HYBRID MICROWAVE INTEGRATED CIRCUITS FOR MILLIMETER WAVELENGTHS

T.H. Oxley, K.J. Ming, G.H. Swallow, B.J. Climer and M.J. Sisson

The General Electric Company Limited, Semiconductor Research Laboratories, Hirst Research Centre, Wembley, England.

Abstract

This paper discusses some initial results which demonstrate the feasibility of hybrid M.I.C. designed for frequencies in the range 26 to 90 GHz. Practical single ended and balanced mixer circuits are described.

Introduction

The monolithic approach to the design of integrated circuits for millimeter wavelengths has a number of disadvantages. Such as, fabrication of active devices within the substrate material, with possible subsequent degradation due to the application of the microwave circuit, lack of device r.f. pre-testing capability and thus selection, and circuit restrictions applied by the high permittivity value of the substrate semiconductor material. Hybrid techniques on the other hand, offer greater versatility and microwave integrated circuits of this form are becoming established for frequencies up to 18 GHz[1]. It is the intention of this paper to describe the extension of such techniques to frequencies as high as 90 GHz, with the initial objective of demonstrating the feasibility of practical mixer circuits for down-converter applications. This has involved the design and fabrication of high cut-off frequency gallium arsenide beam lead Schottky barrier diodes to provide the function of frequency changing, design of waveguide to microstrip transitions, study of propagation in microstrip transmission lines formed on low permittivity ($\mathcal{E}_r \simeq 4$) substrate material, investigation into the design and performance of 3 dB coupler circuits, and finally the design, fabrication and evaluation of single ended and balanced mixer circuit configurations.

Design Studies

Waveguide to Microstrip Transitions

Studies have been carried out to establish the design of a transition from waveguide to microstrip. Broadband stepped ridge waveguide versions have achieved a v.s.w.r. of <1.3:1 over the frequency band of 26 to 40 GHz and <1.5:1 over the band of 60 to 90 GHz. These types of transition have then been used to examine the propagation characteristics of microstrip transmission lines, and to examine circuit performance.

Microstrip Transmission Lines

Transmission lines 500 µm wide on 250 µm thick fused silica ($\mathcal{E}_r \simeq 4.0$) have been used for 50 ohm characteristic impedance. Initial measurements have indicated a line attenuation of about 0.25 dB/cm in the frequency range of 26 to 40 GHz, and about 0.5 dB/cm in the range of 60 to 90 GHz.

Beam Lead Mixer Diodes

Beam lead gallium arsenide Schottky barrier mixer diodes have already been shown to be applicable to hybrid microwave integrated circuits for frequencies up to 18 GHz[2]. Advanced beam lead technologies have been applied to this type of device, and the junctions and beam overlay capacitance parasitics have been minimised to ensure satisfactory operation up to at least 90 GHz. A diode structure is shown in Fig.1. The chip size is about 200 µm x 200 µm x 100 µm. Such devices have been introduced into microstrip transmission line circuits by thermocompression bonding techniques.

Single Ended Mixers

Single ended mixer units for both the 32 to 50 GHz and 60 to 90 GHz frequency bands are shown in Fig.2 and 3 respectively.

A similar unit for 26 to 40 GHz is a design aimed specifically at a practical system application as a down-converter to 1.25 GHz, which requires operation within the frequency range of 32 to 40 GHz, but with an input v.s.w.r. <1.5:1 for a channel band of 500 MHz. This was achieved by use of a broadband r.f. circuit (v.s.w.r. <2.5:1 over 26 to 40 GHz) and a mechanical tuning facility to provide the desired performance at any required channel frequency. The measured conversion loss of this unit is about 6 dB. The overall noise figure performance is about 12 dB in conjunction with a 5.5 dB, 1.25 GHz 500 MHz bandwidth i.f. amplifier.

The 60 to 90 GHz mixer is a non-optimised experimental model, basically aimed as a circuit for evaluation of beam lead diodes. The input v.s.w.r. of this mixer is <3.0:1 over the band of 60 to 90 GHz, and has a conversion loss of about 14 dB down converting to 2.5 GHz.

Balanced Mixers

The balanced mixer shown in Fig.4, is designed for the frequency band of 30 to 40 GHz. This uses ridge waveguide transitions for the signal and local oscillator inputs. Power split and isolation between the r.f. ports is provided by a rat race 3 dB coupler. Such coupler designs give an isolation up to 40 dB and power split equal within ± 0.75 dB for a 10.0 GHz bandwidth. A matched pair of beam lead gallium arsenide Schottky barrier diodes are thermocompression bonded into the circuit. The noise figure performance of this unit is <10.0 dB (including a 2 dB i.f. noise figure contribution) over the frequency band of 30 to 40 GHz. The input v.s.w.r. and isolation between ports is ~2.0:1 and ~20 dB respectively. Diode r.f. matching to 50 ohms is not provided in this particular circuit, thus the overall performance may be improved markedly by the incorporation of diode matching circuit elements. The design of matching circuits is at present being explored.

The balanced mixer circuit of Fig.5 is designed for a frequency of about 35 GHz. This unit employs probe transitions in place of the ridge type. These consist of a length of microstripline from which the ground plane has been removed and which projects through an E-plane slot into the waveguide. This provides a simpler transition and more compact mixer than the previous design of Fig.2. However, the use of this transition restricts the bandwidth properties of the mixer. Initial evaluation of this unit indicates an overall noise figure performance of <10.0 dB (F.i.f. ~2 dB), and input v.s.w.r. of ~2.0:1 over a frequency band of 1.5 GHz.

Conclusions

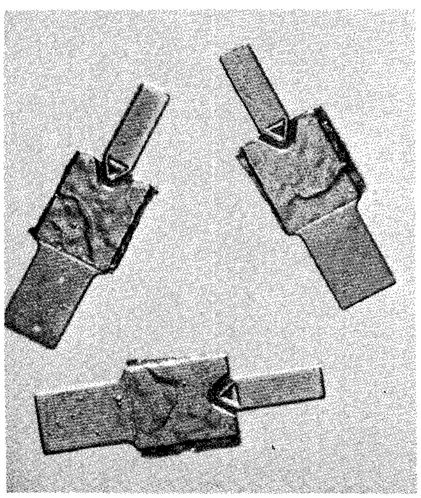
The results of these studies to date have indicated the feasibility of hybrid microwave integrated circuits for application up to about 90 GHz. It is considered that further studies will result in improved overall mixer performance of these hybrid circuits. Further work is then envisaged to apply these techniques to the design of complex microwave integrated circuit receivers for telecommunication applications, and for use in low power transmit-receive radar systems.

Acknowledgement

This paper incorporates work carried out under a CVD contract and is published by permission of the Ministry of Defence (Procurement Executive).

References

1. Oxley, T.H. and Ming, K.J. 'A J(Ku)-band Microwave Integrated Receiver', 1971 European Microwave Conference, Stockholm, Sweden, August 23-28 1971
2. Oxley, T.H. and Swallow, G.H. 'Beam Lead Mixer and Detector Diodes for Microwave Integrated Circuit Applications', Proc. Eighth International Conference on Microwave and Optical Generation and Amplification, September 7-11th 1970.



X70

Fig. 1
Beam lead GaAs Schottky barrier diode

<u>Note</u>: Eventual commercial exploitation, if any, of devices or components covered by this paper, will be undertaken by A.E.I. Semiconductors Ltd., Lincoln, England.

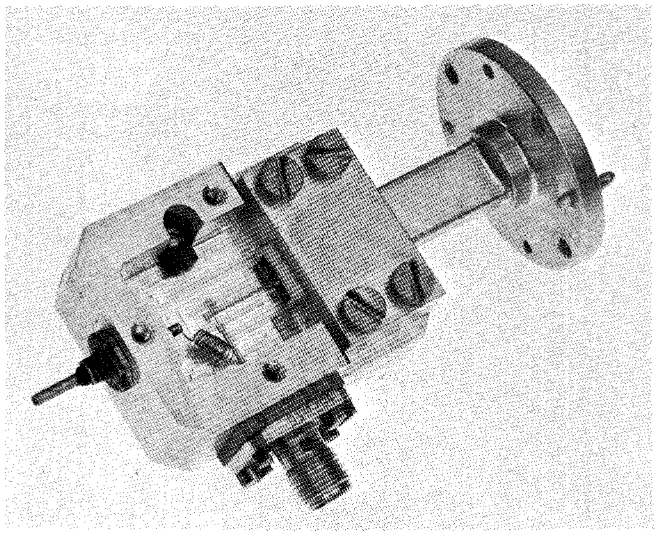


Fig. 2
26 to 40 single ended mixer

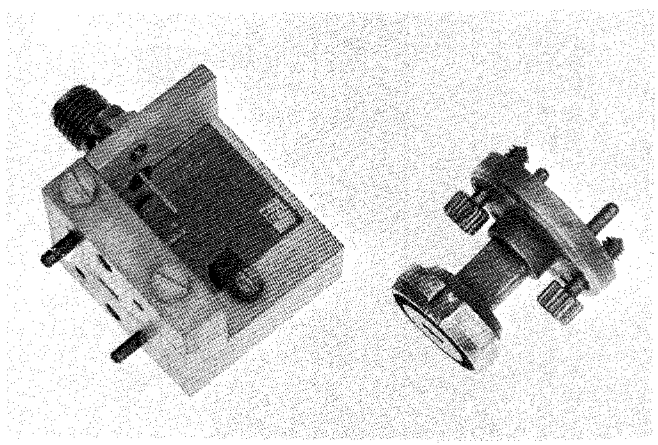


Fig. 3
60 to 90 GHz single ended mixer

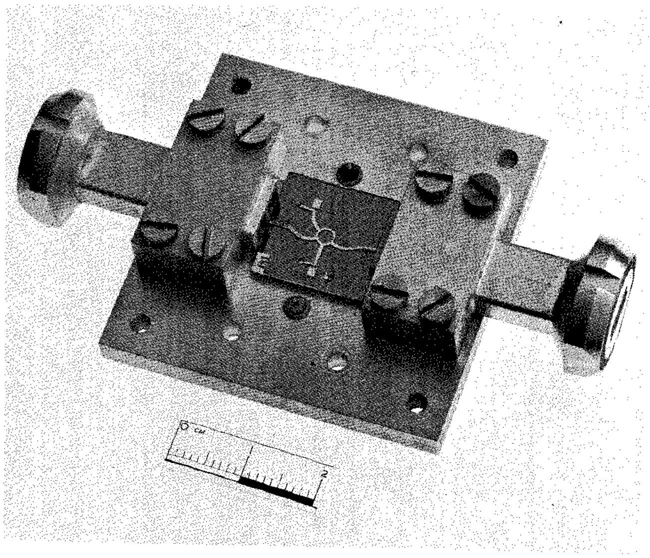


Fig. 4
35 GHz balanced mixer with
ridge type transitions

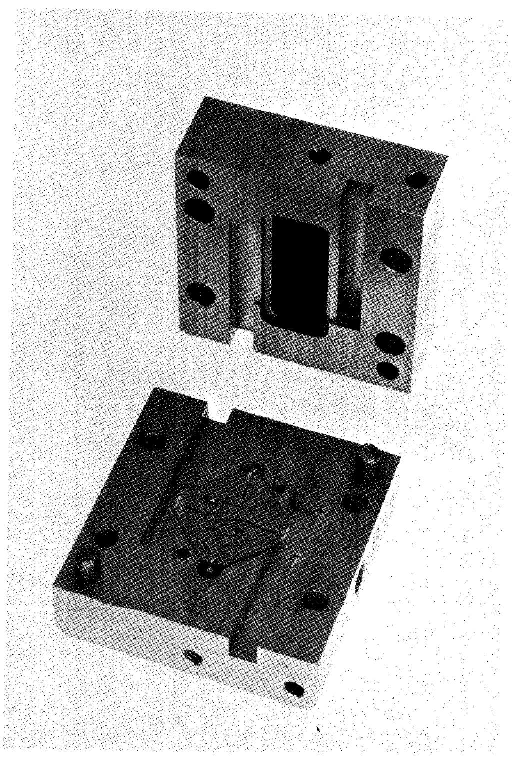


Fig. 5
35 GHz balanced mixer with
probe type transitions