

MIRAGE: System Overview and Status

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ABSTRACT

Santa Barbara Infrared's (SBIR) MIRAGE (Multispectral InfraRed Animation Generation Equipment) is a state-of-the-art dynamic infrared scene projector system. Imagery from the first MIRAGE system was presented to the scene simulation community during the SPIE AeroSense 99 Symposium. Since that time, SBIR has delivered ten MIRAGE systems. This paper will provide a brief overview of the MIRAGE system and discuss developments in the emitter materials science effort. Overview data will be shown demonstrating the successful development of a high temperature, high stability emitter structure.

Keywords: Infrared, Scene Simulation, Scene Projection, and Emitter Array

1.0 OVERVIEW

MIRAGE is a complete infrared scene projector system with Command and Control Electronics (C&CE), Digital Emitter Engine (DEE), Thermal Support Subsystem (TSS), and Calibration Radiometry Subsystem (CRS). Optional MIRAGE subsystems include a Real-time Image Playback System (RIPS) and a custom Projection Optics Subsystem (POS) tailored to a customer's specific application. A block diagram illustrating the interconnection of these MIRAGE subsystems is presented in figure 1 below.

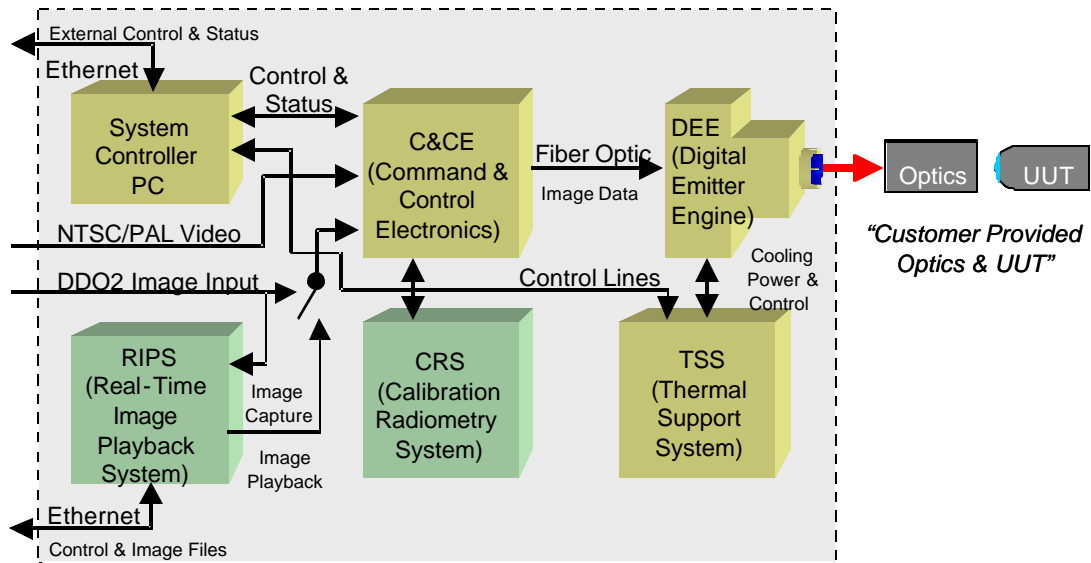


Figure 1.0, MIRAGE interconnect block diagram

1.1 Emitter Array

At the heart of MIRAGE is a 512x512 emitter array, employing key innovations that solve several problems found in previous designs. The read-in integrated circuit (RIIC) features both rolling-update (raster) and “snapshot” updating of the entire 512x512 resistive array. This solves the synchronization problems inherent in “rolling-update” only type designs. The MIRAGE custom mixed-signal RIIC accepts 16-Bit digital scene information at its input and using on-board D/A converters and individual unit-cell buffer amplifiers creates accurate analog scene levels. This process eliminates the complexity, noise and speed/dynamic range limitations associated with external generation of analog scene levels. With the additional benefits of a hybrid fabrication process, high thermal stability, and a 200Hz update rate, MIRAGE is the most advanced dynamic infrared scene projector system available. A description of each of the MIRAGE subsystems and their advanced features is provided in the following sections.

1.2 Real-time Image Playback System (RIPS)

The optional RIPS is a stand-alone PC based image capture and playback system. The RIPS accepts real-time (or slower than real-time) input images in a wide range of digital image formats, including the Silicon Graphics DDO2 format, and stores those images on a high-speed fiber channel disk array for later image playback and analysis. As shown in figure 1.2, the RIPS consists of a standard dual processor Pentium III PC, a COTS high-speed data I/O board, a COTS fiber channel disk array and controller, a custom DDO2 input/output board, and setup and control software. The RIPS provides the following functionality:

- Capture DDO2 input images from an SGI Onyx2 and store the images on the disk array while simultaneously passing the DDO2 images through to another device (i.e. projector, UPI, UUT, etc.)
- Reads digital image sequence files transferred from another computer over Ethernet and stores them on the disk array for later image playback
- Provides a playback utility to allow the user to display the images to the PC monitor for analysis or for selection of a playback sequence
- Playback utility also allows the user to playback any sequence of images from the disk array to the DDO2 output port in real-time synchronized to an external user supplied frame sync (e.g., from the SUT/UUT)
- User can setup and control the complete RIPS from another computer over the standard Ethernet interface between the PC and the user’s computer.

The key specifications for the RIPS are:

- Maximum DDO2 input/output rate: 50 Mbytes/sec (e.g. 512x512 images at 100 Hz)
- Disk array storage capacity: 144 Gbytes
 - = 49 minutes of 512x512 images at 100 Hz,
 - = 81 minutes of 512x512 images at 60 Hz,
 - = 163 minutes of 512x512 images at 30 Hz.

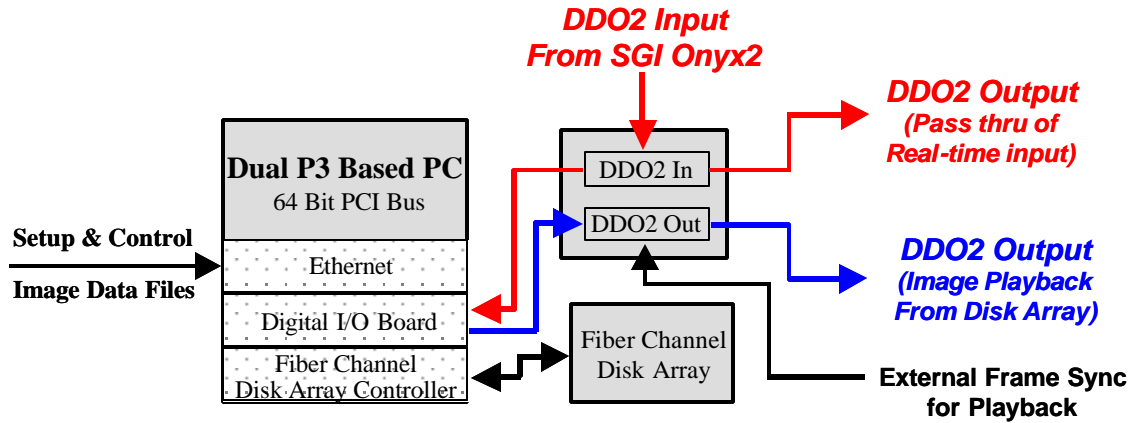


Figure 1.2 RIPS interconnect block diagram

2.0 Accomplishments

The primary accomplishments over the last year have been in the area of the emitter array. SBIR demonstrated the potential of the Rockwell Science Center (RSC) Transfer Thin Film Membrane (TTFM) process to produce high performance emitters in 1999. Optimizing the process for high performance and yield has been the focus since that time. In particular, improving operability, maximum apparent temperature, stability, and throughput have been the goal. The first step was to establish a baseline process that was well documented and repeatable. Repeatability was defined as producing >99.5% operable parts from several consecutive matings. Each 'Mating' consists of two emitter arrays. The arrays are designated with a L(left) or R(right) suffix. For example, Mating 13 consists of arrays M13-L and M13-R. Both are fully functional emitter arrays. With the process well documented and repeatable SBIR was able to make specific process changes to improve performance without risking 'losing the recipe' along the way.

The first nine months of 2000 were spent working with the baseline process and performing off-line experiments to improve emitter maximum temperature and stability. In October, 2000 Matings 9, 11, and 12 yielded parts with greater than 99.5% operability, proving process repeatability. At this point, SBIR and RSC inserted the process change to provide higher maximum apparent temperature and greater output stability. Mating 13, which completed in December, 2000 is the last of the baseline process parts. It yielded 99.6% operability on both arrays. A performance summary of Matings 9-13 is shown in table 2.1.

Mating	Operability	Status	Comments
M9-R	>99.5%	At customer site	First part completed with established baseline process
M9-L	>99.5%	At customer site	First part completed with established baseline process
M10-R	<50%	Used for system installation	Misalignment at photo step degraded performance
M10-L	<50%	Used for system installation	Misalignment at photo step degraded performance
M11-R	>99.7%	At customer site	
M11-L	---	Inoperable	Physical damage after fabrication
M12-R	>99.9%	At customer site	Best part produced to date
M12-L	98.6%	At customer site for system installation use	RIIC contact issue degraded operability
M13-R	99.6%	Customer owned, at SBIR	Last of pre-high temperature baseline
M13-L	99.6%	NUC development at SBIR	Last of pre-high temperature baseline

Table 2.1 Baseline emitter array operability

High operability has been demonstrated on baseline emitter arrays. Equally important is low occurrence of structural flaws such as row outages, column outages, or clusters of dead pixels. The in-process screening tests performed on each array guarantee that row and column outages never occur on finished parts. These RIIC flaws are easily detected prior to mating an emitter to the RIIC. Cluster outages are limited through careful inspection of the emitter array before mating. In-process tests following mating identify any other potential flaws that are not readily visible. The test and selection part of emitter processing allows for consistently high yield of very high operability parts. Figure 2 below demonstrates an operability map of Mating 12-R. As the map shows the pixel outages are few and randomly distributed across the array. The only structural set of outages are in the lower left corner, which is generally outside of the field of interest.

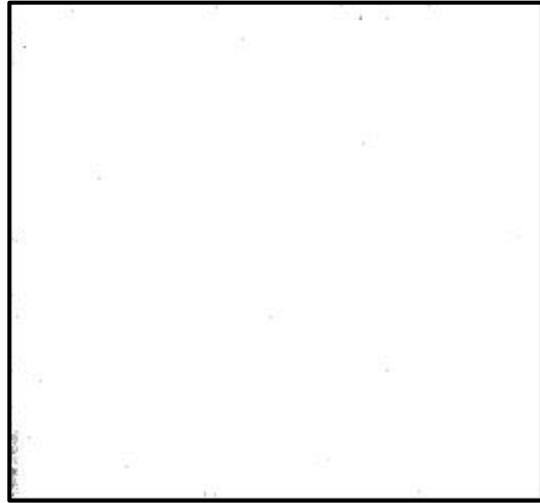


Figure 2 Mating 12-R shows greater than 99.9% operability

2.1 High Temperature Process Upgrade

In November, 2000 the process was optimized to improve emitter stability, maximum apparent temperature, and spectral performance. The changes were based on measured optical constants of the absorber and dielectric layers of the emitter stack before and after high temperature anneal. The first arrays produced using the new process are from mating 14. Initial test data, acquired in March and April of 2001 show impressive results. Apparent temperatures of 689K were measured along excellent upper dynamic range stability. The mating 14 array showed only 0.2K of apparent temperature drift during 100 minutes at 536K.

The approach taken to improve performance was to measure the infrared optical constants of the various layers of the emitter structure. These constants are unique to the layer materials, index of refraction, absorption coefficients, and deposition techniques. Constants were acquired from witness samples from emitter deposition runs and reacquired after exposure to several different anneal environments. The measurements describe the performance of the baseline structure and allowed SBIR to generate accurate emissivity models of the emitter structure. The emissivity model is key to choosing process upgrades that yield on the first iteration.

Numerous materials were evaluated by measuring optical constants and sheet resistance following various anneal environments. These tests and modeling resulted in the new emitter stack fabricated on Mating 14. The Mating 14 parts, first delivered in March, 2001, show excellent maximum apparent temperature and stability performance.

Stability over time at high temperature was measured for the Mating 14a-R emitter array. The stability measurement was made at 75% power after the part had seen a 12 hour anneal at maximum power. A 10x10 box of emitter pixels were powered at a level of 49152 counts (3/4 of 16 bits) for a period of 100 minutes. As the part was running, a 320x256 InSb IR camera recorded the box's output every 15 seconds. Figure 2.1 records the results of the stability measurement. The first part of the graph shows the turn-on point of the array. The following points show a very slow drop in signal totaling to 0.2K over 100 minutes. The data shown are exactly what the camera recorded, including any drift in room temperature, camera DC offset, etc.

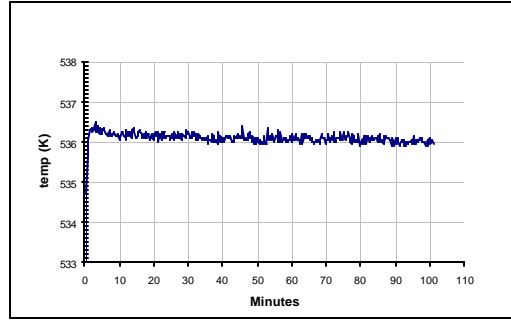


Figure 2.1 A 10x10 box of emitter pixels from Mating 14a-R are stable to 0.2K at an apparent temperature of 536K.

2.2 Maximum Apparent Temperature

Improvement in apparent temperature was gained through higher, more stable emissivity. Measurements of apparent temperature vs emitter current were made for both the baseline and high temperature processes. A 50x50 box of emitter pixels was driven at several power levels with the emitter current and output radiance recorded. The graphs in figure 2.3 clearly show the improvement in performance of the new Mating 14 array.

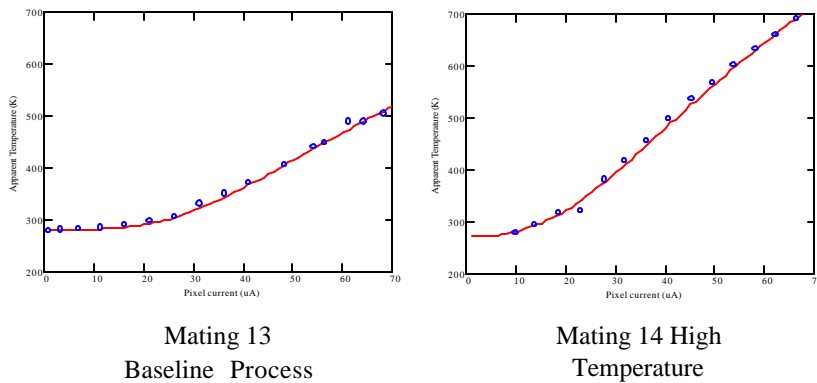


Figure 2.2; The apparent temperature of Mating 14 is clearly superior to its predecessor at similar power input levels.

The single points in the graph represent measured values. The smooth lines represent the predicted apparent temperature using the emissivity model. As the data show, the model is quite consistent with the measured data.

2.3 Anneal Stability

Another critical aspect of the emitter array is anneal stability. Because of the high emitter operating temperatures material properties can change over time. This can change emissivity with an accompanying change (typically drop) in apparent temperature.

As figure 2.3 shows, a two hour anneal initiates a change in apparent temperature of about 8 K on the Mating 14 high temperature array. A slow rise in apparent temperature follows over several hours. The rise corresponds to 17mK per minute. This behavior was predicted by test structure data acquired in December 2000. The test structures also predicted that the change in apparent temperature over time gradually flattens out to zero over a twelve hour time frame.

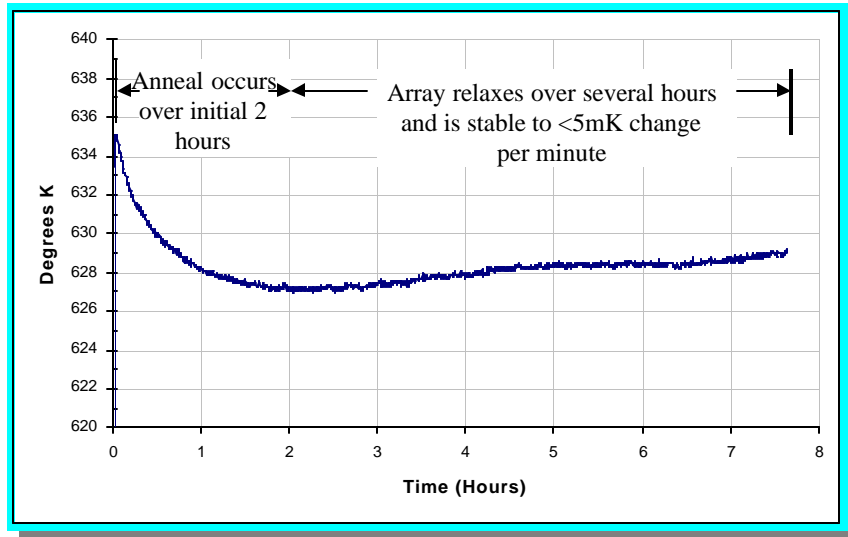


Figure 2.3; Array output versus time at full power. The 2 hour anneal and then slow rise in apparent temperature was predicted by test structure measurements.

The anneal measurement was made using the same 320x256 InSb camera as was used for measuring stability. A 25mm lens on standoffs was used to capture data from the entire array. As with the stability measurement, data was acquired at 15 second intervals. The anneal was performed with the entire array powered on at full output. There is some reduction in apparent temperature as compared with the 50x50 box measured in 2.2. This effect is probably due to voltage drops with the array sinking 20 Amps as opposed to 170 mA in the other measurement. Further tests are planned to characterize maximum apparent temperature versus number of pixels driven.

2.4 Rise Time

An emitter pixel's rise and fall time are determined by its thermal mass, thermal conductivity and power input. The emitter temperature rise time is profiled by a 1/e time constant. The 1/e time constant determines the time required for a pixel to slew from one apparent temperature to another. The SBIR emitter design utilizes a feature called 'overdrive' where an extra boost is given to the pixel's output to speed this transition. Overdrive has proved effective in reducing rise time to 5 milliseconds in the mid 30% of the dynamic range as shown in figure 2.4.

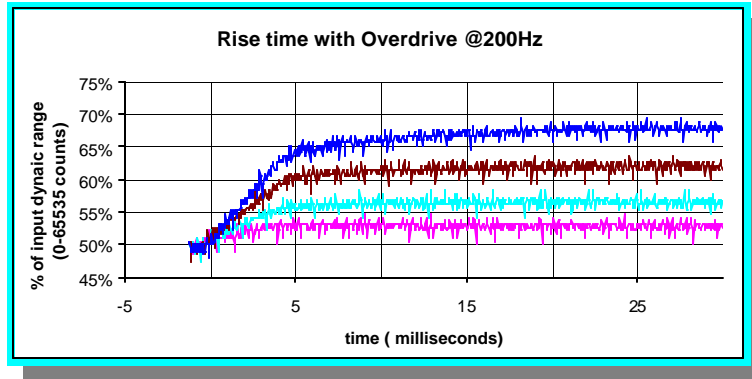


Figure 2.4 Using overdrive at a 200Hz frame rate provides a mid dynamic range rise time of 5 ms.

Performing a 10-90% transition across the entire dynamic range requires more time. This is because overdrive is only effective where there is extra headroom to provide a signal boost. When driving to full power, there is no extra power available. In the range where overdrive is not improving rise time, 14 - 20 milliseconds are required for the full transition.

2.4.1 Rise Time in Snapshot and Raster (rolling) Modes

The array may operate in snapshot mode or raster mode. In snapshot mode, the entire array updates to a new frame of video data at the same time. The update time is approximately 10 microseconds. Snapshot mode is valuable as it simplifies synchronization with the UUT and provides a complete image over the vast majority of the frame time. Once the array is updated, the output image is stable except for the emitter pixels transitioning per their $1/e$ time constant. Raster mode, on the other hand, updates each pixel separately and, thus, requires a far longer portion of the frame time to update the entire array. There are rise time benefits and weaknesses in both modes, depending on the UUT and its frame rate.

Snapshot mode allows for the simultaneous updating of all pixels on the emitter array. The snapshot circuitry adds a term to the pixel rise time equation because the signal between two successive frames is shared during the pixel addressing cycle. In the non-overdrive case this charge sharing allows 70% of the full transition to take place from one frame to the next. A transition of greater than 95% requires 3 frames. Overdrive compensates for this feature in mid dynamic range but not for large frame-to-frame swings. With the array updating at 200Hz a full swing across the full dynamic range requires 17 ms.

With the emitter array operating in raster mode, pixel rise time is determined only by the $1/e$ emitter time constant. The measured value for the time constant is 7 ms on a mating 14 array. 10-90% rise times have been measured at 14 ms on the same part. The benefit of raster mode is that the chip updates at 200Hz regardless of frame rate. For example, if the MIRAGE system is operating at a 60Hz frame rate, the emitter array will fully update in 5 ms and then hold for 11 ms until the next frmsync pulse is generated. This allows transitioning pixels most of the frame time to reach their final destinations. In contrast, snapshot mode requires at 3 frames regardless of frame time to complete a large transition.

2.4.2 Future Work on Rise Time

SBIR plans on turning attention toward rise time over the near term. The goal is to reduce 10-90% emitter rise time to 5ms. This will be achieved through continued analysis, materials study, and tuning of the emitter structure. The analysis will provide options for geometry changes to better optimize the time constant without impacting maximum apparent temperature. RIIC chip designs are under review as well to eliminate the frame-to-frame charge sharing of the current design.

3 Future Emitter Tasks

The test data acquired thus far is only a small fraction of what is needed to characterize the high temperature design. Array testing will continue throughout the year to more fully describe output stability and repeatability. Array nonuniformity correction work will continue as well. The goal is to demonstrate less than 0.1% array nonuniformity after correction. Mating 14 demonstrated a maximum apparent temperature of just below 700K. Mating 15 and beyond contain a small geometry change that will improve apparent temperature, perhaps into the 750K range. While these tasks are progressing, design and analysis work will continue so as to provide even higher maximum temperatures and faster rise times.

4. 1024 x 1024 Emitter Development

SBIR has been engaged in planning for a 1024x1024 device for two years. The first approach was the LAISE concept which addressed the issues surrounding producing a very large integrated circuit and meeting key emitter performance requirements. The design currently being planned leverages from the LAISE concept and adds performance features identified by the HWIL community over the last two months. Requirements obtained from the community for the new design reflect the differing needs that exist. Some of the trades being evaluated concern maximum frame rate, maximum apparent temperature, rise time, and percent of the array at maximum apparent temperature at one time. The customer requirements are being folded into a single emitter array specification. The current revision of the integrated spec is shown in table 4.1 below. The spec is then flowed down to the emitter pixel and RIIC levels.

	customer consensus	design under consideration
Operational Temperature (Background)	233K to 295K	330K to 70K (goal)
Format Size	1024 x 1024	√
Pixel pitch size	≤ 45 microns	√
Frame rate 1024x1024	200Hz (snapshot)	√
Read-in	snapshot or raster (selectable)	√
Max Apparent Temp (K) MWIR	600K (desire: 800K)	√
Max Apparent Temp (K) LWIR	400K (desire: 450K)	
Temperature Resolution (after NUC) MWIR Tbg = 600K	1 K	√
Temperature Resolution (after NUC) LWIR Tbg = 300K	20 mK (< 10 mK desired)	30mK (LWIR T _{BACKGROUND} =300K)
Windowing (1)	Dynamic desired	Centered 1024 x 512 window @ 400Hz, Background edge at 1 to 10Hz (drive electronics to window)
Pixel response	5 ms from 10% to 90% (radiance) across the full dynamic range	√
Spectral Band	3- 14 microns	√

Table 4.1 1024x1024 Preliminary Emitter Array Specification

The emitter and RIIC spec flowdown is anticipated to be complete in the first week of May, 2001. It is likely that the flowdown will result in a series of performance/design/risk trades that will drive revisions in the top level specification. The revised spec is anticipated to be provided to the community at the end of May.

5. SUMMARY

The MIRAGE system has made important strides in emitter materials science. These are evident in the high apparent temperatures approaching 700K and high stability performance at 0.2K over 100 minutes demonstrated by Mating 14. SBIR is looking to further optimize the emitter design with 10-90% rise times

in the 5 millisecond range. While the emitter process is being optimized, design work is being planned for an upgrade to 1024x1024 arrays. The customer community is supporting a survey of critical performance requirements and these are being flowed down into emitter and RIIC chip specifications. The spec development process is planned to complete by the end of May, 2001.

6. REFERENCES

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