A Schottky-Diode Balanced Mixer for 1.5 THz

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***Abstract*— We report on the first THz balanced mixer/upconverter using a Schottky diode MMIC chip. Using an optically pumped laser at 1562 GHz as an LO source with a coupled power of about 1 mW, and an IF frequency of 10 GHz, we obtained a sideband output power of 23 uW (sum of two sidebands). As a mixer we obtain a conversion loss of 12.4 dB DSB and a noise temperature of 5600 K DSB. Response is believed to be similar over a band 1250-1650 GHz.**

I. Introduction

In the THz range there is a need for room temperature mixers to act as both downconverters and upconverters using laser local oscillators. In these applications the relatively high LO power required by Schottky diodes is not a problem. In these applications mixers primarily use whisker contacted Schottky diodes in cube-corner mixers, originally reported 30 years ago [1]. While the cube-corner mixer is very simple, it has a very poor beam pattern and is compatible only with whiskered diodes. This paper reports on the first THz balanced mixer built using a planar diode MMIC in waveguide. The requirement to develop this mixer came from a need for a frequency agile sideband generator at 1.5 THz with >10 µW output power which would use a laser as one input and a 5-40 GHz microwave synthesizer as the other. The typical cube corner in this application can produce only 1 µW and impedance matching is difficult with high offset frequencies.

II. Mixer Design

The application was a proof of concept, so it had to use existing devices. The MMIC used in this work was designed as a frequency doubler for 1.5 THz, developed at JPL for the Herschel HIFI program [2]. THz varactor diodes are essentially the same as mixer diodes since high doping ($5x10^{17}/cm^3$) is needed to avoid velocity saturation, and breakdown voltage is low (~4V) since large drive voltage amplitude is not practical. The device is built on 3 µm thick GaAs with beam lead contacts for ground and bias. The circuit geometry is the same as that for a balanced mixer as shown in figure 1, except that there is no external terminal for the IF port. The IF port was added by contacting the input waveguide probe with a gold wire, and bringing this wire out through a 50 ohm microstrip line. A balanced mixer has the advantage of separate LO and signal ports, and in principle, high isolation between them. This means that no diplexer is required at the mixer input. The doubler chip as used in the mixer is shown in Fig 2.

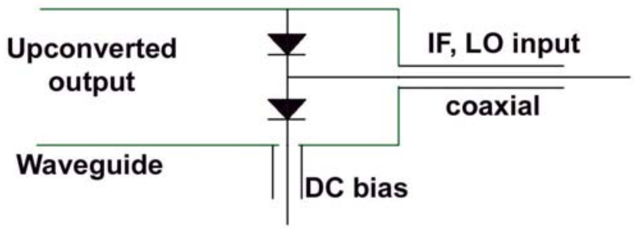

Fig 1. Schematic diagram of a balanced mixer with coaxial input on the right and waveguide output on the left. The doubler circuit is identical except that the input frequency is half of the output.

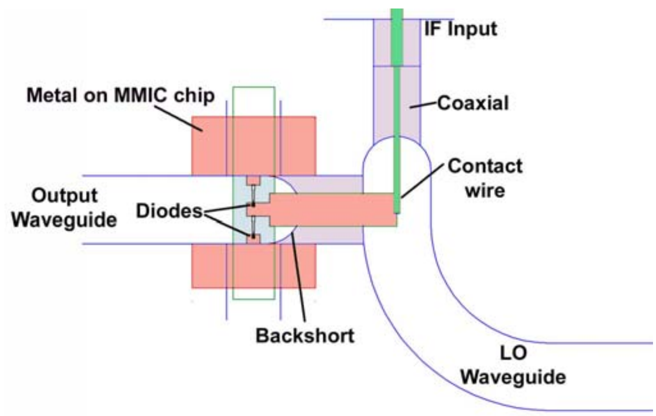

Fig 2 Balanced mixer cross section using a diode designed for a balanced doubler. The contact wire is 6 um gold alloy. Blue shaded areas are TEM lines, and reddish areas are metal on the MMIC chip.

The block was machined with conventional tools in brass with a CNC micro-milling machine [3], and the block was then gold plated. Both waveguides are 80 x 160 um, stepping up to square cross section before transitioning to diagonal feedhorns on both input and output ports. The final aperture sizes of each were 1.5 mm (diagonal). Details of the block are shown in Figure 3. The IF port used a K type connector to allow tests up to 40 GHz, but no care was used to maximize the IF bandwidth by design of the IF circuit.

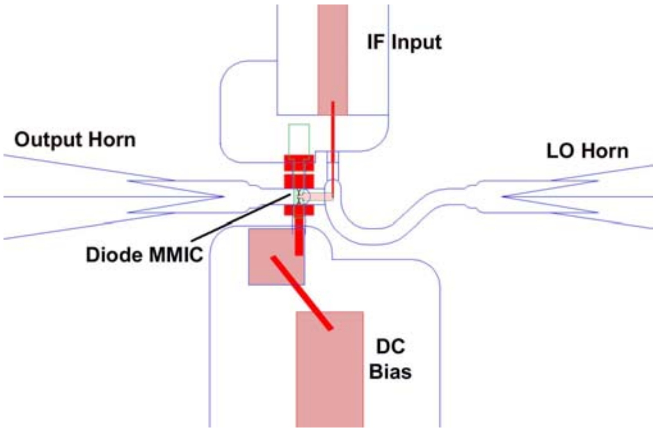

Fig 3. Balanced mixer cross section showing the input/output horns and DC and IF circuits. A parallel plate capacitor bypasses the bias port at IF frequencies while an on-chip capacitor bypasses this port at the RF.

III. Upconversion Results

Tests were done using an optically pumped laser at 1562 GHz, with a power level of ~10 mW which was attenuated to 1 mW at the mixer input (as measured by a coupling aperture comparable to that of the feed horn). The IF frequency was 10 GHz with 1 mW power level. DC bias of 0.5 mA was applied with the conversion efficiency rising with bias. The sum of these inputs totals about 2.5 mW which is all dissipated in two diodes on a poor heat sink, so there was some concern about increasing the power levels beyond this point. At this drive the output power in the two sidebands is 23 µW with only 4.5 µW of LO feedthrough (~23 dB LO-RF isolation). The THz input and output power was measured with a waveguide calorimeter (Erickson Instruments PM4 [4]) built in WR10 waveguide with no transition between the horn and the waveguide in the sensor. The size of the horns and WR10 waveguide are fairly similar so coupling was expected to be good.

Figure 4 shows the power output vs drive power. Output power is increasing with each of the inputs, up to the maximum applied, so there is the potential for significantly higher output power if the diodes do not burn out. These diodes are known to fail at ~5 mW DC input, serving as an absolute limit, but the RF coupling to the diodes is not well known. The prediction from Agilent ADS is that with 1 mA bias and twice the LO and IF power, the output power will double.

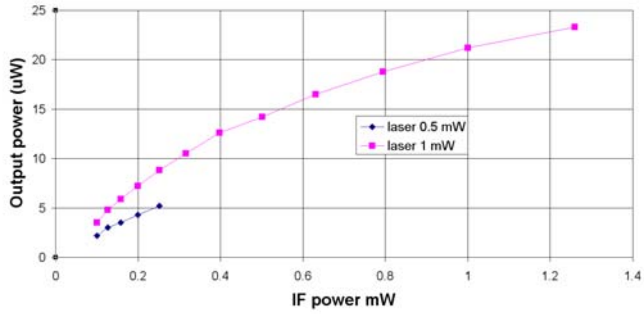

Fig 4. Output power vs input drive at 1562 GHz.

Tests at higher offset frequencies showed the same power output up to an IF of 40 GHz, using the same drive level at the mixer diodes as derived from the bias voltage. IF coupling is not flat across this band, so the IF power varied with frequency. The bandwidth is predicted to be 1250-1650 GHz, and two other laser frequencies (1272 and 1621 GHz) have been tested. At both the input power was poorly calibrated because the laser mode was very poorly matched to the feed horn, but the DC bias conditions were the same as at 1562 GHz, so the power reaching the diodes is the same. Output power was 17 µW at 1272 GHz with 2.5 µW of LO feedthrough power, while at 1621 GHz the output was 21 µW with 5.5 µW of feedthrough. Thus the output circuit coupling is fairly flat over the band, but we can say nothing about the input circuit. This result confirms the prediction that LO to RF isolation is better at lower frequencies in this band.

IV. Downconverter results

Measurements have been made as a conventional mixer downconverter only at 1621 GHz.. The IF source was replaced by a 3 GHz IF amplifier with an isolator on the input, and an IF noise temperature of 214 K. With an estimated LO power of 1 mW (the same as for upconversion testing) and a bias current of 1 mA, the Y factor of the receiver was measured with room temperature and liquid nitrogen cooled loads. This yields a complete receiver noise temperature of 9300K DSB. Conversion loss is 12.4 dB DSB and the derived mixer noise temperature is 5600 K DSB. This noise is a substantially lower than cube-corner mixers at similar frequencies and the beam pattern should be much better [5]. In fact it compares rather favorably with HEB mixers, given that these results are at room temperature, but it should be noted that THz Schottky mixers show relatively little noise reduction when cooled to 20 K, perhaps by only a factor of two, due to the high doping of the diodes. However, this mixer has very wide IF bandwidth, potentially extending beyond 40 GHz.

V. Future work

To follow up this work, a new wafer run is planned to make devices specifically as mixer/upconverters. The same design will be used with an added IF terminal, but in addition the design will be scaled to as high as 3 THz. For higher power, four anode circuits also will be tried.

At these higher frequencies a quantum cascade laser could be the LO, leading to a simple all solid state LO with wide tunability. The IF offset frequency can be exceed 100 GHz. For use as an LO, image rejection is possible using an SSB upconverter design, which is relatively simple to fabricate

Conclusions

Planar Schottky diode MMIC's can serve as efficient upconverters and low noise mixers well into the THz range, offering room temperature operation. This new balanced mixer also separates the LO and IF ports, making an extremely simple, compact receiver requiring no LO/signal diplexer.

Acknowledgments

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