Development of Multiplier Based Sources for up to 2 THz

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***Abstract* — Nonlinear diodes are used to extend the functionality of microwave electronics into the terahertz frequency band. Systems using this technology achieve useful transmitter power and receiver sensitivity throughout the frequency range from about 100 GHz through several terahertz. This talk reviews this nonlinear diode technology, with emphasis on the ongoing research and development that will enable this terahertz technology to transition from a tool for basic science into commercial systems suitable for broader applications. Emphasis is placed on terahertz sources. Three recent VDI sources are described.**

***Index Terms* — Terahertz sources, terahertz multipliers.**

I. Introduction

GaAs Schottky barrier diodes have been used as the nonlinear element in high frequency mixers and multipliers since at least the 1950's. Initially these were point contact diodes [1]; then lithographically defined anodes contacted by whiskers to minimize capacitance [2], and more recently planar diodes [3,4] and integrated diode circuits [5,6]. Most terahertz systems are based on frequency multipliers and / or mixers. However, direct detectors, sideband generators (upconvertors), phase shifters and other components have also been demonstrated. The excellent performance achieved with today's generation of terahertz components has been made possible by three areas of technological innovation.

1) The development of advanced fabrication technologies that have allowed the precise fabrication of terahertz diodes and integrated diode circuits.

2) The use of advanced computer aided design tools to simulate and optimize both the linear and nonlinear portions of the circuit.

3) The development of innovative circuit designs that take full advantage of the CAD tools and the advanced fabrication technologies, to achieve new levels of performance.

The advent of planar diodes has been particularly important because the removal of the whisker-contact eliminates the most difficult and least reproducible part of the component assembly. In addition, planar diode chips allow the integration of many diodes into the circuit, thereby allowing the realization of more advanced circuits and greater power handling than was possible with whiskered diodes. Integrated diode circuits have allowed the circuit designer to pursue more aggressive designs, knowing that they will be precisely manufactured. This, plus a great deal of design innovation, has led to the development of multipliers and mixers that operate over complete waveguide bands without any sort of tuning, thereby eliminating the need for mechanical tuners. This makes the components much more versatile, while also reducing manufacturing complexity and increasing repeatability and reliability.

The present generation of components has allowed the development of sources and receivers to well above 1 THz. In fact, it seems that any measurement in this frequency band can now be achieved, provided that the scientific goal justifies the expense of developing the required terahertz components. However, achieving a technology that is also suitable for the broader range of medical, industrial and commercial applications requires that the technology continue to evolve. Emphasis must now be placed not only on performance specifications such as power, bandwidth, sensitivity and resolution, but also on the more practical characteristics such as size, power usage, ease-of-use, versatility, reliability and cost.

Considering the future of this technology, the theory of the GaAs Schottky diodes is well understood and the fabrication technology is fairly advanced. Although continued evolution is expected in these areas, most of the recent progress has come through the development of more advanced component designs. However, the most compelling challenge that must be overcome in order to achieve the full potential of this technology is the full integration of complete sources and receivers. To date the CAD tools have been used primarily to optimize individual components, which are then cascaded together to achieve multiplier chains and heterodyne receivers. Very little effort has been placed on understanding the complex interactions between the individual nonlinear components. A better understanding of these interactions and greater levels of system integration will yield terahertz systems that are much better suited for the wide array of emerging applications of terahertz technology.

II. A 1.9 THZ SOURCE FOR RADIO ASTRONOMY

Radio astronomy has long been the primary motivating application for the development of terahertz technology. Presently the main challenge is achieving sufficient local oscillator power for heterodyne receivers throughout the frequency band. Above about 1 THz cryogenically cooled

HEB mixers are used. Fortunately these mixers require only of order 1μW of power to achieve full saturation. The system shown in Fig. 1 generates 1-3 μW at room temperature and can be tuned from about 1.8 – 1.9 THz. It is actually an amplifier / multiplier chain (AMC), meaning that it lacks the fundamental oscillator that sets the frequency and determines the linewidth and stability. Rather, the user inputs a signal via a coaxial connector. The VDI AMCs are typically optimized so that this signal is <20 GHz and < 18dBm, so that standard commercial signal generators can be used. To control the terahertz output frequency the user sets the input frequency; there are no other adjustments. The linewidth and stability of the terahertz output are degraded by the multiplication factor, n, (in this case 144) and the phase noise is degraded by 20log(n), as expected from simple theory.

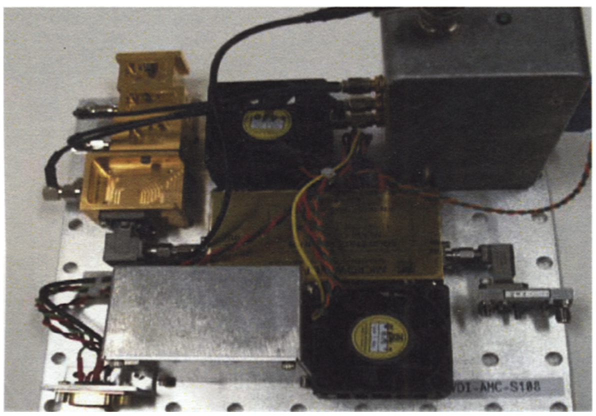

Fig. 1: A 1.8-1.9 THz amplifier/multiplier chain.

III. An 800 GHz TxRx System

A complete TxRx system operating in the 800 – 840 GHz frequency range is shown in Fig. 2. The Tx signal and the receiver LO are locked to the same 10 MHz crystal reference, thereby maintaining a very narrow and well defined IF frequency as the Tx frequency is swept. The synthesizer is digitally controlled by the user and its frequency can be set in 1 Hz steps. Considering the multiplication factor of 48, the output frequency can thereby be set in steps of 48 Hz. The Phase Noise at the output is measured as -75dBc/Hz at 10kHz offset. The transmitter power is ~5mW and the receiver noise figure is about 10dB. The system has a demonstrated dynamic range of 125dB, without using an IF amplifier.

IV. A 200 GHz TxRx with Phase Measurement

The use of a single crystal reference for the Tx and Lo signals allows the simultaneous measurement of both the amplitude and phase of the received signal. VDI has recently demonstrated this measurement with a 200 GHz, fixed frequency system. The system, similar to that shown in Fig. 2, yielded a dynamic range of 60dB (limited by the final IF detector) and a phase measurement precision of better than +/- 1 degree.

V. Conclusion

Nonlinear diode technology can be used to translate the functionality of microwave technology throughout the terahertz frequency band. This paper has focused on the development of terahertz sources and TxRx systems. The three systems described demonstrate useful power levels to nearly 2THz, a complete turn-key 820 GHz TxRx system with 40 GHz of electronic tuning band, exceptional dynamic range and frequency stability of a few 10's of Hz. The measurement of phase with a precision of about 1 degree has also been demonstrated.

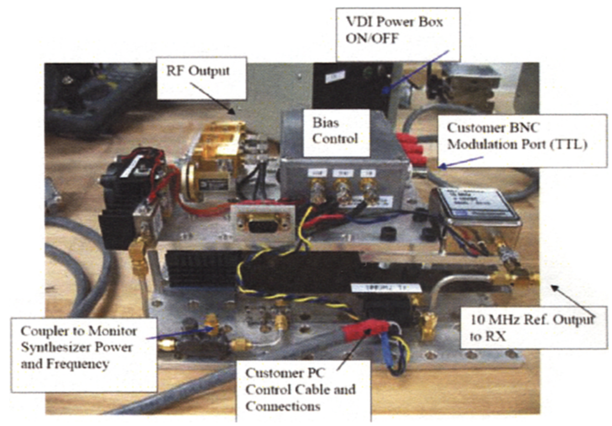

Fig. 2: An 800-840 GHz Phase –Locked TxRx System.

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