A 220 GHz Communications Link Utilizing Frequency Multipliers

Ali M. Darwish1, Joe Qiu2, Edward Viveiros1, and H. Alfred Hung1

1Army Research Laboratory,
2800 Powder Mill Rd., Adelphi, MD 20783
2Army Research Office,
4300 S Miami Blvd, Durham, NC 27703

Abstract: A solid-state 220-GHz communication link is presented. It utilizes a novel, complex modulation technique to achieve efficient power transmission with the highly-nonlinear frequency multipliers. The transmitter operates with coherent power combining of two frequency multiplier chains to achieve precise, linear amplitude and phase modulation, despite the strong multiplier nonlinearity. Several modulation schemes (OOK, BPSK, and QPSK) are demonstrated at the saturated output of 20 dBm. This transmitter scheme offers an alternative to the conventional mixer up-converter approach which when operated in linear mode results in lower efficiency.

Keywords: THz communications, complex digital modulation, sub-mm-wave communications.

Introduction
The interests in millimeter-wave (mmW) and THz semiconductor technologies are witnessing very rapid development [1]–[3]. In addition, interest has been growing in using high-mmW and THz frequencies for communications [4] – [7] and imaging [8]. Power combining has been utilized to obtain significant output power [9]-[10]. Operating frequencies in the 0.2 – 1 THz range often exceed the cutoff (f_t) and the maximum frequency of oscillation (f_max) of most semiconductor devices. As such, the availability of many active components (such as low-noise amplifiers, power amplifiers, and active mixers) is limited, and one is left with passive components. As a result, the attainable solid-state output power available at this frequency range is limited. Many transmitters have relied on the use of frequency multipliers and/or passive mixers to generate and modulate signals. Most of these blocks are either intrinsically nonlinear (e.g. frequency multipliers) or are operated nonlinearly (e.g. saturated amplifiers) to obtain the highest power. Thus, most of the communication links demonstrated in this frequency regime, so far, have relied on simple modulations such as on-off keying (OOK), or low order phase modulations such as binary phase shift keying (BPSK), quadrature phase shift keying (QPSK). However, the spectral efficiency of such modulation schemes is already limited, compared to the even higher order modulations (such as 32QAM) that have varying-amplitudes.

Supporting communications links with varying-amplitude modulations at the high frequency regime introduces several problems. First, power generation and amplification are difficult. Second, there are strong nonlinearities present, in most cases, caused by the use of multipliers and the desire to obtain maximum power from amplifiers and mixers. Third, setting up a frequency plan to eliminate unwanted signals (such as image rejection) requires low-loss high-order filters that are difficult to realize. Thus, many of the demonstrations are done with double-side band signals.

This paper presents an alternative. By combining two multiplier changes coherently, and modulating their phase, one can produce a modulated LO signal without the use of a mixer.

Direct Quadrature Transmitter
The paper introduces the concept of direct quadrature transmitter (DQ-transmitter). It relies on combining two frequency multipliers coherently. By modulating their phases, one can produce a modulated LO signal without the use of a mixer. Fig. 1 shows a schematic of the architecture.

Starting with a pure tone at 10 GHz, say, the power is equally split into two paths. Each path contains a phase shifter followed by a frequency multiplier. Here, for illustration, it is assumed that the multiplier has a 24x multiplication factor, and 10 dB conversion loss. After that, the power is combined coherently and transmitted. The process may be represented mathematically as the vector addition of two vectors, a, and b, as shown in Fig. 2.
Figure 2. Example of construction of an arbitrary vector C ($= |C|\angle \phi c$) using two equal amplitude vectors a ($= |a|\angle \phi a$), and b ($= |b|\angle \phi b$).

Experimental Results of DQ-Transmitter
A picture of the DQ-transmitter experimental setup is shown in Fig. 3. A frequency synthesizer source is used to supply a 12.22 GHz continuous wave (CW) tone which is power divided into two equal signals. After that, a 12.22 GHz analog phase shifter is used to set the phase of each signal. The 12.22 GHz signal is then frequency multiplied by $\times 2$, and $\times 3$ passive Virginia Diode Inc. (VDI) parts. The 73.33 GHz ($= 12.22 \text{ GHz} \times 6$) signal is fed to a Northrop Grumman Aerospace Systems (NGAS) tripler/amplifier which generates a 220 GHz amplified signal. The amplifier has a saturated output power of 60 mW. The two branches are then combined using a hybrid coupler to generate around 100 mW. The signal is radiated using a horn antenna with 20 dBi of gain. The receiver is composed of a horn antenna, with 20 dBi of gain, feeding a VDI subharmonic mixer with a local oscillator (LO) with frequency equal to 108 GHz. The IF frequency, around 4 GHz, is fed to a low noise amplifier (LNA), and received using a standard receiver. The LO is generated by tripling a 36 GHz using a VDI multiplier.

Two key tests are conducted to verify the ability to modulate the amplitude, and the phase of the transmitted signal.

First, amplitude modulation can be verified by modulating the phase of one of the channels. Suppose, one of the channels is modulated with a square wave that changes the phase between 0° and 180°. Then, the amplitude of the signal should go from maximum (constructive interference, for 0° case) to minimum (destructive interference, for 180° case). That is what is observed. Fig. 3 shows the result of this test. The ratio of power during ON/OFF periods is over 100 which indicates effective addition/cancellation of the vectors.

Second, phase modulation can be verified by modulating the phase of both channels between 0° and 180°. The result should be a binary phase shift keying (BPSK) signal at the output. Fig. 4 shows the result of this operation. One can clearly see in the IQ constellation, the two discrete states. This case shows the phase modulation capability of the system. Excellent signal quality was observed. The Figure also shows the receiver spectrum.

Acknowledgement
The authors would like to thank Dr. Dev Palmer, and Mr. Bruce Wallace of DARPA, for the mmW components received from their Programs, and used in the experiment.

References


8. UR Pfeiffer, Y Zhao, J Grzyb, R Al Hadi, “A 0.53THz reconfigurable source array with up to 1mW radiated power for terahertz imaging applications in 0.13μm SiGe BiCMOS,” 2014 IEEE International Solid-State Circuits Conference Digest of Technical Papers (ISSCC), pp. 256 – 257, San Francisco, CA, 2014.
