A W-BAND MONOLITHIC BALANCED MIXER*

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ABSTRACT

A fully monolithic balanced mixer fabricated on a GaAs substrate for operation at W-Band (75 to 110 GHz) is described. The overall size of the mixer chip is 0.075"x 0.075"x0.004". A minimum conversion loss of 4.6 dB has been measured at 91.1 GHz for narrow band operation. For broadband operation, a conversion loss of less than 8 dB has been achieved over an RF range of 73.6 to 83.6 GHz with a corresponding IF range of 8 to 18 GHz.

INTRODUCTION

Monolithic GaAs mixers fabricated in a crossbar configuration[1] have been previously reported for use at W-Band (75 to 110 GHz) frequencies. Although excellent results have been obtained, these mixers are generally considered waveguide mixes, which are not suitable for use in a planar integrated circuit structure. In addition, a W-Band crossbar mixer requires a substrate area of about 0.12x0.4 inch; too large for integrated circuit applications. This paper describes a W-Band fully monolithic mixer fabricated on a .004 inch thick GaAs semi-insulating substrate. The overall size of the entire mixer is 0.075x0.075 inch. The mixer is constructed in a planar circuit configuration utilizing a combination of microstrips, slotlines and coplanar striplines in an open structure. The typical conversion loss of the mixer was less then 8 dB for broadband operation, while for a narrow band case, a minimum conversion loss of 4.6 dB was measured at 91.1 GHz.

MIXER CIRCUIT DESIGN

A balanced mixer configuration utilizing a pair of in-situ Schottky barrier diodes and a planar slotline and coplanar stripline hybrid junction has been employed in the design of the W-Band monolithic mixer. Figure 1 shows the circuit configuration of the mixer design fabricated on a .004 inch thick semi-insulating GaAs substrate. The overall chip size is 0.075x0.075 inch. The mixer consists of a pair of Schottky barrier diodes, two coplanar stripline sections, one slotline section, and a microstrip low-pass filter. At the junction where the diodes are located, the slotline and the coplanar stripline sections form a magic tee junction, in which the diode pair is connected in series with respect to the slotline section and in parallel with respect to the coplanar stripline section. On the other end of the slotline

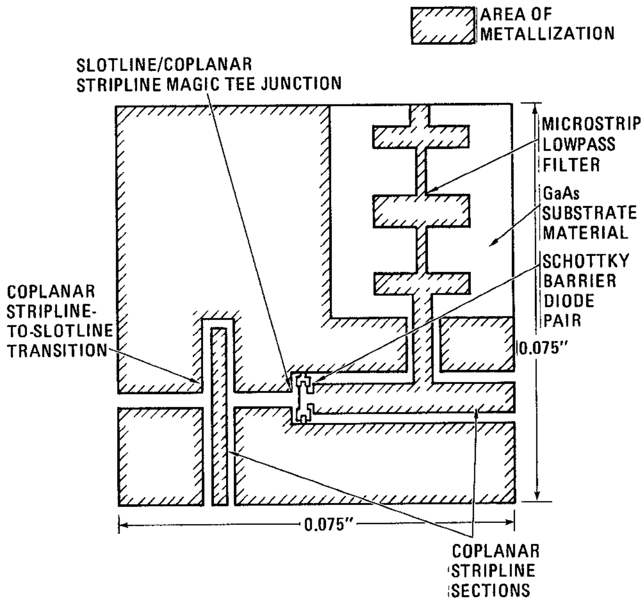

Figure 1. Planar Monolithic Mixer Configuration.

section, a coplanar stripline-to-slotline transition is provided for coupling the LO power to the diodes. In actual operation, the RF and LO are fed to the respective coplanar stripline ports. The IF is taken out via a microstrip low-pass filter. The dimensions of the mixer circuit are determined by matching the impedance of the diode pair to that of the slotline and coplanar stripline sections, over the operating frequency of interest. For the present design, the characteristic impedance is approximately 100 ohms for the slotline section, and 50 ohms for the coplanar stripline section. The detailed geometry of the Schottky barrier diode pair at the coplanar stripline and slotline magic tee junction is shown in Figure 2. The in-line arrangement of the diode fingers facilitates alignment of the Schottky barrier gate during processing of the diode wafer. The design of the coplanar stripline-to-slotline transition is based on a low frequency model[2] extended to W-Band. The equivalent circuit of this transition is shown in Figure 3. The open-circuit series stub is made with a coplanar stripline stub with a characteristic

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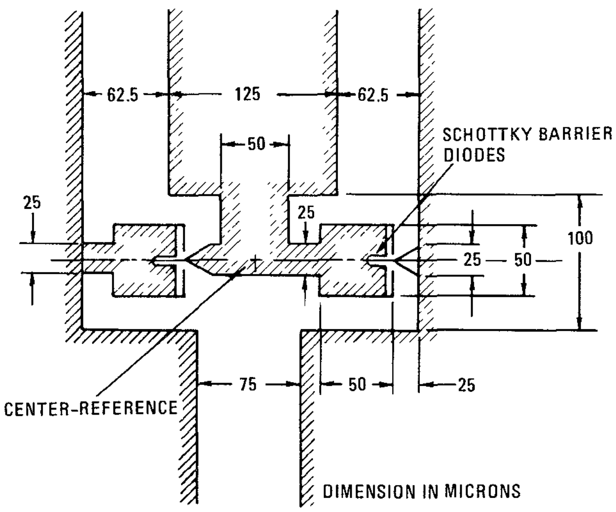

Figure 2. Diode Arrangement at the Magic Tee Junction.

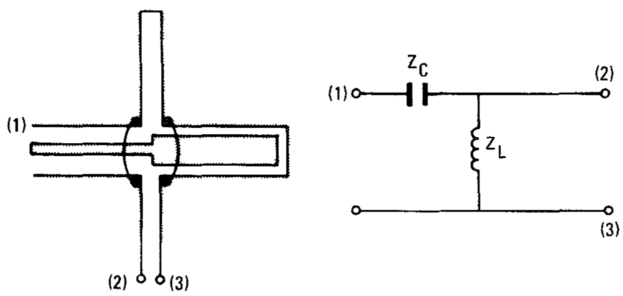

Figure 3. Equivalent Circuit of the Coplanar Stripline/Slotline Transition.

impedance Z_C, while the short-circuit paralleled stub is made with a slotline stub with a characteristic impedance Z_L. To obtain proper conditions of excitation, the two ground planes of the coplanar striplines must be connected with low impedance bonding wires. All the stubs are approximately a quarter wavelength at the center frequency of the operating band. The advantage of the coplanar stripline-to-slotline transition is its planar structure, which eliminates the two-side processing step required for the microstrip-to-slotline transition.

MONOLITHIC MIXER FABRICATION

The successful fabrication of millimeter-wave monolithic circuits requires the development of several key technologies in GaAs. These include:

- Controlled growth of uniformly thin epi-layers less than 0.15μm thick
- Optimized ohmic contact alloy composition and alloying temperature to reduce diode series resistance.
- Ultra-fine geometry lithography for defining the Schottky gate junction.

Using these technologies, the monolithic mixer is fabricated on a GaAs semi-insulating substrate with a multilayer structure grown by VPE techniques. The epitaxial layer structure is n on n^+ grown on a semi-insulating substrate. The n and n^+ layers have the following characteristics:

Layers	Carrier Concentration (cm^{-3})	Thickness (μm)
n	1 - 2 x 10^{17}	0.1 - 0.15
n^+	1 x 10^{18}	2 - 3

The processing procedure for the fabrication of the monolithic mixers follows, in general, conventional GaAs monolithic microwave integrated circuit techniques. The two Schottky-barrier diode junctions are fabricated on the substrate by a metal-liftoff technique. Figure 4 shows the processing sequence for the fabrication of the monolithic mixer. First, a two layer epitaxial structure of n on n^+ is grown on a GaAs semi-insulating substrate by VPE. Ohmic contacts are then formed on the diode area by depositing and alloying the ohmic-contact metallization, AuGe/Ni/Au, followed then by proton bombardment, to convert the n and n^+ layers outside of the diode area to a high resistivity layer for isolation. The Schottky-barrier contact is formed by depositing T/Au metallization on the open slot area in the ohmic-contact pad by chlorobenzene-assisted metal lift off. Also, RF circuits and interconnects are deposited at the same time as the Schottky-barrier metal. A complete mixer chip is shown in Figure 5.

RF PERFORMANCE

For RF evaluation, the W-Band monolithic mixer chip was mounted on a test fixture as shown in Figure 6. In the test fixture, waveguide-to-coax transitions utilizing special miniature coax lines are provided for the RF and LO inputs. The IF output of the mixer is simply taken out via an OSM coax connecter. On the mixer chip, air bridges formed by gold ribbons are bonded across the ground planes of the coplanar stripline sections. These air bridges serve not only as common ground lines to equalize the ground

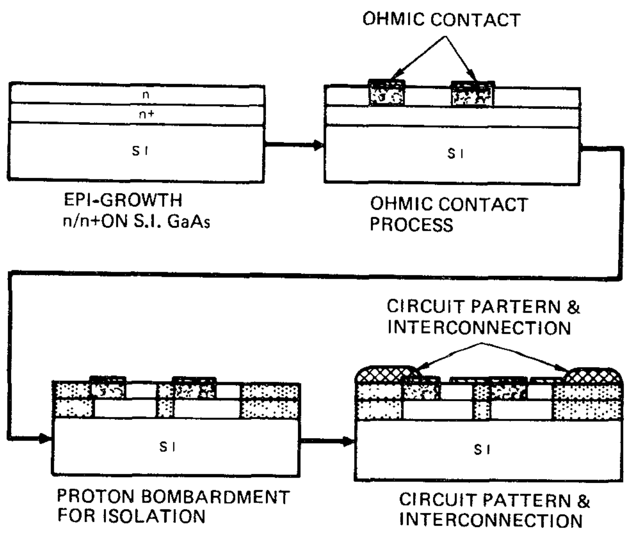

Figure 4. Monolithic Mixer Circuit Processing Sequence.

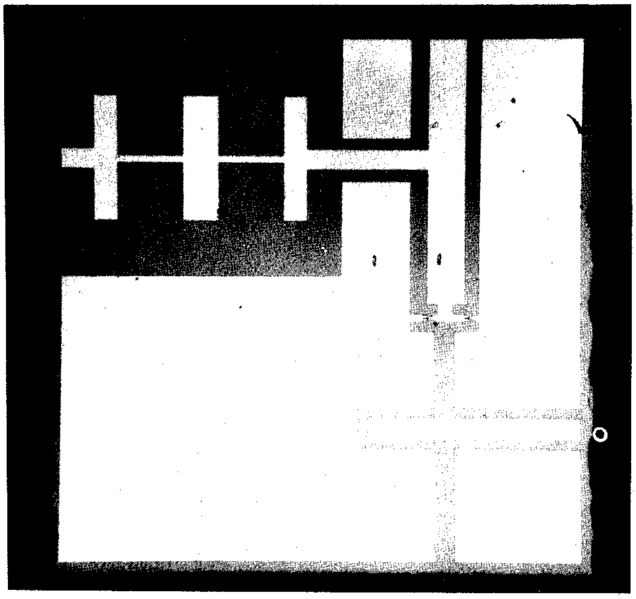

Figure 5. Monolithic GaAs Mixer Chip.

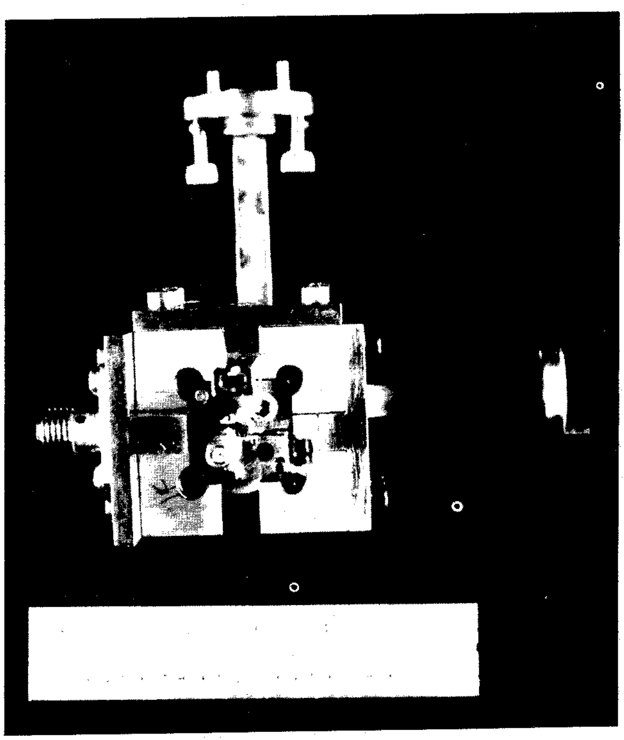

Figure 6. W-Band Monolithic Mixer Test Fixture Assembly.

potential of the coplanar stripline, but also as a choke to block off the slotline mode propagating down to the coplanar stripline section. The Schottky barrier diodes on the monolithic mixer chip had typical dc characteristics as follows: diodes series resistance R_S = 10 ohms, ideality factor n = 1.1, and diode junction capacitance C_j = 25 fF. RF performance of the monolithic mixer is very encouraging. The conversion loss of the mixer measured over a 10 GHz bandwidth covering 73.6 to 83.6 GHz is 8 dB, as shown in Figure 7. For a narrow band operation, a minimum conversion loss of 4.6 dB was measured at 91.1 GHz.

CONCLUSIONS

In conclusion, a planar W-Band fully monolithic mixer with excellent RF performance was successfully fabricated on a .004 inch thick GaAs substrate using planar integrated circuit techniques. The entire mixer chip measures only 0.075x0.075 inch. Minimum conversion loss of 4.6 dB was measured, which is comparable to that of its waveguide counterpart. An extremely broad IF bandwidth of 8 to 18 GHz was also achieved by the present mixer design with a typical conversion loss of 8 dB. The truly planar structure of the present mixer design offers potentially low cost batch-processing of millimeter-wave integrated circuits and future integration of millimeter-wave components, all on a single GaAs substrate in an open planar structure.

ACKNOWLEDGEMENTS

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RFERENCES

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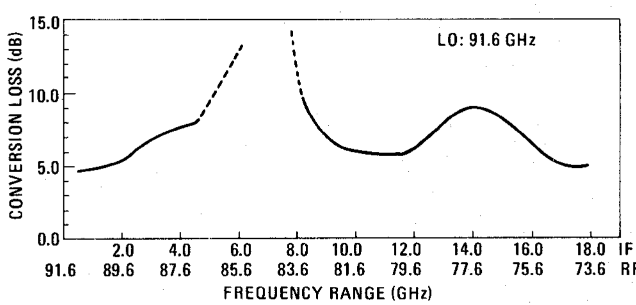

Figure 7. W-Band Monolithic Mixer Conversion Loss versus Frequency.