Ka-BAND MONOLITHIC GaAs BALANCED MIXERS

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ABSTRACT

A monolithic GaAs balanced mixer chip has been optimized and integrated with a hybrid MIC IF preamplifier in a wafer-type package with significant improvement in RF bandwidth and reduction in chip size. A double sideband noise figure of less than 6 dB has been achieved over a 31 to 39 GHz frequency range with a GaAs chip size of only .05 X .43 inches. This includes the contribution of a 1.5 dB noise figure due to IF preamplifier (5-500 MHz).

INTRODUCTION

The performance of GaAs devices has been steadily improved with recent advances in material, process and device technology. Monolithic integration of passive elements and active devices on GaAs substrates becomes increasingly attractive for use at millimeter-wave frequencies as opposed to the more conventional MIC hybrid approach where the effects of parasitics are difficult to control. However, high performance millimeter-wave monolithic ICs are not yet cost effective. They are either too large in size or too simple in functionality. Fully monolithic integration of multiple device structures requires advanced material technology that is still in laboratory development. A competitive alternative is to combine monolithic GaAs IC and hybrid MIC in a manner that takes advantage of each approach. Only circuit elements which are critical for matching of active devices at millimeter-wave frequencies are monolithically integrated on the GaAs substrate. Significant reduction in chip size can be achieved. This paper describes the result of a Ka-band balanced mixer/IF preamplifier which consists of a monolithic GaAs balanced mixer chip and a hybrid MIC IF preamplifier integrated in a wafer-type waveguide package. The passive elements on the monolithic GaAs chip consist of coupling circuits for only the millimeterwave frequencies. The bulky low pass filter is incorporated with the bipolar IF preamplifier on a hybrid MIC.

MIXER CONFIGURATION

The GaAs chip is used as a suspended stripline and is coupled to local oscillator power and RF signal via two full-height waveguide ports. It consists of two planar mixer diodes and matching circuits for LO and RF waveguides. There are several unique features of the mixer that significantly reduce complexity and take advantage of the monolithic circuit technique. The diodes are electrically in series with respect to the RF waveguide. The RF impedance of a single mixer is usually much lower compared to that of waveguide. With two diodes in series, the RF input impedance of the chip at the signal port can be matched easily with straight full-height waveguide. The RF bandwidth of this mixer can be greatly increased to nearly full waveguide bandwidth if reduced-height or ridged waveguide is used to match the impedances of circuit and chip over the desired frequency range.

The diodes are electrically in parallel with respect to the local oscillator and are in a direction such that the induced LO currents in the diodes are out of phase. This eliminates the need for a magic tee to cancel the noise contributed by the local oscillator. The conventional waveguide magic tee is inherently a narrow band component and is very expensive to make, particularly at millimeter-wave frequencies. Furthermore, the two diodes are physically close to each other and can have nearly identical parameters because they are monolithically fabricated. Such a well matched diode pair gives excellent LO noise suppression. The isolation between the local oscillator and signal ports can be very high over a wide range of frequencies since the electric field of the dominant TE_{10} mode in the RF and LO ports are orthogonal.

MONOLITHIC CHIP

The monolithic mixer described above has been fabricated with the advanced semiconductor technology available in our laboratory. The diodes are fabricated with VPE-grown nn+ layers on a semi-insulating substrate and isolated by proton bombardment. A high-quality nn+ layers is grown on a 10 mil semi-insulating GaAs substrate. The n+ layer has a doping density of 2 X $10^{18}cm^{-3}$ and is 2 micron thick and the n layer which is on top of n+ layer has a doping density of 1 X $10^{17}cm^{-3}$ and is 0.1 micron thick. A very abrupt nn+ transition has been reproducibly achieved with a doping

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gradient of 200 ± 50Å per decade. A direct liftoff technique was used to form both Schottky barrier and ohmic contact metallizations. The chip is then bombarded by high energy protons everywhere except at the diodes which are protected by a thick layer of photoresist and gold metal. This proton bombardment process isolates the diodes from the circuit parasitics. Diodes with a zero-biased cutoff frequency of better than 600 GHz have been achieved. Figure 1 shows the IV characteristics of a monolithic diode pair. After the protect layers are removed, overlay metallization is then deposited for the RF matching circuits. Individual monolithic circuit chips are cut from the large wafer and mounted in the wafer package as shown in Figure 2. A hybrid MIC IC preamplifier with a DSB noise figure of 1.5 dB over 5-500 MHz is integrated with the monolithic chip in the package. The complete test circuit is shown in Figure 3.

RF PERFORMANCE

Significant improvement in RF bandwidth and reduction in chip size have been achieved. Figure 4 shows noise figure vs. frequency of a monolithic chip from 30 to 40 GHz. A double sideband noise figure of less than 6 dB has been achieved over a 8 GHz bandwidth with a GaAs chip size of only .05 X .43 inches. This includes the contribution of 1.5 dB noise figure from IF preamplifier which has a bandwidth of 5-500 MHz. This performance gives an improvement of RF bandwidth by a factor of 4 and a reduction of chip size by a factor of 5 with respect to a result reported previously.[1] The isolation between the local oscillator and signal ports of the mixer is very good as indicated in Figure 5. A isolation better than 20 dB over the 26-40 GHz has been achieved.

CONCLUSIONS

A monolithic GaAs balanced mixer chip with a minimum chip size can be integrated with a hybrid MIC IF preamplifier in a unique circuit configuration to achieve high-performance and potentially cost-effective components for millimeter-wave receiver applications.

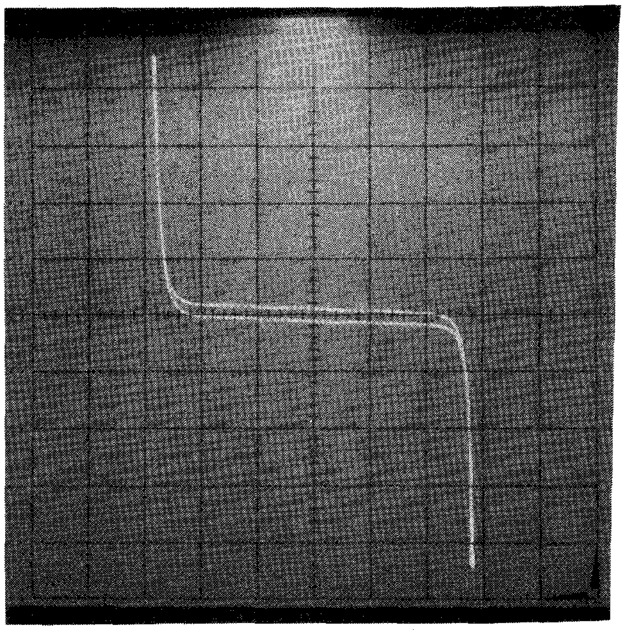

Figure 1. IV characteristics of the monolithic diode pair.
Horizontal: .2 Volts/Div:
Vertical: 1 μA/Div.

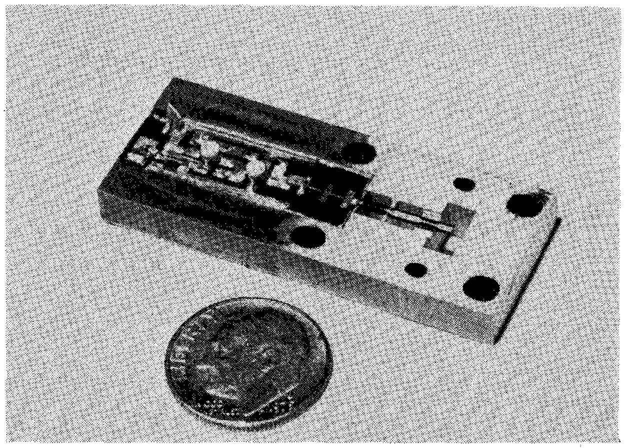

Figure 2. Ka-band monolithic GaAs balanced mixer chip integrated with a hybrid MIC IF preamplifier on a wafer-type package.

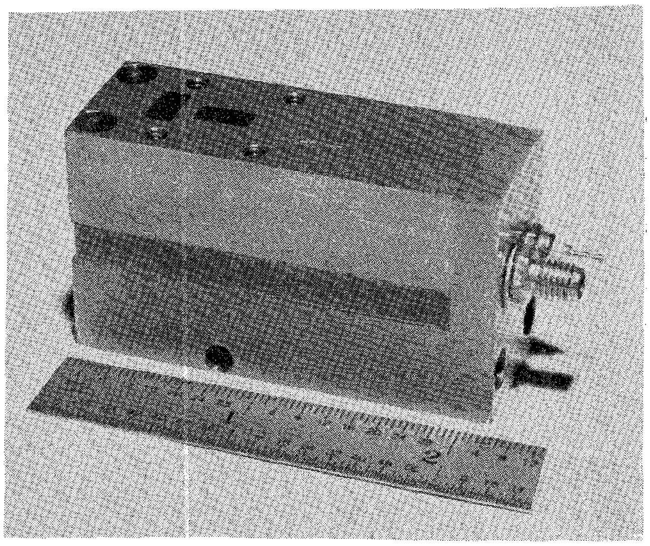

Figure 3. Ka-band monolithic GaAs balanced mixer and hybrid IF preamplifier.

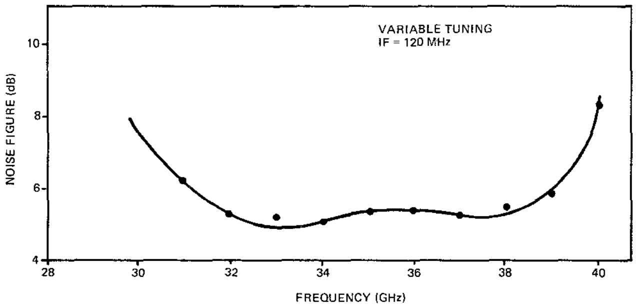

Figure 4. Monolithic mixer noise figure vs. frequency (including 1.5 dB IF preamplifier noise).

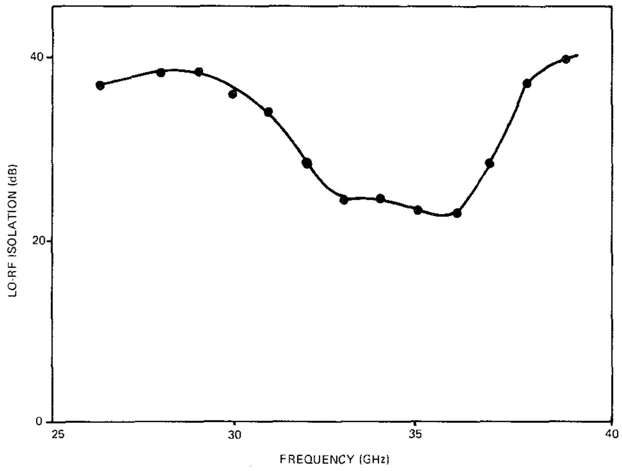

Figure 5. Monolithic mixer LO-RF isolation vs. frequency.

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REFERENCES

(1) C. Chao, A. Contolatis, S.A. Jamison and E.S. Johnson, "Millimeter-wave Monolithic GaAs Balanced Mixers," 1980 Gallium Arsenide Integrated Circuit Symposium, Las Vegas (Paper 32).