Ultra-low Cost Ubiquitous THz Security Systems

Fangjing Hu [#1], Stepan Lucyszyn [*2]

EEE Department, Imperial College London,
London, United Kingdom
[1] f.hu10@imperial.ac.uk
[2] s.lucyszyn@imperial.ac.uk

***Abstract* — This paper introduces an ultra-low cost THz system for ubiquitous security applications operating in the far/mid-infrared parts of the electromagnetic spectrum. By extending the recently reported "THz torch" concept, this technology can be used to implement frequency division multiplexing (FDM) and frequency-hopping spread spectrum techniques for secure RFID tag and smart key fob applications. Results from a "THz torch" FDM wireless link are presented for the first time. Here, an ultra-low cost 4-channel FDM system has been demonstrated with an end-to-end bit rate of more than 40 bps. This represents an eight-fold increase in bit rate, and over twice the distance, when compared to previously reported results.**

***Index Terms* — Low cost, RFID tag, security, smart key fob, THz, wireless link.**

I. Introduction and Background

Terahertz systems are notoriously very expensive, from complete systems down to individual active devices and passive components. For this reason, there are very few ubiquitous commercial applications in the far-infrared (300 GHz to 30 THz) and mid-infrared (30 THz to 120 THz) parts of the electromagnetic spectrum; notable exceptions to this are relatively basic ultra-low cost human body detection systems (for applications ranging from security to energy-saving lighting systems) and fire detection systems.

An example of an ultra-low cost wireless communications system can be found in ubiquitous near-infrared remote controls, which operate at a wavelength of 940 nm (i.e. 319 THz). This technology has been around since the early 1980s. However, to date, there has been little reported R&D into similar systems at longer wavelengths.

One very recent example was the first ever working proof-of-concept ultra-low cost THz short-range wireless link; demonstrating a maximum data rate of 5 bps over a 0.5 cm range [1]. Simple ON-OFF keying digital modulation was reported, operating between 25 and 50 THz, using the "THz torch" system architecture shown in Fig. 1. While only a low data rate was experimentally demonstrated, this does not represent a fundamental limitation, as a number of technological enhancements are possible [1].

The "THz torch" concept has the benefits of: (1) being very easy to manufacture in large volumes; (2) inherently ultra-low cost; (3) providing tuneable spectral peaks; (4) having an array of alternative enabling technology solutions; and (5) because it operates in a virtually unused part of the electromagnetic spectrum, offers covert operation for security applications. Indeed, with such large amounts of freely available spectrum and high atmospheric attenuation, there is an extremely low probability of intercept and code grabbing, making this technology ideal for security applications. As a result, the "THz torch" concept is expected to have its niche in security applications that do not require high data rates but must be ultra-low cost for ubiquitous applications (e.g. secure RFID tags and smart key fobs).

To this end, this paper reports on recent work that extends the basic "THz torch" concept for implementing an ultra-low cost THz short-range wireless link that utilizes frequency-division multiplexing (FDM).

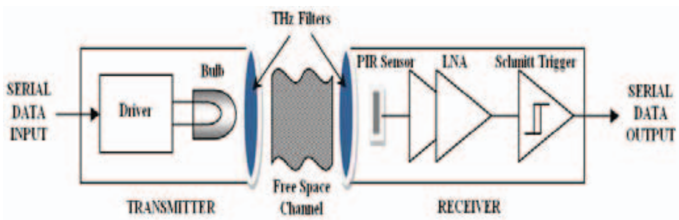

Fig. 1. Basic architecture for ultra-low cost ON-OFF keying "THz torch" wireless links (optional parabolic reflectors/collimator lenses are not shown) [1].

II. Basic "THz Torch" Technology

Each individual FDM channel is similar to the one illustrated in Fig. 1. Details of the individual components that make up the "THz torch" source & sensor pair transmission channel have been previously described in detail [1].

Each bulb is biased to have its peak spectral radiance at approximately 80 THz. Therefore, the four different channel filters have been selected to have non-overlapping pass bands in the spectral range below 90 THz with >70% transmittance.

The measured effective bit rate against distance for a 5-bulb transmitter and single pyroelectric infrared (PIR) sensor receiver, both housed within 1 cm diameter packages, has been previously shown to give an overall end-to-end bit rate of 5 bps over a 0.5 cm range. This is primarily limited by the turn-ON and turn-OFF thermal time constants for the incandescent bulb, and to some extent the detectivity, sensitivity and relative responsivity of the PIR sensor technology used. Therefore, while the measured performance, to date, has been rather limited, in terms of data rate and range, a number of recommendations were given in [1]. One of these was the use of a mechanical modulator. Therefore, for this prototype proof-of-concept demonstrator, a conventional optical chopper was employed.

III. "THz Torch" Multiplexing Schemes

In communications systems, multiplexing schemes offer important benefits; including increased overall end-to-end data rates (when individual channels are band-limited), increased robustness to interference (both natural and manmade) and enhanced protection from interception.

To increase data rates beyond those of individual source & sensor pair transmission channels and make the overall wireless link more robust to interference, frequency division multiplexing is one solution.

A simple "THz torch" FDM system can be implemented by assigning non-overlapping spectral ranges to different source & sensor pair transmission channels, as illustrated in Fig. 2. Energy is simultaneously transmitted through all the source & sensor pair transmission channels. With reference to Fig. 2, an input data stream is separated out into its multiple channels; each channel contains a unique spectral range of incoherent electromagnetic energy (i.e. thermal emission from its incandescent light bulb source). The bandwidth, selectivity and transmittance of the associated channel filters are chosen to allow roughly equal levels of energy transfer through each channel.

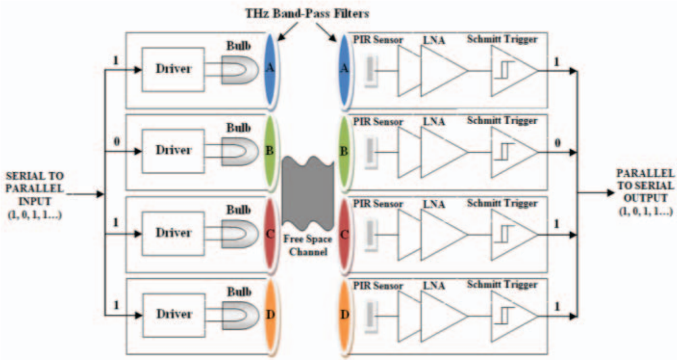

Fig. 2. Example of ultra-low cost THz FDM system architecture.

In addition to FDM, a frequency-hopping spread spectrum (FHSS) system can be implemented to further increase the level of security, where data is transmitted at different times within similar predetermined bands across the far/mid-infrared parts of the electromagnetic spectrum. With both FDM and FHSS applications, a number of standard 'off-the-shelf' filters and windows can be employed with sufficient bandwidth, selectivity and transmittance to create filter banks for multi-channel FDM and FHSS applications.

A simple "THz torch" FHSS system transmits energy in just one source & sensor pair transmission channel at any given time, as illustrated in Fig. 3. While there is no advantage in the overall end-to-end data rate there can be a significant enhancement in security.

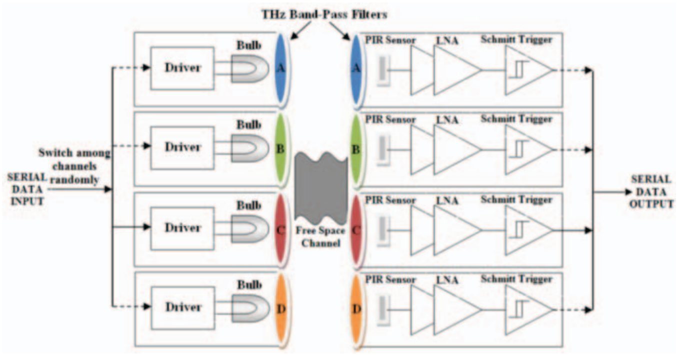

Fig. 3. Example of ultra-low cost THz FHSS system architecture.

IV. "THz Torch" FDM Working Demonstrator

The first working proof-of-concept FDM system is demonstrated for the first time. Here, 4 channels were defined within the far/mid-infrared parts of the electromagnetic spectrum to ideally give equal transmission of energy. The four filters selected for this application were sourced from Northumbria Optical Coatings Ltd [2]; the associated specifications for each of the 1 mm thick filters are listed in Table 1 and their measured transmittances are given in Fig. 4.

TABLE I
Optical Properties of FDM Channel Filters

Northumbria Optical Coatings Ltd	Specifications		
Stock codes	50% Cut Off [THz] ([μm])	50% Cut On [THz] ([μm])	Average Transmittance [%]
SLWP-8506-000240	N/A	34 (8.801)	~79.6
SWBP-6177-000111	42 (7.059)	57 (5.295)	~84.2
SWBP-4596-000070	60 (5.004)	72 (4.188)	~75.7
SWBP-3685-000091	75 (4.001)	89 (3.372)	~72.2

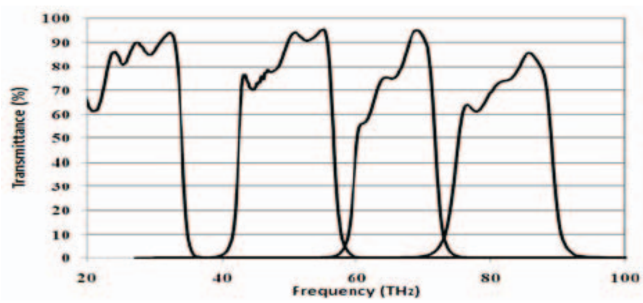

Fig. 4. Measured transmittance responses for filters in Table 1.

As with the demonstrator in [1], for each individual source, five bulbs were assembled into a compact ∅ 1cm packaging can. Within this can, a conformal reflective film was used to maximize the level of thermal emission in the forward direction. Four source & sensor pairs were then mounted face-to-face on two boards.

It is worth noting that the proximity of adjacent sources and sensors (on the same board) may have to be considered. For example, in order to avoid adjacent channel interference. This is not important in this application, as there are a number of simple solutions that can be considered (e.g. the use of simple collimating lenses and/or, as used here, increased band separation and filter selectivity). However, for this particular experimental setup, the source & sensor pairs have to be spatially separated in order to allow them to be completely shielded by the blades of the ∅ 12 cm optical chopper, as shown in Fig. 5.

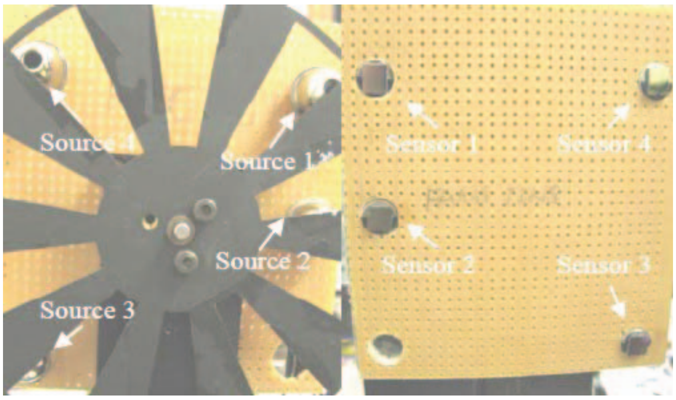

Fig. 5. Assembled source array behind the optical chopper (left) and sensor array (right).

In this "THz torch" FDM wireless link experiment, all the bulbs were biased to work at a temperature of 772 K, to give the desired peak spectral radiance at approximately 80 THz [1]. The separation distance between associated source and sensor was fixed at 1 cm, as seen in Fig. 6.

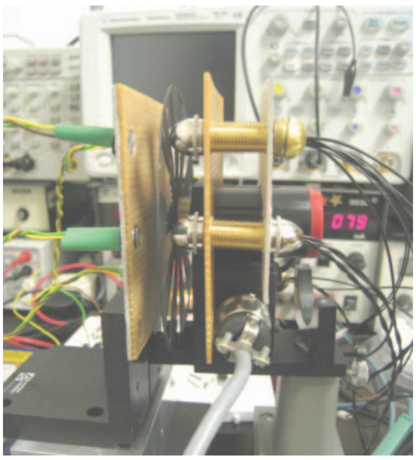

Fig. 6. Experimental setup for "THz torch" FDM wireless link.

The output voltage from each sensor is very small (typically < 5 mV) and back-end processing is needed. The analogue circuitry consists of a 2-stage very high gain (80 dB) low-noise amplifier (LNA), employed for signal amplification (and DC blocking) and a Schmitt trigger for analogue-to-digital conversion.

The maximum bit rate for each individual channel was measured to be 10.3 bps, as shown in Fig. 7. It was found that the recovered signal of the source & sensor pair using filter SWBP-3685-000091 was distorted if the chopping frequency is increased further. This is because the bandwidth of this filter is smaller than desirable.

Fig. 7. Output bit steams from the four channels showing the recovered data rates at 10.3 bps.

The maximum effective bit rate of the FDM system was obtained by converting the parallel outputs into one series data stream. In this experiment, as expected, the maximum end-to-end data rate was measured to be 41.2 bps, corresponding to 4x data rate of each individual channel.

V. Conclusion

This paper has introduced an ultra-low cost THz system for implementing a short-range wireless communications link using frequency division multiplexing. The experimental results show a maximum effective bit rate of more than 40 bps. This represents an eight-fold increase in bit rate, over twice the distance, when compared to previously reported results.

While still in its infancy, these "THz torch" demonstrators 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

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References

[1] S. Lucyszyn and F. Hu, "Ultra-low cost THz short-range wireless link", *IEEE MTT-S IEEE International Microwave Workshop Series (IMWS 2011) on Millimeter Wave Integration Technologies*, Barcelona, Spain, Sep. 2011

[2] http://www.noc-ltd.com/catalogue