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ACTIVE IMAGING OF RANGE TARGETS
AT 1.2 MILLIMETERS (U)

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Several years ago P. W. Kruse (1) and R. L. Hartman et. al (2) showed that for detection and tracking of "obscured" targets at ranges up to 3 km, submillimeter wavelengths in the atmospheric windows between 0.74 - 1.3 mm offer great potential advantages over wavelengths in both the optical and in the microwave regions. At submillimeter wavelengths a significant reduction over the conventional microwave antenna size needed for a given resolution can be realized. Submillimeter waves also penetrate fogs and aerosols much more effectively than do the shorter optical and IR wavelengths. We have demonstrated active target imaging through the atmosphere with a submillimeter wave laser operated at a wavelength of 1.2 mm. Copper corner cube targets were imaged over a maximum atmospheric path of 650 meters (two-way) using an 0.3 meter antenna.

The system used (3) has a CO₂ pumped SMMW gas laser which is passed through a beam expander to a 0.3 meter diameter f/5 primary mirror and then to a computer controlled two-axis scan mirror which directs the beam down a target range adjacent to the laboratory building. The return beam is collected through the same optics and sent by a beamsplitter to the detector, and the signal is sent to the computer from a lock-in amplifier.

The targets consisted of a trio of copper corner cubes at 100 meters from the primary, and a single copper corner cube at 325 meters. The cubes at 100 meters were 30 centimeters on a side, and the cube at 325 meters was 90 centimeters on a side.

The output of the SMMW system at the scan mirror is on the order of a hundred microwatts. The detectors used were Golay cells, and the chopping frequency was 13.5 Hz. The scan mirror is an Aerotech tracking gimbal which is limited to 500 steps per second, at 0.25 arcsecond per step, and thus each image scan required two hours to complete. This is not a fundamental restriction to the frame rate, as faster detectors and faster scan

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mechanisms exist or can be constructed. Table 1 shows the current system parameters and some near-term improvements.

Figure 1 shows scanned images of the three corner cubes at 100 meters. The variation in relative signal strength is due to the difference in construction among the three cubes. The images are reversed left to right from the actual scene.

The images are all 40 x 40 pixels. Those in the left column are the original data, those on the right are the result of one pass with a 3 x 3 recursive median filter after the image was recorded. (a) shows that the system was detector noise limited and that only cooperative targets were detected. None of the support structure or surrounding terrain features are visible in the processed image on the right. (b) was taken with an iris in the return beam focal plane set at a 30 millimeter aperture. (c) is the same as (b) but with the iris closed to a 7 millimeter aperture.

This aperture gave a peak signal of one-half that of case (b). In (c) the signal on the right in the processed image was thresholded in the computer display so that the white center section corresponds to the FWHM. The cubes were six feet apart horizontally and vertically. In the other images the threshold was set to show low level pixels, and the apparent diameters of the targets do not correspond to the measured FWHM.

Figure 2 shows the corner cube at 325 meters. (a) is with the 7 millimeter aperture and (b) is with the 30 millimeter aperture. Note in (b) the presence of interference fringes due to unwanted radiation scattered from the components in the optical train.

Figure 3 is an isometric plot illustrating the effect of the recursive median filter after one application. Note that the strongest return is clipped as a result of the graphics display program. The recursive filter differs from the standard median filter in that the new value of a pixel is substituted before the filter mask is shifted to the next set of data points. This filter gives effective random noise reduction in a single pass. N. C. Gallagher (4) has shown that in one-dimensional signals, a single pass of a recursive median filter produces a root function that is not altered by additional passes. We observe that in two dimensions there are low-level changes in our images with repeated passes of the 3 x 3 recursive filter; but that the initial pass has by far the major smoothing effect on the images.

Two measurements of the FWHM were made, one using the iris and the other by measuring the FWHM of the scanned images. As a check, the system was centered on a corner cube, then scanned in each axis to the half-power points, and the change in location was visually observed with a sighting telescope which looked through the scan mirror. The FWHM measured in this

way was, in both axes, about 5/3 the length of the side of the corner cube, or 5 milliradians. The FWHM measured from the scanned images was 5.4 milliradians. Both of these are $\pm 10\%$ measurements. The iris measurement corresponded to 4.6 milliradians, and was good to $\pm 8\%$. The Rayleigh limit for a plane-wave, using a 30 cm aperture and a wavelength of 1.2 millimeters is $1.22 \lambda/D = 4.88$ milliradians.

Since the resolution of an active system depends only on the transmitted spot size, these numbers show that the transmitted beam was the size of a diffraction limited plane-wave Airy disc at the target. The resolution can be improved by operating with shorter wavelengths and larger antennas.

Based on previously developed criteria (5) for detection and recognition of military targets, the experimentally determined resolution of 5 mr would be sufficient to recognize a M-48 tank at a range of ~ 0.5 km and to determine its orientation at a range of ~ 1.5 km using a one-meter diameter antenna, and operating in the atmospheric "window" near 0.75 mm wavelength.

In addition, the resolution of an active system using coherent laser radiation can be significantly improved by operating with a Gaussian beam profile, as shown in figure 4. Gaussian beams have a beam waist located beyond the primary mirror antenna as indicated in the figure, and thus the apparent angular spot size as seen from the primary is a function of the range. The solid curve shows this for the current system of 0.3 meter aperture and 1.2 mm wavelength, and the dashed curve for a 0.5 meter aperture at .75 mm wavelength. In general, this gives smaller apparent spot sizes than would be expected using the Rayleigh criteria. Since it requires neither shorter wavelengths nor larger primary apertures, this gain in resolution is one reason to prefer an active coherent imaging system over a passive and/or incoherent system.

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2. R. L. Hartman, W. L. Gamble, B. D. Guenther, and P. W. Kruse, "Submillimeter System for Imaging Through Inclement Weather", The Optical Submillimeter Propagation Conference, Puerto Rico, 6-10 December 1976.
3. G. A. Tanton, J. F. Osmundsen, R. L. Morgan, H. C. Meyer, and J. G. Castle, Jr., "Atmospheric Propagation of Submillimeter Waves: Observed Correlations with Fog Conditions at 0.89 mm Wavelength", Technical Report RR-80-3, US Army Missile Command, February (1980).
4. N. C. Gallagher and G. L. Wise, "A Theoretical Analysis of the Properties of Median Filters", IEEE Trans. on Acoustics, Speech, and Signal Processing, Vol. ASSP-29, pp 1136-1141, December (1981).
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TABLE 1.
SUBMILLIMETER WAVE IMAGING

<u>CURRENT SYSTEM</u>	<u>NEAR TERM IMPROVEMENTS</u>
<u>RANGE SYSTEM</u>	
Corner Cubes	Non-cooperative military targets
<u>DETECTORS</u>	
Golay cells, 10^{-9} W/√Hz N.E.P., 10 Hz BW	InSb bolometer, 10^{-12} W/√Hz, up to 1 KHz BW. Ge bolometers, 10^{-14} W/√Hz, 100-500 Hz BW. Heterodyne detectors, $\sim 10^{-20}$ W/Hz, GHz BW.
<u>SMMW LASER</u>	
1.6 m cavity 100 μw at 1.2 mm output.	2.5 m cavity, CO ₂ pump, gas laser, output of 10's of mw, improved optical and mechanical design, operation in 0.89 and 0.75 mm regions.
<u>OPTICS</u>	
f/5, 30 cm primary Two-axis full aperture scan	one-axis counter rotating mirrors, one-axis tilting mirror, focal plane scanner.
<u>CONTROLLER</u>	
HP 21MX Computer	Upgraded F-series mainframe
<u>SOFTWARE</u>	
Scanning program Median filters Simple Algebra	standardized mag tape format, expanded image manipulation, range data processing, program compatibility

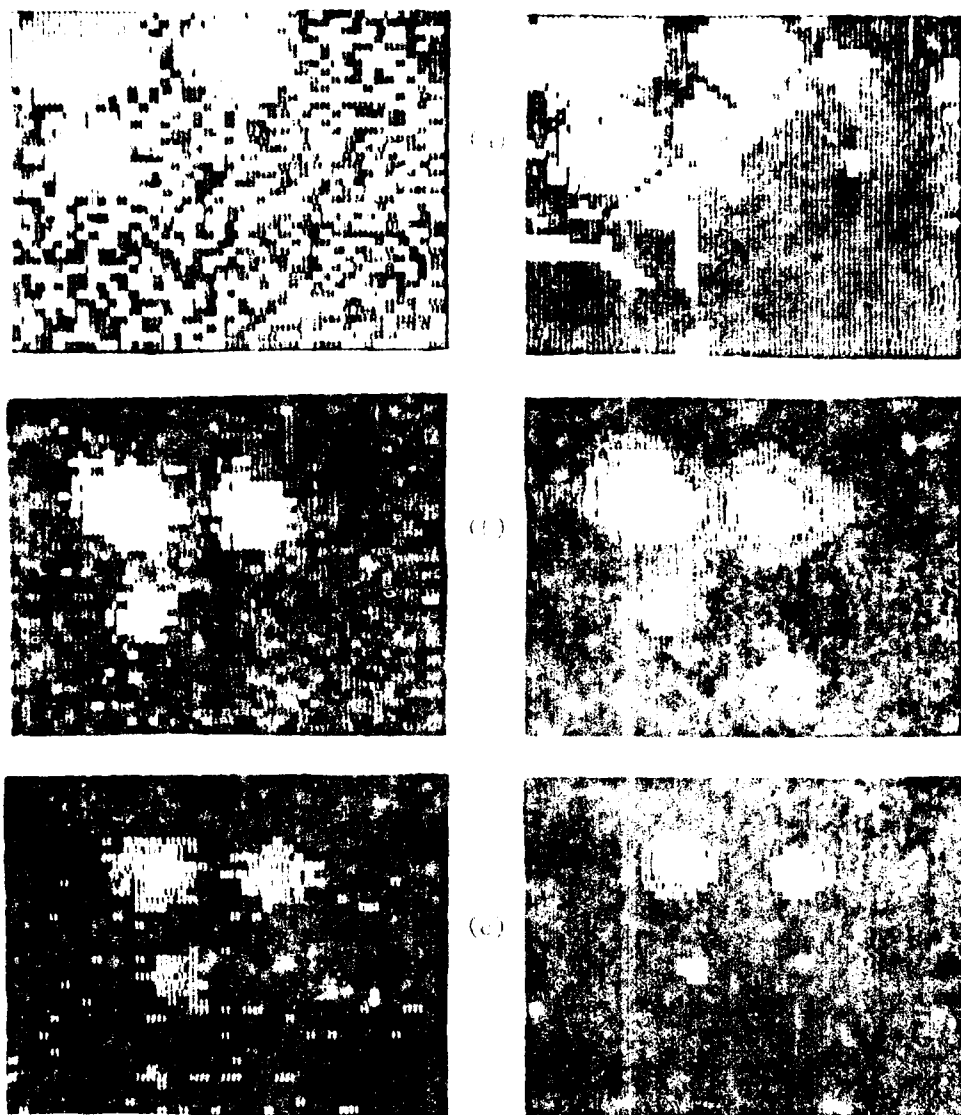


Figure 1. THREE 30 cm CORNER REFLECTORS AT 10.70 Hz

The images in the left column are the original data, those on the right are the result of one pass with a 3×3 smoothing median filter after the image was recorded. (a) three corner reflectors, (b) and (c) consist of an aperture in the focal plane, (b) 30 cm aperture, (c) 1 m aperture. This aperture gave a peak signal of approximately one half that of a 30 cm.

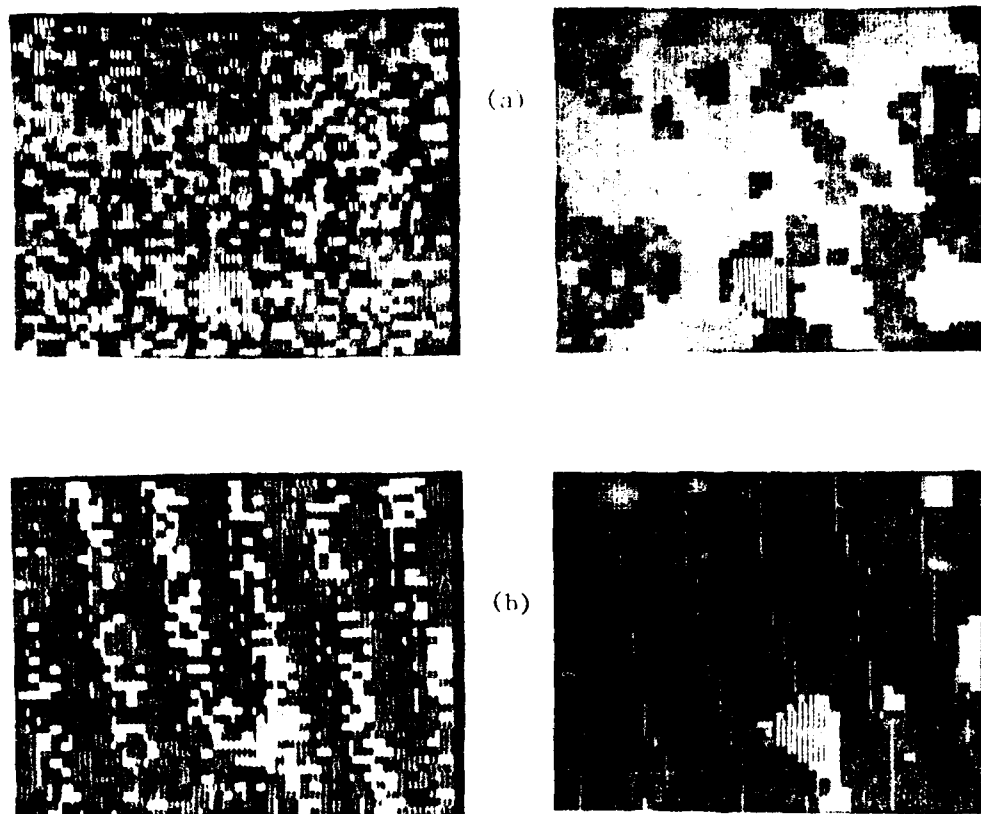
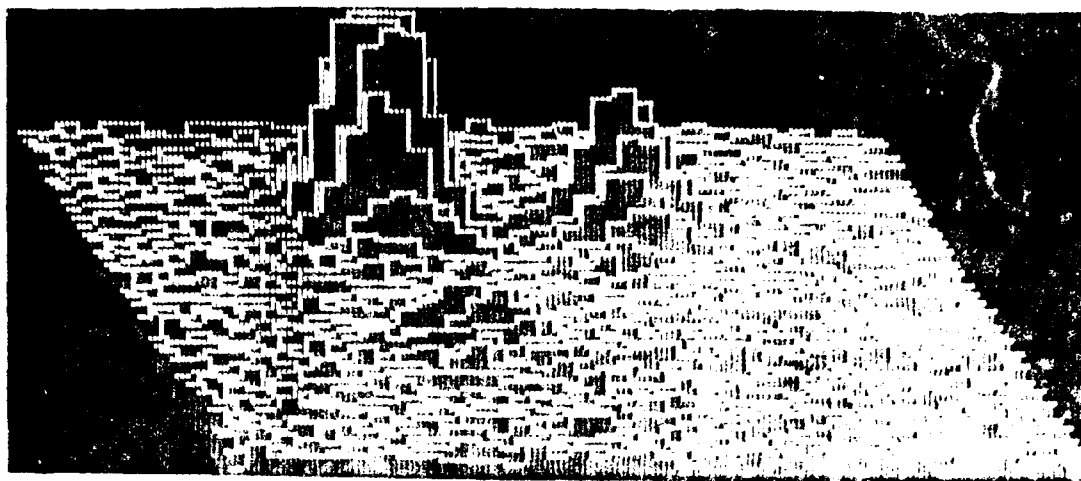
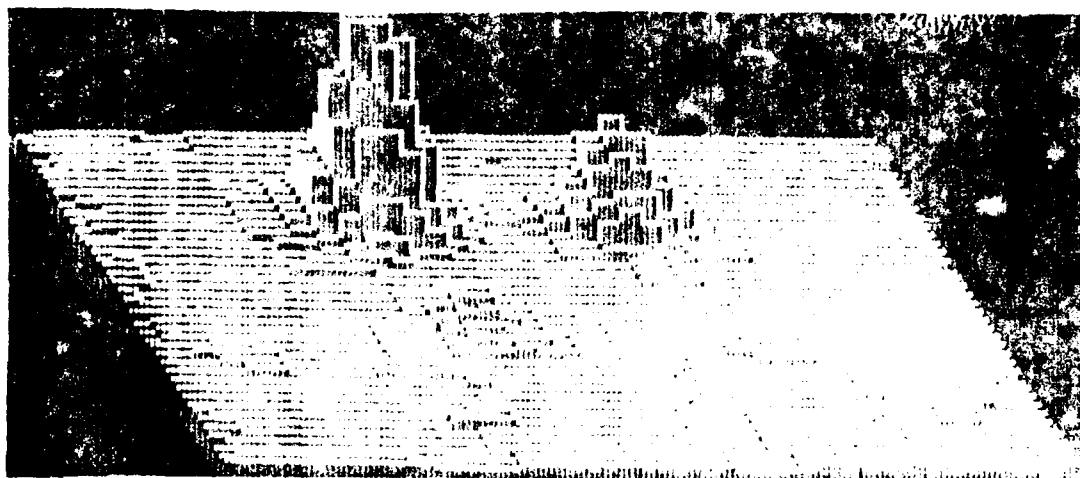


Figure 2. ONE 90 cm CORNER REFLECTOR AT 325 METERS

- (a) (Left) Original data, with a 7 mm focal plane aperture step.
(Right) Same image after application of a 3 x 3 recursive median filter.
- (b) (Left) Original data, with a 30 mm focal plane aperture step.
(Right) Data after software filtering. The interference fringes are due to the optical components in the scanning system.



(a)



(b)

Figure 3. ISOMETRIC PLOT OF RANGE IMAGE

- (a) Original data, showing three corner reflectors with a 7 mm focal plane aperture stop.
- (b) Two dimensional 3 x 3 recursive median filter applied to the original data.

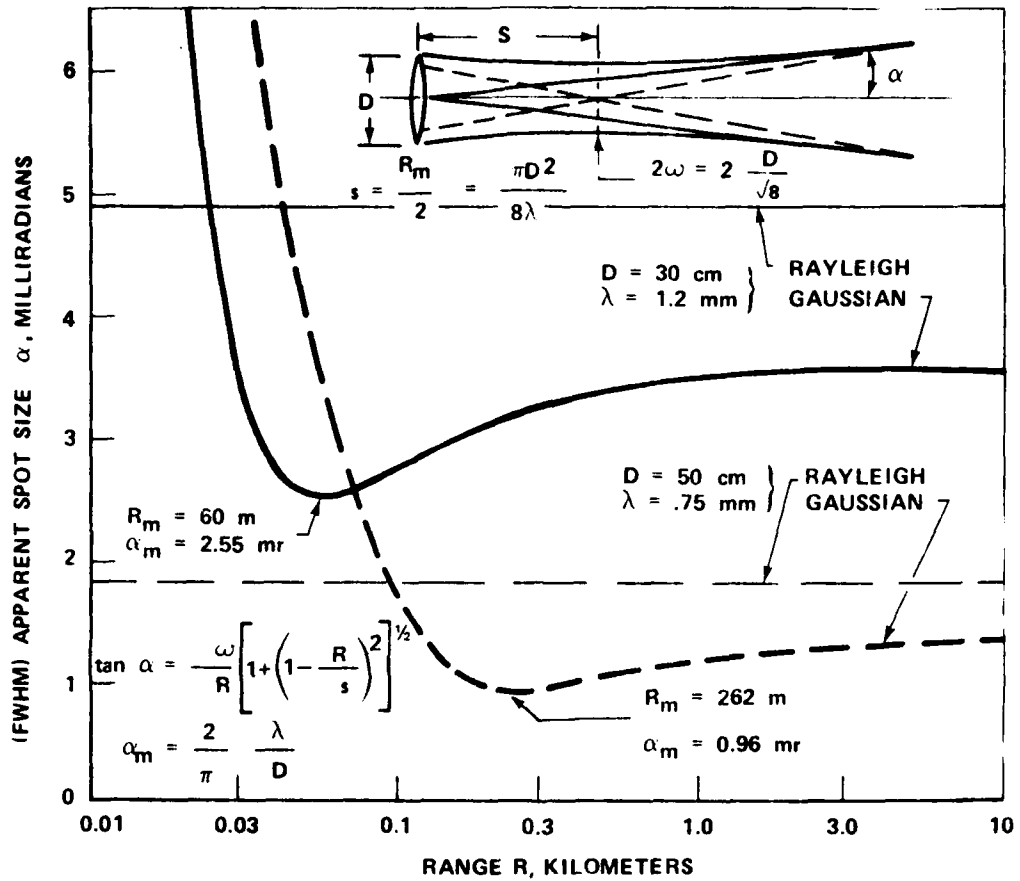


Figure 4. Apparent spot size of a Gaussian beam compared to a classical optical beam in the image plane of a lens, plotted as a function of range.