Terahertz Science, Technology, and Communication

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Abstract: The term “terahertz” has been ubiquitous in the arena of technology over the past couple of years. New applications are emerging every day which are exploiting the promises of terahertz – its small wavelength; capability of penetrating dust, clouds, and fog; and possibility of having large instantaneous bandwidth for high-speed communication channels. Until very recently, space-based instruments for astrophysics, planetary science, and Earth science missions have been the primary motivator for the development of terahertz sensors, sources, and systems. However, in recent years the emerging areas such as imaging from space platforms, surveillance of person-borne hidden weapons or contraband from a safe stand-off distance and reconnaissance, medical imaging and DNA sequencing, and in the world high speed communications have been the driving force for this area of research.

Science at Terahertz Frequencies: Terahertz science is fascinating. One of the most pivotal quests for the human being has been to find the answer to the vital question of, “from where we all came from?” It turns out that the answer to that lies in the terahertz part of the electromagnetic spectrum. It’s well known that most of the radiation in the universe is emitted at wavelengths longer than 10 microns (<30 THz), and this peaks at about 100 microns (3 THz), if we exclude contributions from the cosmic microwave background (CMB). Even for the CMB, the peak radiation is at 2 mm wavelengths (150 GHz). By studying the minute fluctuations of the electromagnetic waves coming from the distant stars and galaxies at terahertz frequencies, one can study how stars are formed, galaxies are evolved, and how planetary systems come about. Even for our own planet Earth, terahertz radiation is an indicator for tracers of global warming and ultimately the health of the planet we live in. For planetary bodies beyond our own planet, terahertz emission is associated with atmospheric dynamics and trace constituents in planets, moons, and comets. Instruments at the terahertz frequencies have the potential to reveal information about planetary atmospheres, surfaces, and subsurface water and ice contents [1]. Recently, through a high resolution spectrometer at terahertz frequencies operating in space, it was revealed that the water on planet Earth might have come from comets and water molecules are formed in stars at an astonishing rate. Moreover, a recent study with terahertz spectrometer found that the water in a young Sun-like star reveal high-velocity "bullets" moving at more than 200,000 km/h from the star [2]. This can be compared to the velocity of a bullet from an AK47 rifle, which is 2500 km/h or 80 times slower. It is a surprise that water molecules are observed at this high velocity – they should have been destroyed in the shock where temperatures exceed 100,000 degrees.

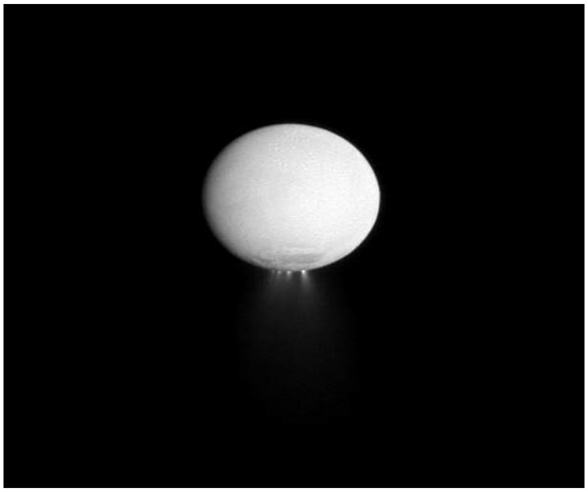

Fig. 1: Image showing Saturn's moon Enceladus raining down water on Saturn revealing the origin of water vapor in Saturn's upper atmosphere. Enceladus is the only moon in the Solar System known to influence the chemical composition of its parent planet.

Observations reveal that water very likely reforms rapidly in the hot and dense shocked gas. The conditions are so favorable that approximately 100 million times the amount of water in the Amazon River is formed, every second. Fig. 1 presents an image taken at terahertz frequencies by the Herschel Space Observatory showing how Saturn's moon Enceladus rains down water on Saturn [3]. In spite of these fascinating scientific potential, the terahertz frequency range (loosely defined as 100 GHz < ν < 10 THz) still remains one of the least utilized electromagnetic bands because of the unavailability of commercial source and sensor components, sub-systems, and instruments [4].

In this talk, an overview of the state of the terahertz technology will be presented. The talk will detail the science and other applications that specifically require technology at terahertz frequencies. The challenges of the future generation instruments and detectors at these frequencies in addressing the needs for critical astrophysical, planetary, and earth observing missions will also be discussed.

Terahertz Imaging Applications: One of the emerging areas of terahertz applications is security imaging. Demand for new surveillance capabilities for usage in airport screenings and battlefield security check-points has led to the development of terahertz imagers and sensors. There are several advantages of imaging at terahertz frequencies compared to microwave or infrared: the wavelengths in this regime are short enough to provide high resolution with modest apertures, yet long enough to penetrate clothing. Moreover, unlike in infrared, the terahertz frequencies are not affected by dust, fog, and rain.

Several groups around the world are working on the development of terahertz imagers for various applications. One option is to use passive imaging techniques, which were very successful at millimeter-wave frequencies, by scaling in frequencies to terahertz range. However, the background sky is much warmer at terahertz frequencies due to high atmospheric absorption. Since passive imagers detect small differences in temperatures from the radiating object against the sky background, at these frequencies passive imagers do not provide enough scene contrast for short integration times. On the other hand, in an active imager, the object is illuminated with a terahertz source and the resulting reflected/scattered radiation is detected to make an image. However, the glint from the background clutter in an active terahertz imager makes it hard to provide high fidelity images without a fortunate alignment between the imaging system and the target.

The JPL group has developed an ultra wideband radar based terahertz imaging system that addresses many of these issues and produces high resolution through-clothes images at stand-off distances [5]. The system uses a 675 GHz solid-state transmit/receive system in a frequency modulated continuous wave (FMCW) radar mode working at room temperature. The imager has sub-centimeter range resolution by utilizing a 30 GHz bandwidth. It has comparable cross-range resolution at a 25m stand-off distance with a 1m aperture mirror. A fast rotating small secondary mirror rapidly steers the projected beam over a 50 x 50 cm target at range to produce images at frame rates exceeding 1 Hz.

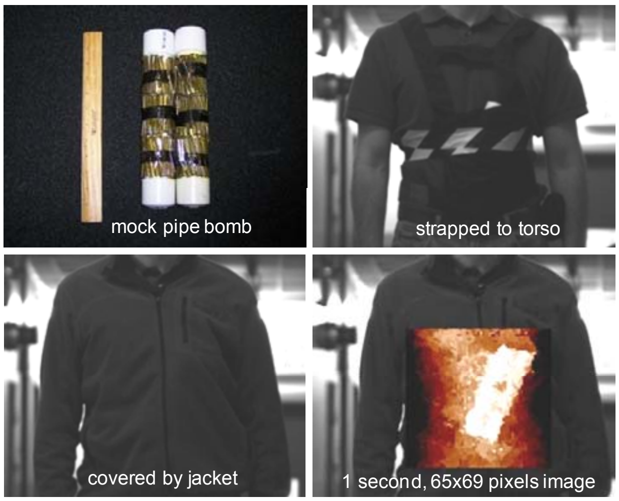

Fig. 2: Through-clothes concealed weapon imaging with a 675 GHz FMCW radar at 25 m stand-off distance.

Fig. 2 shows a radar image taken in 1 second using our 675 GHz FMCW radar at 25m stand-off distance. In this talk we will explain in detail the design and implementation of the terahertz imaging radar system. In this talk, we'll show how by using a time delay multiplexing of two beams, we achieved a two-pixel imaging system using a single transmit/receive pair. Moreover, we'll also show how we improved the signal to noise of the radar system by a factor of 4 by using a novel polarizing wire grid and grating reflector.

Terahertz Communication Applications: Communications at terahertz frequencies have gained attention in recent years as the high fractional bandwidth potentially offers multi-Gb/s wireless data-links [6]. While the data-rate increases linearly with the carrier frequency for a fixed fractional bandwidth, the free space path losses increase with the square of frequency, quickly leading to limited transmission ranges unless very high power and phased-array based transmitters are used. However, there are specific applications where communication requirements are very high data rates over short distances, and terahertz communications is going to play a key role in those areas in not so distant future. Some example of those applications are high-speed wireless data transfer between handheld devices such as smart phones, home-entertainment devices to high-definition television sets, and super high speed wireless links between high volume servers in data centers. It will not be unreasonable to think that we'll have 10 Gb/s or higher wireless communication links over short distances pretty soon, even with simple data modulation schemes. In this talk we'll discuss in detail the potential of high-speed terahertz communication links, its challenges, and potential solutions.

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