DEVELOPMENT AND TESTING OF A RECEIVER AT 230 GHz

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Abstract

A superhetrodyne receiver operating at 230 GHz has been developed and tested. The hybrid mixer consists of a Schottky barrier diode in a rectangular waveguide and a stripline circuit whose performance was optimized using low frequency scaling techniques. Ultra-low capacitance, low-noise Schottky barrier diodes were developed for use in the mixer. The local oscillator signal is provided by a frequency doubler pumped by a 115 GHz klystron. The output of the doubler is coupled into the mixer using a cavity. The IF amplifier is a 1.4 GHz parametric amplifier with a noise figure of 0.8 dB. The total double sideband noise figure of the receiver is 13.4 dB corresponding to a noise temperature of 6000 K.

Introduction

A superhetrodyne receiver operating at 230 GHz has been developed for use in atmospheric attenuation and radio astronomical studies. It consists of a mixer incorporating a low-noise GaAs Schottky barrier diode mount in a millimeter-wave integrated circuit, a varactor doubler pumped by a klystron at 115 GHz to supply the local oscillator signal, a cavity to couple the local oscillator into the signal waveguide, and an IF parametric amplifier operating at 1.4 GHz. Figure 1 is a block diagram of the receiver and Fig. 2 is a photograph of the complete receiver. The millimeter-wave integrated circuit was originally built and optimized at 6 GHz, approximately 37 times lower in frequency, using a diode whose junction capacitance and parasitics were appropriately scaled from those of the diodes which were finally used. The individual components and the performance of the receiver are described in the following paragraphs.

Schottky Barrier Diodes

Planar Schottky-barrier diodes were fabricated on n-type epitaxial gallium arsenide supplied by both Monsanto Corp. and Plessey Ltd. In order to achieve a small junction capacitance the diode area was made as small as was compatible with current photolithographic processing techniques. To avoid a concomitent increase in the diode's spreading resistance we used gallium arsenide with an extremely thin (<2500 Å), relatively highly doped ($\sim 3\times 10^{17} cm^{-3}$) epilayer.

Briefly, the diode processing was done as follows. An SiO_2 passivating layer was RF sputtered onto the surface of the semiconductor to a thickness of about 4000 Å. The wafer was then lapped to a thickness of 150 μm and a plated gold, tin-nickel layer was alloyed into the back to obtain the ohmic back contact. Specially developed photolithographic and etching techniques were then employed to open up an array of holes with a diameter of 1 μm up to 2 μm in the sputtered silica layer. Finally, gold was electroplated into the holes to form the gold-GaAs Schottky junctions. A flow chart of the processing steps starting from a clean slice to the final diodes is shown in Fig. 3.

Table I gives the characteristics of the diodes made for use in the mixer. The Schottky barrier ideality factor n was found to be similar for each batch and measured values ranged from 1.10 to 1.20. The idealty factor is derived from the slope of the current-voltage characteristics shown in Fig. 4 and the equation[1]

$$n(T) = \frac{q}{kT}\frac{\partial V}{\partial(\ell n J)} \qquad (1)$$

where V is the applied voltage, J the forward current and $q/kT = 40\ \text{volt}^{-1}$ for T = 290 K.

Table I

Characteristics of Diodes Used in the Mixer

GaAs Batch #	Hole Diameter	Spreading Resistance	Capacitance $1\ fF = 10^{-15}F$
32	1 μm	20 Ω	3 fF
50	2 μm	10 Ω	12 fF

Mixer

Because of the successful application of millimeter wave integrated circuit techniques at lower frequencies[2] it was decided to build a mixer-detector at 230 GHz incorporating some of these techniques. A great advantage of this approach is that it is possible to optimize a scaled low frequency version of the circuit for which measurements and circuit adjustments are much simpler. Figure 5 is a photograph of the mixer shown split down the center of the waveguide E-plane.

The mixer consists of a waveguide input (WR-4, 0.043"×0.0215") and a waveguide-to-stripline transition to which a 20 μm diameter, 150 μm long, eutectic Au-Cu wire which is shaped into a C-spring is bonded. The other end of the wire is etched to form a point and is used to contact one of an array of diodes on the surface of a 200 μm × 200 μm chip of semiconductor mounted on a screw in the broad face of the waveguide. The stripline circuit is evaporated and photoetched on a 50 μm quartz substrate and is suspended in a channel with cross sectional dimensions of 250 μm × 500 μm. One end of the circuit protrudes into the waveguide to form the waveguide-to-stripline transition. Following this is a low-pass filter and a 50 Ω line to the IF output connector.

The detector consists of two halves split along the waveguide E-plane. In assembling the detector, the stripline circuit is put in place before the two halves are screwed together. The screw with the semiconductor chip mounted on it is then screwed in until electrical contact is made with one of the diodes. Should this diode be burned out or contact otherwise be lost, contact can be made to another diode on the chip by simply inserting the screw in a little further. This construction has been found to be quite sturdy and rugged.

Local Oscillator

The local oscillator signal is provided by a frequency doubler pumped by a Varian klystron operating at 115 GHz. The doubler consists of a four-port E-plane waveguide junction, a Sharpless wafer mount and a sliding short for matching purposes. The diode which is mounted in a Sharpless wafer is a diffused GaAs-junction varactor supplied by C. A. Burrus.[3] The efficiency of the doubler was not measured because devices for measuring low levels of millimeter-wave power above 100 GHz are not readily available. However, a crude estimate based on the amount of the second harmonic current gives an efficiency of about 3% to 4%.

The output of the doubler is coupled into the signal line by means of a cylindrical coupling cavity operating in the TE011 mode. The coupling loss between the local oscillator input port to the cavity and the mixer port was measured to be 10 dB at the local oscillator frequency. Since the local oscillator output from the cavity splits in two, half being lost out the feed horn, the coupling loss through the cavity itself was 7 dB.

With approximately 150 mW into the multiplier the 230 GHz mixer detector measured 2.5 mA directly at the output of the multiplier. However with the coupling cavity in place the detected local oscillator current was 0.3 mA.

Receiver Performance

The receiver noise figure was measured by noting the difference in receiver response if an absorber consisting of carbon-loaded polyurethane foam (Emerson-Cuming microwave absorber AN-72) at ambient temperature is placed in front of the feed horn and then replaced by one at liquid nitrogen temperature. This hot-load cold-load technique is described in recent work performed by Penzias and Burrus.[4] Using this method the double sideband noise figure of the complete receiver was measured to be 13.4 dB which corresponds to a noise temperature of 6000 K. This noise figure includes a 0.8 dB contribution of the 1.4 GHz IF parametric amplifier.

Discussion

The performance of the present receiver is limited by the low level of local oscillator at the mixer, viz. 0.3 mA of rectified signal. Measurements performed by R. A. Linke[5] using similar diodes at 140 GHz, where local oscillator power can be supplied by a klystron directly, have shown that 2.5 mA of rectified LO signal is needed to minimize the noise figure. If the LO signal is attenuated until a current of 0.3 mA is flowing in the mixer diode, the noise figure is increased by 3 dB. It should be noted also that a relatively low Q cavity* had to be employed at 230 GHz in order to obtain a diode current of 0.3 mA. This in turn meant that at our rather low IF frequency (1.4 GHz) some klystron and multiplier noise was incident on the mixer and also that the signal suffered some attenuation passing the coupling cavity. These problems could be partially alleviated by raising the IF frequency, however the fundamental problem of low LO level remains.

It may be possible using current technology to build a balanced doubler. In addition, instead of a simple coupling cavity, a directional filter might be built so that no LO power would be lost through the signal port. Both these improvements could theoretically result in a 6 dB increase in available LO power, however the result would be a complicated, rather narrow band receiver having many tuning adjustments.

The stripline mixer detector proved to be very sensitive and rugged. The conductor pattern of the detector which is fabricated by photolithographic processing steps can be more accurately reproduced than the machined parts of current millimeter-wave detectors.

Acknowledgements

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References

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* With a transmission loss of 7 dB, $\frac{Q\ \text{loaded}}{Q\ \text{intrinsic}} = 0.55$.

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5. R. A. Linke, personal communication.

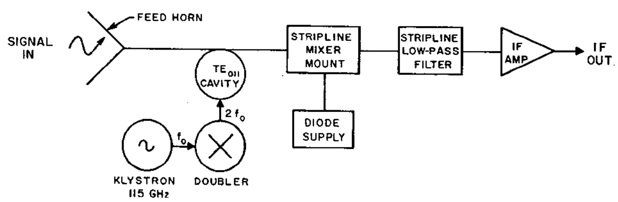

Fig. 1 Block diagram of receiver including feed horn, klystron source and IF amplifier. The waveguide components are in rectangular waveguide WR-3 with inner dimensions 0.043"×0.0215".

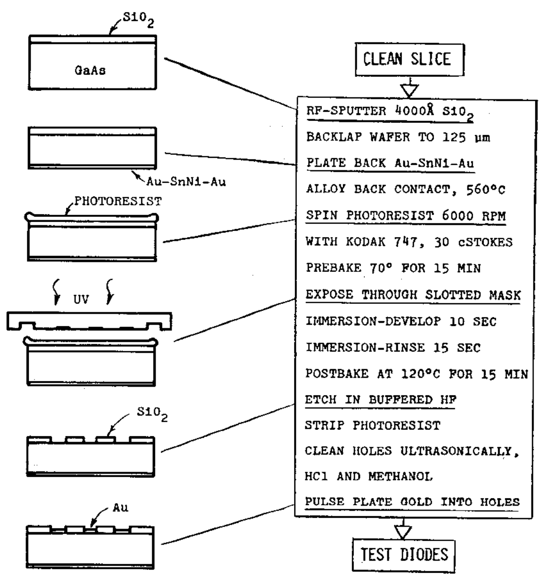

Fig. 3 Flow chart for fabricating millimeter-wave gallium arsenide Schottky-barrier diodes starting from clean slice and ending with testing of the diodes. The slotted mask allows exposure of 1 μm dots and 2 μm dots with excellent dimensional tolerances because the photoresist buildup on the edge of the wafer does not prevent close contact with the photomask.

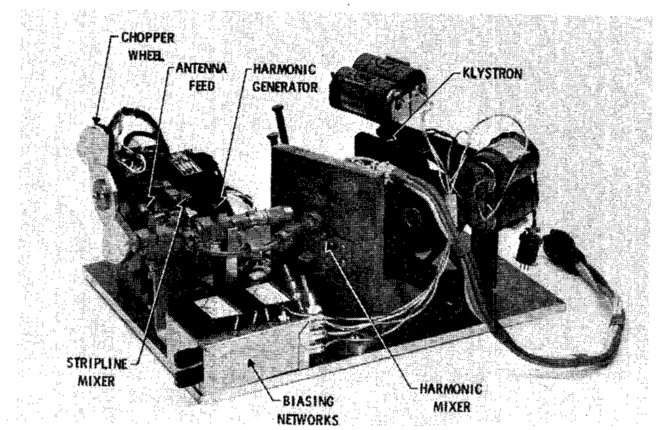

Fig. 2 Photograph of receiver including chopper wheel to modulate the calibration signal input.

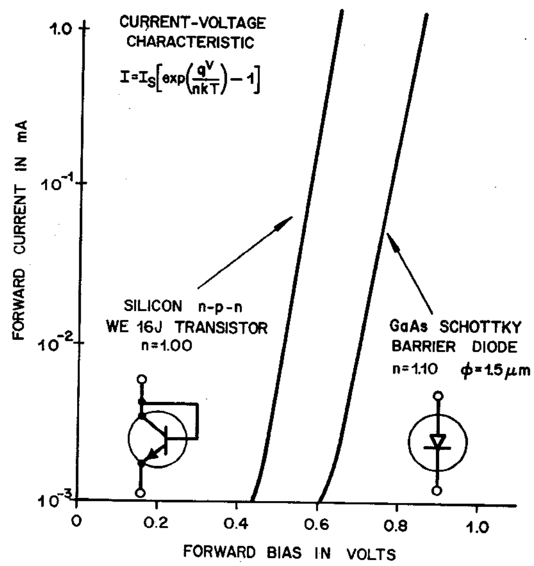

Fig. 4 Forward current-voltage characteristics of Schottky barrier diodes. The WE16J silicon n-p-n base-emitter transistor characteristic is plotted for comparison.

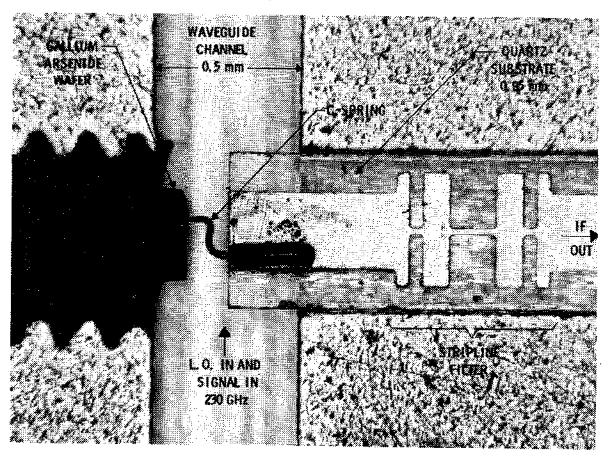

Fig. 5 Hybrid mixer diode mount including gallium arsenide wafer on a 0.75 mm O.D. diameter screw, C-spring and stripline low-pass filter on a 50 μm thick silica substrate.