A MONOLITHIC W-BAND CPW RAT-RACE MIXER WITH HBT IF AMPLIFIER

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ABSTRACT

This paper reports on a fully monolithic W-band Schottky diode down converter with an IF amplifier using heterojunction bipolar transistors (HBTs). We use a coplanar wave guide (CPW) as a transmission line element for a rat-race, because a CPW requires one-side wafer processing only. The conversion gain is +9.5 dB with the HBT amplifier and -8.8 dB without the HBT amplifier at an RF of 95 GHz. The isolation from the LO port to the RF port is 29 dB with the HBT amplifier and 27 dB without the HBT amplifier.

INTRODUCTION

HBTs have good performance with high-frequency integrated circuits, and Schottky diodes also have a very high cut-off frequency. The integration of these two devices is relatively easy because the collector epitaxial layer can be used for the Schottky diode [1]. We use this combination for a W-band down converter.
A rat-race is suitable for a high-frequency mixer. We used a CPW transmission line as an element of the rat-race because CPWs require only one-side processing of the wafer. Microstrip lines require backside processing and via holes, therefore, the fabrication process of microstrip lines is complicated in comparison to the CPWs' process.

CIRCUIT CONFIGURATION

Figure 1 shows a schematic diagram of the down converter. The mixer section uses a rat-race and two Schottky diodes. This configuration has been used for high-frequency mixers [2-7]. A rat-race has four ports that mach to 50 Ω, so we assigned an LO signal, an RF signal, and two diodes to them. An IF signal with a lower frequency than the LO and RF signals can be derived from any point of the rat-race. We connected the IF port at the opposite position of the RF port on the rat-race through a quarter wave length CPW and a shunt capacitor for filtering off the RF and LO signals. The IF frequency is low enough to go through the filter. This circuit acts as a high-impedance element at a W-band frequency, so there was no influence on the rat-race characteristics in the W-band. We connected an HBT IF amplifier after the filter. Two HBTs are used in the amplifier with feedback resistors and bias circuits.

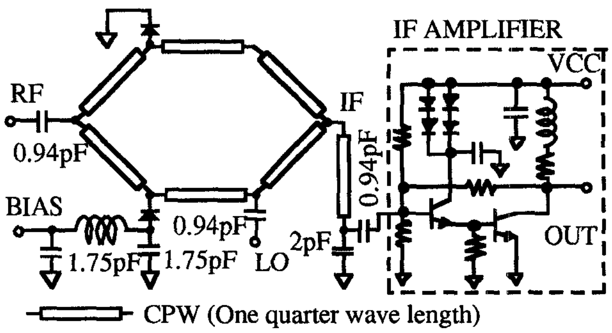

Figure 1. Schematic diagram of the monolithic down converter.

FABRICATION PROCESS

This IC is fabricated on a 4-inch MBE-grown GaAs wafer. A cross section of the devices is shown in Figure 2. An HBT with a transition frequency of F_T=50 GHz and a maximum

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oscillation frequency of F_{MAX}=50 GHz uses an AlGaAs/GaAs system. A Schottky barrier diode is realized at the collector layer with a cut-off frequency of Fc=1.3 THz (4 Ω, 31 fF). MIM capacitors with a 31 nF/cm^2 capacitance, thin film resistors with a sheet resistance of 25 Ω/sq. and two gold interconnection layers with polyimide insulation are also integrated.

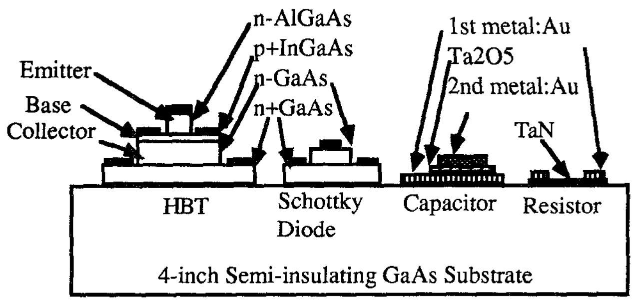


Figure 2. Cross section of the devices.

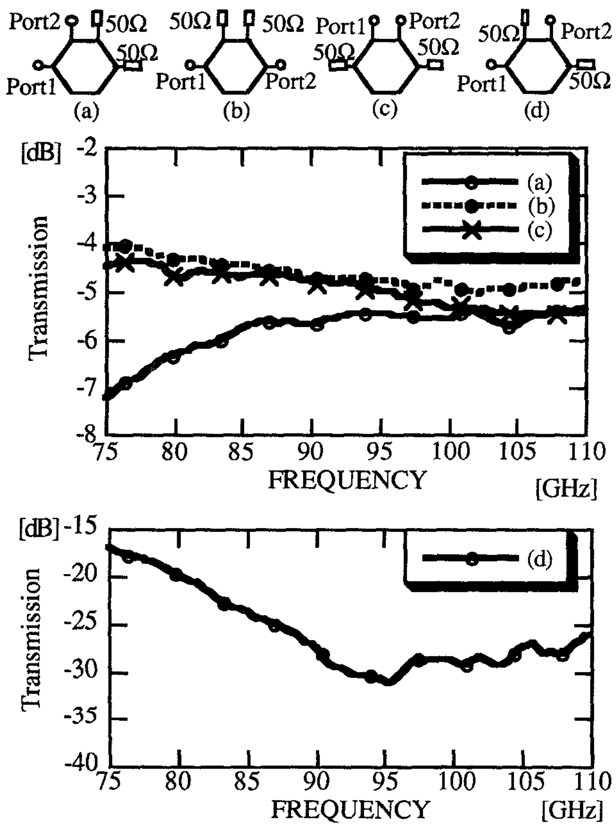


Figure 3. Transmission of the rat-race without diodes and IF connection.

RAT-RACE CHARACTERISTICS

We measured a simple rat-race circuit without diodes using on-wafer probes and a W-band network analyzer, the HP85109C. Because a rat-race has 4 ports and the network analyzer can measure only 2 ports simultaneously, we designed 4 configurations of the rat-race in input, output and terminating resistor positions. The results are shown in Figure 3. Transmission is from -7 dB to -4 dB and isolation is 17 dB or more in the 75 GHz to 110 GHz frequency range. In this design the center conductor width and the grand-to-grand spacing of the CPW are 6 μm and 30 μm, respectively.

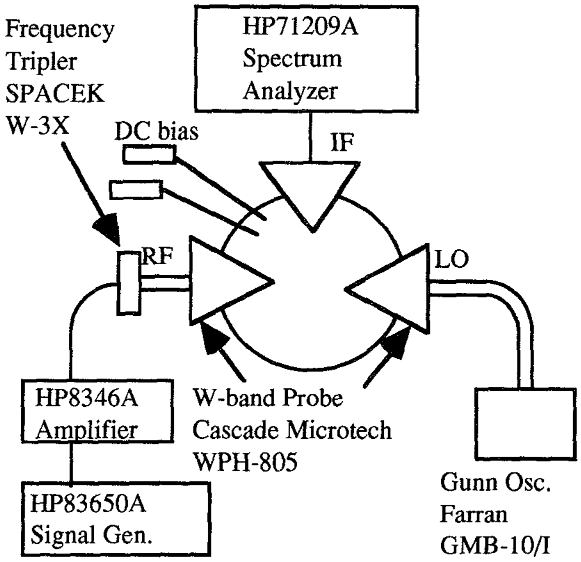


Figure 4. Setup for measurement of down converters.

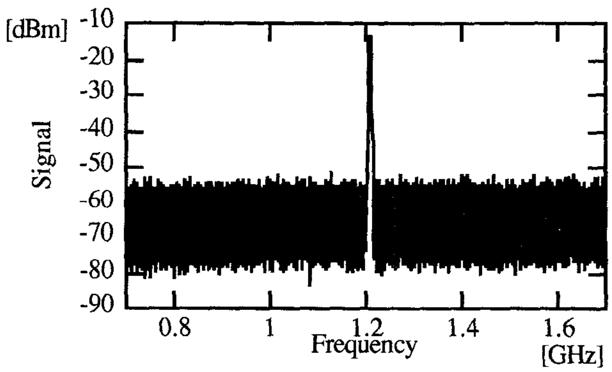


Figure 5. Down-converted IF spectrum using quarter-size diodes.

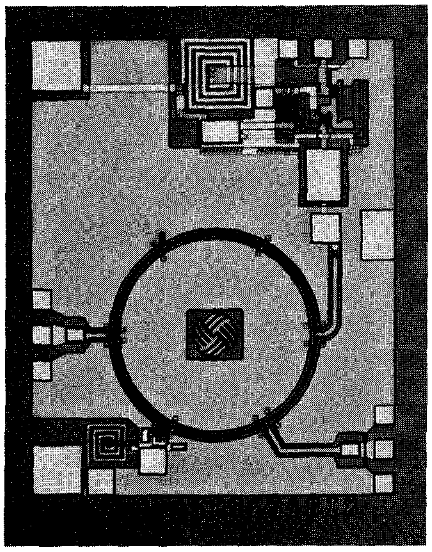
We also measured a wider center conductor CPW that has 16 μm of the center conductor width and 84 μm of grand-to-grand spacing. Its transmission is 1dB better than the narrower center conductor CPW type in the same frequency range. So the conductive loss should be improved to reduce the total insertion loss.

DIODE SIZE CONSIDERATION

Impedance matching of the diodes is important in a rat-race configuration. Fifty ohms of impedance is assumed for each port. We tested the rat-race down converters with different size diodes, and measured the conversion loss with a 100 GHz / -5 dBm RF input and a 98.8 GHz / +4 dBm LO drive. They include normal-size diodes (2.1 μm x 20 μm), half-size diodes (2.1 μm x 10 μm) and quarter-size diodes (2.1 μm x 5μm). Figure 4 and Figure 5 show a setup for the measurement, and the measured IF signal of the circuit with quarter-size diodes, respectively. The circuit using the quarter-size diodes generates the strongest 1.2 GHz IF signal. It is 4dB better than the normal-size diodes' data, and 1dB better than the half-size diodes' data. It is also confirmed by the measurement of these diodes' impedance.

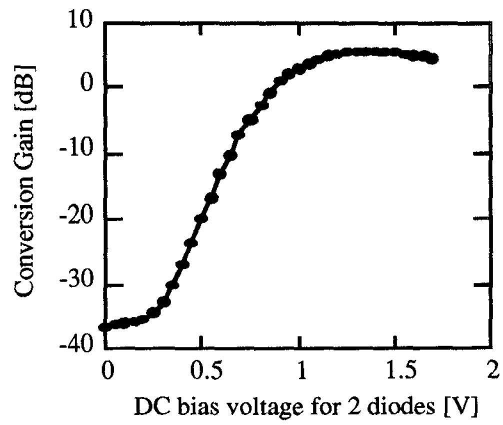
TOTAL PERFORMANCE

Figure 6 is a photograph of the down converter IC. The chip is 1.2 mm by 1.4 mm in size. At the present time, we only have a design with a narrower CPW and normal-size diodes. Figure 7 shows the DC bias voltage for the two series diodes versus the conversion gain. The conversion gain is saturated where the DC bias voltage is higher than 1 V. Figure 8 shows the measured conversion gain and the leakage from the LO port to the RF port versus the LO frequency. The frequency difference between RF and LO is equal to 1 GHz. With an HBT IF amplifier, the total conversion gain is around +9.5 dB and the isolation is 29 dB at LO=95 GHz and RF=94 GHz. According to a separate measurement, the gain of the HBT IF amplifier is 21 dB at 1 GHz. The frequency characteristics of the down converter that uses the quarter-size diodes without an HBT IF amplifier are shown in Figure 9. At an LO of 95 GHz, its conversion gain and isolation are around -8.8 dB and 27 dB, respectively. The combination of quarter-size diodes and an HBT amplifier will give good results but is not yet measured.



Lower left : DC bias; Center left : RF signal; Lower right : RF signal; Top : HBT amplifier; Top left : HBT DC bias; Top right : IF signal.

Figure 6. Photograph of the down-converter.



LO=99 GHz, +4.2 dBm
RF=100 GHz, -13.6 dBm
Figure 7. Diode DC bias versus conversion gain.

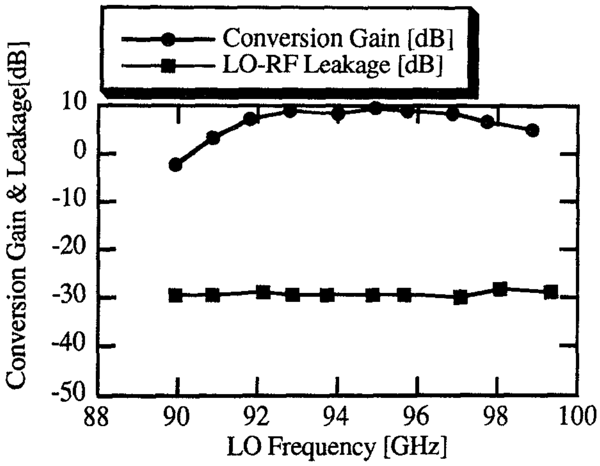


Figure 8. Conversion gain and leakage with normal-size diodes and HBT IF amplifier.

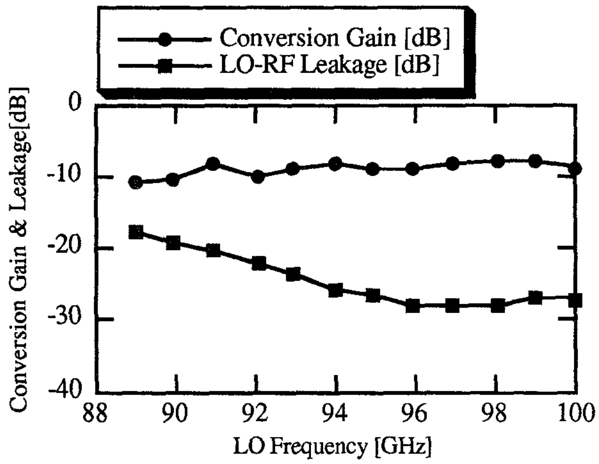


Figure 9. Conversion gain and leakage with quarter-size diodes and no HBT IF amplifier.

CONCLUSION

We have described a W-band diode mixer with an HBT amplifier. The combination of high cut-off Schottky diodes and HBTs works very well as a high-frequency down converter. This combination can be used for the integration of other circuits such as a power amplifier and a diode frequency multiplier for LO port driving. We also used a CPW as an element of the rat-race for easier processing. The measured characteristics of the rat-race using a CPW transmission line show good performance for a high-frequency mixer application.

Our approach is one method for a monolithic frequency converter in a very high-frequency region.

ACKNOWLEDGMENT

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