THz Technology for Space Communications

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***Abstract* — As space instruments become ubiquitous along with advancing capabilities, one of the central challenge is to provide more efficient communication links, between the control center and the instrument or between a cluster of satellites or instruments. Similarly, high-data rate communications between a mother ship and a lander is highly desirable not only for navigation but for science data as well. THz communications systems present a number of advantages in implementing efficient data-links between various scenarios for space applications. This review article will discuss some of the recent advances in solid-state coherent sources that has now made it possible to design and implement THz communication systems specifically for space applications. An example architecture at 240 GHz has been suggested as it is now possible to achieve >100 mW of output power at 240 GHz. With highly sensitive and linear heterodyne mixers, such a system could potentially provide higher data rate capability than in use today.**

Index Terms — THz technology, Schottky diodes, THz communications

I. Introduction

Future space missions can leverage existing RF technologies to create new subsystems for point-to-point communications. Recent terahertz (THz) technologies have largely been developed for wireless commercialization [1]. These include supporting a wide range of networking applications, from sensing to cellular transmissions [2]. In the case of space communications, THz-range components along the link can significantly impact the link budget, which then dictate the transmission coverage distance. Additionally, in low-earth orbit (LEO), the signal will have different levels of attenuation over specific bandwidth ranges due to water absorption [3]. Beyond LEO range, attenuation due to water absorption will taper off. Depending on the aerial range where communication [4] will occur, then, the system can be designed in terms of operational frequency and transmit power.

The THz source can be achieved by cascading a series of GaAs Schottky diodes, serving as frequency multipliers, to cover a broad spectrum of the desired operational frequencies. Using fabrication technology developed at JPL, microwatts of power can be achieved at THz frequencies [5]. InP HEMT frequency converters [6] and photo-mixers [7] have also been used as the source in previous link demonstrations. A similar backend utilizing the GaAs Schottky diode can recover the transmitted signal by serving as the local oscillator and detector [5]. Quantum cascade vertical-external cavity surface-emitting lasers (VECSELs) [8] have also been explored for possible use as a local oscillator.

In comparison, previous NASA missions have utilized free-space optics (FSO) for communications [9]. These operate at infrared wavelengths for uplink and downlink of pulse-position modulation (PPM)-encoded Mb/s-rate data. Detection is conducted through photon-counting, with the mode of detection requiring more stringent alignment than for the RF-channel.

From a system point of view, performance is maintained or optimized by reducing channel loss, while introducing gain through both the transmission and reception antennas [10]. In order to maintain signal quality throughout the link, the signal can be amplified with monolithic microwave integrated circuit (MMIC) amplifiers prior to recovery [11]. For space communication, designing the system must be done with the consideration of maintaining signal integrity at each step of the link.

II. THz Sources

One of the main reasons THz communication is a reality today is the recent development of compact, broadband coherent sources in the THz range [5]. There are a number of solid-state approaches for generating THz radiation including

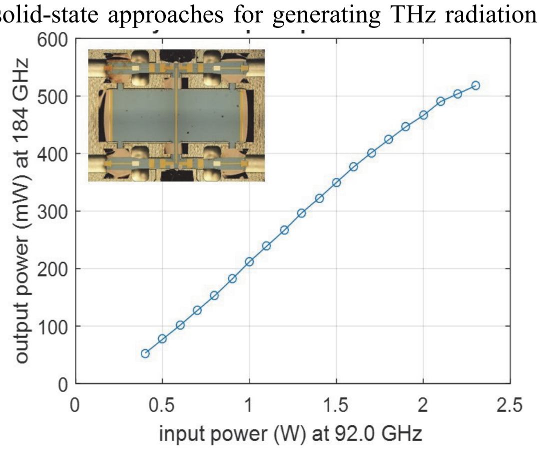

Figure 1: Novel chip topologies have now enabled relatively high power sources in THz range. This particular chip provides over 500 mW at 184 GHz.

photomixers [12], Resonant Tunneling Diodes (RTDs) [13] and Heterostructure Barrier Varactors (HBVs) [14]. However, for the THz range, Schottky diode based frequency multipliers have been the most popular due to compactness, relatively low dc power consumption, acceptable performance at room-temperature (with possibility of improvement upon cooling), high-fractional bandwidth (15-20% typical), frequency agility and tunability, temperature stability, and spectral purity. In recently developed competitive approaches such as Indium Phosphide based MMICs, output power levels of approximately 50 mW in the 200 GHz range[15], 7 mW in the 400 GHz range, 2-3 mW in the 600 GHz[16] range and ~1 mW at 850 GHz [17] have been demonstrated using power combining techniques. Beyond 1 THz, devices such as Quantum Cascade Lasers (QCL) are quickly progressing and offer attractive power levels but require cryogenic cooling. Moreover, due to poor beam quality, the useful output power is drastically reduced as reported in [18]. QCLs have other disadvantages such as the need for frequency locking, and limited bandwidth

Several factors over the last decade have now made it possible to provide considerable more power in the 200-2000 GHz range. Availability of high power amplifiers, both at W-band as well as Ka-band (GaN), along with more nuanced thermal design and power-combining, have enabled chips that can handle increased input power. Accurate device models, more precise control of waveguide dimensions during CNC machining, and better circuits have increased efficiency.

The inset in Fig. 1 shows how planar multiplier diode chips are packaged in waveguide blocks to achieve frequency multiplication. Fig. 1 shows the 200 GHz tripler that can handle more than 500 mW of input power and provide better than 100 mw of output power. Fig. 2 shows a summary plot of measured output power at room temperature from Schottky diode frequency multiplier chains.

While THz multiplier diode technology has made good progress in the last twenty years there are significant opportunities for improvement. Work on newer material

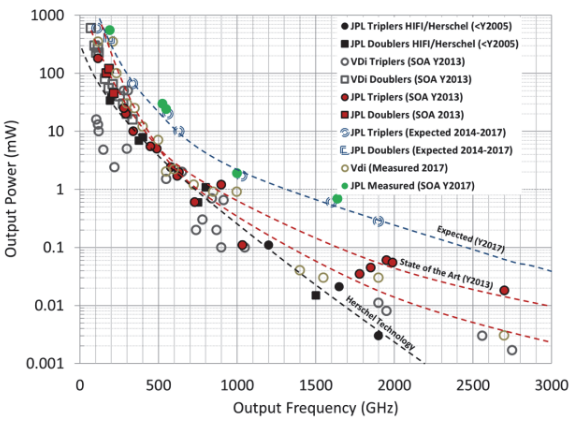

Figure 2: Solid-state sources can now provide sufficient power to design and implement THz communication systems.

systems such as GaN for the first stage multipliers is still desirable while packaging and fabrication of higher frequency diodes continues to be challenging.

III. THz Communication Systems

Free space optical communications has recently been highlighted by NASA for future interplanetary missions. However, electronically generated THz communications systems provide a number of distinct advantages. Compared to free-space optical systems, the much longer THz wavelengths leads to much larger beam widths, broadening the tolerance for beam accuracy between the transmitter and the receiver. THz-band communication also eliminates the larger power and weight requirements inherent in 1.064-micron laser-based systems. Atmospheric attenuation can be considerable at THz frequencies, particularly if water vapor concentration is high. Not only is this a nonissue at orbital altitudes, it can instead be considered an advantage from a security standpoint. The fact that orbital THz communications cannot penetrate the troposphere makes interception from the ground virtually impossible. Conversely, THz signals from Earth cannot reach space, effectively eliminating terrestrial spectral noise, interference/jamming signals, and other concerns. Finally, the terahertz band is not yet regulated. Hence, apart from applications in ultra-short-range laboratory scale testing, there are currently no active services (i.e., communications) on Earth at terahertz frequencies. In total, the possibility of actively interfering or passively eavesdropping from ground based systems is extremely low.

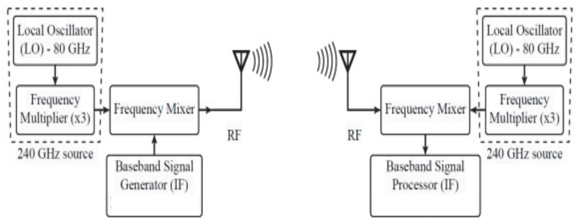

Figure 3: Advanced THz components are utilized for a broadband communication link at 240 GHz.

Several topologies can be used to build a THz communication system. A nominal scheme that relies on high quality submm-wave components is shown in Fig. 3 for operation around 240 GHz. This presents a robust architecture that can be scaled. A link budget analysis using this scheme has been carried out and the results are shown in Fig. 4. This suggests a useful range of hundreds of kilometers and transmission data rates of multi Giga-bits-per-second (three orders of magnitude larger than current satellite links based on microwave and millimeter-wave technology), when considering antenna gains/directivity in the order of 65 dB [19].

IV. Summary

Recent advances in solid-state multiplier and mixer technology have now made it possible to implement THz communication systems that provide a much higher data rates and reduced tolerance requirements for data transmission schemes, important components for enabling future space applications.

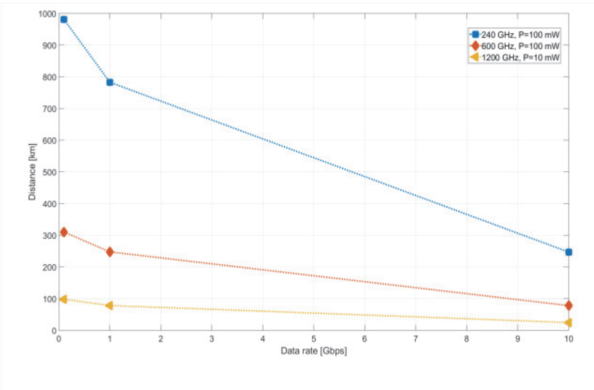

Figure 4: Communication links with high data rate are practical for some applications. The transmit power is shown in the legend for three different frequencies. Additionally this data is based on the following assumptions: Mixer conversion loss of 7dB, Receiver Noise Figure of 9 dB, and Transmit/receive antenna gain of 65dB. QPSK modulation and Bit Error Rate=10^{-6} are also used for this simulation.

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