Rise-Time Enhancement Techniques for Resistive Array Infrared Scene Projectors

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ABSTRACT

Santa Barbara Infrared (SBIR) produces high performance resistive emitter arrays for its line of IR Scene Projectors (IRSPs). These arrays operate at frame rates up to 200 hertz. The inherent properties of the pixels can result in transitions between two temperatures that are more than the 5 millisecond frame time. Modifying the pixel drive level on a frame by frame basis can lead to improvements in the measured rise times. This paper describes a new capability developed by SBIR that improves the rise time of the pixels. It discusses the process by which array drive levels are modified to achieve quicker transitions together with test results showing improved rise time. In an example transition cited here, the risetime is reduced by more than a factor of two from 8.3 ms to 3.7 ms.

Keywords: Scene Projection, LFRA, Mirage XL, WFRA, Rise Time, Overdrive, IRSP

1. INTRODUCTION

Over the past decade Santa Barbara Infrared (SBIR) has produced several generations of infrared scene projectors (IRSPs). The evolution of the technology behind these systems has led to large formats with high frame rates. The 1024 x 1024 Large Format Resistive Array (LFRA) is able to operate in full-frame mode at speeds up to 200 hertz. When running at this maximum speed, the emitter pixels are only allowed 5 milliseconds to transition from one temperature to another as the scene being projected changes from frame to frame. Due to the physical properties of the micro emitter structure of the pixels, 5 milliseconds is sometimes an insufficient time to allow full transition to the desired apparent temperature. In this case it takes multiple frames for the pixel to achieve the target temperature and is thus problematic when simulating highly dynamic scenes requiring a transition between each frame at high frame rates. Furthermore, the rise time of the pixel is dependent on the transition being commanded, and this relationship is an inverse one. As the commanded transition gets smaller, the rise time actually becomes longer. This means that a transition from off to maximum temperature is the fastest possible scenario. Since the majority of transitions in scene simulations involve smaller transitions, most of the simulation will have longer and variable rise times. Achieving consistently short rise-times regardless of transition is crucial to providing accurate simulations.

SBIR has developed a method, known as overdrive, for improving the rise time of the emitter pixel. This method involves modifying the pixel drive level from frame to frame to a level other than that which would normally produce the desired temperature in a steady state condition. This technique can significantly improve rise time without causing artifacts, such as overshoot. This paper will discuss this modification process and present measurement data that demonstrate the resulting pixel performance improvement.

2. OVERDRIVE CONCEPT

As the frame time of the IRSP drops below the natural rise time of a pixel, an incongruity develops in that 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 not always capable of meeting the rise time requirement for full transitions, but when the transition is only part of the total dynamic range of the IRSP this problem is exacerbated. The need for comparable rise times for all transitions during a simulation necessitates an algorithm that can be applied to the scene data in real time. The algorithm should decrease rise times while not overshooting the intended drive level. The algorithm used must also be achievable using available hardware to perform the requisite processing. Previous work demonstrated the feasibility of overdrive[1]. In the following, the actual implementation, calibration and initial results of the overdrive algorithm are presented.

2.1 Rise time

The time it takes a resistive pixel to heat up and reach the newly commanded temperature depends on the magnitude of the transition and the target temperature. As mentioned above, for transitions between zero and the maximum commandable temperature, rise time will be at its minimum. 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. This drive dependence can be seen in Figure 1. This data reflects measurements of a small subset of pixels whose rise times were averaged to produce one curve per case for varying drive transitions. For this discussion, the rise time is expressed as 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 (0% drive) 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. Figure 1 clearly shows a decrease in rise time as the change in commanded temperature or drive increases.

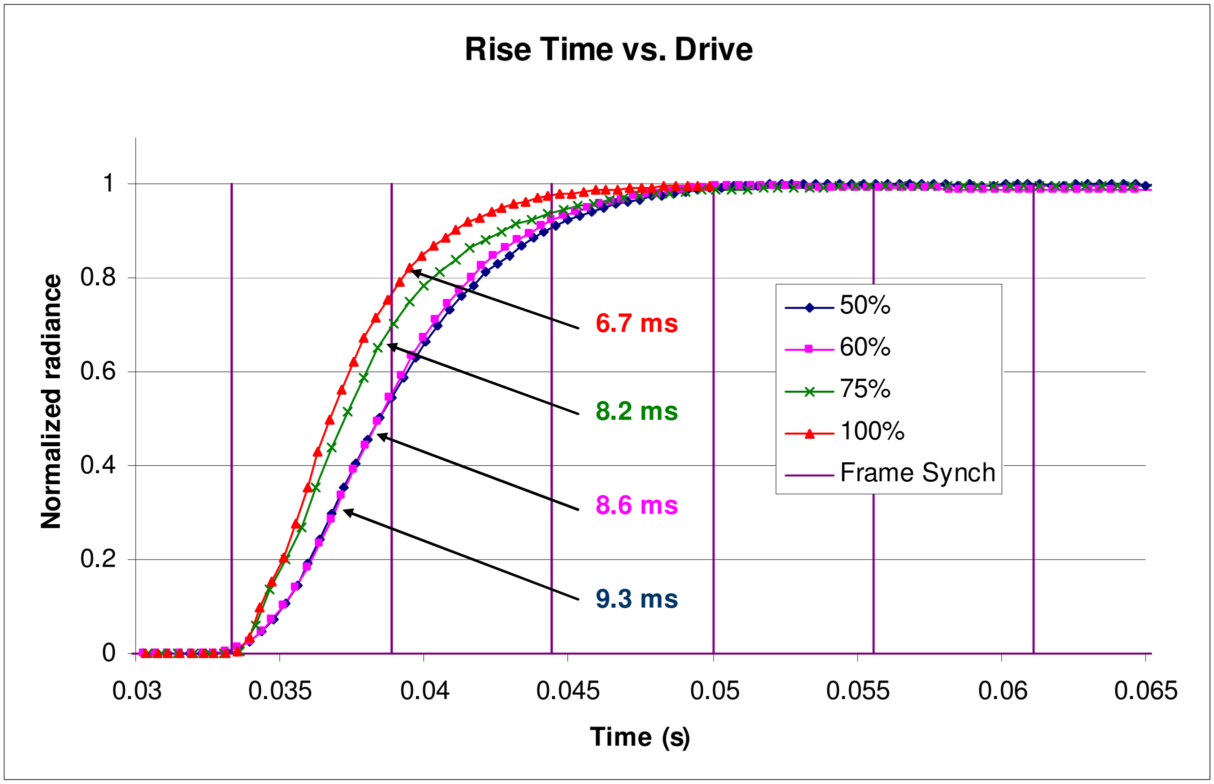

Figure 1. Rise time as a function of drive. Each plot is from OFF to 50%,60%,75%,100% drive. The rise time is fastest for the greater transitions. Each measurement was made on the same group of pixels

2.2 Overdrive

In order to compensate for the variations in pixel rise time due to drive level, and to improve all rise times in general, overdrive 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 radiance-per-unit-time slope than the non-overdriven frames, the emitter achieves the desired apparent temperature quicker than its natural rise time.

Overdrive works by knowing what the current drive level is and what the newly commanded drive level will be, and then substituting a higher drive than originally intended for the first post-transition frame. The subsequent frames are set to the intended drive level as is shown in Figure 2. By having a higher drive level for the first frame, the rate at which the pixels heat up is increased. This allows the pixel to reach the intended radiance by the start of the second frame. If this subsequent frame were not changed the pixel would follow its natural rise time curve towards a higher radiance level than intended. However for overdrive, the subsequent frames are at the drive level that causes the desired radiance level upon reaching equilibrium. Ideally, by the start of the second frame this radiance level has already been reached, allowing the pixel to simply settle at the intended radiance level. If the first frame 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 previous frame. In this case the overshoot causes the pixel to reach a higher temperature than intended for each frame, and with each consecutive frame's drive increasing, the pixel would never have a chance to settle. The cumulative effect of compounding overshoot for frame after 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.

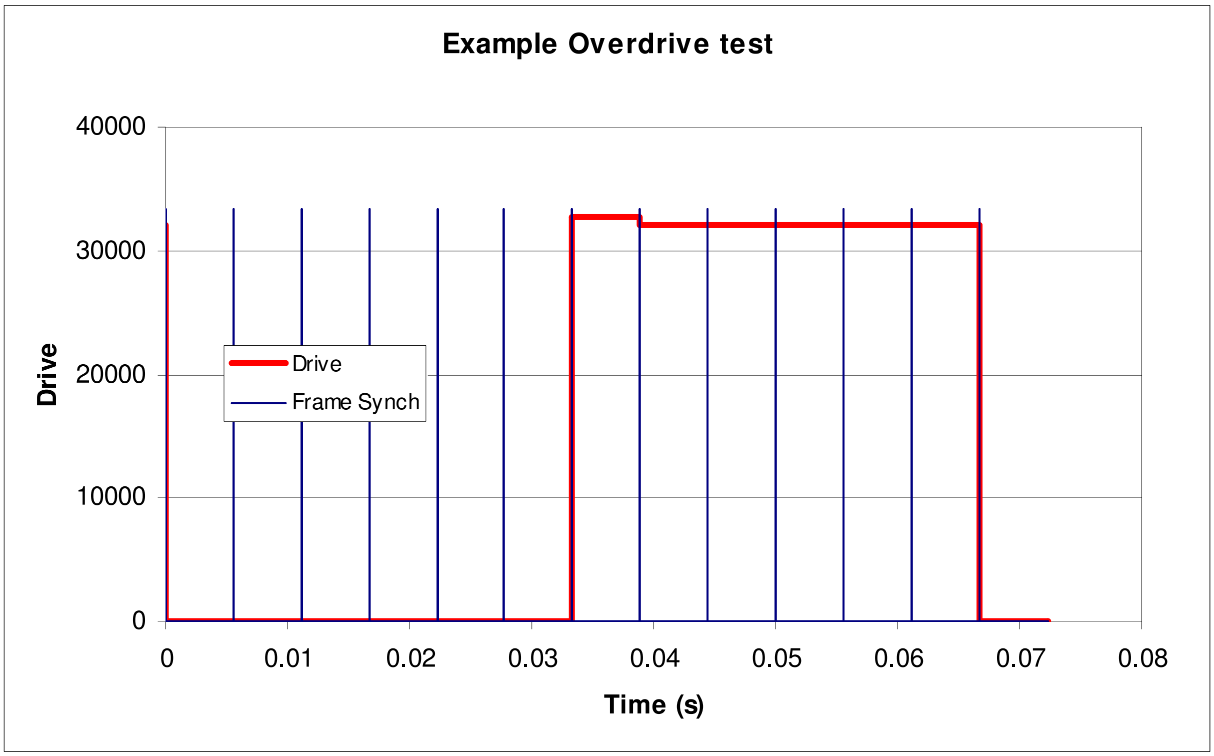

Figure 2. Frame by frame drive levels employed in overdrive. The first frame is intentionally set to be higher than the intended drive level in the subsequent frames.

3. IMPLEMENTATION

During initial testing of the overdrive algorithm, custom movies with specific overdrives built into them were used. While useful for early experimentation, this method of generating overdriven frames is not compatible with closed-loop simulations. Since the initial experimentation with overdrive, SBIR has developed a method for performing programmable overdrive modifications on any scene being sent into the IRSP in real time. This method was developed using the existing architecture of the command and control electronics (CnCE) of the LFRA system.

As currently implemented, the user specifies a look-up table (LUT) containing overdrive values. This LUT contains 16384 possible overdrive values, and the address of each corresponds to a different frame to frame transition. A sample LUT applying 10% overdrive in the 50% to 90% drive case, as well as 14% overdrive in the 60% to 80% drive case, is shown in Figure 3. This mapping is defined so that for each 14-bit address in the LUT, the first seven bits correspond to the seven highest-order bits in the pre-transition pixel value, and the second seven bits correspond to the seven highest-order bits in the post-transition pixel value. Each of these memory locations contains a 32-bit word that describes the exact overdrive value to be applied to that range of transitions. This overdrive level is defined as a fraction of the transition, and can range from 0 to 100% of that transition in steps as small as one bit of the 16-bit dynamic range. Once the overdrive LUT has been constructed, it can be loaded into memory and then applied to the incoming data stream.

LUT Row Number	Memory Address	Transition Range	Overdrive Value (Hex)	Overdrive Value (Percentage)
1	0	0 through 511 to 0 through 511	0	0
2	1	0 through 511 to 512 through 1023	0	0
3	2	0 through 511 to 1024 through 1535	0	0
. . .	. . .	. . .	. . .	. . .
8307	8306	32768 through 33279 to 58368 through 58879	0	0
8308	8307	32768 through 33279 to 58880 through 59391	19A00000	10%
8309	8308	32768 through 33279 to 59392 through 59903	0	0
. . .	. . .	. . .	. . .	. . .
9831	9830	38912 through 39423 to 52224 through 52735	23D70000	14%
. . .	. . .	. . .	. . .	. . .
16384	16383	65024 through 65535 to 65024 through 65535	0	0

Figure 3. The structure of the overdrive lookup table. The actual LUT is simply a text file wherein the rows correspond to memory addresses there is only one eight-digit hex value per line.

Rise time measurements can be very challenging. Ideally, a fast single element detector would be focused onto a single or small group of pixels and used to measure the ride time directly. However, in practice, this alignment is difficult. In addition, it is beneficial to measure multiple points on an array in order to obtain representative performance and attempting numerous measurements with a single element detector would be very time consuming. A better solution would be to measure rise time with an imaging sensor. However, a hurdle presents itself when attempting to measure rise time using a MWIR camera that runs at 60 hertz. The camera's frame time is over 16 milliseconds. This is clearly a problem when the goal is to measure rise times of less than 5 milliseconds. Thus a special data collection method was developed to overcome this hurdle. This method uses an asynchronous data collection technique originally developed at KHILS. The IRSP is set to project at 180.3 frames per second, while the camera grabs frames at a rate of 60 per second. This scene drives the pixels at the low level for three frames, then transitions to the high level for three additional frames, making the effective frame rate 60.1 Hz, just slightly different than that of the camera. This frame set is projected in a loop as frames are grabbed using IRWindows4, the latest version of SBIR's automated Electro-Optical software. The software is configured to only grab every sixth frame from the camera and follows the "beating" of the two slightly mis-matched frequencies. The first camera frame f0 is grabbed at time t=0 seconds, five camera frames are skipped, and frame f6 is grabbed at time t=0.1 seconds. However, since the camera and IRSP are being run asynchronously, the IRSP has completed three full cycles of six frames each by this time and is in fact 0.000166 seconds into its next frame as this camera frame is grabbed. This concept is demonstrated graphically in Figure 4. By exploiting this frequency difference, the pixel radiance can be sampled at an equivalent frequency of just over 6000 hertz, providing the temporal resolution necessary to measure the improved rise times.

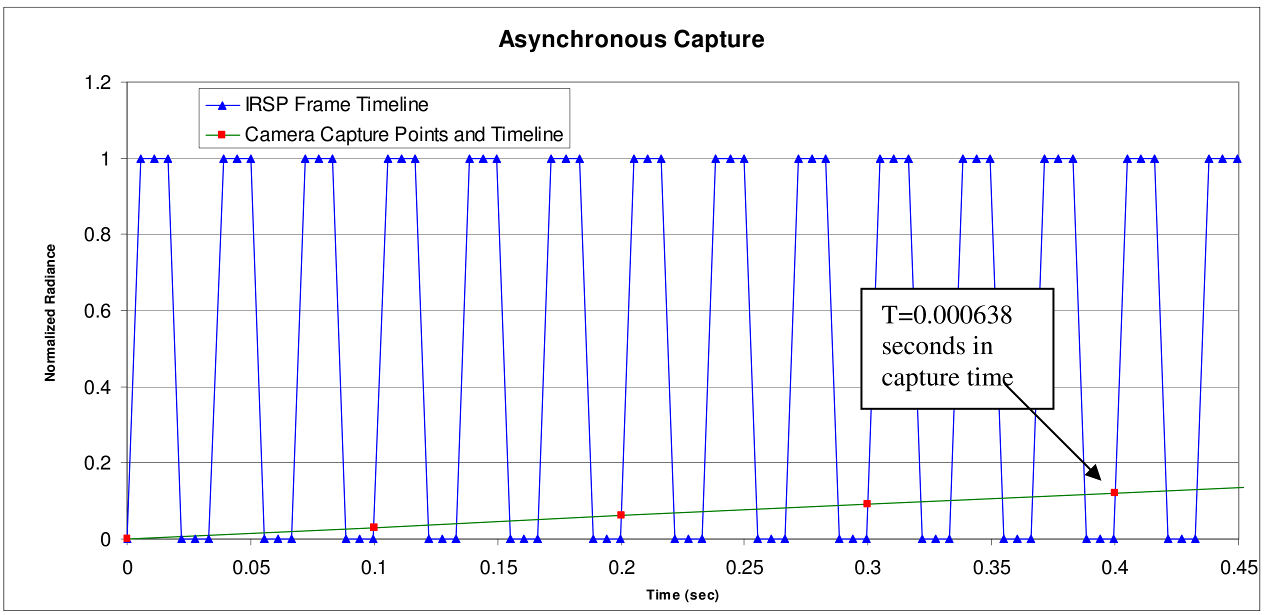

Figure 4. A graphical representation of the asynchronous capture technique, showing only the first five camera capture points. This pattern continues until a full rise and fall cycle for the pixel has been captured.

4. TEST RESULTS

4.1 Validation

The experimental results of the use of overdrive were measured using looped low to high movies as described above. Each individual frame consisted of a grid of pixels sparsely spaced across the array. Single pixels, evenly spaced in the horizontal and vertical directions, were driven at the same level per frame, and thus all experienced the same transition. The rise times of a subset of these pixels were then averaged together to determine the rise time for that particular transition.

The first step was to validate the algorithm as implemented in real time using the IRSP CnCE hardware. A custom LUT was constructed applying overdrive to the 50% to 90% drive transition. Data was captured using the asynchronous method, and then compared to data taken previously using pre-fabricated overdrive movies. As figure 5 shows, the measured data from the two cases are very similar, and the average per point difference is about 0.1% in radiance. Having verified this equivalence it was possible to move on to the calibration process.

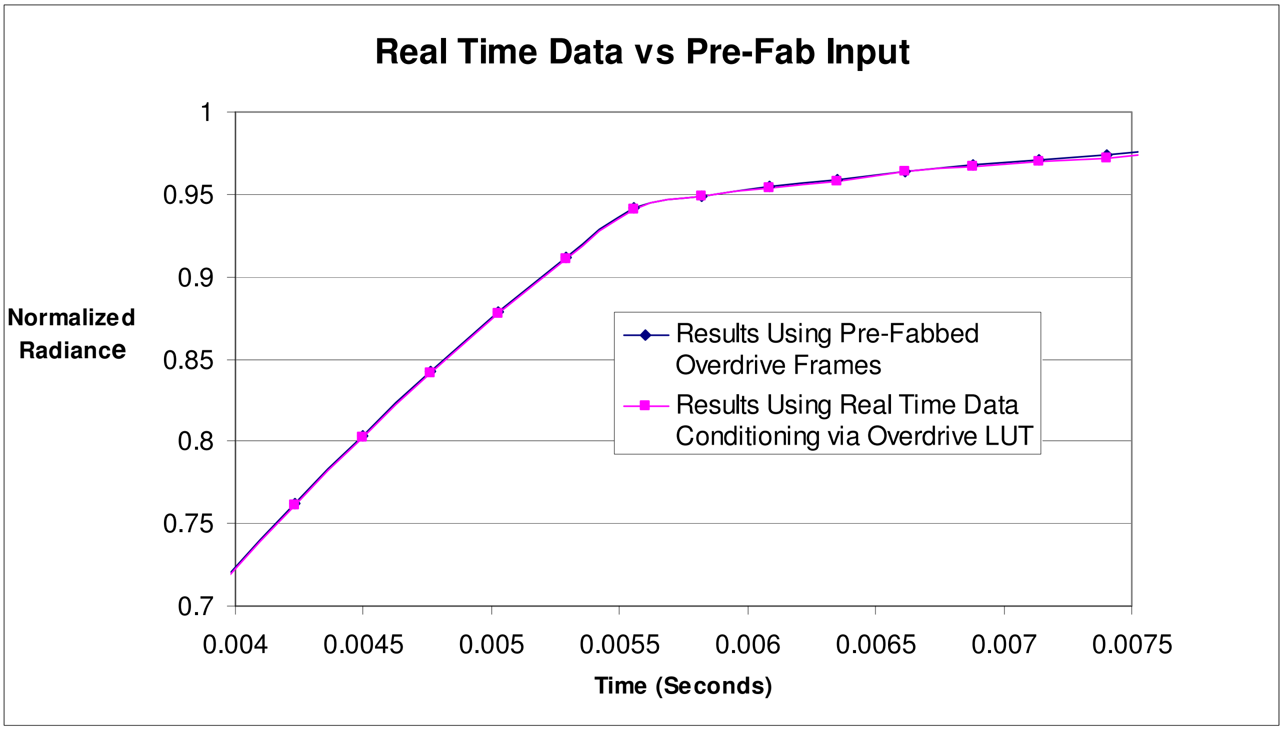

Figure 5. Comparison of rise time measurement results between tests using pre-fabricated overdrive frames and applying overdrive in real time using CnCE hardware.

4.2 Initial Results and Calibration Process

Initial results were quite promising. For each transition tested, the rise time was measured without overdrive as a baseline. In the case of the 0% drive to 80% drive transition this baseline rise time was found to be 8.3 milliseconds. Next the rise time would be measured with overdrive implemented, but it was not known a priori what the optimal level of overdrive would be. Before the overdrive table could be loaded, the proper factors had to be determined through a calibration procedure. This procedure involved generating movies similar to that shown in Figure 2, where the first frame of a transition was overdriven by a known amount. This amount was varied until an optimal response was achieved. The results can be seen in Figure 6. The data clearly shows the sensitivity of rise time to overdrive level. Overdrive is expressed as a percentage of the transition size in the figures below. Generally, it took several attempts to arrive at the optimal level of overdrive. The initial attempt at 4% overdrive led to a significantly improved rise time of 4.3 milliseconds, but it seemed that the rise time could be improved even further. Thus the next attempt used 6% overdrive. As is clear from the figure, this led to a large overshoot. Overshoot as discussed previously, is undesirable and can even be dangerous to the pixels, so the overdrive was brought down to 5%. The results from this data capture looked quite good, but upon close inspection a very small overshoot is still evident. Yet another attempt, this time at 4.8%, yielded an optimal result. The plot shows a steep slope of increasing radiance, and then an immediate level-off at the desired apparent temperature. This led to an optimized rise time of 3.7 milliseconds for the 0% drive to 80% drive transition, a drastic improvement over the original 8.3 milliseconds.

As encouraging as this result was, it is again the smaller intermediate transitions that are most in need of improvement. The 70% drive to 80% drive transition was addressed next. Without overdrive this transition took 7.7 milliseconds, almost as long to cover 10% of the dynamic range as it took to cover the full 80% discussed in the previous paragraph. The previous experience allowed the optimal level to be dialed in with fewer attempts in this case, as figure 7 shows. The initial attempt of 16% overdrive was close, but slightly sub-optimal. Pushing the level up to 18% on the next attempt yielded the desired result. In this case the rise time was improved to 4.3 milliseconds which, while not quite as good as the previous case, still achieved the goal of under 5 milliseconds for all transitions.

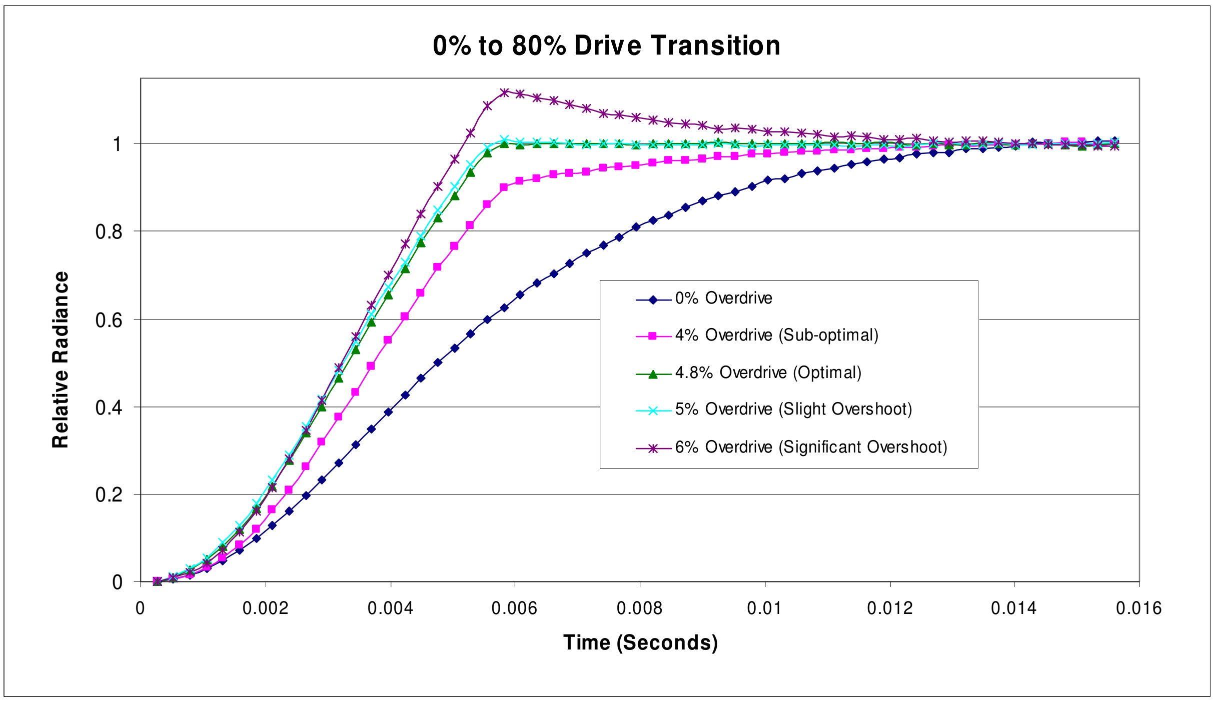

Figure 6. Radiance versus time for five different overdrive levels in the 0% to 80% drive case. The 4.8% overdrive plot shows the structure of an optimized overdrive scenario.

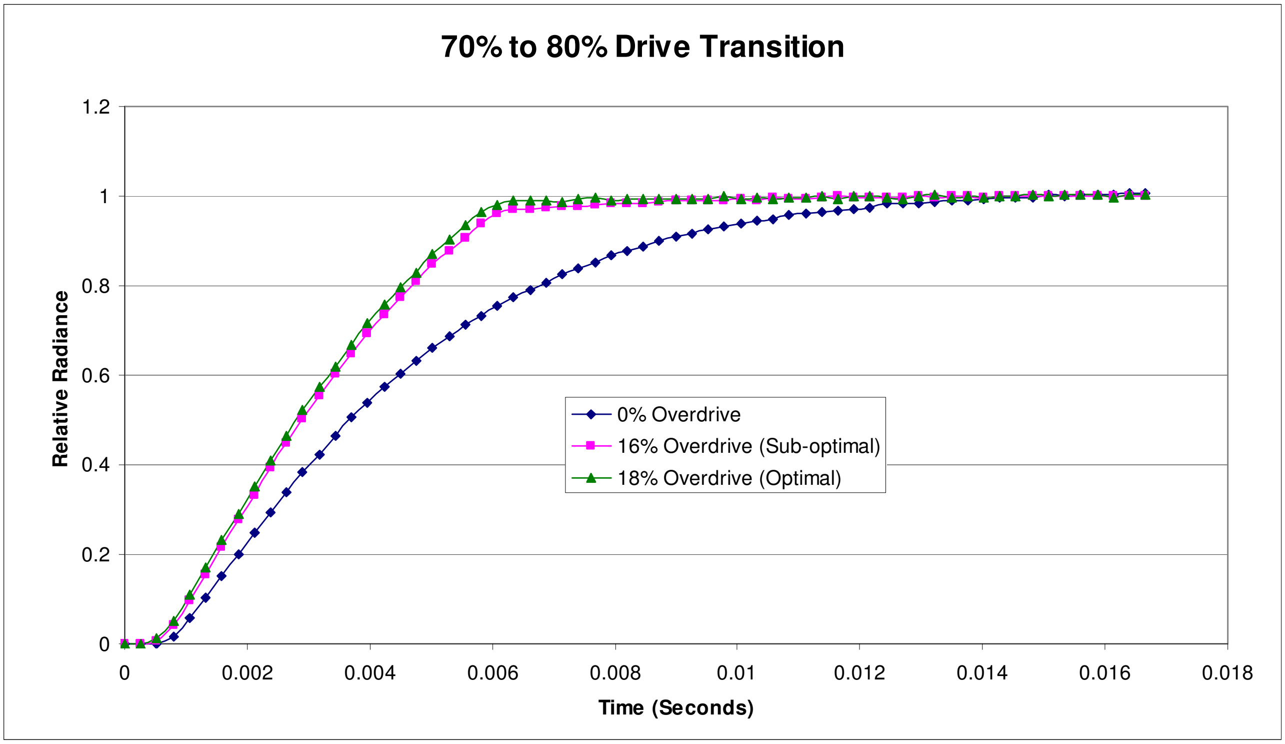

Figure 7. A similar plot for the 70% to 80% drive intermediate case.

4.3 Results for Additional Cases

The examples above give detailed insight into the calibrations process. In order to completely fill the calibration table discussed in Section 3, a large range of transitions needed to be optimized. To this end, an additional twelve transition cases were explored. In each case the level of overdrive was carefully tuned to achieve optimal rise time. The results are shown in tables 1 and 2 below.

Rise Time w/o Overdrive (in milliseconds)

	50	60	70	80	90
90	X	X	X	X	X
80	X	X	X	X	7.5
70	X	X	X	7.7	7.9
60	X	X	8.0	8.1	7.9
50	X	8.9	8.4	8.3	8.0
0	X	9.2	9.2	8.3	8.1

Table 1 Rise times for 14 cases without overdrive.

Rise Time w/ Optimal Overdrive (in milliseconds)

	50	60	70	80	90
90	**X**	**X**	**X**	**X**	**X**
80	**X**	**X**	**X**	**X**	4.5
70	**X**	**X**	**X**	4.3	4.3
60	**X**	**X**	4.3	4.2	4.3
50	**X**	4.6	4.3	4.0	4.1
0	**X**	4.3	4.0	3.7	4.1

Table 2. Improved 10%-90% radiance rise times for all 14 cases covered in Table 1.

The table shows two key positive results. First, for every transition studied, it was possible to bring the rise time down below the originally stated goal of 5 milliseconds. This means that 200 hertz operation would no longer be hindered by pixel rise time in any of these cases if overdrive was properly employed. The other improvement that emerged was an increased consistency in rise times. Without overdrive the rise times varied as much as 1.7 milliseconds across the cases studied. Once overdrive was implemented that range dropped to 0.8 milliseconds.

4.4 Full Transition Measurement

As mentioned in section 2, rise time is normally taken to be the time between the 10% level and 90% level of the transition in radiance. However, the 0% to 100% rise time is also a very relevant number, as it involves the actual commanded temperatures. Having used overdrive to improve settling behavior as well as radiance rate of change, significant improvements in 0 to 100% rise times seemed possible. The data confirms this to be true. In the case of the 70 to 80% drive transition discussed previously, the non-overdrive rise time lengthens to 8.4 milliseconds when measured from the lowest settled level to the highest settled level. The use of overdrive again improves things dramatically, as this time drops to 4.9 milliseconds. Again, these improvements are observed for all transitions, as table 3 shows.

Rise Time w/ Optimal Overdrive (0-100radiance)

	50	60	70	80	90
90	**X**	**X**	**X**	**X**	**X**
80	**X**	**X**	**X**	**X**	4.9
70	**X**	**X**	**X**	4.9	5
60	**X**	**X**	5.3	5.2	5
50	**X**	5.4	5.6	5.3	5
0	**X**	5.6	5.5	5.2	5.2

Table 3. Full transition (0-100% radiance) times for all cases covered in section 4.3.

4.5 Frame Rate Effect on Performance

As a final note, the critical relationship between overdrive and array frame rate should be discussed. Under normal circumstances rise time can be measured successfully at various different IRSP frame rates. This was not the case when measuring the effect of overdrive. This is due to the fact that overdrive is more effective as the IRSP frame rate goes up. Obviously, the goal in reducing rise time is to increase the rate of change of the pixel's temperature. This is done by increasing the pixel drive level, but it has also become evident in this study that it is easy to cause pixel overshoot if the pixel is driven high for too long. Thus, the strategy for maximizing the effect of overdrive should be higher drive for a shorter time. Since overdrive is engaged for a minimum of one IRSP frame, and higher frame rates mean lower frame times, running the array faster allows for higher overdrive levels without causing overshoot. Comparing data taken at IRSP frame rates of 120 hertz and 180 hertz clearly shows the difference. As Figure 8 shows, when testing the 0 to 90% drive case at 120 hertz overshoot started to occur at an overdrive level of only 2%. Additionally the rise time was only improved to 5.7 seconds. Compare this to the 180 hertz data, wherein optimal overdrive was achieved at 4.6% leading to a rise time of 4.1 milliseconds, and the advantage of higher frame rates is obvious. Finally, while the maximum speed 200 hertz case was not measured in this study, this trend would suggest that overdrive could go up slightly and thus rise times decrease even further at the highest possible frame rate.

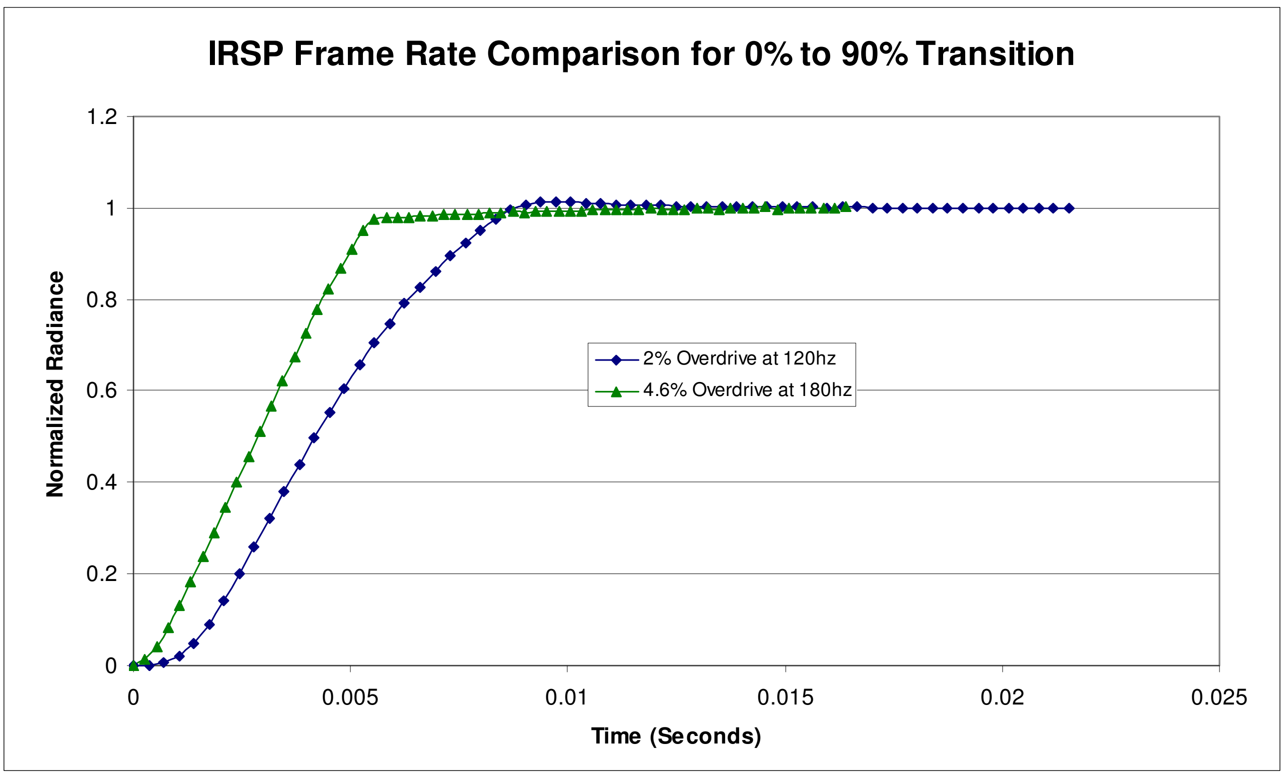

Figure 8. Comparison of rise time curves between 120hz IRSP operation and 180hz IRSP operation.

5. SUMMARY

When the evolution of SBIR's IRSP technology included 200 hertz operation, a new demand of 5 millisecond rise times was placed on the emitter pixel. Since the physical properties of the pixel do not always allow such quick transitions using standard drive means, especially for smaller, intermediate transitions, a new solution was critical. This solution involves an overdrive algorithm that works by driving the first frame of a commanded pixel transition at a higher level than the subsequent frames. Overdrive results in a significantly faster rate of change in radiance, and therefore a much shorter rise time, while still settling at the commanded temperature without overshoot. Experimental data has shown rise times dropping from the 8 to 9 millisecond range without overdrive to the 4 to 5 millisecond range with overdrive applied. These faster rise times are possible for a wide variety of drive transitions, and remain close to 5 milliseconds even when measured in the 0 to 100% fashion rather than the standard 10 to 90% manner. SBIR has implemented overdrive to allow simple applications of highly accurate overdrive levels to numerous transitions via the use of a look-up table stored in the memory of the IRSP's Command and Control Electronics. This has made overdrive easy to integrate into the LFRA system, and should allow for similar use in upcoming systems such as the Wide Format Resistive Array (WFRA).

REFERENCES

[1] K. Sparkman, et al "Performance Improvements in Large Format Resistive Array (LFRA) Infrared Scene Projectors (IRSP)" Proc. SPIE 6942, 3-6 (2008).