Accurate infrared scene simulation by means of microlithographically deposited substrate

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ABSTRACT

A few years ago, a microlithographic deposition process on infrared-transmitting substrates was developed in order to produce realistic infrared scenes for FLIR testing[1]. In recent months, the performance of this product, named Thermoscene, has been improved by improving the control over the production process. The two main results are:

1. An increase of the number of simulated grey levels from 15 to 290, without reduction of the total number of pixels.
2. A decrease in imperfections, such as unwanted holes in the mesh deposition, to almost zero.

The Thermoscene is useful as a component of infrared simulators[2], to project realistic infrared scenes through collimating optics to a FLIR, missile seeker, etc., for testing purposes.

1. INTRODUCTION

The limits of the state of the art in infrared imaging have been pushed ahead rapidly in recent years. Testing these imagers has proven a complicated task in itself. FLIRs and missile seekers need to be tested in a dynamic infrared environment opposite realistic infrared images that can move across the imager's field of view in variable trajectories and velocities. To create an infrared image of, say, a tank or other object, has been possible for some years. This was done when the first Thermoscenes were developed[1]. They were composed of a mesh of individual pixels, where for each pixel, the ratio between the opaque and transmissive areas was controlled. This resulted in a half-tone infrared picture. The mesh was achieved by depositing a layer of metal on a germanium substrate. When this mesh was placed in front of a uniform infrared source, this technique simulated varying grey levels, and enabled production of pictures of real-life objects. The technology was limited to 15 or so grey levels, and it represented the first attempt at achieving this simulation technology.

However, a typical FLIR has inherent resolution in the range of 8-bit digitization, or 256 grey levels. The 15 grey levels seemed, therefore, inadequate. Added to that, the number of defects in the image, caused by holes in the deposition, was in the order of 10 per square centimeter and up to a pixel in size. These holes remained an area of concern of the Thermoscene technology. It thus was necessary to significantly

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improve the quality and performance of these Thermoscenes. The work that was carried out achieved this goal: the result is a better infrared image, offering more than 280 different grey levels and an almost complete elimination of defects.

2. PRODUCTION

To produce an improved Thermoscene, all the steps of the process have been rethought. New materials were sought as possible infrared substrates. Depending on the waveband of the system where the Thermoscenes are installed, different materials are selected. Sapphire has proven itself as a suitable substrate. Zinc Selenide and Zinc Sulphide are also suitable. These materials have higher infrared transmission percentages than Germanium. They also transmit visible light, a fact that makes it much easier to evaluate the final product.

The infrared substrate gets coated with a thin film of IR-opaque deposit. This film is metallic and of relatively low emissivity. A UV photo-resist layer is laid on top of that. This prepares the substrate for the final processing, later on.

New methods of synthesizing the Thermoscene image have been devised and implemented. Real life objects have been made into Thermoscene infrared transparencies: missile plumes, ships and battlefields that originated in real FLIR systems have been developed into Thermoscene targets. Synthetic targets and clutter images have also been generated using proprietary computer programs. With these programs, it is possible to synthesize clutters with controlled contrast and correlation lengths, depending upon the application requirements.

Once each image is selected, whether it be a real-life or synthetically generated pattern, it is converted into a digitized computer file. This file contains the grey level data of each pixel in the image, as well as a precise indication of its position in the overall image's grid.

This file is fed into a computer that generates a master image from it. At this stage the image can be initially evaluated and debugged. Once an adequate picture is reached, it gets plotted on a photo plotter and enlarged by a factor of 10. With this hard copy in hand, the image can be further debugged. Any detail that was overlooked so far is detected here, by scrutiny under a microscope. Pixel sizes are measured for consistency and general contrast is checked against the original image data, and any doubts about the correctness of the image can be checked and cleared at this stage.

When the final master plot is approved, it is reduced to its final size and photographed on a high resolution soda-lime emulsion window. With this window, the final processing is carried out. The coated infrared substrate gets coupled to the high resolution mask and a contact exposure to ultraviolet light is made. The light that passes through the transparent areas of the mask breaks down the photoresistive layer that protects the IR-opaque layer underneath. The exposed substrate is then etched to remove the unprotected opaque coating and thus the final thermoscene is achieved. Further coatings raise the emissivity of the opaque areas of the mesh and the Thermoscene is ready for incorporation into larger IR imager testing and simulation systems.

3. ACHIEVING THE GREY LEVELS

One of the major improvements in the Thermoscenes has been the development of capability to produce a Thermoscene having over 280 grey levels. In the work carried out, 256 grey levels were required. This requirement posed several problems: could it be achieved by refining the tried and tested general methods, or would a completely new course of action be required? Preliminary examination of this question indicated that the known methods could be used, with only the method of calculating pixel shapes requiring re-design. The 256 grey level requirement meant that it would be necessary to maintain strict control of the structure of the grey level of each pixel. Only this way would it be possible to achieve repeatable pixels of the same grey level, while having a detectable difference in the transmittance of one grey level compared to the other grey levels above and below it on the grey level scale. The following method was devised: the image's final dimensions and the spatial resolution of the system it was intended for, dictated the size of the individual pixel: a square of 64 x 64 microns. Each pixel was then subdivided into a matrix of 17 by 17 (total: 289) square sub-pixels, 3.8 by 3.8 microns, into which the photo plotter was commanded to draw black, opaque dots. The more sub-pixels were darkened, the darker the overall pixel became (figure 1, a and b), starting from the pixel's center and spiralling outward.

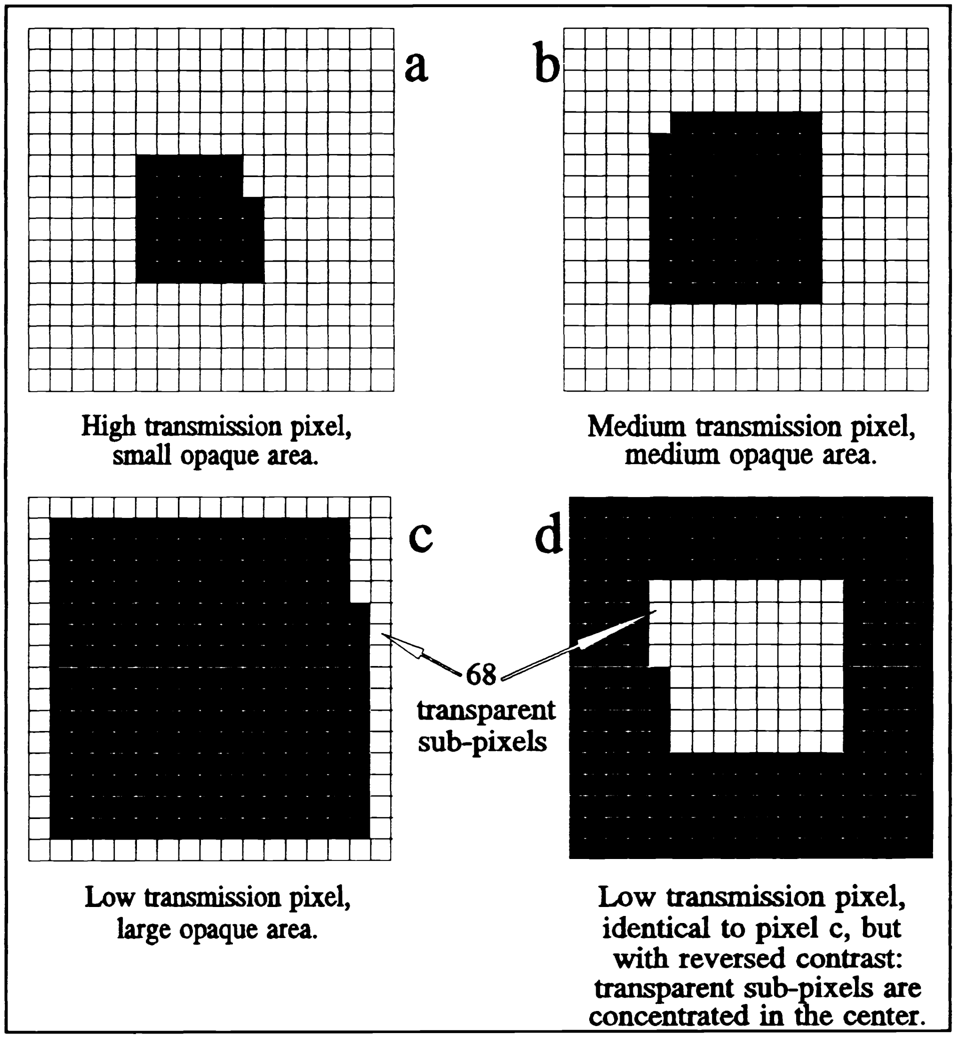

Figure 1: Samples of pixels with different grey levels.

This method of defining grey levels seemed to be a perfect solution. However, a new problem arose. It was a result of the nature of the etching process. It is difficult to control the etching process when the etched width is smaller than 6 microns. A transparent area of less than 6 microns might be left fully or partially opaque, while opaque lines might get etched away altogether. This introduces an uncertainty and a larger potential inaccuracy as with pixel c of figure 1.

Therefore, another limitation was added: no part of the pixel, be it opaque or transmissive, was allowed to be less than 6 microns wide. How, then, could the required number of grey levels be achieved? The answer was to reverse their contrast. Take pixel c in figure 1. The width of its transparent rim is mostly one sub-pixel wide – less than the required 6 microns. The total number of transparent sub-pixels is 68. By reversing the contrast, the transparent area is concentrated in the center of the pixel (figure 1, pixel d), forming a compact enough shape for the etching process to handle successfully and accurately.

Thus, a new method was devised to plot all the necessary grey levels repeatably.

4. QUALITY CONSIDERATIONS

Two main factors are of interest during inspection: the variation in transmission between different grey levels and the number of imperfections in the final product.

4.1 Transmission variation between the different grey levels

A test was conducted to prove that each of the 256 different grey levels exhibits a measurable transmission variation from the other grey levels. To measure this, a special Thermoscene was manufactured, having 256 identically sized squares, each one for a different grey level (figure 2).

1. The Thermoscene (figure 3, item 1) was mounted on a specially prepared X–Y stage and holder.
2. The Thermoscene was aligned in the focal plane of a f/6 5" diameter off–axis reflective collimator.
3. A limiting cone (2) was positioned on the collimator's entrance aperture. It was dimensioned so that it only allowed energy from the measured grey level to enter the collimator, precisely on the collimator's line of sight (LOS). The diameter of the cone where it was closest to the Thermoscene was about 2mm, while the grey level aspect length was about 2.4 x 2.4mm. This allowed a large proportion of the grey level to appear in the measurement while still allowing for a certain measure of inaccuracy in the alignment of the grey level.
4. A blackbody was positioned behind the Thermoscene and set to 1000°C.
5. An SR 5000 spectroradiometer was aligned on the collimator's line of sight. It was configured for the following experiment:
   - Field Of View: 2.4mrad.
   - Detector: InSb.
   - Experiment wavelength: 3.8μ.
   - Chopper: External.
6. A chopper was mounted on the blackbody aperture and set to a frequency of 700Hz.
7. The chopper frequency output was connected to the SR 5000 spectroradiometer. The chopper phase delay was synchronized so as to achieve the highest detection signal from the SR 5000.
8. A small folding mirror (3) was positioned on the LOS to enable convenient viewing of the Thermoscene using an autocollimator.
9. The SR 5000 and the autocollimator were boresighted so as to ensure that both these instruments were aligned on the same LOS.

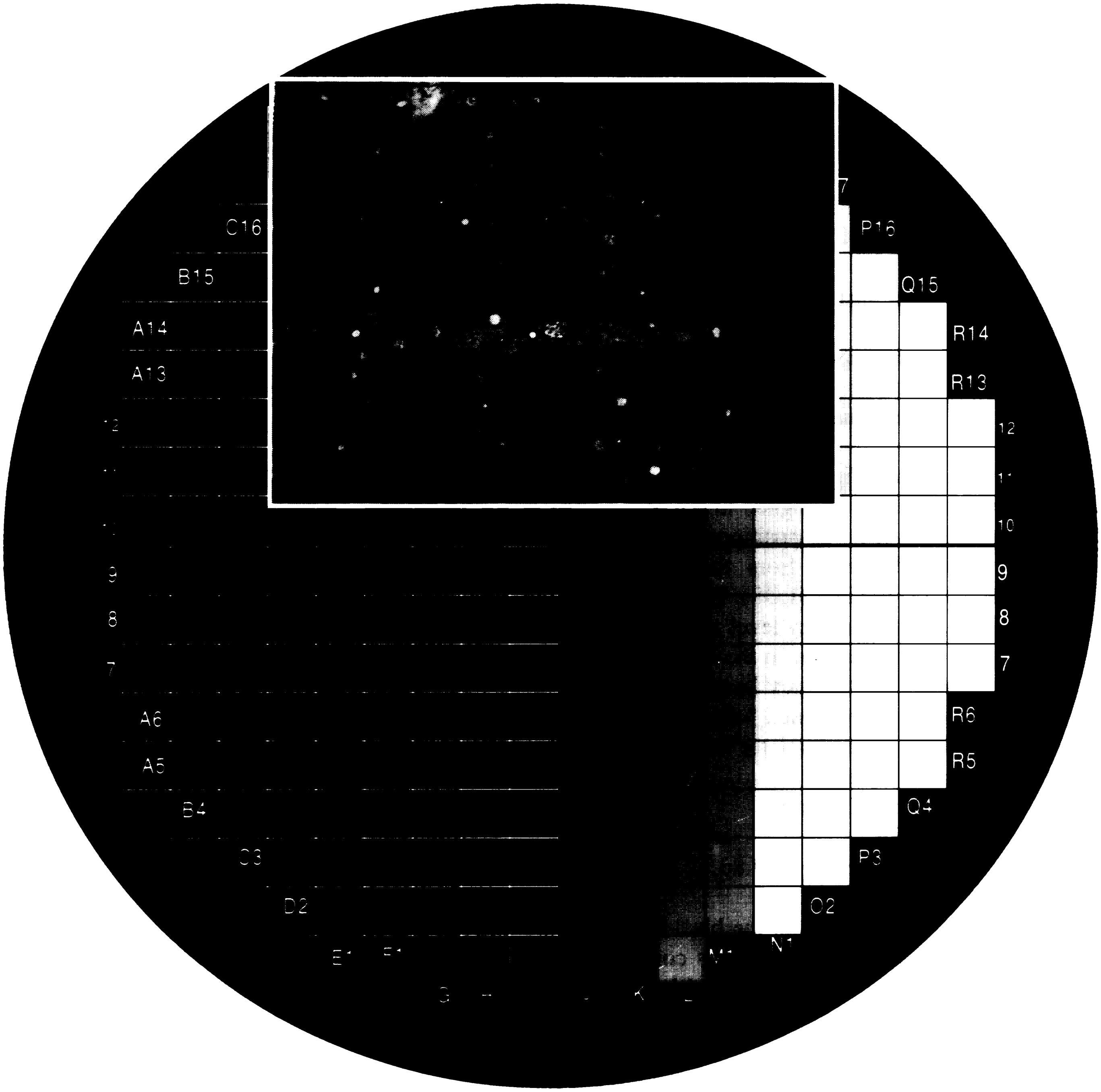

Figure 2: *256-grey-level Thermoscene.*
<u>Inset:</u> A microscope view of individual pixels.
Droplets are part of the high emissivity coating.

The test set-up was as follows:

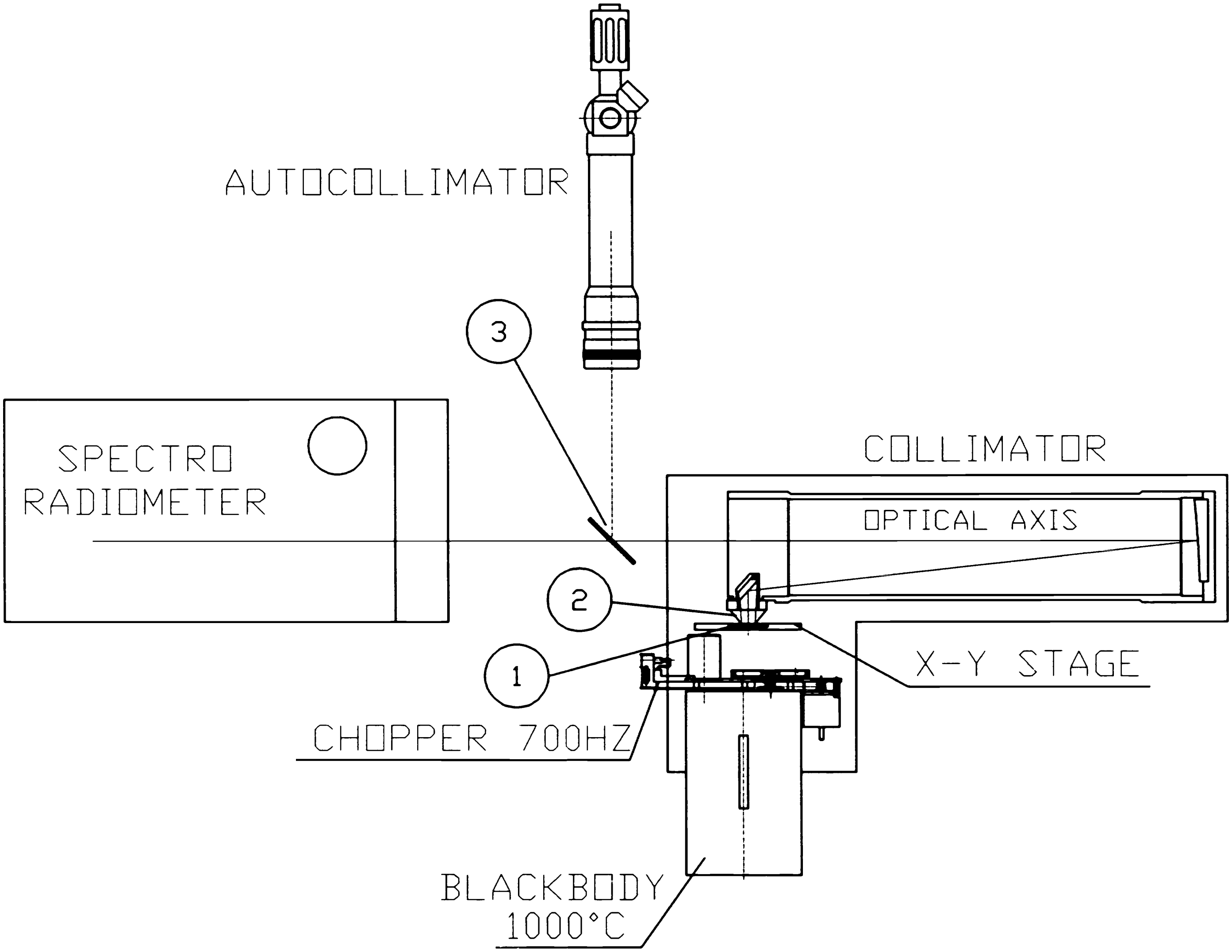

***Figure 3:** The test set-up*

4.2 <u>The Transmission Resolution Test</u>

The goal of this test was to examine whether a measurable difference in the transmission of the 256 grey levels was achieved. Such a difference would have to be larger than the noise level of the radiometer signal.

The test was carried out as follows:

1. The X-Y stage was aligned so as to position the first grey level (R7 in figure 2), which was the 100% transmissive grey level, on the LOS.
2. The detector voltage was measured and written down.

3. The SR 5000 was covered and the X–Y stage was aligned on R8, the next grey level.
4. The detector voltage was measured and written down.

Figure 4 shows the result of a typical radiometric measurement of two successive grey levels, as recorded by the spectroradiometer. Note that the voltage difference is larger than the noise level, indicating that the desired resolution was achieved.

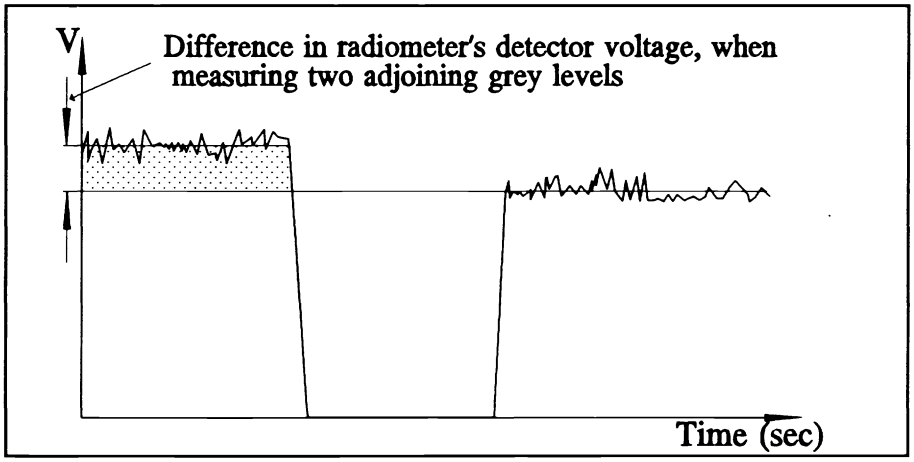

Figure 4: *Radiometric measurement of two successive grey levels.*

4.3 Absolute Transmission measurement

The goal of this measurement was to place each transmission result on a scale of 1 to 256, to graphically depict the change in the transmission levels from one grey level to the next. It should be noted that during production, the difference between the successive grey levels of the lower transmission region (where the reversed contrast was used) was set to double that of the higher transmission. In figure 5, a portion of the measured absolute transmission levels is shown for the two extremes of the transmission curve. The brighter grey levels show a steeper curve, as explained above.

The procedure described in the previous test was repeated for all the grey levels, in groups of 10–12. Each group was saved in a separate computer file for post-processing.

Occasionally, the X–Y stage was brought back to the R7 position to make sure the spectroradiometer's position on the grey scale grid was correct. In addition to that, a method was devised for tracking the drifts in the ambient temperature or the blackbody temperature. This enabled compensating for the drift, to ensure the reliability of the results.

4.4 Imperfections

Imperfections were classified in two categories: (1) imperfect grey levels and (2) flaws in the IR–opaque deposition and etching processes. In the first category, the strict control of the shape of each pixel eliminated this problem: the accuracy of each pixel's shape was maintained throughout the production process. In the second category, the use of improved vapor deposition and high emissivity coating methods, plus tight control of the cleanliness of the process, yielded infrared transparencies having a negligible number of visible flaws. When observed through a FLIR, the simulated image looked crisp and clear, and formed an accurate reproduction of the initial data from which the Thermoscene was made.

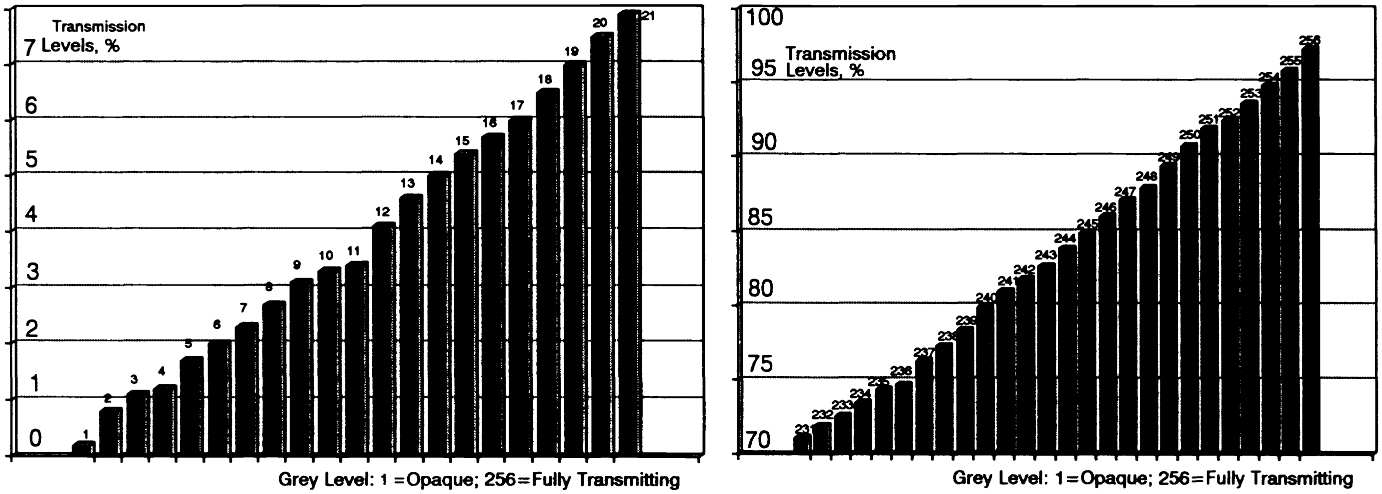

Figure 5: *Levels of transmittance at the two grey level extremes. Note the higher gradient in the region (right), resulting from the doubling of the increment between the grey levels.*

5. TYPICAL SIMULATION APPLICATIONS

Figure 7 shows a layout diagram of a single optical channel of an infrared scene simulation system in which Thermoscene technology is used. The blackbody emitter head emits a uniform beam of infrared radiation. The beam passes through the target Thermoscene and emerges as a modulated infrared image. The image passes through an array of lenses that make up the zoom optics. The beam that exits the zoom optics is a collimated image of the simulator target.

The target Thermoscene is mounted on a motorized target wheel that has several different targets on it. This enables the user to select different images for his simulation scenarios (land vehicle, aircraft, ship, animal, human figure etc.).

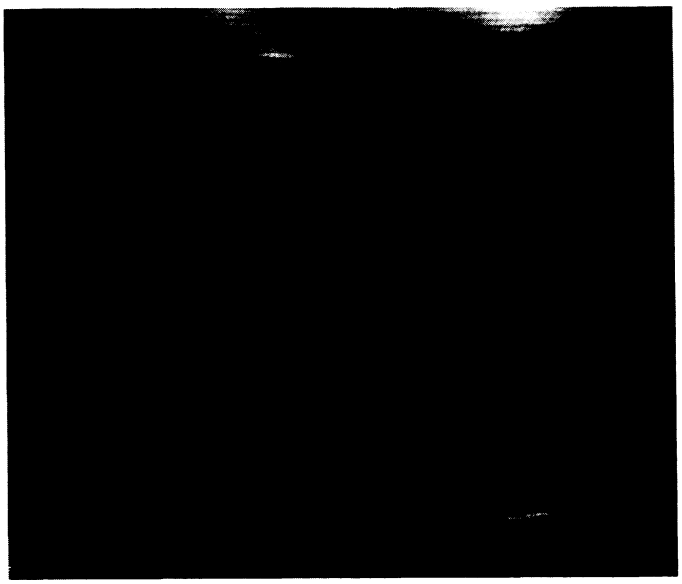

Figure 6: *A 256 grey level real life Thermoscene image of sea and clouds used in a simulator.*

The zoom optics simulates the varying distance (range) between the observer and the target. These optics are driven by computer-controlled electromechanical drivers.

The emerging collimated beam passes through an array of beam combiners (not shown here). There, it is superimposed on a background scene (see example, figure 6) that gets generated separately in a similar scene generator having a background Thermoscene. By controlling the beam combiners' angular positions in the θ and ϕ axes, the target can move with respect to its background in any desired direction, thus simulating dynamic horizontal and vertical motion of the target.

The background Thermoscenes (not shown) are also mounted on a motorized wheel that enables selection of different backgrounds to suit different simulation scenarios.

Further additions to the system can be made. Multiple targets can be generated and combined into the scene, all moving and varying their ranges independently.

Heat sources (electro–optic countermeasures such as flares) can be incorporated into the scene. Other visual effects can also be added.

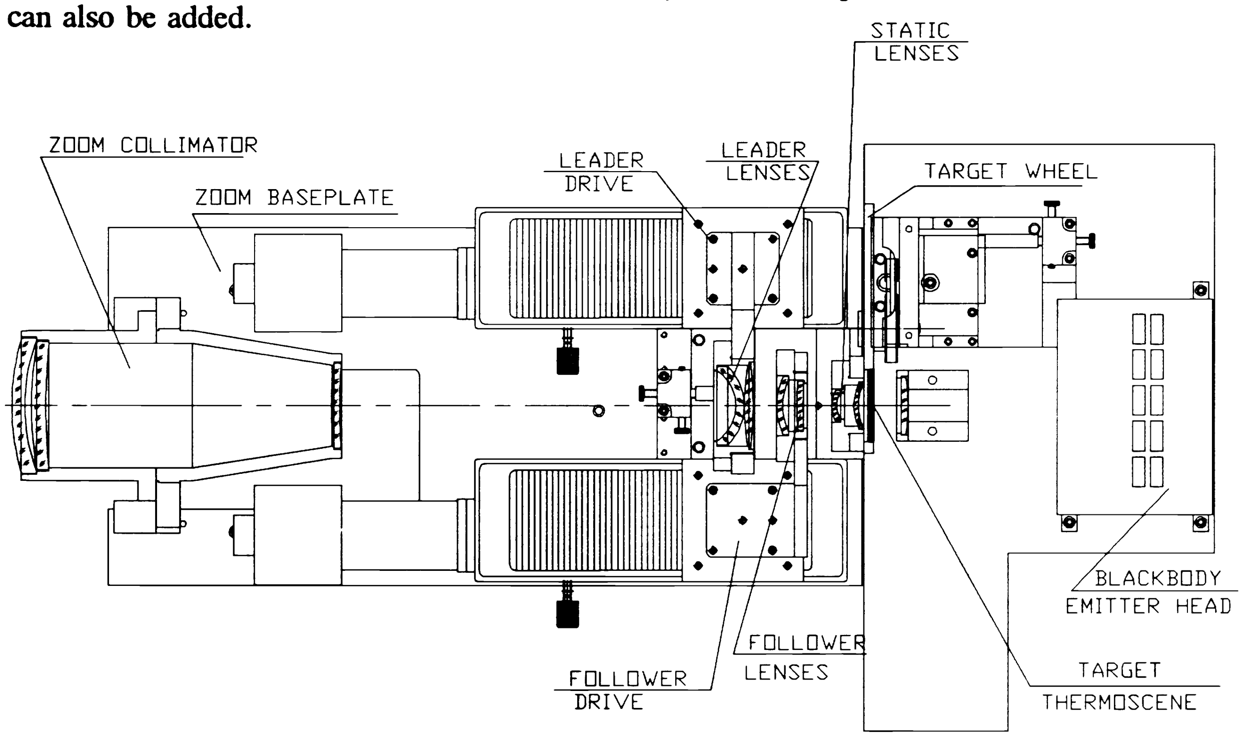

***Figure 7:** Typical application of a Thermoscene in a dynamic infrared simulation system.*

6. SUMMARY

The improvement of the Thermoscene technology now enables simulation of high resolution, complex infrared images. The range of applications for such technology has expanded from crude, static image projection into complex dynamic infrared scene simulation use. The much improved half tone resolution permits advanced testing of infrared sensing and imaging systems in a laboratory environment.

7. REFERENCES

1. *S. Ghilai, U. Gera, D. Cabib, A. Lapin, Y. Liran, Infrared transparencies (thermoscenes) for simulation of infrared scenes as a tool to improve FLIR testing, SPIE Proceedings 819–12, San Diego, (18–20 August 1987).*

2. *E. Ben David, D. Cabib, IR simulation of missile closing on a moving textured object with a textured background and EO countermeasure, SPIE Procedings 1687–59, Orlando, FL. (20–24 April, 1992).*