Improved 'THz Torch' Technology for Short-range Wireless Data Transfer

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***Abstract* — This paper reports recent developments in the '*THz Torch*' technology, for short-range wireless data transfer. The ultra-low cost '*THz Torch*' concept was recently introduced as an ultra-secure non-contacting technology in the physical layer. Previous results reported a 10 bits/s link over a single channel, across a distance of 1 cm. In this paper, some fundamental limitations of this technology are analyzed and potential methods are proposed to further increase the data rate and working distance of the communications link. The improved single-channel system demonstrates a bit rate of 380 bits/s over a 1 cm range, which presents a factor of 38 improvement.**

***Index Terms* — THz Torch, low cost, terahertz, wireless link, short-range, contactless.**

I. Introduction

The terahertz (THz) frequency spectrum is receiving increasing interest from within both the scientific community and engineering community. With the latter, there is real motivation for finding ubiquitous applications to commercially exploit the 'THz gap'. To do this, improvements in our analytical [1-2] and numerical CAD [3] modelling techniques must be found, as well as in designing metal-pipe substrate integrated waveguides (SIWs) [4-6], antennas [7], terahertz multi-chip modules (T-MCMs) [8] and demonstrating new applications [9, 10].

The '*THz Torch*' technology was very recently introduced by the authors as an ultra-low cost alternative for short-range (i.e. contactless) wireless data transfer. The simplest form of the '*THz Torch*' system is to implement basic ON-OFF keying digital modulation, having an architecture shown in Fig. 1. The first ever working proof-of-concept provided a maximum data rate of 5 bits/s over a 0.5 cm range [9]. This technology can be easily extended by utilizing multiplexing schemes, e.g. frequency division multiplexing (FDM) and frequency-hopping spread spectrum (FHSS). A 4-channel FDM wireless communications system was later presented for the first time, demonstrating a 40 bit/s data rate over a 1.0 cm range [10].

In this paper, we analyze some fundamental limitations of this technology to further improve the maximum bit rate and transmission range. Some possible improvements are proposed and verified experimentally.

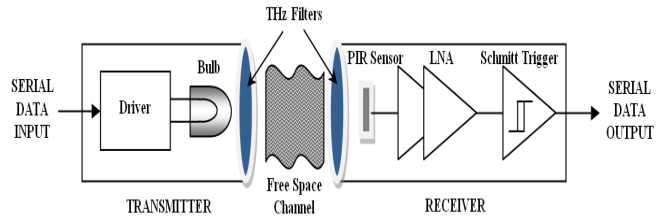

Fig. 1. Basic architecture for ultra-low cost ON-OFF keying '*THz torch*' wireless links [9].

II. Basic THz Torch Technology

Various approaches, based on either electronic or photonic technique, have been used to generate terahertz radiation. For ultra-low cost applications, blackbody radiation is considered to be the best option, due to its affordability, availability and tuneability. Here, we simply use miniature light bulbs (e.g. Eiko 8666-40984) to generate incoherent electromagnetic energy by thermal emission. Although miniature bulbs are not perfect blackbody radiators, because of the low emissivity of tungsten filament, high absorption of the glass envelope, and spatial radiation losses, etc., one can still obtain reasonable transmission rates for applications that include security key fobs and RFID.

Two types of sensors are normally used for the detection of blackbody radiation, based on either photon detection or thermal effects. The former includes photoconductive and photovoltaic sensors, which have high sensitivity and fast response time, but are normally expensive and may need additional cooling. The latter include thermopile, bolometer and pyroelectric (PIR) sensors, which are cheaper and can work at room temperature. The pyroelectric sensor has been selected here, due to its low cost (e.g. less than one-tenth of that for a thermopile), simple structure and wide spectral response. The PIR sensor used in our earliest experiment is the Murata IRA-E710ST1 [9, 11].

Two identical bandpass filters are employed in both transmitter and receiver front ends, using commercially-available 5 to 14 μm long wave pass silicon optical filters [9, 11]. In the frequency range from 25 to 50 THz, the transmittance is >70%.

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The back-end processing of the receiver consists of a high gain low-noise amplifier (LNA), employed for signal amplification (and DC blocking), and Schmitt trigger for analogue-to-digital conversion.

III. Fundamental Limitations of THz Torch Technology

To further improve the maximum bit rate, as well as the transmission range, the fundamental limitations of *'THz Torch'* technology have to be investigated.

A. Thermal Time Constant of the Filament

If the incandescent light bulb is modulated direct by electrical signals [9], the first limitation is the heating (cooling) thermal time constant of the filament, which is defined as the time taken to go from 10% to 90% of the temperature difference between initial and final steady-state temperatures. For a quiescent bias current of 44 mA, which gives the peak radiance at 80 THz, the measured heating and cooling thermal time constant are 590 ms and 2,415 ms, respectively. Since the PIR sensor can only detect the change of temperature (ΔT) of the source, the increased bit rate will result in a smaller ΔT. The effect of bit rate on ΔT is as shown in Fig. 2. As bit rate increases then •T decreases and so it becomes more difficult to detect the signal.

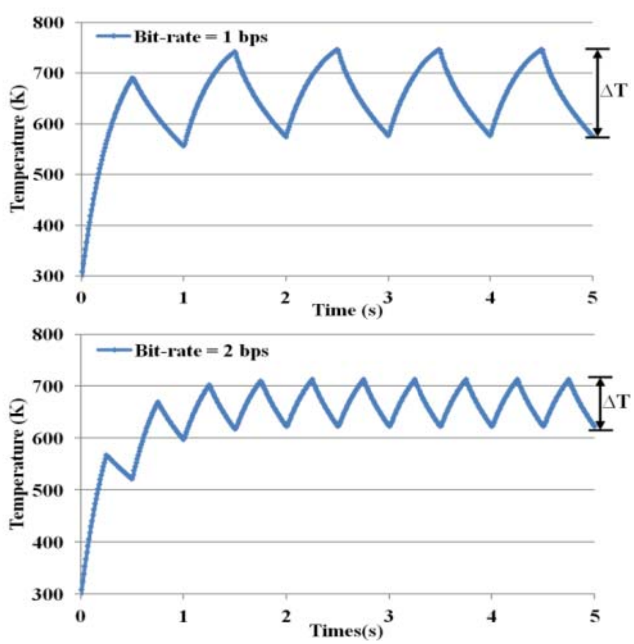

Fig. 2. The effect of bit rate on ΔT

One solution is to employ a non-direct method of modulation (i.e. external modulator), so that the electromagnetic energy is pulsed from a continuously illuminated bulb. For proof-of-concept purposes only, one can simple employ an optical chopper [10]. The transmitter and receiver were positioned 1.0 cm apart, to create a short line-of-sight communications link.

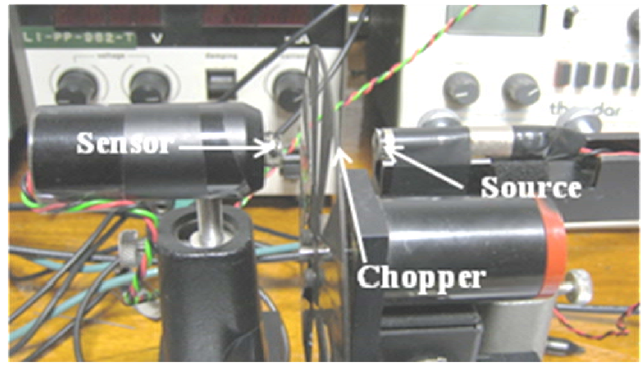

Fig. 3. Experimental setup using a mechanical chopper

Three values of quiescent biasing current of 44, 50 and 60 mA were considered, giving peak radiances at 80, 93 and 108 THz, respectively. As shown in Fig. 4, the maximum bit rate for the same biasing current (I = 44 mA) is measured to be 50 bits/s, which represents a ten-fold increase in bit rate and over twice the distance, when compared to the result without using a chopper over the same 25 to 50 THz spectral bandwidth [9].

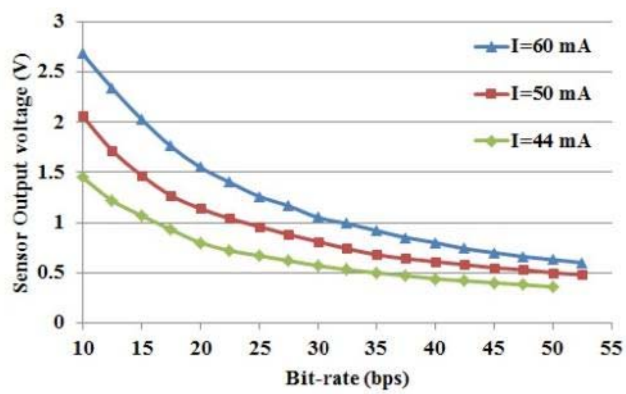

Fig. 4. Experimental results for different biasing current with an optical chopper

B. Frequency Dependency of Responsivity for PIR Sensors

The Murata IRA-E710ST1 is designed for low frequency applications, normally between 1 to 10 Hz. Its frequency dependency for responsivity, as shown in Fig. 5, decreases dramatically as the chopping frequency increases [11]. To further improve the data rate, it is necessary to employ a faster PIR sensor that has better responsively roll-off characteristics.

LME-553 from InfraTec has a responsivity that remains almost constant between 10 and 300 Hz, as shown in Fig. 6 [12]. As a result, it is more suitable for higher bit rate applications. Furthermore, since the LME-553 is a current type sensor, its responsivity is more than a few orders magnitude higher than those of a voltage type PIR sensor (e.g. IRA-E710ST1) [13].

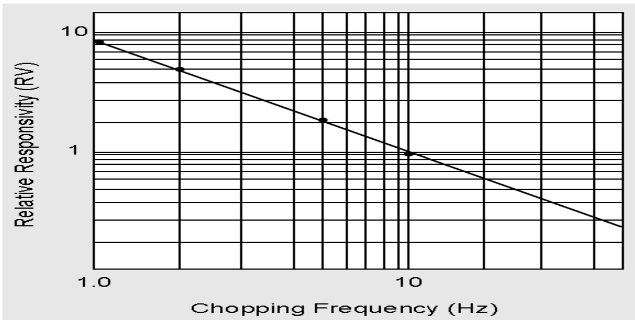

Fig. 5. Frequency dependence for responsivity of Murata IRA-E710ST1

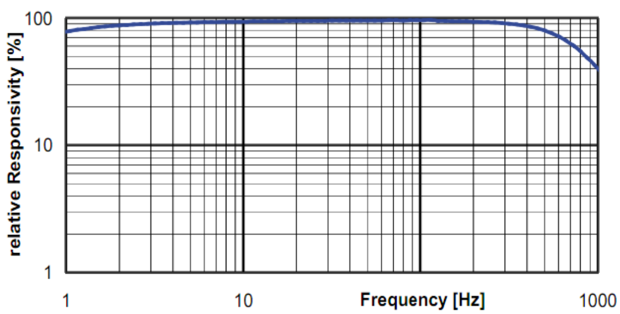

Fig. 6. Frequency dependence of responsivity of LME-553

Experiments using the LME-553 were carried out with the same quiescent biasing current, i.e. 44 mA, for the incandescent light bulbs. The distance between the source and the sensor was also kept at 1.0 cm. The preliminary result demonstrates a maximum bit rate of 380 bits/s, as shown in Fig. 7.

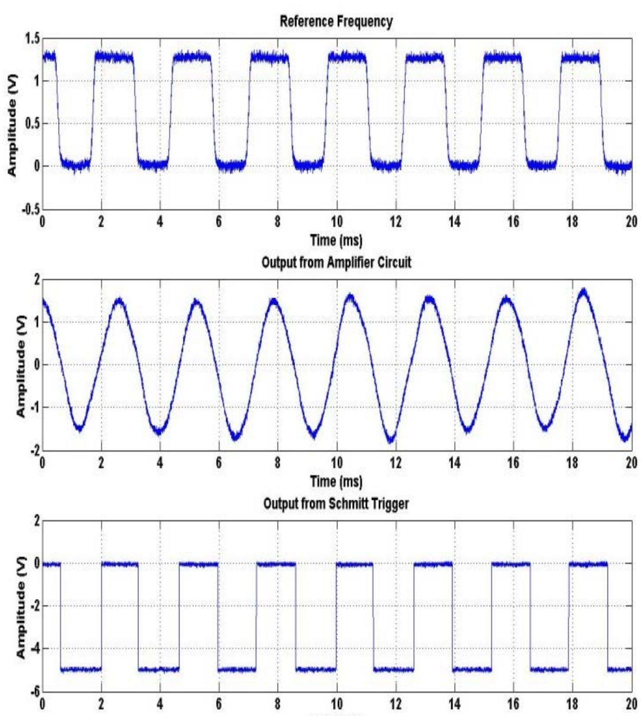

Fig. 7. Measured signals using the LME-553 detector for 380 bits/s operation

C. Absorption of Bulb Glass Envelopes

Incandescent light bulbs have a hermetically-sealed envelope, to prevent the hot tungsten filament from oxidizing in air. The material used as for these envelopes (e.g. fused silica or soda-lime glass) normally has a good transmittance in the optical and near infrared spectral ranges. However, since the *'THz Torch'* operates from *ca.* 10 to 100 THz, the absorption of the glass envelope cannot be neglected. If the envelope is replaced by materials that are more transparent in this spectral range (e.g. potassium bromide), higher output power levels, faster data rates and longer distances can be expected.

D. Free Space Attenuation of THz Waves

The *'THz Torch'* concept has been demonstrated to work over short ranges. The range can go up to 2.0 cm at the expense of a lower data rate (e.g. 15 bit/s). This is due to high free space attenuation in air and beam spreading. As shown in Fig. 8 [14], transmittance is observed from 21 THz (14 µm) to 40 THz (7.6 µm), with high attenuation outside this frequency band. Experiments in a vacuum, argon or nitrogen environments could be carried out to further investigate the effect of free space attenuation on the transmission range. Since distances are of the order of a centimeter, the dominant losses are found with beam spreading and so collimating lenses (not used thus far) can be introduced to significantly improve the range of operation.

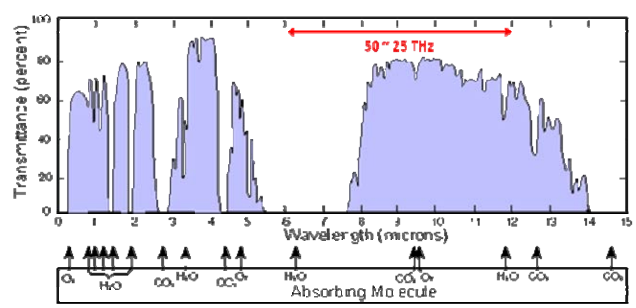

Fig. 8. Atmospheric transmittance from UV to far infrared [14]

IV. Conclusion

This paper has reported recent developments in the *'THz Torch'* technology for short-range wireless communications. After introducing some of the key fundamental limitations, possible methods are proposed for improving the maximum bit rate and transmission range. Some approaches have been verified experimentally, showing a maximum data rate of 380 bits/s (a factor of 38 improvement over previously reported results for the same distance). It is believed that with other technical enhancements, currently being investigated with both transmitter and receiver designs,

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higher data rates (e.g. several kbits/s) can be expected without adopting the use of expensive components.

While still in its infancy, the *'THz Torch'* technology will serve as inspiration for further R&D into similar systems, while potentially opening up this part of the electromagnetic spectrum to more ubiquitous commercial applications, such as ultra-low cost security systems and absorption spectrometers.

ACKNOWLEDGEMENT

This work was supported by the UK's Engineering and Physical Sciences Research Council (EPSRC) under Platform Grant EP/E063500/1 and China Scholarship Council (CSC).

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