MILLIMETER-WAVE HYBRID-OPEN MICROSTRIP TECHNIQUES

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SUMMARY

This paper discusses some of the recent advancements in the application of hybrid-open microstrip techniques to integrated mm-wave receiver components and sub-systems in the frequency range of 26 to 110GHz.

INTRODUCTION

The open-microstrip transmission medium in conjunction with hybrid techniques has found wide acceptance for MIC applications up to at least 18GHz, and the design and reliability aspects are now well proven for systems requirements. Many technological advancements have been made since these techniques applied to mm-wave frequencies were first reported (Ref. 1). Including progress in active devices, these have resulted in improvement in performance, reproducibility, reliability and integration aspects with practical application to many systems requirements in the 26 to 110GHz frequency range.

ACTIVE DEVICES

The improvements in beam lead GaAs Schottky Barrier mixer diode technology since it was initially introduced (Ref. 2), is indicated in Table 1. Devices of the DC1338/1339/1346 types all indicate advanced rugged structures by the incorporation of glass dielectric layers. The DC1346 represents the result of recent research at the GEC Hirst Research Centre to effect rugged, high cut-off frequency diodes (Ref.3) The micro-LID is a recently introduced quartz chip-carrier, which has proved invaluable for the circuit incorporation of special active devices, without the complexity of beam leading. Devices which may be circuit-mounted by this means include: low Barrier height GaAs and Si Schottky Barrier mixer and detector diodes, NIP-Schottky Barrier high Burnout mixers, high reverse breakdown GaAs up-Converter mixers, Si noise diodes etc.

FABRICATION ASPECTS

Z-cut quartz is now generally used in place of fused silica for the substrate material. Substrates about 250μm and 125μm thick are normally accepted for the 26-40GHz and 75-110GHz frequency ranges respectively. The thermal expansion properties of Z-cut quartz allow substrate-box attachment by soldering and the fabrication of circulators/isocirculators using the ferrite disk insert technique established for MICS (Ref. 4). Substrate sizes of about 45mm square can provide the basis of multi-circuit function single substrate integration. The establishment of sputtered thin films onto quartz provides complex circuit patterns defined by conventional thin film techniques.

Applying the microwave frequency ferrite insert technique, can realise circulators or isocirculator circuit functions (Ref. 5). A NiZn ferrite with $4\Pi MS$ about 0.5T (5000 gauss) and diameters in the range 2mm to 0.6mm are normally employed in the 26-110GHz range. The triangular geometry is preferred for impedance matching. In general, isolation/return loss and insertion loss characteristics of >20dB and 0.5 to 1.0dB respectively are achieved for a 10% bandwidth at 26-110GHz.

Stepped ridge waveguide to microstrip transitions can provide full frequency coverage of the waveguide size. In addition these may be built into the box wall for compact structures, and glass windows may be used for hermetic enclosures.

26-40GHz COMPONENTS

The balanced mixer provides the basis for many receiver applications. A SSB overall noise figure (ONF) of about 8.0dB (F_{if} = 1.5dB) is a realisable standard by the incorporation of GaAs beam lead diodes (DC1308/1338).

The combination of two balanced mixers with local oscillator (LO) fed in quadrature and signal in phase, on a single substrate (size about 45 x 30mm), with the intermediate frequency (IF) recombined in quadrature, provides the basis for image rejection mixers or SSB up-converters. Such units can be designed for IFs in the MHz to GHz range. A down-converter unit can provide an ONF of about 10.0dB (F_{if} = 1.5dB) with >20dB rejection for a 10% bandwidth. A SSB up-converter can provide about 1mW RF output per sideband with about 10mW drive at IF and LO.

The application of the micro-LID can provide the versatility to realise a broader range of components. For example: solid state noise sources with excess

TABLE I

Mm-Wave GaAs Mixer Diode Typical Characteristics

	DC1308 DC1338	DC1309 DC1339	DC1346	MICRO LID
Total capacitance C_T (pF)	0.08	0.06	0.03	0.035
Junction capacitance C_j (pF)	0.04	0.02	0.01	0.025
Stray capacitance C_s (pF)	0.04	0.04	0.02	0.01
Series resistance R_s (ohms)	7	10	6	8
Cut-off frequency f_{co} (GHz)	∿600	∿900	2,500	∿900

TABLE II

Typical Performance Characteristics of the 85GHz Balanced Mixer

Frequency Range	79-92GHz
Overall Noise Figure (F_{if} = 1.5dB)	8.5dB typical
Conversion loss	7.0dB typical
IF range	500MHz to 1GHz*
IF impedance	50ohms nominal
LO and signal port VSWR	2.5:1 max
Isolation (LO to signal port)	15dB min.
AM noise rejection	25dB min.
LO power (with bias)	(10mW (5mW min.
Operating and storage temperature	-55°C to 125°C

Note * IF design capability in the KHz to 4GHz range.

noise ratio (ENR) of about 25dB and stabilities of <± 0.5dB over a broad RF bandwidth and extended operating temperature range; high burnout mixers incorporating the NIP-SBD combination with an overload capability of about 4W peak pulse power for a two diode balanced mixer, compared with the normal 400mW peak; reduced local oscillator drive mixers incorporating low barrier height GaAs devices, which only require about 1.0mW LO power for a two diode balanced mixer compared with the normal 3.0mW; broadband flat response detectors by incorporating silicon SBDs; and as already indicated SSB up-converters.

The application of the components techniques can realise complex integrated sub systems. The individual circuit functions can be incorporated on a single substrate to provide compact, high reliability front-ends suitable for military type environments. Low frequency IF and BITE circuitry may be incorporated following standard MIC practice.

60-110GHz COMPONENTS

Practical hybrid-microstrip components at 60-110GHz may be based on the 26-40GHz technology. Mixer circuits are particularly well established, but circulators/isocirculators, PIN switches, SSB up-converters, broadband flat detectors etc., have also been produced.

Harmonic Mixers

The two port harmonic mixer is used to extend the frequency range of frequency counters and the present design of spectrum analyser. The mixer unit consists of a microstrip circuit with a waveguide RF port and a coaxial LO and IF port through which dc bias is also supplied. Units can be designed for 40-60GHz, 60-90 GHz and 75-110GHz RF, with a minimum detectable signal (MDS) in the -40 to -50dBm range (100KHz bandwidth), for a LO frequency range up to 10GHz.

The three port harmonic mixer has application to mm-wave attenuation and frequency measurement standards and phase locked loop systems stabilising oscillators. In addition, the new generation of spectrum analysers will require three port external mixers to extend their frequency range beyond 100GHz. The mixer unit consists of a microstrip circuit with a waveguide RF port, a coaxial LO port and a coaxial IF port. A diplexer provides isolation between the LO and IF. Units can be designed for 60 to 90GHz and 75 to 110GHz RF, with LO in the 8 to 12GHz and 12 to 18GHz ranges and IF covering DC to 4GHz and DC to 8GHz respectively. THe conversion loss is approximately (3n + 6)dB where n is the harmonic number.

Balanced Mixer

The balanced mixer circuit shown in Figure 1 consists of a 3dB rat race coupler and two single-ended mixers. The signal and LO Ports are in the appropriate waveguide size. The IF is extracted via a single SMA coaxial output port. ± 15v DC applied to the solder PINS applies the appropriate 0.5v FWD diode bias. Balanced mixers can be designed for any centre frequency in the 60 to 110GHz range. Typical performance features are indicated in Table II for an 85GHz mixer.

Particular attractive features are: wide operational instantaneous signal bandwidth approaching 30% (no external tuning required); 50ohm IF output impedance allowing direct coupling into the majority of IF amplifiers (particularly in the GHz range); high LO am noise rejection; low conversion loss combined with diode noise temperature ratio (Nr) of about 1.0 (IF > 1.0MHz) providing a predictable low ONF performance; rugged structure suitable for military environments. The operation over the temperature range of -55°C to 125°C is shown in Figure 2. The structure provides the ability to integrate a microstrip isocirculator to improve the LO port VSWR.

In addition, tests have shown that the am noise rejection can be improved to better than 30dB by individually optimising the applied dc bias; the low conversion loss of about 7.0dB is critically dependent on the cut-off frequency of the mixer diode, for example the DC1346 results in about 1dB improvement in conversion loss compared with the DC1309/1339; dc bias is a recommended feature for low conversion loss at acceptable LO power, 0.5V being normal with 10mW LO power, although the LO power can be reduced to about 5mW without a significant performance degradation.

Special circuits, however, can be designed for zero bias operation, particularly for zero IF applications. These normally provide about 8.0dB conversion loss with 10mW LO drive as shown in Figure 3, but lower drive levels provide optimum ONF.

A 94GHz SSB up or down converter mixer circuit is shown in Figure 4. Currently this provides about 10dB conversion loss for frequency down conversion with 20dB image rejection. This indicated the integration feasibility also being applied to complete receiver front-ends.

CONCLUSIONS

The hybrid-microstrip technology applied to the design of mm-wave components and sub-assemblies, provides comparable performance to similar circuit functions using waveguide techniques, but with the added advantages of; instantaneous broadband capability, compact rugged structures suitable for military environments, and application to the integration of multi-circuit functions.

The current work at 75-110GHz on similar active device and circuit aspects to those established in the 26-40 GHz region, is demonstrating that the technology is readily transferable. Hybrid-microstrip techniques are thus available to develop complex multi-circuit integrated front ends, to meet the requirements of many military and civil applications.

ACKNOWLEDGEMENT

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FIGURE 1
94GHz BALANCED MIXER CIRCUIT

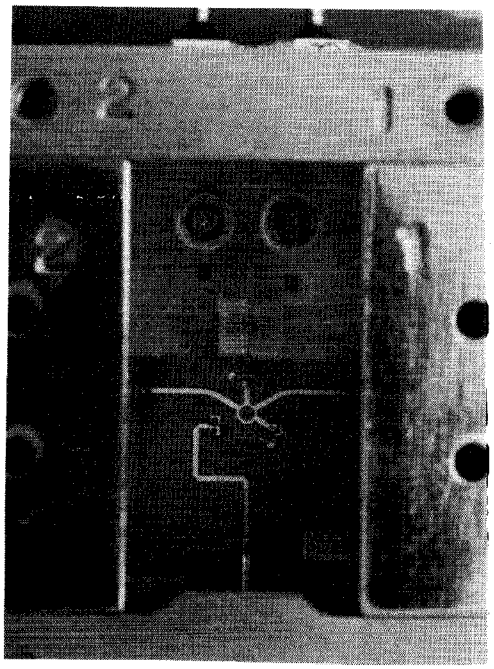

FIGURE 2

VARIATIONS IN OVERALL NOISE FIGURE (ONF) WITH TEMPERATURE FOR 85GHz BALANCED MIXER

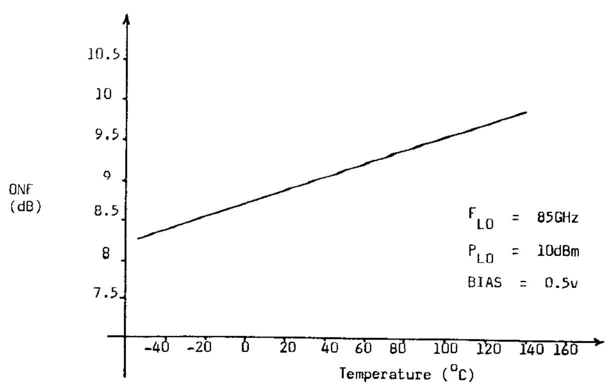

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FIGURE 3

VARIATION OF OVERALL NOISE FIGURE (ONF) WITH IF FREQUENCY FOR A ZERO BIAS 85GHz BALANCED MIXER

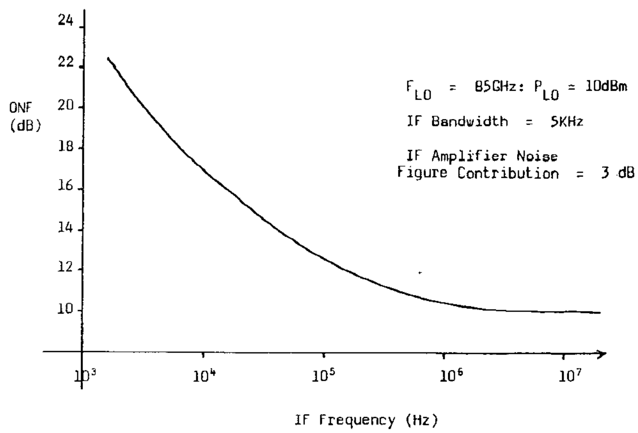

FIGURE 4
94GHz SSB UPCONVERTER CIRCUIT