Terahertz imaging of subjects with concealed weapons

Jason C. Dickinson[*a], Thomas M. Goyette[a], Andrew J. Gatesman[a], Cecil S. Joseph[a], Zachary G. Root[a], Robert H. Giles[a], Jerry Waldman[a], and William E. Nixon[b]

[a]Submillimeter-Wave Technology Laboratory, University of Massachusetts Lowell, 175 Cabot Street, Lowell, MA 01854

[b]U.S. Army National Ground Intelligence Center, 2055 Boulders Road, Charlottesville, VA 22911

ABSTRACT

In response to the growing interest in developing terahertz imaging systems for concealed weapons detection, the Submillimeter-Wave Technology Laboratory (STL) at the University of Massachusetts Lowell has produced full-body terahertz imagery using coherent active radar measurement techniques. The proof-of-principle results were readily obtained utilizing the compact radar range resources at STL. Two contrasting techniques were used to collect the imagery. Both methods made use of in-house transceivers, consisting of two ultra-stable far-infrared lasers, terahertz heterodyne detection systems, and terahertz anechoic chambers. The first technique involved full beam subject illumination with precision azimuth and elevation control to produce high resolution images via two axis Fourier transforms. Imagery collected in this manner is presented at 1.56THz and 350GHz. The second method utilized a focused spot, moved across the target subject in a high speed two dimensional raster pattern created by a large two-axis positioning mirror. The existing 1.56THz compact radar range was modified to project a focused illumination spot on the target subject several meters away, and receive the back-reflected intensity. The process was repeated across two dimensions, and the resultant image was assembled and displayed utilizing minimal on-the-fly processing. Imagery at 1.56THz of human subjects with concealed weapons are presented and discussed for this scan type.

Keywords: Terahertz, imaging, concealed, scanner, transceiver

1. INTRODUCTION

The terahertz region of the spectrum is generally considered to be the frequency range between 0.3 THz and 3 THz. The wavelengths in this region therefore vary from around 1 millimeter to 0.1 millimeter. These long wavelengths are known to penetrate common clothing materials, and are short enough to produce substantial detail of items concealed beneath clothing. This study is intended to provide a demonstration of the phenomenology of terahertz imaging and a discussion of the difficulties encountered. Since the Expert Radar Signature Solutions (ERADS) program currently operates indoor compact radar ranges in this frequency region, standard active radar techniques are applied to the problem of concealed weapons detection.

Since 1981 the Submillimeter-Wave Technology Laboratory (STL) at the University of Massachusetts Lowell has performed radar signature measurements of physical scale models of tactical vehicles using submillimeter-wave transceivers. The development and application of these systems has been funded by the U.S. Army National Ground Intelligence Center (NGIC) under the ERADS program. Currently STL and NGIC have six compact radar ranges operating at frequencies up to 1.6 terahertz. The terahertz sources and receivers, anechoic chambers, and computer controlled positioning apparatus available at STL made the data collection for concealed weapons straightforward, requiring only minor changes to the existing 1.56THz and 350GHz systems[1]. Previous work described high resolution, active transmission, terahertz imagery of a clothed mannequin with a concealed weapon, measured in the ERADS/STL 1.56THz and 350GHz compact ranges using azimuth/elevation (Az/El) collection techniques. A brief review and additional results will be presented.

---

[*] Correspondence: Email: Jason_Dickinson@uml.edu; Telephone: (978) 934-1381; Fax: (978) 452-3333

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **MAY 2006**	2. REPORT TYPE	3. DATES COVERED **00-00-2006 to 00-00-2006**
4. TITLE AND SUBTITLE **Terahertz imaging of subjects with concealed weapons**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Massachusetts Lowell,Submillimeter-Wave Technology Laboratory,175 Cabot Street,Lowell,MA,01854**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**12**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Due to the stringent positioning requirements of Az/El data collection techniques, a system which was better suited to demonstrate the measurement of human subjects was considered, and a prototype system was investigated, utilizing the available 1.56THz transceiver system. The prototype system employed a raster style spot scan implementation, where a focused spot is rastered across the target subject at high speed. A description of this system and imagery data will be presented.

In separate terahertz materials scaling projects, an extensive library of materials transmission spectra were collected for a broad range of terahertz frequencies and compiled. A sampling of the data is available online at the STL web site http://stl.uml.edu and in reference (2) of this conference.

2. THE 1.56THZ TRANSCEIVER SYSTEM

The 1.56THz transceiver system at STL uses two carbon dioxide lasers paired individually with two far-infrared lasers. All four units are designed for extremely long term power stability over periods of several days. The transceiver proved to be an ideal test-bed for collecting measurements of the clothed mannequin, in order to gauge the overall feasibility of using terahertz to penetrate clothing and perhaps reveal concealed metallic weapons. The system has excellent sensitivity, which is obtained through a combination of fairly high transmitter beam power (100+ milliwatts) and sensitive heterodyne receivers.

A sensitivity of approximately 10^{-19} W/Hz is typical for the 1.56THz system's receiver. The receiver plays a crucial role in measuring the low-level signal back-reflected from the subject at useful standoff distances. Corner-cube mounted Schottky diode mixers provide sensitivity for heterodyne detection in the 1-2 THz range. The heterodyne nature of the receivers allows extraction of the amplitude and phase of the backscattered signal, which is essential for the complex Fourier post-processing of the Az/El measurements.

Transmitting beams over moderate distances of 10-30 meters at frequencies in the terahertz region can be problematic as this frequency range is highly susceptible to water vapor absorption. At 1.56, THz there is a narrow "window" of low water vapor absorption, where the effect is limited to approximately 0.1-0.2 dB of loss per foot for compact range humidity conditions near 20% RH (relative humidity). The output power, over 100 milliwatts, in the transmitter laser beam allows sufficient power to easily transmit through the nearly 80 foot round trip distance to and from the subject.

3. THE AZ/EL MEASUREMENT TECHNIQUE

The Az/El technique utilizes full-beam illumination of the target and achieves high resolution images by viewing the target through a 2D angular aperture similar to synthetic aperture radar[1]. Using data collection techniques commonly employed in all ERADS compact radar ranges to generate radar backscatter imagery, a clothed mannequin was rotationally incremented, following a precise trajectory along azimuth and elevation axes. Complex Fourier transform post-processing along the orthogonal azimuth and elevation axes orient pixel values in vertical and horizontal cross-range. The post-processed images created have a resolution of around 1.1 mm per pixel. Figures 3.1 through 3.3 show Az/El images collected in the 1.56THz and 350GHz systems. Data collection time for a full 360 degrees of imagery was typically 3-5 hours, with individual image frames (as shown) corresponding to 1-2 minutes per frame. A complete description of this has been presented in reference (1).

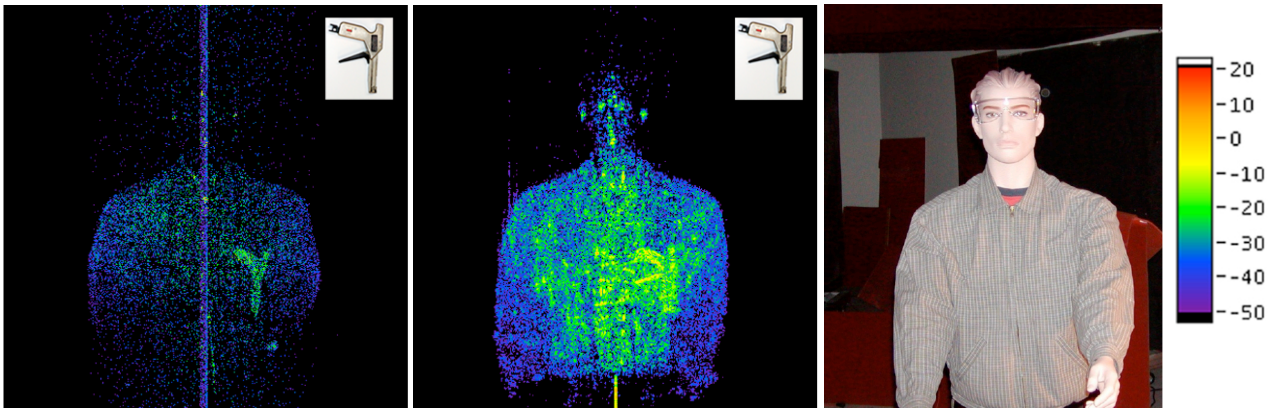

Figure 3.1. Azimuth/elevation collection of a clothed mannequin with a concealed, metal tie-wrap “gun”(inset). Left image taken at 1.56THz. Center image taken at 350GHz (dBV^2 color scale). Photograph of subject as measured on right. Note the penetration through the black plastic wrapping of the trigger handle at 350GHz. The black plastic wrap is heavily attenuating at 1.56THz and minimally attenuating at 350GHz, allowing the handle metal to reflect brightly.

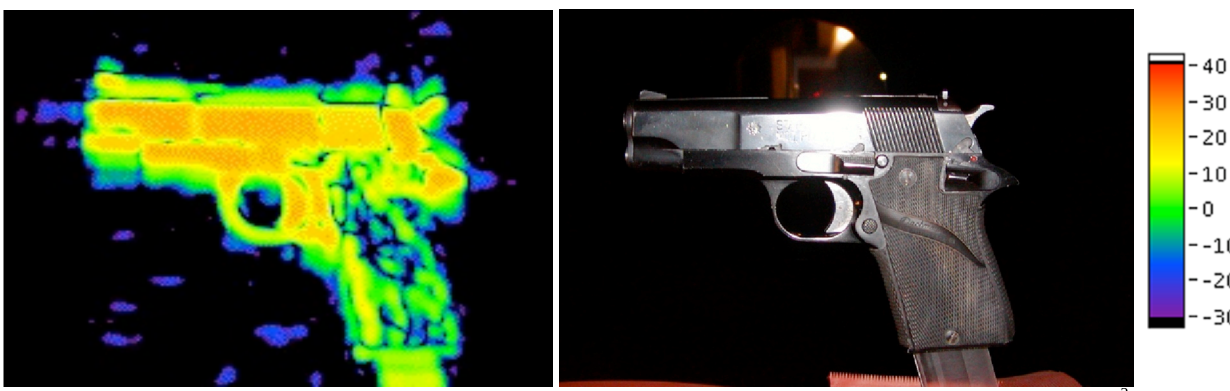

Figure 3.2. A 350GHz Az/El image (left) of a .45 Caliber handgun and a photograph of the measured gun (right) (dBV^2 color scale).

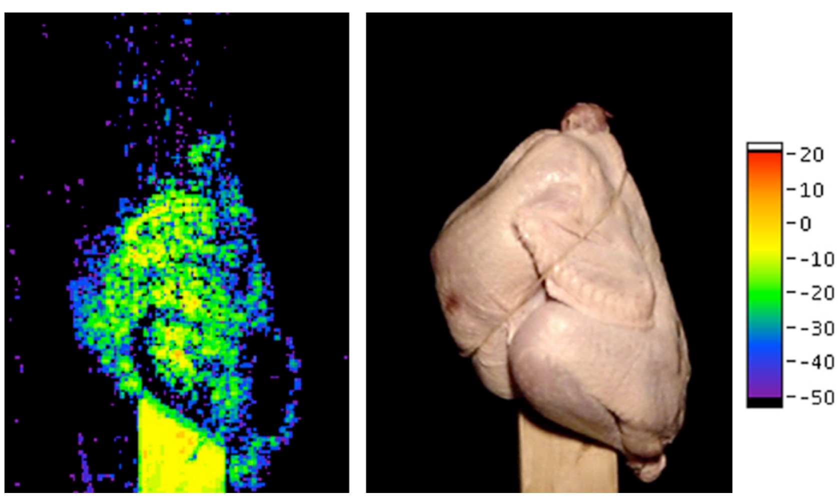

Figure 3.3. A 350GHz Az/El image (left) of a roaster turkey and a photograph of the turkey as measured (right). The raw roasting turkey was measured to approximate the reflection characteristics of human skin (dBV^2 color scale).

The azimuth/elevation collection technique relies heavily on the slow and controlled phase change of the complex target as a function of the angular position change. In order to satisfy the Nyquist limit, the phase change occurring at the target extremities can not change more than 90 degrees ($\pi/2$) of phase per data collection angular position increment or phase wrap (aliasing) will occur. This maximum allowable phase change is examined in equation (1), where the unambiguous cross-range (image width) is a function of the data collection angular increment[3]. For the post-processed image resolution, equation 2 is used. Effectively the larger the angular integration, the finer the resolution of the image, and the finer the data collection, the wider a target can be. The ultimate image resolution is tied into the processed angular window *width* for the horizontal resolution, and the processed angular window *height* for the vertical resolution (equation 2).

$$R_{unamb} = \lambda / 2\theta_{increment} \qquad (1)$$

$$\Delta R_c = \lambda / 2\Delta\theta_{integrated\ angle} \qquad (2)$$

The Az/El data collection capability acts as an excellent study in terahertz phenomenology of a complex target shape composed of multiple dielectric materials. A difficulty of the Az/El data collection method lies in the intolerance to unexpected changes in received phase. Motion outside of the predicted collection path causes phase corruption, resulting in severe image distortion. The required precision of the data collection angles limits the Az/El measurement type for measuring a live subject, possibly even if an array of receivers were employed. Measurements require the target subject to remain motionless, except for a controlled series of angular changes in its position. For a system operating at 1.56THz, unpredicted movements of more than a small fraction of the 191 micron wavelength over the course of several hours would cause image distortion. Therefore, a different method of data collection was devised for practical THz measurements of freestanding humans. Section 5 describes a spot scanning system that is more practical for this application.

4. MATERIAL CONSIDERATIONS FOR DESIGN OF A TERAHERTZ SCANNER

Figure 4.1 shows a transmission plot of a small sampling of measurements taken at STL of clothing materials as a function of terahertz frequencies from 300GHz to 1.5THz. Comparisons of numerous Az/El images with terahertz materials spectra show good agreement between the Az/El clothed mannequin measurements and the materials transmission data[2]. While reflectivity of metals across the terahertz region is near unity[4], most clothing materials are transmissive enough to pass some terahertz energy, whichcould make a properly designed system useful for homeland defense applications.

Materials properties of various common clothing, building materials, and plastics have been collected over a wide range of terahertz frequencies. It is difficult however to perform the same type of terahertz material characterization on live tissue. In order to approximate the reflective properties of skin and tissue, a supermarket roasting turkey was measured at 350GHz in an Az/El scan configuration. A sample image is shown in Figure 3.3. The reflection of the turkey skin appears to be similar to the reflective properties of the fiberglass mannequin. It should be noted however that the absorption properties between fiberglass and human skin are expected to be different.

The terahertz spot scanner, described in detail in the next section, may prove to be a useful tool in performing novel measurements of living tissue. If an optical system were redesigned to manipulate the terahertz beam across small scan areas with a small beam focus, living tissue could be examined at high speed and at close range. Pulsed terahertz radiation has been used *in-vivo* to show contrast between healthy skin and a basil cell carcinoma[5]. Use of a CW based terahertz scanner operating at some optimal frequency may offer high speed, non-contact, high resolution imagery to detect numerous skin conditions, from cancerous tissue to burn depth.

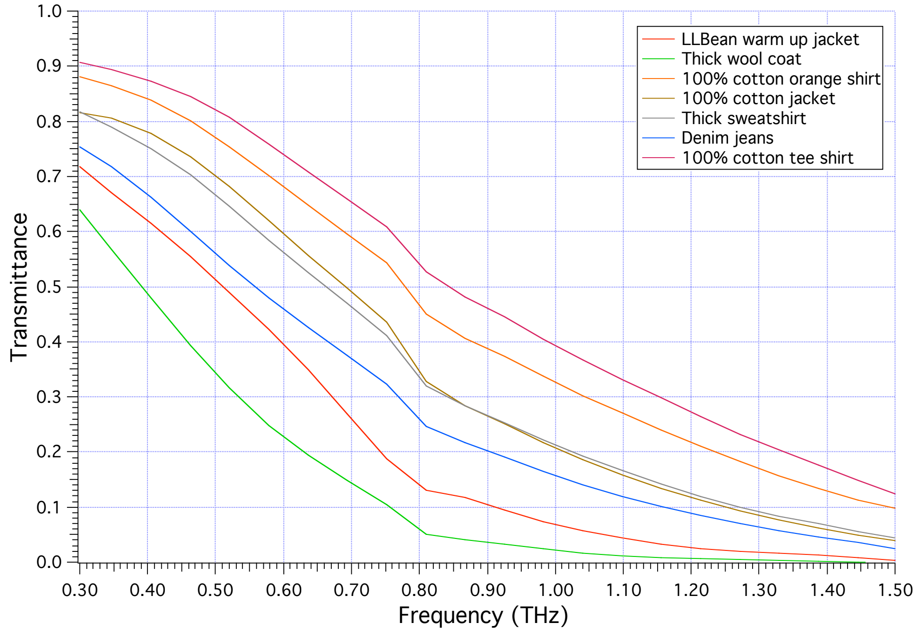

Figure 4.1. Plot of transmission through common clothing materials over terahertz frequencies from 0.3 THz to 1.5 THz. Apparent feature at 800 GHz for all samples is a spectrometer artifact.

5. THE PROTOTYPE SPOT SCANNING SYSTEM AT 1.56THZ

The transition from the compact radar range setup, with full-beam illumination, to a high speed spot scan system would enable characterization of complex target subjects without the stringent positioning requirements. In order to study the terahertz characteristics and phenomenology of clothing materials on humans, the spot scan method was devised, and a prototype system was assembled. Figure 5.1 is a simple illustration of the difference in spot size from the full-beam illumination and the prototype spot scan beam size. The following sections are arranged to describe in general the issues associated with delivering a focused spot at the target subject located several meters away.

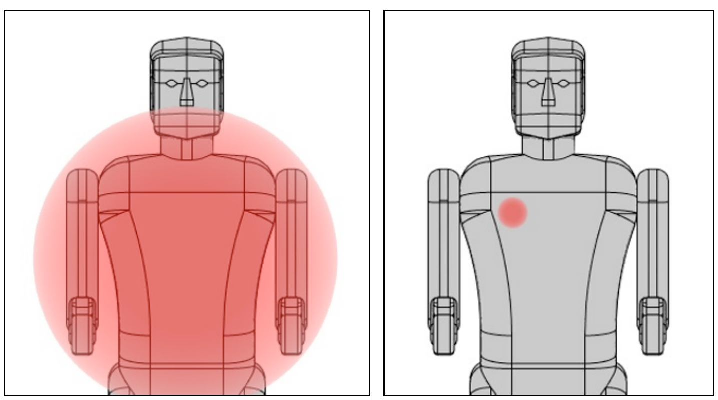

Figure 5.1. Relative sizes of the illumination beam for the full-beam system (left) and the spot scan systems (right).

5.1 Terahertz beam considerations

Optical systems utilizing terahertz beams are “quasi-optical”, that is, the wavelength is nearly long enough be behave as an RF signal, yet short enough to be manipulated by optical components, but the size of the optics must take diffractive effects into account.

The distance between the final optic in the illumination beam path and the target subject is referred to as the “standoff distance”. The beam emerging from the last transmit optic, usually a focusing mirror, propagates freely through the air until it reaches the subject. It is usually desirable to maximize this distance, in order to remotely operate a scanner system as far away as possible from the subject that may have a concealed weapon. The common misconception for a terahertz system is that the beam can propagate across great distances as a narrow, focused beam. All types of light experience some form of diffraction effect as they propagate, and terahertz Gaussian beams tend to experience fairly rapid expansion as they propagate. Figure 5.2 shows the diffraction of a 1cm terahertz beam at 300 GHz, 1.5 THz, and 3 THz over a distance of 2 meters using standard diffraction calculations.

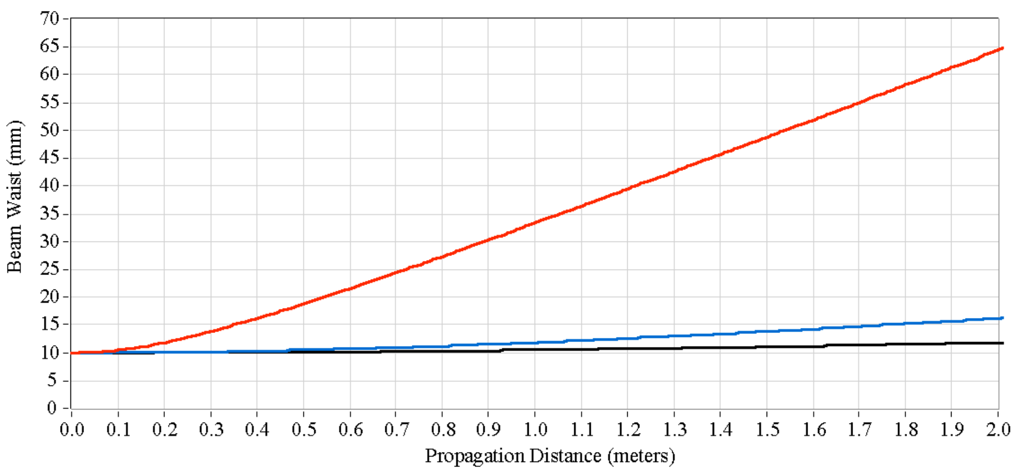

Figure 5.2. Initial Gaussian beam waist size of 10mm, propagated over 2 meters, for three frequencies, 0.3THz (red, upper), 1.5THz (blue, middle), and 3THz (black, lower).

5.2 Terahertz optic sizing

Because the intensity of a Gaussian beam drops off radially from the center, it does not have a crisp edge where beam energy stops. A terahertz beam “spot” is subject to numerous interpretations. Figure 5.3 shows the values for several common terms used to describe the size of a beam. “Full width at half maximum” (FWHM) is a common reference, as are “beam waist (ω)” and “pi omega (πω)”. In order to strike a balance between practical optical component size and the utilization of the majority of beam power, the size of πω is commonly used for the minimum diameter of an optical component in a Gaussian optical system. The diameter of πω contains 99% of the beam intensity, with only 17% ripple[6]. For example: A Gaussian beam with a 25mm beam waist would have a FWHM size of nearly 30mm, and in order to satisfy πω would require a minimum optic diameter of 78.5 mm.

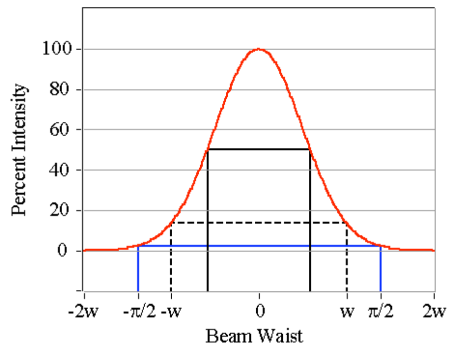

Figure 5.3. A Gaussian beam intensity profile, showing beam width definitions FWHM (black) , $1/e^2$ (dotted), and πω (blue).

5.3 Terahertz Standoff issues

In order to calculate the minimum size of the last optic in the terahertz transmission path, Gaussian beam propagation calculations were used. Gaussian beams are subject to time-reversal, so a simple approach to calculate parameters of a focused spot several meters away is to mentally reverse the propagation direction. If a 12mm spot FWHM (10mm waist) at 1.5THz is desired 10 meters away, the approach would start with a 10mm beam waist and propagate it 10 meters to calculate the required optic diameter. Figure 5.3 shows the 10mm beam diffraction over 20 meters. The beam waist at 10 meters is approximately 62mm. Using πω the final illumination beam optic size would be (π * 63mm =) 198mm diameter, approximately 7.75 inches. If a 20 meter standoff was desired, Figure 5.4 shows the beam waist at 20 meters to be 125mm, approximately double the beam waist size at 10 meters. For 20 meters of standoff the πω optic required would be 393 millimeters, or 15.5 inches in diameter. Table 5.1 shows the required optic diameter for several permutations of beam frequency, beam size, and standoff distance.

Table 5.1. Focusing optic diameter (πω in mm) as a function of final beam waist size (mm) and standoff distance (meters) at 1.5THz.

	5 meter	**10 meter**	**20 meter**	**30 meter**
5mm	198	393	801	1209
7.5mm	132	258	534	801
10mm	110	198	402	603

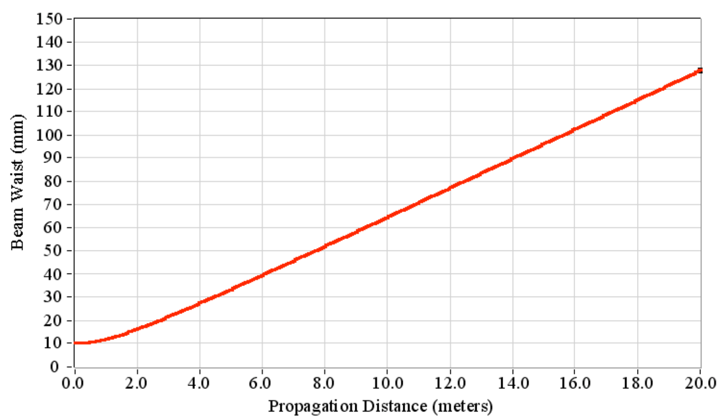

Figure 5.4. 1.56THz Gaussian beam waist size starting at 10mm, propagating 20 meters.

5.4 Prototype spot scanner for measuring human subjects

The existing compact radar range uses an outgoing beam to illuminate the target object. Power back-reflecting from the target then retraces the illumination beam path and is collected by the receiver. In order to measure human subjects, a new technique was devised and tested, with slight modifications to the existing STL 1.56THz measurement system. The simplest approach to measuring a live subject was to focus the 1.56THz terahertz illumination beam onto a spot on the target subject, and receive any back-reflected power. The process was repeated at fairly high speed across the target subject in a raster style scan. The raster style was chosen for the uniform sampling across a rectangular area of interest.

A 10 millimeter diameter spot on a target subject several meters away was the initial goal for the focused beam. Using Gaussian beam calculations, a simple optical configuration was designed. A large scanning mirror was chosen for the design. Figure 5.5 shows a schematic of the prototype optical layout.

A prototype system was assembled from available optical and mechanical components at STL. A large mirror, 17 inches in diameter with a 72 inch focal length was sufficiently large for the experiment to prevent diffractive distortions of the 1.56THz beam over the required propagation distance. A two axis computer controlled positioning stage was assembled, scan control and display software was written in National Instruments LabVIEW®. Initially, stepper motors were used to deflect the two axes on the scanner mechanisms with an angle sufficient to scan a one meter by one meter area, several meters away. However, the final prototype system enables scans that are much wider than one meter, the final scan size was approximately 5 meters across by 1-2 meters tall with only a small time penalty for the additional data collection.

Major components of the scanner system are shown in Figure 5.5, the beam path is as follows: A beam originates at the terahertz source, expands to fill a focusing mirror, illuminates the planar reflector on the two axis scanner, and propagates some distance to the target subject (possibly a human subject) located at the beam focus. The terahertz beam reflects off of the subject, retraces backwards through the optical system, and is received by a detector. The down-converted signal is then digitized and displayed on a computer screen in false color, corresponding to intensity of the returned terahertz energy. For this spot scanning system, the process would repeat for each spot location on the target subject, building a complete 2D image.

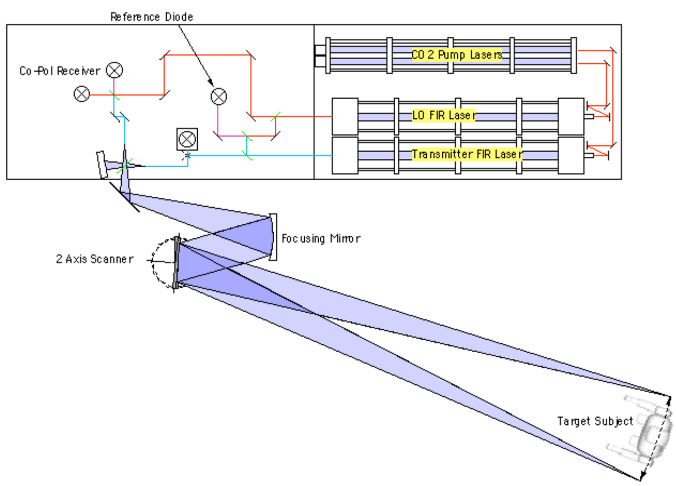

Figure 5.5. An overview of the optical design, showing relative locations of the monostatic transmitter/receiver, focusing mirror, two-axis scan mirror, and the target subject, initially a mannequin.

In order to be minimally invasive to the already operational and highly complex optical paths of the standard 1.56THz compact range setup, only simple optical rearrangements were made. Following a few unsuccessful preliminary scans, it was determined that the system would need to be modified from a slightly bistatic system, where the receiver and transmitter have slightly different beam paths, into a strictly monostatic one, where the paths are identical. The prototype optical design, while simple, was not capable of receiving a beam off the outgoing optical axis.

Following a review by the University's Institutional Review Board, the testing of human subjects was considered. With the prospect of a scan system illuminating a person with a focused beam from a terahertz laser, acceptable radiation exposure limits for eyes and skin were consulted. The 1.56THz transceiver's far-infrared laser output is just over 100 milliwatts. The beam is manipulated through the numerous mirrors, beam splitters, and lenses, and then propagated approximately 30 feet, before the focused illumination beam reaches the target subject. The spot size was nominally 10 millimeters, and the terahertz beam power measured at the focus location was between 2 and 5 milliwatts, far below the recognized non-ionizing radiation exposure limit of 1000 watts/square meter[7]. The loss of power down to 2-5 milliwatts can be directly attributed to atmospheric water absorption over the beam pathlength and the need to use several beam splitters to establish a monostatic path.

6. RESULTS

Because the entire spot scan system was a simple assembly of available hardware integrated with an existing ultra sensitive 1.56THz transceiver, a goal of the project was simply to produce imagery to demonstrate the terahertz phenomenology of a complex target. The time required to collect the imagery was of little concern. Initial scans of a 6 foot tall clothed mannequin were collected from head-to-toe in approximately 7 minutes, with a 2 meter standoff distance. The unusually short standoff was more of a logistical problem than an optical limitation. In order to unobtrusively retrofit the existing transceiver, a 5 meter standoff was folded, to minimize the modifications to the existing system. The transmitter beam is sent out in vertical polarization and can be received in either vertical or horizontal polarization. The preliminary images were novel, but the 10 millimeter spot size, even oversampled in both the horizontal and vertical directions, was still coarse. Figure 6.1 shows a measurement of a human subject with a 10 millimeter spot, 1.56THz beam (right). On the left is a photograph of the subject, taken immediately following the terahertz scan. A concealed handgun is taped to the chest of the subject, underneath a cotton tee shirt. This image was collected using a vertical polarization transmit beam and a horizontal polarization receiver (VH pol).

Additional modifications were made to the Gaussian optical design, in order to produce a smaller spot size at the target. The initial 10 millimeter spot size was acceptable, but additional resolution was desired. The results of the second optical design were quite favorable, with a roughly 6mm spot size and approximately 3 meters of standoff.

The images in figure 6.2 show the actively illuminated, continuous wave (CW), 1.56THz spot scanner image of a live subject with the reduced terahertz spot size of 6mm. The image on the right is the terahertz image. On the left is the subject photograph, taken immediately following the scan. A concealed weapon is present on the subject, beneath the cotton shirt. The image also shows a dark "L" or pistol-like shape, pointing upwards towards the subject's left shoulder.

The terahertz images shown in figures 6.1 through 6.3 are nominally 1000 by 1000 pixels, clearly oversampled for a 5-6 millimeter diameter beam. Scan times ranged between 5 and 10 minutes, and were limited solely by the two-axis scanner device. Both images were oversampled by approximately a factor of 10 to 20, mainly due to the scanner mechanism in use. Image collection times could easily be reduced by simply reducing the oversampling, and increasing the speed of the two axis scanner.

Additional terahertz system modifications are under consideration, which could dramatically shorten the time per scan. The tentative goal would be one entire scan, or frame, per second, although multiple frames per second would allow a more real-time surveillance of human subjects in motion.

The 1.56THz transceiver has the ability to collect co-polarization and cross-polarization imagery. The transmit beam used for all data collections described was vertically polarized. By examining vertical polarization receive (VV), and horizontal polarization receive (VH), additional image enhancements should be possible. The prototype system was not capable of collecting both polarizations simultaneously, but measurements were conducted back-to-back switching between V and H receivers.

Figure 6.1. Imagery collected using the prototype, active illumination, CW, 1.56THz system on the right. Spot size is approximately 10 millimeters. On the left is a photograph of the subject taken immediately following the scan. A concealed weapon can be seen in the terahertz image as an inverted “L”. Polarization shown is cross-pol (VH).

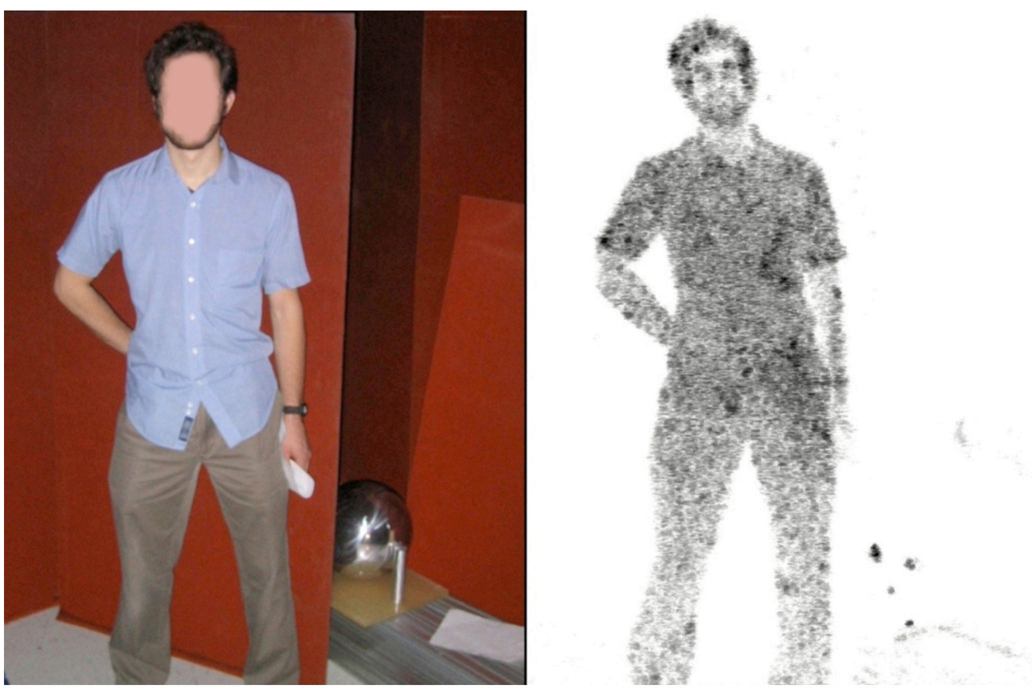

Figure 6.2. Imagery collected using the prototype, active illumination, CW, 1.56 terahertz system on the right. Spot size is approximately 6 millimeters. On the left is a photograph of the subject taken immediately following the scan. A concealed weapon can be seen in the subject’s left breast pocket (reader’s right). Polarization is cross-pol (VH).

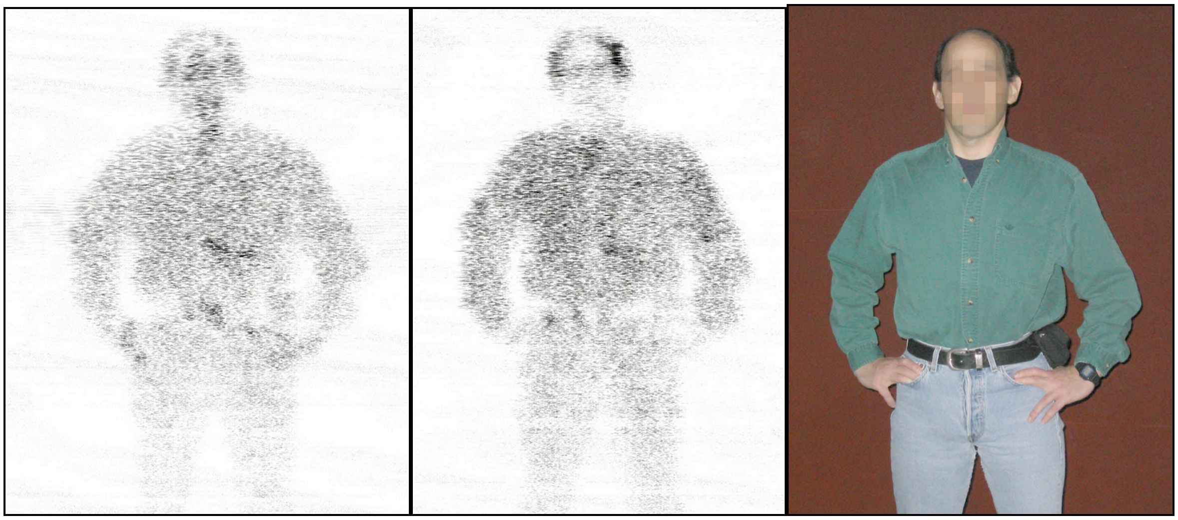

Figure 6.3. 1.56THz co-pol receive(VV) on left, and cross-pol receive (VH) in center. Photograph of the subject is on the right.

Figure 6.3 shows two 1.56THz images of the same human subject and scene, taken several minutes apart. Note the differences in the co-polarization terahertz image (left), and the cross-polarization (center). Also notice in figures 6.1, 6.2, and 6.3 that the subject's hair appears to rotate the incident polarization more than the surrounding skin. Additional polarization effects may prove to be interesting in the exploitation of terahertz imagery of human subjects.

CONCLUSIONS

Two measurement techniques have been demonstrated to produce terahertz imagery of dressed mannequin and human subjects. A review of two measurement techniques has been described, and imagery was presented at 1.56THz and 350GHz. The imagery taken at 1.56THz shows the difficulty in penetrating several layers of cotton material, since there is little back-reflected power. The 350GHz imagery, on the other hand seems to indicate the possibility of too much penetration through the clothing, since there is considerably more back-reflection from the mannequin body. Effectively, the contrast required to detect the concealed weapon is dramatically reduced in the 350GHz images, as there is too much backscatter from all objects to be able to discern the weapon from the mannequin body. Reviewing clothing materials transmission spectra, higher transmission occurs at longer wavelengths. Az/El measurements conducted the 1.56THz and 350GHz showed agreement with the materials spectra. Based on the two measurements at 1.56THz and at 350GHz of the clothed mannequin, it would seem that a system designed for the express purpose of detecting weapons or contraband under clothing should have a base frequency between 1.5 THz and 350GHz.

A clothed mannequin with a concealed weapon served as an excellent terahertz phenomenology study of a complex target containing numerous material types. Limitations of the Az/El technique prevent the practical measurements of human subjects, so an alternative scanner prototype was considered.

A spot scanner system was designed and assembled using available optics and mechanical components for a two axis scanner device, and imagery was collected at 1.56THz in a retrofitted compact radar range system. The beam was directed as a 6mm nominal spot, out to several targets approximately 11 feet away. A two axis scanner directed the focused spot across the target subject in a raster scan pattern. Reflected terahertz energy was redirected back towards the heterodyne receiver, and image plots were generated using a two dimensional false color display. The scanner consisted of a simple two axis large planar reflector, which was operated a fairly slow speed as a proof-of principle concept for spot scanning a terahertz subject.

REFERENCES

1. Jason C. Dickinson, Thomas M. Goyette, Jerry Waldman, "High Resolution Imaging using 325GHz and 1.5THz Transceivers", in *Session 9: Systems*, G. Narayananan, Editor, Proceedings of the Fifteenth International Symposium on Space Terahertz Technology (STT2004), 373-380, 2004.

2. A.J. Gatesman, A. Danylov, T.M. Goyette, J.C. Dickinson, R.H. Giles, W. Goodhue, J. Waldman, W.E. Nixon, W. Hoen, “Terahertz Behavior of Optical Components and Common Materials”, in *Terahertz for Military and Security Applications IV*, Proceedings of SPIE Vol. 6212, 2006 (in print)

3. D.L. Mensa, *High Resolution Radar Cross-Section Imaging*, Artech House, Boston, MA 1991.

4. A.J. Gatesman, R.H. Giles, J. Waldman, "High-precision reflectometer for submillimeter wavelengths", JOSA B, Volume 12, Issue 2, 212-214 February 1995.

5. Ruth M. Woodward, Anthony J. Fitzgerald, Vincent P. Wallace, "Tissue classification using terahertz pulsed imaging", *Advanced Characterization, Therapeutics, and Systems XIV,* Proceedings of SPIE, Vol. 5318: 23-33

6. Anthony E. Siegman, *Lasers*, p667, University Science Books, Mill Valley, 1986

7. “Guidelines on Limits of Exposure to Laser Radiation of Wavelengths between 180nm and 1mm”, Health Physics Vol. 71, No. 5, pp 804-819, 1996.