1400 – 1900 GHz Local Oscillators for the Herschel Space Observatory

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ABSTRACT

JPL continues to develop robust planar, all solid-state sources to cover the 1414 to 1908 GHz band. These sources will be used as local oscillators to drive hot electron bolometer (HEB) heterodyne mixers on the Herschel Space Observatory to observe high-resolution spectra in the interstellar medium such as the N+ and C+ fine structure lines at 1461 and 1901 GHz, water lines at 1661, 1670, and 1717 GHz, and OH lines from 1834 to 1838 GHz. We report our current progress and present recent results. Results include a 175 K measurement of 88 μW at 1544 GHz and a room temperature measurement of 1 μW output power at 1810 GHz.

I. INTRODUCTION

The Herschel Space Observatory is a 3.5 meter diameter passively-cooled telescope scheduled to launch in 2007. Its three science instruments (PACS, SPIRE, and HIFI) will observe the cosmos from 450 to 5000 GHz (60 – 670 μm) [1]. Band 6 of the Heterodyne Instrument for the Far-Infrared (HIFI) [2] is a heterodyne spectrometer to cover 1414 to 1908 GHz. Table 1 provides a brief summary of the four local oscillator chains that will be required to pump HEB mixers to cover this band. The design operating temperature of the local oscillators is 120 K.

When the development of heterodyne receivers for the Herschel Space Observatory was initiated, state-of-the-art submillimeter sources typically consisted of cascaded whisker-contacted Schottky-diode frequency multipliers driven by phase-locked Gunn oscillators [3,4]. Frequency tuning was achieved with mechanical tuners, and multipliers were mechanically fragile. Above about 900 GHz, the available power was too low to pump a mixer, and so compact solid-state sources gave way to massive FIR lasers, where changing frequencies implies changing the gas in the laser, and frequencies produced must be chosen from a finite list of available laser lines. The goal of the effort described here is to produce mechanically robust, low volume, low mass, solid-state sources to pump heterodyne mixers from 1414 to 1908 GHz. Furthermore, these sources must be electronically tunable over at least 140 GHz of bandwidth, and must be suitable for high-reliability space applications.

Band	Chain	Output Frequency	Goal Output Power
Band 6 Low	6a	1414 – 1584 GHz	2.1 μW
	6b	1472 – 1696 GHz	2.1 μW
Band 6 High	6c	1704 – 1908 GHz	2.1 μW
	6d	1704 – 1908 GHz	2.1 μW

Table 1. Requirements and nomenclature for the four local oscillator chains comprising band 6 of the HIFI instrument for HERSCHEL. The operating temperature is 120 K.

II. IMPLEMENTATION

The requirements given in Table1 will be implemented by multiplying high-power W-band sources by three or four cascaded frequency multipliers. Table 2 shows three available power amplifier bands [5] and all configurations under consideration to multiply these bands up to the required output frequencies. Note that while the 6a and 6b chain configurations are fixed, there are several configurations under consideration to reach band 6 high.

All multiplier devices with output frequencies below 1 THz are based on the JPL substrateless process [6-8] in which the GaAs substrate under the integrated circuit is etched away to maximize conversion efficiency. The final, highest-frequency multipliers are based on the JPL membrane process [8,9], in which the circuit is fabricated on a 3 μm thick GaAs membrane. Figure 1 shows a membrane-based 1500 GHz balanced doubler with the device sitting inside the split waveguide block. A photo of the assembled multiplier chain along with the W-band power amplifier is shown in Figure 2. All multipliers employ balanced, multi-diode configurations to achieve high efficiency, high power, and broad bandwidth (approximately 8 to 13%) without any mechanical tuning. Low-loss waveguide matching circuits further contribute to the efficiency of these designs.

Power Amp	71 – 79.5 GHz 230 mW	88 – 99.5 GHz 230 mW	92 – 106 GHz 230 mW
x2x2x2x2		1408 – 1592 GHz Chain 6a	1472 – 1696 GHz Chain 6b
x2x3x3			1656 – 1908 GHz Band 6 high
x2x2x3x2	1704 – 1908 GHz Band 6 high		
x2x2x2x3	1704 – 1908 GHz Band 6 high		

Table 2. Possible configurations for band 6. The three columns represent available power amplifier bands, while the four rows show possible configurations of frequency doublers and triplers. Note that there are three different possibilities for band 6 high.

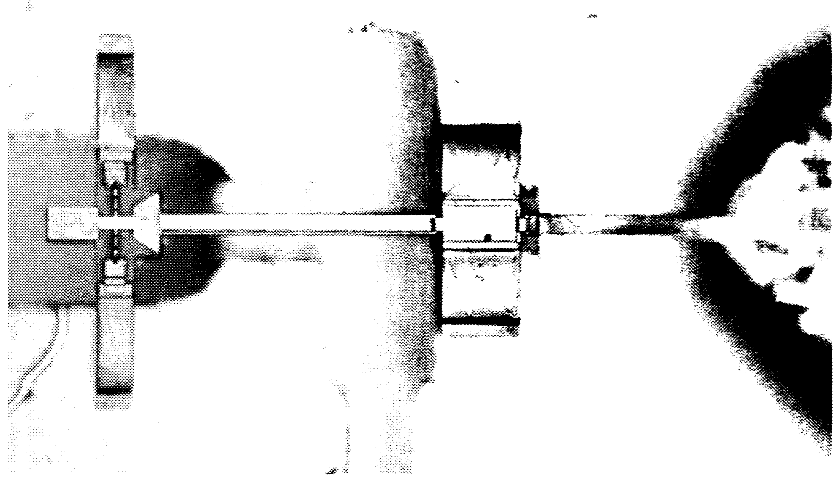

Figure 1. A 1500 GHz balanced doubler. The input signal at 750 GHz enters through a waveguide tuning circuit from the left. Two Schottky diodes are located in the input waveguide, with cathodes grounded by beam leads. The 1500 GHz output signal is launched into the output waveguide at the bottom of the picture toward an integrated diagonal horn. DC bias for the diodes is brought in from the right.

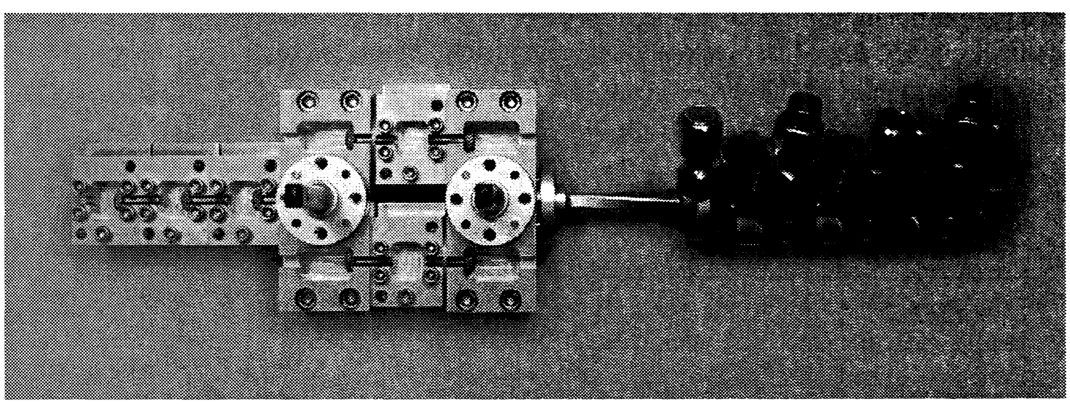

Figure 2. A 1500 GHz development local oscillator. From left to right: the 94 GHz input signal is amplified by a four-stage power-combined power amplifier, passes through a length of rectangular waveguide, and is multiplied up to 1500 GHz by four cascaded frequency doubler modules. The last multiplier includes an integrated diagonal horn, launching a Gaussian beam to the right. Note the absence of mechanical tuners: this source is electronically tunable over more than 100 GHz of bandwidth. Total length is about 20 cm.

III. RESULTS

Table 3 lists a summary of typical measured efficiencies and output powers for the multipliers being developed at JPL for the HIFI band 6 local oscillators. It should be noted that the measurement uncertainty ranges from less than 1 dB at the lowest frequencies and highest powers to about 3 dB for the highest-frequency measurements.

Figure 3 shows preliminary measurements of a 1500 GHz source. The W-band drive power into the first frequency doubler was 150 mW. The first two multiplier stages (200 and 400 GHz doublers) were originally developed for HIFI band 5 [6,7,10], the third stage 800 GHz doubler was a prototype for the 6b chain, and the final multiplier is the flight-model 1500 GHz doubler for the 6a chain. Although the frequency ranges of the stages are not optimally matched (low frequency performance should be improved by using all chain 6a multipliers) and none of the measurements were made at the nominal operating temperature of 120 K (multiplier efficiency improves with cooling, as clearly demonstrated in the figure), this chain is still able to meet the required output power over at least 120 GHz of bandwidth. The power needed to optimally pump an HEB mixer in this band has been experimentally demonstrated to be about 1 μW [11]. To improve the long-term stability of this chain, the excess power across the band will be traded for increased lifetime by running at lower W-band input power, reduced diode current densities, and more conservative bias voltages. A more detailed look at this chain will be given in [12].

Output Frequency	Multiple	Intended Use	Typical Efficiency	Typical Power
176 – 199 GHz	2	Chain 6a, stage 1	30%	40 mW
352 – 398 GHz	2	Chain 6a, stage 2	20%	8 mW
704 – 796 GHz	2	Chain 6a, stage 3	Untested	
1408 – 1592 GHz	2	Chain 6a, stage 4	2%	30 μW
184 – 212 GHz	2	Chain 6b, stage 1 Band 6 high, stage 1	30%	40 mW
368 – 424 GHz	2	Chain 6b, stage 2	Untested	
736 – 848 GHz	2	Chain 6b, stage 3	15%	1 mW
1472 – 1696 GHz	2	Chain 6b, stage 4	Untested	
552 – 636 GHz	3	Band 6 high, stage 2	Untested	
1704 – 1908 GHz	3	Band 6 high, stage 3 or 4	0.02%	1 μW
152 – 159 GHz	2	Band 6 high, stage 1	Untested	
304 – 318 GHz	2	Band 6 high, stage 2	Untested	
608 – 636 GHz	2	Band 6 high, stage 3	Untested	
1704 – 1908 GHz	2	Band 6 high, stage 4	Untested	

Table 3. Multipliers being actively developed for band 6. Typical efficiencies and powers represent peak values for room temperature measurements, or values with several percent bandwidth at 120 K. Best measured peak powers at 120 K are about a factor of two higher in all cases except the 1704 – 1908 GHz tripler, which has only been tested at room temperature.

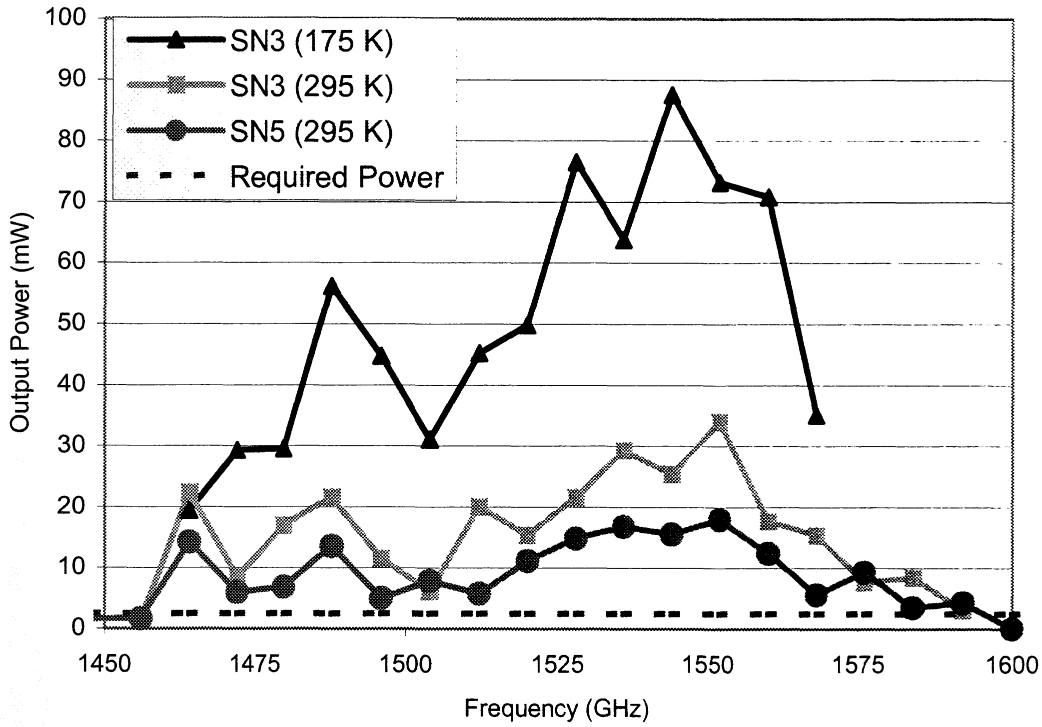

Figure 3. Output power as measured from a chain nearly identical to that shown in Figure 2. The W-band drive power into the first frequency doubler was 150 mW. The two measured multipliers use the exact same device geometry. Differences in the measured performance at room temperature are probably due to variations in fabrication and assembly, and coincidentally are representative of the overall measurement accuracy. The required power shown is the 2.1 μW specification for Herschel.

Implementing solid-state sources to cover the 1700 to 1900 GHz band is substantially more difficult than for the 1400 to 1700 GHz band. Not only do Schottky diode multipliers become less efficient at higher frequency, but also frequencies above 1700 GHz cannot be reached from currently available power amplifier bands with four cascaded frequency doublers. Therefore, at least one multiplier must be a tripler. Since the most difficult multiplier to design and build for this chain is the highest frequency stage, a tripler covering the 1700 to 1900 GHz range was designed and fabricated even before a solid-state 600 GHz driver chain was complete. Several triplers were assembled with devices of varying anode sizes, and were tested with a high-power 600 GHz backward-wave oscillator (BWO) at the University of Cologne. Figure 4 shows frequency sweeps of 3 different devices with 3 mW of input power, and Figure 5 shows the relation of output power to input power. All of these results were measured at room temperature, and it is expected that the performance will improve upon cooling. Based on these preliminary results, to obtain power levels that are sufficient for pumping HEB mixers in this frequency range, very high input power will be required. However, the devices used for these tests have anodes that are not perfectly formed, leading to high parasitic shunting capacitance. Moreover, there is significant uncertainty in the optical coupling between the BWO and the tripler, and the tripler and the power meter. We believe that drive stages for this multiplier will have enough power to sufficiently drive this multiplier in the final implementation. A detailed description of this tripler will be given in [13].

IV. CONCLUSIONS

Mechanically robust, broadband, electronically tunable, lightweight, compact terahertz sources suitable for pumping heterodyne mixers for space applications have been developed and demonstrated. In particular, 88 μW of peak RF power were measured at 1544 GHz and 175 K. This represents a substantial improvement in capability for deploying THz heterodyne receivers. The high power available and convenient electronic tunability also open up possibilities of a host of other applications. The next challenge is to produce LO sources with sufficient efficiency and reliability to meet flight hardware requirements in the 1700 – 1900 GHz range.

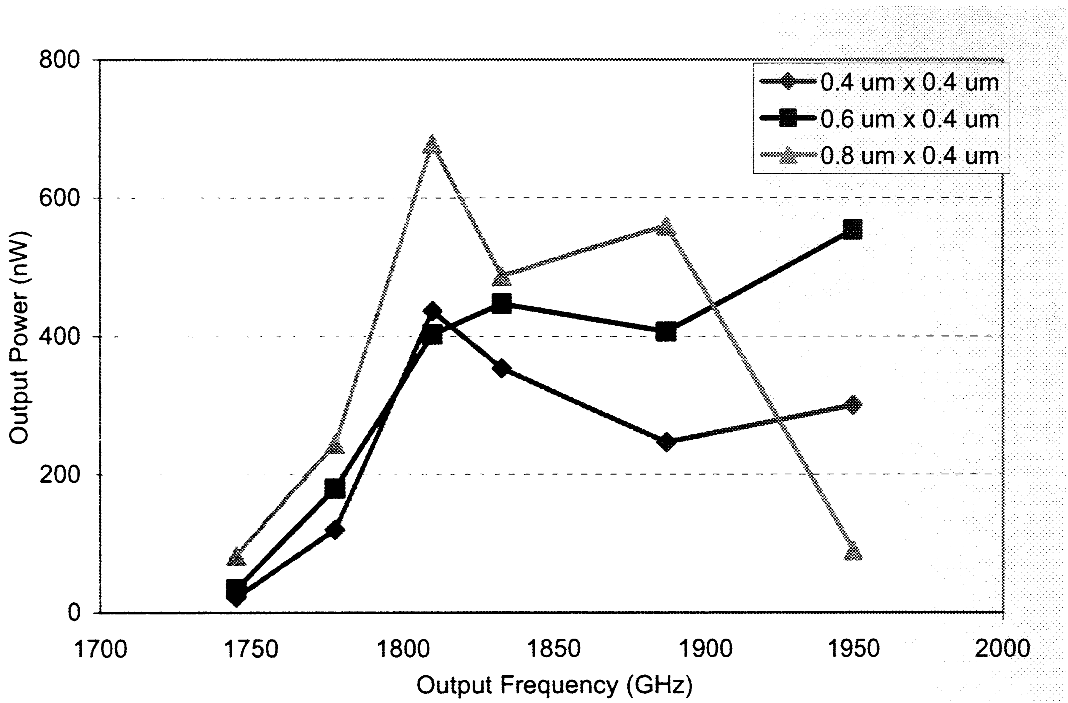

Figure 4. Measured frequency response of 1800 GHz tripler with approximately 3 mW input power at room temperature for devices with three different anode sizes.

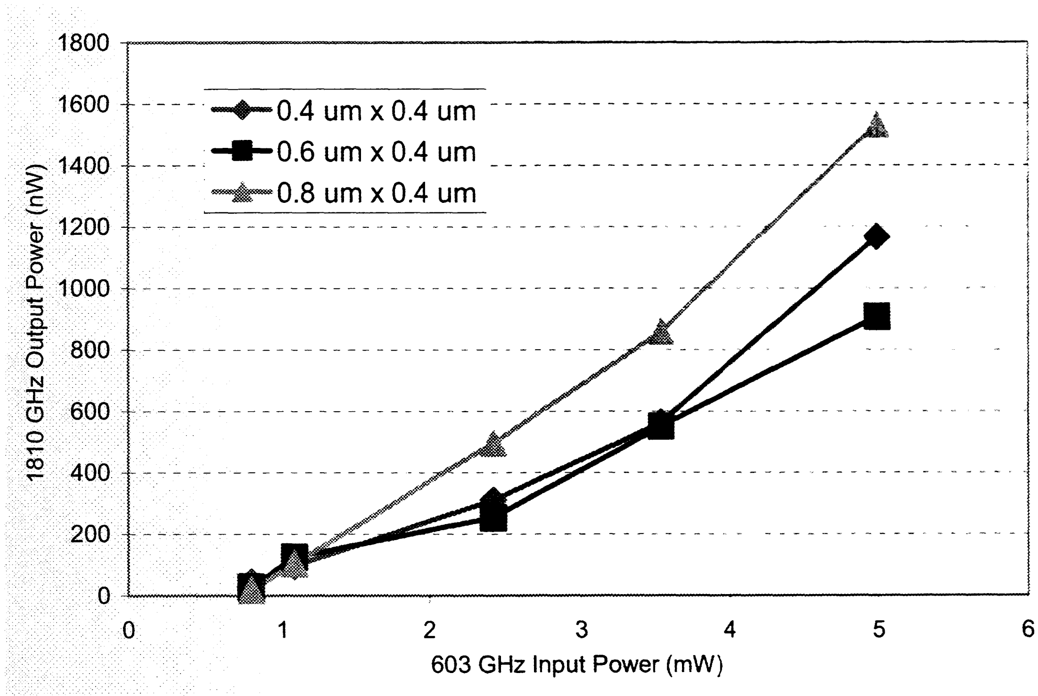

Figure 5. Measured output power of 1800 GHz tripler as a function of input power at room temperature for devices with three different anode sizes. The upward curvature shows that efficiency improves with increased input power: the multiplier is under-pumped, even with 5 mW of incident input power.

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