of K', as defined in Figure 5, are used to find the inductance, L, per centimeter and the capacity, C, per centimeter. In calculating the capacity, note that only half the width is filled with the GaAs dielectric. The transformation can also be used to find an approximate formula for series resistance, R, per centimeter

$$R = (1 + \frac{k}{3}) R_c$$

where R_c is the resistance per centimeter of the center conductor, and k is defined as in Figure 5.

The transformation shown in Figure 6 allows calculation of the DC shunt conductivity, G, per centimeter. It is assumed that it is valid to equate this to the AC conductivity and simply add it to the lossless parameters found as discussed above. Experimentally, this seems to be a good assumption if the predicted loss due to the shunt conductivity is less than about 20 dB per millimeter. From the parameters, R, L, G, and C, the length, and the source and load impedances, transmission loss, scattering parameters, and VSWR can be calculated for any frequency by use of the well-known transmission line formulas.



$$w = u + iv = F(Z/a,k)$$

$$Z = x + iy = a \, Sn\,(w,k)$$

$$k = a/b$$

where F = incomplete elliptic integral, 1st kind

Sn = Jacobian elliptic sine function

k = modulus

a = half width of the center conductor

b = half the ground plane separation

K = complete elliptic integral

K' = complementary elliptic integral

Figure 5. Schwarz-Christophel Transformation of the SAMP Cross Section, Shown in Figure 2, to Parallel Plate Stripline Cross Section

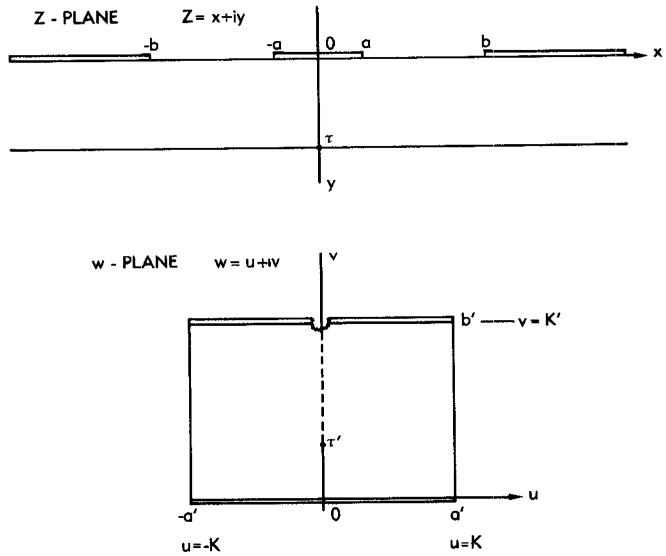
Calculations based on the above considerations agree with the experiment as shown in Figure 3. Manufacturer data on the GaAs wafer and measurements of the SAMP center conductor resistance were used to calculate the SAMP off-state loss. Typical MIC board and connector loss of 1.5 dB was added to get the dashed line in Figure 3. Most of the experimental points show slightly less loss. This is probably due to the simplifying assumptions of the theory. The additional variation with frequency of the experimental points is probably due to the effects of VSWR on the MIC coplanar line.

Conclusion

A new microwave switching device, SAMP, which is a uniform coplanar transmission line, has been described. This device, along with the related AMP device, is expected to become a useful MIC component.

Acknowledgment

The authors are grateful to M. Cardwell of Plessey and A. Cornfeld of COMSAT for growth of the GaAs epitaxial wafers used in this work, to J. Reynolds for materials characterization, to W. Chang for fabrication of the MIC boards and heatsinks, and to Dr. E. S. Rittner for his continued support of this program.



$$Z = \frac{2\tau}{\pi} \sinh^{-1}\left[\sinh\left(\frac{\pi a}{2\tau}\right) Sn\,(w,k)\right]$$

$$w = F\left[\frac{\sinh\,(\pi Z/2\tau)}{\sinh\,(\pi a/2\tau)},\ k\right]$$

$$k = \frac{\sinh\,(\pi a/2\tau)}{\sinh\,(\pi b/2\tau)}$$

Figure 6. Schwarz-Christophel Transformation of the Conducting Layer Only to Parallel Plate Cross Section. (F, Sn, k, K, and K' have the same meanings as in Figure 5)

References

1. P. L. Fleming, T. Smith, H. E. Carlson, and W. A. Cox, "CW Operation of AMP," International Electron Devices Meeting, December 5-7, 1977, Technical Digest, pp. 93-96.

2. P. L. Fleming, "The Active Medium Propagation Device," Proc. IEEE (Letters), Vol. 63, No. 8, August 1975, pp. 1253-1254.

3. P. L. Fleming, "Planar Transmission Line Comprising a Material Having Negative Differential Conductivity," U. S. Patent No. 3,975,690.

4. C. P. Wen, "Co-planar Waveguide: A Surface Strip Transmission Line Suitable for Nonreciprocal Gyromagnetic Applications," IEEE Transactions On Microwave Theory and Techniques, Vol. MTT-17, No. 12, December 1969, pp. 1087-1091.