Solid-State LO Sources for Greater than 2THz

T.W. Crowe, J.L. Hesler, S.A. Retzloff, C. Pouzou, G.S. Schoenthal Virginia Diodes Inc., Charlottesville, VA, USA

Abstract—Over the last several years, VDI has been developing THz sources based on microwave frequency amplifiers and a cascaded series of frequency multipliers. These are intended to be used as local oscillator sources for astronomical receivers, such as those on the SOFIA airborne observatory. In 2010 a 1.9 THz source with greater than ten microwatts output at room temperature was presented at this conference. VDI has now completed the initial development of similar sources for use at 2.5 and 2.7 THz. The measured output power is about 3 microwatts and is sufficient to fully pump an HEB mixer.

This effort required the development of improved millimeter-wave varactor multipliers with better thermal grounding for greater power handling, the optimization of the THz multipliers for operation at low power levels and the development of improved assembly and testing techniques. This paper discusses some of the challenges of achieving useful sources at such high frequency and reviews the results that have been achieved to date, with emphasis on the new 2.51THz source that has recently been used on the SOFIA aircraft for astronomical observations.

Index Terms—Terahertz sources, frequency multipliers, radio astronomy.

I. INTRODUCTION

THE needs of the radio astronomy community have long driven the development of terahertz technology. The relatively recent development of high quality HEB mixers for use in the frequency range above 1 THz is presently enabling the development of low noise, high spectroscopic resolution heterodyne receivers for investigations of the dynamics of molecular clouds, particularly in star forming regions. The primary benefit of these new mixers is their greatly reduced local oscillator (LO) power requirement. Even after the inclusion of significant losses in the LO coupling to the HEB element, a power level of only a few microwatts is considered sufficient in the 1-3THz frequency range. This low level enables the use of sources based on high-quality microwave oscillators followed by amplifier-multiplier chains (AMCs). These sources offer very high quality signals with broad frequency tuning. Developing a commercial source for these LO systems has been the primary goal of this project.

II. PREVIOUS DEVELOPMENT OF A 1.9THZ SOURCE

At the 2010 ISSTT meeting, VDI presented the results for a 1.9THz source that was developed for use on the German Receiver for Astronomy at Terahertz Frequencies (GREAT) [1,2]. A simple block diagram of this source is depicted in Fig.

1. The signal from the user supplied synthesizer is coupled into the AMC via a coaxial line. This signal is first frequency doubled and then amplified in a commercially available component [3]. A series of three VDI varactor doublers then increases the frequency. The varactor doublers are selected because of their high efficiency and power handling. The power from the final doubler is then coupled into the integrated x9 frequency multiplier. This final component consists of two frequency triplers that are integrated into a single housing. This integration eliminates a high frequency flange and reduces the intervening length of lossy waveguide between the triplers. A diagonal horn antenna is machined into the housing to couple the output power into free-space (~25dBi). The power generated by this source is shown in Fig. 2.



Fig. 1: A simple block diagram of the 1.9THz source.



Fig. 2: The measured power from the 1.9THz source, using several different builds of the final WR0.51x3 frequency tripler. The variation is due to both design changes and the quality of the assembly.

III. EXTENSION OF THE TECHNOLOGY TO >2THZ

A. The High-Power Driver Modules

For the 2.7 THz source, it was decided to maintain the same system design, while increasing the operating frequency of all of the components. Fortunately, excellent power amplifiers are readily available in the 34-40GHz frequency range [3], and VDI had previously developed varactor doubler designs for the required frequency bands. However, the power handling of these doublers was found to be insufficient. Specifically, the best previous power generated near 300GHz was of order 20-25mW, whereas a level approaching 50mW was used to pump the x9 multiplier to 1.9THz.

One method to significantly increase the power of the frequency multipliers is to employ in-phase power combining. Essentially, a waveguide splitter is used to share the available input power between two identical frequency multiplier circuits, and the output powers are then recombined in waveguide. Provided the two paths are identical, the output power will be combined in-phase, yielding a power increase of about 3dB. However, for this effort VDI decided to initially focus on improving the power handling of the varactor doubler designs through the improvement of the electrical and thermal circuits. Once the power is maximized in this manner, power combining can then be implemented in future research.

Typical performance of the varactor multiplier chains is depicted in Fig. 3. In order to ensure coverage of the full frequency range desired (~2.5-2.75THz), two driver chains were developed to pump the final broadband x9 multiplier. As is shown in the figure, the goal power level was achieved, although without much margin.



Fig. 3: The measured power from the two driver chains (xnAmpx2x2x2) that were developed for sources at ~2.5 and 2.7THz. The goal power level of ~50mW was achieved without waveguide power combining.

B. The THz x9 Multiplier

The VDI THz sources use an integrated x9 multiplier, as described above. However, during development a discrete tripler to the WR1.0 waveguide band was first developed and tested. The measured power from this tripler is depicted in Fig. 4. The results were quite good, with power levels of greater than 0.5mW across much of the frequency band. Further, it should be expected that the power coupled to the

final tripler may be significantly greater when the two units are integrated in close proximity within a single housing, since this will significantly reduce the waveguide and atmospheric losses.



Fig. 4: The measured power from the WR1.0x3 frequency tripler when driven by the power levels shown in Fig. 3.

The final x9 multiplier is shown in Fig. 5, on the right-hand side of the image. The integrated diode circuits for the final tripler were fabricated in the VDI cleanroom facility. The anode area was of order 0.5 square microns and the circuit thickness was less than 10 microns. However, the circuits were relatively easy to handle and once proper assembly procedures were developed, the component yield was acceptably high.



Fig. 5: The VDI x9 multipliers to the WR0.51 (left) and WR0.34 waveguide bands. Each component has an integrated diagonal horn antenna (~25dBi). In the case of the lower frequency x9, the horn protrudes from the housing.

The test results presented at the conference are shown in Fig. 6. These measurements were performed with a VDI-Erickson PM4 Power Meter at room temperature in an openair environment. The maximum power level was about 2uW, and the tuning band of each system was about 100GHz. Since these measurements were made without any special humidity control and with significant path length between the horn antenna and the absorbing element of the power meter, it is clear that the power generated is likely significantly greater than shown. In fact the general structure of the curves, including the deep trough at 2.65THz is largely explained by the expected atmospheric losses.



Fig. 6: The measured power from the VDI-WR0.34x9 components, as presented at the ISSTT in April 2011.

IV. LO SOURCE INTEGRATION AND TESTING FOR GREAT

The development of these sources was supported by the Max Planck Institute for Radioastronomy for use on the GREAT instrument. Two systems were delivered in April of 2011 for integration into GREAT. An image of the 2.67THz module is shown in Fig. 7. It should be noted that these sources use no tuners, neither mechanical nor electrical. Rather the frequency is set simply by adjusting the input signal from the synthesizer. Also, the only bias required is for the power amplifier and the three varactor doublers, and these values are all fixed. The frequency triplers do not require external bias.

Both sources were subsequently shown to have sufficient power to fully pump the HEB mixers developed by the University of Cologne [4].



Fig. 7: An image of the VDI 2.67THz AMC module that was integrated into the GREAT instrument for flights on SOFIA.

V. DIGEST UPDATE

The two VDI sources were flown on SOFIA in July of 2011, when the 16OH line was successfully detected [5]. After that flight, VDI had an opportunity to upgrade the 2.5THz source with the specific goal of re-tuning the system for measurement of the isotopic 18OH line at ~2.51THz. During this period VDI was also able to test the system over a greater operating band. The resulting data is shown in Fig. 8, which also

includes a graph showing relative atmospheric losses, which map very well the structure of the measured data. This upgraded source was successfully flown again on GREAT/SOFIA in November 2011, resulting in the successful detection of the 18OH line [5].



Fig. 8: The measured power of the improved 2.5THz source measured across a broader frequency band. A graph of atmospheric absorption is also shown, which correlates well with the structure of the measured power. This shows clearly the effect of the atmospheric losses on these measurements.

VI. CONCLUSION & DISCUSSION

This work has shown that all-solid-state sources can be developed for applications well above 2THz. The sources described here are based on high quality microwave oscillators and amplifier-multiplier chains. The resulting peak power is in the range of 3uW near 2.5THz, which is sufficient to fully pump HEB mixers. Further, this power is measured at room temperature in an open laboratory environment without any attempt to reduce atmospheric absorption. Significantly more power is available if the source is placed in an evacuated chamber and/or cryogenically cooled. Additional power will also be achieved when power combining is implemented in the high power varactor multipliers. This is particularly true since the THz multipliers are known to be under-pumped, and therefore their efficiency will increase with greater input power.

Most importantly these new sources are frequency agile and have excellent frequency stability, since they are referenced to the input synthesizer. In fact, the VDI source has shown some 200GHz tuning bandwidth with no adjustment other than the setting of the synthesizer frequency.

These results, as well as similar results reported by another group at the symposium [6], yield confidence that this technology can meet the immediate needs of the radio astronomy community, including the development of instruments for the important [OI] line at 4.7THz and array receivers in throughout 1-3 THz band.

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