Performance Improvements in Large Format Resistive Array (LFRA) InfraRed Scene Projectors (IRSP)

Kevin Sparkman[a], Joe LaVeigne[a], Jim Oleson[a], Greg Franks[a], Steve McHugh[a], John Lannon[b], Steve Solomon[c]

[a]Santa Barbara Infrared, Inc., 30 S. Calle Cesar Chavez, #D, Santa Barbara, CA 93103
[b]RTI International, 3021 Cornwallis Rd., Research Triangle Park, NC 27709
[c]Acumen Scientific, P.O. Box 6084, Santa Barbara, CA 93160

ABSTRACT

Santa Barbara InfraRed (SBIR) is producing high performance 1,024 x 1,024 Large Format Resistive emitter Arrays (LFRA) for use in the next generation of IR Scene Projectors (IRSPs). The demands of testing modern infrared imaging systems require higher temperatures and faster frame rates. New emitter pixel designs, rise time enhancement techniques and a new process for annealing arrays are being applied to continually improve performance. This paper will discuss the advances in pixel design, rise time enhancement techniques and also the process by which arrays are annealed. Test results will be discussed highlighting improvements in rise time, uniformity and reduced numbers of defective pixels.

Keywords: Scene Projection, LFRA, Mirage XL, WFRA, Mirage HD, Mirage II, Rise Time, Over drive, Anneal, IRSP

1. INTRODUCTION

Santa Barbara Infrared (SBIR) has been producing infrared scene projectors (IRSPs) since 1998. The IRSP are based on a micro emitter structure for each pixel. The original mirage system was a 512x512 emitter array. The emitters were capable of apparent temperatures of up to 500K. The early pixel designs could transition from off to maximum apparent temperature within 13ms. Improvements in IRSP resistive arrays sprouting from these humble origins have been leveraged to produce arrays for the LFRA[1] program that are 1024x1024 providing maximum apparent temperatures over 700K and rise times of 5ms. Many improvements were needed to leap from 512x512 arrays to 1024x1024 and 768x1536 in the case of the WFRA program. Large format resistive emitter arrays require a great deal of expertise to produce with acceptable yield. Increased size requires a mature process to deliver high operability arrays with maximum apparent temperatures over 700K. The improvements to the pixel design responsible for this increase in performance is described in section 2 of this paper.

As arrays get larger the demand for increased performance is growing as well. Faster frame rates are desired along with higher temperatures. The pixel architecture and materials are chosen carefully to meet the needs of both temperature and speed. The time it takes a pixel to transition from one commanded temperature to another higher temperature is known as the rise time. The pixels need to reach the newly commanded temperature within one frame time which can be as brief as 5ms. A new enhancement technique to improve the rise time is described in section 3 of this paper.

In league with the demand for faster rise times is the need for increased uniformity of the arrays. Before a resistive array can be taken to high apparent temperature it must first be annealed. Annealing is a process by which pixels are driven to a high temperature to stabilize the physical properties in a controlled fashion. During this process arrays are often left with a non-uniform output. A process to mitigate this effect is described in section 4 of this paper.

2. EMITTER PIXEL DESIGN IMPROVEMENTS

Designing pixels is a balancing act between speed, maximum temperature and material choice. The pixels used on the MIRAGE XL system must meet a specification defined by the LFRA program. The original pixel design used on LFRA met the maximum temperature specification of 700K in the 3-5 micron band but did not meet the 5ms rise time requirement. The pixel was redesigned to have a shorter leg to achieve the LFRA rise time requirement. Shortening the leg allowed for faster rise times but came at a cost to the maximum temperature at the same drive current. To maintain the maximum apparent temperature of 700K, more current is required than with the old pixel design. There is enough headroom available in the drive circuitry of the LFRA Read In Integrated Circuit (RIIC) to provide the additional current required to meet the maximum temperature requirement.

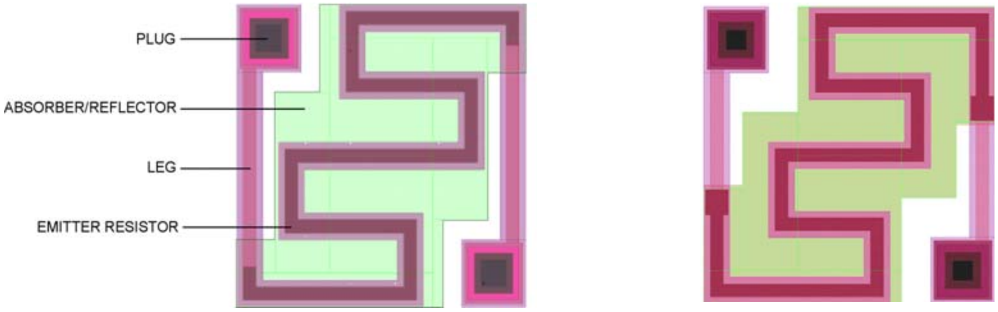

Fig. 1. Pixel layout, left original LFRA pixel with a 25µm leg, right new LFRA pixel design with a 15µm leg. The new LFRA pixel has a shorter leg allowing for faster rise times while maintaining the maximum temperature.

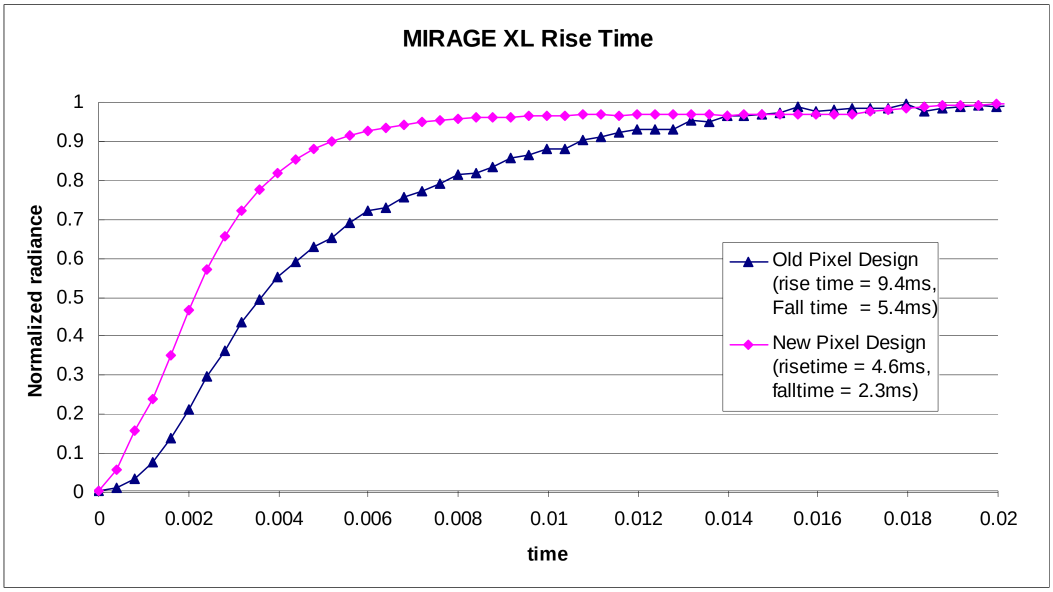

Fig. 2. Pixel rise time, Comparison of New and old pixel design rise time

3. RISE TIME ENHANCEMENT (OVERDRIVE)

As the frame time of the IRSP approaches or exceeds the natural rise time of a pixel, an incongruity develops; the time allowed for the pixel to reach the newly commanded temperature is shorter than the time the pixel would naturally take to reach the new temperature. The MIRAGE XL pixel is capable of meeting the rise time requirement for full transitions, but when the transition is only part of the total dynamic range of the emitter the rise time increases above the frame time. The need for comparable rise times for all transitions during a simulation gives rise to the need for an algorithm than can be applied to the scene data in real time. The algorithm simply needs to make the rise time faster while not overshooting the intended drive level. The goal of the experiment was to demonstrate the feasibility of overdrive for less than full transitions of the emitter pixel.

3.1 Rise time

The time it takes a pixel to heat up and reach the newly commanded temperature depends on the size of the transition. If the difference between the starting temperature and the ending temperature is the maximum dynamic range of the emitter then the rise time will be at its fastest. That is, commands from off to full on will result in the fastest rise times possible. When a pixel transitions between intermediate temperatures, as is the case for most scene simulation regimes, the transitions take longer than the full scale transition rise times. The rise time is drive dependent as can be seen in Figure 3. A small subset of pixels was measured for rise time under varying drive transitions. For this discussion, The rise time is taken to be the time between the 10% radiance level and the 90% radiance level of the transition. The pixels were first measured for a maximum transition case, off to 100% drive; the rise time for this case was 6.7ms. Next, the same pixels were measured for a transition between off and 75% drives, and the rise time was found to be 8.2ms. This was continued for the off to 60% and off to 50% drive levels. The rise times were 8.6ms and 9.3 ms respectively. The rise time decreases as the change in commanded temperature or drive increases.

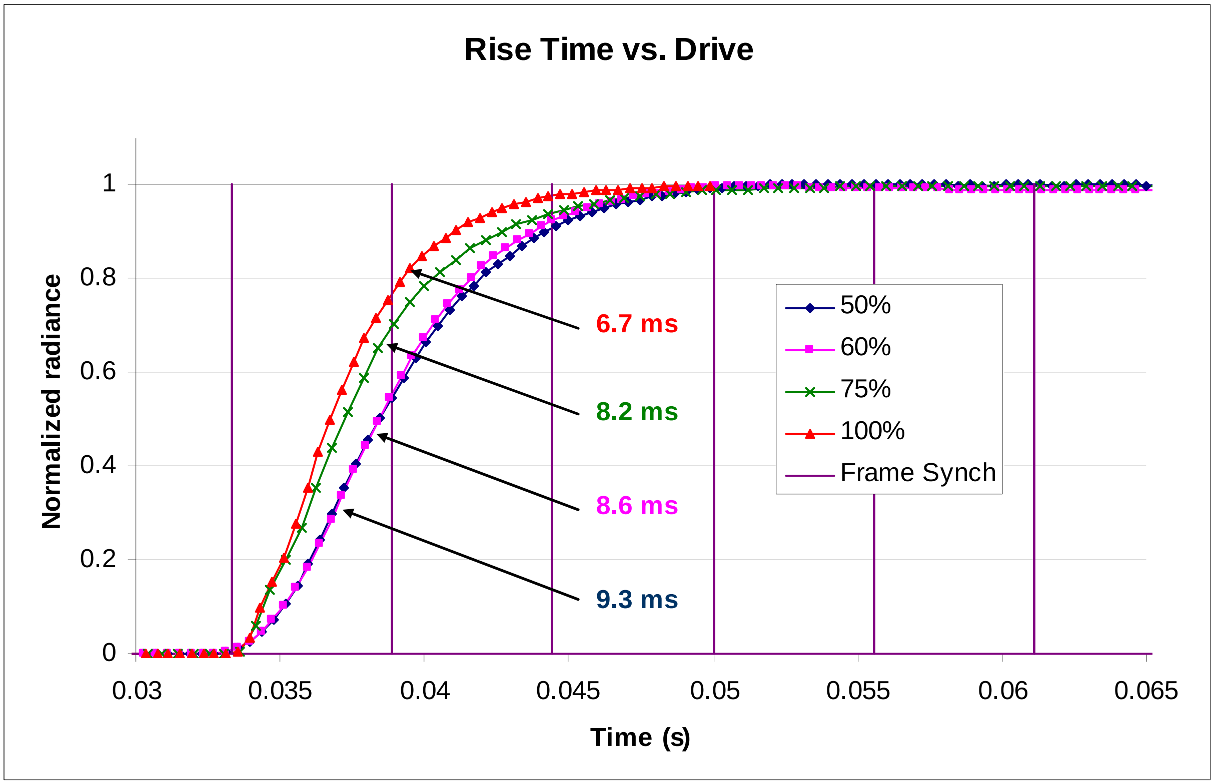

Fig. 3. Rise time as a function of drive. Each plot is from off to 50%,60%,75%,100% drive. The rise time is fastest for the greater transitions. Each measurement was made on the same group of pixels

3.2 Overdrive

In order to compensate for the variations in pixel rise time due to drive level, over drive is employed. Overdrive exploits the differences in the rate of change in radiance for different drive level transitions. By having the first frame of a transition use a higher drive level and therefore a steeper slope than the non-overdriven frames, the emitter achieve the desired apparent temperature quicker than its natural rise time.

Over drive works by knowing what the current drive level is and what the newly commanded drive is; a drive level higher than the intended drive level is substituted for the first frame. The subsequent frames are set to the intended drive level. This can be seen in Figure 4. By having a higher drive level for the first frame the rate at which the pixels heats up is increased. This allows the pixel to reach the intended radiance by the start of the second frame. If the next frame were not changed the pixel would follow its natural rise time curve. However for overdrive, the subsequent frames are at the intended drive level; which by the start of the second frame the radiance level has already been reached, allowing the pixel to simply settle at the intended radiance level. If the first frame or overdrive value is set too high the temperature will overshoot and take longer to settle to the intended temperature.

The perils of overshoot become evident in the case where the drive for a particular pixel in each frame projected in a scenario is higher than in the last frame. In this case the overshoot causes the pixel to reach a higher temperature than intended for each frame. The cumulative effect of overshoot on each frame would be to cause the pixel temperature to run away and the final frame would have a much higher and less accurate temperature than expected. In order to prevent accumulating errors, the overdrive algorithm employed must ensure that a pixel never overshoots its desired radiance.

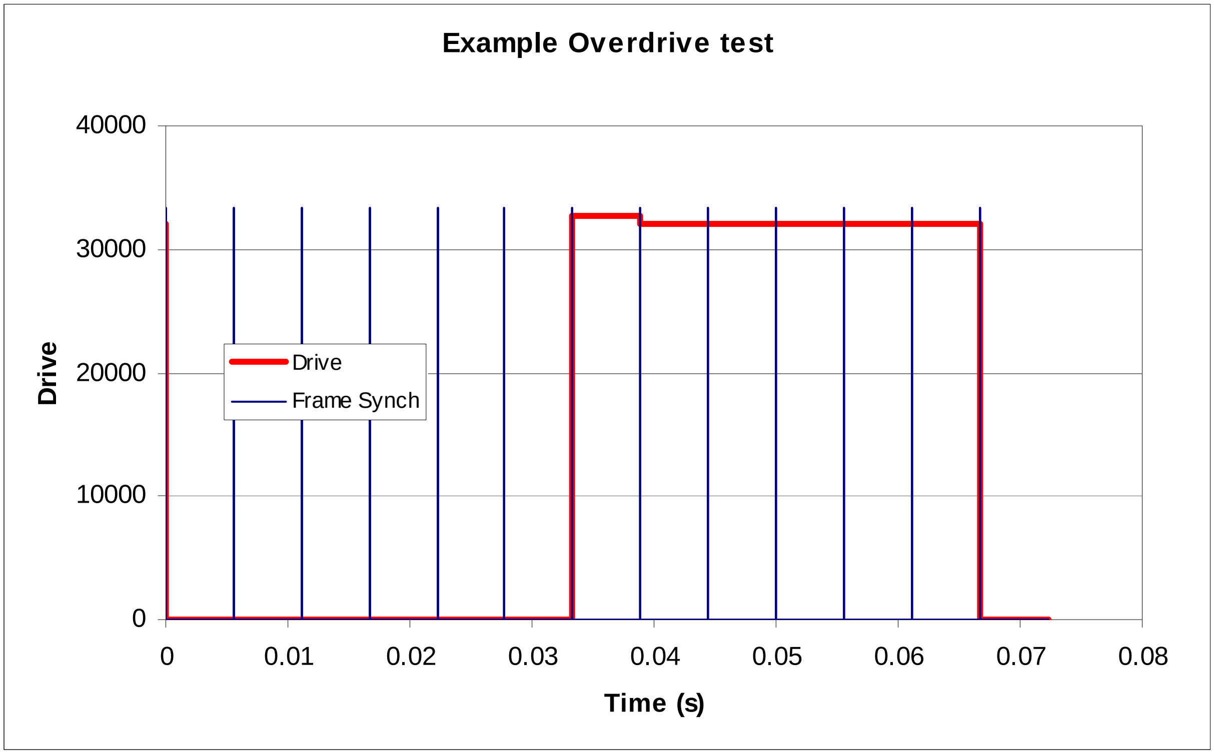

Fig. 4. Frame by frame drive levels employed in overdrive. The first frame is intentionally set to be higher than the intended drive level in the subsequent frames.

3.3 Overdrive results

The concept of overdrive was demonstrated to make a first pass at implementing the algorithm in an IRSP. The concept was confirmed by taking a small group of pixels and measuring the rise time at different transitions. The rise time was measured by creating a movie with a set of frames at a lower drive level and then a reciprocal set at a higher drive level. The resulting movie of frames was measured asynchronously with an IR camera. First, the rise time was measured with all the high frames at the same level. Then differing amounts of overdrive were added to the first frame in the high frame set. The results of the overdrive between off and 75% drive can be seen in Figure 5. For this transition size, the appropriate amount of overdrive was found to be 2% over the target. The rise time was improved from 8.2ms to 4.5ms by having one frame of 77% drive before the frames of 75% drive.

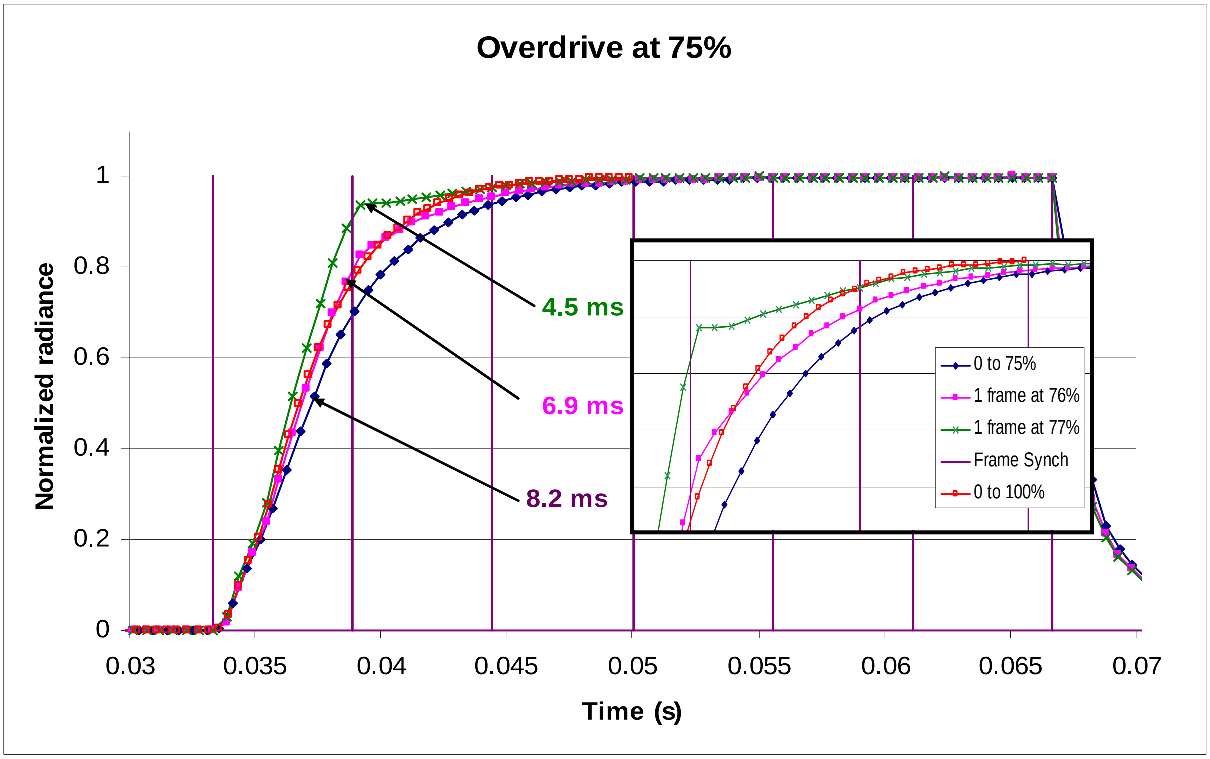

Fig. 5. Results from overdrive at 75% drive, Overdrive frame set to 76%, 77%, 75% and 100% shown also. Inset shows final settling at intended drive level.

Similarly the rise time was measured for an off to 50% drive case. The natural rise time was 9.3ms, but the addition of a frame with drive 51.5% before the remaining 50% drive frames reduced the rise time to 4.7ms, as seen in Figure 6.

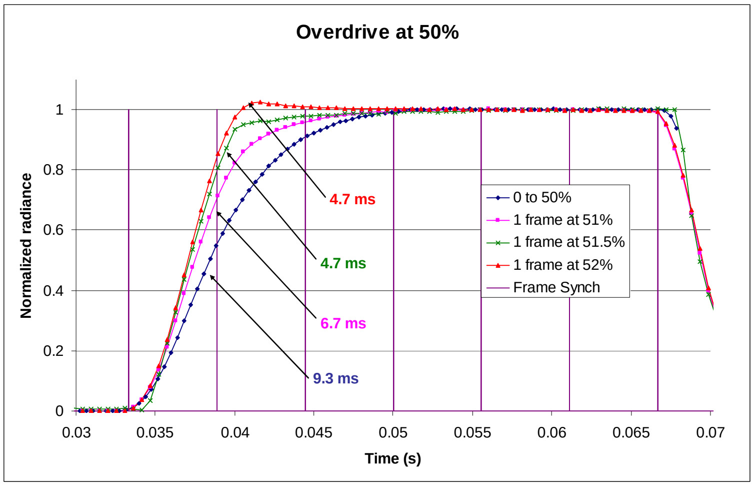

Fig. 6. Results from overdrive at 50% drive, Overdrive frame set to 51%, 51.5% and 52%.

Finally, the rise time was measured for a transition between 50% and 75% drive. This is a more typical transition for in IRSP. The natural rise time was 8.1ms, but the addition of a frame with drive 77% before the remaining 75% drive frames reduced the rise time to 4.3ms, as seen in Figure 7.

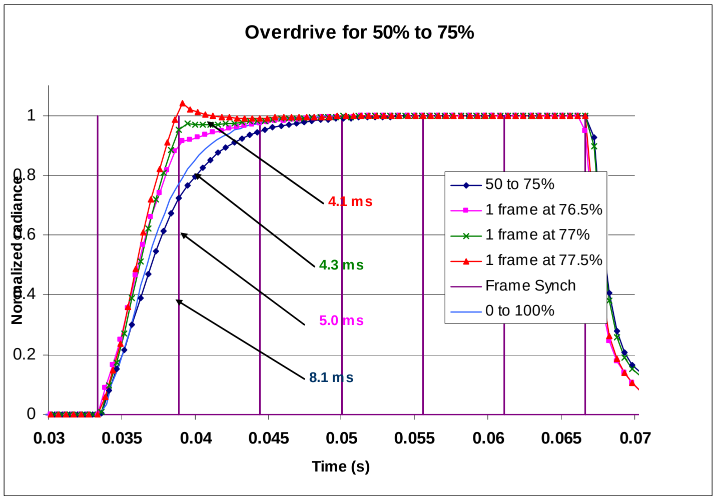

Fig. 7. Results from overdrive between 50% drive and 75% drive, Overdrive frame set to 76.5%, 77% and 77.5%.

Initial results are promising; they show that it is possible to change the rise time of a pixel by employing the overdrive technique. Overdrive can help improve 0 to 90% rise times up to the order of the frame rate, but improvements beyond the 95% level appear limited by overshoot and pixel settling times.

4. ADAPTIVE ANNEAL

The MIRAGE XL 1024x1024 RIIC can deliver enough current to the pixels to reach temperatures approaching their physical limit. As the pixel temperature becomes too high, physical changes causing performance degradation can occur. These changes include pixel resistance, emissivity and morphology. A cautious approach to reaching higher apparent temperatures is required. Omitting the anneal process or failure to properly anneal the pixel can cause permanent changes to the pixel. Fixed patterns can be burned into an un-annealed array and pixel damage may results from overheating pixels.

4.1 Annealing

Annealing is a process by which pixels are driven to high apparent temperatures after fabrication to stabilize their physical properties in a controlled, non degrading way. Several changes take place within the pixel during the excursions to high temperature. The most notable change is to the pixel resistance. As the pixel is heated to temperatures where annealing occurs the resistance changes, the resultant change to the resistance can be seen in Figure 8. As the pixel is heated its resistance increases, reaches a maximum, and then decreases. The resistance decreases and eventually stabilizes at the desired value. Caution must be taken during this process to prevent ’over-annealing’ and pushing the resistance back up, as seen in the plot in Figure 8. The result of over-annealing is the burnt pixel of Figure 9.

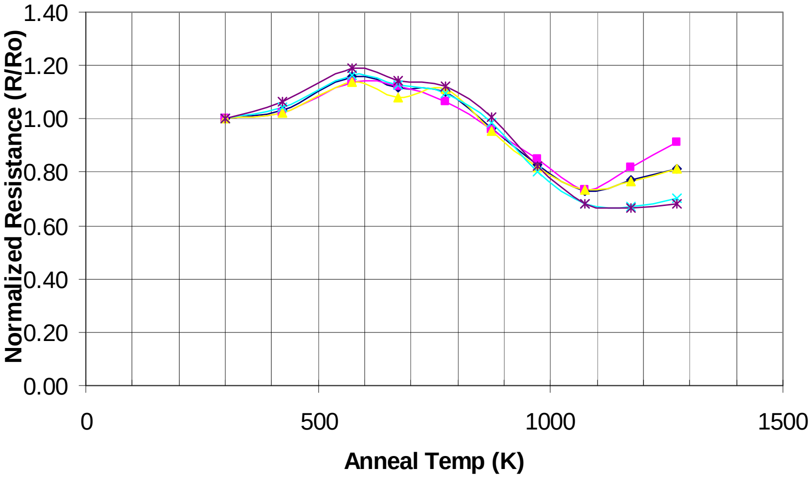

Fig. 8. Normalized resistances plotted against anneal temperature. The normalized resistance increases then after achieving a maximum decreases and then stabilizes.

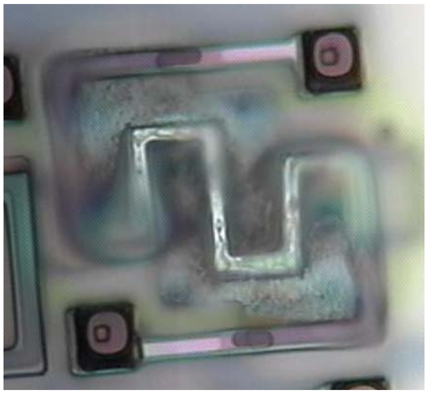

Fig. 9. Image of an over annealed pixel.

Another potential issue for pixels reaching high temperatures during the anneal process is warping. The pixel structure can physically warp as seen in figure 10. When the pixels warp the center of the pixel is deflected downward causing the tuned optical cavity to shrink and then change the in band radiance level. Warping is cause by stress within the pixel structure due to the more rigid short leg. Rapid initial heating increases the risk of warping. To reduce the effects of warping and burned pixels a new anneal process is needed. The new anneal process accommodates variations in pixel resistance and helps prevent warping.

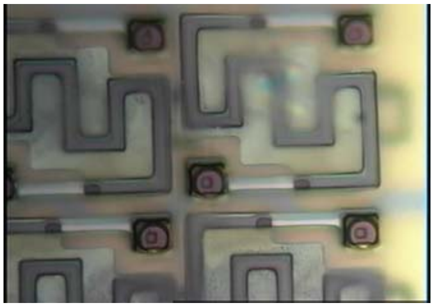

Fig. 10. Image of warped pixel. Upper right pixel is warped with center of pixel deflected downward. Upper left pixel in image is normal.

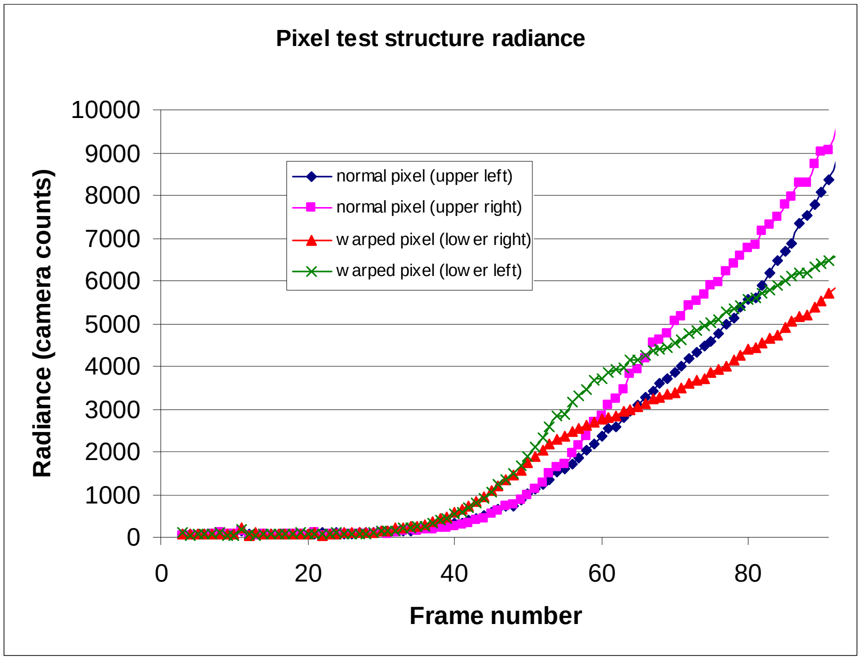

Fig. 11. Radiance of warped pixel compared to a normal pixel. The warped pixels have a loss in radiance due to a change in the optical cavity

4.2 New anneal procedure

The first step in the anneal process is to overcome any resistance differences between the pixels that might cause current limits. As pixels anneal their resistance changes, as seen in Figure 8, some pixels are further along in this curve than others. The nominal voltage across the emitter pixel is 5.0V; this was raised to 5.6V to prevent the pixels from current limiting if their resistance is too high. The next step is to measure each pixel's radiance with a uniform drive level. The measurement was accomplished with the Calibration Radiometry System (CRS). The CRS drives the input to the IRSP with a sparse array of pixels. For the purposes of this measurement each active pixel is separated from the next active pixel by 24 off pixels in the horizontal and vertical directions. The spacing allows for the infrared camera to properly collect the total radiance from each pixel using several camera pixels, without overlap of the radiance from the adjacent emitter pixels. After the sparse grid is measured the pattern is shifted over one pixel and the measurement is repeated. This process is repeated until every pixel in the array has been measured at the selected drive level.

Once the entire array has been measured at the selected drive level, the radiance distribution of pixels is analyzed using image analysis software. The pixels that have reached the predetermined anneal temperature are segregated and disabled to prevent further annealing. The drive level is then incremented and the array radiance is measured again using the same process. This cycle continues until all the pixels have achieved the predetermined anneal temperature.

The iterative approach prevents over annealing of pixels that have a different resistance than the array average. As pixels reach the anneal temperature they are disabled allowing the remaining pixels to be driven harder on subsequent passes to achieve the anneal temperature. The result of this adaptive anneal is to greatly reduce the number of burnt and warped pixels that would have otherwise resulted from a single drive level anneal of the entire array.

4.3 Uniformity adjustment

Following anneal, the array's non-uniformity is measured at a uniform drive level. The non-uniformity results primarily from variations in pixel resistance, though emissivity and morphology also play a part. Once the uniformity is measured, any pixels that are hotter than the normal distribution are annealed further. The additional anneal causes the pixel resistance to decrease further. Only the pixel needing additional anneal are activated by the CRS during the measurement. The normal distribution of pixels is left un-annealed. The process is continued by incrementally increasing the drive to the pixels requiring further anneal and then re-measuring the entire array to regenerate the array distribution until the distribution is within an acceptable range.

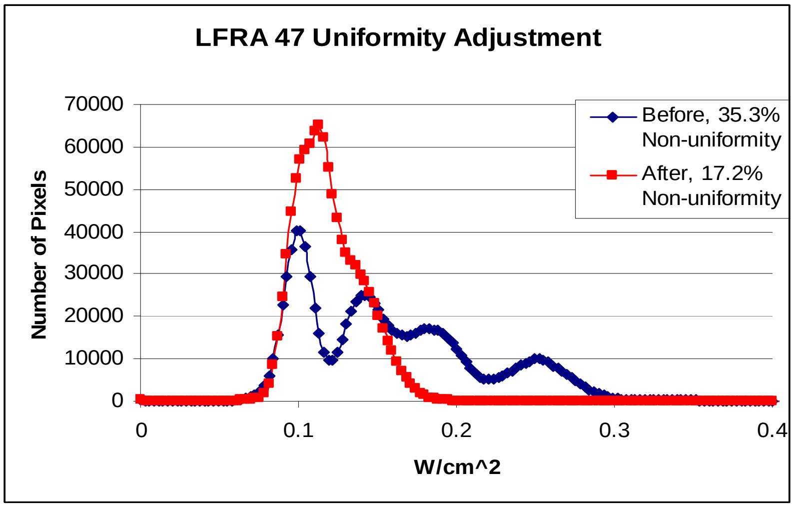

Fig. 12. Representative data showing how outliers were annealed further to reduce the non-uniformity. Initial non-uniformity after anneal was 35.3%, the non-uniformity after uniformity adjustment was 17.2%.

4.4 Stability anneal

Following anneal and uniformity adjustment the array must be stabilized. The pixels will continue to change resistance as they are driven until they reach equilibrium, as seen in Figure 13. The pixels are driven at an apparent temperature below the anneal point and above the specification requirement for approximately 5 to 10 minutes. The stabilization is intended to prevent the array from changing over time after delivery. Prior to delivery, the drive limit in the IRSP is set to a point below the stabilization level.

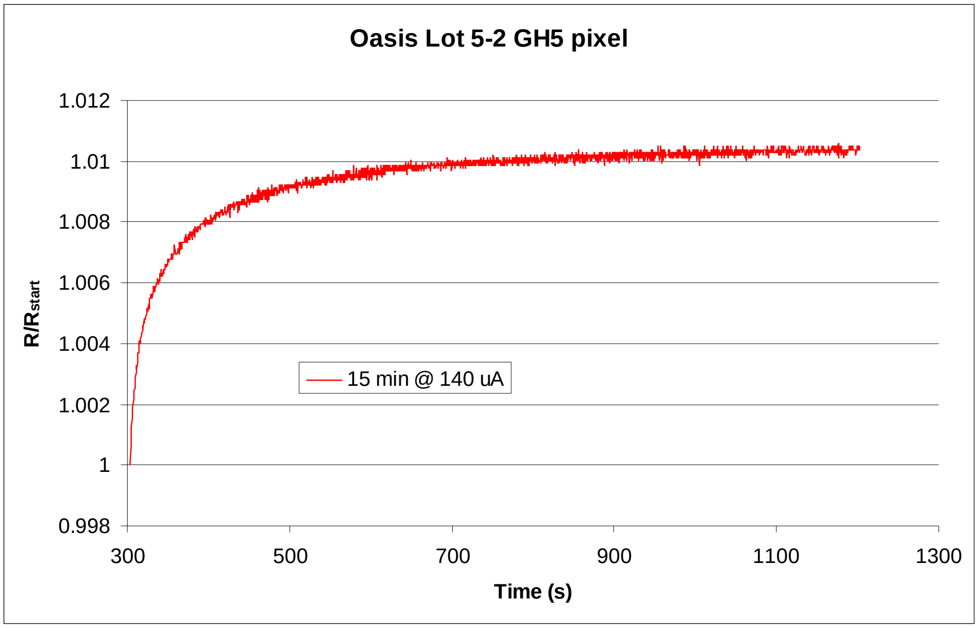

Fig. 13. Normalized pixel resistance over time.

4.5 Adaptive anneal results

In addition to annealing pixels on a more individual level the post anneal non-uniformity can be improved by choosing individual pixels to receive more annealing and hence bring them closer to the array average distribution. Adaptive anneal significantly reduced the number warped and over-annealed pixels. To date two arrays have been fully annealed using the adaptive anneal process and the results are shown in Table 1.

Table 1. In process non-uniformity measurements, non-uniformity was measures after anneal and after the uniformity adjustment process as well as during final acceptance testing.

Array #	Post anneal non-uniformity	Non-uniformity After uniformity adjustment	Non-uniformity at maximum drive
LFRA 45	41.1%	29.0%	13.3%
LFRA 44	43.3%	26.3%	24.0%
LFRA 47	35.3%	17.2%	In process

5. SUMMARY

Numerous improvements have been made to the pixel design, processing and operation of the Mirage XL IRSP. Improvements to rise time were made by redesigning the pixel to have a shorter leg. The shorter leg allowed the pixel to meet the 5ms rise time specification. In addition to improved rise time the maximum apparent temperature was still maintained. For smaller transitions overdrive can be applied to achieve faster rise times and overcome the transition size dependency of the rise time. Adaptive anneal is able to overcome the inherent non-uniformity of the as deposited pixel resistances and morphologies of the pixels. In addition to annealing pixels on a more individual basis the post anneal non-uniformity can be improved by choosing individual pixels to receive more annealing and improve the array uniformity. These improvements will be applied to future Mirage XL deliveries and other upcoming programs such as WFRA[1].

REFERENCES

[1] J. Oleson, et al " Large Format Resistive Array (LFRA) InfraRed Scene Projector (IRSP) Performance & Production Status," Proc. SPIE 6544, (2007).