Local Oscillators from 1.4 to 1.9 THz

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***Abstract*—Local oscillators have been produced for band 6 of the Heterodyne Instrument for the Far Infrared (HIFI) on the Herschel Space Observatory and for the Harvard-Smithsonian Center for Astrophysics Receiver Lab Telescope (RLT) in northern Chile. These local oscillators pump hot-electron bolometer (HEB) mixer front-ends to perform high resolution spectroscopy of the interstellar medium. Local oscillator assemblies amplify 1 mW input signals in the 86 to 107 GHz band before multiplying the frequency by 16 or 18 with cascaded chains of Schottky diode frequency doublers and triplers, ultimately covering nearly the entire 1.4 to 1.9 THz band with 3 µW or more at the nominal operating temperature of 120 K. Peak output power at the nominal operating temperature is typically 30 µW or higher. Room temperature performance is sufficient to pump HEB mixers with moderately reduced bandwidth compared to cryogenic operation, with room temperature output power typically in the 1 to 10 µW range. The chain outputs are Gaussian beams produced by diagonal horns integrated into the final stage multiplier blocks. Beam pattern measurements at 1.8 THz confirm the predicted performance of the horns.**

***Index Terms*—local oscillator, varactor, Schottky diode, frequency multiplier, submillimeter wavelength.**

I. INTRODUCTION

The results presented here are for planar Schottky diode multipliers electronically tunable with about 10% bandwidth. Power amplifiers driven by commercial synthesizers produce 100 mW in the 86 to 107 GHz band [1,2]. Three or four frequency doublers and/or triplers are cascaded after the W band source. All multipliers are balanced designs implemented with monolithic circuits mounted in split-waveguide blocks. The frequency doublers each have two parallel branches of diodes, while the triplers each have two anti-parallel branches. The low frequency multipliers (below 1 THz) use “substrateless” technology implemented with 1 to $2 \cdot 10^{17}$ cm^{-3} doped GaAs, while the multipliers above 1 THz are fabricated on 3 µm thick GaAs membranes with $5 \cdot 10^{17}$ cm^{-3} doped active layers [3-6]. The first stage multipliers have 3 anodes in series in each branch (for 6 anodes total), and the second stages have 2 series anodes in each branch (for 4 anodes total). All multipliers above 700 GHz have only 1 anode per branch, or 2 anodes per multiplier. Multipliers with output frequencies above 1 THz have di-

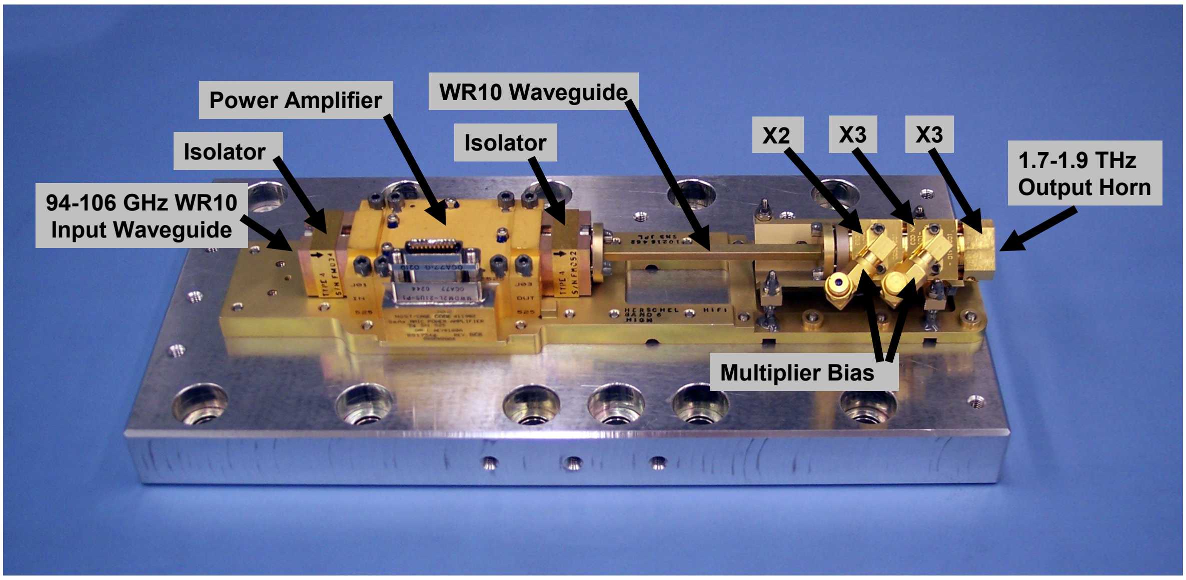

Figure 1. A 1.7 to 1.9 THz local oscillator chain. The signal flows from left to right, with the output at the 18th harmonic of the W band input. The first two frequency multipliers are biased through SMA connectors, and the last stage is unbiased. The maximum envelope of the chain including the gold-colored mounting plate and space for a Ka to W band tripler at the input is less than 250x60x40 mm^3.

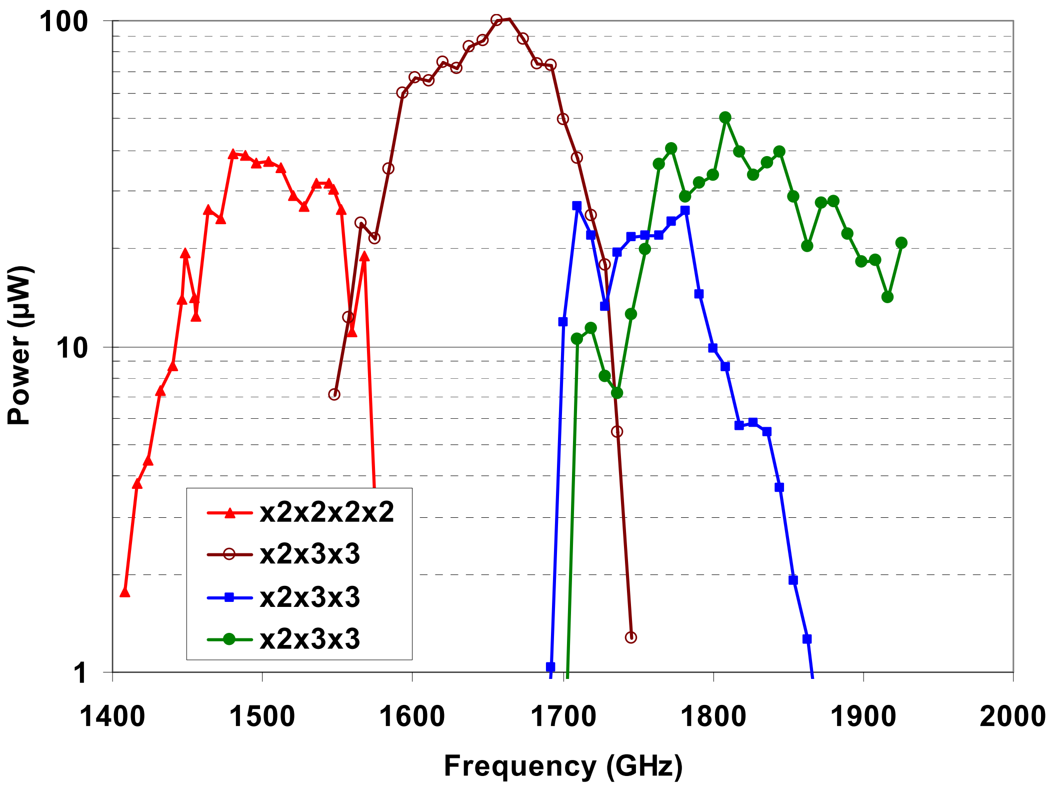

Figure 2. Output power of four local oscillator chains measured at 120 K. For comparison, reported measurements of the optimum LO power incident on the HEB mixer lens at these frequencies ranges from about 0.2 to 1.0 µW [15]. The chain inputs were around 1 mW in the 86-107 GHz range, and the power driving the multiplier chain after the W band power amplifier was 100 mW.

agonal horns integrated into the waveguide split blocks. Further information about the multipliers is given in [7]-[12]. A complete chain is shown in Figure 1.

II. MEASURED RESULTS

1. Output Power: Chain output power at room temperature was measured with a waveguide calorimeter [13] calibrated with a DC load. The measurements were not corrected for the loss of the connecting waveguides between the device under test and the meter. Chain output power at cryogenic temperatures was measured with a Golay cell calibrated against a Keating meter [14]. All optical measurements were corrected for the losses in the Mylar windows, but were not corrected for other optical losses including non-ideal mirror reflectivity and water vapor absorption. Figure 2 shows the output power measured at 120 K. Four sources cover the entire 1.45 to 1.92 THz band with 10 µW or higher output power, with a useable bandwidth of 150 to 200 GHz per chain. The peak measured power was 100 µW at 1.665 THz. Figure 3 gives an indication of the capability of these sources at room temperature. Although the output power is reduced by roughly a factor of five relative to the cryogenic measurements, the peak output power of 20 µW with broad bandwidth over 4 µW shows that these sources are well suited as local oscillators for HEB mixers even at room temperature.

2. Output Beam: Figure 4 shows the measured beam pattern from the diagonal horn of a x2x3x3 chain at 1.818 THz. The source was rotated about the calculated center of the radius of curvature of the beam with the detector held stationary. The power passed through a small iris approximately 700 mm away from the horn before being measured with a bolometer. The beam is well described by a Gaussian beam with 380 µm beam waist, plus side lobes in the diagonal plane caused by the cross-polar component that is expected for all diagonal horns [16].

3. General purpose lab sources: For the maximum possible output power, the DC biases for the local oscillator chains are adjusted as a function of frequency. Biasing two amplifier gates, two amplifier drains, and up to four multipliers as a function of frequency is further complicated by safety issues, since incorrect bias settings can easily damage the Schottky diodes. For routine laboratory use, we have set up several terahertz sources with reduced bias requirements and simplified operation, with built-in protection to minimize the potential for operator error to damage the multipliers. To achieve this, we have constructed simple passive circuits to bias the multipliers with their own rectified current. A large resistor in series with each multiplier limits the maximum current, and a suitable low-leakage Zener diode in parallel limits the maximum reverse-bias voltage. A potentiometer for each multiplier allows the bias to be optimized over a limited range if needed, and analog current meters are used for diagnostics. Two to four such bias circuits (depending on the number of multipliers to be biased) are mounted in a single small project box. The chains are driven with commercial SMA to WR10 active sextuplers, to provide a total multiple of 96 (x6x2x2x2x2) or 108 (x6x2x3x3). Power amplifier gates are either grounded or set with voltage dividers on the amplifier drain bias line. Thus, the total equipment required to operate the terahertz source is the chain with passive bias box, two or three power supplies for the active sextupler and power amplifier, and a 10 mW 14-18 GHz SMA source. The output power of the chain may be smoothly varied either electronically by adjusting the drain voltage of the final power amplifier stage or by adjusting a mechanical WR10 waveguide attenuator between the power amplifier and first frequency doubler. The output is a Gaussian beam in the 1.4-1.9 THz range. These general-purpose chains were assembled from "seconds," i.e. hardware unsuitable for other purposes due to issues such as amplifiers with low output power and multipliers with low efficiency or mistuned frequency response. Furthermore, passive bias reduces the bandwidth, especially if the only tuning is changing the frequency of the 14-18 GHz source. Nonetheless, a x96 laboratory chain produced 11 µW at 1.46 THz with 50 GHz of bandwidth above 2 µW, and a x108 chain produced 10 µW at 1.62 THz with 30 GHz of bandwidth above 2 µW.

4. Gas cell and heterodyne mixing tests: Results such as those shown in Figures 2 and 3 were measured with incoherent power meters that provide little useful information regarding the frequency, spectral purity, and noise properties of the output signal. Therefore, additional tests were necessary to confirm the suitability of these sources for use as local oscillators in heterodyne receivers. Gas cell measurements of methanol with a 1.6 THz general-purpose laboratory source described above confirmed that at least 99.8% of the power was in the desired harmonic of the input signal, in this case the 108th harmonic [17]. Two of these x108 chains were used at SRON in the Netherlands to measure HEB mixer beams, with one chain acting as the local oscillator and the other acting as a source with a fixed frequency offset. Mixer beam scans with 80 dB signal-to-noise ratio confirmed the performance of these sources [18]. The ultimate test came from a x96 chain (x6x2x2x2x2) that was lent to the Harvard-Smithsonian Center for Astrophysics. This chain was used at the Receiver Lab Telescope (RLT) in northern Chile to detect the ^{12}CO J=13→12 transition at 1.497 THz in Orion KL [19]. Experience from these tests show that the chain output power is clean and low-noise as long as the source driving the chain is clean and the amplifier is operated in saturation with adequate bias.

III. CONCLUSION

Compact solid-state electronically tunable broadband sources have been demonstrated to provide complete coverage from 1.45 to 1.92 THz with 10 µW or higher output power. Each frequency multiplier chain has a useable bandwidth of approximately 150 to 200 GHz. The peak measured power was 100 µW continuous at 1.665 THz operating at 120 K. Spectral purity has been confirmed at the 99.8% level or better with gas cell measurements, and mixer tests confirm the suitability of these sources for use as local oscillators in highly sensitive heterodyne receivers. General-purpose multiplier chains have been demonstrated that trade off optimized performance in favor of simplified room temperature operation, requiring only two power supplies and a low power 14-18 GHz source for operation.

The results presented in this paper reflect the current state of the art, and do not yet reflect inherent limits in the capabilities of this technology. The power amplifiers used are typically operated with output power reduced by 3 to 6 dB from the maximum available power. Increasing total anode area and reducing doping may increase the power that can be safely handled by the driver-stage frequency multipliers to enable the full capability of the power amplifiers to be utilized without reducing multiplier lifetime. Power combining could also increase available drive power. Higher drive power would enable higher total multiples to reach higher frequencies. Multiplier designs are not yet fully optimized, leaving room for new designs with increased efficiency and bandwidth as well as simplified fabrication and assembly. New micromachining techniques will enable the manufacture of more complex waveguide circuits at higher frequencies than currently demonstrated. Operation at 77 K (liquid nitrogen)

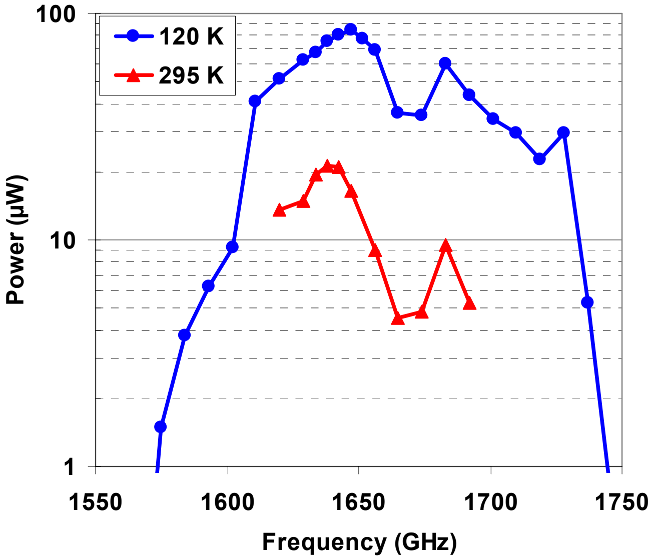

Figure 3. Room temperature and 120 K measurements of a single x18 chain. Although the increase in output power with cooling is dramatic, there is still sufficient power at room temperature to comfortably pump an HEB mixer over a wide band.

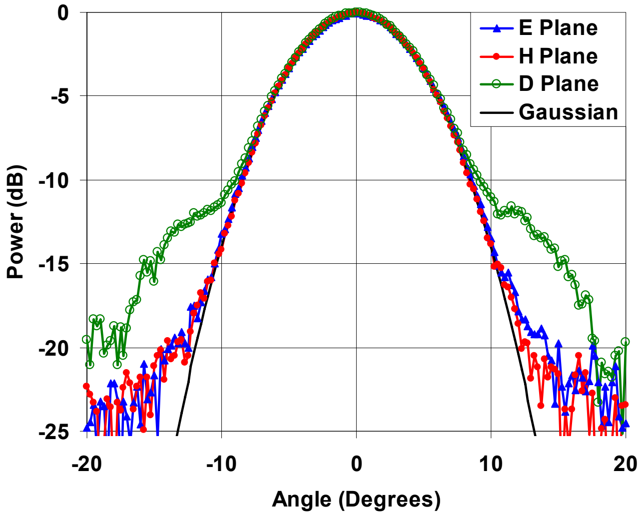

Figure 4. Measured beam pattern from the diagonal horn at 1.818 THz. The source was rotated about the calculated center of the radius of curvature of the beam while the power passing through an iris was measured with a bolometer.

instead of 120 K can further improve efficiency and increase output power. Continued advances in power amplifier technology may also drive the capability of frequency multiplied sources.

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