# Terahertz Acoustic Optical Modulator and its Application on Free Space Communication

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**Abstract:** We demonstrate in this paper a terahertz free space communication system based on acoustic optical modulation and heterodyne detection. A high resistivity silicon acoustic optical modulator (AOM) was used to modulate a continuous terahertz wave at 2.52 *THz*. A pyroelectric detector was used to detect the modulated terahertz signal via heterodyne detection mode. A modulation frequency of 937 *kHz* and sampling rate of 1kbit/s was achieved.

**Keywords:** Terahertz, Free space communication, Acoustic optical modulation

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## 1. INTRODUCTION

Recently wireless communication in terahertz frequency band has been gradually investigated with the development of terahertz devices including sources, detectors and modulators. Compared with conventional microwave wireless technology, terahertz systems have the potential to provide a much broader bandwidth, more directional transmission ( useful to reduce the size of the antenna ) and more secure communication. Currently there are few technical problems which need be solved to develop suitable sources, modulators and receivers. Considerable work has been carried out into components and systems for terahertz communications [2-10]. One of the key components is the modulator. Direct modulation of terahertz sources including photoconductive antennas and quantum cascade lasers have been reported [2-4]. External modulation based on semiconductor devices with a quantum well structure has also been demonstrated [5-6]. However the operating temperature must be extremely low, which is not suitable for practical applications. For room temperature operation, a terahertz semiconductor modulator with a modulation frequency of 23 *kHz* was demonstrated [7]. Terahertz modulators based on electrically and optically driven active metamaterials were also reported. The modulation frequency up to 2 *MHz* was achieved [8-10].

In this paper, we demonstrate a potential signal communication system at room temperature using an acoustic optical modulator （AOM） and a pyroelectric heterodyne detector. The AOM provides a simple method for modulation over a in broadband frequency range. In an AOM, a traveling acoustic wave at frequency $\omega_A$ causes the incident terahertz wave at frequency of $\omega_T$ to diffract, as shown in Figure 1. The diffracted beam is frequency modulated by the acoustic wave at $\omega_A$. The diffracted beam together with the undiffracted beam are focused onto the pyroelectric detector that works in a heterodyne mode. Pyroelectric detectors have broad detection bandwidth at room temperature, from visible to terahertz frequencies. In addition, they are capable of responding to modulation frequencies of the order of several tens of MHz. When the pyroelectric detector works in heterodyne mode, the detector output will contain a signal component with frequency $\omega_A$ that is proportional to $\sqrt{P(\omega_T)P(\omega_T-\omega_A)}$ [11]. Where $P(\omega_T-\omega_A)$ and $P(\omega_T)$ are the power of modulated beam and unmodulated beam respectively. Consequently, the noise is reduced by needing only a narrowband filter for the broadband signal. The signal to noise ratio is therefore significantly improved by using the heterodyne detection technique. A noise equivalent power of $10^{-13}$ *W/Hz* can be achieved by using the pyroelectric detector working heterodyne mode [12]

## 2. EXPERIMENT SET UP

A high resistivity silicon crystal with dimensions 3 *cm* x 3 *cm* x 3 *cm* was used for the AOM material since it has good transmission and acoustic optical properties in the terahertz frequency range. A PZT 8 transducer with dimensions 3 *cm* x 3 *cm* was attached to the side of the silicon crystal. The resonant frequency of the transducer was 937 *kHz*. A backing layer was used to minimize the acoustic reflection at the interface surfaces of the transducer as well as the silicon crystal. Figure 2 shows the experimental setup of the communication system. Continuous terahertz radiation at 2.52 *THz* with power of 150 *mW* was generated via $CO_2$ pumped methanol vapour laser. The terahertz beam was transmited through the AOM. RF pulses of 150 *W* peak power at 937 *kHz* were applied to the transducer via a signal generator and a power amplifier. An electrical impedance matching circuit was used to adapt the transducer impedance to the 50 $\Omega$ impedance of the power amplifier. The transmitted beams after the AOM, including both modulated and unmodulated waves, were collected and focused onto the pyroelectric detector by a 90° off axis parabolic mirror. The output signal of the detector was acquired by a lock-in amplifier at the reference frequency of 937 *kHz*. A digital oscilloscope was used to display the signal of the lock-in amplifier. Electrical pulses synchronized with the RF pulses were to trigger the oscilloscope. The time constant of the lock-in amplifier is set to be 100 $\mu s$ in order to resolve the signal pulse with 2 *ms* pulse width on the oscilloscope.

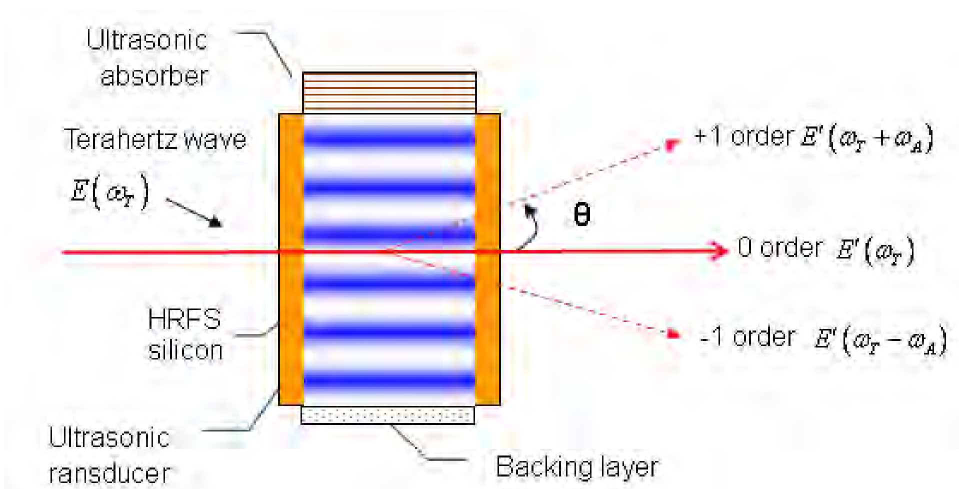


Fig. 1 Sketch of the terahertz acoustic optical modulator (THz-AOM)

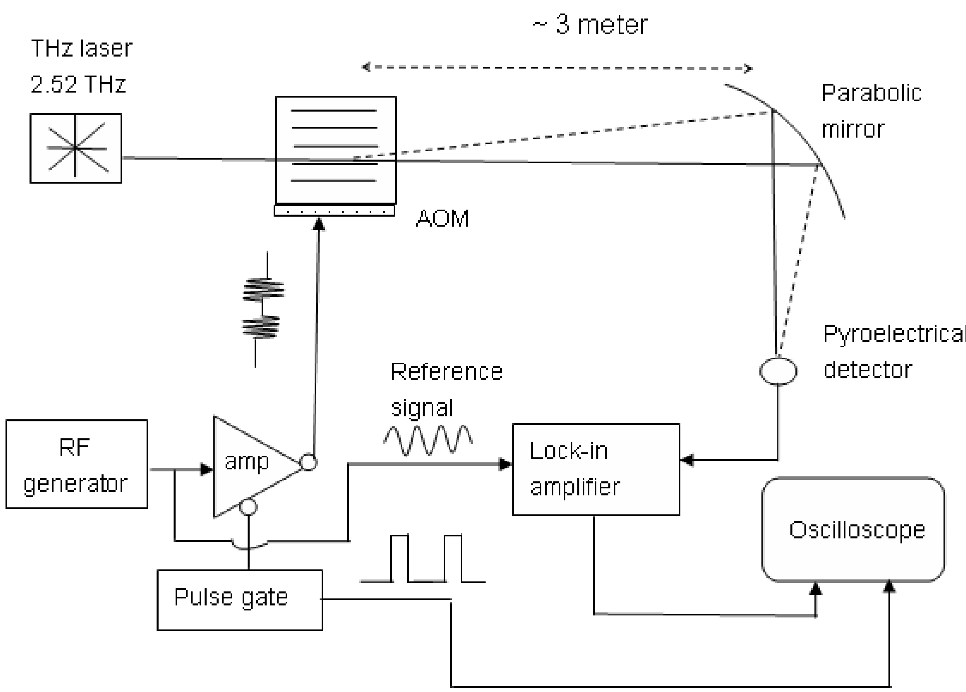


Fig. 2 Experimental set up for terahertz signal transmission using an acoustic modulator and pyroelectric heterodyne detector

## 3. EXPERIMENT RESULTS

The inset of Figure 3 shows the displayed signal of the oscilloscope. The received signal (solid line) with pulse width of 2 *ms* is synchronized with the modulating pulse (dash line). The signal amplitude (voltage peak to peak) linearly increases with the of the amplitude of the modulating signal , as shown in Figure 3. The signal reaches saturation when the power of the modulating signal increases above 10 *mW* due to the saturation of the power amplifier. In order to evaluate the communication system, ASCII coding was applied to the modulating pulses in order to send text information via the communication system, as shown in Figure 4. A Labview program was used to code the modulating pulses into the AOM and decode the received signal pulses from the detector. A signal to noise ratio of 40 was measured. A sampling rate of 1 Kbit was achieved when modulating pulses with pulse width of 1 *ms* were applied. The sampling rate was limited by the time constant of the lock-in amplifier. The sampling rate could be improved by using a low noise preamplifier before the lock-in amplifier. Increasing the modulating frequency would also contribute to a higher sampling rate. A Schottky mixer could be used to replace pyroelectric or heterodyne detectors which would provide a higher signal to noise ratio.

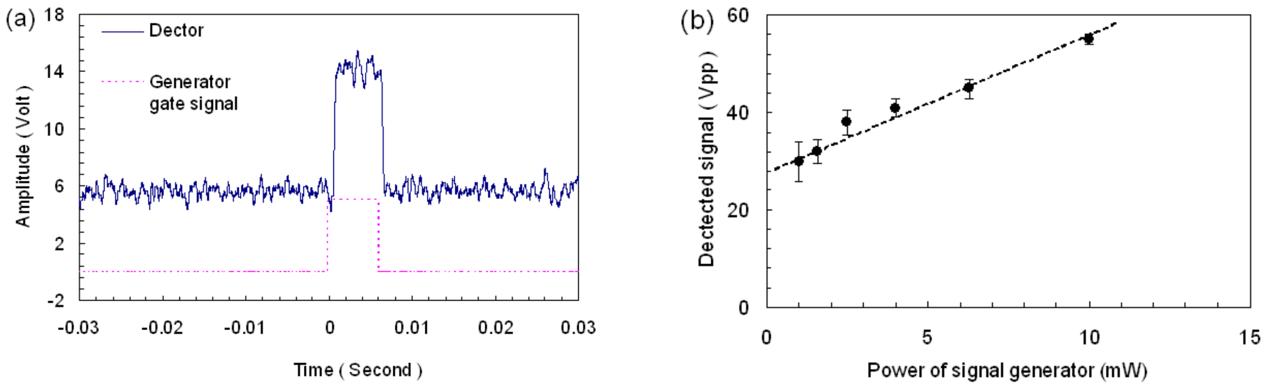


Fig. 3 （a）shows the detected heterodyne signal at frequency of 937 *kHz* when the modulating signal is 2 *ms* pulse with a carrier frequency of 937 *kHz*. (b) Modulation power dependence of the detected signal. There is a 28 volts offset for detected signal.

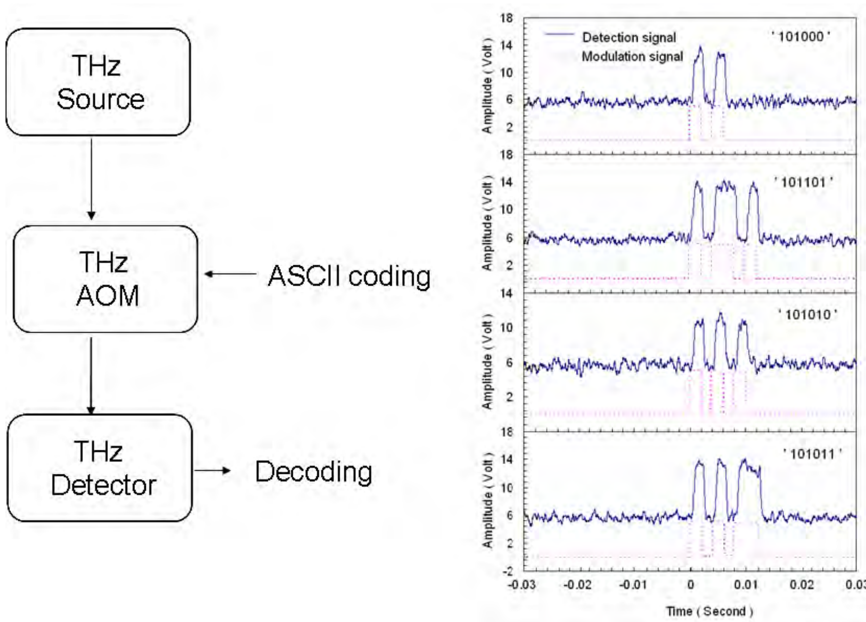


Fig. 4 Experimental results of terahertz digital signal transmission of an ASCII code using modulation pulse train.

## 4. CONCLUSION

We have demonstrated signal transmission at a carrier frequency of 2.52 *THz* using a high resistivity silicon AOM and pyroelectric detector working in a heterodyne mode. A modulation frequency of 937 *kHz* and a sampling rate of 1 *kbit/s* were achieved.

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