Development and Characterization of an Easy-to-Use THz Source

Jeffrey Hesler, David Porterfield, William Bishop, Thomas Crowe, Andrey Baryshev, Ronald Hesper and Jochem Baselmans

***Abstract*— A primary challenge in creating the next generation of submillimeter-wave receiver systems for space science is generating the required local oscillator power. Full waveguide band performance and power levels suitable for array receivers are desired. Also, the sources must be suitable for use at remote installations. This means they should be compact, reliable and electronically tunable. This papers presents the recent development and testing of a terahertz LO source that meets these requirements. This source uses GaAs Schottky barrier diodes to frequency multiply the power from a millimeter wave amplifier. The final element in the multiplier chain is a frequency tripler to the WR-0.65 waveguide band, spanning from 1.1 – 1.7 THz. This tripler generates of order ten microwatts of power when pumped with 3mW. The complete x72 active multiplier chain is about six-inches in length and requires only milliwatt power level input. It has been tested to demonstrate excellent spectral purity, frequency and power stability and low noise. The construction of the multiplier chain and the test results are reviewed.**

***Index Terms*—Terahertz sources, HEB mixers, frequency multipliers.**

I. The Active Multiplier Chain

Virginia Diodes has developed a series of broadband frequency multipliers based on integrated diode circuits. A tripler to the WR-0.65 waveguide band has recently been demonstrated. It requires only milliwatts of input power anywhere in the 367 – 567 GHz band to generate roughly ten microwatts in the 1.1 – 1.7 THz output band. A complete source based on an input signal from a standard low frequency (<25GHz) synthesizer and generating 5-20 microwatts across a 100 GHz electronic tuning band has been demonstrated. This active multiplier chain (X72) is shown in Figs. 1. It consists of an input doubler/amp with cooling fan (Spacek Labs [1]), an integrated (x2x2) frequency quadrupler and a cascade of two frequency triplers. The entire chain is only six-inches in length and it has no mechanical tuners. The terahertz signal is radiated by an integrated diagonal horn antenna.

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Fig. 1: A THz source consisting of a low frequency coaxial input, an integrated doubler/amplifier, a quadrupler and two triplers. It has generated up to 25 microwatts in the WR-0.65 waveguide band. Total length is six-inches. No mechanical tuners are used.

A primary aspect of the VDI frequency multipliers is the integrated diode circuit technology, depicted in Fig. 2. This image shows an integrated GaAs-on-quartz diode circuit/mounted into a waveguide housing. The quartz circuit incorporates two waveguide probes, frequency filters, impedance matching elements, other passive circuit elements and the GaAs diode mesas. The GaAs material is only several microns thick and is present only in the areas required to define the Schottky and ohmic contacts. The GaAs epitaxial material is bonded to the quartz at the wafer level. The critical diode regions are then defined photolithographically and all other GaAs material is removed. The integration process minimizes shunt capacitance, achieves alignment precision at the micron level and completely eliminates the need for handling, aligning and soldering microscopic diode chips. The circuit shown in Fig. 2 is actually a 220 GHz phase shifter [2] where the diode bias is used to modulate the diode capacitance, thereby achieving up to 180 degrees of phase shift.

The output power of the frequency quadrupler is shown in Fig. 3. This component is a cascade of two varactor doublers mounted into a single housing. The bias voltage on each doubler can be adjusted to achieve maximum tuning band. The total efficiency of the quadrupler peaks at about 10%.

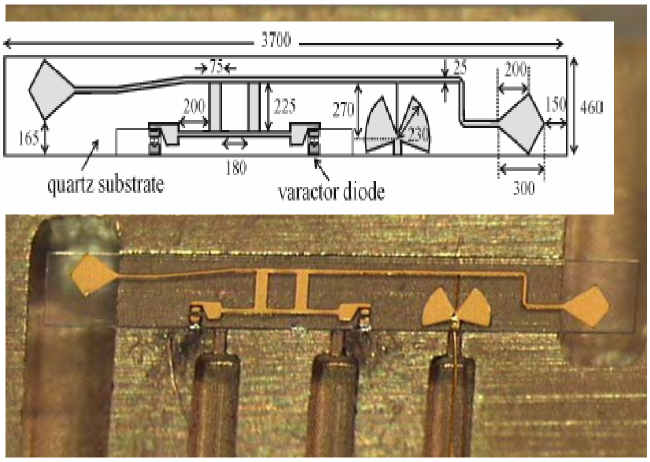

Fig. 2: An integrated GaAs-on-quartz diode circuit mounted in a waveguide housing. The diode bias is used to control the diode capacitance, thereby achieving control of the phase of the transmitted signal. 180 degrees of phase shift is achieved at 220 GHz [2].

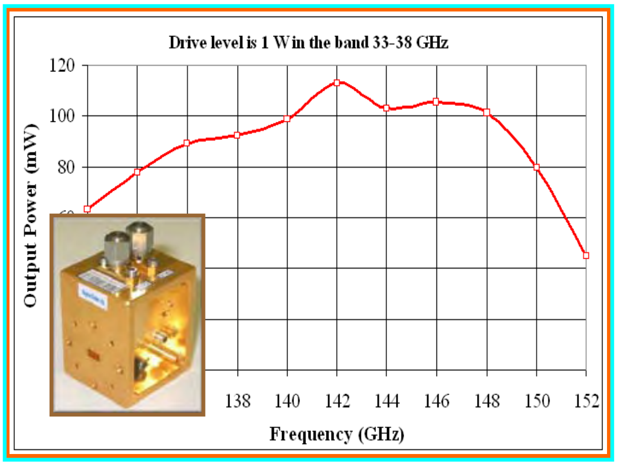

Fig. 3: The output power from the Q145 frequency quadrupler. The bias of the two doubler stages can be adjusted to achieve maximum bandwidth, as shown in the graph. However, similar performance is achieved with fixed voltage bias over most of the frequency range.

The output power of the first frequency tripler is shown in Fig. 4. This component operates across the entire WR-2.2 waveguide band. It has a typical efficiency of 3-5%, depending on the input power level and frequency. Significant ripple is seen in the graph, particularly at the lower edge of the band. This is unfortunately fairly common in cascaded multiplier chains and is generally caused by standing waves between the non-linear components. Good impedance matching can reduce this effect to negligible levels. However, this is often difficult to achieve across the entire waveguide band, particularly since the input impedance of each component will change with the input power level.

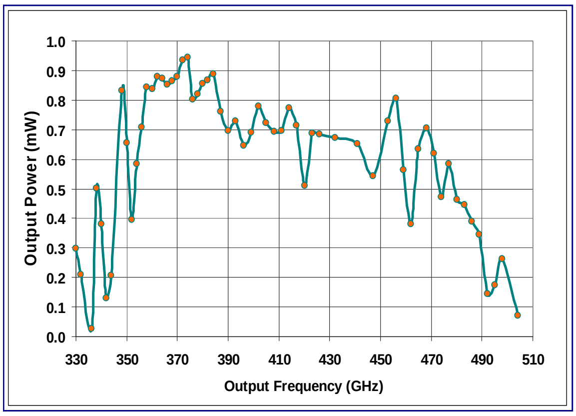

Fig. 4: The measured output power of the WR2.2x3 frequency tripler when driven with about 25mW. The ripple pattern is caused by standing wave effect, as described in the text. When driven with greater power levels, several milliwatts of output power are achieved.

The output power of the complete active multiplier chain is shown in Fig. 5. The input power to the final tripler is also shown. Two separate drivers, consisting of the input doubler/amp and quadrupler were used to achieve this data. The first generated about 2-3mW input to the tripler and produced an 8-12 microwatt output from 1250 – 1320 GHz. The second driver had lower power 0.5-2 mW, but greater bandwidth. It generated about 2-4 microwatts from 1350 – 1535 GHz. Other driver modules can be used to achieve coverage over the frequency band from 1.1 – 1.7 THz and we have achieved as much as 20 microwatts near 1.3 THz using a higher power driver. An important future goal is to achieve individual drivers that cover the entire frequency band with sufficient power.

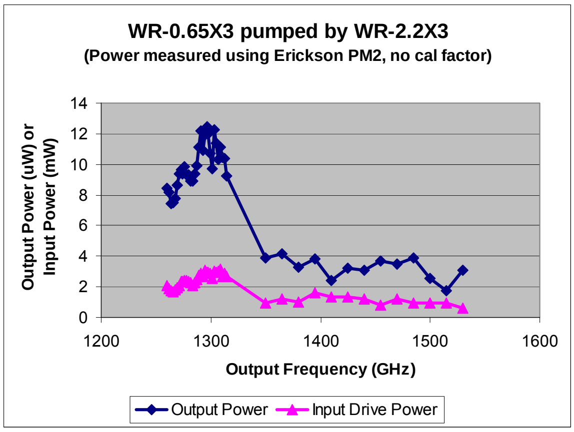

Fig. 5: The measured output power from the active multiplier chain. Two different driver modules, consisting of the input doubler/amp and the quadrupler, were required to achieve this data.

II. Terahertz Source Evaluation

One of the active multiplier chains was tested extensively at SRON with the goal of demonstrating its suitability for use as a local oscillator for HEB mixers in astronomical receivers [3,4]. Although the power level has already been shown to be sufficient by direct measurements, other requirements include narrow linewidth, lack of spurious signals, stability and low noise. In these measurements the active multiplier chain was driven with a standard Rohde & Schwarz synthesizer (SMP). The terahertz power was coupled to the bolometer with a mylar beam splitter and the LO coupling loss was about 13dB. The coupled power was adjusted with a rotating polarizer.

Spectral analysis by Fourier Transform Spectroscopy indicates that the output signal is very pure, with unwanted harmonics and other signals at least 20 dB below the main signal. Figure 6 shows a spectral measurement of ethanol gas (with a small amount of water). This result indicatess the narrow linewidth of the source and the lack of significant spurious signals.

The source was then used to pump an HEB mixer. Figure 7 shows the IV of the mixer at various LO pumping levels. This result shows that the source had sufficient power to fully saturate the mixer. Figure 8 is a graph of the receiver noise temperature (uncorrected) as a function of bias voltage and LO power. The measurements were made with standard hot/cold (300/78K) load techniques and a 1.5 GHz IF amplifier with 80 MHz bandwidth. Regions of excellent performance (Trec ~ 1,300K, DSB) were measured. This result is comparable to the best results achieved to date [5,6,7,8] and equivalent to those achieved with the same receiver and other LO sources including a molecular gas laser. This indicates that the solid-state LO is not adding any significant additional noise to the receiver.

Finally, the IF power was measured for a period of minutes with hot and cold sources. It is well known that the IF power is a sensitive function of the LO power coupled to the junction, so a stable IF power level indicates good amplitude stability of the source. Figure 9 shows the result of these measurements; which indicates that the source is indeed stabile enough for astronomical measurements.

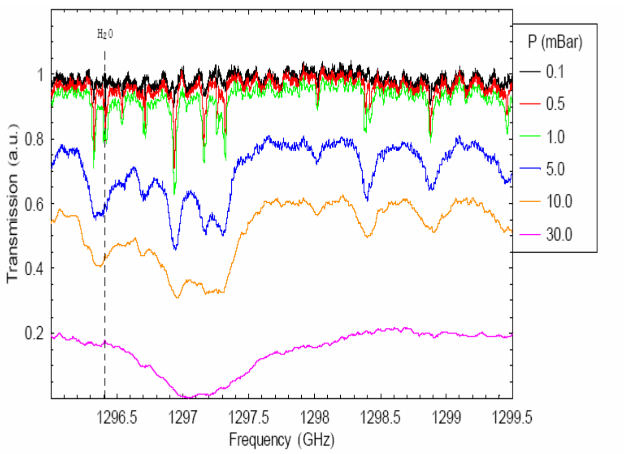

Fig. 6: A measurement of the absorption lines of ethanol and water at various pressures in a one meter long gas cell. These results indicate the narrow linewidth of the terahertz source and the lack of spurious signals.

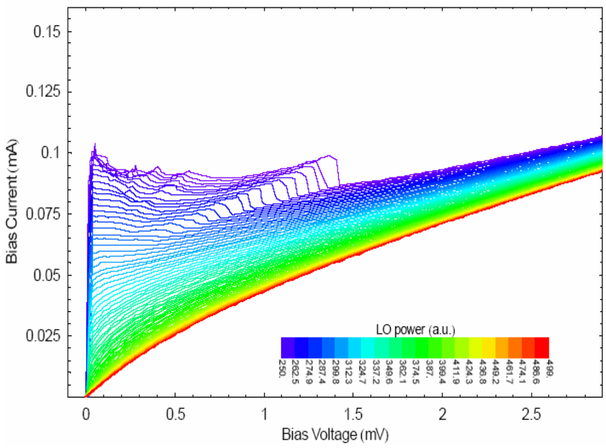

Fig. 7: The pumped IV curve of the HEB junction, showing that the source fully saturates the device.

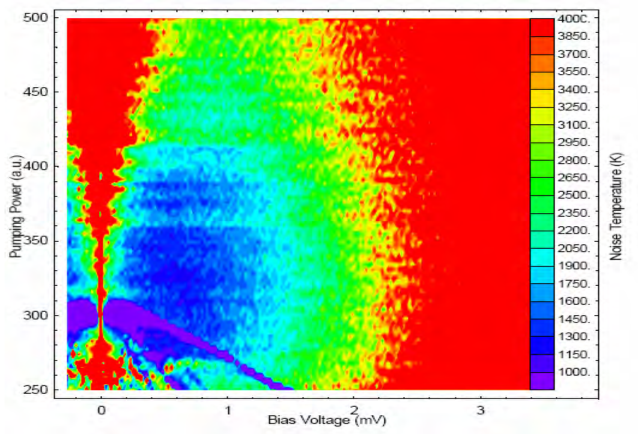

Fig. 8: The mixer noise temperature of the HEB as a function of Bias and LO Power at about 1.3 THz. The mixer is fully pumped and achieves excellent noise temperature. Best performance is achieved in the dark blue regions (1,300K); the narrow purple strip is a spurious response of the mixer.

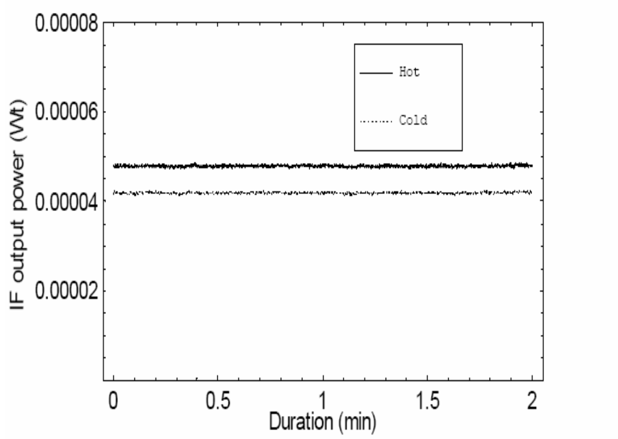

Fig. 9: The IF output power from the mixer as a function of time for hot and cold load conditions. Since the IF power is very sensitive to LO power level, this result indicates that the source has excellent amplitude stability, as is required for astronomical measurements.

III. Conclusion

This paper has reviewed the construction and evaluation of an active frequency multiplier chain for use as a terahertz local oscillator for HEB mixers in radioastronomical observations. The active multiplier uses a commercially available millimeter-wave amplifier and a chain of planar and integrated frequency multipliers to increase the frequency to the WR-0.65 waveguide band (1.1 – 1.7 THz). The chain has been designed to be driven by a standard commercial sweeper or synthesizer below 20 GHz with less than 100mW required to saturate the amplifier. The complete multiplier chain has a length of less than six inches and has no mechanical tuners of any type. The multiplier chain generates power levels in the 5-20 microwatt range and can be rapidly swept across a wide frequency band. The final two triplers in the chain achieve full waveguide band performance. However the driver amplifier and the integrated quadrupler have more limited bandwidth. Typically this limits the tuning band of the final source to of order 100 200 GHz, depending on the power level required and the specific frequency region desired. This drawback can be overcome either by developing better drivers, or reducing the power required by the triplers. Both paths will be pursued in future research.

The analysis of the source was performed at SRON. These measurements included analysis of the spectral purity and linewidth, demonstration that the source readily saturates an HEB mixer, the measurement of low noise mixer performance and evaluation of the amplitude stability via a measurement of the IF power over time. In all regards the source performed very well, indicating that it is well suited for use as an LO for HEB mixers.

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