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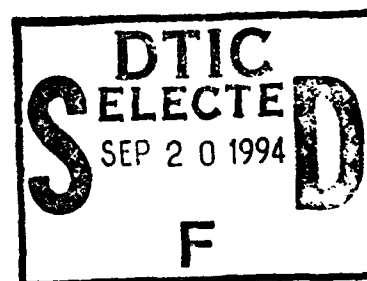
Large Area Thermal Target Board:

An Improvement to Environmental Effects
and System Parameters Characterization

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13. ABSTRACT (Maximum 200 words) Recent field tests have provided excellent opportunities to use a new characterization tool associated with the Mobile Imaging Spectroscopy Laboratory (MISL) of the Battlefield Environment Directorate, formerly the U.S. Army Atmospheric Sciences Laboratory. The MISL large area (1.8 by 1.8 m, uniform temperature, thermal target) was used for characterization and isolation of phenomena which impact target contrast. By viewing the target board from closeup and distant ranges simultaneously with the MISL thermal imagers, the inherent scene content could be calibrated and the degrading effects of atmospheric propagation could be isolated. The target board is equipped with several spatial frequency bar patterns, but only the largest 3.5-cycle full area bar pattern was used for the distant range of 1.6 km. The quantities measured with the target board include the inherent background change, the contrast transmission, and the atmospheric modulation transfer function. The MISL target board has a unique design which makes it lightweight with near perfect transition between the hot and cold portions of the bar pattern. The heated portion of the target is an elongated rectangular oven which is tilted back at a 30° angle to form a 1.8 by 1.8 m square when viewed from the front. The cold bars are positioned in front of the heated oven surface and can be oriented in either the vertical or horizontal direction. The oven is mounted on a lightweight trailer for one- or two-man positioning. An attached metal and canvas structure is used to shield the entire target from both solar loading and cooling winds. The target board has a thin aluminum sheet front surface which is insulated from the oven's heating structure. The heaters are placed in an insulated enclosure behind the front surface and distributed with increasing separation from bottom to top to create a uniformly heated front surface. In operation, the oven surface maintained a ± 1 °C uniformity when heated to typical temperatures of 10 to 20 °C above ambient background temperature.				
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1. Introduction

Over the past 20 years thermal imagers have emerged as a common extension to human vision with applications in many fields, including the military. What is not commonly well understood in their application is the degree to which meteorological and environmental effects can alter either the inherent thermal infrared (IR) signature of an object against its background or the radiance field of the object and background scene as it propagates through the atmosphere to the distant imager along horizontal lines of sight on the order of 1 or more km. [1] Anyone who has tried to calculate actual temperatures from calibrated apparent temperatures in thermal imagery knows the utility of blackbody (BB) sources and target boards. [2] However, when the imagery is taken from a range of 1 or more km, the size of the target board becomes very important. [3,4]

In 1988, small heating pads, 30 by 38 cm, and similar sized sources were used at 1.5-km ranges with the Mobile Imaging Spectroscopy Laboratory (MISL) near-field/far-field comparison technique to extract contrast transmission values. [5] However, the temperatures of these sources were not resolvable and produced transmission values that were lower than model predictions by a factor of two. Before this, several other types of solar and internally heated target boards were used, but each had drawbacks. The easiest to make are black and white painted plywood. These can be made quite large, but they are very susceptible to the presence of direct solar loading. Moreover, night and cloud cover ruin their universal use. A target board using cold sky reflections through variable aperture bar patterns on an ambient temperature surface has some very good applications, but cloud cover and rain can limit its use as well. During the course of thermal imaging experiments with the MISL and Simultaneous Multispectral Absolute Radiometer and Transmissometer (SMART) system, several types of heating pads or thermal oven targets were tried with varying success. An exposed target board with a vertical surface is subject to vertical gradients due to the surface heat rising to the top of the board and the side-to-side gradients caused by wind. Target boards which use liquid for heating and cooling are better, but for large areas

(approximately 2 by 2 m) their weight and power requirements restrict their application as remotely placed down-range targets and their cost is prohibitive. A large area target board that was shielded from and not dependent upon the weather was needed.

2. Background

During the past decade a wide variety of calibration sources have been used in collecting IR imagery for research at the Battlefield Environment Directorate (BED) of the Army Research Laboratory (ARL), formerly the U.S. Army Atmospheric Sciences Laboratory (ASL). In 1982, at the Scenario Normalization for Operations in Winter (SNOW) 1B test at Camp Grayling, MI, it became apparent that a large area BB was required for far-IR imagery calibration (in the range of 1 to 2 km). The ASL SMART system's 0.15 by 0.15 m BB source temperature could not be resolved by the Inframetrics, Inc., model 525, 8- to 12- μ m imager, even with a 10 power (10X) lens at only 600 m. A passive black and white plywood bar target was used at the SNOW 2 tests in January 1984. With bar spacings of 0.15 m between bars, only the spatial frequency could be resolved using a 10X lens at the same 600-m range. The problem with passive targets is that variability in weather affects them adversely.

Placing BB sources close to the imager while viewing distant terrain and objects helps overcome internal calibration of the imager, but does not address the difference between apparent temperature (as measured by the distant imager) versus actual or inherent temperature (as measured by the closeup imager), nor does it account for spatial distortions of scene features. Therefore, downrange thermal target boards are needed and they must be large in area.

The best passive large area target board found was based on a design by Mr. Giorgi of the U.S. Army Electronic Proving Ground, Fort Huachuca, AZ, in the early 1970's and used surface emissivity differences and sky reflections. This concept was expanded upon by Dr. Bartell, et al., [6] between 1975 and 1977 in constructing a large area 1.4- by 3.0-m target board with six different bar spacing patterns. This board used a large reflecting surface tilted back from the vertically positioned front surface containing the ambient temperature cutout bar patterns. The cold bars were

produced by viewing the cold sky reflections from the tilted reflecting surface through the bar pattern holes in the front surface. This produces very sharp transitions between the warm and cold bars.

One of these target boards was available for use at the Dusty Infrared Test Site, White Sands Missile Range (WSMR), NM, in June 1983 through the Instrumentation Directorate (ID) at WSMR, NM. The target board worked well at a 1-km range except for the restriction from the atmospheric problems: dust, rain, and night. A tarpaulin was used to shield the flat black surface to give a more uniform temperature as in figure 1.* The small hole pattern was used to vary the temperature difference (ΔT) between hot and cold bars. The target board was viewed using 8- to 12- μm imagers from a range of 1 km (figure 2). The imager on the left was an ID imager with 0.38-m collection optics located 5 m above the ground. The imager on the right was the ASL SMART imager used with the transmissometer receiver 0.9-m optics located 2-1/2 m above the ground.

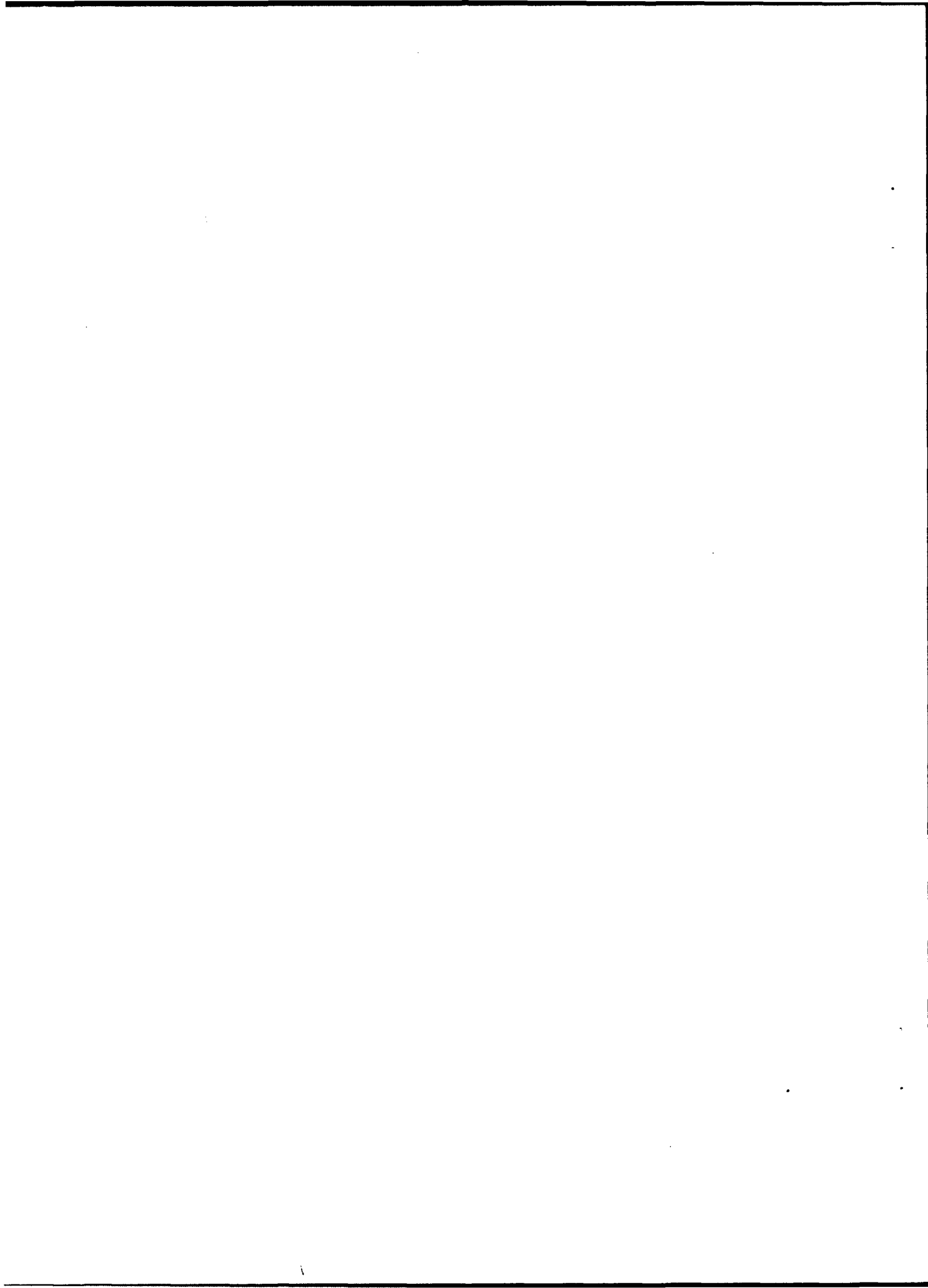
Some interesting phenomena occurred when the reflective target board was used at 1-km range and a painted plywood target board at 2-km range as shown in figure 1. Figure 3 shows an 8- to 12- μm image of the reflective target board using approximately a 25X lens with the ID imaging system. The target board at 1 km is completely resolved and shows no degradation of the bars due to optical turbulence around noon when viewed from the 5-m platform height. The target boards are viewed down a dirt road which is nearly level for 600 m and then sloped up approximately 1 m between 600 m and 1 km. The rise in the road continues out to 2 km with another 2-m rise over the last kilometer to the second target board. The target board at 2 km has twice the dimensions for the patterns so that both boards appear the same size from the 0-km position. Both boards were observed in the same scene at 09:00 (figure 4) and again at noon (figure 5) using the SMART imager with 25X lens to show the problem of optical turbulence with 2-1/2-m-high horizontal viewing. Note the 2-km target board requiring

*All figures appear beginning on page 14.

solar loading has low contrast with only the largest pattern discernable in the morning at 09:00 compared with the reflection based board that has good contrast for all the patterns.

After the turbulence degradation shown above had been observed, the SMART system imager was mounted for testing on top of the SMART van for the SNOW 2 test in 1984. At a 5- to 6-m height above ground, optical turbulence was no longer a problem but the platform stability was. All of these problems were considered in the design of the MISL. The outriggers support a massive vibration isolation table in the van. The imagers are located at a 3-m height to characterize what is commonly observed by military hardware. The viewing port for the Fourier Transform Spectrometer (FTS), which cannot cope with turbulent variations in its downrange source, was positioned at a 5-m height and sticks out of the roof of the MISL van (figure 6). Now only one thing remained to be solved: an appropriate large area target board was required.

By 1988, several active large area bar pattern solutions had been tried. A German-made bar pattern was used with white heated and nonheated panels at a field test in October 1985. The panels did not show sensitivity to changing solar loading, but did have problems with wind-induced, side-to-side temperature gradients, and the straight up and down construction resulted in vertical temperature gradients as well. Also, the transition between hot and cold bars was not sharp. Heating strips and heating pads were also tried with similar results. The best active target board found was a 2- by 2-m board produced by the Thermofilm, Corp. for the Canadian Defense Research Establishment Valcartier (DREV). This target board was constructed as rectangular ovens for the hot bars. There was still appreciable vertical gradient, but it was fairly lightweight and reasonably priced.



3. MISL Target Board Design

A large area target board that was lightweight, easily transportable, and reasonably priced was required. In order to be used in measuring the temperature sensitivity and spatial calibration or imaging systems, the board needed to be uniform temperature over the individual bars and have sharp transition between the hot and cold bars. The design flaw of a vertical thermal gradient in the most recently constructed target board with variable spatial frequency panels based on the DREV design and constructed by OptiMetrics, Inc. (OMI) for another agency at WSMR, NM, had to be eliminated.

Hence, a tilted oven approach with removable front spatial frequency front panels was used in a similar manner to the Bartell group approach [6] for their reflective bar target. Using a 0.6-cm-thick insulated aluminum front surface painted flat black and placing heaters in the middle of the 12-cm-thick oven so as not to touch the front surface allowed the heat to rise against the backside of the front surface and follow it up the target board oven front surface. By placing the heaters closer together at the bottom of the board and farther apart at the top, a uniform vertical heating of the front surface of a small 0.6- by 0.7-m test oven tilted at 30 ° was obtained and extrapolation was made to the desired effective 1.8- by 1.8-m heated oven (a portion of the new target board with three columns of heaters as in figure 7). Target dimensions of 1.8- by 1.8-m were used instead of the NATO standard 2.3 by 2.3 m because 6-ft aluminum sheet is the standard width in the U.S. and much cheaper to obtain. The aluminum sheet used was 1.8-m wide and 2.1-m high with the oven tilted 30 ° back from the vertical. The oven front surface was painted flat black for high emissivity. The cold bars were formed from another aluminum sheet positioned vertically and in front of the heated oven. This sheet was painted flat white and had cutout bar patterns. Two different board patterns were made with different 3.5-cycle (four hot bars) bar spatial frequency spacings. These boards are easily installed or removed and can be positioned for either vertical or horizontal bar patterns. The oven portion has a pivot connection about the center height, so that the target board can

be rotated with the front painted surface facing down for shipment. The target board and supports are mounted on a single-axle flatbed trailer. Figure 8 shows the improved OMI target board completed at the end of their contract in the fall of 1989. Before this large area target board could be used for measurement calibration, it had to be weatherized. A second U.S. government contractor, Science Technology, Corp., was used to accomplish the necessary wind, rain, and solar shielding. The result was a metal frame with sheet metal bowed roof and water-repellant material for covering the three nonfront sides.

Figure 9 shows this lightweight, easily moved, large area target board with uniform temperature bar pattern with near-perfect temperature transition between hot and cold portions. A rheostat is used to adjust oven temperature, and the ambient temperature bar pattern can be easily positioned for either horizontal or vertical bars. In addition, because the oven surface is flat black and the front sheet flat white and both surfaces are shielded from solar radiation (ensuring all-weather thermal operation), artificial visible light sources (e.g., flood lamps) can be used to illuminate the bar target for visible and thermal day or night operation in any kind of weather.

The first attempt at using the thermal bar target in a snow-covered terrain environment was encouraging though short lived due to an electrical short that disabled the power generator in February 1990. [7] It was not until August 1990 that the wiring and generator problems were corrected and the target board was used in conjunction with ASL's Target Contrast Characterizer (TCC) portion of the MISL at another field test. At this test when the target board was viewed with the front bar pattern sheet removed to expose the effective 1.8- by 1.8-m heated surface, it became apparent that the extrapolation of heater positioning from the small test oven to the larger area one was not perfect. The bottom central portion of the board was too hot as shown in figures 10 and 11. Heater elements around this hot spot (see figure 7) were removed selectively to obtain the desired configuration for a uniform surface temperature as shown in figures 12 and 13.

With the target board now operating as desired, the results of its use were very fruitful. First, for a 10 to 20 °C ΔT above a nominal background of 20 °C, the oven maintained a ± 1 °C uniformity over the whole surface except for a 5-cm border where the temperatures transitioned toward the ambient temperature. The far-field, far-IR imager with a 17X lens was used to view the target board from a range of 52 m to assess the temperature uniformity of the heated oven surface as well as the ambient temperature bar target patterns. At the 52-m range, the scene temperatures of the target board were fully resolved. The temperature uniformity held over several days and nights with varying humidity, windspeed, and could cover although no precipitation fell.

Next, the hot-to-cold bar pattern temperature transitions were measured. Again using the far-IR imager with a 17X lens from a range of 52 m, the large area target board with a vertical bar pattern attached and a small area BB with essentially a knife-edge (a thin aluminum foil sheet painted flat white) temperature transition were simultaneously viewed. The resolution limit of the imager is 0.12 mrad using the 17X lens determined as the 50 percent point on the imager slit response function curve and corresponds to 4.2 c/mrad. This causes an oversampled image in that the imager's instantaneous field of view and is several times larger than the image pixels. The measured modulation transfer functions (MTF) for the knife-edge and large area target board bar edges were derived using the technique's of Tatian [8] and Warnick [9] recently used by Jordan. [10] These plots are shown in figure 14 and are indistinguishable from one another within the measurement error (about 3 percent for the spatial frequencies less than 3 c/mrad based on 1,000 edge samples). Since the analysis performed with the MISL are based on images taken with the thermal imager, the MISL target board provides near perfect transitions between the individual bars.

Finally, use of this target board in conjunction with the MISL has allowed several unique measurements to be obtained. Because of the uniform surface temperatures and sharp transitions across the known spatial distribution of the target board, the optical transfer function of the TCC near-field and far-field imagers could be measured directly from field data. In addition, comparison of near-field and far-field registered imagery has resulted in the first direct measure of the far-IR atmospheric modulation transfer function due to optical turbulence the effects of which could be seen but not measured quantitatively in 1983 by using passive target boards. [11] With the front bar pattern sheet removed, the exposed effective 1.8- by 1.8-m oven surface and a registered uniform temperature background were used to measure directly the contrast transmission over a 1.5-km path between the near- and far-field. [1] Comparison with low resolution transmission code (LOWTRAN) calculations were within a couple percent. Finally, with the bar pattern in place the spatial non-uniformity of aerosol obscurant clouds were accurately measured. [12]

4. Conclusions

The MISL target board's unique design of tilting the top of an effective 1.8- by 1.8-m large area oven back by 30 ° resulted in a uniform temperature hot surface. This 10 to 20 °C above ambient surface with ± 1 °C variation over the surface with an ambient temperature notched-out bar pattern in front provides almost perfect hot-to-cold transitions. In addition, the weather shielding is very effective in eliminating solar loading heating and wind cooling. The use of the MISL target board during field testing has provided a means to quantify several physical parameters that previously had not been accurately measured. Among these parameters were far-infrared contrast transmission, optical turbulence, and dust cloud attenuation.



Figure 1. Large reflective-based target board at 1-km range position with sun shield. To the right at the 2-km range position is a black and white target board with twice the spatial dimensions.

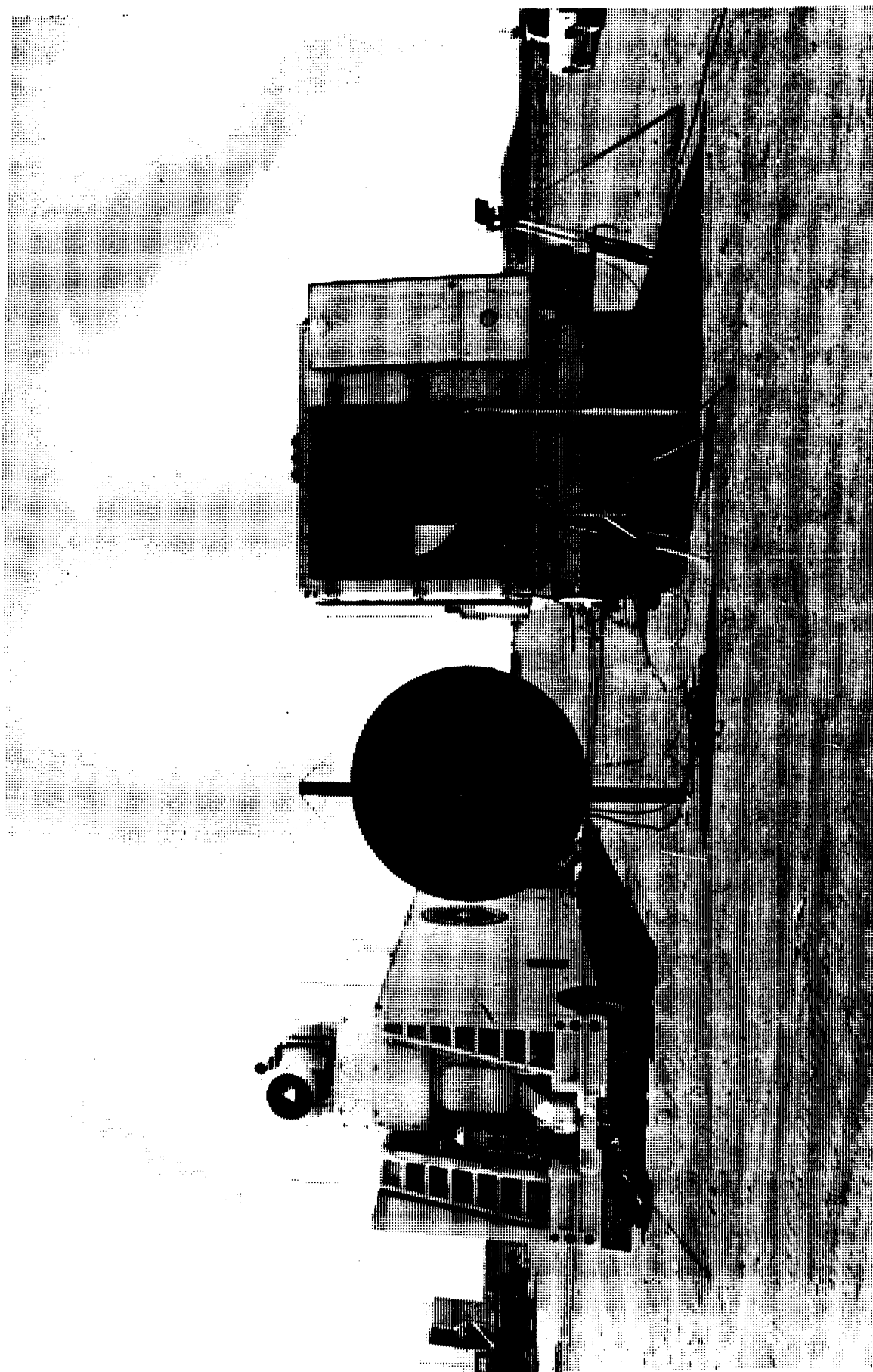


Figure 2. Two 8- to 12- μ m imaging systems used to view the large area target board.



Figure 3. An 8- to 12- μ m (ID) image of the 1-km position target board showing all of the panels resolved.

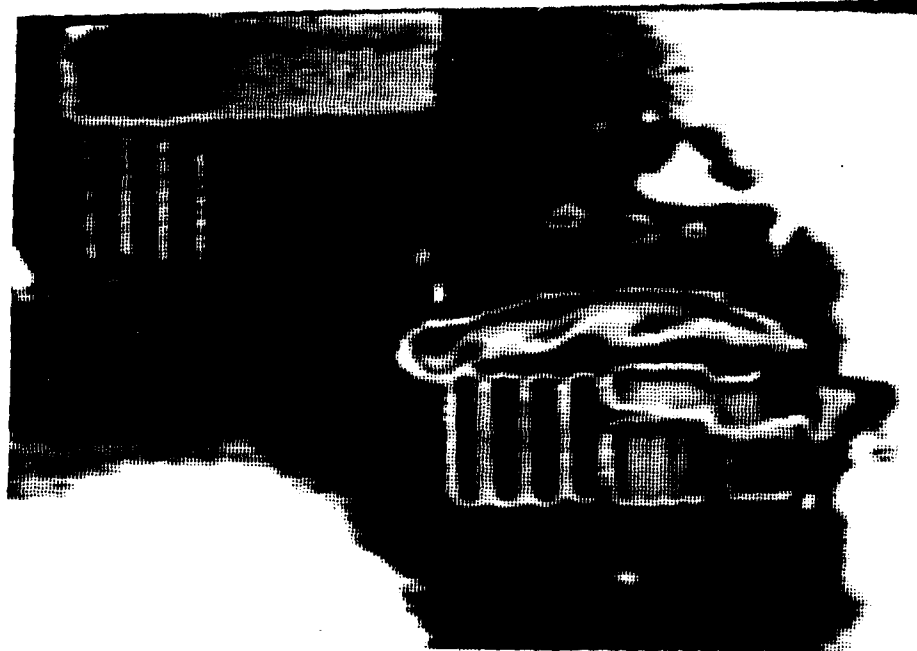


Figure 4. A colorized 8- to 12- μ m (SMART) image of both large area target boards at 09:00 with no turbulence.



Figure 5. A colorized 8- to 12- μ m (SMART) image of both large area target boards taken in the afternoon showing the effects of horizontal path optical turbulence.

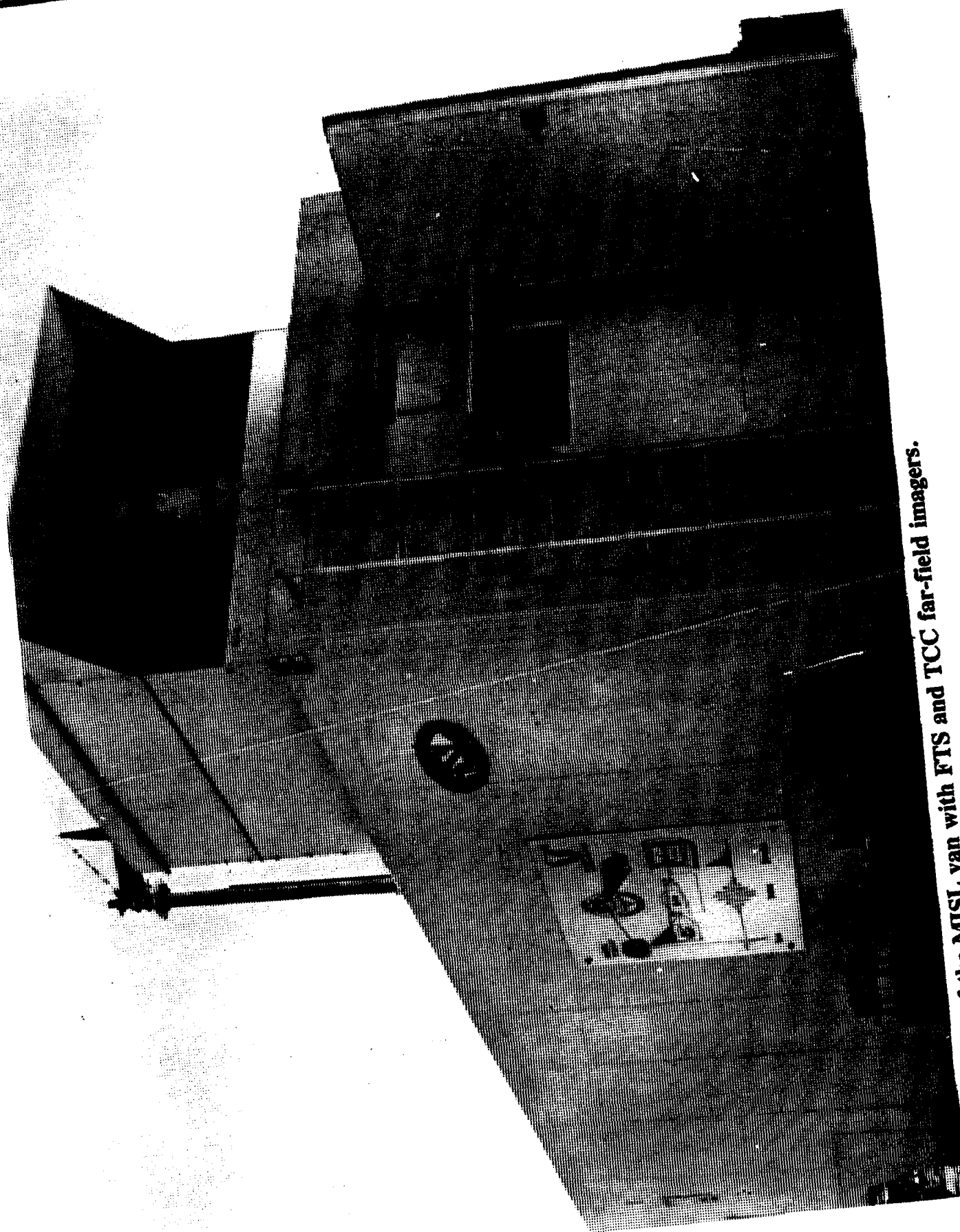


Figure 6. View of the MISL van with FTS and TCC far-field imagers.

MISL TARGET BOARD OVEN DESIGN

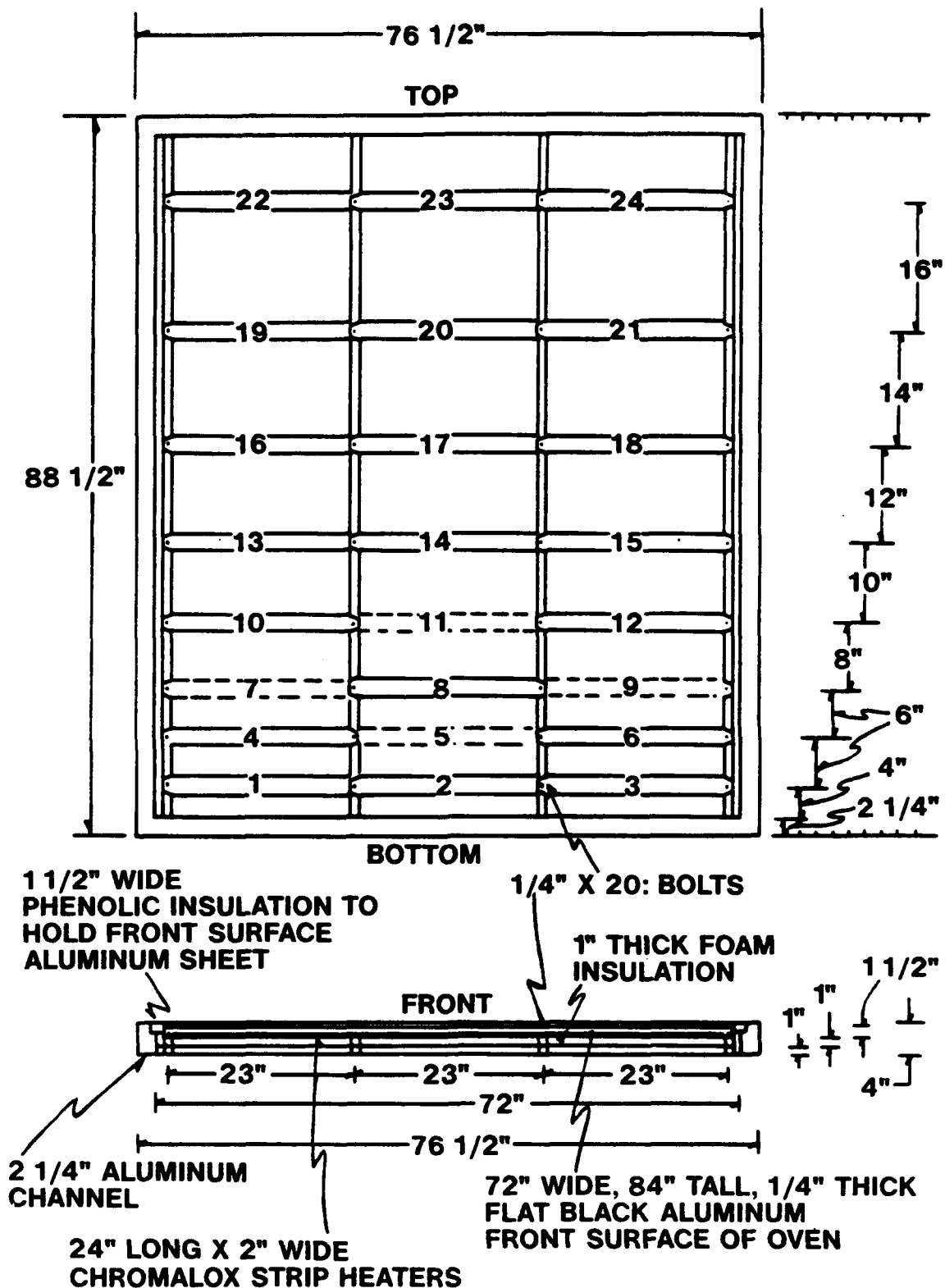


Figure 7. Heater positions for the MISL target board oven.

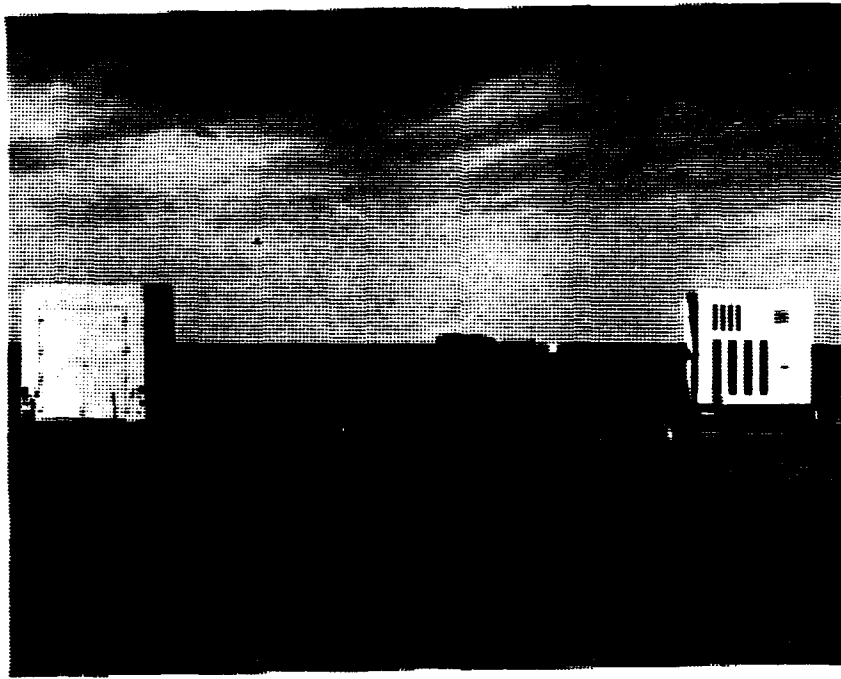


Figure 8. MISL target board beside a ½-ton truck showing four spatial patterns without solar or wind shielding.



Figure 9. MISL target board with single 3.5-cycle vertical bar pattern with solar and wind shielding.

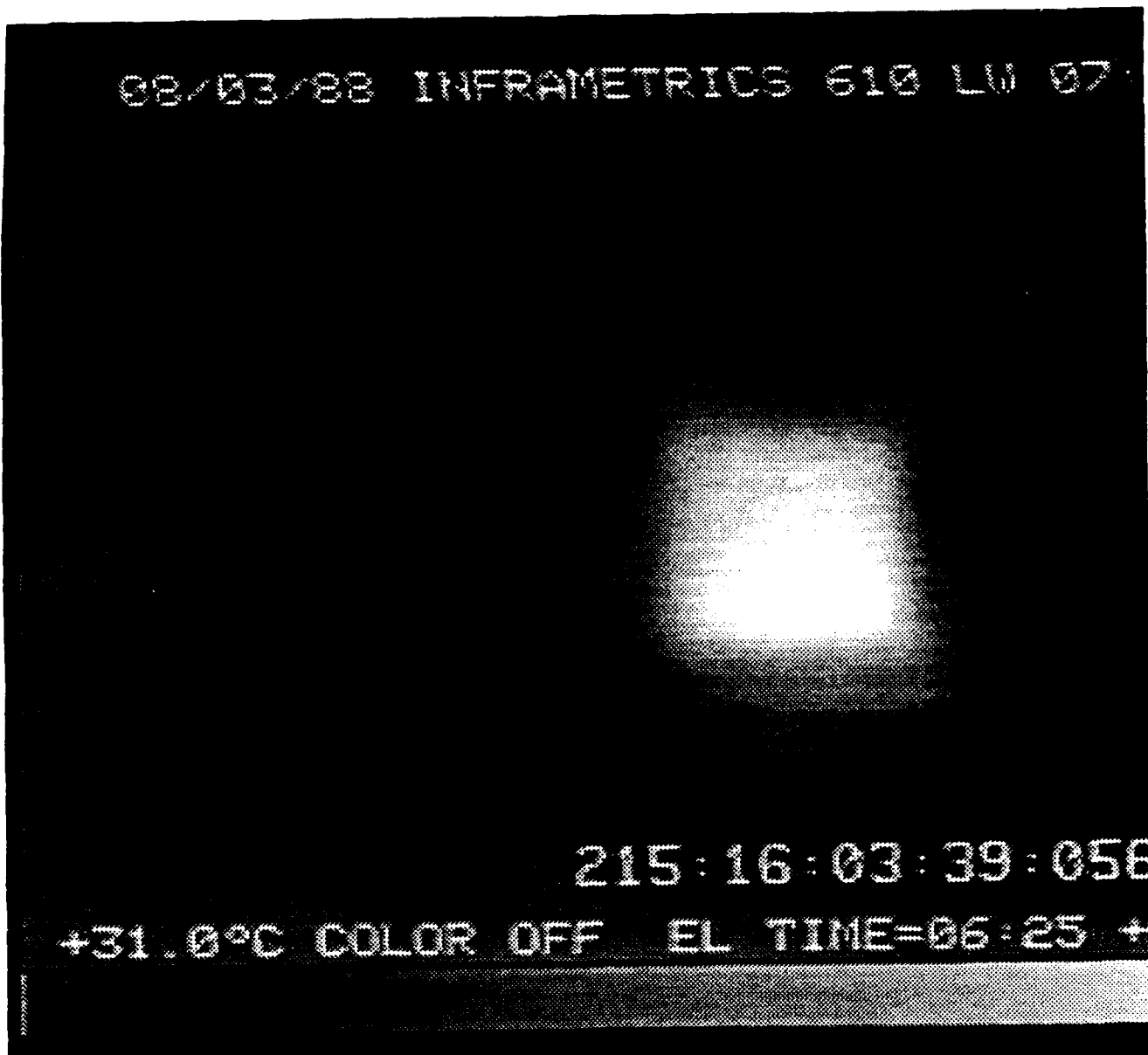


Figure 10. An 8- to 12- μ m image on 20 °C range of the MISO target with hot spot.



Figure 11. An 8- to 12- μm image on 20 °C range of the MISL target with hot spot (colorized image).



Figure 12. An 8- to 12- μm image on 20 $^{\circ}\text{C}$ range of the MISO target with no hot spot.

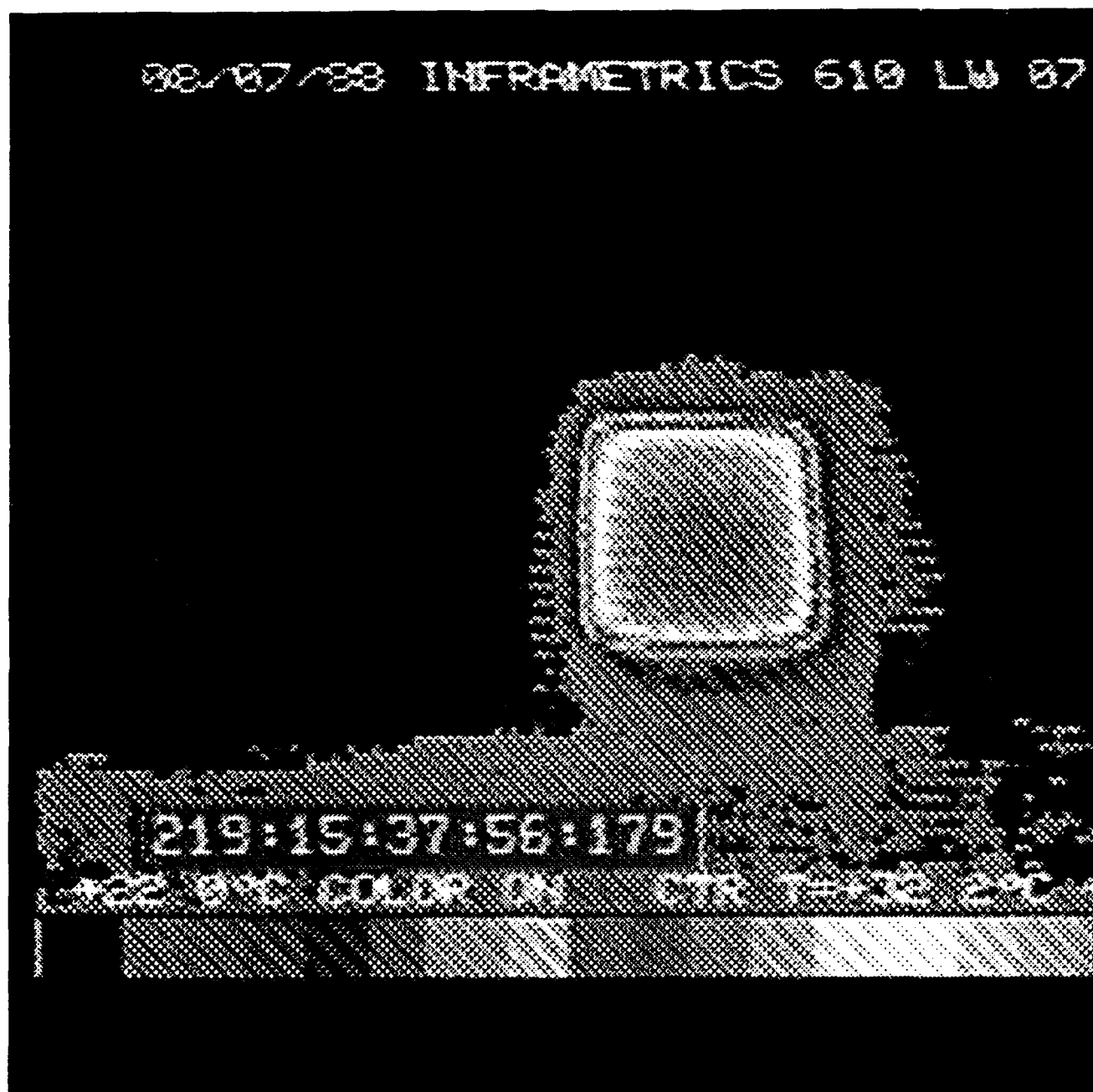


Figure 13. An 8- to 12- μ m image on 20 °C range of the MISL target with no hot spot (colorized image).

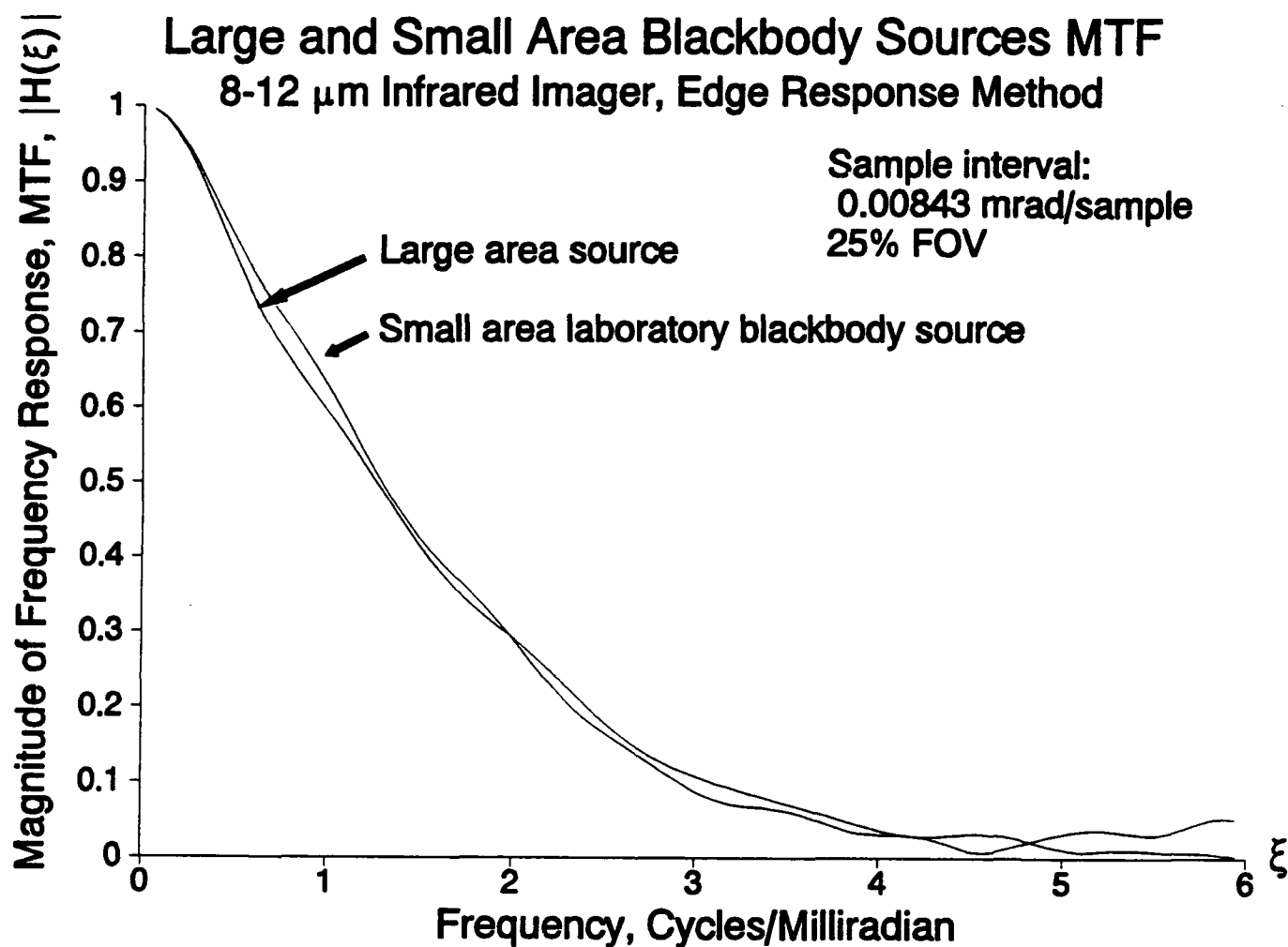


Figure 14. Modulation transfer functions of a small area BB with essentially a knife-edge and the large area target board bar pattern transition as measured using the MISL far-IR imager.

References

1. Watkins, W. R., *AGARD Conference Proceedings 502* (NTIS, 5285 Port Royal Road, Springfield, VA, 22161), p 26-1, 1992.
2. Watkins, W. R., S. B. Crow, and F. T. Kantrowitz, *Opt. Eng.*, 30:1563, 1991.
3. Schott, J. R., *SPIE Proceedings*, 1968:448, 1993.
4. Watkins, W. R., B. L. Bean, and P. D. Munding, *Rev. Sci. Instrum.*, 65:519, 1994.
5. Watkins, W. R., F. T. Kantrowitz, and S. B. Crow, *SPIE Proceedings*, 1115:179, 1989.
6. Bartell, F. O., A. G. DeBell, B. B. Fannin, J. S. Nissley, W. L. Wolfe, and G. M. Giorgi, *SPIE Proceedings*, 124:198, 1977.
7. Kantrowitz, F. T., W. R. Watkins, D. R. Billingsley, and F. R. Palacios, *SPIE Proceedings*, 1311:180, 1990.
8. Tatian, B., *J. Opt. Soc. Am.*, 55:1014, 1965.
9. Warnick, J., *Master's Thesis*, Rochester Institute of Technology, 1990.
10. Jordan, J. B., *SPIE Proceedings*, 1968:674, 1993.
11. Watkins, W. R., D. R. Billingsley, F. R. Palacios, S. B. Crow, and J. B. Jordan, *SPIE Proceedings*, 1486:17, 1991.
12. Crow, S. B., W. R. Watkins, F. R. Palacios, and D. R. Billingsley, *SPIE Proceedings*, 1486:333, 1991.

Acronyms and Abbreviations

ARL	Army Research Laboratory
ASL	Atmospheric Sciences Laboratory
BB	blackbody
BED	Battlefield Environment Directorate
DREV	Defense Research Establishment Valcartier
FTS	Fourier Transform Spectrometer
ID	Instrumentation Directorate
IR	infrared
LOWTRAN	low resolution transmission code
MISL	Mobile Imaging Spectroscopy Laboratory
MTF	modulation transfer function
OMI	OptiMetrics, Inc.
SMART	Simultaneous Multispectral Absolute Radiometer and Transmissometer
SNOW	Scenario Normalization for Operations in Winter
TCC	Target Contrast Characterizer
WSMR	White Sands Missile Range

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