# "Record Breaking" High Apparent Temperature Capability of LCoS-Based Infrared Scene Projectors

Jack R Lippert, Hong Wei, Haiping Yu, and Le Li
Kent Optronics, Inc.
40 Corporate Park Dr.
Hopewell Junction, NY 12533
jacklippert@kentoptronics.com (850)862-0196
leli@kentoptronics.com (845) 897-0138

## ABSTRACT

A newly fabricated Infrared Scene Projector (IRSP) configured for the Long Wave IR (LWIR) regime has demonstrated simulated apparent temperatures exceeding 1500 $^{o}$C, more than doubling the maximum temperature capability of prior pixilated scene projector devices. Since the entire array surface is capable of this high temperature output, the same device can be used to generate both the moderate temperature scene background and an unlimited number of high temperature targets in the scene, without having to optically combine a few discrete "hot spot" generators. This performance was enabled by advances in a new large pixel, high voltage, 16-bit backplane Spatial Light Modulator (SLM) coupled with an intense spectral illumination source, and special formulation liquid crystal (LC). The new LC formulation and SLM configuration also achieves an effective usable frame rate of up to 200Hz capability. Performance characterization and resulting data will be discussed in the paper.

This effort was accomplished in a Phase 2 SBIR sponsored by the Missile Defense Agency (MDA).

## KEYWORD LIST

Infrared Scene Projectors, Hardware-In-the-Loop Simulation, LWIR Imagery, High Apparent Temperature, Liquid Crystal, LCoS Spatial Light Modulator, high frame rate

## INTRODUCTION

The new Liquid Crystal on Silicon (LCoS) technology used in the subject Infrared Scene Projector is particularly better suited for achieving higher temperature capability than the prior established resistor array technology. The LCoS Spatial Light Modulator (SLM) is a reflective-based technology which does not have to be at the simulated physical temperature, but can reflect the emitted energy from an external source exceeding the melt temperature of physical resistors. Since there are no high currents on the SLM array, there are no scene dependent voltage/current droop issues associated with projecting high intensity outputs. The use of a limited spectral width illumination source overcomes the associated system problems of massive heat rejection needed if using extreme high temperature blackbody sources. In the long wave infrared (LWIR), there are many readily available illumination sources that can economically provide sufficient power to exceed 1500 $^{o}$C (even 3,000 $^{o}$C) maximum apparent temperature, while still achieving enough contrast for an ambient "dark state" (~15-20 $^{o}$C). Additionally, the new 512x512 pixel LCoS backplane has larger size pixels (37.5 micron) which exhibit much less diffraction at the LWIR wavelengths. Digital mirror arrays, the dominant alternative reflective technology, has 17 or 13 micron sized pixels. Finally, the new LC formulation, combined with a unique design implementation, can achieve a system performance of 200 Hz or faster operation. The system has been packaged along with a reflective collimator into the bench top mount display system shown in Figure 1. To have the system installed on a Flight Motion Simulator (FMS), the packaging would have to be modified with considerations for setback distance and a refractive collimator to handle the FMS related inertial loads.

Figure 1: The High Output Temperature IRSP in a bench top collimator configuration

## DESCRIPTION and PERFORMANCE

The high output temperature IRSP is based on a new high voltage Spatial Light Modulator backplane that has 512x512 pixels on 37.5 micron pitch. The approximate 90% effective fill factor yields the largest area reflective pixel in the dynamic array IRSP community. This pixel size is a significant improvement in reducing the inherent diffraction associated with LWIR wavelengths. The associated diffraction spreads the reflected energy from a pixel into an Airy disk whose spot size is defined by

$$\text{Radius} = 1.22 \text{ Lambda} * F / D,$$

where F is the system optical focal length and D is the cross section size of the individual pixel, respectively. In the extreme case of a single pixel at LWIR wavelengths, the LCoS pixel would exhibit less than half of the diffraction associated with smaller 17 micron pixel arrays. At the LWIR wavelength of 10.6 micron, this combination leads to a point spread function on the order of the center distance between adjacent pixels for the LCoS example, but several pixels for the smaller DMD. Furthermore, the on-axis light propagation path, along with a flat pixel array plane, eliminates edge effects when large number of pixels are “powered” to the same value forming a large smooth area. Digital mirrors may be tilted to the same angle, but discrete separation spacing between each mirror still exhibits diffraction. As the LCoS projected spot area encompasses a larger number of contiguous pixels, the deleterious effects from diffraction become less significant .

The standard Liquid Crystal formulation used in past shorter wavelength systems, and prototype IRSP equipment, was not well suited for use at the LWIR wavelengths (8-12 micron), due to slower electro-optical (EO) response speed and excessive light absorption. A special formulation was developed exhibiting a higher transmission at thewavelengths of the LWIR illumination source. The transmission plot for an exemplary newly developed LC formulation is shown in Figure 2. The new formulation transmits approximately 80%, for example at the 10.6

micron wavelength, versus the prior formulation transmitting ~65%. This enhanced transmission not only allows higher output temperatures, but would absorb less parasitic heat, reducing cooling requirements.

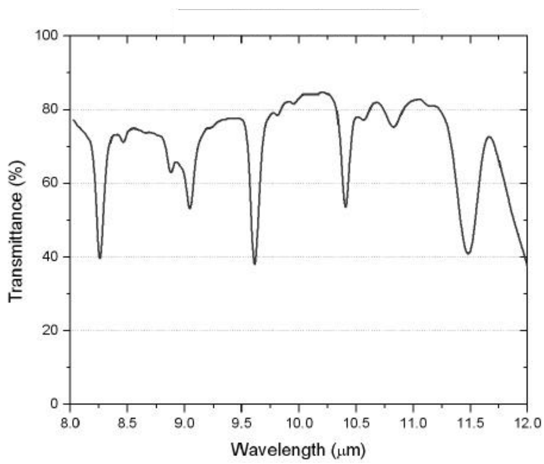



Figure 2: Transmission Plot for the New Formulation Tailored for LWIR Wavelengths

The overall purpose of this LCoS-based IRSP system design is to achieve high quality imagery, fast frame rate, and higher apparent temperature capability than possible with other technology dynamic IR Scene Projectors. Success was demonstrated with an emulation of an ascending rocket, projected with the system and recorded with a LWIR camera sensitive from ~8 to 12 micron. In this example, the original source imagery is not from IR data, but a visible image, so interpretation is not straight forward. What is important is the thermal scale delta of the image projected to demonstrate LCoS capability. The camera had three scaling ranges over which its measurements could be calibrated, but was otherwise limited in its adjustments. For example, integration time of the camera pixels was fixed and could not be user controlled. The largest range scale of this camera was from 150 $^{o}$C to 1550 $^{o}$C. A captured displayed frame from the rocket scenario is shown in Figure 3 below. The evident 1400 $^{o}$C delta temperature range demonstrated is a "record breaking" output for both LCoS-based and resistive array-based IR Scene Projectors, more than doubling the Blackbody Apparent Temperature (BAT) of prior technology systems.

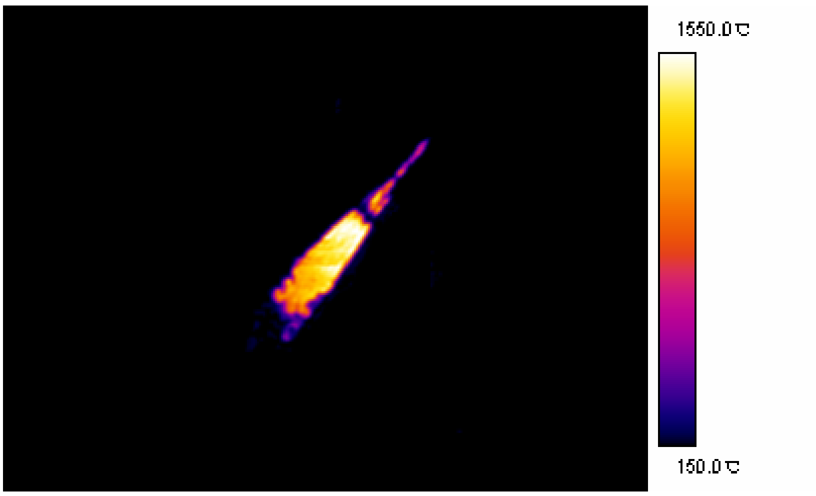



Figure 3: IR Camera Capture of Projected Frame from High Temperature LCoS-Based IRSP Demonstrating 1400 $^{o}$C Delta Temperature Capability

While the camera shows dramatic results, it did not have the dynamic range required to measure the LCoS IRSP's full capability or contrast ratio. To further identify this potential, the blackbody apparent temperature of our IR scene projector was calibrated via a Blackbody source and a single pixel sensor, a Boston Electronics' Photovoltaic LWIR detector (PD-10.6), viewing the output from the IRSP system. The calibration procedure is explained as follows: The Blackbody source was placed at the location of the LCoS SLM while the single pixel sensor was placed at the location of the IR camera. The Blackbody source was then manually set at several temperatures from 15C up to 500C. The readings from the single pixel sensor were then recorded at each Blackbody blackbody temperature to establish a look-up table so that the sensor's output can be directly related to a calibrated BAT. While the IRSP high-end capability is beyond the Blackbody maximum, requiring extrapolation, the minimum, as shown in Figure 4, is the critical factor for the contrast determination. A signal lock-in amplifier (Stanford SR510) was employed to increase the precision required for the low level radiance emanated when the projector is in the "Dark" state.

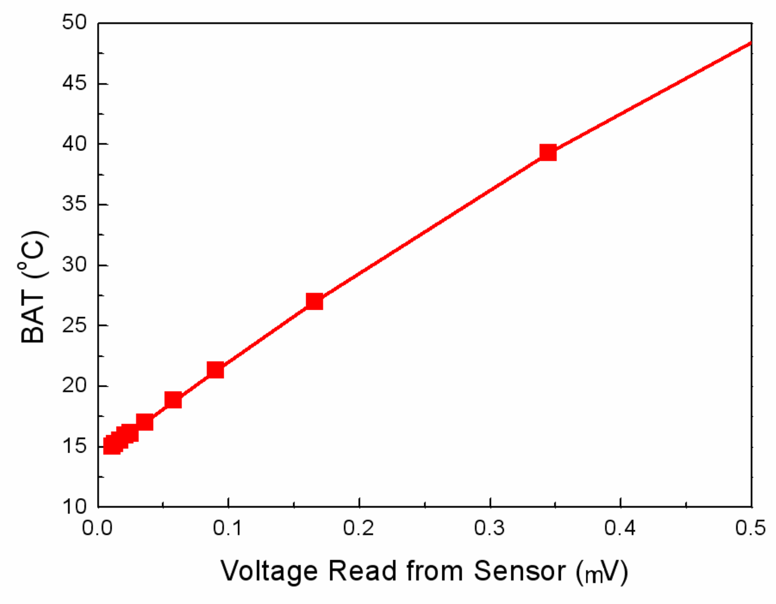



Figure 4: Calibration of the Detector Sensor's Output with BAT

The state having the strongest output intensity was projected from the LCoS IRSP system, and the corresponding detector's $I_{max}$ was recorded. Subsequently, the darkest state having the lowest output intensity of $I_{min}$ was commanded and projected from the IRSP system. The contrast ratio was calculated as $I_{max}/I_{min}$. During the measurements, all the pixels in SLM were switched at the same time to simulate a single pixel scenario, and the illumination source for the IRSP remained constant. The $I_{min}$ would read zero when the illumination source was turned off, indicating the low level reading was valid and not clamped. These measurements indicate a system contrast ratio of 21,000 ± 5,000:1. The large uncertainty in the contrast ratio is due to the large noise of $I_{min}$. While this unprecedented advancement in IRSP contrast ratio is overkill for the LWIR, it will be a valuable parameter for future mid-wave infrared (MWIR) projector systems where a ~10,000:1 ratio is needed to attain a useful 1000 $^{o}$C delta temperature range.

The simulated performance is also dependent upon the overall system Field of View (FOV) since the output energy must be spread over a larger area than the emitting device array. However, for FOVs smaller than our in-house camera/lens, the available power can simulate even higher apparent temperatures, even exceeding 3000 $^{o}$C. Figure 5 shows achievable blackbody apparent temperatures calculated as a function of FOV for two cases of commercially available source illumination power.

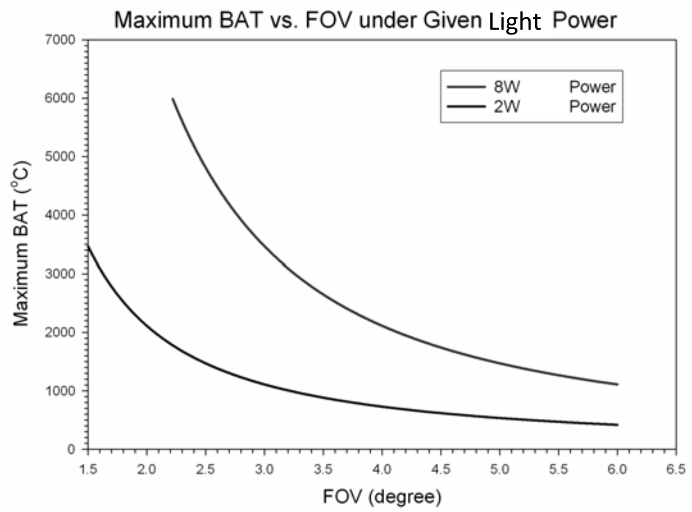



Figure 5: Calculated Available Power Can Exceed 3000 $^{o}$C Simulated Apparent Temperature for Small FOV Sensors

The new enhanced temperature capability opens up new regimes of possible simulation testing. The LCoS-based system can be used to simulate both the moderate temperature "background" items of the scene as well as high temperature items, like engine exhaust plumes, muzzle flashes, flares, and thermal countermeasures. Prior less capable systems needed additional components such as hot spot generators, e.g., blackbodies or laser sources, with complex steering optics to fold in the few hot spots into the projected scene. Each spot required its own source and optical path making a system capable of projecting more than just a few spots over burdensome and suffer from beam combining losses. Since the LCoS system is capable of the high temperature anywhere and even over the entire array, the number of "hot spots" is unlimited and large areas of maximum output are not subject to "current droop" as with resistor arrays.

The useful frame rate of the LCoS IRSP system is based upon both the activation speed of the LC formulation and the Kent Optronics proprietary design of the IRSP system. The frame rate performance parameter of >100 Hz was specified for the described system. The measured rise time of 8.3 milliseconds, and fall time of 0.6 milliseconds, exceeded the 100 Hz goal. To better demonstrate that the speed performance is a design trade-off choice, a special test cell was fabricated with the same material, but with a thinner layer of LC. Figure 6 shows an example of 3.72 ms rise time, and a fall time of 0.6 milliseconds, supporting operation at over 200 Hz.

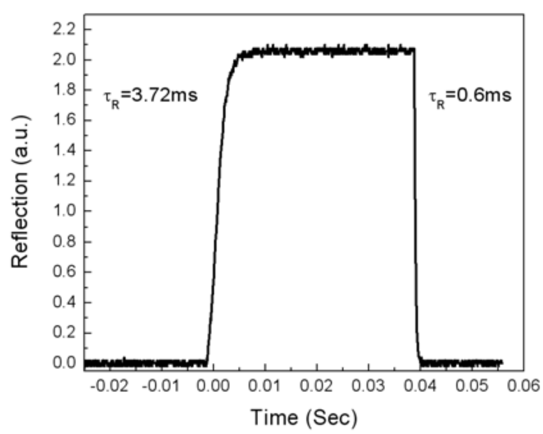
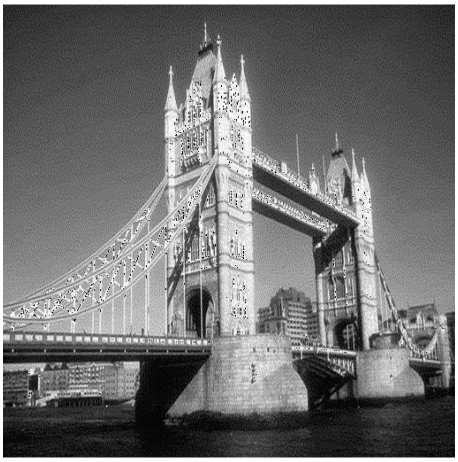



Figure 6: Measured Response of the Test Cell Designed for 200 Hz Operation

At LWIR wavelengths, there is sufficient illumination power available to maintain high temperature capability, but for faster than 200 Hz designs, the ultimate high temperature capability would be reduced somewhat.

Since in-house IR Camera resources were a smaller format than the IRSP, a larger format LWIR Camera (640x480) was obtained to evaluate the spatial resolution of this new 512x512 LCoS-based IRSP system. An example of the original visible-based image and the captured IR image projected by the IRSP is shown in Figure 7. The output image is the raw output projection without any Non-Uniformity Correction (NUC) applied. The raw uniformity can vary depending upon the particular SLM backplane involved. For this particular SLM, the raw uniformity was measured at ~80%, defined as the $I_{min}$ divided by $I_{max}$ from projected frames of uniform command. Typical Non-Uniformity Correction (NUC) techniques are envisioned to reduce the raw 20% variance to down to <2%.

A



B

Figure 7: Source Image (A) and Captured IR Image (B) Projected by the IRSP

IR source imagery was projected in the form of movie files taken from sequential IR Camera data viewing representative real-life scenes. A single frame from the beginning of each of these movies was captured and is shown in Figure 8. These are again raw images where there was no attempt to NUC the output.

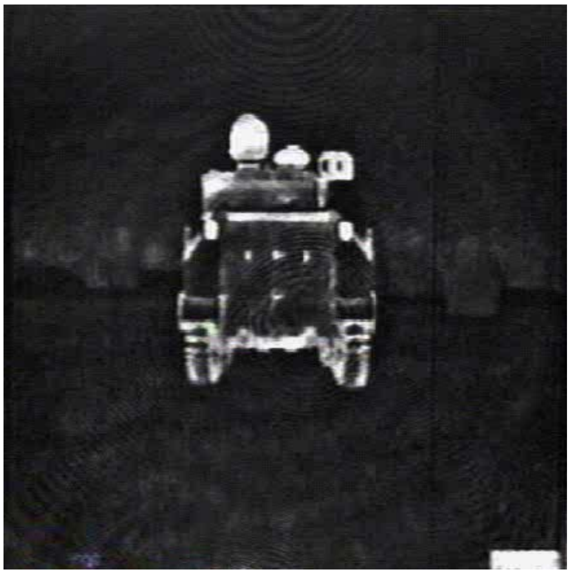


Figure 8: Captured Opening Frames from Projected “Movie” where Source Imagery was IR Data

## SUMMARY

The described LWIR LCoS-based IRSP has "raised the bar" in demonstrated performance capabilities. The "record breaking" apparent temperature, combined with superior dynamic range and high speed transition states of radiance, has resulted in this technology device achieving the highest overall performance for pixilated dynamic IR Scene Projectors. The simulated temperature range, from ambient to over 1500 $^{o}$C, is achieved without optically folding in external subsystems. The LWIR LCoS IRSP offers high performance with simplicity, size reduction, and eventually lower overall cost for future simulation systems. This same technology is now being applied to the realm of MWIR scene projectors. Advancements in performance similar to those demonstrated in the LWIR band are expected.

## ACKNOWLEDGEMENTS

The authors wish to thank the Missile Defense Agency for sponsoring this work under a Phase 2 SBIR (contract #: F08630-03-C-0205) and a Phase 2 STTR (contract #: HQ0006-05-C-7265), Boulder Nonlinear Systems for providing the liquid crystal on silicon (LCoS) panel, Prof. S. T. Wu and his group in University of Central Florida for supporting the liquid crystal material, and Mr. Don Snyder, Air Force Research Laboratory/MNGG, for all his guidance and support as our technology transition focal point for this project.