A Planar-Diode Frequency Tripler at 1.9THz

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Abstract **— A fix-tuned 1.9 THz frequency tripler utilizing membrane based GaAs Schottky diodes has been designed and fabricated. The chips are three microns thick with no supporting frame. One micron thick beam leads are used to ground the diodes and to hold the circuit in a split-waveguide block. Both unbalanced and balanced designs have been considered. Preliminary tests at room temperature indicate that the balanced tripler covers the band 1780-1900GHz with output power around 0.5µW when pumped with 3mW. Up to 1.5µW at 1810 GHz was measured when the input power was increased to 5mW.**

I. INTRODUCTION

Recent progress in hot electron bolometer mixers has demonstrated very attractive sensitivities well into the THz regime. This progress, however, would not be sufficient to enable robust space borne heterodyne instruments unless dramatic progress is demonstrated towards building practical terahertz local oscillator sources. Planar Schottky diodes have revolutionized the field of multiplied sources, and in the last few years decisive progress has been made towards implementing practical planar Schottky diode varactors in the THz range [1-5]. However, so far, no solid-state chain has been demonstrated with enough power to pump an HEB mixer at 1.9THz, where very important astronomical lines can be found. The goal of the present work is to develop and demonstrate a robust LO chain at 1.9 THz that enables high spectral resolution observations from space.

Within this context, the present paper will discuss the design, ongoing development, and fabrication of a 1.9 THz frequency tripler. Preliminary results will be presented and discussed.

II. DESIGN CONSIDERATIONS

Balanced vs. unbalanced approach: Two different tripler topologies were considered for development. One utilizes a single diode while the other uses two diodes in a balanced configuration. At the onset of this study it was not obvious as to which approach would lead to the best results in terms of output power and bandwidth. The issue can be summarized as follows: for a given input power, the strongest possible non-linearity is created by pumping a single (unbalanced) diode. For a balanced tripler, the power is shared and thus the non-linearity that appears in each diode can be dramatically reduced. On the other hand, using two diodes in a balanced configuration allows one to control the matching of the diodes at the idler-frequency (second harmonic of the input signal) much more easily than using a single anode. The question of available input power (in the 600-650GHz range) is thus very germane. Based on the fact that multiplier technology even at 600 GHz is still evolving, it was decided to pursue and fabricate chips based on both balanced and unbalanced circuit configurations.

Design methodology: A common method employed to design and optimize diode multiplier circuits is to first optimize the diode parameters (anode size, doping) using non-linear harmonic balance codes. The optimum diode embedding impedances are calculated so that input and output matching circuits can be designed using linear circuit synthesis. This approach is relatively fast and has been shown to work very well with balanced doublers [2], since the input and output circuits can be optimized nearly independently. However, we found this method not to be optimal for frequency triplers. Due to the fact that there are three frequencies involved in the circuit, and that both input and output signals are in the same propagating mode in a large part of the circuit, there is no way to optimize the circuit independently for each harmonic. We therefore used a hybrid approach: non-linear codes were used to optimize simultaneously the diode physical structure along with the embedding circuitry for maximum performance, but at a few frequency points to avoid non-convergence of the nonlinear harmonic balance simulator. The design parameters obtained from the nonlinear simulations were used as the starting point for the synthesis of the input and the output matching circuits in two independent simulations using a linear circuit simulator. Finally, the complete circuit including both the input and the output matching elements was simulated in a nonlinear harmonic balance simulator across the entire bandwidth of interest.

Diode model used in the simulation: A practical approach is used whereby a simplified model as described in [1] is used. Based on this approach, we modeled the 1.9THz Schottky diode as a standard Schottky diode with R_s x

$C_j(0) = 120\ \Omega \cdot \mathrm{fF}$, where R_s is the series resistance and $C_j(0)$ is the junction capacitance with zero bias voltage. The break down voltage and the current saturation were calculated separately and were used as design limits for the diode maximum reverse voltage and the maximum peak forward current. Proceeding this way, no complex physical model had to be implemented in the non-linear simulator. This simplification was very important to solve convergence and speed problems.

Simulation results: Figure 1 shows the schematic for the balanced circuit configuration. The top half shows the detail of the chip where the anodes are formed while the bottom shows the chip in its entirety when mounted in a waveguide housing. Note the small features that are required for this design to be implemented. The simulated results for the balanced and unbalanced triplers are shown in Figure 3 for an input power of 2.5 mW. Further calculations showed that the balanced tripler should have a higher efficiency than the unbalanced tripler as long as the input power is above 1 mW. Based on this information it was decided to fabricate, assemble, and test the balanced option. Due to the high expected RF series resistance of the anodes (about 120 Ohms to 150 Ohms for anodes with 1fF to 0.8fF of capacitance), the calculated maximum efficiencies for both the balanced and unbalanced configuration were low, i.e. 31dB and 34dB respectively.

The 1.9THz balanced tripler (see Figure 1) has two diodes positioned on each side of the high impedance line. The diodes are connected in series at DC. One has its anode grounded at one side of the channel by a first beam-lead, the other has its cathode grounded to the other side of the channel by a second beam-lead. Due to the symmetry of the field at the fundamental frequency (TEM mode), the diodes appear in an anti-parallel configuration at RF. The second harmonic is trapped in a virtual loop and cannot propagate in other parts of the circuit. This topology offers the advantage of a very small phase shift between the two anodes and the possibility to tune the matching at the idler frequency by adjusting the length of the beam-leads that ground the diodes. By using a mesa size of 7x7µm, we were able to place the device in a 46x25µm channel, which is important to prevent higher order modes from propagating inside the channel.

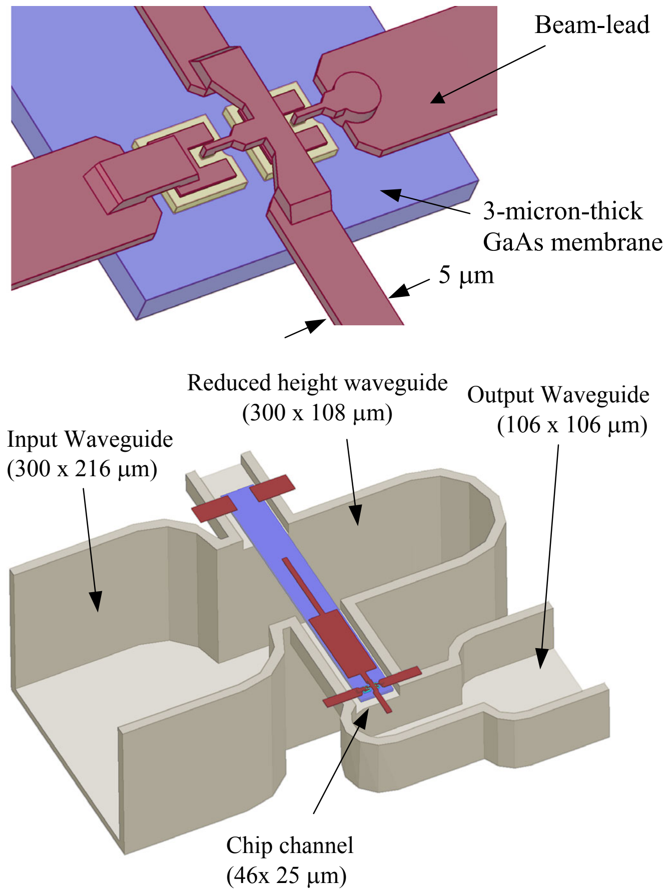

Figure 1: 1.9THz balanced triplers. The top view shows a detail of the anode area. The chip is held in the middle of the channel by beam-leads. The balanced circuit does not allow for biasing.

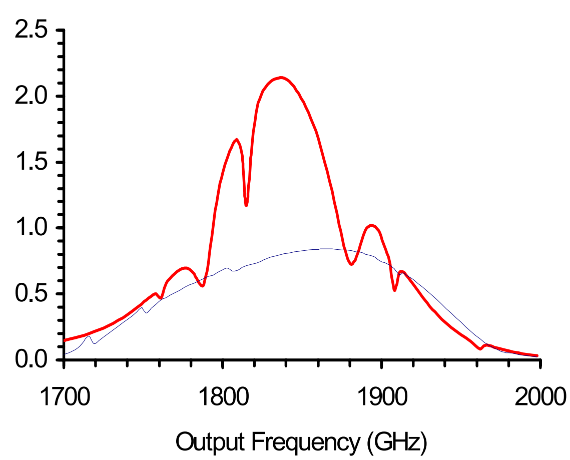

Figure 2: Calculated output power of the 1.9 THz balanced (dark) and unbalanced triplers. Input power of 2.5 mW is assumed. Cj(0)=1fF for the unbalanced tripler and Cj(0)=0.8fF for the balanced tripler.

III. PRELIMINARY RESULTS

The 1.9THz tripler chip has been fabricated using a GaAs frame-less membrane based process [6,7]. The chips are based on a three-micron thick GaAs membrane. A $5\cdot10^{17}cm^{-3}$doping is used. A close up of the anode area is shown in Figure 3. Split waveguide blocks have also been designed and manufactured. An integrated diagonal horn is used at the output. Appropriate waveguide steps are used to match device impedance.

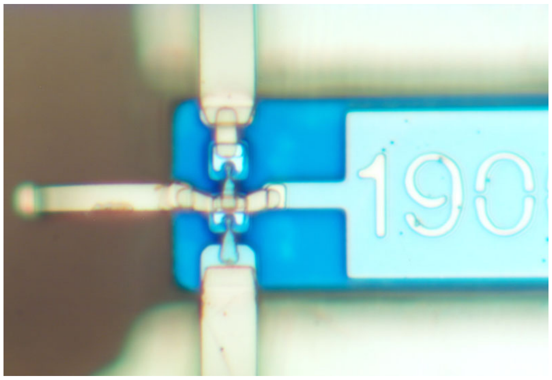

Figure 3: Detail of the diode area of the 1.9THz tripler chip.

To test the 1.9THz tripler with sufficient input power, a phase-locked (Russian made) 600GHz BWO was used. This fundamental source had an over-sized output waveguide terminated by a pyramidal output horn. We connected a 600GHz Picket-Potter horn at the input of the 1.9THz tripler and used a pair of polyethylene lenses to couple to the BWO beam. The 600 GHz Picket-Potter horn, followed by a mono-mode waveguide section, acted as a perfect mode-filter of the BWO output beam. Thus, by connecting a calorimeter fabricated by Erickson Instruments, Inc. to the horn's waveguide flange, we could calibrate the single-mode input power. The greatest difficulty encountered in the experiment was measuring sub-microwatt power at 1.9THz. We used a Golay cell that was calibrated at lower frequencies by comparison to the Erickson calorimeter. We used the same calorimeter to confirm the power measurements above a microwatt. We limited the optical path between the 1.9THz horn and the power sensor to less than 2 cm in order to minimize attenuation from water vapor absorption lines and to maximize the coupling efficiency. Output power numbers reported here do not include any correction factors, however, it is felt that the uncertainty of the measured output power at this frequency is within a factor of 2.

Figure 4 shows the frequency response of three 1.9THz triplers with different anode sizes. The nominal design is for the 0.4x0.8 micron anodes. The smaller anodes were fabricated to mitigate variations in the processing of such small anodes. The multipliers were pumped with a nominal 3 mW signal at various frequencies in the design band. Given the uncertainly of the measurement along with the requirement of very tight mechanical tolerance we feel that the agreement between the simulated performance and the measured performance is encouraging. To our knowledge, these results are the highest obtained with planar-diode frequency multipliers at 1.9THz. Furthermore, the output power seems to be in the range where it could be used to successfully pump HEB mixers. Confirmation of this will be investigated by attempting to use this multiplier to pump HEB mixers in the near future. Solid state sources in the 600 GHz range are also under-development which can be used to successfully facilitate a complete solid state chain.

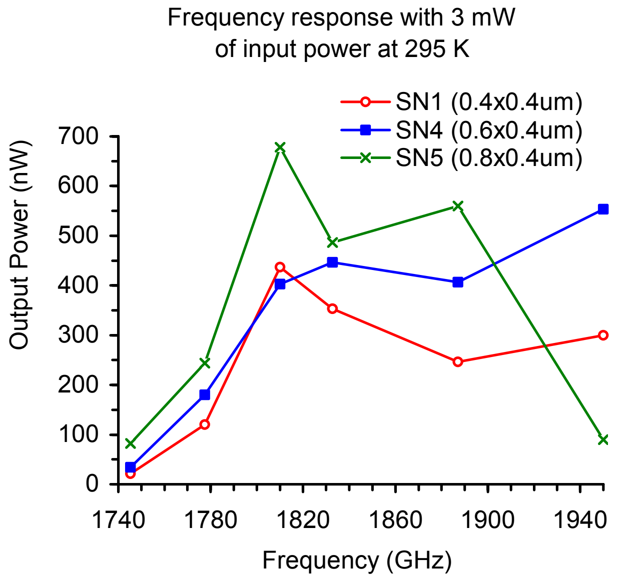

Figure 4: Output power versus frequency for the 1.9 THz tripler at room temperature. Three different anode sizes have been investigated. Input power is a nominal 3 mW.

For further confirmation that the measured signal was not due to leakage, spectroscopic measurements in the 1750-1800GHz band were conducted at the University of Cologne (Physikalisches Institut). Spectroscopic measurements confirmed the spectral integrity of the signal and due to the inherent ease of use of the multiplier a number of spectroscopic measurements were possible in a very limited time. The higher output power at 1950 GHz from two of the multipliers needs further investigation. The design of the block is done to block any leakage of the harmonics but it could be possible that the second harmonic leakage contributes to the measured power at 1950 GHz.
Figure 5 shows the measured output power at 1810 GHz as a function of input power. Simulations indicate that

saturation should occur around 5 mW of input power. The measurements however indicate that the multipliers have not been saturated with 5mW of input 'incident' power. This fact may indicate that the coupling of the input power to the diodes is not as good as expected. A second possible reason could be that the actual size of the anodes is slightly larger than expected. However, in the absence of measured return loss it is difficult to predict the true input power. It should be noted though that a maximum of 1.5 microwatts of output power is possible with this configuration and this power is more than sufficient to drive HEB mixers.

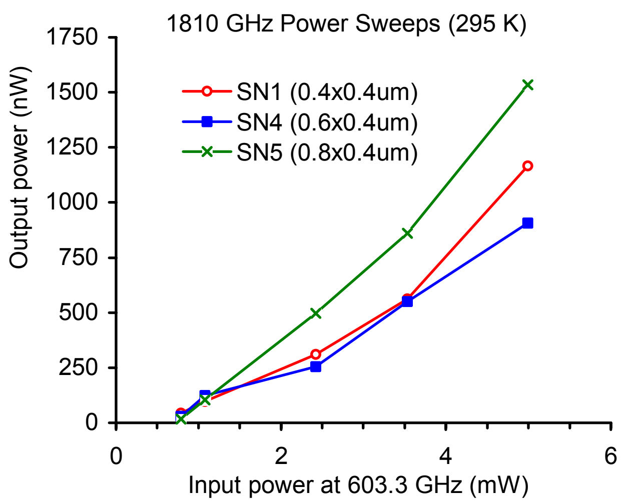

Figure 5: Output power measured at 1810GHz versus input power for three different multipliers at room temperature.

CONCLUSION

A 1.9 THz tripler based on planar GaAs Schottky diodes has been demonstrated. Preliminary results in terms of output power and bandwidth are close to the predictions. The performance is expected to improve upon cooling. It is believed that the balanced design provides the best opportunity to obtain sufficient power to drive HEB mixers in this frequency range.

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