High Power Local Oscillator Sources for 1-2 THz

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ABSTRACT

Recent results from the Heterodyne Instrument for Far-Infrared (HIFI) on the Herschel Space Telescope have confirmed the usefulness of high resolution spectroscopic data for a better understanding of our Universe. This paper will explore the current status of tunable local oscillator sources beyond HIFI and provide demonstration of how power combining of GaAs Schottky diodes can be used to increase both power and upper operating frequency for heterodyne receivers. Availability of power levels greater than 1 watt in the W-band now makes it possible to design a 1900 GHz source with more than 100 microwatts of expected output power.

Keywords: Schottky diodes, frequency multipliers, local oscillators, heterodyne receivers

1. INTRODUCTION

Submillimeter-wave spectrometry is a proven flight technique that is essential for NASA's unique goals, such as atmospheric remote sensing [1], study of cosmic water profiles [2, 3], comet characterization [4], and investigation of cosmological phenomena with radio telescopes [5]. Recent results obtained from HIFI have shown spectacular emission and absorption spectra with unprecedented resolution [6]. Beyond space-based instrumentation, terahertz imaging for homeland security has also been getting much attention with recent demonstration of sub-cm resolution imaging at 670 GHz [7]. One of the most challenging aspects of terahertz technology is the lack of compact, reliable, efficient, and broadband sources in the terahertz range. Sources are required for a variety of applications, either as transmitters or as local oscillators (LO) for heterodyne detectors. This article will present a brief review of how recently developed technologies can now be utilized to design and build sources that improve on the performance that was achieved by the HIFI LOs. The goal of this work is to build broadband electronically tunable sources that go beyond the frequency coverage provided by HIFI, and moreover produce higher power levels to enable THz array receivers.

2. W-BAND POWER AMPLIFIERS

Two recent developments are worth mentioning in regards to available power sources in the 75-110 GHz range. The first is the approach of waveguide power combining from existing GaAs pHEMT MMIC devices. The existing devices provide significant gain with respectable bandwidth and can easily be power combined to increase the total output power. A 4-way power combining scheme has been implemented. A driver amplifier's output is divided 4 ways, which are then amplified and recombined to provide a single waveguide output. The schematic of the block and results obtained from this approach are shown in Figure 1. 90-degree quadrature hybrid couplers are utilized at the input and output of this construction.

The second development worth mentioning is the rapid advancement in GaN based power amplifier technology. Recent results reported in [8] have shown that a single GaN - MMIC can be expected to provide power output in the range of 500-750 mW. Furthermore, by power combining 4 chips, power in excess of 3 W has been measured. Similarly, power combining in a rat-race structure has demonstrated power levels in excess of 5 W [9]. The combination of being broadband and having a fairly flat output power profile at these frequencies now makes it possible to utilize this technology as the driving source for high power frequency multiplier chains.

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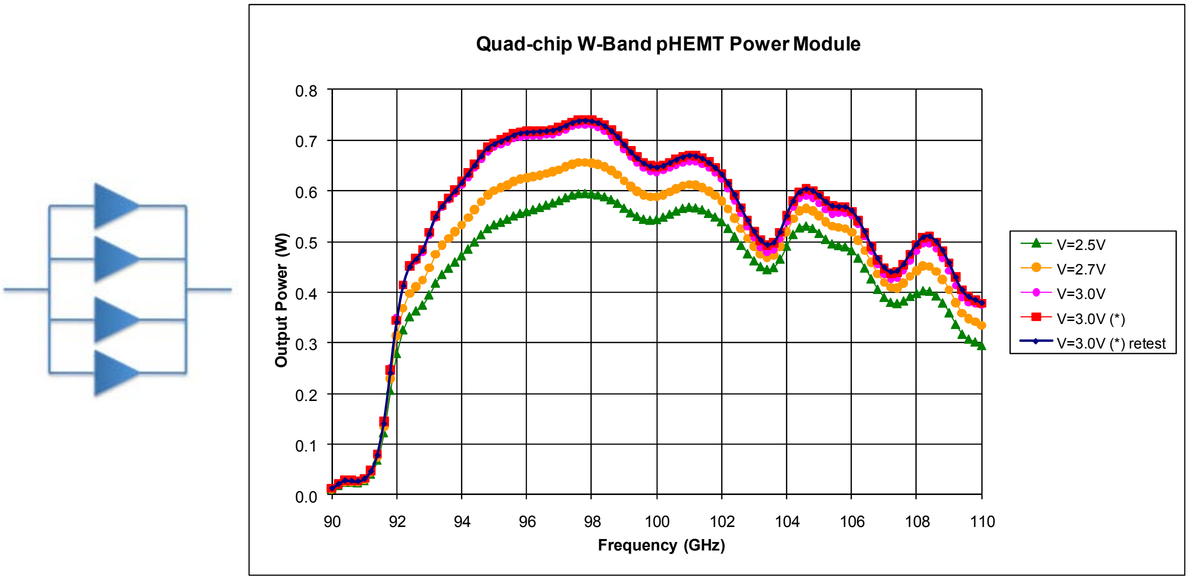


Figure 1: 90-degree quadrature hybrid couplers are utilized to power combine 4 MMIC power amplifier chips. The resulting module provides well-behaved output power across the design band.

3. POWER-COMBINED MULTIPLIERS

The large amount of available power at W-band now puts the onus on the multiplier designer to successfully harness this power. A number of approaches have been identified to achieve this goal. For a given multiplier design, as the input power is increased, the multiplier will either experience thermal heating or reverse breakdown, both of which will result in catastrophic failure. To improve the thermal handling of multiplier chips, an approach based on utilizing diamond substrates has been previously reported [10]. The second limitation to frequency multiplier power-handling occurs when the input signal to the multiplier becomes large enough to drive the diodes into reverse breakdown. Increasing anode area, increasing the number of anodes per chip, re-optimising doping levels, and moving to a high thermal conductivity substrate or GaN[11] will allow additional improvements in single-chip power handling.

Results obtained with single chip multipliers up to 1900 GHz for the Heterodyne Instrument for Far-Infrared on the Herschel Space Observatory have been presented in [12]. Recently, an improved 1300-1450 GHz chain based on a x2x3x3 scheme has been built for the CASIMIR instrument on SOFIA [13]. The chain and the components used to build it are shown in Figure 2. The first stage doubler for this chain is actually built on a “thick” 30-40 micron membrane. This is mostly done in order to get a better thermal sink for the chip heating. The second stage tripler is based on a 4-anode design. This is an improvement over the HIFI designs where a similar tripler was based on 2-anodes. The final result from this chain is shown in Figure 2(f). When compared to the results obtained with the HIFI multipliers, this chain shows about a factor of two enhancement in output power.

However, chip thickness or substrate thickness and number of anodes per chip can only be increased up to a limit. In order to avoid unwanted waveguide modes, both of these design parameters are eventually constrained. Increasing power handling capability beyond this point requires novel approaches such as sandwiching dual chips, as suggested in [14]. Another simple approach that has been suggested before and demonstrated is to power combine multiplier circuits in a waveguide based circuit[15]. This approach offers a number of advantages. It is a straightforward concept and does not require any new technology development at the chip level; in fact, existing chips can be utilized. The power combining and dividing functionality is accomplished in the waveguide, allowing for a low-loss transmission media. Moreover, this approach provides an easily scalable design, both in frequency as well as in power. Traditional designs such as the Y-junction and the 90-degree hybrid couplers have been utilized for this approach.

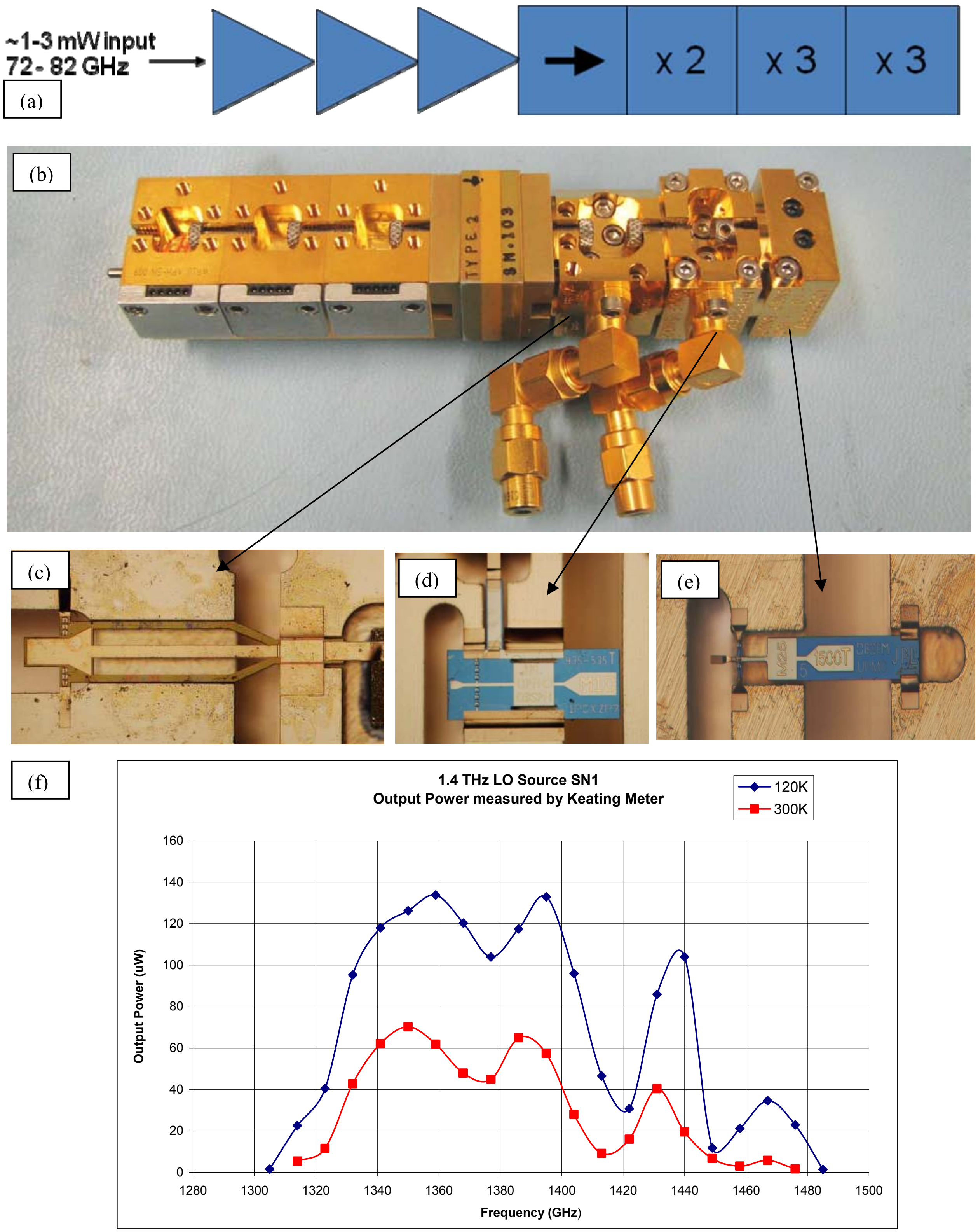


Figure 2: The multiplier scheme for the 1300-1450 GHz chain, x2x3x3 is shown in (a). The actual chain is shown in (b). M1, M2 and M3 chips are shown in (c-e). M2 utilizes multiple anodes for higher input power handling. The results from the chain are shown in (f) and represent enhanced performance over similar chains produced for HIFI.

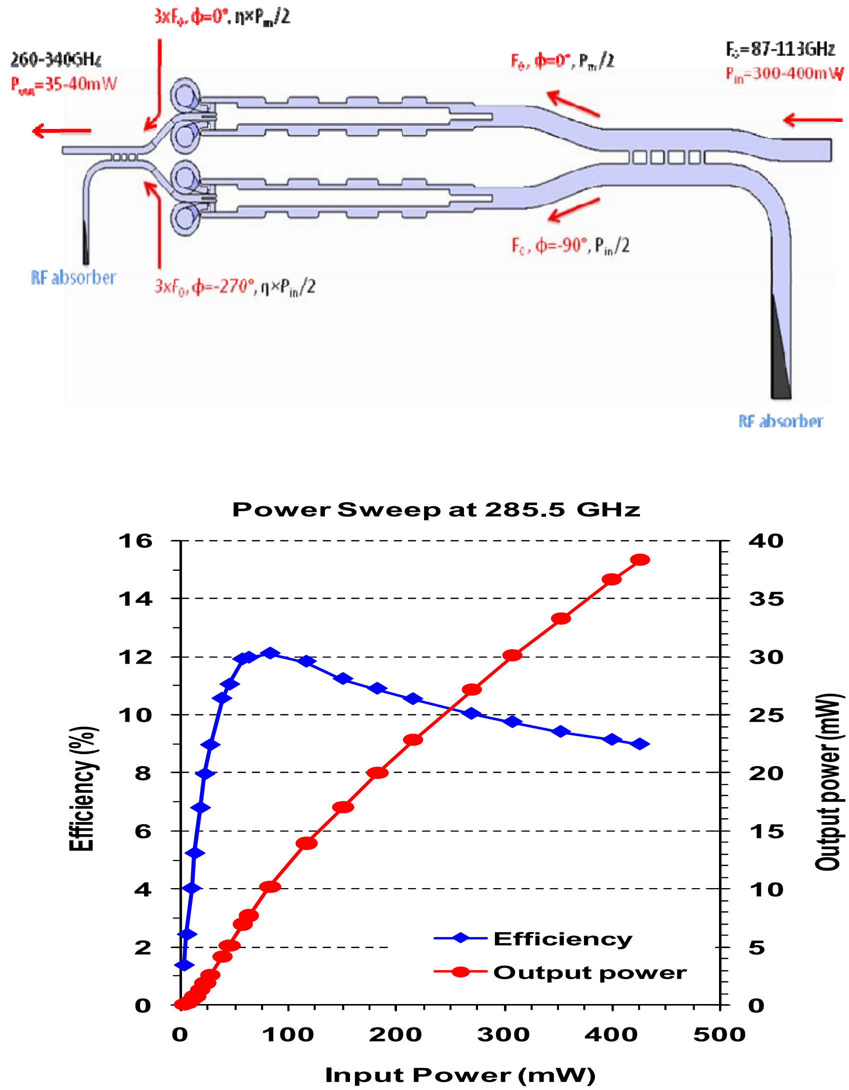
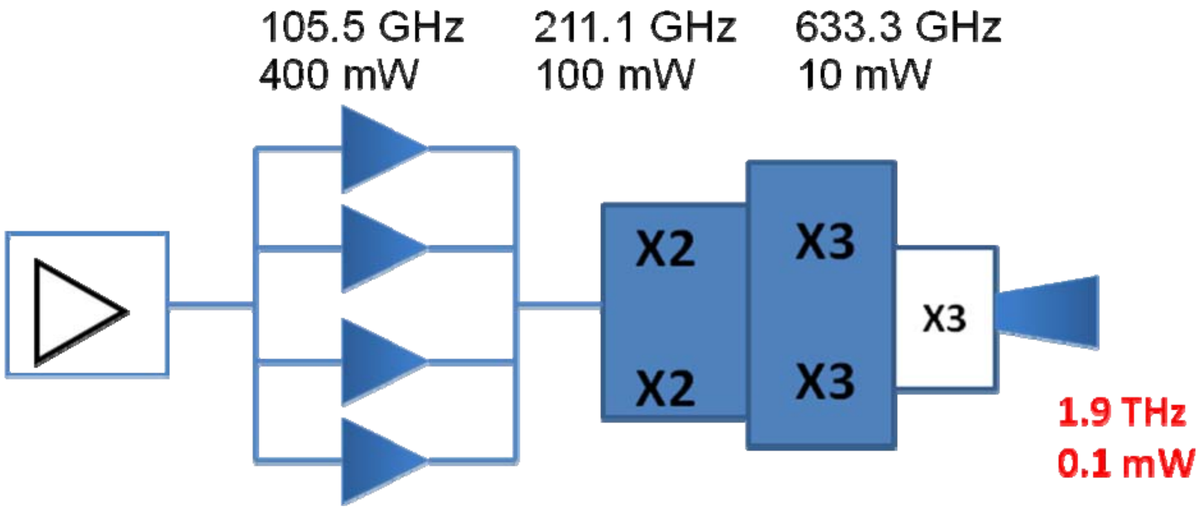


Figure 3: Schematic of the quad-chip design. A combination of Y-junctions and 90-degree hybrids are used to power combine.. The measured room temperature performance for 286.6 GHz is shown in the bottom plot.

A two-chip in-phase power-combined frequency tripler working around 300 GHz has been demonstrated [15]. In this paper we report on a quad-chip design for a tripler working in the 260 to 340 GHz range. Figure 3 (top part) shows the schematic for this tripler circuit. It utilizes four identical chips with twenty-four anodes. This design also uses branchline quadrature hybrid couplers and internal loads to provide good return loss and isolation at both the input and output. Despite the high frequencies involved and large fractional bandwidth, the power combining is nearly ideal, with the power-combined version performing with almost identical bandwidth and conversion efficiency as the single-circuit version except with four-times the power handling. The conversion efficiency of the power-combined tripler exceeds 10% for input powers ranging from 1.4 mW to 17 mW per anode with 24 anodes. The peak efficiency reaches a record 12% at 285.5 GHz and is obtained with around 100 mW of input power. With around 400 mW of input power the efficiency degrades to around 9%. This can be attributed to chip heating. The high efficiency over a large dynamic range makes this power-combined frequency tripler very versatile.

Figure 4: Proposed scheme for the high power 1900 GHz chain. Dual-chip multipliers will be utilized to increase input power handling. It is expected that such a chain will be able to generate around 0.1 mW of output power.



The Pin vs. Pout data shown in Figure 3 indicates that the efficiency of the multiplier starts to saturate at around 100 mW of input power. However, the saturation effect is not very hard and the efficiency decreases only by about 20% when the input power is increased by a factor of 2. The output power from the circuit however, shows no saturation even with 400 mW of input power. Output power of more than 40 mW has been measured around 300 GHz with these power combined triplers. Recently a quad-chip 300 GHz tippler pumping a dual-chip 900 GHz tripler produced more than 1 mW of output power at room temperature [16]. The power combined tripler source can be used to drive higher frequency multipliers. Work on the final stage 2700 GHz tripler is currently underway.

4. A 1900 GHZ LOCAL OSCILLATOR CHAIN FOR ASTROPHYSICS ARRAY RECEIVER

The proposed scheme for obtaining a high power 1900 GHz chain is shown in Figure 4. The power combined power amplifier modules will be utilized to drive the first stage multiplier. A x2x3x3 scheme will be utilized. The first stage doubler will be a dual chip design with relatively thick substrate material. The diamond substrate material described in [10] will be utilized and should allow this circuit to be pumped with more than 400 mW of input power. It is expected that this circuit will produce 100 mW of output power at 211.1 GHz. This in turn will be used to pump a dual-chip 633.3 GHz tripler with six anodes each. This is expected to produce 10 mW of output power at 633.3 GHz, which will then be used to pump the final stage tripler. With a predicted 1% efficiency for the final stage tripler, we expect to achieve 0.1 mW of output power at around 1900 GHz. This will present an enhancement factor of at least 2 over the performance obtained with HIFI hardware. This power level is now sufficient to pump an array of HEB mixers in the 1900 GHz range to map the ionized oxygen line in our galaxy.

5. CONCLUSION

Increased available power at W-band has now made it possible to design high power sources in the 1-3 THz range. However, it is necessary to design first stage multipliers with increased power handling capability. Waveguide based power combining techniques present a simple solution towards enabling high power sources. It is expected that by utilizing these techniques more than 0.1 mW can be obtained around 1900 GHz from a frequency multiplied source..

6. ACKNOWLEDGEMENT

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