Document Title: Millivison Millimeter Wave Imagers

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Document No.: 181652

Date Received: March 28, 2000

Award Number: 95-IJ-CX-K007

18 1652

FINAL REPORT

MILLIVISION® MILLIMETER WAVE IMAGERS

The National Institute of Justice
Office of Science and Technology
Washington, DC

COOPERATIVE AGREEMENT
PROJECT No. 95-IJ-CX-K007

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Millimetrix

A FINAL REPORT
to
The National Institute of Justice
for
Cooperative Agreement
Project No. 95-IJ-CX-K007

MILLIVISION® MILLIMETER WAVE IMAGERS

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15 April 1997

1.0 INTRODUCTION

This report summarizes the development efforts undertaken with support from NIJ Agreement 95-IJ-CX-K007 (Agreement). Agreement development efforts were focused on systems for the detection of weapons and other contraband concealed under people's clothing using the technique of passive millimeter wave imaging.

Many commercial and military applications of millimeter wave imagers demand sensitivities and frame rates that preclude the use of traditional single element scanners, especially for passive (radiometric) applications. We will describe here technology being developed in part with Agreement support to overcome these limitations through the use of focal plane array imagers. We will also describe some specific examples of both radiometric and radar imagers based in part on technology developed under the Agreement and currently under development at Millimetrix to address needs in the security and law enforcement markets. These systems all operate near 100 GHz.

The Millivision* family of focal plane array (FPA) imagers use a lens as the primary optic to achieve minimum off-axis aberrations for large field-of-view applications. These imagers also typically employ a folded optics configuration using a transreflector and twist reflector combination for compactness and to provide a convenient element (the twist reflector) for active optical processing. Both coaxial and unblocked folded configurations are employed.

Focal plane arrays for both active and passive imagers can range from a (very sparse) single element at one extreme to the other extreme of a completely filled, two dimensional array with elements optimally spaced so that adjacent beams in the object plane overlap at the half-power (-3 dB) points along both axes. There are many possible configurations between these extremes. The sparseness and exact configuration of the array depends on the needed sensitivity and frame rate, the desired field of view, and the technique available for scanning (frequently called dithering when on a small scale) of the array. Scanning or dithering is frequently used to fill in the under sampled image generated by the sparse array by scanning the array in such a manner as to completely sample the image within the desired field of view. Dithering is also required, even with a filled array, in order to properly sample the highest accessible spatial frequencies.

* Millivision® is a registered trademark of Millimetrix, LLC.

Achieving the sensitivity necessary to produce needed contrast-to-noise ratios is an especially limiting factor for radiometric imaging. The tradeoff is between the system noise temperature (receiver temperature plus scene temperature) of each array element and the sparseness of the array. The output noise fluctuation from each element is governed by the radiometer equation and is inversely proportional to the square root of the dwell time in each position. Thus, if it is necessary to dither a given element to generate 16 pixels to fill in for an unfilled array, the noise in each pixel will be 4 times higher than generating the same image at the same frame rate in a filled array. The output noise fluctuation from each channel is proportional to the system noise, so that in this example, the fourfold degradation caused by dithering can be overcome by decreasing the system noise by a factor of four. For most applications of current interest, the scene temperature is 250 to 300 K. Thus, even with an ideally perfect (unachievable) zero receiver noise temperature, there is a scene background-related limit to the ability to reduce system noise to accommodate the time multiplexing of an element in a sparse array to fill out the desired field of view. Practically, one reaches a point of diminishing returns with receiver noise temperatures of much less than 300 K (3 dB noise figure).

Achieving minimum practical receiver noise temperatures near 100 GHz requires the use of MMIC low noise amplifiers (LNAs). Millimeter wave MMIC LNAs are, however, characterized by relatively large, intrinsic low frequency gain fluctuations. To achieve limiting noise fluctuations as predicted by the radiometer equation for most applications requires implementation of load comparison or some other technique to minimize the adverse effects of these gain fluctuations. The technique used must also be compatible with flat field algorithm requirements. An active optical element using wave processing MMICs has been developed to implement load comparison and flat field algorithms in some Millivision® passive imagers.

For applications demanding video frame rates, the technology used for dithering also becomes important as electro-mechanical means become impractical. Millimetrix, with support in part by the Agreement, is developing an electronic beam scanning/dithering technology using active optics employing wave processing MMICs for this purpose. Customers always need more resolution, more sensitivity, and a wider field of view all in the smallest possible package and at the lowest cost. Key elements of the Millivision® imager design are the dithering hardware and the image processing algorithms to achieve the highest resolution image by optimizing access to the highest spatial frequency information available to the sensor.

Millivision® focal plane arrays consist of a fairly large number of receiver elements arrayed along the focal surface of the optical system. Several architectures of the individual receiver channels in the array are possible. We have elected to use at this time a subharmonic heterodyne or homodyne approach employing either mixer input or LNA input circuits.

Key to the generation of usable images, both for radar but especially for radiometric images, is the achievement of a uniform response to scene brightness (a flat field) over the field of view of the image. The algorithms to generate acceptably flat fields and their hardware requirements for both radar and radiometric imagers are briefly described.

The detection of weapons and other contraband concealed beneath people's clothing is the application of millimeter wave imaging supported by the Agreement and currently being pursued by Millimetrix. Several systems are currently being developed to address this market need. A 94 GHz radar-based through wall imaging system (TWIS) is also being developed to address needs of the law enforcement and defense communities. This system, although not directly supported by the Agreement, makes use of the basic Millivision® technology developed under the Agreement. There are clearly many other applications of the radar and radiometric video rate imaging capability in addition to the security, law enforcement and DoD needs addressed by the systems currently under development.

2.0 OPTICS FOR FOCAL PLANE ARRAY IMAGERS

Millimetrix' Millivision® imagers make extensive use of Gaussian optics. The primary optic is a lens, the design of which is selected to provide minimal aberrations over the (sometimes rather large) fields of view required. Considerable effort, supported in part by the Agreement, has gone into designing and analyzing lens types for the imaging application. Extensive use is also made of various types of Gaussian optics filters, wave plates, and other passive elements in the design of these imaging systems. Perhaps the most innovative and unique aspect of the optics design is the use of a new class of active optics employing arrays of MMIC chips to perform certain signal processing functions of the free space electromagnetic wave.

2.1 Folded Optics

Millivision® cameras typically use folded optics to make the sensor package more compact. Folding is accomplished using a combination of transreflector and twist reflector. The coaxial folded optics configuration is shown in Figure 2-1 and the unblocked configuration is shown in Figure 2-2. In addition to making the overall sensor more compact, the folded optics provide an element, the twist reflector, that can be used in the active optics processing of the scene energy before coupling to the transmission line circuitry of the focal plane array. These folded configurations also accommodate injection of the local oscillator and reference signals and facilitate rapid focus changes by minimizing travel of the focussing elements, typically the twist reflector and FPA assembly.

The coaxial folded optics configuration, shown schematically in Figure 2-1, has the following advantages:

1) Compactness. The volume between the primary lens and the focal plane array is re-used resulting in only 1/3 the volume of the unfolded counterpart.

2) Optimum resolution. The central blockage produces a ring-like illumination of the primary optic resulting in high angular resolution.

3) Simplified focus mechanism. Focus motions of the twist reflector/focal plane array assembly are multiplied threefold.

4) Smaller active optics elements. The twist reflector active area is only 4/9 of the main optic area.

5) On-axis real estate. The central area of the main optic, which is blocked by the FPA, is available for LO and control signal injection and for a boresighted visual TV camera.

The major disadvantage of the coaxial configuration is the on-axis blockage caused by the FPA blockage of the twist reflector which reduces beam efficiency. To keep blockage within acceptable levels, limits the field of view that can be implemented.

For applications where large fields of view and maximum sensitivity are required, the alternative unblocked folded optics configuration, such as is shown in Figure 2-2, is available. Its primary advantage relative to the coaxial configuration is minimal blockage, the ability to support much larger fields of view, and the ability to better isolate the LO. The major disadvantages of this configuration are its larger size and the larger active optics twist reflector required.

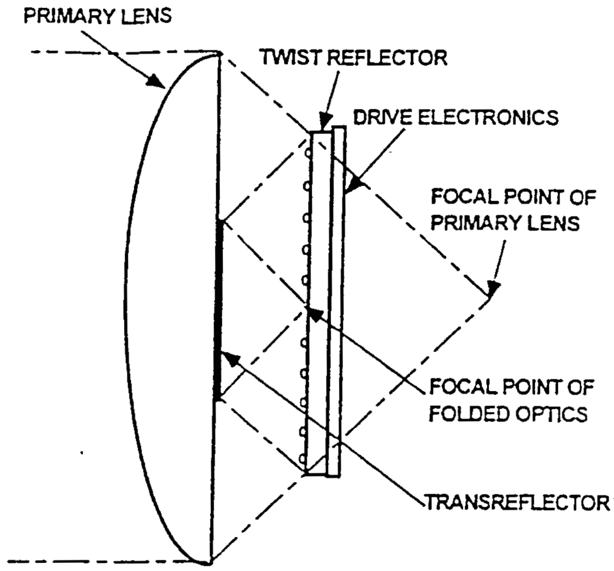

Figure 2-1. Coaxial Folded Optics Configuration

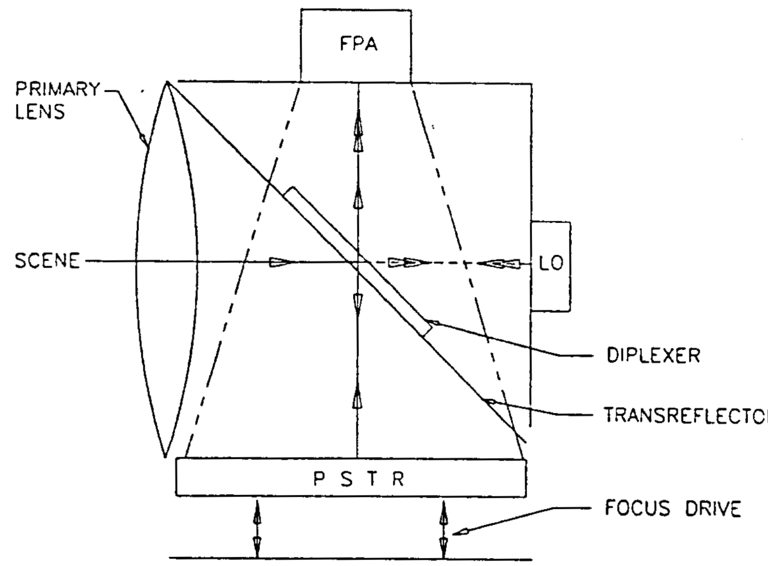

Figure 2-2. Unblocked Folded Optics Configuration

2.2 Active Optics for Load Comparison

Load comparison must be implemented in many Millivision® sensors to deal with receiver gain fluctuations and as part of the flat-field algorithm used to generate a suitable image. In the load comparison mode, each receiver channel input is switched between viewing the scene and viewing a common comparison load.

The adverse effects of gain fluctuations can be reduced by switching each receiver channel input between a comparison load and the scene at a rate higher than the high frequency cutoff of the receiver gain fluctuation spectrum and then differencing the two outputs. This load comparison process allows the output noise to be dominated by the statistical noise as predicted by the radiometer equation rather than the effects of gain fluctuations. A good load comparison scheme is especially important when W-band LNAs are used in the FPA. Switching rates are typically near 1 kHz. An ambient temperature comparison load is desirable, as it is very close to relevant scene temperatures. This results in an approximately balanced comparison, further minimizing the effects of gain fluctuations.

The comparison load response of each channel is also needed for implementation of the flat-field algorithm. The effective load temperature for each channel should be the same for a uniform response over the entire field of view. Stability of the comparison load temperature is less critical.

A load switching twist reflector (LSTR) is used to implement load comparison in Millivision® imagers. The twist reflector in a folded optics configuration can be made up of a quarter wave plate (QWP) backed by a reflecting surface. The QWP converts an incoming linearly polarized signal to a circularly polarized signal. Upon reflection, the handedness of the circularly polarized signal is reversed and when passed through the QWP, emerges in as a linearly polarized signal orthogonal to the incoming signal - thus the "twist reflector" nomenclature.

The reflecting surface, when a passive optical element, is typically a metal plate. In the active optics implementation of the twist reflector, the plane metal reflector is replaced by an array of active devices called wave processing MMICs. For the LSTR case these wave processing devices are GaAs MMICs that have the property that in one bias state they are excellent reflectors and in the other bias state they are excellent absorbers. In the reflective state, the element becomes a twist reflector and the focal plane array views the scene. In the absorptive state, the element becomes absorptive and the focal plane array views this absorptive element as a comparison load. The LSTR implementation and operation is described in more detail by Huguenin, et al (1996).

The LSTR comparison load, by virtue of its location in the optical train, is viewed equally by all channels. Thus the LSTR comparison load meets the uniformity criterion for flat-field algorithm implementation. An example of an LSTR element for 300 mm primary optics which was developed under the Agreement is shown in Figure 2-3.

2.3 Active Optics for Phase Shifting

Staring imagers require an internal means for scanning/dithering the focal plane array with respect to the scene in order to fully sample the highest spatial frequencies of the scene present in the focal plane. For an optimally filled FPA, a 2×2 scan of each channel is necessary for Nyquist sampling. A 4×4 scan provides for 2× over sampling. For an unfilled array, even larger scan matrices are required.

A phase shifting twist reflector (PSTR) is used for fully sampling of the focal plane image in Millivision® staring imagers. The PSTR uses an array of GaAs wave processing MMICs to make up the reflecting element in the QWP-reflector implementation of the twist reflector. Each element of the multi-element reflector array has the property that the phase of the reflected signal can be controlled by appropriately adjusting the bias to the element. In this manner, suitable phase gradients can be imposed across the reflector resulting in a tilt of the wavefront; i.e., a scanning of the image. The PSTR controller stores all of the necessary bias conditions for each element of the array for each scan matrix position. A photograph of an operating 64 element array PSTR with control electronics for use with 150 mm primary optics is shown in Figure 2-4.

Current PSTR device designs are suitable for dithering fully sampled focal plane arrays. A next generation of phase shifting wave processing MMIC devices are under development that will allow low loss scanning of multiple beamwidths to permit use of sparse arrays in large field of view imagers.

3.0 FOCAL PLANE ARRAYS

3.1 FPA Architectures

The array elements for the focal plane arrays (FPAs) for millimeter wavelength imagers are individual receivers with feed antennas. Array element spacing for optimally sampled arrays is such that the far field beams overlap at the half-power (-3dB) points. The physical spacing of elements in the focal plane depend on the focal length of the main optic, the illumination of the main optic, and the operating wavelength. For typical f/D ratios of near unity, moderate edge tapers, and wavelengths near 3 mm, the spacing is approximately 4 mm along each axis in the focal plane. It is necessary to implement a complete FPA channel in a volume approximately 4 mm × 4 mm × whatever length is needed along the optical axis.

Millivision® FPAs use slot antennas printed on the same substrate as the millimeter wave front end portion of the receiver elements. Slot antennas are endfire antennas which achieve their gain as a

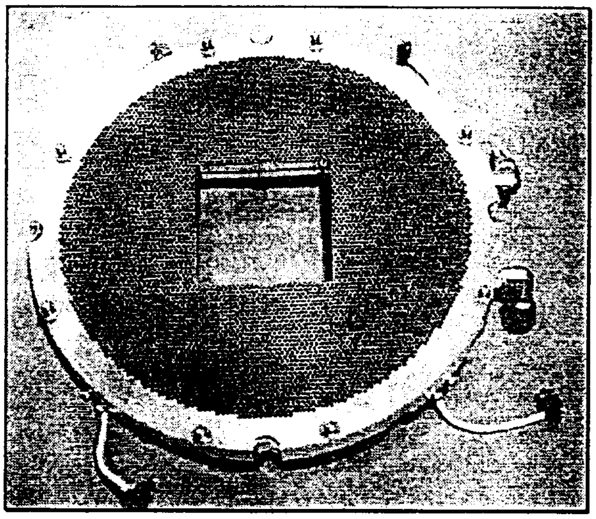

Figure 2-3. LSTR Comparison Load.

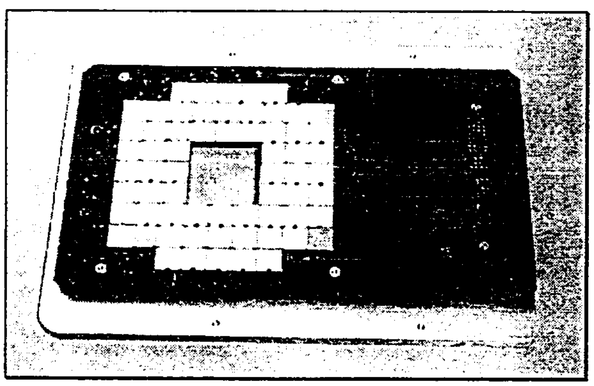

Figure 2-4. 64 Element Phase Shifting Twist Reflector (PSTR) and Control Electronics.

result of their length, allowing array elements to be optimally packed and also have reasonably efficient illumination of the main optic. The ability to simply print these antennas on an existing substrate is also very cost efficient.

Several receiver architectures can be used to achieve the necessary gain for the array elements. The simplest architecture is to achieve the 60 to 70 dB of pre-detector gain using an amplifier at the operating frequency. This is traditionally called a tuned radio frequency (TRF) receiver. TRF receivers tend to have fairly wide bandwidths, which is good for radiometric applications as long as it is not too wide for the tuned elements of the optics to accommodate. Amplifier gain at millimeter wavelengths is today still quite expensive and not easily available. Also, achieving that much gain stably is a challenge. Low frequency noise fluctuations inherent in millimeter wave MMIC amplifiers are also additive. For these reasons, we have not elected to use the TRF approach at present. The TRF option should become more attractive for some imaging applications as millimeter wave MMIC devices become better and more available in the marketplace.

We have elected instead to employ heterodyne (and homodyne) receivers to achieve the necessary gain and bandwidth for each application. Their biggest negative? These heterodyne/homodyne architectures involve the need for a local oscillator, which adds to the receiver complexity.

3.2 Mixer Input Heterodyne and Homodyne FPAs

The traditional mainstay of millimeter wave receiver architectures is the mixer input super-heterodyne. The main drawbacks of this receiver design for radiometric imaging FPAs are: 1) the difficulty of achieving adequate stable gain at the intermediate frequency (IF); 2) less than optimum receiver noise temperatures; and 3) LO leakage and interactions.

The LO leakage and interaction problem is largely solved by using a subharmonic LO along with appropriate high pass filtering which minimize LO leakage and interaction problems. A disadvantage of the subharmonic LO is the loss of 1 to 2 dB in conversion loss/noise figure. In the Millivision® imagers developed with support from the Agreement, the LO is optically diplexed with the RF scene energy and both are received by the feed antenna. The input mixer is therefore a single ended subharmonic mixer. For radiometric applications, both upper and lower mixer sidebands have signal.

Examples of mixer input FPA elements are shown in Figure 2-5. These are quite adequate for many applications and have the advantage of being relatively low cost.

3.3 Low Noise Amplifier Input

For those applications where lower noise temperatures are required, it is advantageous to add a millimeter wave low noise amplifier at the input. This amplifier makes it easier to increase overall gain and to reduce the receiver noise temperature significantly (typically by up to 7 dB). The amplifier also must deal with the subharmonic LO signal present at the input and generate an LO signal suitable for pumping the mixer following. An LNA input FPA board with 8 elements is shown in Figure 2-6.

4.0 IMAGE PROCESSING ALGORITHMS

Basic algorithms, such as the flat-field algorithm described briefly in Section 4.1 were developed with support in part of the Agreement. The other algorithms described below are being developed under a DARPA sponsored TRP effort carried out jointly with Amerinex Applied Imaging (AAI).

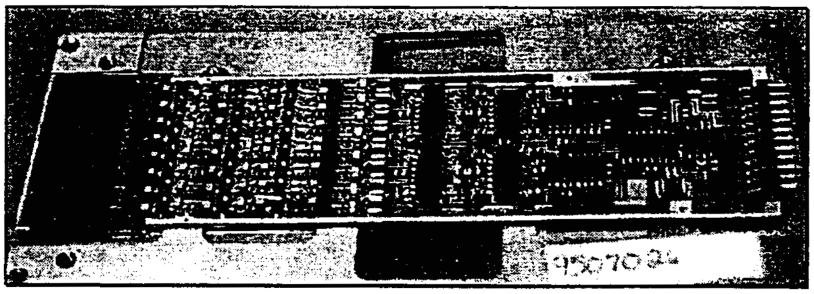

Figure 2-5. Mixer Input Focal Plane Array Elements.

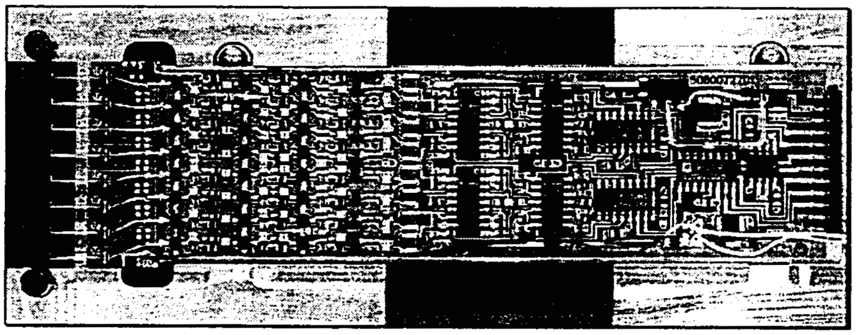

Figure 2-6. Low Noise Amplifier Input Focal Plane Array Card.

4.1 Flat-Field Algorithms

Perhaps the greatest challenge for both hardware and software in implementation of focal plane array imaging is the development of a suitable algorithm for obtaining a flat field. "Flat-fielding" is the process of normalization of individual FPA channel outputs to assure that a scene of uniform brightness results in a uniformly gray image.

Two reference brightness levels are required to normalize the gains and offsets of each channel to produce a flat field. Both of these reference levels need to have a known distribution over the full field-of-view of the sensor. The reference level distributions are ideally close to uniform spatially and change only slowly over time.

Long term running averages of the reference level observations are used to minimize the fraction of time used to observe the reference loads and to minimize the noise uncertainty in the averages. The result is a maximization of the contrast-to-noise ratio while at the same time assuring a suitably flat field.

4.2 Resolution Enhancement Algorithms

The optimum spacing of focal plane array elements from an electromagnetic point of view produces individual channel responses that overlap at the half-power (-3dB) points. This results in an under sampling of the spatial frequency spectrum of the scene image in the focal plane of the input optics. In order to recover the higher spatial frequencies present in the element's transfer function, it is necessary to sample the focal plane image at a higher spatial frequency rate.

This higher spatial frequency sampling is accomplished by scanning (dithering) the focal plane array relative to the image to obtain samples at the desired spatial frequencies. This scanning can be done systematically within the camera, using, for example, a PSTR (as described in Section 2.3) for dithering both axes in the TWIS or Video Surveillance Camera systems, or the sampling can be done by scanning the whole camera over the scene as is done on one axis in the Gateway Scanner or for both axes in the Handheld Scanner.

The adequately sampled focal plane image data is then processed using one of many established "super resolution" algorithms to generate a resulting output image that has higher spatial frequencies present. Increases in resolution of many times the HPBW resolution are possible. Signal-to-noise considerations limit practical resolution enhancement to about 2 × to 3 × for each axis. Multiplicative algorithms, such as the one described by Gleed, et al, "New High-Speed Method for Super-Resolving Passive Millimetre Wave Images", *SPIE International Conference on Passive Millimeter-Wave Imaging Technology*, Orlando, FL, 21 - 25 April 1997, are more useful for video rate imaging than some of the iterative algorithms used by radio astronomers.

4.3 Motion Compensation Algorithms

Motion of the person being scanned during the few seconds of scanning can result in distortions of the output image. Algorithms have been developed that will compensate for limited motions, removing the resulting distortions from the output image. Scanners are required to have simultaneous multiple samples along the direction of scan to implement these algorithms. Alternatively, a visual wavelength TV camera image can be used to remove distortions caused by moderate motion of the subject during the scan. Such motion compensation algorithms are planned to be used in Millimetrix Gateway and Handheld Scanners.

5.0 MILLIVISION® IMAGERS

5.1 Video Surveillance Cameras

A prototype of Millimetrix' future Video Surveillance Camera, developed in part under this Agreement, is shown in Figure 5-1. This passive millimeter wave imaging camera employs Millivision® technology to provide a "real time", 30 frame per second, video image of the field of view under surveillance. The production Video Surveillance Camera will have a field of view of 24 × 36 degrees corresponding to 128 × 192 pixels with resolution of 12 × 12 mm (1/2 × 1/2 inch) and a field of view of 1600 × 2400 mm (5.25 × 8 feet) at 4 meters (13 feet). The camera will typically be mounted on a pan/tilt positioner that will permit remote operator scanning of the area of interest. It will have autofocus capabilities allowing automatic use from 1 meter to infinity. The radiometric background noise in a 1/30 second frame for one pixel will be under 1 Kelvin.

5.2 Gateway Scanner

Millimetrix' future Gateway Scanner product is designed to detect weapons and other contraband concealed under the clothing of people entering sensitive areas through one or more well defined gateways. A prototype Gateway Scanner is shown in Figure 5-2. Although the Gateway effort was not part of the development effort under the Agreement, it does make use of Millivision technology developed earlier under the Agreement.

The Gateway Scanner employs a passive (radiometric) millimeter wave line imager to generate two views of the individual being screened for concealed weapons, plastic explosives, electronic devices and other contraband. Passive imaging enables the detection of a full range of weapons and contraband, is completely people safe, and is very difficult to countermeasure. The line scan camera, which is at the heart of the Gateway Scanner, operates at 94 GHz and employs Millivision® technology.

The primary optic of the Gateway Scanner camera shown in Figure 5-2 is a lens 450 mm in diameter. The camera focal plane array consists of 4 rows of 64 elements each. Adjacent rows are offset horizontally by 1/4 of the channel-to-channel spacing and vertically by the full channel-to-channel spacing to provide for adequate horizontal axis sampling of the image. The output of each of the 256 focal plane array channels is sampled every 3 mm of vertical scan travel to provide the same 1/4 channel-to-channel spacing along the vertical axis. The rms noise for each pixel is between 0.5 and 1 Kelvin.

The imaged area at 1 meter range is 1920 × 768 mm with approximately 3 × 3 mm resolution (640 × 256 pixels) - presumed adequate to determine the projected shape of any contraband. The contrast to rms noise ratio is expected to be about 20:1 or about 13 dB, more than adequate for the detection of concealed weapons, bombs, and most other contraband. The time to screen a person is estimated to be about 30 seconds, with 10 seconds to generate each of two images (front/back) and another 10 seconds for the screenee to enter the booth, turn around between scans, for the operator make a "pass/fail" decision, and for the screenee to exit. A booth can also be configured with two scanning cameras which would permit simultaneous left/right images to speed throughput to 15 seconds or less with a single operator. Automation should improve throughput even further. A digital record of each visual and millimeter wave image of each screenee can be stored for future reference.

The 64 × 4 element focal plane array camera is operated in the total power mode. Each channel is a double sideband, mixer input superheterodyne receiver. Flat field calibration is accomplished using two thermal targets located in the top compartment of the booth (see Figure 5-2) at the screening

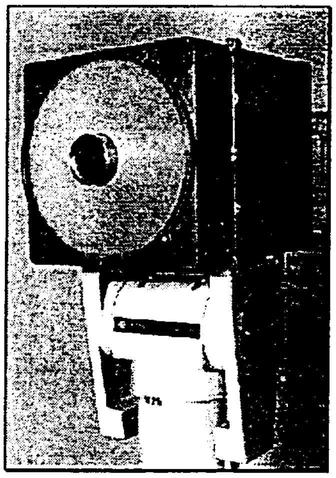

Figure 5-1. Video Surveillance Camera Prototype.

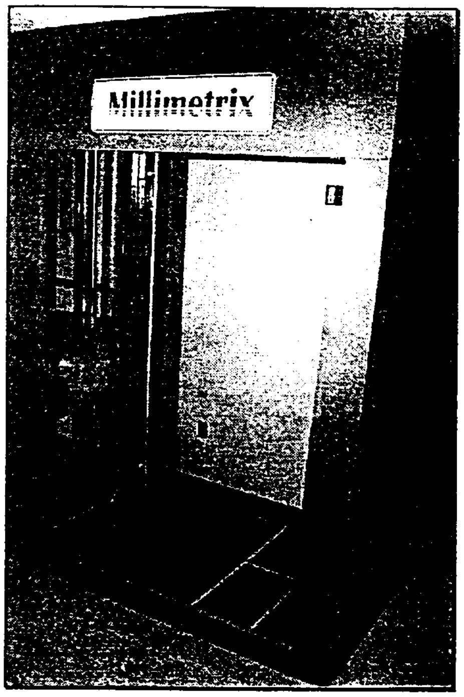

Figure 5-2a. Prototype Gateway Scanner System.

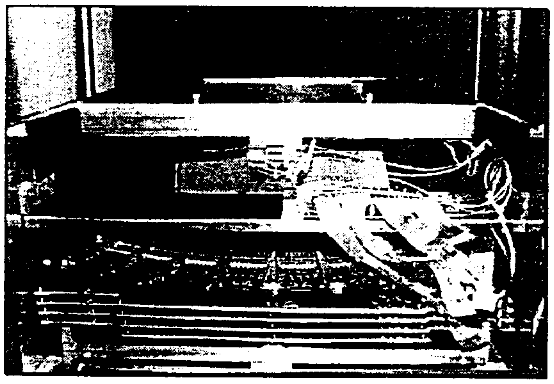

Figure 5-2b. Gateway Scanner Camera.

distance of 1 meter from the camera. These targets are observed at the beginning of every two-image scanning cycle as the scanner moves from top to bottom. The temperatures of the two loads differ by 20 C, typical of the separation between room temperature (approx. 20 C) and body temperature (approx. 37 C). The booth wall opposite the scanner is covered by room temperature absorber to provide an uncluttered background for the image.

Algorithms are being developed to correct for slight movements of the person during the 10 second scans in the displayed images, to further enhance image quality, and to highlight potential weapons, bombs, or other contraband to aid the operator in making a "pass/fail" screening decision.

5.3 Handheld Scanner

The development of the Handheld Scanner demonstration sensor hardware was supported in large part by the Agreement. A mockup of Millimetrix' future Handheld Scanner product is shown in Figure 5-3. The Handheld Scanner will employ an internal battery that allows completely portable operation. The operator will use the device to manually scan a suspect for the presence of concealed weapons or other contraband. The scanning process takes only a few seconds and the resulting image is displayed on an LCD monitor on the backside of the Handheld Scanner in easy view of the operator. This passive device is completely people safe and is difficult to countermeasure.

The Handheld Scanner is a radiometric device operating at 94 GHz and employing Millivision® technology. The primary optic is a lens150 mm in diameter and is used in conjunction with a coaxial transreflector and twist reflector for compactness. A high sensitivity 8 × 8 focal plane array employing MMIC low noise amplifiers is employed. A load switching twist reflector (LSTR) is used for load comparison and flat fielding purposes.

Successive 30 Hz frames are to be overlayed to build up an image of the person being scanned with resolution of about 6 mm at 1 meter. The alignment of successive frames is facilitated by a co-boresighted, frame synchronized visual light TV camera. The evolving millimeter wave image is displayed to the operator who manually controls scan coverage of the screenee over areas of greatest suspicion or likely danger. These key algorithms are being developed with TRP support. Digital storage of operator selected images is provided for future analysis and for use in court as evidence.

In operation, the operator will manually scan the screenee from a distance of between 1 and 3 meters using generally up-down sweeps of the arm to scan the screenee's body while observing the image build up on the LCD monitor located on the backside of the scanner. An image of 64 × 160 pixels covering an area of 768 × 1920 mm at 2 m with 12 mm resolution can be obtained in under 2 seconds. The Handheld Scanner is designed to be controlled by a "trigger" and be "instant-on". The rechargeable battery capacity is targeted for one hour of continuous operation, which with a typical operating duty cycle of 5 - 10%, should last a full day - even on bad days.

5.4 Through Wall Imaging System

Through Wall Imaging Systems (TWISs) are imaging radar systems used to enable surveillance of a room from a convenient and accessible location outside of the room. A prototype TWIS system is currently under development by the MIRTAC consortium led by Millimetrix and supported by a TRP administered by Rome Labs. The future Millimetrix TWIS product is a 94 GHz system that will allow determination of the location of fixed furnishings and other inanimate objects within the room as well as determination of the location, posture, and activity of people within the room. The

TWIS system can also detect the presence of certain weapons, especially in the hands of persons located within the room.

Most building materials appear to attenuate, but not scatter, signals at 94 GHz. Attenuation of many wall/floor/ceiling types is high enough that passive systems cannot be used to "see" through them without significant loss of signal to noise. Passive systems also cannot see or locate exactly the inanimate objects within the room. For these reasons the Millimetrix TWIS product is based on an active radar sensor. A radar transmitter is used to flood the room with a very low level of millimeter wave energy, a level well below any safety standard for maximum permissible exposure. The reflected energy is imaged using a Millivision® focal plane array receiver system and a separate transmitter as shown in Figure 5-4. The transmitter and receiver are offset in a bistatic configuration to minimize coupling due to reflections within the wall.

The imaging radar receiver uses a 300 mm lens as the primary optic with a coaxial transreflector and twist reflector combination that permits folding. A phase shifting twist reflector is used to provide 2×2 electronic scanning of the image with respect to the focal plane array. Processing of the radar data is used to further enhance the resolution, producing 64×64 pixel images in the cross range directions.

A linear, 1.5 GHz bandwidth FMCW waveform is used to achieve 256 range bins over a 20 meter total range with effective resolution of 12 cm. The operator selects any 64 contiguous range bin interval between 1 and 20 meters for display. The resulting 3D image therefore consists of $64 \times 64 \times 64$ voxels at a rate of 15 frames per second. With some augmentation of the radar signal processor, the full $64 \times 64 \times 256$ voxel raw image data can be output to the image understanding processor. The demonstration TWIS system is shown in Figure 5-5.

The Millimetrix TWIS production product is configured to be two-man portable. Two people should be able to carry in and set up the system in just a few minutes. Battery operation will permit over one hour of continuous operation - considered adequate for most applications. If longer term surveillance is required, either a source of local power or larger batteries would be required. The system is designed to work through walls, doors, floors and ceilings - providing a choice of potential sights from which to observe.

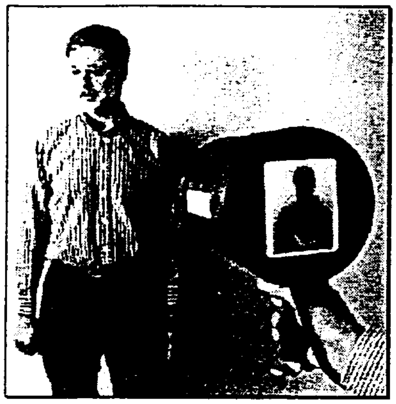

Figure 5-3. Handheld Scanner Product Mockup.

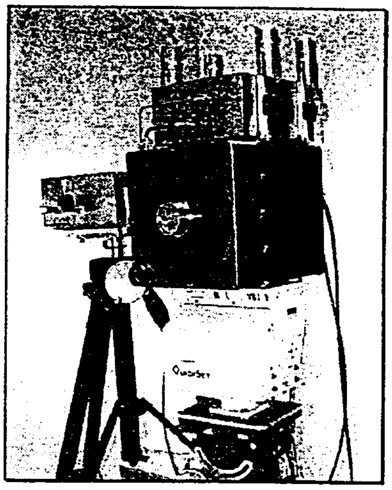

Figure 5-4a. Through Wall Imaging Receiver.

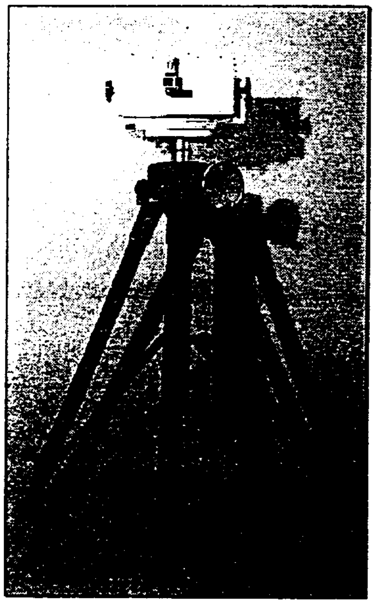

Figure 5-4b. Through Wall Imaging Transmitter.

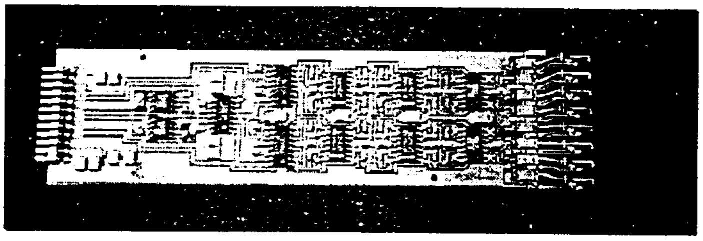

Figure 5-4c. Through Wall Imaging System Focal Plane Array Card.

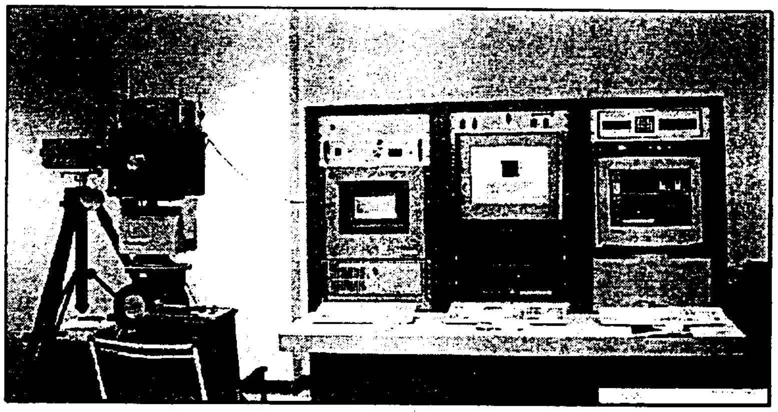

Figure 5-5. Demonstration Through Wall Imaging System (TWIS).

U.S. DEPARTMENT OF JUSTICE
Office of Justice Programs

CATEGORICAL ASSISTANCE PROGRESS REPORT

COPY

In formation provided will be used by the grantor agency to monitor grantee cash flow to ensure proper use of Federal funds. No further monies or other benefits may be paid out under this program unless this report is completed and filed as required by existing law and regulations (Uniform Administrative Requirements for Grants and Cooperative Agreements — 28 CFR, Part 66, Common Rule, and OMB Circular A-110).

GRANTEE MILLIMETRIX, LLC	2. AGENCY GRANT NUMBER 95-IJ-CX-K007	3. REPORT NO. 6
IMPLEMENTING SUBGRANTEE	5. REPORTING PERIOD (Dates) FROM: 7/1/96 TO: 4/16/97	
SHORT TITLE OF PROJECT CWD & Millimeter Wave Imaging	7. GRANT AMOUNT $1,430,000	8. TYPE OF REPORT ☐ REGULAR ☐ SPECIAL REQUEST ☒ FINAL REPORT
NAME AND TITLE OF PROJECT DIRECTOR G. Richard Huguenin President and CEO	10. SIGNATURE OF PROJECT DIRECTOR G.R. Huguenin	11. DATE OF REPORT 4/16/97

COMMENCE REPORT HERE (Continue on plain paper)

The concealed weapon detection development effort was terminated by Millitech in January 1996. A development effort continued on the premises at Millitech from January to early April 1996 that was paid for by the shareholders of Millimetrix, LLC. The majority of the development team was then laid off by Millitech on 8 April 1996. Millimetrix, LLC was formed by Richard Huguenin on 1 July 1996 to develop, manufacture, and sell products for concealed weapon detection (CWD) and was able to hire most of the development team that had been laid off by Millitech. Millimetrix also purchased from Millitech the intellectual property and development facilities related to CWD product development. Millimetrix has continued CWD product development since 1 July using private investor funds.

The 150 mm Test Bed was used during this period to test the Generation IV focal plane array (FPA) that incorporates W-band MMIC low noise amplifiers (LNAs) and to test the first phase shifting twist reflector (PSTR). Both tests were successful.

The Generation IV FPA tested used Lockheed Martin W-band LNAs that we now learn will no longer be available. Lockheed Martin is unable to provide us with the numbers of working devices required. We have investigated other potential sources of MMICs and have purchased a number of devices from TRW for evaluation. We will re-design the FPA to accommodate the TRW devices as soon as resources permit.

The PSTR for the 150 mm Test Bench has been assembled and tested. The measured beam steering is as predicted. We are currently developing a PSTR for radar applications under the MIRTAC consortium's TRP program. We will continue development of this unique and revolutionary device for passive CWD applications when resources become available.

We have had several meetings with Rome Lab personnel during this period. They have been kept abreast of our situation and progress.

CERTIFICATION BY GRANTEE (Official signature) G.R. Huguenin G. Richard Huguenin, President and CEO	14. DATE 17 April 97

FORM 4587/1 (REV. 2-90)