

# Radical Rise Time Enhancement of a Resistive IRSP Array

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## ABSTRACT

Santa Barbara Infrared (SBIR) produces high performance resistive emitter arrays for its line of IR Scene Projector (IRSP) products. These arrays operate in modes supporting up to 400 hertz frame rates. The physical properties of the microelectromechanical emitter pixel structures cause the transition times for temperature slewing to be well over the 2.5 milliseconds required to support 400 hertz operation. This paper expands on a study previously conducted by SBIR to determine the maximum capability of a technique in which the pixel drive of the first frame of a commanded transition is modified to improve transition time. This technique is referred to as overdrive and in this study it was effective in reducing rise and fall times from as much as 6 milliseconds to 2 milliseconds.

**Keywords:** Infrared, IRSP, HWIL, Scene projection, Overdrive, Rise time, Fall time, Mirage XL, Window Mode

## 1. INTRODUCTION

Santa Barbara Infrared (SBIR) produces a line of Infrared Scene Projector (IRSP) systems that are based on a resistive emitter pixel design. Each pixel is a microelectromechanical structure (MEMS) constructed of materials and geometry carefully chosen for the resistive, thermal, optical and mechanical properties. These pixels are designed to meet customers' scene simulation and hardware-in-the-loop (HWIL) testing needs. The variety of those needs dictates a balanced approach with respect to the performance trade space of the pixel design. Optimization of this balance has resulted in a pixel structure that can require more than 6 milliseconds for a complete transition between commanded temperatures. At the same time, increasing frame rates of sensors creates a demand for improved performance of scene projectors. In response SBIR's Mirage XL 1024 x 1024 scene projector system is configurable for very high frame rate operation. When operated in what is referred to as Window Mode, the center 512 rows of the emitter array can be refreshed up to 400 times per second. This special 400 hertz operation mode allows a maximum of only 2.5 milliseconds frame time for temperature slewing of each emitter pixel. This short frame time is significantly faster than the 6 millisecond temperature transition times of pixels without enhancement.

In 2008, SBIR introduced a technique called overdrive to improve these transition times. Overdrive is the calibrated modification of the pixel drive corresponding to the frame that initiates a temperature transition. This initial frame has its drive adjusted from that which would produce the desired apparent temperature in a steady state condition to one that will accelerate the temperature transition. The following frames then return to the normal steady state drive level. In the previous discussion of this process only cases of increasing temperature transitions were discussed, and the target transition time was 5 milliseconds to support 200 hertz operation. This study extends that concept to both increasing and decreasing temperature transitions with a target transition time of 2.5 milliseconds to support 400 hertz operation.

## 2. OVERDRIVE EFFECT ON TRANSITION TIMES

Significant variations from the commanded temperature may be introduced by running the projector system at a speed whose frame time is much shorter than the natural transition time of the pixel. In some cases, the pixel will require as many as three frames to settle at the commanded temperature. In rapidly changing simulation scenarios this may result in significant apparent temperature inaccuracy. Overdrive was developed to improve the accuracy of these types of rapidly changing simulation scenarios.

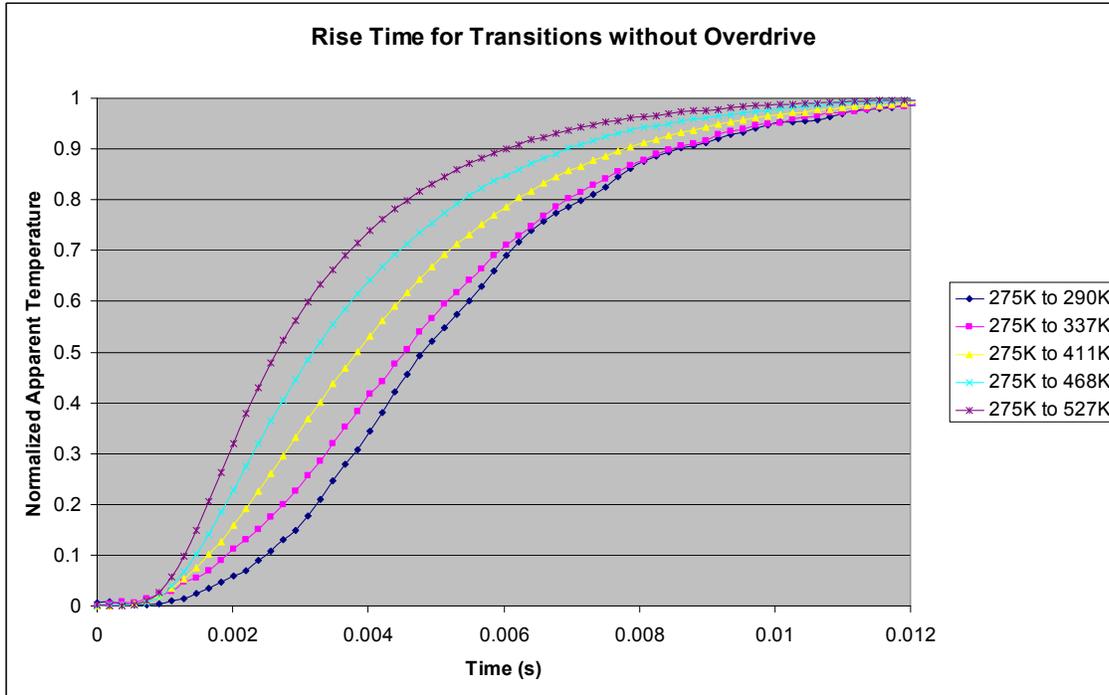


Figure 1 Time series for various transitions without overdrive

In order to understand why overdrive is helpful in solving this problem it is useful to first examine what physical phenomena influence temperature changes in the emitter pixels. In the steady state (and ignoring the small radiative losses for temperatures achieved by these emitters, i.e. less than 700 Kelvin) the electrical power being put into the pixel is roughly equal to the power being conducted back into the substrate through the pixel legs<sup>[1]</sup>:

$$I^2 R(T) = G(T)[T_{phys} - T_{sub}] \quad [1]$$

where  $I$  is the current driving the pixel,  $R(T)$  is the pixel resistance,  $G(T)$  is the thermal conductance to the substrate, and  $T_{phys}$  and  $T_{sub}$  are the physical temperature of the pixel and the substrate, respectively.

Furthermore the rate of pixel temperature change  $\frac{dT_{phys}}{dt}$  is related to the difference of these two terms as follows:

$$C(T) \frac{dT_{phys}}{dt} = I^2 R(T) - G(T)[T_{phys} - T_{sub}] \quad [2]$$

where  $C(T)$  is the pixel's heat capacity. Therefore, transition time is directly related to the magnitude of the temperature change, but also inversely related to the difference between the power being put into the pixel and the power being conducted out to the substrate:

$$t_{transition} = \int_{T_1}^{T_2} \frac{C(T)}{I^2 R(T) - G(T)[T_{phys} - T_{sub}]} dT_{phys} \quad [3]$$

This inverse relationship with the drive power and conductivity terms causes somewhat counterintuitive trends in transition time. Table 1 shows all transitions measured during this study and their corresponding elapsed times when operating without overdrive. The reported time for each transition was measured using the asynchronous camera capture technique discussed in the previous overdrive study conducted by SBIR<sup>[2]</sup>. While it may seem odd that pixels require more time to heat up to 300 Kelvin than to heat up to 500 Kelvin, this is the result of the  $I^2 R(T)$  term. Since the relationship between pixel drive current and apparent temperature is roughly linear, as  $dT_{phys}$  increases  $I^2 R(T)$  increases even more quickly. The importance of the conductivity term becomes obvious when considering fall time. Again it is faster to cool a pixel from 500 Kelvin than it is to cool it from 300 Kelvin, and this is due to the temperature dependence of the conductivity to the substrate.

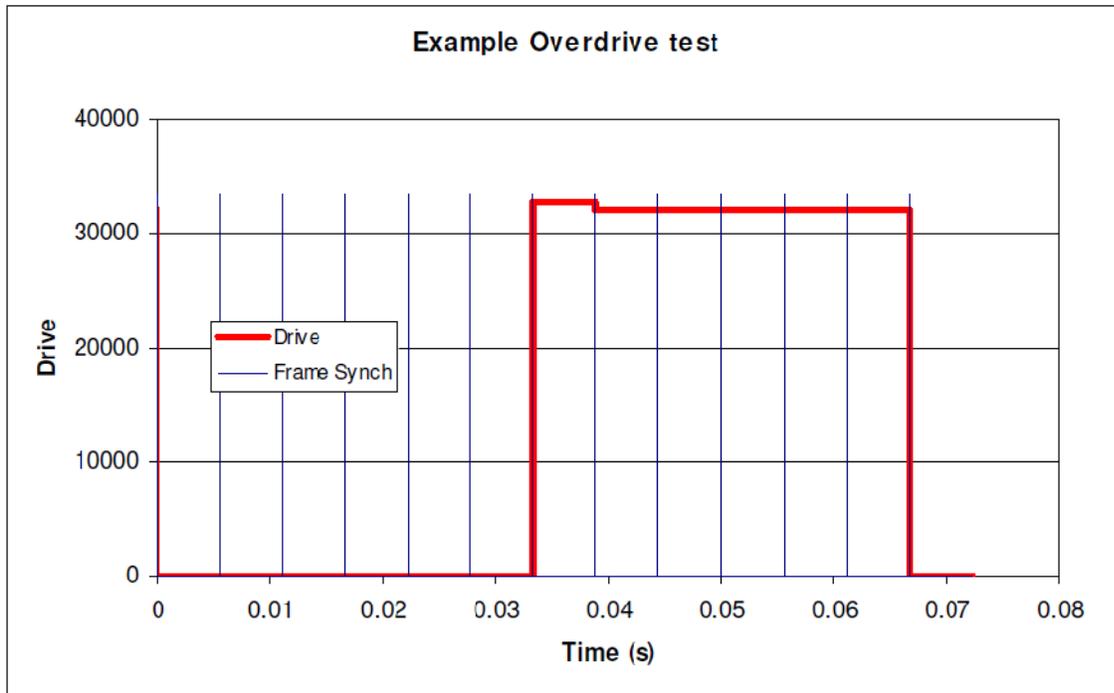
These properties can be exploited when operating at high frame rates, and this is the idea behind overdrive. When overdrive is used, the drive of the first frame of a commanded temperature transition is increased or decreased (see Fig 2) from the drive that will eventually balance Equation [1] at the desired temperature. This drive change represents a change in pixel current for just long enough to accelerate the transition and then return to the equilibrium level of current.

		End Temperature (Fraction of Max Drive)					
		275K (0%)	290K (50%)	337K (60%)	411K (70%)	468K (80%)	527K (90%)
Start Temperature (Fraction of Max Drive)	275K (0%)	x	7.5	6.9	6.3	5.6	4.8
	290K (50%)	5.2	x	6.5	6.2	5.6	4.8
	337K (60%)	4.1	4.8	x	6.1	5.5	4.7
	411K (70%)	2.3	2.7	4.8	x	5.3	4.7
	468K (80%)	2.5	2.9	3.7	4.6	x	4.7
	527K (90%)	2.5	2.8	3.4	4.3	4.8	x

**Table 1 Transition time measurements without overdrive (all times in milliseconds).**

The amount this first frame should be adjusted is dependent on the starting drive level, the ending drive level and the frame rate. For this reason, the optimal amount of overdrive must be calculated for the full range of possible temperature transitions at each frame rate. The level of overdrive that will accelerate a transition from 400 Kelvin to 450 Kelvin by the proper amount will cause a transition from 300 Kelvin to 500 Kelvin to overshoot. This leads to temperature inaccuracy or worse to temperature runaway for consistently increasing temperature simulation scenarios. Furthermore, the proper amount of overdrive for a transition at 400 hertz frame rate will cause that same drive transition at 200 hertz to overshoot. A modification of pixel drive current that is calibrated to last for a 2.5 millisecond frame time will lead to a completely undesired temperature if used for the duration of a 5 millisecond frame time.

Thus when the overdrive process is to be applied to an IRSP system, numerous measurements are made to achieve the fastest possible transition times while preserving temperature accuracy for a given frame rate. All of this data is then compiled into a lookup table used by the Mirage XL Command and Control Electronics (C&CE) to apply overdrive values to scene data in real time. Further information on hardware implementation is available in the report of the previous overdrive study<sup>[2]</sup>.



**Figure 2** A sample input drive sequence using overdrive on the first transition frame.

### 3. TEST RESULTS

In the previous overdrive study conducted by SBIR<sup>[2]</sup>, only transitions of increasing temperature were considered. This is because that work was conducted at a maximum frame rate of 200 hertz and it is rare to have a decreasing temperature transition, also called fall time, require more than the 5 millisecond frame time of this speed of operation. This study extended that work to the 400 hertz frame rates achievable in the Mirage XL IRSP's Window Mode, thus placing a new 2.5 millisecond requirement on all transition times. The measurements in Table 1 show that the pixel fall times are no longer satisfactory, thus necessitating the application of overdrive to transitions of decreasing temperature.

These measurements were conducted by activating a group of pixels that were sparsely distributed across the emitter array. Each pixel was driven with a looped low drive/high drive alternating frame sequence running at 360.3 hertz frame rate. The entire array is imaged during this projection using an Indigo MWIR InSb cooled detector running at 60 hertz. This combination of projector and detector frame rates allows the use of the asynchronous camera capture technique. This technique was developed at KHILS and is the standard method for measurement of pixel transition times at SBIR<sup>2</sup>.

		End Temperature (Fraction of Max Drive)				
		290K (50%)	337K (60%)	411K (70%)	468K (80%)	527K (90%)
Start Temperature (Fraction of Max Drive)	275K (0%)	6.0	7.0	8.0	7.5	10.0
	290K (50%)	x	28.0	25.0	18.0	20.0
	337K (60%)	90.0	x	34.0	25.0	24.0
	411K (70%)	100.0	70.0	x	26.0	26.0
	468K (80%)	100.0	100.0	50.0	x	28.0
	527K (90%)	100.0	100.0	90.0	50.0	x

**Table 2 Optimal overdrive levels for each transition measured as a percentage of that transition in drive counts.**

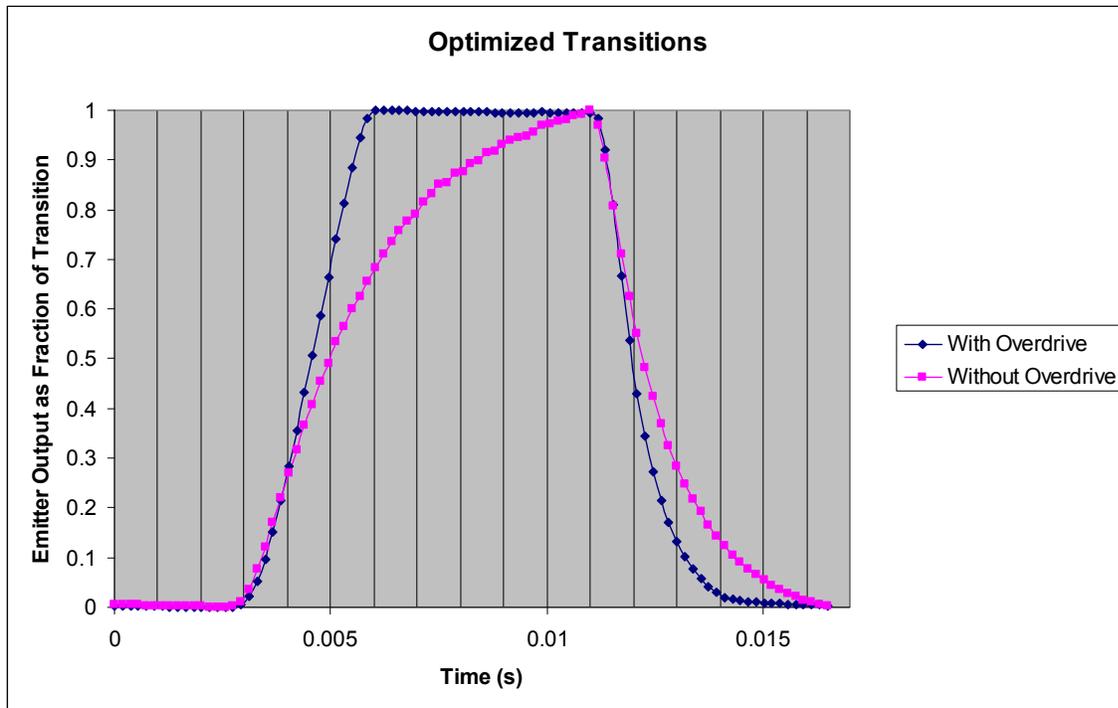
The transition times reported in Table 1 are the average of all of the pixels measured. The numbers reported reflect the elapsed time between the pixel achieving 10% of the commanded transition to 90% of the transition in radiance (and vice versa for fall time). This is consistent with previous studies of rise and fall times<sup>2,3</sup>. In all, there were thirty transitions measured, fifteen that increased in temperature and fifteen that decreased in temperature. Note that the output response of the emitters is non-linear and in these measurements native drive units were used without the extra processing step of output linearization. Due to this factor and difficulties with camera signal-to-noise ratios at very low radiance, only drive levels in the upper half of the IRSP native drive range were used. This still gave a good sampling of apparent temperatures across a delta of roughly 250 Kelvin.

Calibration of optimal overdrive levels for thirty transitions required well over 100 measurements, as each overdrive amount was tuned to an amount that would yield maximum speed without overshoot. Table 2 lists those overdrive amounts as a percentage of the number of drive counts between the levels of the transition. Note that in some instances of decreasing temperature the emitters were essentially turned off for one frame time following the transition so that there was no current flow and the conductive factor could drain heat out of the pixel structure as quickly as possible. Also note that transitions whose final commanded drive is either 0% or 100% cannot make use of this technique. The emitter cannot be driven with less than zero current, and to avoid pixel degradation its drive is not allowed to exceed the normal cap even if it would result in enhanced rise time.

		End Temperature (Fraction of Max Drive)					
		275K (0%)	290K (50%)	337K (60%)	411K (70%)	468K (80%)	527K (90%)
Start Temperature (Fraction of Max Drive)	275K (0%)	x	3.7	3.3	2.0	2.0	1.9
	290K (50%)	5.2	x	3.4	2.0	2.0	1.9
	337K (60%)	4.1	3.2	x	2.2	2.1	2.0
	411K (70%)	2.3	2.0	1.9	x	2.2	2.1
	468K (80%)	2.5	2.3	2.0	2.1	X	2.1
	527K (90%)	2.5	2.4	2.3	2.0	2.1	X

**Table 3 Transition times as measured using optimized overdrive levels (all times in milliseconds).**

Table 3 shows the transition times as measured using the optimal overdrive levels from Table 2. In the very best cases these times dropped not only below the 2.5 millisecond frame time requirement, but all the way down to under 2 milliseconds. Overall 80% of the transitions measured would support 400 hertz operation using overdrive enhancement. Only the lowest temperature transitions would not reach their commanded steady state temperatures in a single frame. Even those - with the exception of transitions falling to zero drive that cannot be overdriven - improved by as much as 50%. Figure 3 plots the camera response time series for the rise and fall transitions between 337 Kelvin and 468 Kelvin drive for both overdriven and non-overdriven measurements. The 62% improvement in rise time and 46% improvement in fall time are graphically obvious. These sorts of improvements were typical throughout the range of transitions tested.



**Figure 3 Example time series of overdriven and non-overdriven measurements for a sample transition between 337K and 468K (both increasing and decreasing) at 360hz frame rate**

#### 4. SUMMARY/CONCLUSIONS

The constraints placed upon pixel design by the performance trade space for resistive emitter IRSPs dictate a structure whose physical properties limit the speed at which temperature transitions can be achieved. Yet increasing frame rates of sensors creates a demand for improved performance of scene projectors. In 2008, SBIR developed a technique called overdrive for improving pixel transition times. Overdrive works by modifying the pixel input drive for the duration of the first frame of a commanded transition to a level beyond that which would produce the desired steady-state temperature. When carefully calibrated, this accelerates the temperature change for just that frame and then the temperature levels off at the desired setting without overshoot for the subsequent frames. Previously the effect of overdrive had only been measured for frame rates up to 200 hertz. Now there is significant experimental data to show that this process will also yield large benefits when operating the Mirage XL resistive array IRSP in its fastest 1024 x 512 Window Mode at 400 hertz. These measurements show substantial improvements in both rise and fall times across a broad range of temperature transitions, with most requiring less than the 2.5 millisecond frame time to complete. The system architecture for implementation of overdrive in window 1024 x 512 mode is no different than that which already exists for full frame 1024 x 1024 operation, thus existing Mirage XL IRSP systems can be optimized for high frame rate performance.

## 5. REFERENCES

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