The Promise of High-Average, High-Peak Power THz Sources:

Standoff Detection of Chemical, Biological, Nuclear, Radiological and Explosive (CBNRE) and Inspection of Personnel and Cargo

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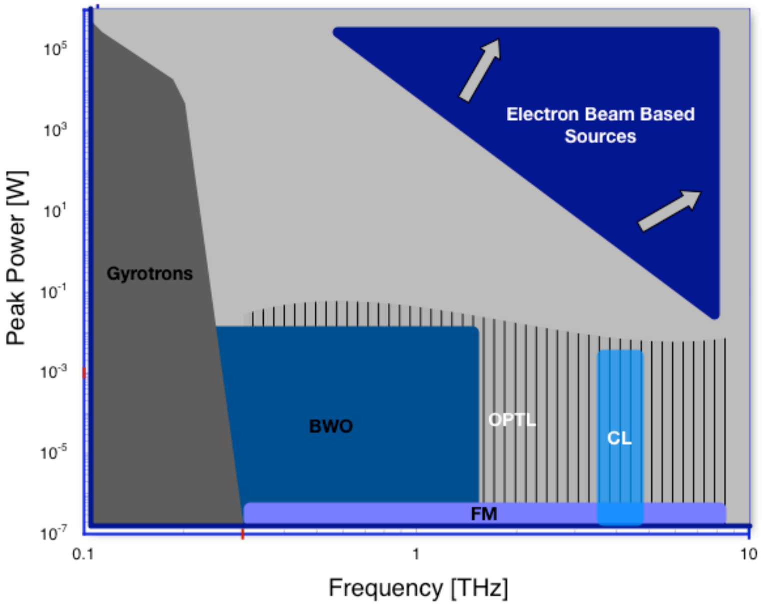
Existing technologies are inadequate to assure the security of the nation through the detection of hazardous substances and weapons, and through the inspection of personnel and cargo. Hazardous substances and specifically Chemical, Biological, Nuclear, Radiological and Explosive (CBNRE) materials pose an imminent danger to the nation and to our interests. These substances can be smuggled into the country in shipping containers, on board vessels, and on persons. Devices employing CBNRE can be used against our forces and our citizens in any theater. Given the diverse range of threats and means of introduction, all possible methods to detect CBNRE must be evaluated. The available systems are limited in speed, range, type of materials, and sensitivity.

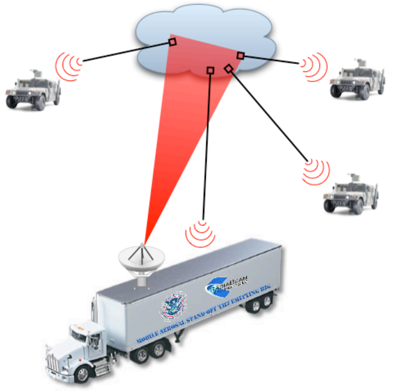
New tools employing Terrahertz (THz) technologies promise to greatly enhance CBNRE detection capability in homeland security applications. The key benefits of THz are that many chemical and organic molecules have distinctive absorption spectra in the THz range, the atmosphere is rather transparent to THz, and THz are safe for humans and organic matter. This white paper reviews available and proposed solutions, and introduces a powerful new source of THz — one based on electron beams. Until recently the THz region of the electromagnetic spectrum (30 - 3000 μm) was considered poorly explored with few sources and detector schemes available. Over the last decade, however, strong interest by both applied and fundamental scientists towards THz spectroscopy and imaging led to rapid advancements in detectors and sources, including cascade lasers (CL), optically pumped terahertz lasers (OPTL), gyrotrons, backward wave oscillators (BWO), and frequency multipliers (FM) (see Figure). While such sources are built or under construction in many facilities around the world, the technology is far from mature, and there is a generic need for a compact, tunable, high peak power radiation source at THz wavelengths.



Electron beam based sources hold great promise. A number of labs have demonstrated THz production using electron beams and various radiation emission schemes. Indeed, THz has long been used as a diagnostic of beam bunch lengths. Electron beam sources can either use short (~ 100s of femtosecond) bunches to directly produce THz (by either bending the electron beam or by striking a transition radiation target); or, can produce pulses of arbitrary length through a collective radiation production scheme such as a free electron laser or the Smith-Purcell effect. Electron beam sources have already delivered orders of magnitude more peak and average power than other coherent THz sources. These sources promise to provide still higher powers in compact, electrically efficient packages.

The transparency of paper, fabrics and similar covering materials and the partial opacity of concrete, plastics, ceramics and other nonmetal materials; and, the relatively short wavelengths; and, the non-ionizing nature of the radiation allows the safe use of THz imaging for high resolution scanning of personnel, urban structures, motor vehicles and other objects. THz imaging can also be useful for mail and parcel screening — with common chemicals and biological agents easily distinguishable from dangerous ones (i.e. Anthrax) — and in airport baggage and passenger screening. Passive THz techniques have already been developed for airports, as warm bodies act as sources (black body radiators). Active sources would greatly extend the range of substances detectable and the resolution and speed of the imaging. For container inspection, while THz do not directly penetrate the thick metal walls, THz could be used on air samples taken from containers and to image fully loaded containers once opened (the back wall of the container would act as a reflector).

Another important application is the detection of chemical and biological hazards (aerosols) in the atmosphere (see Figure). A hazardous organic molecule has a well defined spectral signature in the THz region, and can be detected — even at low concentrations — with a tunable, narrow line-width source. THz spectroscopy can be used to discriminate hazardous materials and it has been shown that not only can explosives be detected, but the specific type of explosive can be determined (i.e. TNT, HMX, RDX, Semtex H, etc.). This technique is particularly suited to an FEL oscillator where the minor radiation absorption by the sample would have a dramatic observable effect on the system gain.



To meet the security demands, RadiaBeam introduces a high peak power, tunable THz source. Such a source can be used as part of a test-bed of multiple inspection and detection schemes, and as a prototype for a fieldable high average power system. The system employs a proven thermionic RF gun, driven by a high efficiency klystron and solid state modulator to produce relativistic (5 MeV), high average current beams. An alpha magnet — using RadiaBeam's proprietary permanent magnet technology — is used to enhance the longitudinal brightness in the electron beam before being passed through any of a number of radiators to produce THz. The majority of the system is based on robust, commercially available components. The prototype system is designed to fit into a small room.

Parameter	Value
THz range	0.1 – 10 THz
Sweepable bandwidth	> 20%
Average Power (at 1 THz)	> 50 W
Peak Power (at 1 THz)	10 MW
Peak Brightness/1%BW (at 1 THz)	~ 10^{28} photons/sec
Minimum pulse length	100 fs
True wall plug efficiency	> 1%

The source would be part of a testing facility where multiple types of the radiators will be evaluated. The facility would also be able to provide critical data to characterize the spectra of CBNRE materials The simplest scheme is a waveguide equipped permanent magnet tapered undulator, which will allow implementation of a single pass FEL (Free Electron Laser) scheme with the energy extraction efficiency on the order of 5% (see Table). Such a scheme would provide tunable fundamental mode and if necessary reach harmonic content through the non-linear harmonics amplification mechanism.

In addition to a single-pass FEL, an oscillator FEL will be considered for its' two advantages: first, oscillators allows better control over the emitted radiation bandwidth and can generate very narrow emission lines; second, oscillators allow for active feed-back for sample analysis.