DOCUMENT 468-16

**OPTICAL SYSTEMS GROUP**

# TESTING AND VALIDATION OF TIMING PROPERTIES FOR HIGH-SPEED DIGITAL CAMERAS - A BEST PRACTICES GUIDE

**ABERDEEN TEST CENTER**
**DUGWAY PROVING GROUND**
**REAGAN TEST SITE**
**WHITE SANDS MISSILE RANGE**
**YUMA PROVING GROUND**

**NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION**
**NAVAL AIR WARFARE CENTER WEAPONS DIVISION**
**NAVAL UNDERSEA WARFARE CENTER DIVISION, KEYPORT**
**NAVAL UNDERSEA WARFARE CENTER DIVISION, NEWPORT**
**PACIFIC MISSILE RANGE FACILITY**

**30TH SPACE WING**
**45TH SPACE WING**
**96TH TEST WING**
**412TH TEST WING**
**ARNOLD ENGINEERING DEVELOPMENT COMPLEX**

**NATIONAL AERONAUTICS AND SPACE ADMINISTRATION**

This page intentionally left blank.

# DOCUMENT 468-16

# TESTING AND VALIDATION OF TIMING PROPERTIES FOR HIGH-SPEED DIGITAL CAMERAS - A BEST PRACTICES GUIDE

## July 2016

**Prepared by**

## OPTICAL SYSTEMS GROUP

**Published by**

**Secretariat**
**Range Commanders Council**
**U.S. Army White Sands Missile Range**
**New Mexico 88002-5110**

This page intentionally left blank.

# Table of Contents

## List of Figures

# List of Tables

# Preface

The accuracy of time stamps in high-speed digital imagery is critically important to weapons systems development and motion analysis of virtually all transient test events; however, the receipt, processing, and appropriate application of IRIG-based timing signals has proven to be one of the greatest challenges facing commercial camera manufacturers.  Likewise, many OSG member organizations have struggled with developing robust test procedures for characterizing and documenting the timing properties of new camera systems and validating the advertised specifications claimed by vendors.

The OSG took on task OS-37 in response to these issues.  The task objective was to identify, recommend, and document accepted procedures for measuring the timing accuracy of high-speed digital cameras using LED-based strobe devices like the LabDITCS.  The resulting best practices guide would suggest general test methodologies and provide detailed operational procedures for existing systems such as the LabDITCS.  It would also describe data collection, reduction, and analysis techniques that ensure optimal interpretation of measurement results

This document provides a best practices guide for measuring timestamp error in high-speed digital video collected at the Major Range and Test Facility Bases.  It outlines steps for configuring test equipment, calibrating precision time code reference clocks, and collecting high-speed timestamped imagery for error analysis.

The report is comprised of four major sections: the main body of the document and three instructive appendixes.  The main body explains why timing characterization tests are important and provides a discussion of the common sources of timing error observed in typical range cameras.  It concludes with recommendations for developing a timing certification program using established test procedures and schedules.

The first three appendixes provide a chronology of the evolution of timing certification test systems and methodologies used at White Sands Missile Range.  Appendix A documents some of the early work in this area and provides the rationale for using fast-response light-emitting diode strobes to test timestamp accuracy.  Appendix B can be used as a standalone operational procedure for sister ranges that use the LabDITCS.  This appendix describes recommended procedures for configuring, calibrating, and operating the LabDITCS to support precision measurements on mission support cameras.  Finally, Appendix C describes new software that automates the data reduction and analysis process for data collected with the LabDITCS.  This data reduction software was developed at White Sands Missile Range, but is available to other ranges that use the LabDITCS system to perform timing certification tests.  This appendix provides the users' guide for that software.

The author wishes to thank Dan Stigers, Ross Cox, Scott McElheny, and Ray Matthias (TRAX Optics Video Maintenance Lab) for their invaluable contributions to the development of this document.  These experienced technicians developed many of the procedures and techniques outlined in this document and their diligent efforts over the years have significantly improved the timing accuracy and reliability of virtually every optical data product produced at White Sands Missile Range.  Additionally, the author would like to recognize Grant Senn for his significant contribution to improving the LabDITCS data reduction process and for writing the LabDITCS Reader Software User's Guide (Appendix C).

For questions about this document, contact the RCC Secretariat.

Secretariat, Range Commanders Council
ATTN: TEDT-WS-RCC
1510 Headquarters Avenue
White Sands Missile Range, NM 88002-5110
Phone: DSN 258-1107 Com (575) 678-1107
Fax: DSN 258-7519 Com (575) 678-7519
Email: usarmy.wsmr.atec.list.rcc@mail.mil

## Acronyms

| | |
|---|---|
| AI | Advanced Illumination |
| CCD | charge-coupled device |
| CMOS | complementary metal-oxide-semiconductor |
| COTS | commercial off-the-shelf |
| DCLS | direct current level shift |
| DITCS | Digital Imager Timing Certification System |
| DocPhoto | documentary photography |
| EDR | extended dynamic range |
| fps | frames per second |
| GMT | Greenwich Mean Time |
| GPS | Global Positioning System |
| IP | internet protocol |
| IRIG | Inter-Range Instrumentation Group |
| LabDITCS | Laboratory Digital Imager Timing Certification System |
| LCD | liquid crystal display |
| LED | light-emitting diode |
| MRTFB | Major Range and Test Facility Base |
| NTP | Network Time Protocol |
| OS | operating system |
| PC | personal computer |
| PPS (pps) | pulse per second |
| PTP | Precision Time Protocol |
| RCC | Range Commanders Council |
| SUT | system under test |
| T&E | test and evaluation |
| TINT | time of integration |
| TSPI | time-space-position information |
| TTL | transistor-transistor logic |
| UTC | Coordinated Universal Time |
| WAO | work authorization order |

## UNITS

| | |
|---|---|
| µs | microsecond |
| HH | Hours |
| Hz | hertz |
| kHz | kilohertz |
| mA | milliamp |
| MHz | megahertz |
| mm | millimeter |
| MM | Minutes |
| ms | Millisecond |
| ns | nanosecond |
| s | seconds |
| SS | Seconds |

This page intentionally left blank.

# 1    Precision Timing Requirements for Imaging Systems

Modern digital imaging systems have the capability to embed timing information on every frame of optical data.  Even ultra-low-cost consumer cameras feature onboard electronic clocks capable of keeping relatively accurate time over extended periods.  Camera firmware uses these internal clocks to apply date and time stamps to captured images, making it easier to organize, store, and interpret them later.  The accuracy of these clocks varies widely and is dependent on a number of factors but, generally, such systems can only provide timing accuracy to within a few seconds.  This is adequate for most amateur and even professional photography applications, but not for high-speed imaging requirements at the test ranges.

Major Range and Test Facility Bases (MRTFBs) are challenged with imaging extremely fast-moving weapon systems and capturing the highly transient phenomena associated with military testing (e.g., rocket launches, weapon fly-outs, aerial intercepts, bomb impacts, explosive events, etc.).  In these applications, the requirements for timing resolution and accuracy are typically measured in milliseconds (ms) or microseconds (µs).  Accurate timing information has always been critical to test and evaluation (T&E) initiatives.  As far back as 1960, the Inter-Range Instrumentation Group (IRIG) of the Range Commanders Council (RCC) developed precision time code standards to address these demands.  Today, these time codes are used to synchronize all of the control facilities, test articles, data collection instrumentation, and support equipment to a common time base.  Figure 1 provides just a few examples of the range assets that rely heavily on precision time code for test conduct.
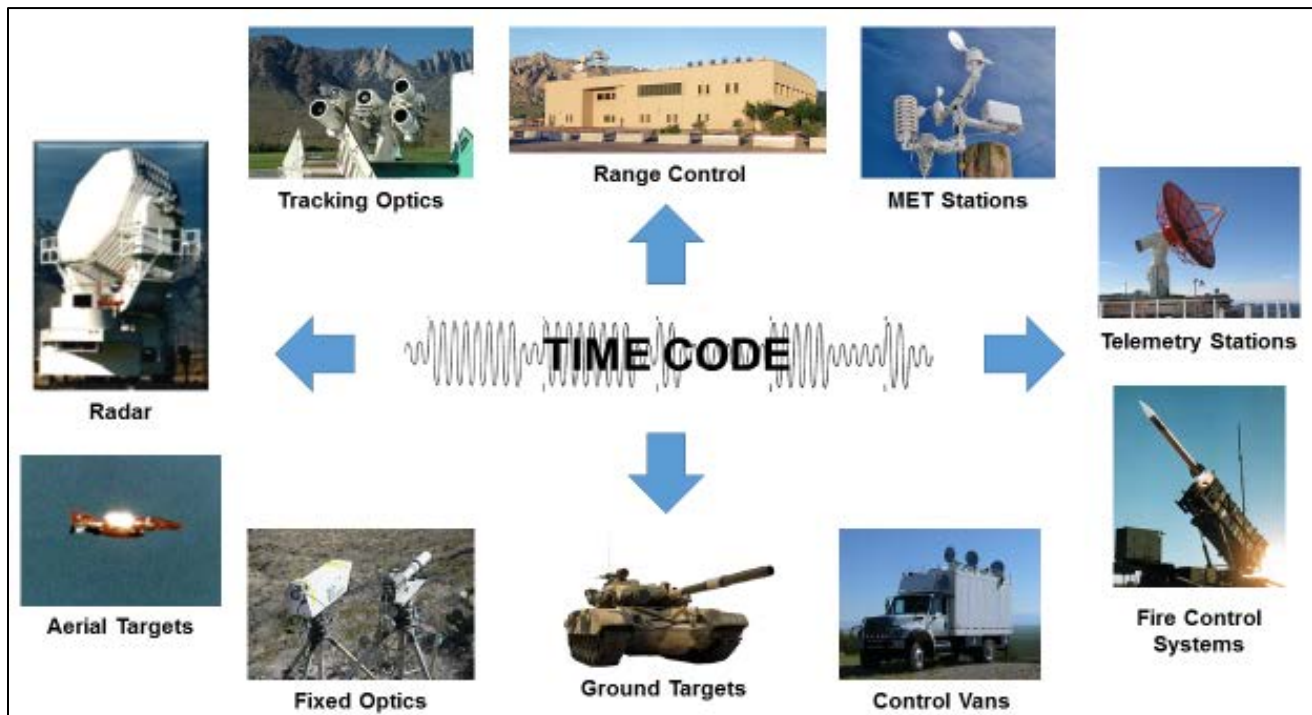


Figure 1.    Application of Precision Timecode Standards Developed by the RCC

In the days of film-based imaging systems, timing information was encoded onto each frame using highly specialized light-emitting diode (LED) arrays built directly into the camera

body.  This approach worked remarkably well but required part of each frame to capture timing data, which made it unavailable for useful imagery.  These systems were also maintenance-intensive and required custom hardware and software to read the timing information off each frame of film.

After decades of processing film, instrumentation-grade high-speed digital cameras began making their debut at the test ranges around the turn of the century.  The first generation of digital cameras offered resolutions on the order of 1K x 1K and frame rates up to 1000 frames per second (fps).  As the technology matured, newer cameras provided finer resolution, better sensitivity, and significantly higher frame rates.  As is the case with so much of the digital technology adopted by the test ranges today, high-speed digital instrumentation cameras were initially developed to support commercial applications and industrial markets.  Many of the vendors tailored early designs around the automotive and entertainment industries, which wanted the higher resolutions and frame rates but didn't need precise timing.  Consequently, many of the early high-speed digital camera models could not accept the IRIG time code standards that had been adopted by the military test range community.  Camera vendors scrambled to incorporate IRIG decoders into their systems, often with disappointing results.  Some of the early cameras exhibited gross timing errors and uncertainties.  Worse yet, the industry didn't have reliable means to even characterize timing accuracy to the precision needed for military applications.  Over time, as manufacturers gained more experience with IRIG timing and developed unique test equipment for measuring timing uncertainty, the accuracy and repeatability began to improve.

Timestamps are perhaps the most under-appreciated data elements collected with modern optical systems.  Image resolution, contrast, dynamic range, and frame rate get all the press when it comes to high-speed video viewed in Range Control; however, most optical data is practically useless to program analysts without accurate timing.  Furthermore, accurate timestamps are what tie optical data to everything else collected during complex test programs and they are absolutely critical to failure analysis when things go wrong.  The following use cases provide just a few of the many applications where accurate timestamps are essential to quality T&E.

## 1.1 Documentary Photography (Time-Stamping Critical Events During T&E)

The most common application for high-speed cameras on the MRTFBs is documentary photography (often referred to as "DocPhoto").  System developers, testers, and analysts need highly resolved imagery to document test conduct, evaluate system performance, and support post-test investigation of any test anomalies.  Imagery must be tagged with Coordinated Universal Time (UTC) so it can be correlated with data from other cameras and fused with data from other range sources, such as radar, telemetry, aircraft sensors, satellites, etc.  Accuracy requirements for DocPhoto timing data vary widely.  In some applications where cameras are used for safety or security surveillance timing accuracy isn't critical.  Accuracy on the order of a few seconds is adequate.  Other applications, however, have much more stringent requirements.  Cameras used to document launch, intercept, or impact events, for example, require much better precision.  Some facilities require timing to be accurate within a few milliseconds or even microseconds.

### 1.1.1 Time-Space-Position Information Measurement

Optical data is often used to derive time-space-position information (TSPI) on objects of interest in the field of view.  The TSPI data extracted from carefully calibrated high-speed cameras often provides the most accurate position data available for some projects.  Many test

ranges use optical tracking mounts to augment and refine position data collected by radars. Tracking vectors from individual mounts distributed over large areas of the range are often triangulated in real time using fiber and wireless networks to provide real-time position solutions.  The image frames from each individual mount must be accurately time-stamped so they can be correlated with data from other tracking systems.  The accuracy of these timestamps directly affects the accuracy of the resulting position measurement.  This was never more evident than following a test at an MRTFB several years ago when an unknown timing error in a new tracking camera resulted in a significant error in position measurement of a cruise missile in flight.  In this case, TSPI extracted from the cameras was being used to validate a new navigation system on the cruise missile.  A cursory analysis of the data immediately after the test showed a 150-foot discrepancy between the trajectory measured by the tracking mounts and the trajectory measured by the onboard NAV unit.  As it turned out, the new tracking camera had an undocumented latency in the imagery, which resulted in the position error.  This error was discovered and measured by the newly minted DITCS and the "ground truth" data collected by the tracking cameras was subsequently corrected for the latency.  The DITCS was the first timing certificate system developed for high-speed digital cameras at WSMR and laid the foundation for the improved Laboratory Digital Imager Timing Certification System (LabDITCS) design.  This system is described in Appendix A.

1.1.2    Performance Scoring (Hit-point, Miss Distance, etc.)

Many modern weapon systems are extraordinarily precise.  They are designed for maximum targeting accuracy to: 1) ensure mission objectives are achieved with optimal efficiency; and 2) minimize collateral damage.  Testing such precise systems requires comparable precision from range instrumentation used to collect data for performance evaluations.  Some programs require centimeter accuracies for hit-point or miss distance measurement.  Here again, the accuracy of position measurement is highly dependent on the accuracy of the timing data.  An error of only 1 ms in the measured time of a kinetic kill intercept event can result in a position error of 3 meters or more, depending on the closing velocities and geometry of the engagement.  Figure 2 shows how nominal timing errors can result in significant position measurement errors for different classes of military targets.
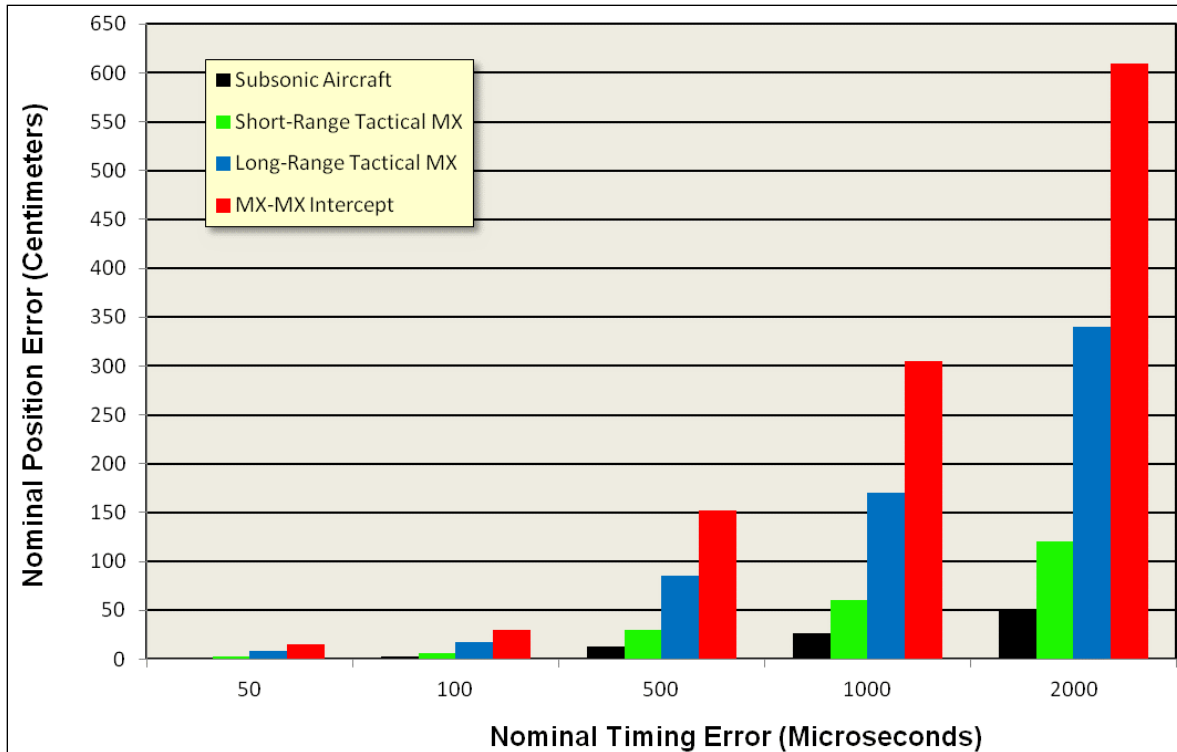
Figure 2.   Why Timing Accuracy Matters (Timing Error = TSPI Error)

### 1.1.3   Data Correlation from Multiple Sensors

Modern testing on the ranges can cover extensive geographical regions and distributed testing often involves instrumentation scattered across multiple test ranges located thousands of miles apart.  It is absolutely essential in these cases that data collected with various instruments is accurately time-tagged so it can be properly correlated and analyzed following the test.  Several years ago a large-scale test involving several ranges experienced an anomaly.  Post-test analysis was severely hampered because so many of the instruments supporting the test from land, airborne, and sea-based platforms had significant timing errors.  Reconstructing trajectories and anomalous behavior turned out to be very difficult and consumed far more resources (personnel, time, and money) than would have been expended had the timestamps from range instrumentation been accurate.

## 2   Range Timing Standards

Modern time standards can be traced back to the establishment of Greenwich Mean Time (GMT) by the British in 1847.  This standard was based on astronomical observations of the mean solar time, i.e., the mean time at which the sun crossed directly over the Greenwich meridian.  The GMT standard was adopted by the international community, including the United States, at the International Meridian Conference in 1884.  With the invention of the cesium atomic clock in 1955, a new methodology for keeping time was devised.  The atomic clock was much more stable and easier to maintain than the expensive array of astronomical instrumentation needed to support GMT.  Consequently, the United States and United Kingdom began synchronizing atomic clocks for precision time-keeping.  The new shared time base was called Universal Coordinated Time (UCT) in the English language or "Temps Universel

Coordonné (TCU)" in French.  The term was later abbreviated to "UTC" in a compromise between English- and French-speaking nations.  This is the primary standard by which the world measures time today.

Serial time codes emerged in the early days of missile and space programs when it became necessary to collect data from instruments widely separated over large geographical areas.  Test facilities needed a means to distribute timing information to a variety of instruments for data correlation and to provide an accurate chronology of test execution.  The IRIG of the RCC began working on the first timecode standard in 1956, at the same time the international community was working on a new world time standard (i.e., UTC).  The standard was published in the document entitled "IRIG Standard Time Formats" in 1960 (IRIG 104-60).  Subsequent documents have been developed and revised by the Telecommunications and Timing Group (TTG) of the RCC over the years.  The most recent version of the IRIG standard is RCC 200-04[1], which was published by the TTG in September of 2004.

Although these timecodes were initially developed to support the recording of radar and telemetry data on magnetic tape, they proved useful for distributing timing information to cameras and optical recorders as well.  The IRIG standard is over 50 years old now, but most data collection equipment at MRTFB facilities still rely on it for timecode distribution, processing, and recording.

With the advancement of modern computer technology and rapid proliferation of network-based instrumentation architectures, two relatively new standards have emerged as potential replacements for IRIG-based timing systems: Network Time Protocol (NTP) and Precision Time Protocol (PTP).  While a thorough discussion of the differences between these protocols and tradeoff analyses of migration to network-based timing is beyond the scope of this document, all three standards are briefly described below.

## 2.1 IRIG Standards

The IRIG standards define a family of serial time code formats that use pulse-width coding.  The IRIG time code signals may be modulated or unmodulated.  Amplitude-modulated signals are the most common for long-haul applications where they are often transmitted via sine wave carrier over twisted pair or coax cable.  The unmodulated format does not use a carrier and relies on direct current level shift (DCLS) to convey timing information.  Figure 3 highlights the differences between these two signals.

---

[1] Range Commanders Council.  *IRIG Serial Time Code Formats*.  RCC 200-04.  September 2004.  May be superseded by update.  Retrieved 11 February 2016.  Available at http://www.wsmr.army.mil/RCCsite/Documents/200-04_IRIG_Serial_Time_Code_Formats/.
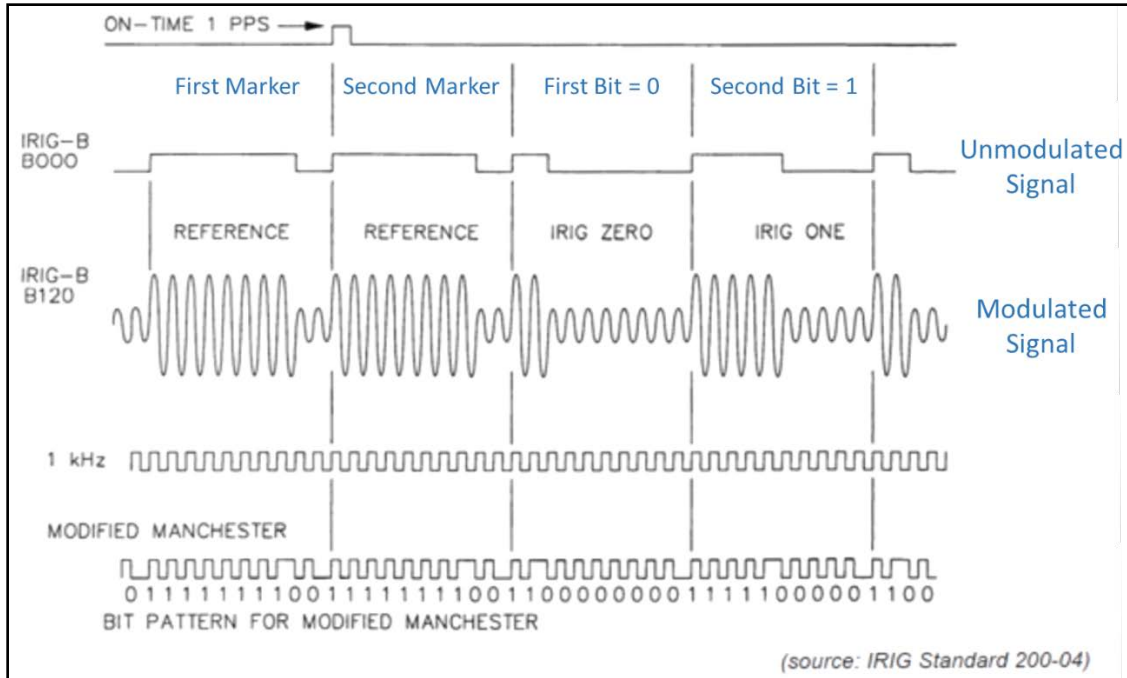
Figure 3.   Comparison of IRIG Timecodes

The IRIG standard actually defines a family of rate-scaled codes that are differentiated by alphanumeric designations: A, B, D, E, G, and H.  The B format is the most common and is characterized by a bit rate of 100 bits per second.  As shown in Figure 3, bit values are determined by the width of each pulse whether it rides on a sinusoidal carrier or not.  The primary differentiator between the IRIG-B format and the other formats is bit rate.  IRIG-G provides the highest bit rate (10,000 bits per second) and IRIG-D provides the lowest (60 bits per minute).  For all formats, each frame of timing data is bounded by two reference markers called "position identifiers."  The bit stream following these markers provides the day of year, hours, minutes, and seconds for the frame.  Because the signals are precisely synchronized to UTC, modern device decoders utilize phasing information to determine fractional seconds within the frame.  Even analog IRIG timecode signals can provide 1-µs accuracy using phase-locked loop circuitry.

Table 1 provides the unique specifications for each IRIG time code format.  The three most common formats still in use on military test ranges are the A, B, and H formats.  The majority of test instrumentation supports the IRIG-B specification.

| Table 1.   Current IRIG Time Code Formats | | | | | |
|---|---|---|---|---|---|
| Format | Carrier Frequency | Bit Rate | Bits per frame (Used) | Frame Time | Frame Rate |
| A | 10 kilohertz (kHz) | 1000 hertz (Hz) | 100 (78) | 100 ms | 10 Hz |
| B | 1 kHz | 100 Hz | 100 (74) | 1000 ms | 1 Hz |
| D | 100 Hz/1 kHz | 1/60 Hz | 60 (25) | 1 hour | 1/3600 Hz |
| E | 100 Hz/1kHz | 10 Hz | 100 (71) | 10 s | 0.1 Hz |
| G | 100 kHz | 10 kHz | 100 (74) | 10 ms | 100 Hz |
| H | 100 Hz/1kH | 1 Hz | 60 (32) | 60 s | 1/60 Hz |

6

## 2.2    Network Time Protocol

As many test ranges move toward network-centric architectures for data collection, network timing protocols like NTP have become an attractive alternative to legacy timing distribution systems based on analog timecode standards.  For many ranges, the network links are already in place for instrumentation control and data acquisition via copper, fiber, and/or microwave paths.  Utilizing these links to pass timing information is an efficient use of existing resources and simplifies test setup.  Nevertheless, NTP has definite limitations.  The protocol uses existing switches, routers, and other network hardware to relay timing information from a reference clock to equipment on the network.  Although it is designed to mitigate latencies and variances in packet transit times inherent to most networks, NTP can only provide reliable timing accuracy to within a few milliseconds.  Consequently, it doesn't provide sufficient timing accuracy for most high-speed imaging applications; however, NTP is a good means to synchronize the internal clocks of computers, digital recorders, and other processing equipment to UTC on a shared network.  This will help ensure filenames, computer logs, and network timestamps are all synced to the same time base.  It may prevent confusion if the complementary metal-oxide-semiconductor (CMOS) battery in a data collection computer dies and the personal computer (PC) associates the wrong date, file creation time, or other erroneous timing data with image data collected in the field.

## 2.3    Precision Time Protocol

This protocol also known by its defining standard, IEEE-1588.[2]  This network protocol is similar to NTP but provides better control, verification, and accuracy of network-distributed timing information.  Like NTP it uses existing cabling and network paths, but requires compatible network devices and clocks to correct for delivery variances between nodes.  With the proper implementation and hardware, PTP can provide sub-microsecond timing information to network-based instrumentation.  Another significant advantage of PTP over legacy timecode distribution systems is the ability to get timing and control over a single cable.  For these reasons, many believe PTP will eventually replace legacy timecodes on the test ranges; however, most current applications for PTP are limited to highly localized installations.  There are significant challenges to implementing PTP over very complex wide-area networks like those in place at the test ranges.  Consequently, timecode-based distribution systems continue to be the most prevalent and cost-effective approach to distributed timing for many range users.

# 3    Overview of Modern High-Speed Digital Cameras

It has been said that a modern high-speed camera is nothing more than a sensor attached to a fairly sophisticated computer with loads of memory.  While this statement oversimplifies the architecture, it is true that most cameras these days have far more information technology components than mechanical or optical components.  Furthermore, virtually every aspect of modern camera operation is controlled by complex firmware and software.  Thousands of lines of code govern exposure settings, frame rate, triggering, image processing and enhancement, data storage and playback, and, of course, time tagging.

---

[2] Institute of Electrical and Electronics Engineers. *IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems*.  IEEE 1588-2008.  Geneva: International Electrotechnical Commission, 2008.

## 3.1    Common Sensors

Two types of digital imaging sensors dominate the market today:  Charge-coupled devices (CCD) and CMOS.  Both technologies were pioneered about the same time in the late 1960s and use the photo-electric effect to convert light into electric charge; however, the two chip designs utilize very different architectures for collecting, transferring, and processing the electric charge into digital values.  These CCD sensors dominated the early market because of superior image quality and they were easier to produce in volume quantities; however, advances in photolithography and fabrication technology eventually gave rise to low-cost CMOS production and better image quality.  Several unique performance advantages of CMOS over CCD have made it the sensor of choice for most of the high-performance digital cameras used by the ranges.

The primary advantages of CMOS over CCD are lower power consumption, better integration (i.e., more functions on the chip), natural blooming immunity, and speed.  An early limitation of CMOS was the inability to support global shuttering.  Indeed most of the low-end CMOS devices today rely on rolling shutters to manage exposure control and data readout; however, the more sophisticated CMOS cameras like those used on the test ranges have additional chip circuitry that supports global shuttering.  This is critical because rolling shutters have unique limitations that affect both the quality of high-speed imaging and the accuracy of timestamping.

## 3.2    Rolling vs Global Shutters

"Shuttering" is the process of exposing an imaging sensor to light for a fixed amount of time equal to or less than the period between frames (i.e., the frame rate).  Shuttering provides exposure control and can help mitigate motion blur due to movement of either the camera or target during image capture.  Many high-speed legacy film cameras used a rotating wheel with an open slit to provide mechanical shuttering of light impinging on the film plane.  Today's digital cameras, however, use electronic shuttering to provide exposure control.  Essentially, the individual photodetectors in each pixel can be turned on and off electronically to set the limits of the charge integration.

The two primary methodologies used for electronic shuttering today are "rolling" and "global."  Imaging sensors that use rolling shutters read out lines of pixels in sequential fashion, rather than simultaneously across the entire array.  Consequently, some pixels in the array are exposed (i.e., integrating charge), while others are being read out.  The exposure and readout of individual rows (or columns) of pixels "rolls" across the array to create a single frame.  This is fine for static scenes, but can lead to a number of deleterious artifacts if there is appreciable movement between frames.  These artifacts can be seen if either the camera moves (as in panning) or an object or target moves within the scene while the camera is stationary.  The primary image artifacts of rolling shutters are commonly referred to as "skew", "wobble", and "partial exposure."  These artifacts are well-documented in an abundance of literature on the subject.  A rolling shutter also complicates time-tagging of the resultant image frame, because different segments of the frame were exposed at different times.  Consequently, a single timestamp for the frame will generate a timing error whose magnitude varies depending on the location of interest within the frame of imagery.

Cameras that employ global shutters take an electronic snapshot of the scene by exposing all of the pixels simultaneously.  All pixels begin integrating at the same time and stop integrating at the same time.  As such, the image frame can be time-tagged at any point during the integration (e.g., beginning, middle, or end) and the tag is valid for all pixels in the array.

Due to the adverse consequences of using rolling shutters for high-speed imaging applications and the associated problems with timestamping, cameras that offer global shuttering are recommended whenever precise timing of high-speed events is required.  The guidelines and procedures outlined in this document were developed for devices with global shutters.

## 3.3    Common Features that can Affect Timestamp Accuracy

Modern high-speed cameras offer dozens of data collection modes and features that vary significantly from one manufacturer to another and even between same-vendor camera models.  Powerful on-board processors and ample memory provide the computational resources to support highly sophisticated camera control functions and image processing capabilities.  Some of the more common features that may affect the accuracy of system timing are described below.

**Shutter Mode** - A few cameras offer both global and rolling shutter modes.  Rolling shutter should only be used when the application demands it.  As discussed above, a global shutter should be selected for high-speed imaging applications and other applications where precision measurements or correlation with other sensor data are required.

**Adjustable Trigger Position** - Most high-speed cameras use a circular buffer architecture for storing images continuously in real time.  The trigger position allows the user to determine how many frames before or after receiving a trigger input will be recorded and saved.  Although rare, timing errors have been encountered when switching from one trigger position to another.  It is recommended this feature be tested to determine if it has any impact on timestamp accuracy.

**Dynamic Range Extension -** Many cameras offer features that can extend the effective dynamic range of the system by varying the integration time from frame to frame based on the light levels detected.  If the software does not provide any hard limits on integration time and the actual time of integration (TINT) is unknown, then it will be difficult to ascertain absolute timestamp error.  If on the other hand the software provides a user-selectable maximum TINT with this feature enabled, it is suggested tests be performed with and without dynamic range extension to determine any impact on timing.

**Segmented Memory -** This is a feature that allows the user to subdivide the entire block of camera memory into segments.  It is useful for capturing multiple high-speed events without having to download the camera memory in between phases.  Significant timestamp errors have been observed in one or more segments with some camera models.  Although software revisions corrected this problem with one particular vendor, it is recommended timing tests be performed with this feature enabled if segmented memory will be required for mission support.

**External Memory Packs -** Many vendors offer external memory devices for extending record time.  Early versions of some vendor software exhibited significant timestamp errors for frames stored in external memory.  Most of these errors have been eliminated with updated software, but it is a good idea to check the quality of timing information on frames stored in external memory if it is available.

**Exposure Synchronization** - Some cameras allow the integration time to be synchronized to an external signal, such as timecode, output from a signal generator or device trigger.  This is another software-driven feature that can introduce timestamp error if not implemented correctly.

**Exposure Offset -** This feature is related to exposure synchronization and provides the ability to delay the start of integration from the external signal.  The same firmware/software-induced errors possible with synchronization can surface with the insertion of timing offsets.  Tests should be performed to ensure the actual offset corresponds to the programmed offset precisely and consistently.

**Time Stamp Position -** Some vendors offer the option of latching time at various points within frame integration (e.g., beginning, middle, or end).  This choice is usually application-dependent.  It is critically important that the data analyst know the position of the timestamp relative to the integration time for accurate analysis of the optical imagery.  Some organizations have standardized on one position or another.  The Motion Imagery Standards Board, for example, has chosen the start of integration as the point of timing reference for a frame.  Other organizations, like White Sands Missile Range (WSMR), have chosen the end of integration.  Regardless of the choice, the point of integration should be recorded as a metadata element associated with the camera imagery to ensure proper analysis of the data.  Tests should be performed at various timestamp positions to confirm actual integration time and proper application of timing information by the camera software.

## 3.4    Other Sources of Error

### 3.4.1   Reference Timing

Obviously, the accuracy of camera timestamps can only be as good as the accuracy of the timecode input.  Test ranges should know the error budgets of their timing equipment and have procedures in place to verify that devices are performing within specification.  Furthermore, all timing instrumentation requires periodic maintenance and re-calibration.  Failure to maintain timing equipment and monitor system performance is one of the leading causes of timing error in optical data.

### 3.4.2   Cabling and Connectors

Poor cabling and connector health can lead to timing error.  Most cameras have internal oscillators that will free-run in the absence of timecode input.  Intermittent connections will cause the internal clocks to drift and reset periodically and may introduce timing error.  It is also critical to ensure that the type and length of cable is compatible with the timecode signal.  For example, unmodulated IRIG (DCLS) signals typically require shorter cable lengths than modulated signals for the same type of cable.  It is also important that timing circuits and distribution systems not be overloaded by daisy-chaining devices.  For more information on proper cabling and loading of IRIG signals, consult the excellent treatment on this topic in NIST Time and Frequency Services.[3]

---

[3] National Institute of Standards and Technology.  *NIST Time and Frequency Services*.  NIST Special Publication 432.  January 2002.  May be superseded by update.  Retrieved 11 February 2016.  Available at http://tf.nist.gov/timefreq/general/pdf/1383.pdf.

### 3.4.3    Architecture

Some older high-speed digital cameras employ separate timing insertion modules that apply timing information after the frames have been flushed from the camera.  These systems are notorious for exhibiting significant timestamp errors that often exceed several milliseconds.  This is particularly true for systems that utilize older serialized transmission protocols and hardware.  Another design that leads to relatively poor timing results is single sampling of the input timecode.  Some systems latch time only once during data capture and extrapolate timestamp values based on clocking and frame rate.  Experience has shown that cameras that embed the timecode receiver/processor in the imaging head and sample reference time frequently tend to provide the best timestamp accuracy.

### 3.4.4    Firmware/Software Modifications

Because timestamps are firmware/software-driven ANY changes to underlying source code can potentially introduce error.  Even though many vendors have adopted quality standards for programming and debugging embedded and published software, modern camera systems are so complex it is nearly impossible to verify every function and operational mode before release.  Due to continually evolving technology and customer requirements, most firmware and software is under regular and periodic revision.  Consequently, it is important to re-test timing properties of existing camera and recording hardware whenever new programs or patches are installed.

### 3.4.5    Software Conflicts

Some timing errors have been identified as platform-specific, i.e., observed on one computer but not on another.  Digital PC recorder architectures have software inside the timing loops.  Therefore, anything that affects the timing subroutines can affect the timing accuracy.  Primary areas that can be problematic can include virus scanners, operating system (OS) housekeeping routines, etc.  It is important to ensure that camera software is fully compatible with the platform being used to control the camera and collect data.  It should never be assumed that timing certification results made with one OS are equally applicable to a newer OS, for example.

### 3.4.6    Metadata

The status of source clock synchronization, the mode of the clock setting, the expected accuracy of the clock, the point of timestamp relative to integration, etc. all need to be captured and recorded with the timestamps and imagery.  The absence, or erroneous reporting, of any of these elements can lead significant, but often undetected, errors in data analysis.

### 3.4.7    Untested Features

It is not uncommon for timing errors to show up in data collected with cameras that have already been certified and performing well for quite some time.  This is often because the camera was configured in an operational mode or using an advanced feature that had never been tested.  The bug was lurking there in some obscure software routine but was never awakened until the right combination of camera settings was chosen.  For this reason, it is critical that timing tests be performed using the operational configuration and settings needed for routine mission support.  While testing all camera modes and features is usually time- and cost-prohibitive, testing those that may be needed at your particular range will save headaches down the road.

### 3.4.8    Component Failure

Changes in timing properties have been observed when certain subcomponents fail inside the camera or recording device.  Obviously, any problems that arise with the timecode

processing circuitry can result in notable timing error.  This is an issue on many of the MRTFBs because of the possibility of overvoltage conditions on the timing input line.  Unstable generator power and exposure to lightning and other environmental factors, like field mice shorting cables, can damage delicate electronic components inside the camera.  For these reasons, it is good practice to disconnect timing lines from field cameras whenever they are not being used.  It is highly recommended that lines be physically removed from all equipment if they are strung across the ground in open field environments over long periods of inactivity (e.g., non-working nights and weekends).  A single lightning strike can seriously damage an entire suite of instruments that are electrically interconnected with coax, Ethernet, or standard field wire.  Experience has shown that timing circuitry is particularly vulnerable.

# 4    General Testing Methodologies

Even though digital high-speed cameras have been on the ranges for at least 15 years, methodologies for characterizing timing accuracy are still evolving.  For a number of years, MRTFBs had no reliable means to assess accuracy other than by correlating the new digital video with other sources.  Initially, data reduction groups relied solely on manufacturer specifications.  Furthermore, many vendors didn't even offer specs because the toolsets hadn't been developed to characterize timestamp accuracy to microsecond accuracy for the newer, extremely fast cameras; however, as more test ranges began replacing legacy film-based systems with digital cameras and military program requirements became more stringent, test methodologies began to emerge for characterizing and validating camera timing properties.

## 4.1    Component Specification Analysis

The earliest approach to determining system accuracy was performing a thorough analysis of system components and their tolerances.  This method provided a theoretical estimate of timing accuracy based on published technical data provided by the manufacturer of integrated circuits, oscillators, processors, etc.; however, it was difficult to predict the effects that complex integration with many other components might have on timing accuracy.  Furthermore, this approach could not account for errors introduced through firmware and software implementations.  As a result, many of the early estimates provided by vendors for timing uncertainty were grossly understated.

## 4.2    Electronic Probing and Signal Analysis

Some manufacturers began designing electronic test points into their circuit boards so they could trace timing signals and measure internal latencies.  This helped identify problems at the component and board level, but still did not address potential error introduced in software.  Timing accuracies generally improved, but not sufficiently for some applications.

## 4.3    Optical Strobes

Around 2000 several organizations began investigating the feasibility of using fast-response LEDs for measuring the accuracy of timestamps provided by new digital cameras.  The idea was to generate an optical strobe or flash at a precisely known instant in time by triggering fast LEDs with precision timecode.  Comparing the precise UTC time of these flashes with the timestamp on each image frame in which they appeared would allow an analyst to measure deltas and characterize systematic error.  [0] provides a detailed history of the research and

development that led to the first LED-based measurement system at WSMR.  A block diagram of the system along with a photograph of the field implementation is provided in Figure 4.  This system was used to perform hundreds of tests on a wide range of imaging systems, which revealed many timing latencies and errors in early camera models.  Vendors used these data to identify problems with timing circuits and improve designs.  Eventually other ranges and manufacturers began designing and building their own LED-based measurement systems.  The advent of these tools greatly improved the accuracy of timestamped imagery throughout the test range community.
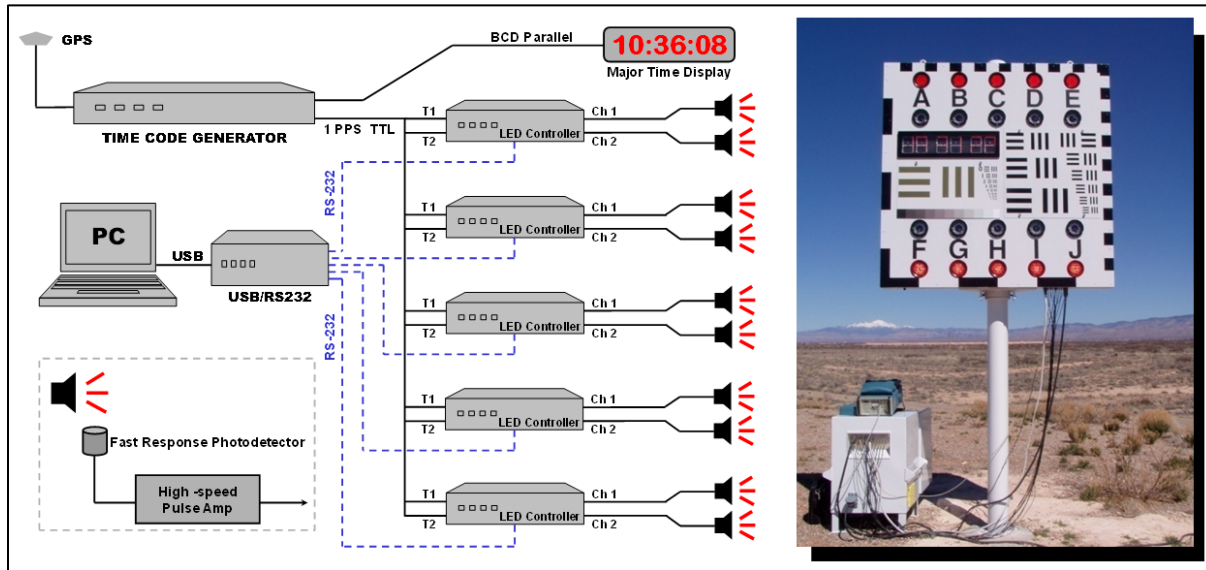


Figure 4.    Early LED-Based Camera Timing Certification System at WSMR

An important feature of the WSMR design was the incorporation of a fast-response photodetector with a filter that was spectrally matched to the LED emitters.  The photodetector allowed the user to verify the timing properties of each flash.  This was accomplished by comparing the output of the photodetector against the 1 pulse per second (PPS) signal from a reference clock (i.e., timecode generator) with a high-bandwidth digital oscilloscope.  The leading edge of the 1 PPS signal was aligned with UTC to a high degree of accuracy (< 400 nanoseconds [ns]) and verified before each test using an atomic reference clock maintained by the WSMR Timing Group.  Well-established calibration and validation procedures before each test ensured the temporal characteristics of each flash were precisely known.

## 5    Fast-Response LED Properties

### 5.1    Wavelength Considerations

Manufacturers can produce LEDs in many visible colors these days and a few even operate at near-infrared, short-wave infrared, and mid-wave infrared wavelengths.  The spectral response of many CMOS camera sensors peaks near the red end of the visible spectrum.  Consequently, red LEDs make good optical strobes for performing timing tests on visible-band cameras.  The systems at WSMR utilize LEDs that have center wavelength of 660 nanometers.  This provides very good contrast for cameras having either monochrome or color CMOS sensors.  This wavelength also provides a fairly good response with CCD imagers and is visible

to the human eye.  When building a custom test set, it is critical to ensure the transmission properties of the LED chosen are spectrally matched to the cameras and lenses that will be tested.

## 5.2    Temporal Considerations

The primary reason LEDs are a good choice for optical strobes in timing measurements is because they have very fast rise and decay times.  Unlike other sources of illumination that are often based on resistive heating or chemical reactions that have long time constants, LEDs produce light through electroluminescence that has a very short time constant.  Consequently, many LEDs can be switched on and off with pulse widths as short as 1 µs.

Figure 5 shows the typical temporal response of an LED.  In this instance, the output of the LED was measured using a fast-response photodetector having a response time of less than 20 ns.  The output of the photodetector is shown on an oscilloscope along with the 1 PPS signal from a precision timecode generator synchronized to UTC.  This particular LED was programmed to come on for 10 µs beginning 10 µs after the UTC second rollover signified by the leading edge of the 1 PPS signal.  As the figure clearly shows, the rise time of the LED was much less than 1 µs, while the decay time was slightly longer.
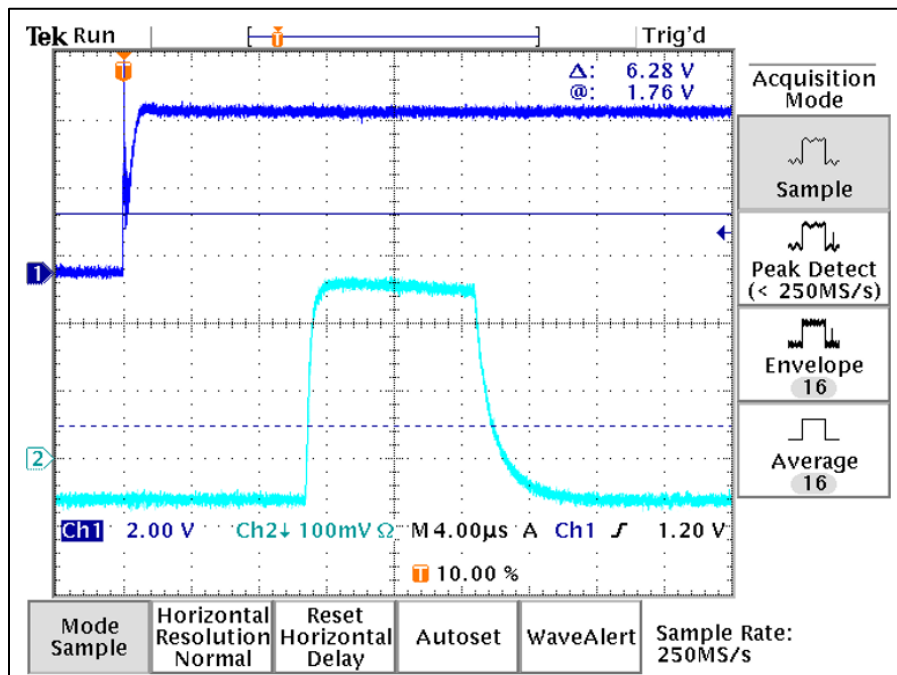


Figure 5.    Typical Temporal Response of LED (Lower Trace) Compared to 1 PPS

## 5.3    Intensity

The intensity of most LEDs is proportional to the electrical current with which they are driven.  Higher drive current will produce more light and provide better contrast in cameras set with very short integration times; however, LEDs have damage thresholds that are determined by the combination of drive current, pulse duration, and duty cycle.  They can be driven very hard for short periods of time with a relatively long duty cycle but will fail when driven too hard with

long pulse widths and/or a short duty cycle.  Most LED controllers have hard limits set for current, pulse width, and duty cycle combinations that might damage individual emitters.  The LED-based timing certification systems used at WSMR have sophisticated control circuits that take this into account.

## 5.4    Uniformity

Light output from LEDs can vary significantly from one unit to the next based on variances in the manufacturing process.  This is especially true for very-low-cost components. Light uniformity becomes important if the relative intensity of a strobe, as it appears in a frame of camera imagery, will be used to determine if the LED is fully on or fully off.  Uniformity is also a factor when using the relative intensity of an LED image to determine if the camera integration time started midway through the strobe pulse or not.  For these reasons, it is important to use high-quality industrial-grade LEDs for testing purposes.  Low-grade units cost much less but exhibit too much variance in performance for use in timing certification systems. The Optics group at WSMR purchased high-quality LEDs and down-selected individual units that showed less than 10% variance in light uniformity when driven by the same source.

## 5.5    Beam Width and Alignment

Most LEDs come packaged with an integrated lens assembly that has specific beam width characteristics.  The choice of beam width is application-dependent but the width should be as narrow as possible to maximize the irradiance at the camera.  This is particularly true if there is significant separation between the LEDs and system under test (SUT) (field applications) or when testing relatively low-sensitivity cameras.

Usually an array of LEDs is needed to perform timing tests.  As such the individual emitters should be precisely arranged and installed such that the optical axes of all the LEDs in the array are properly aligned.  Such boresighting is critical for the same reasons uniformity is important.  The irradiance of each LED should be relatively the same at the sensor plane. Uniform irradiance will aid in the interpretation and analysis of timing test data collected with multiple optical strobes.

Figure 6 provides a list of the LED specifications for temporal, intensity, and beam width properties of the LEDs used in the original DITCS system shown in Figure 4.

| LED Specifications | |
|---|---|
| Supplier | AI, Inc. |
| Type | AlGaAs |
| Diameter | 10 mm |
| Wavelength | 660 nm |
| Divergence | ± 6 Deg |
| Pulsewidth | 1 – 64,000 µs |
| Trigger Offset | 10 – 64,000 µs |
| LED Drive Current | 0 – 4,000 mA |
| LED Luminous Intensity | 0 – 6,000 mcd |
| Rise Time | << 1 µs |
| Decay Time | < 1 µs |
| System Jitter | 3 – 4 µs |
| Operating Temp | 0 to 55 deg C |
| Lifetime | > 100,000 hr |

Figure 6.   Typical Fast-response LED Specifications

## 6   Test Configuration

The following basic components are needed to measure timestamp accuracy using fast-response LEDs:  reference clock, LED controller, LED array, photodetector, camera, and data acquisition system.  Best results will be achieved in the lab, where lighting, temperature, and other environmental conditions can be controlled.  The general idea is to program the LED array to flash at precisely controlled times relative to UTC and then compare the camera timestamp of the flashes to actual time (i.e., UTC).  Some general guidelines for test setup are provided below.

### 6.1   Reference Clock

The accuracy of any verification test will be only as good as the reference timing source. Therefore, it is critically important to ensure the reference clock is synchronized to UTC with an uncertainty much less than the measurement objective.  All output signals generated by the reference clock should be validated before testing.  There are several ways to achieve this, but the most straightforward and reliable means is to compare the 1 PPS signal from the reference clock against the 1 PPS from an atomic master clock.  Many MRTFBs have such devices at their disposal along with small teams of trained technicians who are adept at calibration.  After the 1 PPS has been validated, other timecode outputs like IRIG-B should be checked.  There is a wide range of commercial timecode processors available for time distribution.  Many systems at WSMR use the TRAK-9000 (TRAK Microwave Corporation) to satisfy most timecode generation and processing requirements.  This model provides precision timecode for optical tracking mounts, control vans, and high-speed fixed cameras used in data collection.

### 6.2   Geometry

Test geometry is critical due to the relatively narrow beam width of most LED emitters. It is important to ensure both the camera and LED optical axes are aligned with each other to maximize contrast in the resultant imagery.  It is also important to separate the camera under test and the LEDs sufficiently to ensure the luminance from each LED is imaged uniformly onto the

sensor plane. This can be checked by turning all the emitters on at the same time (using the same drive current) and comparing the relative intensity of the emitters with one another. If the LED array is too close to the camera, some emitters on the edge of the array may appear less bright than emitters at the center because of the angular displacement of the beam pattern (e.g., Lambertian radiation pattern).

## 6.3   Camera Configuration

Ideally, cameras should be tested with the same operational settings as those used for routine mission support. One notable exception to this general rule is the integration time. The limit with which timing errors can be resolved using optical strobes is highly dependent on the width of the LED pulse (i.e., flash) and the exposure time of the camera. Typically, it is best to keep both of these parameters as short as possible. Many LEDs do not exhibit a square emission response when the width of the current pulse falls much below 5 µs. Furthermore, the sensitivity of many cameras will determine the lower limit of integration time with which well-resolved imagery of short-duration flashing LEDs can be obtained. A good rule of thumb is to program the LEDs to come on and off at 10-µs intervals and set the camera integration time to 100 µs. With this particular test configuration, each frame of camera data will capture approximately 10 LEDs illuminated at any given time. Using the relative intensity of the first and last lamp that appears to be illuminated in each frame, the start and stop time of camera integration can be interpolated with about 5 µs of resolution. If there is a requirement to measure timing errors shorter than 5 µs, the width of each LED pulse should be set at 5 µs.

Because camera timing is software-driven, it is important to test most operational modes used in the field. It is not uncommon to find the accuracy of the timestamp varies between operational modes due to the way firmware/software routines manage the different modes. It is also important to disable any modes that allow for variable integration times. The exposure should be a fixed duration that is consistent and well-known. Furthermore, the position of the time stamp within the integration window (e.g., beginning, middle, or end) must be known to properly interpret measurement results.

## 6.4   Strobe Sequencing

Many LED control systems can be designed and programmed to provide a large number of strobe sequence combinations. Through extensive experimentation at WSMR with many of them, the most useful sequence for testing range cameras has proven to be a 10-µs staggered-pulse series triggered by the leading edge of UTC. In this sequence the first LED in the array will turn on (i.e., flash) at the UTC rollover and stay on for 10 µs. The second lamp in the array will turn on at UTC transition + 10 µs and stay on until UTC transition + 20 µs and so forth. Several commercial systems on the market (like the LabDITCS system described in Appendix B) offer 100 fast-response LEDs that can be programmed in this manner. It will take precisely 1 ms to cycle through a 10 x 10 array with this 10-µs staggered program sequence.

If the camera integration time is set to 100 µs, each frame of camera data will show approximately 10 lamps illuminated. The starting position of that block of 10 LEDs relative to the 1 PPS can be used to ascertain the actual time of exposure relative to UTC.

Figure 7 provides a timing diagram for the original DITCS system that had only 10 LED emitters in its array. In this case, the lamps were programmed for a 100-µs pulse sequence and each frame only showed one or two LEDs illuminated.
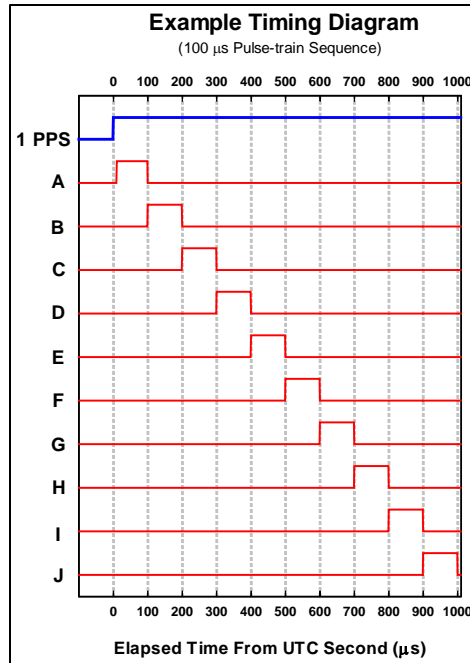
Figure 7.   Timing Diagram for a 100-Microsecond Staggered LED Sequence

## 6.5   System Validation using Fast-Response Photodiodes

Regardless of which program sequence is used to drive the LEDs, it should always be checked with a fast-response photodetector to verify the system is executing the correct sequence before beginning a certification test.  The easiest way to accomplish this is with a multi-channel oscilloscope that can show the output of each LED (as measured by the photodetector) relative to the leading edge of the 1 PPS synchronized to UTC.  It is tempting to skip this step during setup and assume the LED controller and LEDs are behaving as expected; however, if there is an error in the program or latencies in the LED controller it will bias the measurement results and lead to erroneous conclusions about the accuracy of the camera timestamp.

# 7   Data Collection

It would be impractical to test every possible camera configuration for timing accuracy.  Therefore, it is recommended tests be performed with the most common settings used during routine mission support.  It is also recommended that the data collection computer used for timing measurements be configured with the same OS and software as that installed on the camera control computers used for routine mission support.  This will help limit test condition variables and minimize anomalies that could arise from configuration differences between the test setup and actual mission support configuration.

Because errors in timestamps can drift and change over time, large data sets are needed to capture and characterize any trends or transient/anomalous effects.  The following guidelines for data collection are based on extensive experience using LEDs to perform timing certification tests at WSMR.  These recommendations also address some of the commonly encountered sources of timestamp error associated with modern high-speed digital cameras on the test ranges.

**Set recording period to fill camera memory**.  Filling camera memory (i.e., setting recording period to max) provides a statistically significant number of frames for post-test analysis and may reveal time-variant error over relatively long recordings.

**Collect data at low, medium, and high frame rates**.  It has been observed that timestamp error can vary with frame rate.  Consequently, it is advised to bracket the range of frame rates commonly used to collect mission data.  Sampling at low, medium, and high frame rates will likely reveal any frame rate-dependent timing error.

**Record three files at each frame rate**.  It is recommended that at least three full files at each frame rate be collected to provide sufficient statistical sampling of timestamp data.

**Collect data in segmented memory mode.**  Many high-speed digital cameras have a feature that allows the user to configure the camera for multiple triggers to record multiple video files in a single block of memory.  Some segmented memory modes have been particularly prone to errors in timestamping.  A few early camera models showed very accurate time-stamping in standard recording mode, but were characterized by significant timing errors when configured for segmented memory mode.

**Collect data at two or more trigger positions**.  Most circular buffer-based cameras provide more than one user-selectable trigger position.  For example, some cameras can be set up to trigger at the beginning, middle, or end of the recording segment.  It is a good idea to collect data at two or more trigger positions to verify that trigger position does not affect measured timestamp error.

**Keep detailed notes on the LED program sequence and camera configuration**.  It is imperative that configuration settings be accurately recorded prior to each data collection.  These notes will be critical to post-test analysis.

# 8   Data Analysis

Errors in camera timing are measured by comparing the LED indication of UTC observed in each frame to the published timestamp associated with the frame.  Differences can be quantified and statistically averaged over multiple frames to calculate mean errors.  Recording multiple video files with the same camera configuration can add statistical validity to measured results.  Furthermore, additional video files can be collected using different camera configurations and advanced features to determine if certain configuration settings or camera features are responsible for introducing timestamp error.

## 8.1   Manual Data Analysis Methods

It would be impractical to manually inspect thousands of frames collected in a single test.  Therefore a small subset of frames should be selected for detailed analysis.  These frames should be evenly distributed across the entire video file to help identify error drift if it is present.  The approach used at WSMR is to extract approximately 10 to 15 frames from each file for visual inspection and analysis.  Each frame should be visually inspected and the UTC time carefully read from the illuminated LEDs in the array.  Before calculating error, it is necessary to factor in the camera timestamp position.  If the timestamp position coincides with the end of integration and the last illuminated LED is used to determine UTC, then no adjustment is needed.  If, however, the camera timestamp position is set for beginning of exposure and the last LED is used to read UTC, then TINT would be added to the timestamp position before computing the

delta.  Assuming the LED test set has been precisely calibrated and synchronized to UTC, the difference between the camera timestamp and UTC represents the error.  This is expressed mathematically as:

$$\Delta = t_{CAMERA} - t_{UTC}$$

If $\Delta$ is positive, then the camera timestamp is ahead of actual time.  If $\Delta$ is negative, then the camera time is slow or behind UTC.  Because most errors are due to intrinsic latencies in hardware and software processing, the deltas are usually negative.

$$Mean\ Error\ = \frac{1}{n}\ \sum_{k=1}^{n} |\Delta_k|$$

It is instructive to compute the mean of all errors measured for a particular camera configuration.  This mean value can then be used to characterize camera timing performance for that particular model and configuration.  Data analysts can also use it to reduce the overall error budget of TSPI analysis, assuming the errors are fairly consistent.  Experience with a large number of digital high-speed cameras at WSMR has shown that most errors are systematic in nature and tend to be very uniform.  The variance or standard deviation of individual errors can be computed with the mean to provide an indication of uniformity.

## 8.2    Automated Data Analysis Methods

A large number of image processing libraries is now available both commercially and open-source.  If LED test sets are designed to provide fixed registration points so the array can be spatially calibrated, then these libraries can be used to automate the error measurement process.  The LabDITCS test unit described in Appendix B was designed to be machine-readable and WSMR developed custom software for that purpose.  This software is government-owned and can be made available to ranges that use the LabDITCS for timing error measurement. Figure 8 provides a screenshot of the LabDITCS Reader program analysis window.  Green squares in the image were generated by computer analysis of the frame to identify illuminated LEDs on the LabDITCS active emitter display.
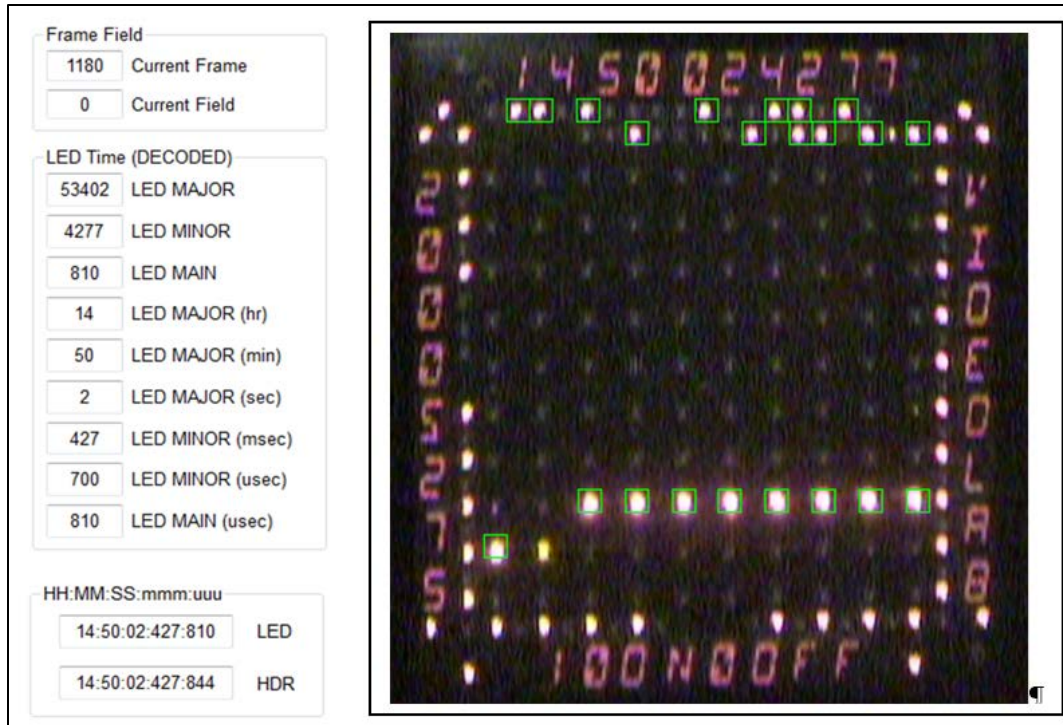
Figure 8.   Example of LabDITCS Reader Program Display

Automated data analysis provides three primary benefits over manual analysis methods. First, it takes much less time.  It can take several hours to manually read and process the 40 to 50 frames typically extracted from a new camera data set.  The LabDITCS Reader program, on the other hand, can process the same data in a matter of minutes.  Secondly, software routines can process many more frame samples than manual reduction methods.  Therefore, better statistical summaries are possible with software-driven analysis.  Finally, software methods apply objective standards to the interpretative process of reading LED status and help eliminate human error in the process.  Consequently, more accurate and consistent results may be achievable with automated analysis.  That being said, automated analysis hasn't been perfected and WSMR is still developing the LabDITCS Reader program.  Transition points (i.e., second and millisecond rollovers) continue to be problematic for automated reading.

## 8.3   Test Results

It is often helpful to graph error measurements to ascertain trends and distributions. Figure 8 shows a chart presenting some of the very first timing errors measured with fast-response LEDs (left-hand side).  These results came from field tests using the DITCS prototype system discussed in 0.  A wide range of different cameras was tested, including film cameras, standard video cameras, and the first high-speed digital cameras at WSMR.  The errors are plotted on a logarithmic scale with a green shaded region that depicts the ±50-μs acceptable level for TSPI production.  Clearly many of the older cameras, and some of the new digital cameras, did not meet this threshold.

The right-hand side of Figure 9 shows results from a test performed more recently with a digital camera still in service on the range.  Here the results from three different frame rates (as recommended in Section 7) are plotted together on one chart.  Visualizing the data in this manner

shows that the errors for this particular camera were fairly consistent and clustered around a mean of 27.5 μs.  Furthermore, the composite distribution shows that the errors were evenly distributed between low, medium, and high frames, indicating the mean measured error is equally valid across all frame rates.  Finally, it should be noted the standard deviation for these samples was 2.87 μs, which is well within the measurement resolution of the test configuration at about 5 μs.  Consequently, the spread in Figure 9 is more likely due to measurement uncertainty than actual variance in the errors.  Averaging across a large data set like this to arrive at the mean error helps mitigate the effects of measurement uncertainty.
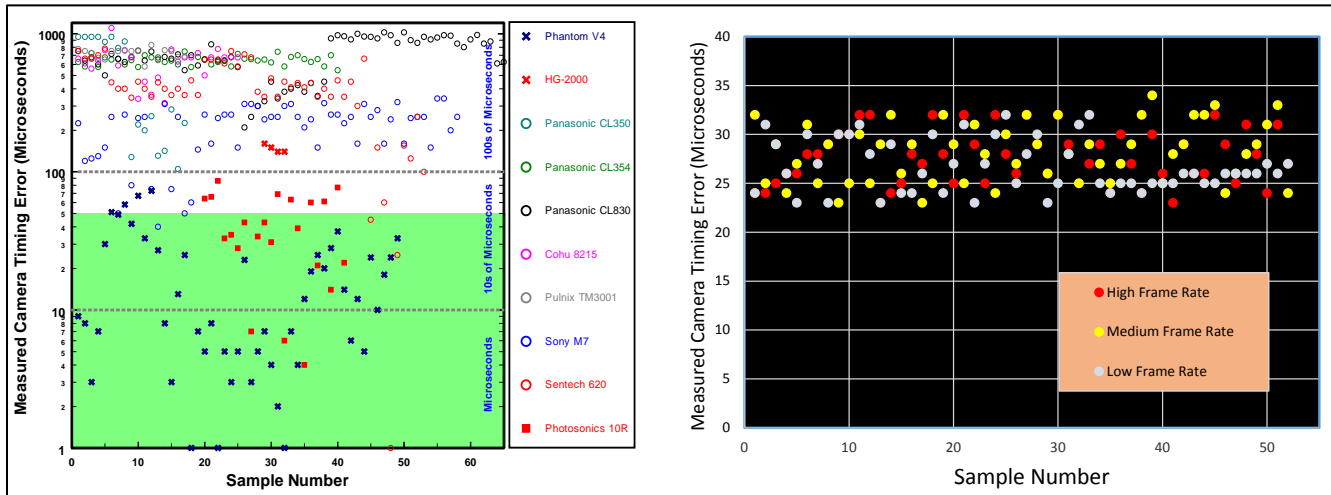


Figure 9.   Camera Timestamp Error Measurements

## 9   Recommended Test Schedules

Ranges that have stringent timestamp accuracy requirements should have a well-documented plan for testing cameras.  This plan should be developed in collaboration with data reduction groups and based on accuracy thresholds needed to satisfy military program objectives.  Precision timing tests are labor- and time intensive.  Great care must be exercised in the setup, calibration, and verification processes before even beginning a timing test.  Consequently, the frequency with which tests are performed should be determined by each organization and tied to their individual requirements and available resources.

Two types of routine tests were developed at WSMR that differ primarily by the number of samples that are collected and analyzed:  Certification Test and Spot Check.  Certification tests are more rigorous and require collecting more samples under multiple operational configurations.  Certification tests are performed to certify that the mean timestamp error from a particular camera model falls at or below ±50 μs.  Spot checks are very limited tests performed on a camera that has already been certified but has undergone some change.  These scaled-down tests usually involve the analysis of several frames collected at the most common camera configuration.  If the mean error from this analysis matches the mean error archived for that camera model, then no further tests are performed.

Based on extensive testing and identification of common sources of timing error, WSMR developed the following matrix for managing the timing certification and inspection process.

Each range has unique requirements and should develop their own test matrix suited to that inventory, but the tests listed in Table 2 provide good guidelines for how to schedule tests.

| Table 2.    Recommended Test Matrix for Digital High-speed Imagers Having Critical Timestamp Accuracy Requirements | | | |
|---|---|---|---|
| **Activity** | **Certification Test** | **Spot Check** | **Notes** |
| Receive new camera model | X | | All new camera models should be tested with a full battery of tests as part of acceptance procedures |
| Receive additional units in model series that has already been certified | | X | If measured errors were consistent for the first unit in model series, spot check should be performed and compared with first unit |
| Upgrade firmware | X | | Any changes to firmware warrants full battery of tests |
| Install major software release | X | | Major software upgrade warrants full battery of tests |
| Install minor software release | | X | Spot check for minor changes to control software |
| Install new OS upgrade | X | | OS upgrade warrants full battery of tests |
| Install software patch | | X | Unless the patch was related to timestamp |
| Return unit to service after repair | | X | Spot check for most board-level repairs |
| Modify camera | X | | Addition of memory, external recording, etc. warrants full battery of tests |
| Timing problem reported with certified camera | X | | Any reports of timing discrepancy from field or data reduction personnel warrants full battery of tests |
| Lifecycle testing (2 years) | | X | Camera timing should be re-verified every two years |

This page intentionally left blank.

## APPENDIX A

**Development of the First Digital Imager Timing Certification System (DITCS) at WSMR**

This appendix provides an excerpted copy of a report generated in 2002 based on initial research into methodologies for characterizing the timing properties of imaging systems at WSMR.  The report was written for Mr. Charles Tapp, a civilian engineer in the Data Reduction branch of Range Operations at WSMR.  It was his vision and commitment to data accuracy and quality that laid the groundwork for the development of the first DITCS at WSMR.  Although the first DITCS was a large field system that was labor-intensive to set up and operate, it was successfully used to measure the timing properties of virtually every type of camera in the WSMR inventory at the time.  This included film-based imagers, standard video cameras, and of course the new high-speed imagers just coming on the market.

The DITCS was used for approximately seven years at WSMR before the concept was further developed, enhanced, and repackaged into the Laboratory DITCS (LabDITCS) by Protected Logic, Inc. discussed in Appendix A.  The following is an abridged version of the original report on DITCS research and development, dated 07 February 2002.  The original document was generated in response to a work authorization order (WAO) request by the government.  It is included in this report to provide a history of the early research and testing of using fast-response LED emitters for timing characterization of high-speed imagers at WSMR.  As the following material has been previously published outside of the RCC, it is reprinted here without editorial review by the RCC Secretariat.

# Digital Imager Timing Certification System (DITCS) Proposal for Prototype Development

# 1.0  Requirements

As a premiere military test center for evaluating new weapons systems and innovative defense technologies, optical instrumentation at WSMR has undergone substantial evolution over the years to support the increasingly challenging test environments that new technologies demand.  Although the inventory of optical support equipment at WSMR has seen many improvements, upgrades, and modernizations over time, there have been relatively few "revolutions" that have brought fundamental change to the way WSMR provides optical data collection and optics test support.  Conceptually, one might suggest the following short list of major innovations that have had a historically notable impact on optical support capabilities:

- *The introduction of hydraulic and electrically-driven mount servo systems*
- *The replacement of fixed optics sites with remotely-controlled mobile systems*
- *The introduction of Visible and Infrared Video-Tracking systems*
- *The introduction of control vans with advanced computer electronics and display technologies to provide quick-look data and real-time analysis.*

In the very near term, WSMR hopes to add to this list of major innovations the introduction of all digital camera systems for event recording and TSPI data collection.  Historically, nearly all TSPI data has been derived, and continues to be derived, from conventional film and video footage of test events.  With the advent of robust, field-ruggedized, high-speed digital cameras, the range has initiated a five year plan to begin replacing its inventory of antiquated film and video systems with more modern and capable digital systems.  As evidenced in the Optics Roadmap, the replacement of old, labor-intensive, and expensive film and video systems is a top priority in the Optics Branch of the National Range (NR-DO).  Digital systems offer a number of distinct advantages over conventional imaging systems.  They are much cheaper to operate over time because media costs are significantly lower.  Digital imagery can be captured and stored at a fraction of the cost of instrumentation length film.  Furthermore, digital cameras are considerably more reliable and easier to maintain than film cameras because they have practically no moving parts.  Finally digital imagery lends itself to more rapid data reduction and analysis because it is already in a format amenable to direct computer processing.  For these reasons, it is expected that the vast majority of film cameras and many of the video cameras will be replaced with all digital systems over the next few years.

WSMR introduced the first high-speed digital imaging systems about two years ago.  Since then, they have been very successfully deployed in support of a wide range of fixed-camera and dynamic tracking missions.  Their application has been limited somewhat however, by the inability to validate system timing.  Various camera manufacturers have adopted different strategies for time-tagging digital image frames.  Presently, no single standard exists.  Worse yet, WSMR has no means of independently verifying the timing specifications proffered by each manufacturer.  For this reason, WSMR's growing inventory of digital imaging systems has not yet been validated and approved for the collection of precision TSPI, except for limited miss distance measurements.  Because many missions on the range involve high dynamics, accurate timing is critical to post-mission reduction.  Missile-missile intercept missions often involve closing velocities that exceed 10,000 ft/sec.  At these velocities, WSMR cannot provide the sub-meter position accuracies required by many projects unless optical data timing is highly accurate.

The DITCS concept grew out of an urgent requirement to develop a timing test set that could be used to test and validate all present and future digital imaging systems.  The idea, promoted by the Government's WAO initiator and supported by the Data Sciences and Data Collection divisions within National Range, is to develop a fieldable system that can be installed at the Instrumentation Test Site (ITS) and provide the capability to measure timing accuracies within +/- 50 µs.  The benefit of developing a fieldable system is that measurements can be made with the actual mount configurations that are used during routine mission support.  As such, all the variables associated with differences between lab and field environments can be eliminated in any rigorous analysis of timing parameters.  The actual requirements of the DITCS task are thoroughly described in the requirements document provided as reference (b).

## 2.0   References

(a)  Contract DAAD07-97-C-0108
(b)  WAO Part I received 11October 2001

(c) Datasheet S6000, 074-13-009 Rev 01 – "Specification Sheet for S6000 Electronic Controller", Advanced Illumination, Inc., August 2000
(d) Datasheet RL4260, 092-13-008 Rev 00 – "Specification Sheet for RL4260 Ring Light", Advanced Illumination, Inc., October 2000

# 3.0  Technical Approach

## 3.1 Background

From the very earliest discussions of this project, a decision was made to seek relatively low-cost, commercially available solutions that would help keep both cost and risk to a minimum. Commercial-Off-The-Shelf (COTS) components bring many benefits to the table besides cost and risk abatement.  COTS-based solutions usually offer shorter procurement lead times and include professional technical documentation for system operation and maintenance.  Furthermore, most COTS providers offer extended warranties and technical support that helps promote rapid integration and initial operating capability (IOC) and further reduces exposure to system failures and/or incompatibilities.

## 3.2 Market Survey

After deciding upon a COTS-based track for this task, a market survey was conducted to determine if readily available COTS equipment could satisfy the critical timing requirements for digital imager timing certification.  Preliminary investigation revealed three candidate technologies with potential application to the problem:  **Stroboscopic Light Sources**, **Fast-response Liquid Crystal Display (LCD) Shutter systems**, **and Light Emitting Diode (LED) systems**.  The merits and detractors of each technology, as they relate to the stated requirements of the work request, are described in turn below.

**Stroboscopic Light Sources** – Most commercially available stroboscopic systems are built around high-voltage xenon flash lamps.  Relatively sophisticated power supplies and precision control systems typically drive these lamps to produce exceptionally bright, short-duration visible flashes. The primary application for this technology is stop-motion flash photography work using high-speed film and digital imaging systems.  Xenon strobes are well suited to this task because they offer extremely fast rise times and provide extraordinary light output levels.  Some systems, for example, can generate $0.6 \times 10^6$ candelas and pulse widths as short as 800 ns.  Other systems can generate as much as $11 \times 10^6$ candelas in light bursts only slightly longer (3 μs).  The primary disadvantages to Xenon strobe systems are cost, weight, and flexibility of control.  Many systems are uniquely tailored for high-speed camera operation and cannot be easily adapted to other less conventional configurations.  Furthermore, the systems are relatively expensive, with unit costs typically exceeding $2,000.  They also weigh considerably more than most lighting systems, because high voltage power supplies are required to drive the lamps.  Finally, most stroboscopic systems examined in the survey provide fairly limited control over critical timing parameters like pulse width, pulse delay, and pulse repetition rate.

**LCD Shutter Systems** – These high-speed optical shutters exploit recent advances in LCD display technologies. Shuttering is accomplished by driving opto ferro-electric LCD display windows between optically transparent and optically opaque states. The switching time between optical states is typically on the order of 100 µs, but can vary substantially with ambient temperature. Although this technology holds promise for providing highly programmable light sources in the future, the current switching times aren't sufficient to satisfy the critical timing requirements of this task. Furthermore, the technology has not yet matured, nor developed broad-based commercial markets, so few suppliers exist and product lines are extremely limited. For example, the only LCD shutter systems evaluated for this project turned out to be too small for practical application in the field (34 mm x 38 mm x 2.2 mm).

**Light Emitting Diode (LED) systems** – Due to their high conversion efficiency, long life, and low cost, LEDs are rapidly supplanting traditional incandescent and fluorescent light sources in many home, business, and transportation applications. LED systems provide brilliant light without the heat generated by conventional incandescent and flash illumination systems. They also exhibit exceptionally fast response times and can be pulsed with precision controllers to achieve rise times on the order of nanoseconds and pulse widths as short as 1 microsecond. Furthermore, most LED systems offer useful lifetimes exceeding 10,000 hours of continuous operation. The only practical limitation of LED's is their intrinsically small size and resultant low intensity output. However, this drawback can be overcome by bundling many LED's into a cluster. As such, the cumulative output of a LED-based device can be scaled by the total number of individual LED's in the cluster.

## 3.3 Product Evaluation

Given the performance, reliability, and cost advantages of LED's, a concerted effort was undertaken to identify LED vendors with product offerings suitable to the DITCS concept. While there is no shortage of LED manufacturers, only a few companies were found that offered turnkey systems having the precise timing characteristics required for digital imager timing certification. One such company, *Advanced Illumination (AI)*, produces LED-based lighting systems for machine vision applications. The company offers an extensive line of LED cluster lights and several electronic controllers that allow the clusters to be pulsed at high drive currents and short pulse widths. For the vast majority of ordinary lighting applications, LED's are driven with a constant current of about 20 to 30 mA. Damage will usually occur if constant-current levels are driven much beyond this range. The AI electronic controllers however, are designed to drive the light heads with very narrow pulse widths using up to 4000 mA of current. Since LED output is proportional to drive current, this allows the AI light heads to produce exceptionally bright light. Furthermore, the AI controllers are fully programmable and allow the user to program a wide range of pulse widths, drive currents, and pulse delay times for each LED flash. The units can be triggered with externally supplied TTL-level signals and offer pulse widths from 1 µs to 64 ms and trigger delays from 10 µs to 64 ms. Both pulse width and trigger delay can be finely resolved within these acceptable ranges because the software allows programming at 1-µs intervals. Furthermore, the controllers allow the heads to be driven with any current level between 1 and 4000 mA. However, the controller will not drive an LED head beyond its specified current limit. As these limits vary from one LED cluster to another, the controllers use an auto-sensing feature to detect the current limit of the LED cluster being controlled. This safety feature is significant because it allows the controller to interface with nearly 30 kinds of LED clusters offered by AI.

Through several telephone and email exchanges with AI engineers, arrangements were made to borrow three different light heads and one electronic controller for evaluation. These systems were provided by AI at "no-cost" and were thoroughly tested and evaluated over approximately one month for suitability to the DITCS project request. Table 1 provides a brief description of each system obtained from AI. For more detailed descriptions and product specifications see the references cited in section 2.0 above.

**Table 1.**  Demonstration Units Obtained for Product Evaluation

| Item | Part No. | No. and (Size) of LEDs | λ nm | Description |
|---|---|---|---|---|
| Electronic Controller | S6000-AS-L | NA | NA | Programmable controller and power supply |
| Ring light | RL4260-STD-L | 60 (5 mm) | 660 | 4" Diameter ring light |
| Spot light | SL1236-STD-L | 10 (10 mm) | 660 | 2" Diameter spot light |
| Back light | BL1960-STD-L | 60 (5 mm) | 660 | 6" x 1.75" Diffuse panel light |

Two sets of tests were performed with the demonstration units before they were returned to Advanced Illumination. First, the systems were tested in a closely controlled lab environment to determine compliance with specifications provided by the manufacturer for control and timing. Secondly, the systems were tested in a field environment at the ITS facility, where the DITCS system is eventually expected to be used. The field tests were conducted to determine if the LED clusters could generate enough light to be seen by typical WSMR sensors using relatively slow (T/# > 8) long focal length lenses and standard tracking mount configurations. Descriptions of each test, along with results, are described in the following sections.

## 3.3.1  Lab Tests

As soon as demonstration units arrived from AI, a fairly elaborate test setup was assembled on a large table in the conference room of building 842 for the purpose of evaluating control and timing characteristics of the LED clusters. A Trak time code generator, obtained from the timing group (NR-TR), was used to supply precise trigger signals to an AI S6000-AS controller. This LED controller can supply power to two separate light heads and can accept up to 2 independent trigger signals, one that drives each cluster. For most bench tests, the 1 pulse per second (PPS) signal from the TRAK system was split and used to supply both trigger inputs to the controller.

The timing department provided a GPS timing module for the TRAK system so it could be synchronized to UTC time using GPS satellites. The 1 PPS signal from the time code unit was used as a common trigger source for the LED controller. After synchronizing with the GPS satellite constellation, the time of the leading edge of this signal is specified to be within 400 ns of each UTC second rollover. Through software and RS-232 control, the S6000-AS was programmed to introduce precise delays between the leading edge of the 1 PPS trigger signal and actual firing time of the light head.

A tee off this signal was also fed into a high-speed digital oscilloscope to facilitate real-time monitoring of each trigger-signal. A fast response photo-detector (Melles Griot, DAH-13) was used to precisely measure the rise time and decay time of each LED cluster. The temporal response of this photo-detector ( < 1 ns) was more than sufficient to measure the much slower rise

of the LED arrays.  Both the trigger signal and voltage signal generated by the photo-detector were displayed on a dual channel oscilloscope to simplify comparison.  As such, any delays between the leading edge of the trigger pulse (1 PPS) and leading edge of the resultant light burst could be precisely measured.  Figure 1 provides an annotated digital photograph of the test setup in building 842.
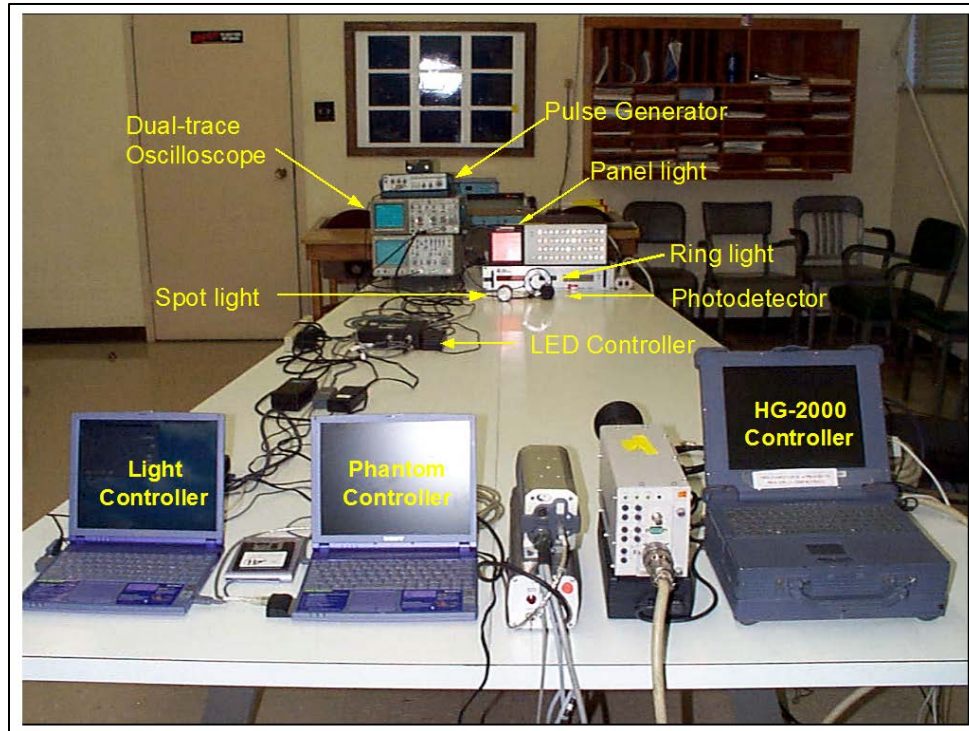


**Figure 1.**  Setup for Lab Tests of LED Demonstration System

As shown in figure 1, three PC's were used to control various elements of the test setup. One PC interfaced directly with the S6000-AS and provided dedicated control of LED timing parameters like drive current, pulse width, and pulse delay.  Two additional pc's served as controllers for the Phantom B&W and HG-2000 high-speed digital cameras.  Several days of testing revealed a number of interesting results.  First, rise time and decay time of each light cluster was determined to be extremely fast.  The time it took each LED cluster to go from completely dark to full intensity was about 600 ns.  Although LED intensity decayed a little over each pulse width, the pulses were very well defined and the pulse decay time was consistently measured at less than 1 μs.  Furthermore, a wide range of programmable delays (from 10 μs to over 1 ms) were tested and found to be accurate within 3 to 4 μs.  The S6000-AS controller has an inherent delay of 3 to 4 μs and a minimum programmable delay of 10 μs.  Therefore, the minimum delay that can be achieved with this system, which was verified during testing, is 13 to 14 μs.  This value, however, was found to be highly consistent and could be used to estimate the precise time of LED ignition with respect to the leading edge of the trigger pulse.  Figure 2, provides a snapshot of the dual-trace oscilloscope for one test in which the electronic controller was programmed to provide a 50 μs pulse using a 10 μs delay from receipt of the trigger signal.  The photo demonstrates the technique used to measure relative timing differences between trigger pulse and resultant light

pulse. The time base on the oscilloscope was expanded to precisely measure pulse width, delay time, rise time, and decay time.
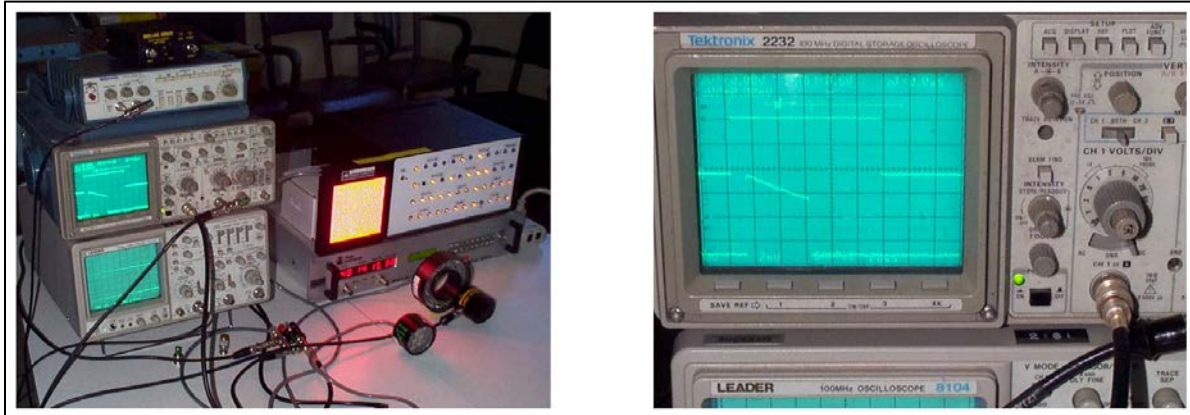


**Figure 2**. A Dual Channel Oscilloscope was used to display the delay and pulse width of each burst of light relative to the system trigger pulse provided by the time code unit. In both photographs, the top trace shows the input trigger signal and the bottom trace shows the resulting light pulse. The time scale for the measurement shown was 20 µs/div.

In addition to verifying specified timing characteristics of the LEDs, the test setup in building 842 was also used to gauge imaging results with modern digital imagers. A B&W Phantom IV camera and HG-2000 were setup with short focal length lenses to record each series of LED tests. Although the clusters saturated the two cameras for all but the very lowest LED current settings, a number of useful images were collected. These images revealed what appeared to be saturated-induced imaging anomalies with the Phantom IV camera and consistent timing anomalies with both cameras. In a series of measurements with the HG-2000 for example, in which the 1 pps was used to trigger data collection, successive tests revealed an 823 µs delay between the leading edge of the trigger and actual beginning of the HG-2000 exposure time. Whether or not this unusually long delay was real or an artifact of the test setup could never be determined in the brief time available. Nevertheless, the precision with which the delay could be measured demonstrates the usefulness of this type of setup for measuring critical timing parameters. Figure 3 shows a typical test series involving the ring light and panel light being imaged by both Phantom and Kodak cameras. The camera systems were fed IRIG time code from the same timing unit that supplied trigger pulses to the LED controller. The Phantom camera was cocked to the left in this test, because the digital windowing feature was used to increase the frame rate of the Phantom beyond 1000 frames per second. As such the camera had to be adjusted so the LED targets fell within the corner sub-window of the relatively wide 50 mm lens field of view.

## 3.3.2 Field Tests

Of course it doesn't matter how well the AI system performs in the lab, if field optics can't see an LED device from afar, the system would have limited use in the DITCS concept. Therefore a series of tests were conducted with PTSM-202 at Scat site using a Phantom IV camera behind a 100-inch lens and an HG-2000 camera behind a 50-inch lens. The LED system was placed on another instrumentation site approximately 3000 feet from PTSM-202. Over two days of testing, eleven sets of measurements were made with the three AI light heads. Excellent results were

obtained with both the ring light and spotlight even under full sun conditions.  The diffuse panel light proved to be too dim for use over this extended range in full sunlight (See figure 4).  However, the other lights when pumped with 4000 mA of current could be clearly seen with both cameras, even with pulse widths as narrow as 10 µs, as shown in figure 5.
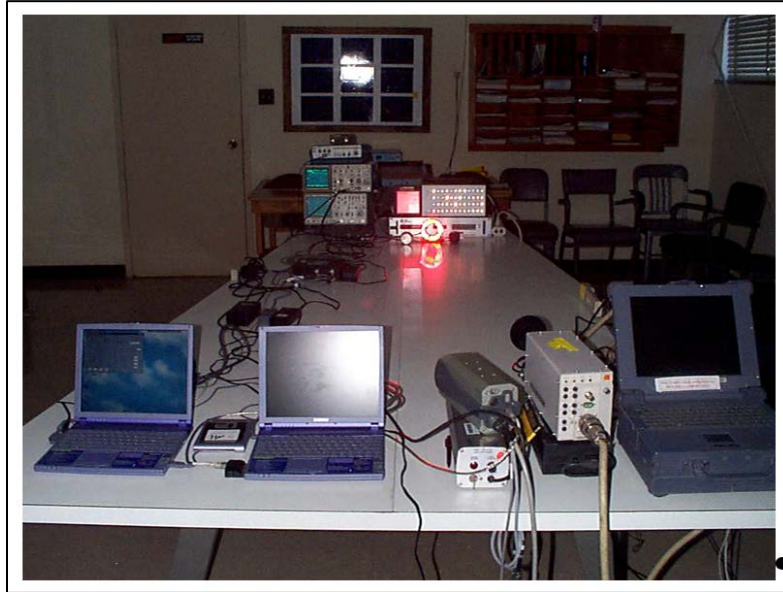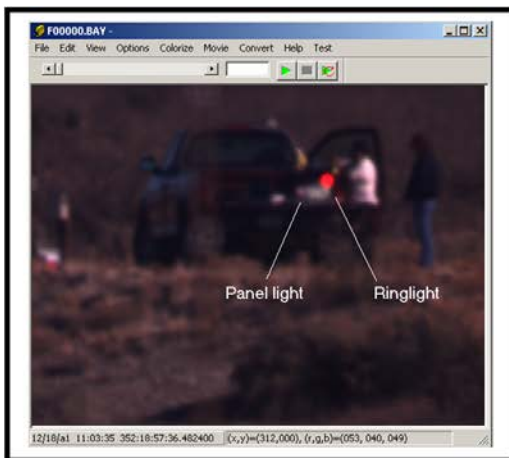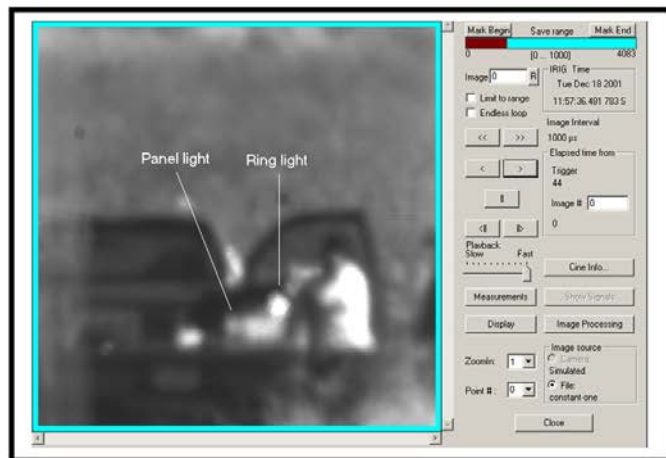


**Figure 3.**  Test setup showing ring light and panel light clusters illuminated.



a)  HG-2000/50" Lens



b) Phantom IV/100" Lens

**Figure 4.**  Field test results with the ring light and panel light at 3000 feet.  These images were collected with a relatively long frame exposure time of 500 µs.  Note the significant difference in image intensity between the ring light and panel light.

a)  HG-2000/50" Lens                    b) Phantom IV/100" Lens

**Figure 5.**  Field test with ring light set for 10 μs pulse width.  Camera exposure time was 100 μs.

Table 2 provides the test matrix for all tests conducted in the field.  All camera recordings were made with a frame rate of 1000 fps.  Camera exposure time was varied from 500 μs down to 50 μs, with most measurements made at 100 μs.  Likewise, pulse width and delay time of the LED's were varied substantially to cover a wide range of operational scenarios.  The most significant finding however, was that both camera systems with their relatively slow lenses were able to see the ring light and spot light clusters with pulse widths as short as 10 μs (see figures 6 and 7).
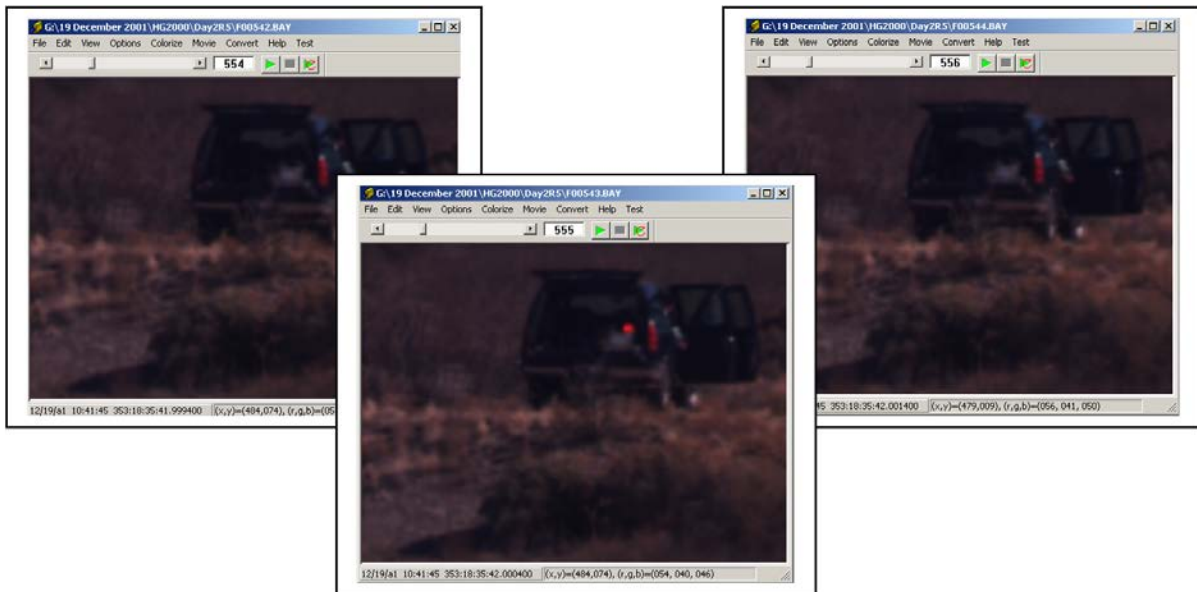


**Figure 6.**  Field test with HG-2000 exposure time set for 500 μs and the ring light pulse width set for 10 μs.  This series shows three successive frames collected at 1000 fps.
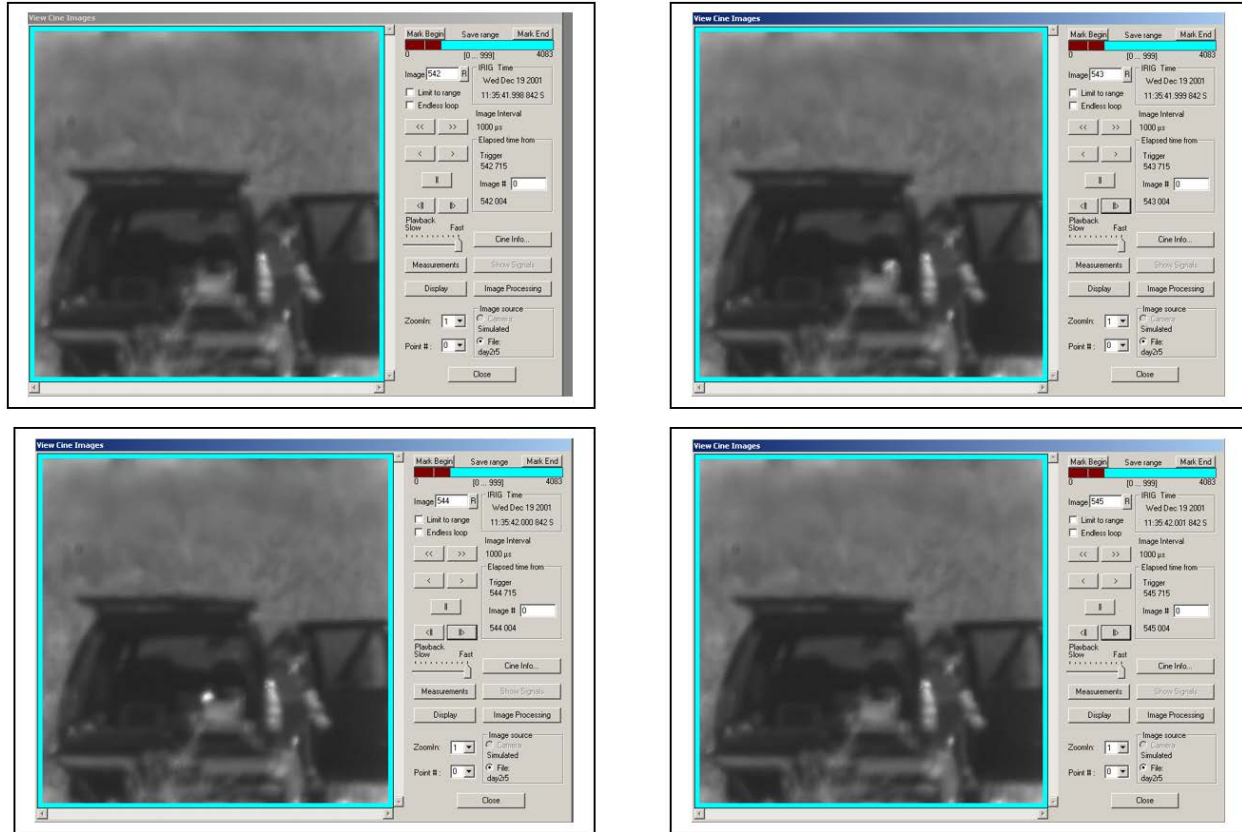
**Figure 7.**  Field test with Phantom camera operating at 500 μs exposure and 1000 fps.
a)   First frame shows scene before lights came on b) second frame shows ring light,
which was programmed with a 10 μs pulse width and 10 μs delay c) third
frame shows spotlight, which was programmed with a 10 μs pulse width
and 700 μs delay from leading edge trigger d) fourth frame
shows both lights extinguished.

**Table 2.**  Field Test Matrix.  All recordings were made with a camera frame rate of 1000 fps.

| Test | Date | Phantom | HG-2000 | Ring Light | | Spot Light | | Panel Light | |
|---|---|---|---|---|---|---|---|---|---|
| | | Exposure | Exposure | Delay | Width | Delay | Width | Delay | Width |
| 1 | 18 | 500 | 500 | NA | Constant | Not Used | Not Used | NA | Constant |
| 2 | 18 | 100 | 100 | NA | Constant | Not Used | Not Used | NA | Constant |
| 3 | 18 | 50 | 50 | NA | Constant | Not Used | Not Used | NA | Constant |
| 4 | 18 | 900 | 990 | 10 | 200 | 10 | 200 | Not Used | Not Used |
| 5 | 18 | 100 | 100 | 10 | 50 | 10 | 50 | Not Used | Not Used |
| 6 | 18 | 100 | 100 | 10 | 50 | 110 | 50 | Not Used | Not Used |
| 7 | 19 | 100 | 100 | 10 | 50 | 110 | 50 | Not Used | Not Used |
| 8 | 19 | 100 | 100 | 10 | 50 | 10 | 50 | Not Used | Not Used |
| 9 | 19 | 500 | 100 | 10 | 50 | 500 | 50 | Not Used | Not Used |
| 10 | 19 | 100 | 100 | 10 | 10 | 500 | 10 | Not Used | Not Used |
| 11 | 19 | 500 | 500 | 10 | 10 | 700 | 10 | Not Used | Not Used |

## 3.4  Proposed Solution

Given the excellent results obtained with the Advanced Illumination LED precision
lighting system, the contractor proposes that the DITCS test set be built around AI products.  There

are many advantages to this approach, not the least of which is that they have already been tested and found to work well.  The systems can generate precisely timed "optical events" with accuracies in the neighborhood of 1 to 2 μs.  Furthermore, AI has developed a modular system that provides significant opportunity for expansion and modification in the future.  Any of AI's 30 light heads can be driven with the same controller.  Therefore other types of light clusters could be added to DITCS in the future should operational requirements change.

In response to the original work request, the contractor has decided to offer a number of additional features that will enhance digital imager diagnostics and certification without much additional cost to the government.  The proposed design offers a number of tools for evaluating other critical imaging parameters besides timing.  The proposed design, shown in Figure 8, also provides tools for assessing spatial resolution, thermal resolution, optical scaling, and laser ranging/tracking accuracy.  Options for adding a calibration lamp and digital light meter to the system are also shown.  A series of removable resolution panels will be interchangeable and designed specifically for the range of most sensor/lens combinations and target separation distances.  The resolution charts provided in figure 8 are for demonstration purposes only and do not necessarily represent the patterns that will eventually be used.
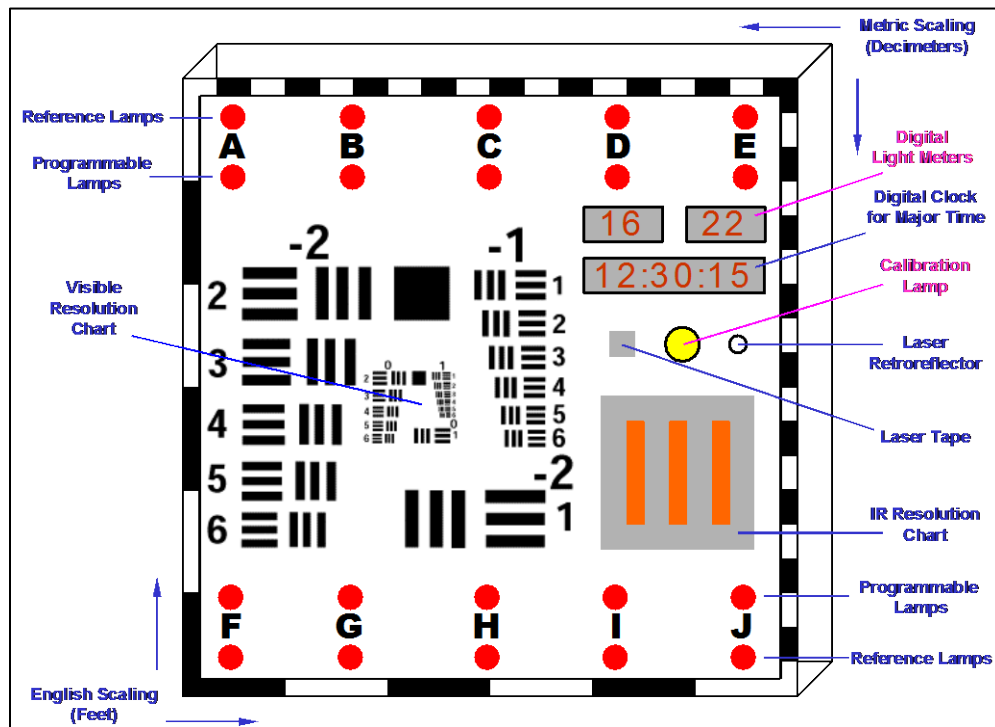


**Figure 8**.  Proposed Design for Digital Imager Test Set

## 3.4.1  Target Board and Support Structure

The contractor will construct the target board from aluminum to ensure durability and keep weight to a minimum.  The frame will be constructed from quality aluminum channel for strength and will be designed to withstand wind loads typical of those encountered at WSMR.  The outer shell will be fabricated from aluminum sheet metal.  The entire structure will be mounted on a 6 foot steel pillar that is securely erected on a concrete base somewhere near the ITS fixture.  The

panel board will be designed so that it can be easily rotated 360 degrees about the pillar to face any of the instrumentation mounds at the ITS.  Furthermore, the panel board will be designed for easy removal to support possible mobile applications in the future.

Based on the projected footprints provided in table 3, a six foot by six foot (6' x 6') panel board is proposed.  This profile will provide enough real estate for all of the various components suggested and will provide a minimum spatial separation of 1 foot between LED lamps.  Red entries in the table show that a 6' x 6' board may be too large for 1/3 and 1/2 video systems that are coupled with a 100" lens.  As these combinations are rare, the advantages of building 6' x 6' structure outweigh the drawbacks.  The blue entries in the table highlight footprints that exceed 100 feet, where 1 foot lamp separations may become difficult to discern.  Again, the contractor feels these footprints will be rare and the six-by-six profile offers the best compromise for the wide range of sensor/lens combinations most often utilized.

**Table 3.**  Projected field-of-view footprints (in feet) for various Sensor/Lens combinations at an expected target range of 2,500 feet.

| Sensor | 20-Inch | 50-Inch | 100-Inch |
|---|---|---|---|
| 16 mm Film | 51.2 x 37.0 | 20.5 x 14.8 | 10.2 x 7.4 |
| 35 mm Film | **124.4 x 93.1** | 49.7 x 37.2 | 24.9 x 18.6 |
| 70 mm Film | **281.3 x 281.3** | **112.5 x 112.5** | 56.3 x 56.3 |
|  |  |  |  |
| 1/3 Video | 23.6 x 17.7 | 9.4 x 7.1 | **4.7 x 3.5** |
| ½ Video | 31.5 x 23.6 | 12.6 x 9.4 | **6.3 x 4.7** |
| 2/3 Video | 43.3 x 32.5 | 17.3 x 13.0 | **8.7 x 6.5** |
|  |  |  |  |
| Phantom | 35.3 x 35.3 | 14.1 x 14.1 | 7.1 x 7.1 |
| HG-2000 | 40.3 x 30.2 | 16.1 x 12.1 | 8.1 x 6.0 |

In addition to the main panel board and support pillar, the contractor will construct a durable equipment shelter at the base of the system to house the control computer and GPS timing system.  Our approach will be to minimize the amount of equipment installed in the panel board.

### 3.4.2  Programmable Lamps

The contractor will purchase ten (10) RL4260-660 ring lights and five (5) S6000-AS electronic controllers from *Advanced Illumination* to provide a fully programmable array of 10 precisely controlled optical lamps.  The lamps will be positioned at 1 foot intervals in two distinctive rows as shown in figure 8.  The user will be able to program a unique pulse width for each lamp in the range of 1 µs to 64 ms at 1 µs intervals.  Likewise the user will be able to program individual trigger delays in the range of 10 µs to 64 ms at 1 µs intervals for each of the 10 LED lamps.  Due to cable limitations the five electronic controllers will be installed inside the main panel board.

A fast-response photodetector will be coupled with the first lamp in the programmable array ("A" in figure 8) to provide an independent means of monitoring system accuracy.  The output of this photodector will be provided on a bnc connector in a signal patch panel at the bottom of the main target panel board.

### 3.4.3  LED Reference System

A set of ten (10) common, constant-current LED lamps will installed in conjunction with the 10 programmable lamps.  The constant-current lamps will serve as place markers for the programmable lamps during low-light and nighttime operations.  A variable power supply will allow the user to vary the intensity of the constant-current lamps so lamp luminance can be tailored to seeing conditions and camera exposure settings.  Bright red LED's will be used for both programmable and reference lamps, because they typically can be driven at higher current levels for longer periods of time than other colors, and because the spectral response of most digital sensor systems is weighted toward the red end.

### 3.4.4  Digital Clock

The BCD output from the reference time code unit will drive a seven-segment display to provide real-time imaging of UTC Major Time (hours, minutes, and seconds).  This display will aid in the diagnosis of gross timing errors larger than those measurable with the strobed array.

### 3.4.5  Interchangeable Resolution Panels

The contractor will construct several interchangeable resolution panels that tracking mount operators can use to assist with lens focusing and image resolution characterization.  As a minimum, three different panels will be fabricated from aluminum sheet metal and painted to provide visible focusing/resolution characterization, infrared focusing/resolution characterization, and a grayscale gradient for image contrast characterization.

**Visible Focusing/Resolution Panel** – This panel will have black bars and numbers painted on a white background.  The width and spacing of the bars will be designed to provide a range of resolutions for the most common sensor/lens combinations.

**Infrared Focusing/Resolution Panel** – This panel will contain a pattern of horizontal and vertical strips of special IR tape against a flat white background.  The low emissivity ($\varepsilon <$ 0.3) IR tape will provide high thermal contrast against the high emissivity ($\varepsilon > 0.9$) flat white paint.  This panel will provide a useful tool for focusing tracking FLIRs and other IR cameras.

**Grayscale Gradient Panel** – This panel will contain a grayscale gradient pattern that progresses from white to black in discreet steps.  The steps will be clearly numbered so relative contrast measurements can be made from the recorded imagery.

### 3.4.6  Laser Targets

Provision will be made for at least two laser-tracking targets.  Space will be allocated on the main DITCS panel board for the application of a small patch of retroreflective tape and the installation of a standard 1" retroreflector target.

### 3.4.7  Painting

The main DITCS panel board will be painted with high-quality, industrial flat white paint to provide good contrast and minimize specular reflections.  The outside perimeter of the board

will be painted with an alternating black and white ruler scheme to aid in image scaling.  Two sides of the board will be painted with English scaling and the other two sides will be painted with metric scaling.  For English scaling a one-foot ruler will be applied.  For metric scaling a decimeter ruler will be applied.

### 3.4.8  Control Computer, Electronics and Shelter

The contractor will fabricate a sturdy shelter at the base of the DITCS test fixture to house the control computer, reference time code unit, and associated cabling.  The GPS antenna will be mounted on top of the main DITCS panel board.  The LED controllers will be mounted inside the panel board and controlled via USB from the control computer.  An eight port RS-232 USB adapter will be installed in the panel board to supply the needed RS-232 signals for each individual LED controller.

### 3.4.9  Cabling

All cabling between the electronics enclosure and panel board will be routed through an approved electrical conduit, which will also serve as a solid system ground.  A patch panel at the base of the panel board will provide access to the photodetector output, the 1 pps trigger signal, analog IRIG-B, and drive signal from the constant-current LED power supply.

### 3.4.10  Future Options

Although not included in this estimate, the panel board will be designed to accommodate the addition of a standard reference lamp and digital light meter in the future.  A standard reference lamp would provide a convenient means for measuring relative sensitivity differences between digital imagers and the light meter could be used to display real time light levels with each digital recording.  Two meters are shown in figure 8, one might provide general readings on the sky and the other could provide real-time light measurements for the DITCS target panel itself.

## 4.0  Schedule

While nearly all of the components proposed for DITCS are readily available and require little lead-time, fabrication of the support structures will have to be coordinated with work on other priority programs.  For this reason, the contractor proposes a very conservative estimate of six months (180 days) from approval of the WAO to complete the design, fabrication, installation, testing, and documentation of DITCS.  If shop support can be accelerated due to shifting mission priorities, this schedule can likely be substantially compressed.

## 5.0  Required Facilities and Special Equipment

Fabrication and installation of the test structures will require assistance from the machine shop, welding shop, paint shop, and carpenter shop.  Testing the DITCS system will require a KTM with digital cameras and long focal-length lenses.

## 6.0  Cost

See attached budget.

# 7.0   Deliverables

Upon completion of this task, the contractor will provide the government with copies of all wiring diagrams, technical drawings, manufacturers operation and maintenance manuals for individual components, and a general operations manual for the completed system.

# 8.0   Qualifications/Conditions

None

# 9.0   Security

Not Applicable

This page intentionally left blank.

## APPENDIX B
**Laboratory Digital Imager Timing Certification Systems Setup, Calibration, and Operational Procedures**

### B.1 Overview

This appendix describes the operational procedures developed at WSMR to set up, operate, and collect data with the LabDITCS developed by Protected Logic, Inc.  This document is not intended to replace the User's Manual provided by the manufacturer and all instructions provided by Protected Logic, Inc. should be read carefully before using the LabDITCS device.  Rather, this appendix provides a set of detailed procedures developed over time at WSMR that can be used to certify the timing accuracy of high-speed digital cameras using the LabDITCS.

The procedures described herein are used by WSMR to certify that the timing accuracy of new and existing cameras falls within ±50 μs of UTC.  This criteria was established by WSMR's Data Reduction group to ensure TSPI derived from photometric analysis of optical data satisfies customer accuracy requirements.  The LabDITCS can be configured to provide even better timing resolution by slightly modifying some of the parameters and procedures described below.

In addition to operational procedures, this appendix describes the data collection, reduction, and analysis techniques developed at WSMR for processing LabDITCS measurements.  Again, these techniques are provided as specific examples of how LabDITCS measurement results can be collected and analyzed to characterize the timing properties of high-speed cameras and recording devices.  The procedures can be modified and tailored to suit individual range requirements.

### B.2 Equipment List

The LabDITCS is a fully integrated test set that is designed to work with several pieces of auxiliary equipment to provide high-fidelity characterization of the timing properties of digital imaging systems.  Table B-1 summarizes the auxiliary equipment needed to perform precision timing certification tests with the LabDITCS.

| Table B-1.   Equipment List for Timing Measurements | | | |
|---|---|---|---|
| **Item** | **Description** | **Requirements** | **Example** |
| A | LabDITCS | N/A | N/A |
| B | SUT (e.g., camera, recorder, etc.) | Global shutter, 100 μs TINT | High-speed digital camera |
| C | Monitor | Standard video monitor for viewing camera output | Sony PVM14L5 |
| D | Reference clock | Traceable to UTC with margin of error less than one millisecond | TRAK-9000 Modular Time Code processor with external GPS antenna |
| E | GPS antenna | Outside antenna with unobstructed view of the sky | TRAK-9000 GPS Module option with external antenna |
| F | Multi-channel digital oscilloscope | 300 megahertz (MHz) Bandwidth Min | Tektronix TDS3034B (4-Channel) |
| G | Photodiode amplifier | N/A | Protected Logic optical J-box |

| H | Fast-response Photodiode | Rise time & decay time less than one (1) µs. | Protected Logic optical probe |
| L1 | DITCS control computer | Windows OS:  XP SP2 | Laptop with LabDITCS software |
| L2 | Camera control computer | Laptop with camera software | Dell Latitude 810 with camera control software |

Figure B-1 provides a basic block diagram of the recommended setup used to perform timing certification tests with the LabDITCS.  Each component in the diagram is labeled with a letter designation corresponding to the equipment list above.  The diagram also provides the cabling layout and shows key signal paths.  These signals are specified throughout the following procedures and are labeled S1 through S5 for easy reference.  They are described in Table B-2 below.
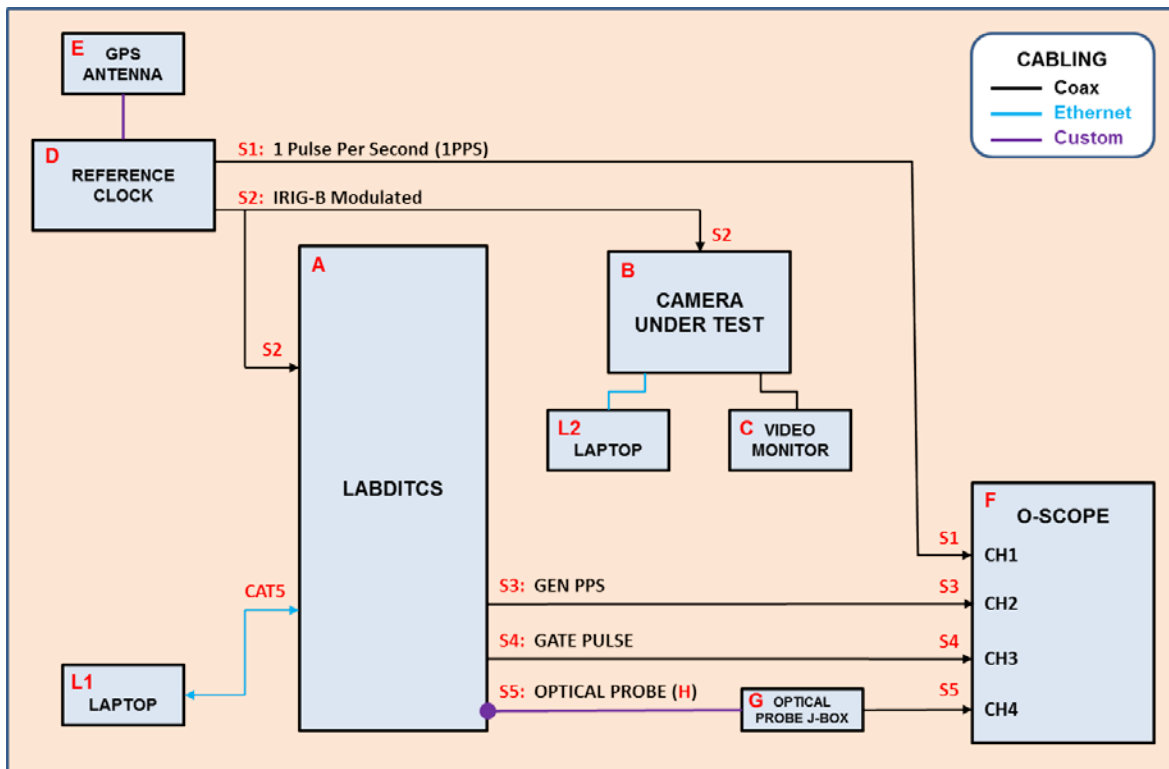


Figure B-1.     Block Diagram of Test Setup

| | Signal Name | Source | Description |
|---|---|---|---|
| **Table B-2.  Description of Key Signals Used for Timing Certification Tests** | | | |
| S1 | 1 PPS | Reference clock | Output from the external reference clock (i.e., TRAK-9000).  The leading edge of this signal is aligned with each UTC second. |
| S2 | IRIG-B modulated timecode | Reference clock | Amplitude-modulated signal carried on a sinusoidal carrier with a frequency of 1 kHz. |

| S3 | GEN PPS | LabDITCS | Transistor-transistor logic (TTL) pulse generated every second by the internal time code processor within the LabDITCS.  This signal is derived from the input timecode. |
| S4 | GATE PULSE | LabDITCS | TTL pulse that goes high when the specific LED emitter specified on the "Program Array" screen in the control software is turned on. |
| S5 | OPTICAL PROBE Pulse | LabDITCS | The electrical pulse generated by a photodiode in response to the optical output of an active LED emitter.  This pulse is used to verify that the LEDs are programmed correctly for the desired test sequence. |

The manufacturer recommends using the LabDITCS internal GPS receiver and antenna as the reference source (see the LabDITCS User's Manual[4]); however, WSMR elected to use an external reference clock (D) to provide precision timecode to the unit for the following reasons.

1) Commonality - the reference source used for certification tests in the lab (TRAK-9000) is the same reference source used to provide timing data to most field systems at WSMR.
2) Familiarity - the TRAK-9000 is a very stable, reliable, and well-documented time code generator/processor.  Furthermore, WSMR maintenance technicians have substantial training and experience with these systems.
3) Traceability - the WSMR Timing Group can use mobile master atomic clocks synchronized to UTC to validate the timing signals generated by the TRAK-9000.  As such, timing signals generated by the TRAK-9000 can be verified to have accuracies within a few hundred nanoseconds of the UTC standard.

The key signals used to perform timing certification tests at WSMR are listed in Table B-2.  S1 and S2 are outputs of the TRAK-9000 external reference clock, while S3, S4, and S5 are signal outputs from the input/output panel on the LabDITCS.

## B.3    Functional Description Of LabDITCS

The LabDITCS uses fast-response LEDs to generate very short optical pulses that convey timing information that changes very rapidly (e.g., the passage of microseconds).  The LabDITCS provides a number of alphanumeric and binary displays to present timing information in both human-readable and machine-readable formats.  Seven-segment displays are provided to show information that changes less rapidly and to show user-supplied information for test documentation.  Figure B-2 provides a functional diagram of the LabDITCS front panel display.

---

[4] Howard Waldie.  "Laboratory Digital Imager Timing Certification System (LabDITCS), User's Manual."  Rev R0. September 2013.  May be superseded by update.  Available on request to support@protectedlogic.com.
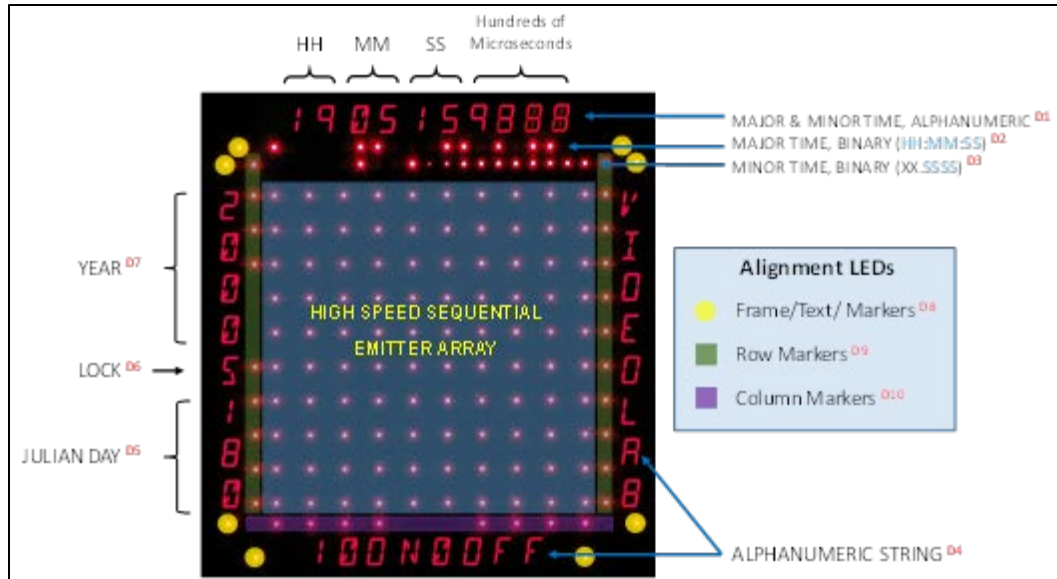
Figure B-2.    Functional Diagram of LabDITCS Display

The LabDITCS derives the Julian date, hours (HH), minutes (MM), seconds (SS), and hundreds of microseconds from the input timecode.  These values are displayed as alphanumeric characters on the left-hand side and at the top of the LabDITCS front panel.  These characters may be difficult to read in the camera imagery depending on the sensitivity of the imaging system and the selected integration time for data collection.  For this reason, the LabDITCS uses individual LEDs to present the minor time in binary form.  The various display elements in Figure B-2 are denoted by red superscripts (e.g., [D1], [D2], [D3], etc.) and are described in greater detail below.

D1    Major & Minor Time - Seven-segment display showing the hours, minutes, seconds, and hundreds of microseconds.  For the purposes of this document, minor time will be defined as any measure of time below one second and major time will be those elements that describe the time equal to or over one second (i.e., year, day, hour, minute, second)

D2    Major Time, Binary - Binary display depicting the number of seconds from the start of the UTC day.  The displayed time on this particular frame is 10000110001101011.  This is the binary expression of 68,715 seconds, which is the equivalent of 19 hours, 05 minutes, and 15 seconds.

D3    Minor Time, Binary - Binary display depicting the number of fractional seconds expressed to hundreds of microseconds (i.e., $10^{-4}$ seconds).  In this particular example, the lamps reflect a time of 988,800 μs.

D4    These two text fields on the bottom and right hand side of the array are user-programmable.  Up to eight characters of alphanumeric text can be displayed in either field.

D5    Julian Day - These three seven-segment characters display a number between 001 and 366 representing the Julian day.

D6    Lock Status Indicator - This character indicates whether or not the LabDITCS internal oscillator is phase-locked to an external reference clock signal.  If the display shows an "S", the LabDITCS is synchronized to the external time signal.  If the display shows an "E", the internal oscillator of the LabDITCS is free-running.  This means the LabDITCS clock will drift from UTC over time.

D7    Year - Four-character display for the year.  (Note: the YEAR value is read from the PC clock, which should be checked prior to making measurements)

D8    Frame/Text Markers - These LEDs can be used to register the LabDITCS display for software-based automated processing systems.  The LabDITCS reader software uses these lamps as registration marks for its image processing algorithms (See Appendix C)

D9    Row Markers - Lamps used to mark the location of each row of LEDs in the high-speed sequential emitter array.

D10    Column Markers - Lamps used to mark the location of each column of LEDs in the high-speed sequential emitter array.

The heart of the LabDITCS is the high-speed sequential emitter array at the center of the panel.  This array is comprised of 100 fast-response LEDs arranged in rows (10) and columns (10).  Each individual LED in this array can be programmed to turn on and turn off at a precisely known time.

**B.4     Test Setup**

Most timing tests should be performed in a lab environment where lighting, temperature, and other environmental factors can be controlled.  For optimal results, an area with semi-permanent fixtures and installations should be dedicated to camera testing.  This area should provide at least 3 meters of unobstructed separation between the front panel of the LabDITCS and the SUT.  The required separation may be greater if long-focal-length lenses are utilized, but 3 meters is typically adequate for nominal lenses in the 35-millimeter (mm) to 50-mm focal length range.

B.4.1    Optimize the Geometry

Due to the relatively narrow beam width of the individual LED emitters on the LabDITCS panel, test geometry is critical.  It is important to ensure the camera is aligned such that its optical axis is: 1) positioned on the center of the active emitter array; and 2) perpendicular to the front panel of the system.  Optimal alignment can be verified by programming the LabDITCS to turn all of the active emitters on (i.e., continuous, not pulsed) and then positioning the SUT to provide maximum uniform intensity across the array as observed by an external monitor connected to the analog output of the camera.  Misalignment is easily discernible when parts of the array seem less bright than others.  Figure B-3 is a photo of the setup used in the WSMR Video Maintenance Lab.  The LabDITCS is hard-mounted to the wall and the camera under test is mounted on a heavy-duty tripod that provides elevation, pan, and tilt adjustment controls.  The high-speed camera is positioned approximately 2 meters from the front panel of the LabDITCS.  The external reference clock (TRAK-9000) is not shown but is positioned just behind the camera.  The two laptop controllers for the LabDITCS and the four-

channel oscilloscope are also not shown but are situated on a workbench just beyond the right edge of the field of view.
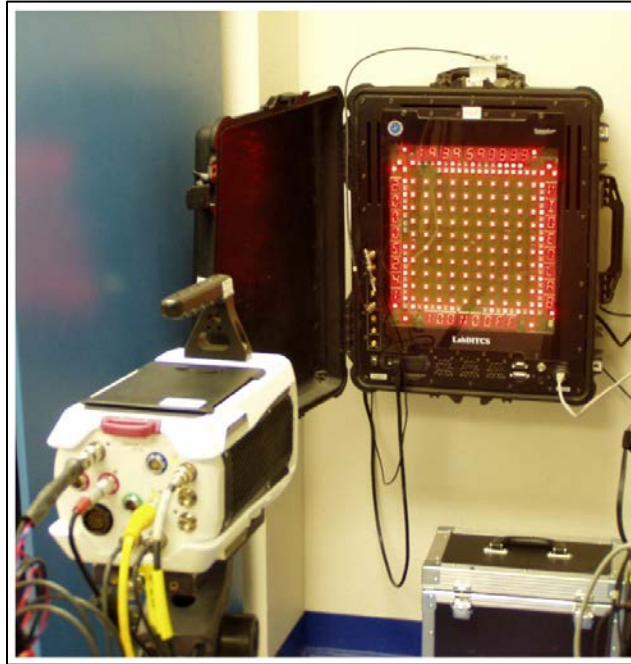


Figure B-3.    Typical Setup for Timing Certification Test

| TIP | Although the LabDITCS is designed for portability, best results are achieved when the unit is mounted on a rigid wall or table for maximum support and stability. |
|---|---|

### B.4.2  Configure the Local Reference Clock

The TRAK-9000 Time and Frequency Modular Time Code Processor is used as the local reference timing source for many optical systems at WSMR (e.g., tracking mounts, control vans, display centers, etc.).  These commercially available units are rack-mountable and have highly stable oscillators that can be disciplined to input reference signals.  The units provide a variety of output timing signal formats.  There are many other manufacturers and models to choose from, but as a minimum the chosen reference clock should provide the following output signals: 1) 1 PPS; and 2) IRIG-B Modulated.  These signals are depicted as S1 and S2 respectively in Figure B-1.  The 1 PPS is typically a TTL signal with 125-µs-wide pulses generated every second.  The leading edge of these pulses should be aligned with each UTC second transition with an error of no more than 1 µs (the TRAK-9000 specification for error is 200 ns).  The IRIG-B modulated signal rides on a 1-kHz sinusoidal carrier and uses amplitude-modulated "marker" pulses and "digit" pulses to define individual timecode frames.  More information on the IRIG-B standard can be found in RCC 200-04, listed in Appendix D.

The reference clock used to drive the LabDITCS should be synchronized to UTC.  This is usually accomplished via a GPS antenna and receiver module that receives and processes signals from GPS satellites.  These satellites carry very stable atomic clocks that are synchronized to each other and to ground-based reference clocks tracking UTC; however, many installations are moving toward network-based timing systems that don't rely on GPS for local synchronization

(see Section 2.2 and Section 2.3 above).  Regardless of the synchronization source, the local reference clock used for these measurements should be disciplined to UTC for optimal precision and accuracy.

It is recommended that the local reference clock be maintained and operated at room temperature, if at all possible.  Most clocks contain an internal oscillator that must achieve a certain operating temperature to provide the specified accuracy of the system.  For this reason, it is recommended the reference clock be powered on at room temperature and allowed to operate for a minimum of 30 minutes before using the system as a truth reference.  If the oscillator is much colder than room temperature when the unit is first powered on it will take it longer to reach operating temperature and synchronize with UTC.

| | |
|---|---|
| **TIP** | Operate the reference clock at room temperature for at least 30 minutes before using the clock to make measurements. |

Even with the availability of GPS or network synchronization it is recommended that the local reference clock be checked against a master reference clock to ensure that it is operating within specification.  For example, WSMR has several mobile master reference clocks that are used to check the accuracy of the local reference clocks.  As a matter of practice, the timecode output signals of the local reference clock are checked against a master prior to any timing certification test at WSMR.  This verification ensures that the 1 PPS and IRIG-B Modulated signals from the external reference clock are traceable to UTC within a few hundred nanoseconds.

B.4.3   Configure the LabDITCS

The LabDITCS can accommodate a variety of time code formats.  Consequently, the IO panel on the LabDITCS offers two inputs and six outputs as described below.

**Inputs**
1)  IRIG - IRIG-A, IRIG-B, or NASA36 timecode signals.

2)  Trigger - Currently not implemented

**Outputs**
1)  TTL Sync - Sync pulse defined by array programming

2)  IRIG B - Generated by the onboard timecode processor

3)  GEN 1 PPS - Generated by the onboard timecode processor

4)  GATE - TTL pulse generated when a specific emitter in the program script fires.

5)  GPS 1 PPS - Generated by the onboard timecode processor

6)  GPS 1MHz - Generated by the onboard timecode processor

Two of the outputs are used by WSMR to perform timing certification tests on its cameras: the GEN 1 PPS output signal and the GATE output pulse.

B.4.3.1   Connect the Hardware

Referring to the block diagram in Figure B-1, connect the various signal paths between the LabDITCS, external reference clock, camera under test, optical probe j-box, and oscilloscope.  The IRIG-B Modulated signal should be split using a BNC-T at the back of the camera.  The digital oscilloscope should provide a minimum of 300-MHz bandwidth.  While two or three channel scopes can be used for these measurements, a four-channel scope is most convenient.

| | |
|---|---|
| **TIP** | Install high-quality coax cabling/connectors and <u>use the shortest cable runs possible</u>. |

Install the LabDITCS control software on a laptop or other suitable computer in accordance with the instructions provided by the manufacturer.  The version of the software used by WSMR has been tested and works well on the Windows XP (SP 2) OS, but it will not work on Windows Vista.

B.4.3.2   Configure the Software

The following procedures provide step-by-step instructions for configuring the LabDITCS to support precision timing tests.  The LabDITCS software is designed to load and execute two types of archive files: **Project** and **Script**.  Project files describe the specific hardware configuration (i.e., type of emitter board installed).  Script files contain intensity commands, sequencing commands, and other control parameters to create custom emitter firing patterns to achieve specific test objectives.

A staggered 10-µs pulse sequence is used at WSMR for nearly all timing certification tests.  This configuration provides approximately 5 µs of timing resolution, which is more than sufficient to satisfy WSMR's timing accuracy requirement of ±50 µs.  This particular pattern is depicted in the pictograph of Figure B-4, which shows the ON time of each emitter in the active array relative to the UTC second transition.  For example LED (1, 1) comes on precisely at the second rollover and goes off after 9 µs.  The second emitter, LED (1, 2) comes on at T + 10 µs and goes off at T + 19 µs.  The third emitter comes on at T + 30 µs and so on.  It takes 1 µs to turn off one LED and turn on the next.  Consequently, each pulse is approximately 9 µs wide but has been graphically depicted as '10' for simplicity.  The last emitter in the array, LED (10, 10) fires at T + 990 µs and the sequence begins anew again at T + 1 ms.  If the camera integration time is set to 100 µs, approximately 10 emitters will be illuminated in each frame.  This is depicted in the pictograph by the red shading.  In this instance, the image would be interpreted to show the exposure beginning at T+330 µs and ending at T+430 µs.  This information would be combined with the major and minor time displays to determine the actual time of the exposure.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
| 2 | 100 | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 |
| 3 | 200 | 210 | 220 | 230 | 240 | 250 | 260 | 270 | 280 | 290 |
| 4 | 300 | 310 | 320 | 330 | 340 | 350 | 360 | 370 | 380 | 390 |
| 5 | 400 | 410 | 420 | 430 | 440 | 450 | 460 | 470 | 480 | 490 |
| 6 | 500 | 510 | 520 | 530 | 540 | 550 | 560 | 570 | 580 | 590 |
| 7 | 600 | 610 | 620 | 630 | 640 | 650 | 660 | 670 | 680 | 690 |
| 8 | 700 | 710 | 720 | 730 | 740 | 750 | 760 | 770 | 780 | 790 |
| 9 | 800 | 810 | 820 | 830 | 840 | 850 | 860 | 870 | 880 | 890 |
| 10 | 900 | 910 | 920 | 930 | 940 | 950 | 960 | 970 | 980 | 990 |

Figure B-4.     Pictograph Representing the Emitter ON Time for a Staggered 10-microsecond Pulse Sequence Script

The following procedures provide step-by-step instruction for configuring the LabDITCS to support a timing certification test using a staggered 10-µs pulse sequence like that described above.  Adherence to these procedures will provide high-speed video that can be analyzed to determine timestamp errors down to about 5 µs.

**Procedure 1:  Establish Communications with the LabDITCS**

Use this procedure to establish communications between the LabDITCS and the control computer hosting the LabDITCS software.  This procedure assumes the internet protocol (IP) address of the LabDITCS has not been changed from its default of **192.168.1.200**.  If the address has been changed from its default, adjust the IP addresses accordingly.

(1)  Connect the IRIG B Modulated output (S2) from the external reference clock (D) to the J8 connector on the front of the LabDITCS (A).  Use the shortest coax cable possible.

(2)  Connect the LabDITCS control computer (L1) to the LabDITCS (A) using an Ethernet cross-over cable.

(3)  Connect AC power to the LabDITCS.

(4)  Power up the LabDITCS (A) using the rocker switch located in the lower left corner.  NOTE: It may take several seconds for the system to initialize and energize the LEDs.

(5)  Power up the LabDITCS control computer (L1).

(6)     Right-click on My Network Places.

(7)     Select Properties.

(8)     Highlight Local Area Connection.

(9)     Select Properties.

(10)    Double-click Internet Protocol (TCP/IP).

(11)    Set the IP address of the computer to 192.168.1.35 as shown in Figure B-5.  Note:  the last digit in this address can be any number between 1 and 254, except 200, which is the default address of the WSMR LabDITCS.
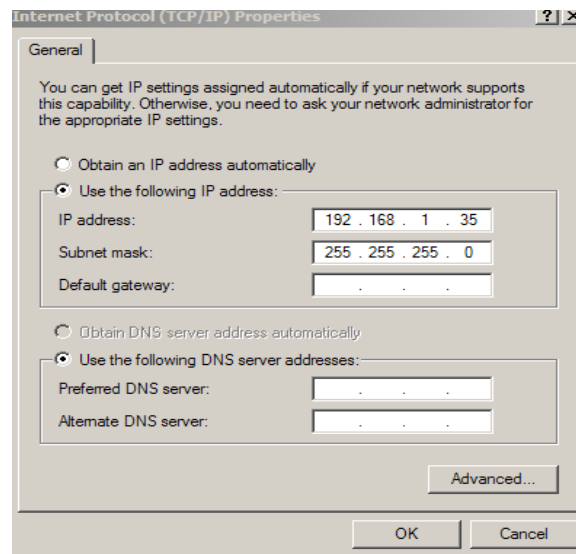


Figure B-5.     Internet Protocol Settings

(12)    Set the subnet mask of the computer to 255.255.255.0 as shown in Figure B-5.

(13)    Select OK.

(14)    Close all open windows.

(15)    On the desktop select Start.

(16)    Select Programs.

(17)    Select Accessories.

(18)    Select Command Prompt.  The command prompt window will appear.

(19)    Type in the ping command:  Ping 192.168.1.200.

(20)    Verify that you get a reply from the LabDITCS as shown in Figure B-6.  The computer is now ready to control the LabDITCS.

Figure B-6.    Ping LabDITCS Results

**Procedure 2:  Create a New Project**

The LabDITCS control electronics are designed to support interchangeable emitter boards.  As such, the software uses the concept of "Projects" to configure control parameters for unique combinations of hardware.  Use this procedure to establish and save a project file for the LabDITCS – Emitter Board combination unique to your installation.  Once a project file has been created and saved, it can be reloaded and used as long as the hardware configuration of the LabDITCS has not changed.

The LabDITCS control electronics are designed to support interchangeable emitter boards.  As such, the software uses the concept of "Projects" to configure control parameters for unique combinations of hardware.  Use this procedure to establish and save a project file for the LabDITCS - Emitter Board combination unique to your installation.  Once a project file has been created and saved, it can be reloaded and used as long as the hardware configuration of the LabDITCS has not changed.

(1)    Double-click the LabDITCS program icon on the Windows desktop.  The LabDITCS window appears like that in Figure B-7.
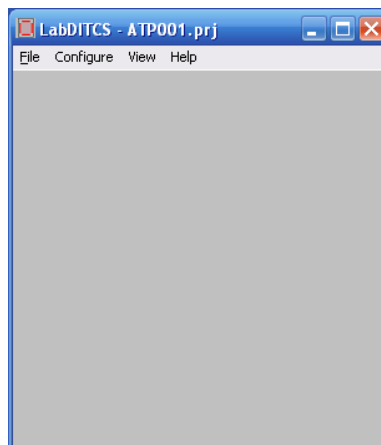


Figure B-7.    LabDITCS Window (with Project Name in Header)

(2)    Select File.

(3)    Select New Project.  The New Project Window should appear as shown in Figure B-8.
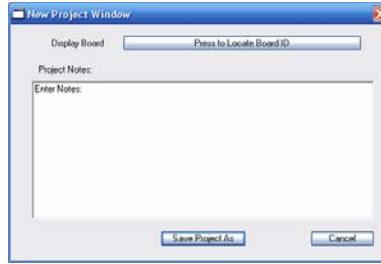
Figure B-8.      New Project Window

(4)    In Project Notes:  Type in a brief description of the type of test this script will support (e.g., VendorX Timing Tests with staggered 10-µs pulse sequence).

(5)    Select Press to Locate Board ID.  The Define Board ID file should appear.

(6)    Select the appropriate Board ID (e.g., D_CFG_03.LDT).

(7)    Select Open.  The New Project window should appear.

(8)    Select Save Project As.  The Save Project window should appear.

(9)    In the File Name box type in a name (Example VendorX_Timing_Tests.prj).  **Note:** you must type the **.prj** extension on the end of the file name.

(10)   Select the Save button.

---

**Procedure 3:  Set Soft Limits for LED Drive Current**

The LabDITCS utilizes high-intensity, fast-response LEDs.  The intensity of emitted light from each LED is proportional to the electrical current with which they are driven.  Although the LEDs are very robust, they can be damaged if overdriven.  Damage thresholds are determined by a combination of drive current and pulse width, i.e., how long the LED is energized.  The damage threshold for current decreases with longer pulse widths, i.e., the longer the LED is energized the less current it can safely handle.  The LabDITCS software calculates the hard limits for drive current and allows the user to specify "soft" limits to regulate intensity.  Soft limits should never exceed the hard limits specified in the Limit Control window.  Use this procedure to set the soft limits for the LabDITCS.

---

(1)    Open the LabDITCS window (Figure B-7).

(2)    Select Configure.

(3)    Select Limits.

(4)    The Limit Control window appears (See Figure B-9).  The hard limits on drive current for the particular Board ID selected are displayed on the left side of the window.  Any attempt to set the soft limits above these values will cause the characters entered to turn red.  Reduce the value to some number below the hard limit.
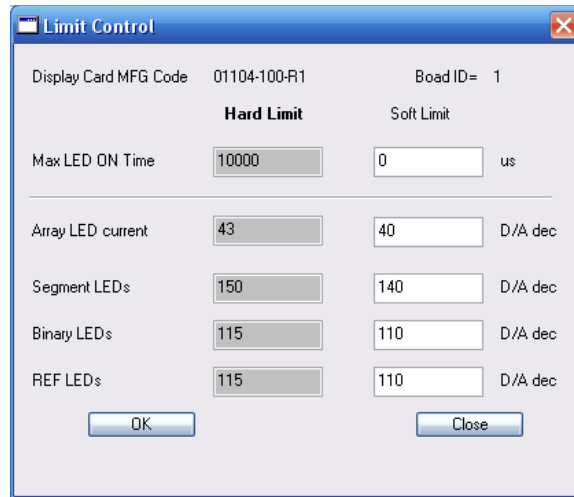
Figure B-9.    Limit Control Window

(5)    Set the soft limits required for your test.  Usually the soft limit values will be just below the hard limit values.

(6)    Select OK.

(7)    Select View.

(8)    Select Display.  The LED_Panel window appears (Figure B-10).
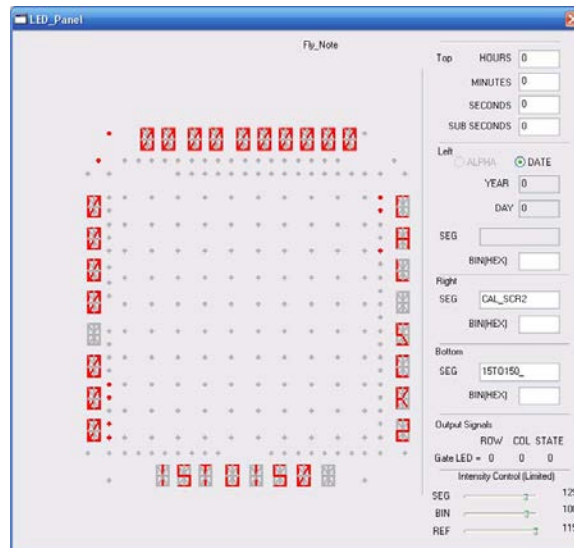


Figure B-10.   LED Panel Window

(9)    Use the "Right SEG" box and "Bottom SEG" box to display custom notes (e.g., "TEST_1", "NAC", etc.).  Note:  Blank spaces are not permitted between characters.  Use an underscore for all blank spaces or the seven-segment displays may show erroneous characters

(10)   The reference LEDs can be turned on individually by hovering the mouse over each grayed-out LED and left-clicking.  The chosen LED will switch to red in the display, indicating that LED will be lit when the script is executed.

(11) On the bottom right under Intensity Control (Limited) move the SEG button to the far right (The range will be from 0 to 150).

(12) Move the BIN Control button to the far right (The range will be from 0 to 115).

(13) Move the REF Control button the far right (The range will be from 0 to 115).

(14) Select the X on the top right of the LED_Panel to close this window.

---

**Procedure 4:  Program the Project Array**

Most timing tests require the use of the high-speed sequential emitter array.  The 100 LEDs in this array can be programmed to strobe in a wide variety of patterns with each optical pulse having very precise timing properties.  The image of these LEDs as they cycle on and off in each frame of camera data is used to determine the actual start and stop time of each integration (i.e., exposure).  This particular procedure establishes a script that will cause the LabDITCS to execute a staggered 10-μs strobe sequence running across the array. Specifically, LED (1,1) will come on at the UTC second transition and go off at T + 09 μs. The second LED in the array, LED (1,2), will come on at T + 10 μs and go off at T + 19 μs.

---

(1) Open the LabDITCS window (Figure B-7).

(2) Select Configure.

(3) Select Array Setup.  The PROGRAM Array window appears as shown in Figure B-11.
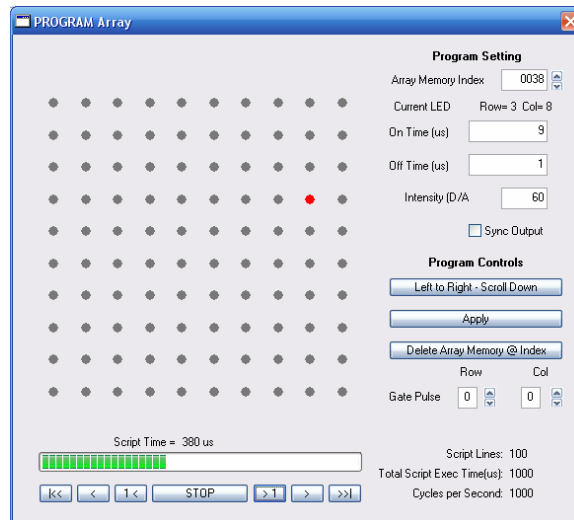


Figure B-11.   Program Array Window

(4) Under the heading "Program Setting", verify or set the Array Memory Index to 0000.

(5) Set the On Time (us) to "9".

(6) Set the Off Time (us) to "1".

(7) Set Intensity (D/A) to 140.

(8) Under "Program Controls" click on the "Left to Right - Scroll Down" button.  The array memory index will change to "0001".

(9)     Click on the "Left to Right - Scroll Down" button 99 more times until the array memory index displays 0100.

(10)    Verify that "Script Lines" reads "100" (Bottom right hand corner of display).

(11)    Verify "Total Script Exec Time (us)" reads "1000".

(12)    Verify "Cycles per Second" reads "1000".

(13)    Verify the program sequence by selecting the back to start button on the controls bar in the bottom left of the display.    |k<

(14)    Now depress the play button.    >

(15)    The script time should start counting from 0 to 1000 μs and a blue bar will progress across the "Script Time" box.  The LEDs will switch from gray (OFF) to red (ON) and transit from left to right and top to bottom across the array (0 to 100).

(16)    Select the Stop button.    STOP

(17)    Close the PROGRAM Array window.  The LabDITCS window will appear.

(18)    Select File.

(19)    Select Save Project As.

(20)    Select the Project file (e.g.  "VendorX_Timing_Test.prj").  Note:  You must type the "prj" extension.

(21)    Select Save.  The Save As window appears.

(22)    Select Yes to replace the existing file.

**Store the Project Script File**

(23)    The LabDITCS window will appear.

(24)    Select Configure.

(25)    Select Script.  The Script Control window appears.

(26)    Select Store LabDITCS Script.  The Save As window appears.

(27)    In the Filename type in a filename (Example:  VendorX_Timing_Test.scr).  **Note:**  You must type in the ".scr" extension.

(28)    Select Save.  The LabDITCS window appears.

**Download the Project Script File to the LabDITCS**

(29)    Under the LabDITCS window, select Configure.

(30)    Select Script.

(31)    Select Download to LabDITCS.

(32)    You should see the LabDITCS LEDS go off for a few seconds while the script loads.  Once it loads you should see LabDITCS LEDS come on along with the reference LEDS you turned on.  You should also see the notes that you stored on the right and bottom segments (Example:  TEST_1 and PHOTRON.

B-15

**Procedure 5:  Upload an Existing Project Script to the LabDITCS**

The purpose of this procedure is to load the video lab timing script into the LabDITCS for evaluating the timing on digital cameras.  The video lab timing script is set to turn on each LED for 10 µs and off for 990 µs in a 10-µs staggered sequence that repeats itself every millisecond.

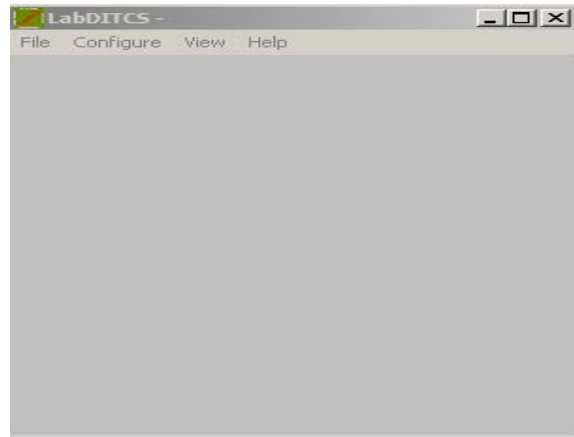(1)     Double-click on the LabDITCS shortcut.  The LabDITCS window appears (Figure B-12).



Figure B-12.    LabDITCS Window (without Project Name in Header)

(2)     Select File.

(3)     Select Open Project.

(4)     Highlight the project file name.  In this example it is "Video Lab 10us_0us.prj" as shown in Figure B-13.
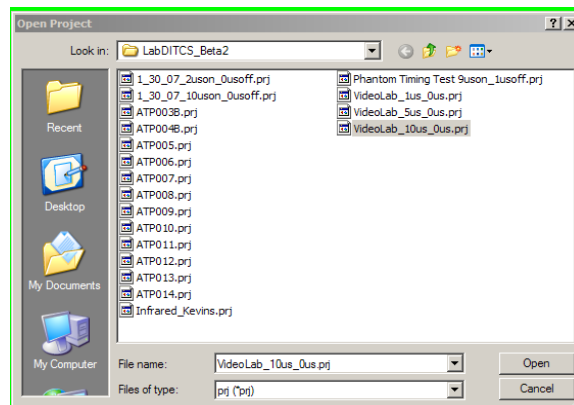


Figure B-13.    Open Project Window Listing Projects

(5)     Select Open.  The Open Project window appears (Figure B-14).
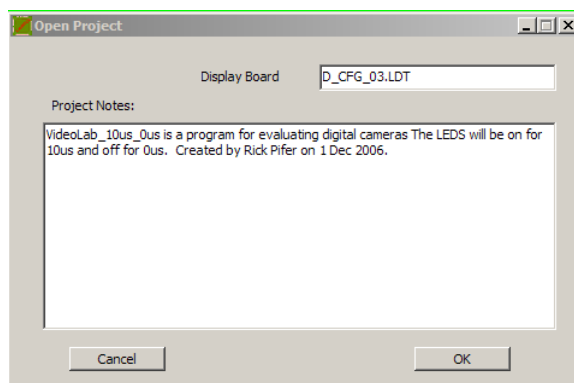
Figure B-14.   Open Project Window

(6)     Select OK.

(7)     Select Configure.

(8)     Select Script.  The Script Control window appears.

(9)     Select Load LabDITCS Script.

(10)    The Open Script File window appears (Figure B-15).
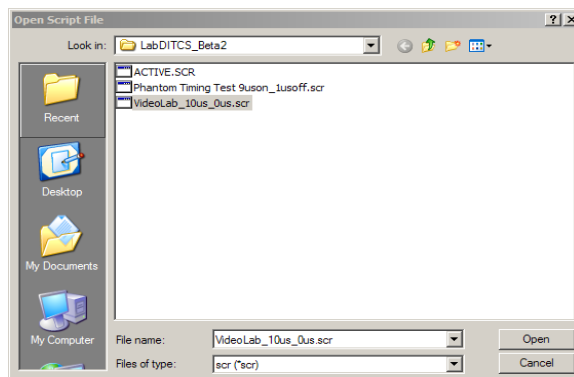


Figure B-15.   Open Script File Window

(11)    Highlight the script file.  In this example it is "VideoLab_10us_0us.scr".

(12)    Select Open.

(13)    Select Configure.

(14)    Select Script.  The Script Control window appears (Figure B-16).
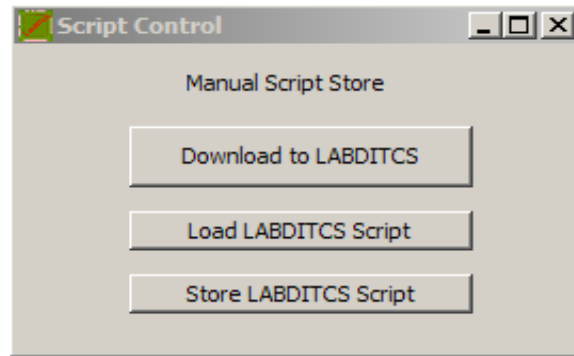
Figure B-16.   Script Control Window

(15)   Select Download to LabDITCS.  The LabDITCS LEDS will go out for approximately 5 seconds while the VideoLab_10us_0us script is loaded into memory.

(16)   Verify on the right segment display VIDEOLAB is displayed.

(17)   Verify on the bottom segment display TIMING is displayed.

(18)   Verify reference LEDS on left, right, and bottom are on.  The system is now ready to run timing tests.

## B.4.4   Configure the Camera

Images captured by the camera of the LabDITCS panel will be evaluated to determine the accuracy of the camera system's timestamp.  Consequently, steps should be taken to optimize the quality of the captured imagery.  For example, high contrast in each image frame helps reduce ambiguity in determining the state of each emitter during the exposure (i.e., whether the emitter was on or off).  This is especially true for automated reading processes that use image processing algorithms to read the captured image frames.  For these reasons, it is important to use good quality lenses that are optimally focused and to configure the camera's integration time and lens aperture for peak dynamic range.

| Procedure 6:  **Configure the Camera** |
| --- |
| Follow these general procedures to configure the camera and lens for testing.  The camera software should be configured as closely as possible to how the system will be used for routine data collection.  Any special modes or features should be turned off, unless they are germane to the test. |

(1)   Verify there are no programmed timing offsets in the camera software.  (Some cameras allow the user to delay the integration time by a set amount.)

(2)   Optimize the lens and camera for white balance, i.e., open the aperture and/or the integration time to provide adequate signal level.

(3)   Perform white balance.

(4)   Stop down the aperture for measurement.

(5)   Turn off extended dynamic range (EDR) or any other special features that segment or extend the integration time.

(6)   Set the integration time to 100 µs.

(7)    Set to max frame rate.

(8)    Set to 8-bit mode, if available.

(9)    Perform black reference just before measurement.

(10)   Adjust the f-stop to slightly under-expose (i.e., < 255 for 8-bit imagers).  Use lens f-stop, multibit contrast mode, and gains to produce an image capable of being evaluated by both the human eye and the LabDITCS reader program.

(11)   Record all memory.

(12)   Trigger the camera.

## B.5    Pre-Test Calibration

The IRIG-B timecode uses reference markers made up of two groups of high-amplitude waves (eight each) separated by two low-amplitude waves that are referred to as position identifiers.  The second position identifier marks the beginning of each frame of timecode data and it should be aligned with the leading edge of the 1 PPS (see Figure B-17).



REFERENCE          IRIG  ZERO          IRIG  ONE

0 0 1 1 1 1 1 1 1 0 0 1 1 0 0 0 0 0 0 0 0 0 1 1 1 1 1 0 0 0 0 0 1 1 0 0
MODIFIED  MANCHESTER
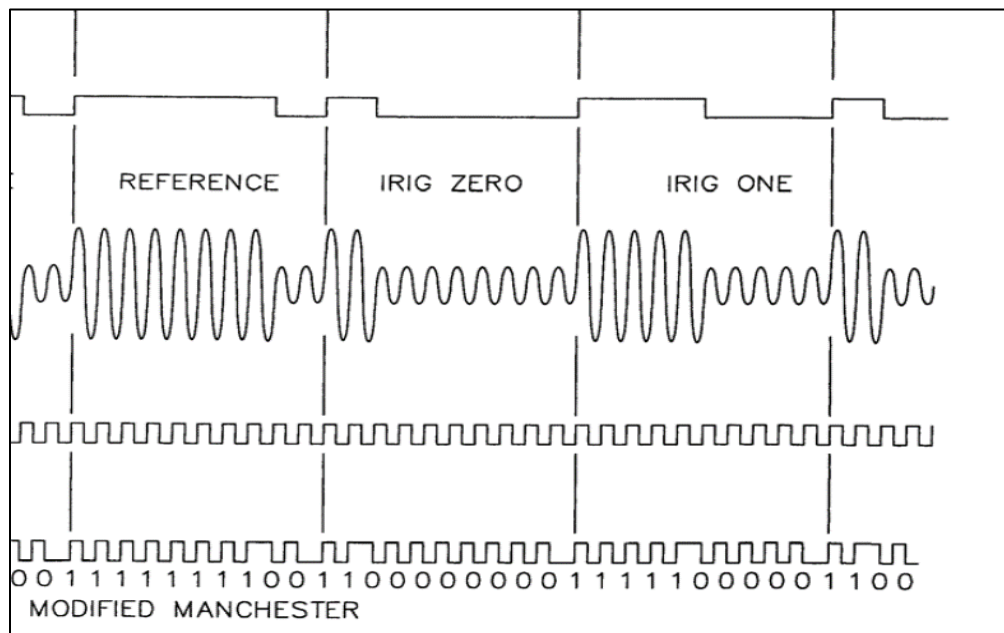
Figure B-17.    Timing Diagram Showing the Alignment of 1 PPS with IRIG-B Modulated Timecode

B.5.1   Validate the IRIG-B Modulated Reference Time

**Procedure 7:  Validate IRIG-B Modulated Reference Time**

The objective of the following procedure is to verify that the IRIG-B Modulated reference timecode is accurate.  Reference clocks (like the TRAK-9000) often use plug-in modules to generate various timecode signals.  Normally, the outputs from these modules are aligned with the 1 PPS signal and consequently with UTC; however, discrepancies have been

observed, even with well-maintained reference clocks that have been recently calibrated. Technicians at WSMR have observed differences of as much as 10 µs between the 1 PPS and IRIG-B Modulated signals from some TRAK-9000 units.  These differences can often be zeroed out by following prescribed maintenance procedures provided by the manufacturer. Because the LabDITCS needs both the 1 PPS and IRIG-B signals to synchronize with UTC, it is important to ensure that both signals are properly aligned and accurate.

(1)    Using the same setup as described above in Section B.2, connect the IRIG-B Modulated timecode signal (S2) from the reference clock to a third channel on the oscilloscope. Alternatively, the GEN PPS (S3) signal can be temporarily disconnected and S2 can be connected onto that channel in its place.

(2)    Verify that the second position identifier as described above is aligned with the leading edge of the 1 PPS signal.  Usually an oscilloscope time base of approximately 10 ms per division will provide a good scale for this initial comparison (Figure B-18).
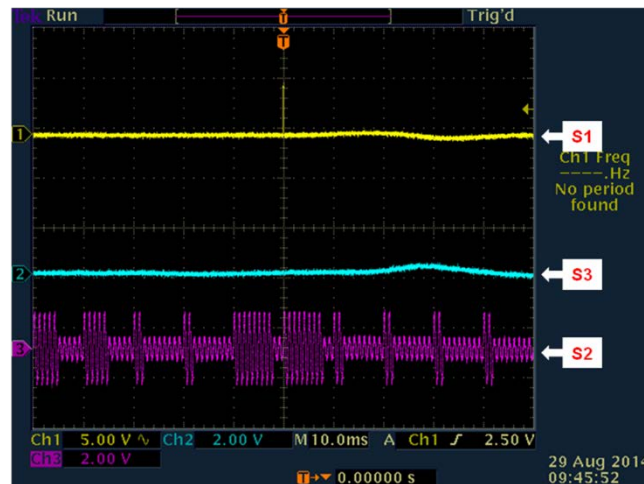


Figure B-18.    Oscilloscope Time Base Display

(3)    Now expand the time base to about 400 µs per division and view the signal cross-over between the low-amplitude wave and high-amplitude wave.  This cross-over marks the beginning of the next frame of timecode data and it should be aligned precisely with the leading edge of the 1 PPS.  (Figure B-19).
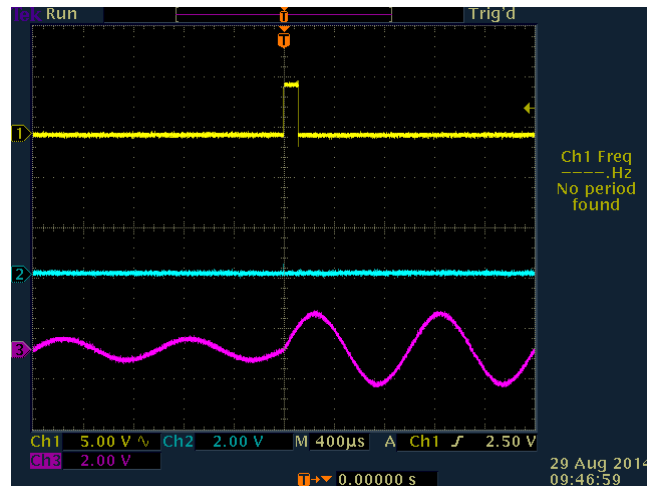
Figure B-19.   Leading Edge of 1 PPS

(4)     Finally, expand the time base to approximately 1 µs per division and make the same measurement.  This setting will allow the user to verify that the IRIG-B Modulated Timecode generated by the reference clock is precisely aligned (error << 1 µs) with the 1 PPS signal generated by the reference clock.  (Figure B-20)
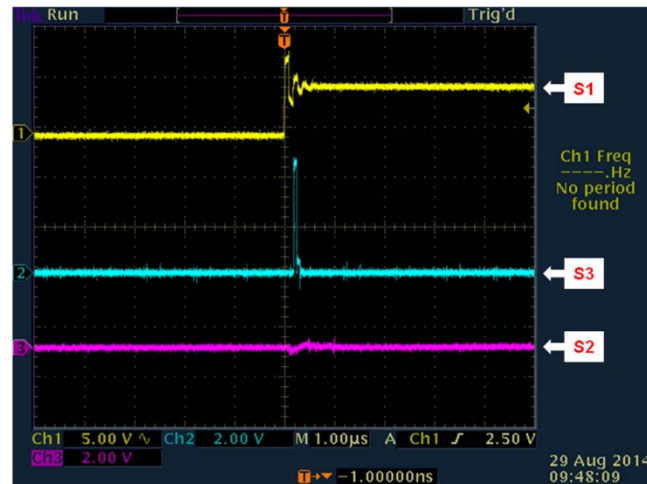


Figure B-20.   Reference Clock 1 PPS Signal

(5)     If the two signals are properly aligned, both the 1 PPS and IRIG-B Modulated timecode signals can be considered on-time with UTC and you can proceed to the next step.  If the two signals are not properly aligned, then the reference clock should be calibrated, repaired, or replaced before making timing measurements with the LabDITCS.

B.5.2   Align LabDITCS 1 PPS Signal to Reference Time

**Procedure 8:  Align LabDITCS 1 PPS Signal to Reference Time**

The purpose of this procedure is to align the 1 PPS signal generated by the LabDITCS ("GEN 1 PPS") with the 1 PPS signal from the reference clock.  This is a critical step because the GEN 1 PPS serves as the heartbeat of the LabDITCS and drives the active emitter board.

> This procedure ensures the LabDITCS reference signal (i.e., GEN 1 PPS) is on time with UTC.

(1)     Connect the LabDITCS to a time code source (e.g., connect the IRIG-B Modulated output of the TRAK-9000, S2, to the "IRIG-B" input of the LabDITCS).  Power up both units and wait at least 30 minutes for internal oscillators to reach their normal operating temperature and stabilize.

(2)     Connect the 1 PPS output of the TRAK-9000 (S1) to channel 1 (CH1) of a multi-channel oscilloscope.

(3)     Connect the GEN 1 PPS output of the LabDITCS (S3) to channel 2 (CH2) of a multi-channel oscilloscope.

(4)     Adjust the amplitude (vertical scale) and time base (horizontal scale) on the oscilloscope to view both pulses on the scope's display.

(5)     Launch the LabDITCS software and open the CodeInputWindow dialog box

(6)     Select the proper time code input format (e.g., select "IRIGB" for IRIG-B Modulated timecode).

(7)     Type "0" into the PPS Propagation Delay (ns) dialog box.

(8)     Press the "Download to LabDITCS" button to enter the value.

(9)     Measure the time difference between the leading edges of the two pulses observed on the oscilloscope (i.e., S1 and S3).  The reference signal S1 should arrive before S3.

(10)    Type the time difference or delta (expressed in nanoseconds) into the PPS Propagation Delay (ns) dialog box.

(11)    Press the "Download to LabDITCS" button to enter the value.

(12)    Measure the time difference between the leading edges of the two pulses observed on the oscilloscope (i.e., S1 and S3).  The difference should be much smaller than the initial value. Repeat these steps until the difference measured on the oscilloscope is much less than 1 μs. (Figure B-21).



(1)  BEFORE Alignment (Latency > 6 μs)      (2)  AFTER Alignment (Latency << 1 μs)
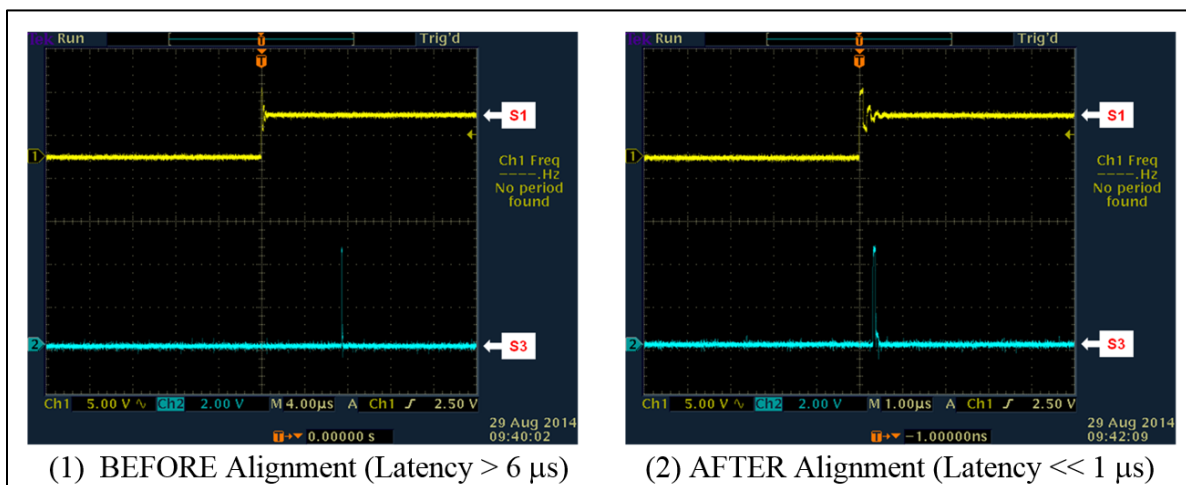
Figure B-21.   GEN PPS Alignment Process

B.5.3   Align Camera Code Out with 1 PPS (Vision Research Cameras Only)

Some Vision Research camera models require an additional manufacturer-supplied calibration when the camera is fed IRIG-B Modulated timecode.  This applies to the PH16 family of cameras (Models V1210, V1212, V1612, V2012, and V2512).  These specific models will exhibit timing errors of 12 μs or more unless a parameter called hw.irigmodphase is not tuned to offset the error.  Vision Research has provided detailed instructions for the process in a document entitled "Procedure for adjusting the time shift that can occur using modulated IRIG on V1610/V1210 cameras."[5]

B.5.4   Verify LabDITCS Program Execution

| **Procedure 9:  Verify LabDITCS Program Execution** |
| :--- |
| Use this procedure to verify that the LabDITCS executes the programmed script correctly.  This step confirms the timing properties of each emitted optical pulse. |

(1)   Connect the 1 PPS from the reference clock (S1) to channel 1 of the oscilloscope.

(2)   Connect the gate pulse signal (S4) to a second channel of the oscilloscope.  This signal is a TTL pulse that goes high when the LED emitter specified on the "Program Array" screen in the control software is turned on.

(3)   Set the gate pulse to Row 1, Column 1 in the PROGRAM array window.

(4)   Connect the output (S5) of the optical probe J-Box (G) to a second channel of the oscilloscope.

(5)   Adjust the oscilloscope to show all three signals.

(6)   Place the optical probe in the aperture of the Lexan cover directly over the emitter (1,1).

(7)   Compare the leading edge of S5 to the leading edge of S1.  They should coincide in time as shown in Figure B-22.  (Note:  the output of the first LED is slightly delayed from the 1 PPS.)
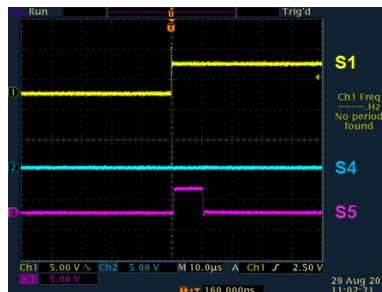


Figure B-22.   0-microsecond Delay

(8)   Move the optical probe to the next emitter, i.e., (1,2).

---

[5] Jim Beurrier, Vision Research/Ametek Materials Analysis Division.  *Procedure for adjusting the time shift that can occur using modulated IRIG on V1610/1210 cameras*.  23 August 2013.  Retrieved 27 July 2016.  Available at http://www.wsmr.army.mil/RCCsite/Documents/468-16_Testing_Validation_Properties_High_Speed_Digital_Cameras/Modulated_IRIG_phase_adjustment.pdf.

(9) Compare the leading edge of S5 to the leading edge of S1. The optical pulse should be delayed precisely 10 μs (Figure B-23).
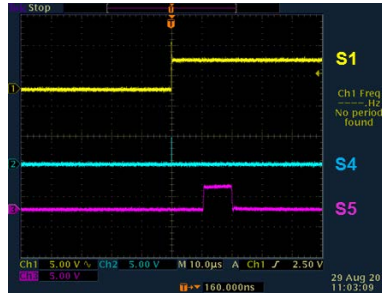


Figure B-23.    10-microsecond Delay

(10) Move the optical probe to the next emitter, i.e., (1,3).

(11) Compare the leading edge of S5 to the leading edge of S1. The optical pulse should be delayed 20 μs (Figure B-24).



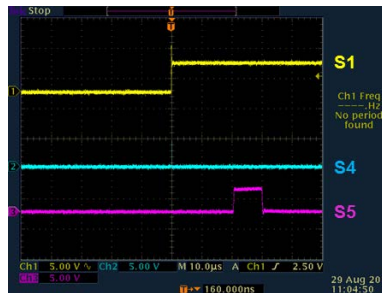Figure B-24.    20-microsecond Delay

(12) Repeat this process for all of the emitters on the first row. The time scale on the oscilloscope may have to be adjusted to see the latter pulses, but use this technique to verify that each LED is coming on and going off at the appropriately programmed time (i.e., a staggered 10-μs pulse sequence, in this particular case).

(13) After measuring the output of the last LED on Row 1, reprogram the gate pulse dialog box in the PROGRAM array window to read Row = 2, Column = 1.

(14) Place the optical probe in the aperture of the Lexan cover directly over emitter (2, 1).

(15) Repeat steps 7 through 12 for the LEDs on Row 2.

(16) Repeat this process for the remaining rows, remembering to reprogram the gate pulse for each new row. Use the gate pulse signal to trigger the oscilloscope for each row of emitters so that the optical probe pulse can be compared to the leading edge of the 1 PPS.

(17) Make note of any LEDs that are improperly programmed. Re-program and re-test the array before collecting measurement data.

## B.6     Data Collection

High-speed imaging data should only be collected after configuring the camera and LabDITCS as described in Section B.4 (Test Setup) and following the detailed calibration and

verification procedures outlined in Section B.5 (Pre-Test Calibration). Furthermore, the data should be collected as soon after calibration as possible to minimize time-variant drift from established tolerances. It is always good practice to minimize the time between data collection and the setup/calibration of any measurement system.

Errors in camera timestamps can be measured by collecting high-speed video of the LabDITCS emitter panel while it runs a pre-programmed sequencing script (e.g., staggered 10-μs pulse sequence). Select frames in the recorded video file can then be analyzed to determine if the camera timestamp associated with that frame varies from the time represented by the seven-segment and binary displays on the LabDITCS emitter panel. Differences can be quantified and statistically averaged over multiple frames to calculate mean errors. Likewise, recording multiple video files with the same camera configuration can add statistical validity to measured results. Furthermore, additional video files can be collected using different camera configurations and advanced features to determine if certain configuration settings are responsible for timing error.

It would be impractical to test every possible camera configuration for timing accuracy. Therefore, it is recommended tests be performed with the most common settings used during routine mission support. It is also recommended that the data collection computer used for timing measurements be configured with the same OS and software as that installed on the camera control computers used for routine mission support. This will help limit test condition variables and minimize anomalies that could arise from configuration differences between the test setup and actual mission support configuration.

| TIP | Configure the control computer exactly as it would be used in the field to collect mission data (i.e., same OS, security settings, camera software version, etc.) |
|-----|-----|

Because errors in timestamps can drift and change over time, large data sets are needed to capture and characterize any trends or transient/anomalous effects. The following guidelines for data collection are based on extensive experience using the LabDITCS to perform timing certification tests at WSMR. These recommendations also address some of the commonly encountered sources of timestamp error associated with modern high-speed digital cameras on the test ranges.

A) **Set TINT to 100 μs.** The TINT should be set to 100 μs to facilitate optimal sampling and analysis using the LabDITCS staggered 10-μs pulse sequence described in the preceding sections.

B) **Set recording period to fill camera memory**. Filling camera memory (i.e., setting recording period to max) provides a statistically significant number of frames for post-test analysis and may reveal time-variant error over relatively long recordings.

C) **Collect data at low, medium, and high frame rates**. It has been observed that timestamp error can vary with frame rate. Consequently, it is advised to bracket the range of frame rates commonly used to collect mission data. Sampling at low, medium, and high frame rates will likely reveal any frame rate-dependent timing error.

D) **Record three files at each frame rate**. It is recommended to collect at least three full files at each frame rate to provide sufficient statistical sampling of timestamp data.

E) **Collect data in segmented-memory mode.**  Many high-speed digital cameras have a feature that allows the user to configure the camera for multiple triggers to record multiple video files in a single block of memory.  Some segmented-memory modes have been particularly prone to errors in timestamping.  A few early camera models showed very accurate timestamping in standard recording mode, but were characterized by significant timing errors when configured for segmented-memory mode.

F) **Collect data at two or more trigger positions**.  Most circular buffer-based cameras provide more than one user-selectable trigger position.  For example, some cameras can be set up to trigger at the beginning, middle, or end of the recording segment.  It is a good idea to collect data at two or more trigger positions to verify that trigger position does not affect measured timestamp error.

G) **Keep detailed notes on LabDITCS and camera configuration**.  It is imperative that configuration settings be accurately recorded prior to each data collection.  These notes will be critical to post-test analysis.  As a minimum, the following parameters should be recorded and associated with each data file collected:

1) Date and time (if not already embedded in file);

2) LabDITCS script filename (e.g., "Staggered_10us_PulseSequence");

3) Camera manufacturer, model, and serial number;

4) Timestamp position relative to exposure (e.g., Beginning, Middle, End);

5) Integration time (i.e., "exposure" time);

6) Frame rate (e.g. 500 fps, 1000 fps, etc.);

7) Trigger position (e.g., Start, Middle, End);

8) Special features (e.g., segmented memory, EDR, etc.).

Each data collection session should produce a series of files that contain sufficient data to measure timestamp accuracy for the critical operational modes described above.  It is permissible to mix variables across some of the tests to minimize the amount of time needed to validate a particular camera.  Technicians at WSMR, for example, often collect data using different trigger positions while generating three separate files at each frame rate.  Special features or operational modes can also be tested by changing the configuration while running through the basic series of tests.  If notable errors are observed during the analysis of these recordings, additional tests can be performed to isolate and determine the root cause.  Table B-3 provides an example of the list of files collected to certify timestamp accuracy for a particular high-speed camera at WSMR.

| File | Filenames | Frames Collected | Time Stamp Position | TINT | FR | Trigger Position | Notes/Special Features |
|---|---|---|---|---|---|---|---|
| | **Table B-3.   Example of File Set Generated During Timing Certification Test of New Camera** | | | | | | |
| 1 | T1_TKO393_6504fps_100us_s1 | 35,465 | End | 100 | 6504 | Start | Camera set at max FR |
| 2 | T2_TKO393_1000fps_200us_s2 | 35,465 | End | 200 | 1000 | Start | Set TINT to 200 µs |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 3 | T3_TKO393_1000fps_100us_ZDH253_c3 | 35,465 | End | 200 | 1000 | Center | Record with WIN 7 Platform |
| 4 | T4_TKO393_500fps_100us_s1 | 35,465 | End | 100 | 500 | Start | |
| 5 | T5_TKO393_500fps_100us_EDR50us_s2 | 35,465 | End | 100 | 500 | Start | EDR set to 50 us |
| 6 | T6_TWT753_500fps_100us_ c3 | 71,010 | End | 100 | 500 | Center | Record with another Ser. No. |
| 7 | T7_TKO393_125fps_100us_PCC023_s1 | 35,465 | End | 100 | 125 | Start | Record with Field Computer |
| 8 | T8_TKO393_125fps_100us_16bit_s2 | 20,314 | End | 100 | 125 | Start | Record in 14-Bit Mode |
| 9 | T9_TKO393_125fps_100us_c3 | 35,465 | End | 100 | 125 | Center | |
| 10 | T10_TKO393_1000fps_100us_sseg1 | 11,820 | End | 100 | 1000 | Start | Segmented Memory - PH1 |
| 11 | T11_TKO393_1000fps_100us_sseg2 | 11,820 | End | 100 | 1000 | Start | Segmented Memory - PH2 |
| 12 | T12_TKO393_1000fps_100us_cseg3 | 11,820 | End | 100 | 1000 | Center | Segmented Memory - PH3 |

The table shows that the recommended basic sequence of three files was collected at each frame rate range (i.e., fast, medium, and slow). File 1 was collected at 6504 fps, which is the maximum frame rate for this particular camera. Files 2 and 3 were collected at 1000 fps, which is a more common high-frame rate selection used at WSMR. Files 4 through 6 were collected with a frame rate of 500 fps and files 7 through 9 were collected with a relatively slow frame rate of 125 fps.

As Table B-3 clearly shows, slight nuances in the configuration for each data collection can help illuminate timing errors that may surface with different operational modes. File 2, for example, was collected with the camera TINT set to 200 µs. This modification to the standard configuration can be used to test the accuracy of the TINT setting in the camera software. With the strobes at 10 µs, the recorded imagery should show 20 LEDs are on in each frame if the TINT is truly 200 µs. Likewise, file 8 was collected in 14-bit mode rather than 8-bit mode to verify that bit depth did not impact timing accuracy.

Finally, a short series of files was collected with segmented memory. These data were collected to ensure that timestamp accuracy was not affected by partitioning the memory and using multiple triggers to generate multiple image sequences.

## B.7    Data Reduction & Analysis

There are two primary methods for reducing and analyzing LabDITCS image files to measure timestamp error: Manual and Automated. The most straightforward approach involves visually inspecting and interpreting select image frames in each file. Any error can be measured by subtracting the UTC time displayed on the LabDITCS from the timestamp provided by the camera. Ideally, every frame would be analyzed in this manner. Manual inspection, however, is labor-intensive and takes considerable time.

### B.7.1   Manual Data Reduction and Analysis

It would be impractical to manually inspect thousands of frames collected in a single test. Consequently, it is suggested that a small subset of frames be selected for analysis. It is also recommended that the selected frames be evenly distributed across the entire video file to help characterize drift if it is present. The approach used at WSMR is to extract approximately 10 to 15 frames from each file for visual inspection and analysis. Each frame is visually inspected and

the UTC time is interpreted from a combination of the alphanumeric displays, binary displays, and high-speed sequential emitter array.  Figure B-25 summarizes this process.
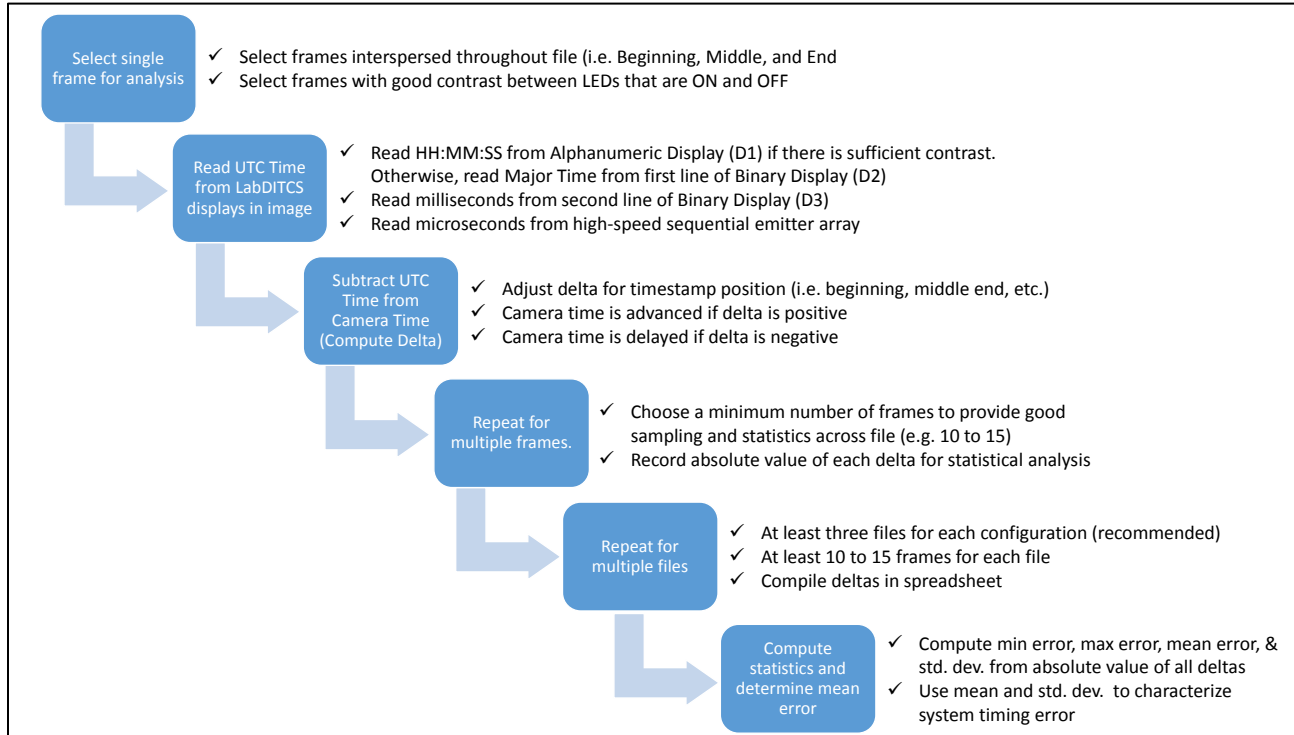


Figure B-25.   Manual Data Reduction Process

The UTC time is displayed on the LabDITCS panel using a combination of alphanumeric and binary displays.  Major time (i.e., hours, minutes, and seconds) can often be read off the alphanumeric display at the top of the panel if there is sufficient contrast; however, some cameras do not have sufficient sensitivity to provide adequate contrast at such low integration time (i.e., 100 μs) and this display is hard to read.  In these cases, the first line of the binary display can also be used to read the major time.  The binary coded time represents the total number of seconds from the start of the UTC day.  Table B-4 shows how the binary coded major time translates into UTC hours, minutes, and seconds.

| Table B-4.  Major Time Expressed in Binary Coded Time and UTC | | |
|---|---|---|
| **Binary Display (17 LEDs)** | **Seconds from Start of UTC Day** | **UTC Time (HH:MM:SS)** |
| 00000000000000000 | 0 | 00:00:00 |
| 00000000000000001 | 1 | 00:00:01 |
| 00000000000000011 | 3 | 00:00:03 |
| 00000000000111100 | 60 | 00:01:00 |
| 00000111000010000 | 3600 | 01:00:00 |
| 01000111100000010 | 36610 | 10:10:10 |
| 01101101011100011 | 56035 | 15:33:55 |
| 10001111111001110 | 73678 | 20:27:58 |

Minor time (i.e., milliseconds) can be read from the second line of the binary display. This row of LEDs encodes the first four digits of the fractional second (e.g., 00.XXXX seconds or $10^{-4}$ seconds).  Although milliseconds can also be read from the alphanumeric display, experience has shown the binary display is more reliable for many camera configurations.  This is because the LabDITCS LEDs are much brighter than the seven-segment display and consequently more readable when using short exposure times.  Table B-5 shows how the binary coded minor time translates into UTC fractional seconds.

| Table B-5.   Minor Time Expressed in Binary Coded Time and UTC Fractional Seconds | | |
|---|---|---|
| **Binary Display (15 LEDs)** | **Decimal Equivalent ($10^{-4}$ Seconds)** | **UTC Fractional Seconds** |
| 000000000000000 | 0 | 0.0000 |
| 000000000000001 | 1 | 0.0001 |
| 000000000000011 | 3 | 0.0003 |
| 000000001100100 | 100 | 0.0100 |
| 000001111101000 | 1000 | 0.1000 |
| 000011111001110 | 1998 | 0.1998 |
| 001100110110110 | 6582 | 0.6582 |
| 010010110101001 | 9641 | 0.9641 |

Microseconds are read from the high-speed sequential emitter array.  The number of LEDs illuminated in each frame will be dependent on the LabDITCS program script and the camera TINT.  Using the LabDITCS staggered 10-µs pulse sequence script (described in Procedure 4) and an integration time of 100 µs, approximately 10 LEDs should be on in each frame.  This number is approximate because the start of frame integration rarely coincides with the precise ON time of each LED.  That is, some LEDs will be half-way through their ON time (e.g. 10 µs) when frame integration begins.  In these cases, the first LED will be dimmer than the second LED because the camera only integrated light for 5 µs before the LED went out.

The relative brightness of the LEDs can be used to provide finer resolution of the actual TINT.  The two diagrams in Figure B-26 depict the first two rows of the LabDITCS panel.  In the first diagram, the camera exposure is aligned with the cycle time of the LEDs.  In the second diagram, the camera exposure is offset.  If the timestamp occurs at the end of the exposure, then diagram A would be read as precisely 400 µs because only 10 lamps are illuminated and the last lamp went off at 140 µs.  Diagram B shows a more realistic case where the LED time and integration time are not in sync.  Here, the end of exposure time would be interpreted as 145 µs.
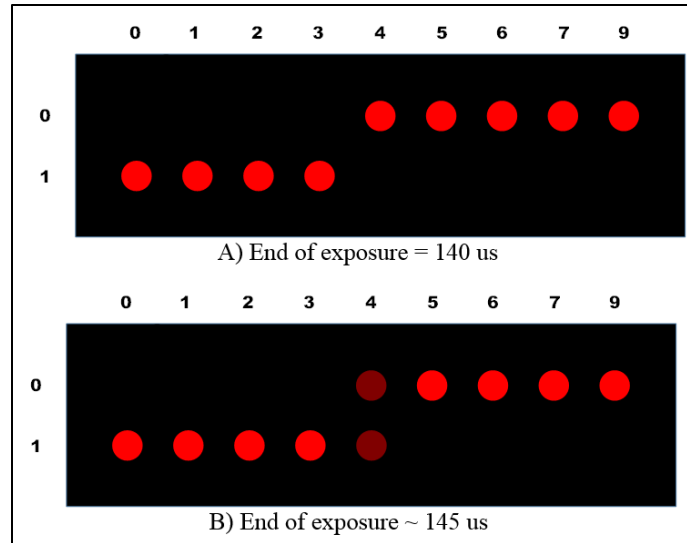
Figure B-26.   Examples of How Microseconds Can be Read from First Two
Rows of LabDITCS Display Panel.

Theoretically, the relative brightness of the LED image could be used to provide even finer temporal resolution during analysis, particularly if the imagers were digitized and numerically reduced; however, due to slight non-uniformities among LEDs and other variables affecting individual luminance, it is recommended that interpolation be limited to no more than one half the LED ON time.  In the case of a 10-µs staggered sequence, this would equate to 5 µs.

Figure B-27 graphically depicts the manual data reduction process for a single image frame taken from an actual timing certification test.  The camera integration time was set at 100 µs and the timestamp position was set to end of exposure.  The LEDs were programmed with the staggered 10-µs strobe sequence described above.  Major time was read from the first line of the binary coded time display.  The minor time was read from the second line of the binary coded time display and the microseconds were read from the high-speed sequential emitter array.  As such, the actual time of this exposure was determined to be 15:34:13.180255.  Subtracting this value from the camera timestamp on this frame (15:34:13.180229) results in an error of −26 µs.  This means the camera time was 26 µs delayed from UTC.
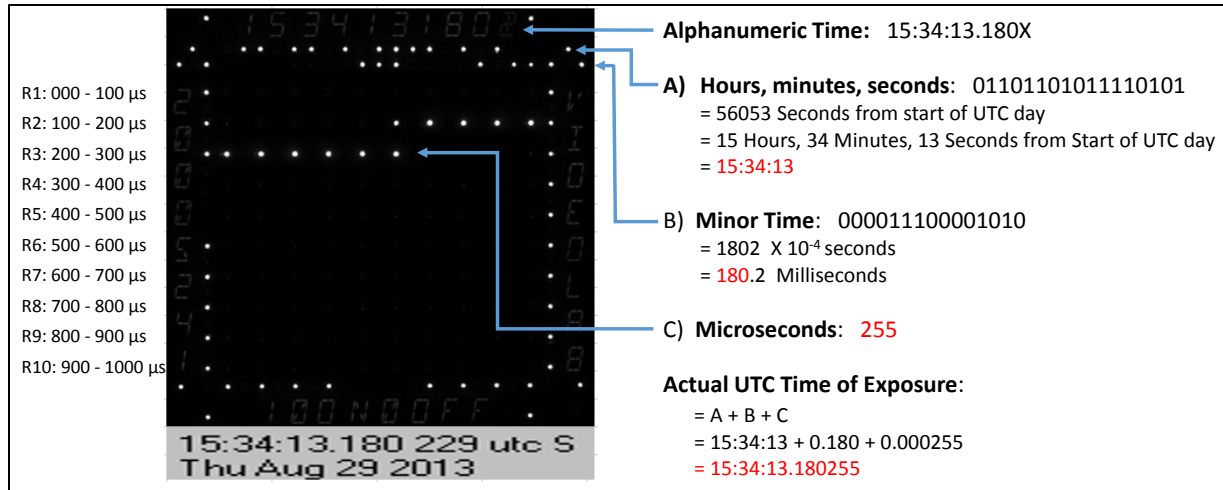
Figure B-27.    Sample Image Showing How to Read UTC from LabDITCS

Additional frames throughout the video file should be selected for analysis, as well as frames from other files generated during the data reduction process.  The deltas should be recorded along with the setup parameters specific to each test.  An Excel workbook was developed at WSMR for capturing, organizing, and analyzing these data.  The WSMR Timing Analysis workbook is comprised of multiple worksheets that contain data from each series of tests.  For example, there is typically a separate worksheet for each frame rate tested and each worksheet contains data from several data collections performed at that specific frame rate.

The following ancillary information is recorded on each spreadsheet to aid in analysis.

- File Name
- Test Date
- Test Location
- LabDITCS Serial Number
- Camera Serial Number
- Position of Timestamp (i.e., beginning, end)
- Camera Integration Time
- Camera Frame Rate
- LabDITCS Program Script

Formulas were written into each analysis spreadsheet to subtract the UTC time (LabDITCS time) from the camera time (i.e., timestamp) and adjust the resulting delta for timestamp position.  The spreadsheet then averages all deltas to compute the statistical minimum, maximum, and mean error.  It also calculates the standard deviation.  These values are then used to characterize the timing properties of the camera under test.  Figure B-28 is a screenshot of part of the spreadsheet that shows the raw data and deltas between camera time and UTC.  This sheet summarizes the analysis of three separate files collected at a high frame rate.  A total of 52 frames was analyzed and used to compute the deltas shown in the right-hand columns.

| TEST CONFIGURATION | Frame # | LabDITCS Time HH:MM:SS.SSSSSS | Camera Time HH:MM:SS.SSSSSS | SFSOD | Binary Representation of Camera Time — Major Time | Minor Time | Raw Delta (Microseconds) | Corrected Delta (Microseconds) | Absolute Delta |
|---|---|---|---|---|---|---|---|---|---|
| File Name: PH1_TKO393_6504fps_100us_s1.cine | 0 | 13:24:43 .781595 | 13:24:43 .781571 | 48283 | 010111100 10011011 | 001111010 000111 | -24 | -24 | 24 |
| Date: 8/29/2013 7:54 AM | 2217 | 13:24:44 .122465 | 13:24:44 .122441 | 48284 | 010111100 10011100 | 000010011 001000 | -24 | -24 | 24 |
| Site: Video Lab | 4434 | 13:24:44 .463335 | 13:24:44 .463310 | 48284 | 010111100 10011100 | 001001000 011001 | -25 | -25 | 25 |
| Mount: Lab Visible DITCS SN002 | 6651 | 13:24:44 .804205 | 13:24:44 .804179 | 48284 | 010111100 10011100 | 001111101 101001 | -26 | -26 | 26 |
| Camera EIN: TKO-393 B&W | 8868 | 13:24:45 .145075 | 13:24:45 .145049 | 48285 | 010111100 10011101 | 000010110 101010 | -26 | -26 | 26 |
| Time Stamp Location: End | 11085 | 13:24:45 .485945 | 13:24:45 .485917 | 48285 | 010111100 10011101 | 001001011 111011 | -28 | -28 | 28 |
| Exposure Time: 100 | 13302 | 13:24:45 .826815 | 13:24:45 .826787 | 48285 | 010111100 10011101 | 010000001 001011 | -28 | -28 | 28 |
| Frame rate: 6504 | 15519 | 13:24:45 .167685 | 13:24:45 .167656 | 48285 | 010111100 10011101 | 000011010 001100 | -29 | -29 | 29 |
| Array Diodes Program: 10 usec On | 17736 | 13:24:46 .508555 | 13:24:46 .508525 | 48286 | 010111100 10011110 | 001001111 011101 | -30 | -30 | 30 |
| Hardtape: P66288 | 19993 | 13:24:46 .855575 | 13:24:46 .855545 | 48286 | 010111100 10011110 | 010000101 101011 | -30 | -30 | 30 |
| Folder: E:\Software timing test | 22170 | 13:24:47 .190295 | 13:24:47 .190263 | 48287 | 010111100 10011111 | 000011101 101110 | -32 | -32 | 32 |
| | 24387 | 13:24:47 .531165 | 13:24:47 .531133 | 48287 | 010111100 10011111 | 001010010 111111 | -32 | -32 | 32 |
| | 26604 | 13:24:47 .872025 | 13:24:47 .872002 | 48287 | 010111100 10011111 | 010001000 010000 | -23 | -23 | 23 |
| | 28821 | 13:24:48 .212895 | 13:24:48 .212871 | 48288 | 010111100 10100000 | 000100001 010000 | -24 | -24 | 24 |
| | 31038 | 13:24:48 .553765 | 13:24:48 .553740 | 48288 | 010111100 10100000 | 001010110 100001 | -25 | -25 | 25 |
| | 32255 | 13:24:48 .740885 | 13:24:48 .740857 | 48288 | 010111100 10100000 | 001110011 110000 | -28 | -28 | 28 |
| | 35465 | 13:24:49 .234430 | 13:24:49 .234403 | 48289 | 010111100 10100001 | 000010100 101000 | -27 | -27 | 27 |
| | | | | 0 | | | | | |
| File Name: PH2_TKO393_1000fps_100us_s2.cine | 0 | 13:59:26 .331735 | 13:59:26 .331703 | 50366 | 011000100 10111110 | 000010011 110101 | -32 | -32 | 32 |
| Date: 8/29/2013 8:39 AM | 2217 | 13:59:28 .548765 | 13:59:28 .548737 | 50368 | 011000100 11000000 | 001010101 101111 | -28 | -28 | 28 |
| Site: Video Lab | 4434 | 13:59:30 .765795 | 13:59:30 .765770 | 50370 | 011000100 11000010 | 001110011 101001 | -25 | -25 | 25 |
| Mount: Lab Visible DITCS SN002 | 6651 | 13:59:32 .982835 | 13:59:32 .982803 | 50372 | 011000100 11000100 | 010011001 100100 | -32 | -32 | 32 |
| Camera EIN: TKO-393 B&W | 8868 | 13:59:35 .199865 | 13:59:35 .199836 | 50375 | 011000100 11000111 | 000011110 001110 | -29 | -29 | 29 |
| Time Stamp Location: End | 11085 | 13:59:37 .416895 | 13:59:37 .416870 | 50377 | 011000100 11001001 | 001000001 001000 | -25 | -25 | 25 |
| Exposure Time: 200 | 13302 | 13:59:39 .633935 | 13:59:39 .633903 | 50379 | 011000100 11001011 | 001100011 001011 | -32 | -32 | 32 |
| Frame rate: 1000 | 15519 | 13:59:41 .850965 | 13:59:41 .850937 | 50381 | 011000100 11001101 | 010000100 111101 | -28 | -28 | 28 |
| Array Diodes Program: 10 usec On | 17736 | 13:59:44 .067995 | 13:59:44 .067969 | 50384 | 011000100 11010000 | 000001010 100111 | -26 | -26 | 26 |
| Hardtape: P66288 | 19993 | 13:59:46 .325035 | 13:59:46 .325003 | 50386 | 011000100 11010010 | 001010010 110010 | -32 | -32 | 32 |
| Folder: E:\Software timing test | 22170 | 13:59:48 .502065 | 13:59:48 .502036 | 50388 | 011000100 11010100 | 001001110 011100 | -29 | -29 | 29 |
| | 24387 | 13:59:50 .719095 | 13:59:50 .719069 | 50390 | 011000100 11010110 | 001110010 010110 | -26 | -26 | 26 |
| | 26604 | 13:59:52 .936135 | 13:59:52 .936103 | 50392 | 011000100 11011000 | 010010010 010001 | -32 | -32 | 32 |
| | 28821 | 13:59:55 .153165 | 13:59:55 .153136 | 50395 | 011000100 11011011 | 000010111 111011 | -29 | -29 | 29 |
| | 31038 | 13:59:57 .370195 | 13:59:57 .370170 | 50397 | 011000100 11011101 | 000111001 110101 | -25 | -25 | 25 |
| | 32255 | 13:59:58 .587215 | 13:59:58 .587188 | 50398 | 011000100 11011110 | 001011011 101111 | -27 | -27 | 27 |
| | 35465 | 14:00:01 .797265 | 14:00:01 .797236 | 50401 | 011000100 11100001 | 001111100 100100 | -29 | -29 | 29 |
| File Name: PH3_TKO393_1000fps_100us_ZDH253_c3.cine | -17732 | 15:33:55 .448985 | 15:33:55 .448961 | 56035 | 011011010 11100010 | 001000110 001001 | -24 | -24 | 24 |
| Date: 8/29/2013 9:53 AM | -15515 | 15:33:57 .666025 | 15:33:57 .665995 | 56037 | 011011010 11100101 | 001101000 000011 | -30 | -30 | 30 |
| Site: Video Lab | -13298 | 15:33:59 .883055 | 15:33:59 .883028 | 56039 | 011011010 11100111 | 010001001 111110 | -27 | -27 | 27 |
| Mount: Lab Visible DITCS SN002 | -11081 | 15:34:02 .100085 | 15:34:02 .100061 | 56042 | 011011010 11101010 | 000001111 101000 | -24 | -24 | 24 |
| Camera EIN: TKO-393 B&W | -8864 | 15:34:04 .317125 | 15:34:04 .317095 | 56044 | 011011010 11101100 | 000110001 100010 | -30 | -30 | 30 |
| Time Stamp Location: End | -6647 | 15:34:06 .534155 | 15:34:06 .534129 | 56046 | 011011010 11101110 | 001010011 011101 | -26 | -26 | 26 |
| Exposure Time: 100 | -4430 | 15:34:08 .751185 | 15:34:08 .751162 | 56048 | 011011010 11110000 | 001110101 010111 | -23 | -23 | 23 |
| Frame rate: 1000 | -2217 | 15:34:10 .964225 | 15:34:10 .964196 | 56050 | 011011010 11110010 | 001010110 101001 | -29 | -29 | 29 |
| Array Diodes Program: 10 usec On | -1 | 15:34:13 .180255 | 15:34:13 .180229 | 56053 | 011011010 11110101 | 000011100 111010 | -26 | -26 | 26 |
| Hardtape: P66288 | 1 | 15:34:13 .182255 | 15:34:13 .182229 | 56053 | 011011010 11110101 | 000011100 011110 | -26 | -26 | 26 |
| Folder: E:\Software timing test | 2217 | 15:34:15 .398295 | 15:34:15 .398263 | 56055 | 011011010 11110111 | 000111110 011110 | -32 | -32 | 32 |
| | 4430 | 15:34:17 .611325 | 15:34:17 .611296 | 56057 | 011011010 11111001 | 001011111 100000 | -29 | -29 | 29 |
| | 6647 | 15:34:19 .828335 | 15:34:19 .828330 | 56059 | 011011010 11111011 | 010000001 011011 | -25 | -25 | 25 |
| | 8864 | 15:34:22 .045395 | 15:34:22 .045364 | 56062 | 011011010 11111110 | 000000111 000101 | -31 | -31 | 31 |
| | 11081 | 15:34:24 .262425 | 15:34:24 .262397 | 56064 | 011011011 00000000 | 000101000 111111 | -28 | -28 | 28 |
| | 13298 | 15:34:26 .479455 | 15:34:26 .479431 | 56066 | 011011011 00000010 | 001011001 111010 | -24 | -24 | 24 |
| | 15515 | 15:34:28 .696495 | 15:34:28 .696464 | 56068 | 011011011 00000100 | 001101100 110100 | -31 | -31 | 31 |
| | 17733 | 15:34:30 .914525 | 15:34:30 .914498 | 56070 | 011011011 00000110 | 010001110 111000 | -27 | -27 | 27 |

Figure B-28.    Sample Analysis Sheet used to Compute Deltas Between Camera
Time and UTC

Typical timing tests involving high-speed cameras usually generate huge files.  These
files are maintained for a short while after analysis, but are eventually deleted to make room for
additional data.  Consequently, WSMR analysts often take screenshots of select frames used in
analysis for archival purposes.  These frames are embedded in the analysis spreadsheet for
inspection as a permanent record of the manual analysis.  Figure B-29 shows another part of the
analysis spreadsheet that contains the statistical results and screenshots of some of the analysis
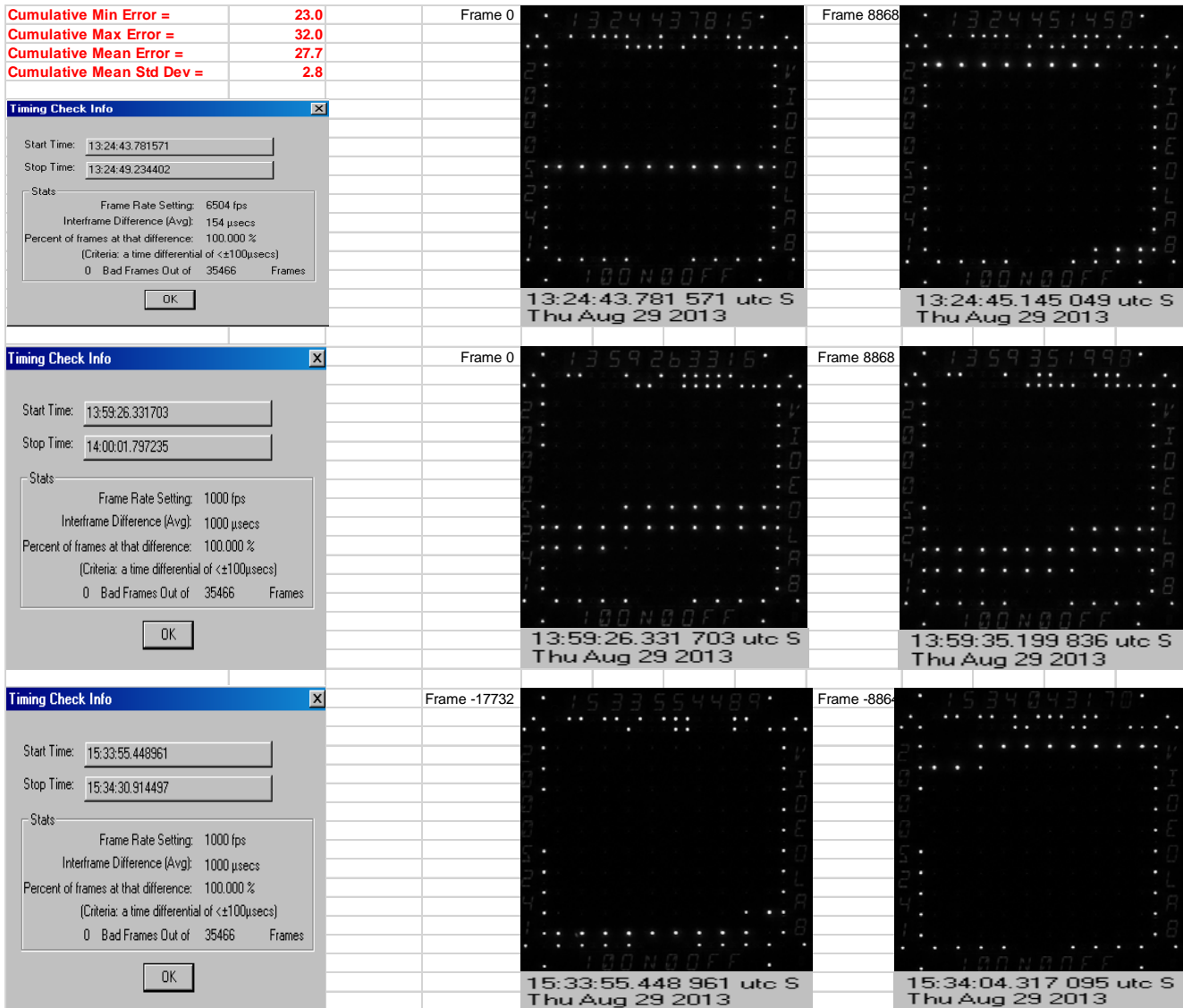frames.

Figure B-29.   Composite Results and Screenshots of Select Frames Used in
Analysis (High Frame Rate Files)

The first three screenshots on the left-hand side of Figure B-29 show results from a custom program written at WSMR to check each file for anomalous timestamps.  This program reads the video file for several vendor file formats and computes the time delta between each frame in the file.  If the delta is significantly more than the expected inter-frame time, the software flags the timestamp as suspect.  These frames are counted and the sum presented on the program display window.

The screenshots on the right-hand side of Figure B-29 provide a few of the frames used in the timing analysis.  Each image frame clearly shows the UTC time on the LabDITCS displays for that exposure.  This time is subtracted from the camera time at the bottom of the image to determine the timing error.

Finally, the composite statistics for the 52 deltas measured in this particular test are presented in red type.  The cumulative mean error for this camera was determined to be 27.7 µs.

Testing and Validation of Timing Properties for High-Speed Digital Cameras - A Best Practices Guide
RCC 468-16 July 2016

This value falls well within WSMR's criteria of ±50 μs and is therefore acceptable. Furthermore, the standard deviation of 3 μs indicates low variance between samples. Indeed, this camera exhibited nearly identical mean errors for tests performed at other frame rates. Camera timing always trailed UTC by approximately 23 μs, regardless of frame rate.

The WSMR Timing Analysis Workbook is available for download at the RCC website, . This blank Excel workbook, labeled "Example – Blank Timing Certification Data Template", can be used as is to record measurement data collected with the LabDITCS and automate statistical analyses and summation of results. Of course, range users can create their own spreadsheets and/or databases if desired, but many of the statistical functions needed for proper analysis of LabDITCS data have already been incorporated into this template file. In addition, the RCC website provides several files that have actual measurement data collected with operational high-speed digital cameras. These files provide an example of how LabDITCS results can be used to characterize timing properties of the camera (or digital recorder) and perform a thorough timing evaluation for certification. The files are located at https://wsdmext.wsmr.army.mil/site/rccpri/osg/DTEC/Shared%20Documents/OS-37%20Shared%20Resources/.

Figure B-30 provides one more screenshot of an analysis worksheet showing select frames used in the analysis of this particular camera. In this series of tests, the frame rate was nominally 1000 fps, although one recording was made at the maximum frame rate of 6504 fps. As seen at the bottom of the figure, this workbook contained analyses for three other significant test conditions: Medium frame rate (i.e., 500 fps), slow frame rate (125 fps), and segmented memory.
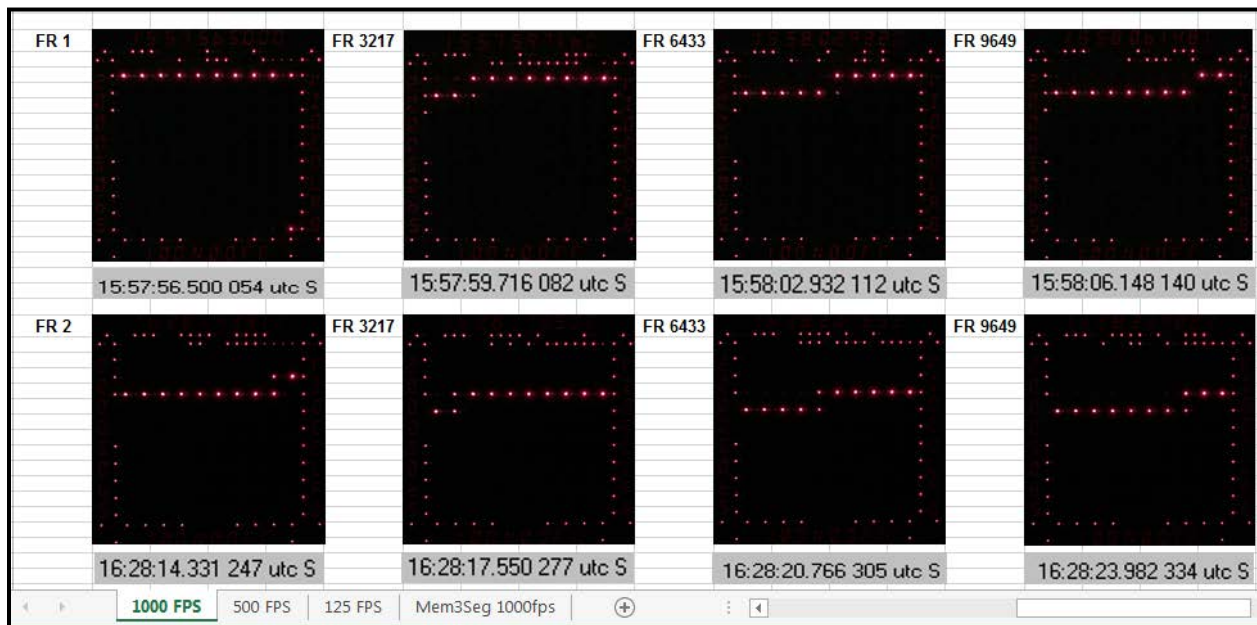


Figure B-30.   Additional Screenshots of Select Frames Used in Analysis (High Frame Rate Test Series)

B.7.2   Automated Data Reduction and Analysis

Engineers at WSMR developed a software program called LabDITCS Reader, which uses advanced image processing routines to decode LEDs on the LabDITCS front panel and determine the UTC time at which each frame was exposed.  Because LabDITCS Reader was written to read image frames sequentially in their native format, it can process a large number of individual frames in a short period of time.  The software also logs all measurements electronically, thereby eliminating time and potential error through manual entry into notebooks, spreadsheets, etc.

Nevertheless, the LED decoding process is not perfect.  Transition points (i.e., second and millisecond rollovers) continue to be problematic for automated reading.  More sophisticated algorithms are being developed and tested to detect and correctly read rollover samples.  LabDITCS Reader is contractor-developed, government-owned software and available to other ranges that have an interest in the program.  Contact the Range Operations Optics Branch at WSMR for more information.

## B.8   Conclusions

The LabDITCS provides a robust, proven toolset for assessing timing properties of new and existing visible imaging systems (digital, analog, film).  By following very careful setup, configuration, and calibration procedures, this system can provide timing measurement/characterization precision to within ±5 us.  Fast-response, LED-based test sets like LabDITCS can be used by the ranges to characterize optical sensors, recorders, and other support equipment to verify that timestamp accuracies satisfy mission requirements.

This page intentionally left blank.

# APPENDIX C
## Laboratory - Digital Imager Timing Certification System (LabDITCS) Reader
## Users Manual (BETA)

This appendix includes a copy of the User's Manual for the LabDITCS Reader Software that was developed at WSMR to help automate and streamline the reduction, processing, and analysis of LabDITCS data. This program is government-owned and may be available by contacting the author listed below. This beta version of the User's Manual is attached as-is to provide the reader with a general notion of the capabilities and limitations of the software.

**NOTE: As the following material has been previously published outside of the RCC, it is reprinted here without editorial review by the RCC Secretariat.**



Prepared by:
TRAX
PO Box 398
WSMR, NM 88002-0398

Principal Point(s) of Contact:
Grant C. Senn, grant.c.senn.ctr@mail.mil
Date Prepared: 2013-01-04
Document Number: Version 1.0

CHANGE LOG

This record shall be maintained throughout the life of the document. Each published update shall be recorded. Revisions are a complete re-issue of entire document. A revision shall be made whenever the cumulative changes reaches ten percent (10%) of this document's content.

| CHANGE / REVISION RECORD | | | |
|---|---|---|---|
| Date | Page/Paragraph | Description of Change | Made By: |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

Table of Contents

# Table of Figures

**1.     LabDITCS Reader Overview**

This document provides information on how to use the LabDITCS Reader developed by the WSMR Vision Lab.

## 2. LabDITCS Graphical User Interface (GUI)

This section describes the LabDITCS Graphical User Interface (GUI).

### 2.1 MAIN GUI

The following figure shows the main LabDITCS Graphical Unser Interface (GUI)
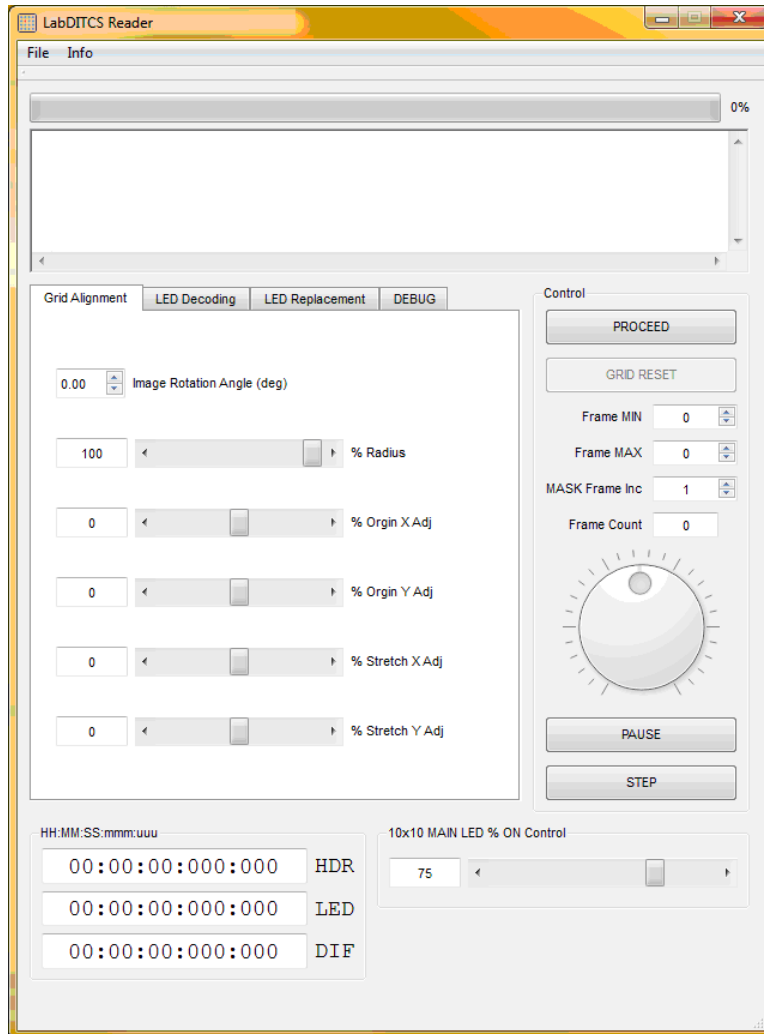


Figure 1 Main GUI

## 2.2 Progress Bar and Status Window

The Progress Bar and Status Window display the current progress and status. The status window will display prompts to the user during playback.
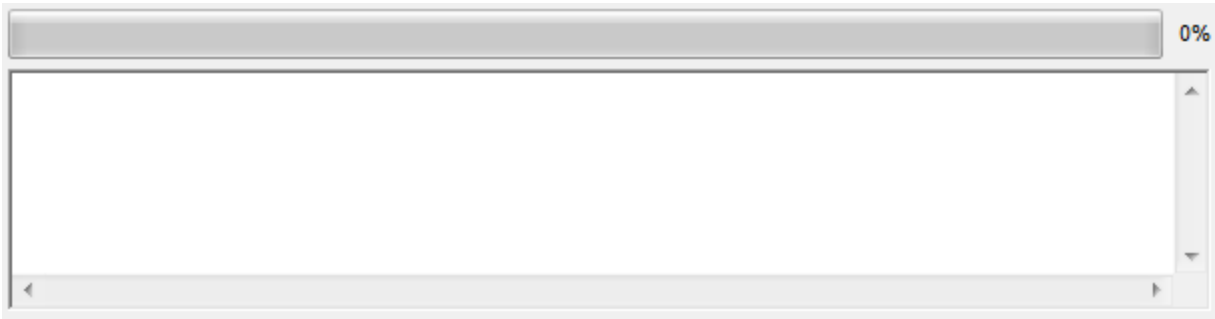


Figure 2 Progress Bar and Status

## 2.3 Grid Alignment Controls

The Grid Alignment Tab is used to adjust the grid overlay such that the LEDS are as close as they can be to the center of each grid summation box. An example of the grid overlay is show in Figure 3.
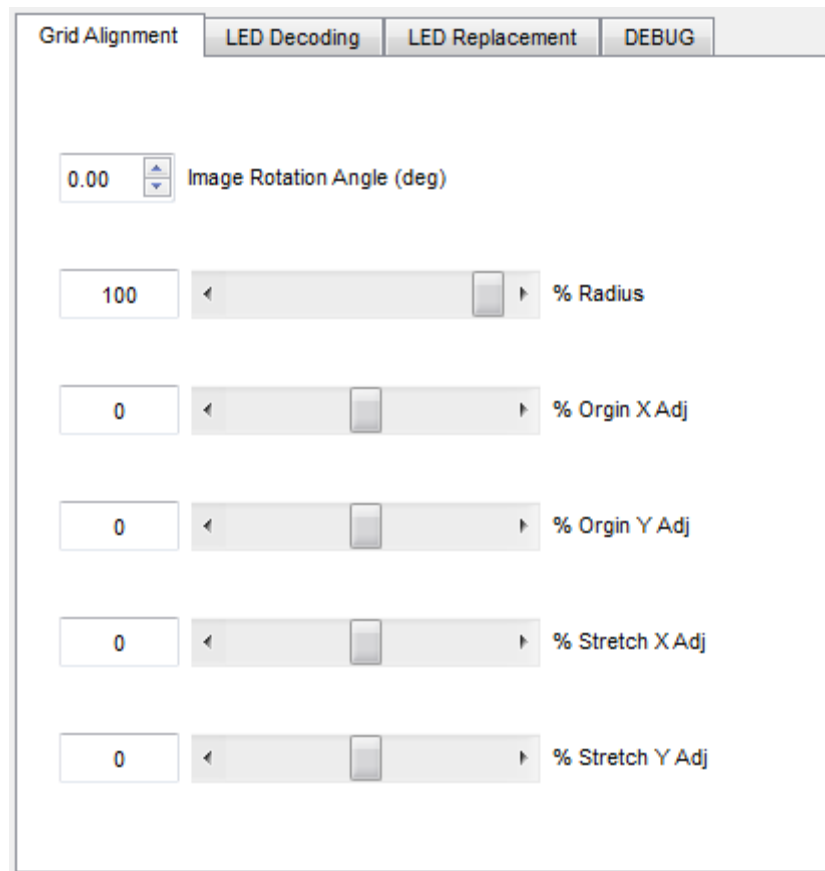


Figure 3 Grid Alignment Tab
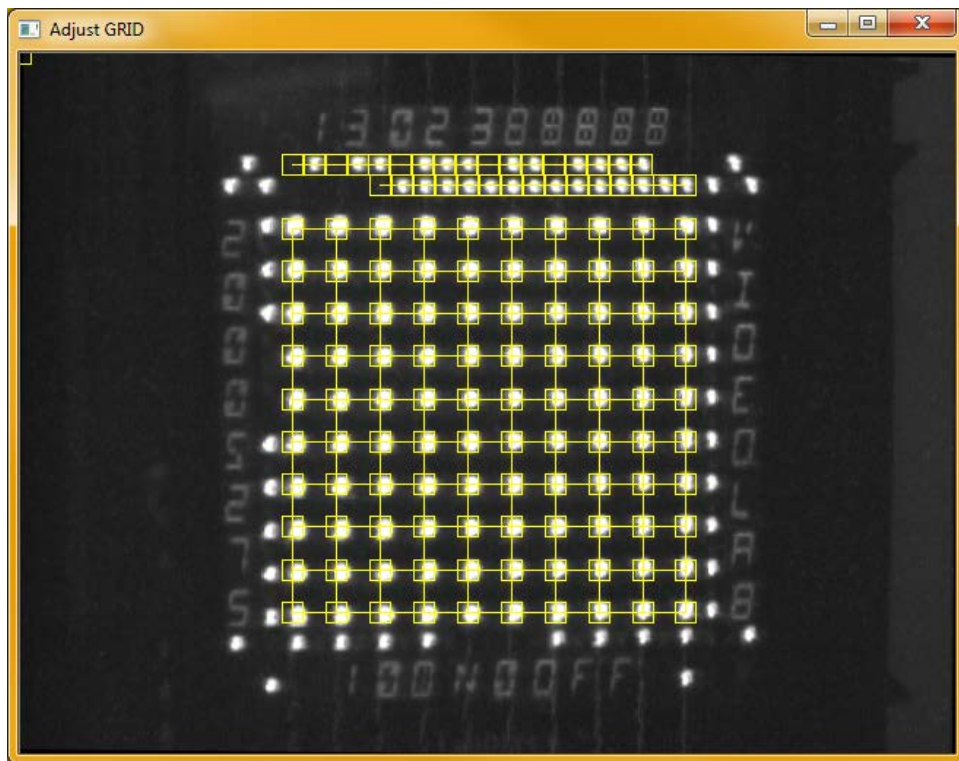
Figure 4 Grid Overlay Example

### 2.3.1. Image Rotation Angle (degrees)

The Image Rotation Angle is used to adjust the rotation of the image. If for example your camera was not aligned with the LabDITCS, you can rotate the image to align the grid.

### 2.3.2. % Radius

The % Radius adjusts the radius of the LED pixel summation boxes. For example if the intensity of one LED is bleeding over into an adjacent LED (ghosting) you can reduce impact of this artifact by reducing the size of the LED pixel summation box by reducing the radius percentage.

### 2.3.3. % Origin X Adj

The % Origin X Adj moves the whole grid horizontally.

### 2.3.4. % Origin Y Adj

The % Origin y Adj moves the whole grid vertically.

### 2.3.5. % Stretch X Adj

The % Stretch X Adj expands or contracts the spacing of whole grid horizontally.

### 2.3.6. % Stretch Y Adj

The % Stretch Y Adj expands or contracts the spacing of whole grid vertically.

### 2.4 LED Decoding per Frame

The LED Decoding Tab displays the LED decoding results of the current frame.
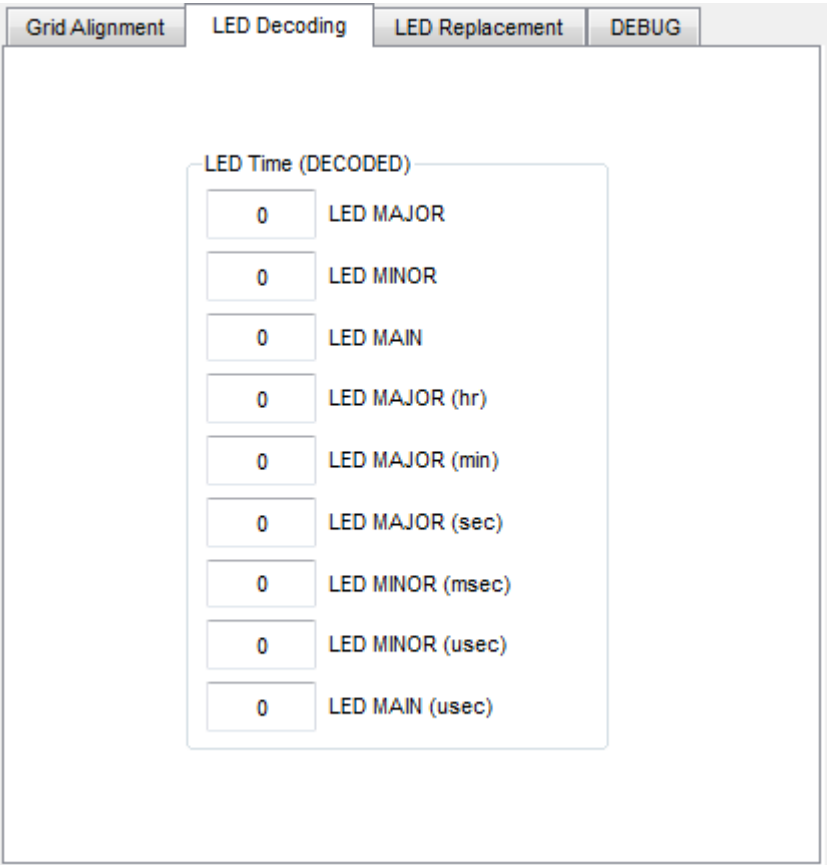


Figure 5 LED Decoding Tab

## 2.5 LED 10x10 Replacement

The LED Replacement tab options are used when not all of the 100 LEDS of the 10x10 MAIN are illuminated. In such a case the users must select one of the illuminated LEDS.

The 10x10 MAIN consists of 10 columns and 10 rows, as shown in Figure 16, with an index from 1 to 10 for each. To select the LED with the blue border shown in Figure 9 the user would set the MAIN ROW value to 1 and set the MAIN COL value to 3.

To enable the MAIN LED Replacement option the user must check the Enable box, at which point the summation value of the selected LED will be used for each of the 100 LEDS in the 10x10 MAIN.

Note it is important to select an LED whose illumination appears to match the other illuminated LEDS best. For example, the LED at row 1 column 4 is not as illuminated as the rest, and therefore would not be a good LED to choose as the replacement LED. Note this option affect the Percent on value described in section 2.6 the LED 10x10 Define Percent on Control.
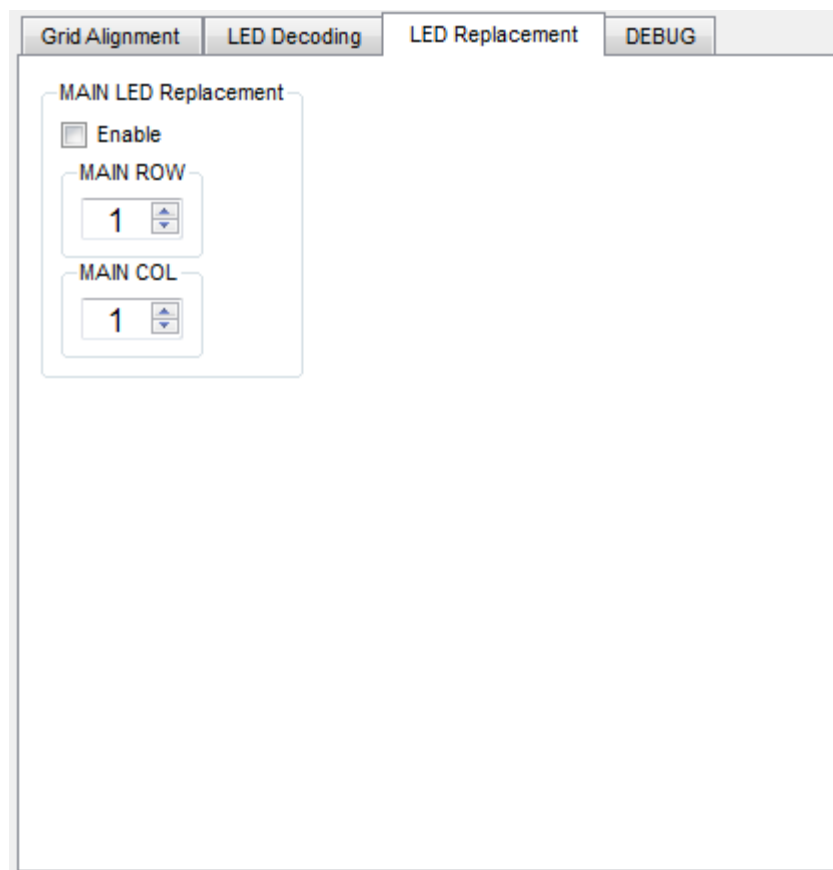


Figure 6 LED Replacement Tab

Figure 7 MASK MAX example with all 100 MAIN LEDS illuminated
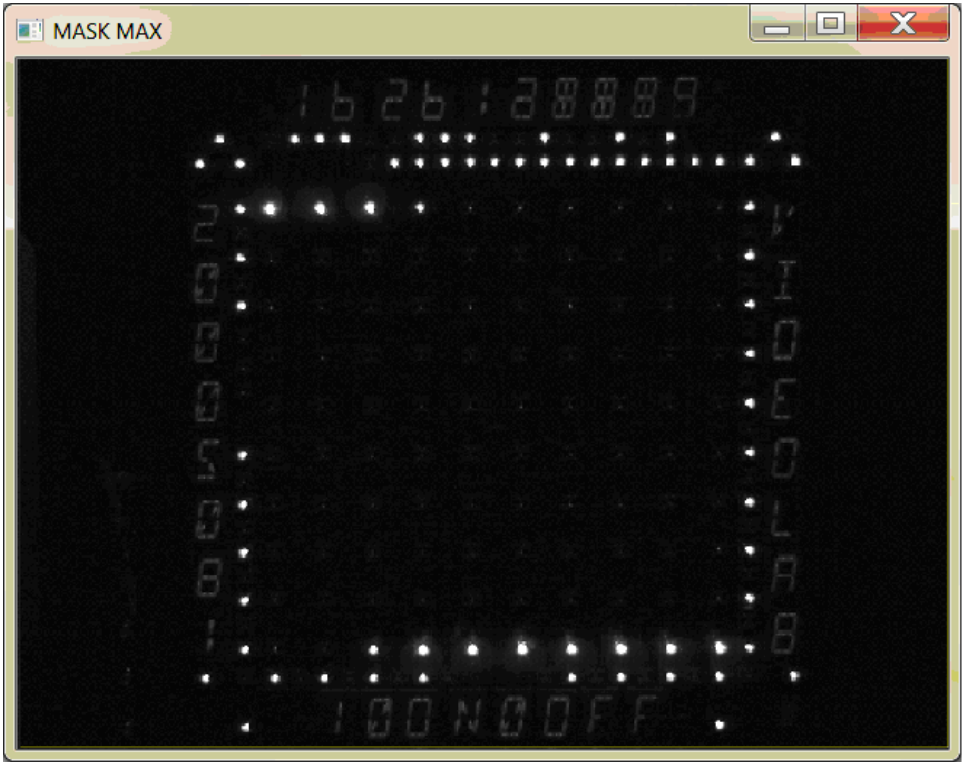


Figure 8 MASK MAX example with 12 of 100 MAIN LEDS illuminated
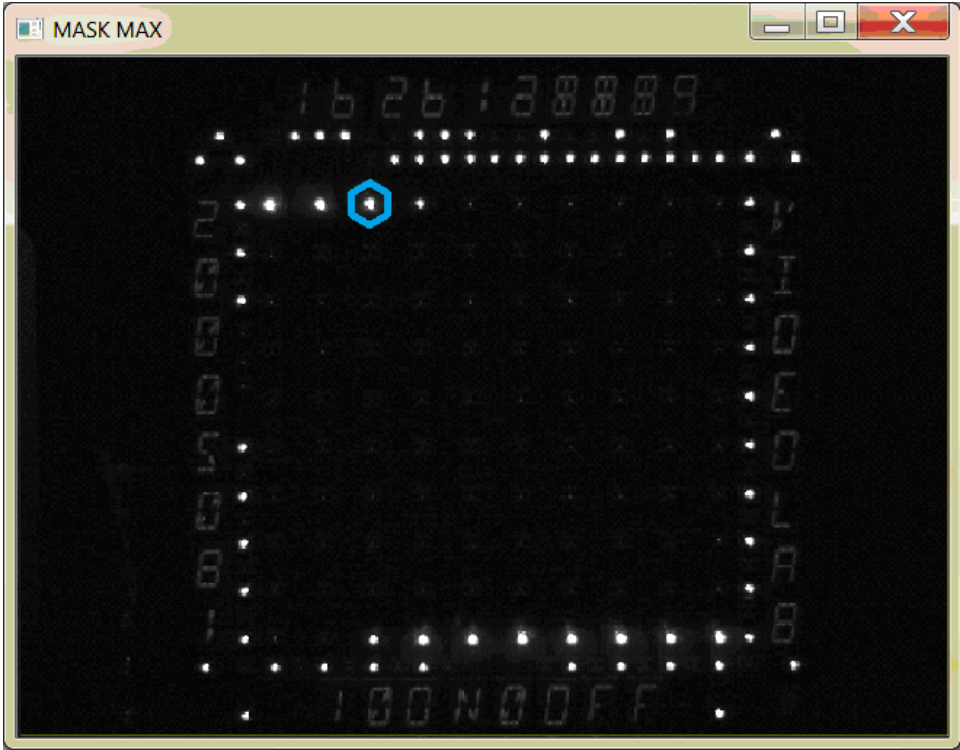
Figure 9 MASK MAX indicating row 1 column 3 LED with a blue border

## 2.6 LED 10x10 Define Percent on Control

The LED 10x10 Define Percent on Control is used to control the level at which an LED in the 10x10 matrix is considered to be on. The percent value is relative to the MAX MASK summation.



Figure 10 LED 10x10 Define Percent On Control

**2.7     Playback Control**

The Playback Control is used to control the processing playback of the video. You can select which frames to process and the speed of the playback by spinning the knob. The default speed is set to 50%.
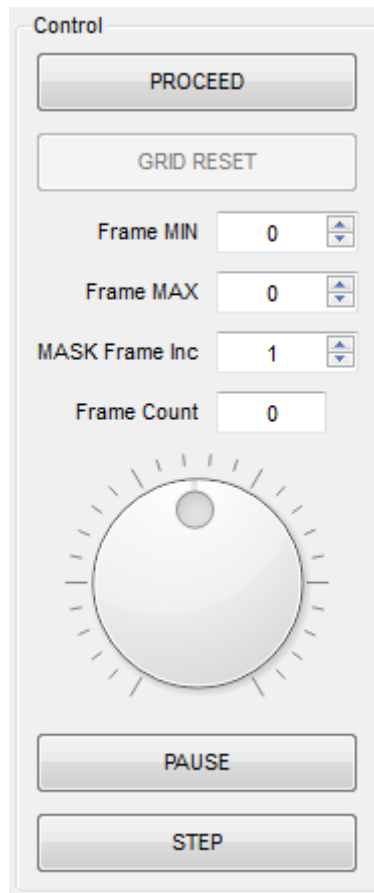
Figure 11 Playback Control

2.7.1.  PROCEED Button

The PROCCED Buttons is used to advance the state of the processing. The user will be prompted when to hit the PROCEED button in the status window shown in Figure 2.

2.7.2.  GRID RESET Button

The GRID RESET Button is used to reset the grid calculation by allowing the user to re-select the four corners. The button is typically disabled and only active when this option is available.

2.7.3.  Frame MIN

The Frame MIN adjustment allows the user to select the starting frame for analysis. The default is the first frame.

### 2.7.4.  Frame MAX

The Frame MAX adjustment allows the user to select the ending frame for analysis. The default is the last frame

### 2.7.5.  MASK Frame Inc

The MASK Frame Inc adjustment allows the user to select the increment value used during MAX MASK creation. To speed up processing of large video files it is recommended that this be set to an odd value bigger than one.

### 2.7.6.  Frame Count

The Frame Count displays the current frame count during playback processing.

## 2.8  Header Time vs. LED Decoded Time Display

The Header Time vs. LED Decoded Time Display shows the current frame header time stamp along with the current frame LED Decoded results. The difference of the two is also displayed.
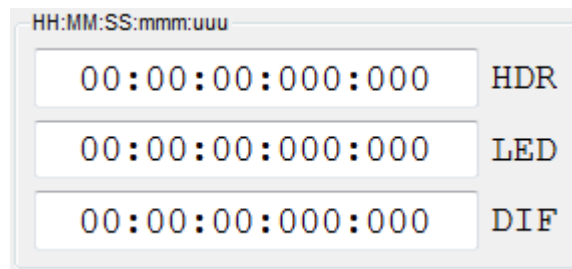


Figure 12 Header Time vs. LED Decoded Time Display

## 2.9     LabDITCS Four Corner Alignment LEDS

The following figure shows the location of the four alignment LEDS. The alignment LEDS are used to calculate the size and location of the grid overlay. After the MAX MASK is created the user will be prompted to click on the four LEDS in the following figure.

*NOTE at this time the user must click on the four corners in the order shown in the following figure.*
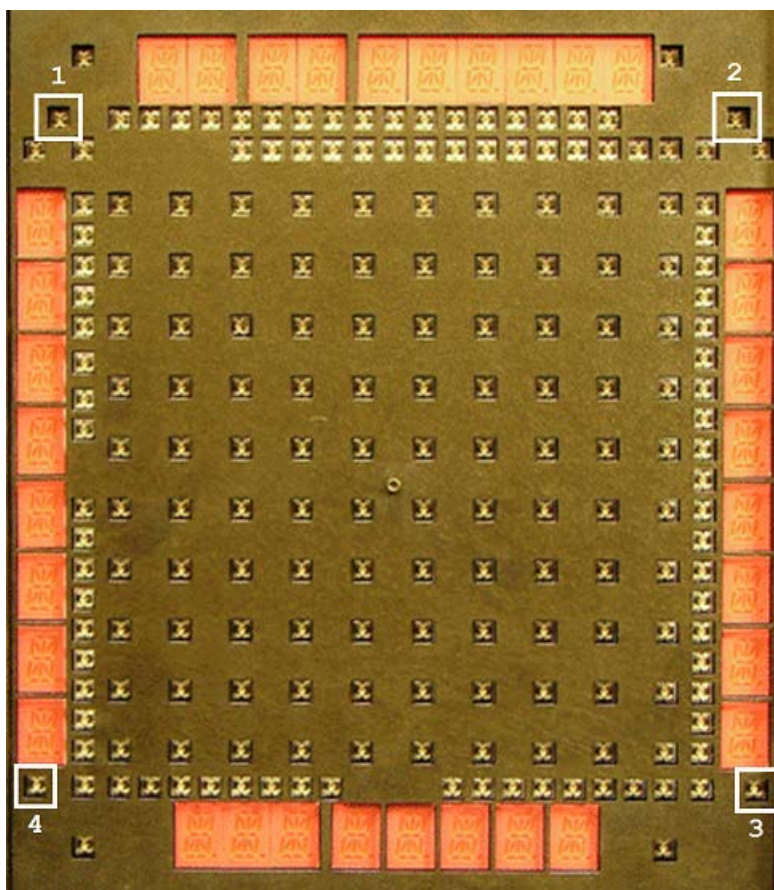


Figure 13 LabDITCS Four Corner Alignment LEDS

## 2.10    LabDITCS MAJOR MINOR MAIN LEDS

The following figures show the location of the LabDITCS MAJOR, MINOR and MAIN LEDS
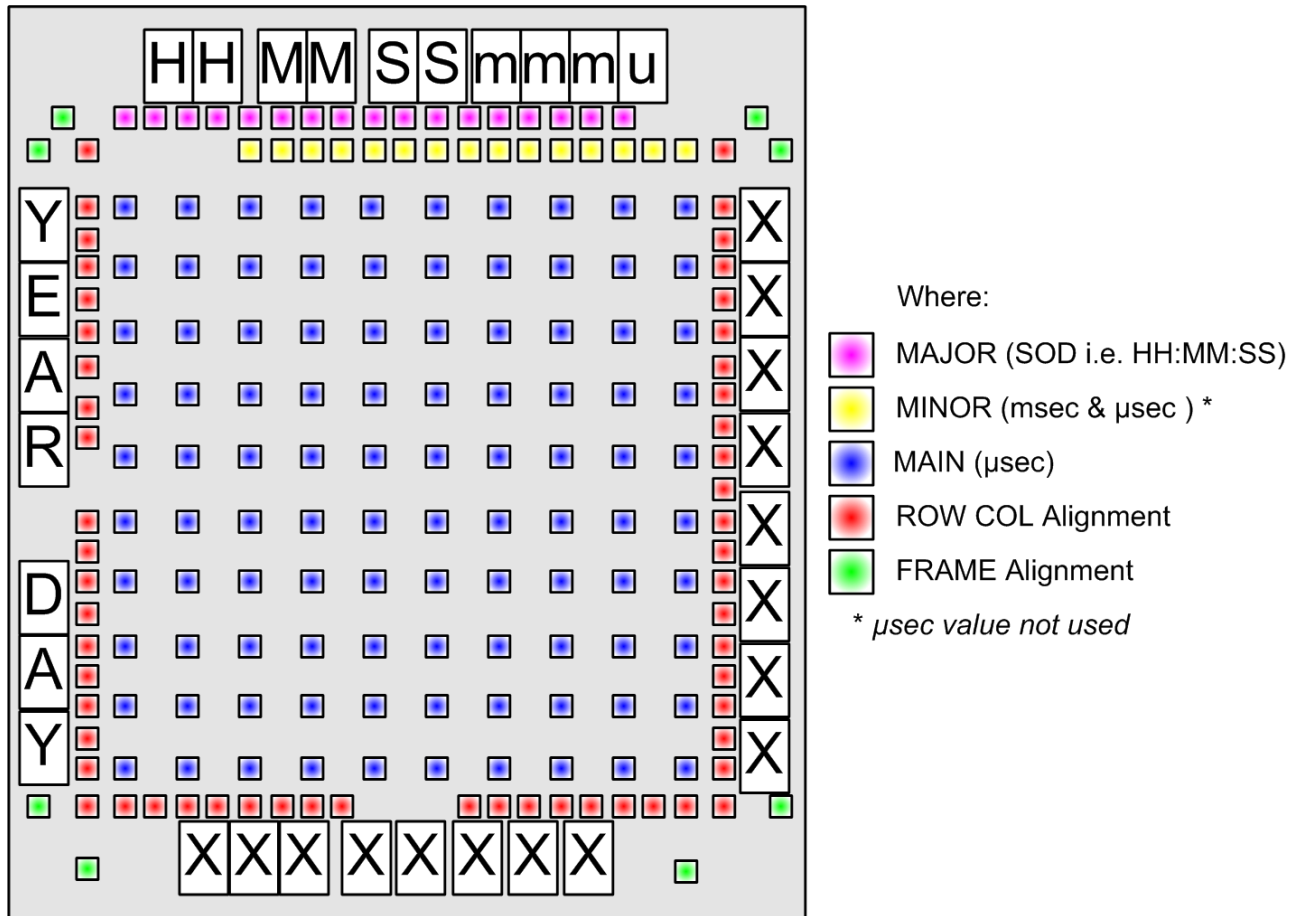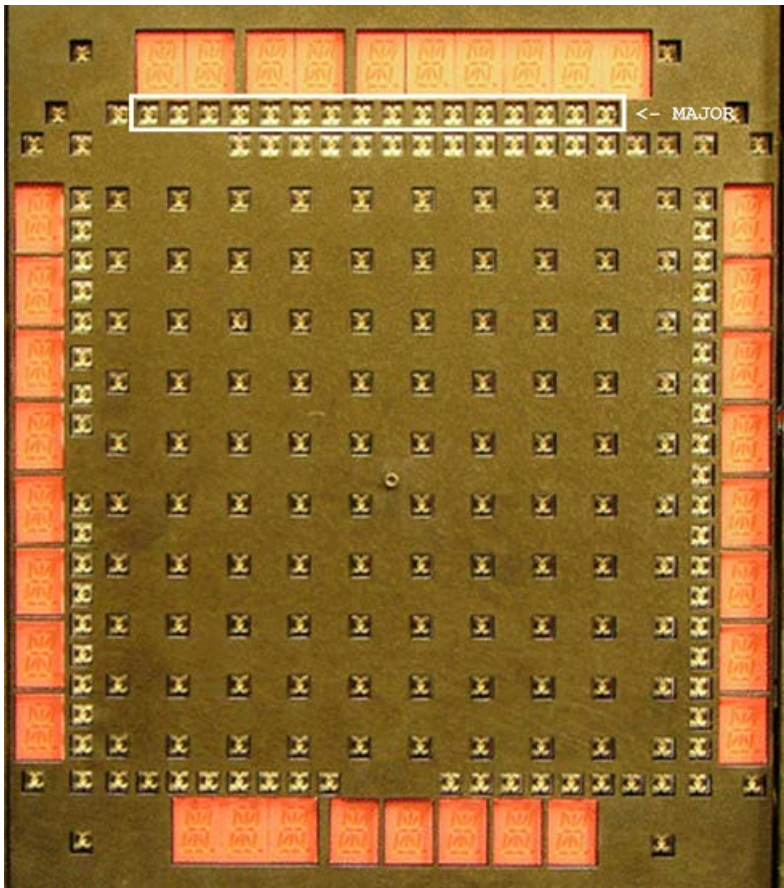
Figure 14 LabDITCS MAJOR LEDS
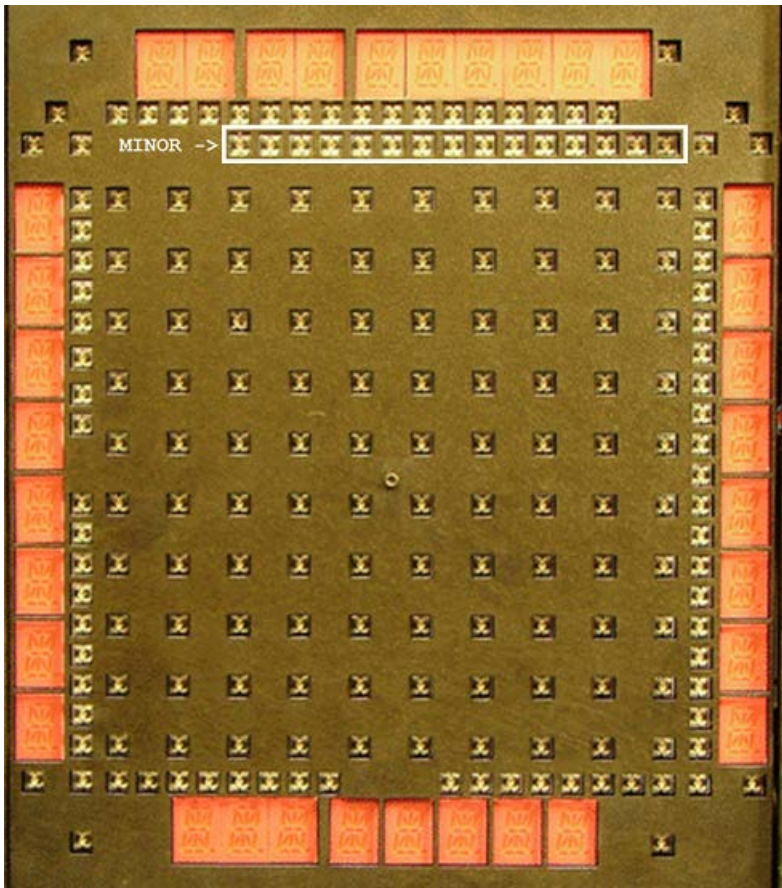
Figure 15 LabDITCS MINOR LEDS
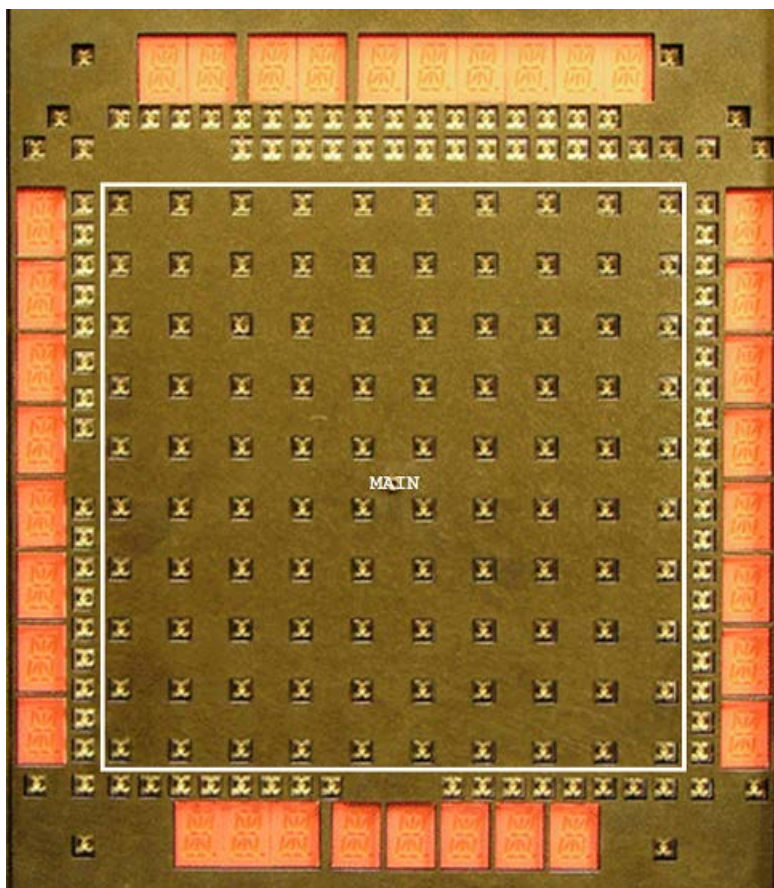
Figure 16 LabDITCS MAIN LEDS

## 2.11    Log Files

The log files are saved in the C:\WSMR directory for the corresponding log file. The log file name will be the same as the processed video file and appended with the current time and *.csv extension. The log file can be opened up in EXCEL for viewing and post processing. But we recommend you use the MATLAB script provided for post processing.

## 3. Video Processing Example

This example is provided to show the typical steps in using the LabDITCS reader. The following example makes use of the example.dig video file. The example.dig file is included as part of the LabDITCS Reader install and is located at c:\xxxx

### 3.1 Step 1 : Open File and Select Frames

From the File menu shown in Figure 17 select Open.
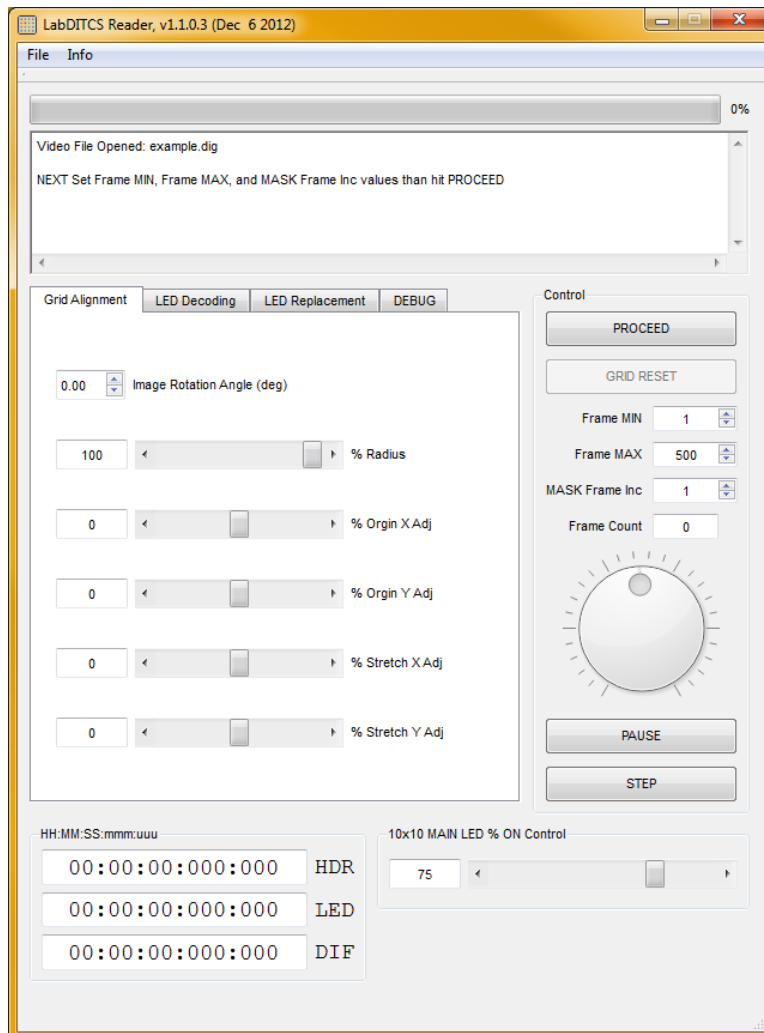


Figure 17 Open File and Select Frames GUI

Upon selecting Open from the File menu a Windows Open Document text box opens up that enables the user to navigate to the location of the video file. After opening the video file the LabDITCS Reader will update the Status Window with the name of the video file followed by a user prompt. The prompt informs the user to set the frame min, frame max, and the mask frame increment values prior to hitting proceed. In this example the defaults values are used.

## 3.2 Step 2 : Create the MASK MAX

Next step click the proceed button to create the MASK MAX.
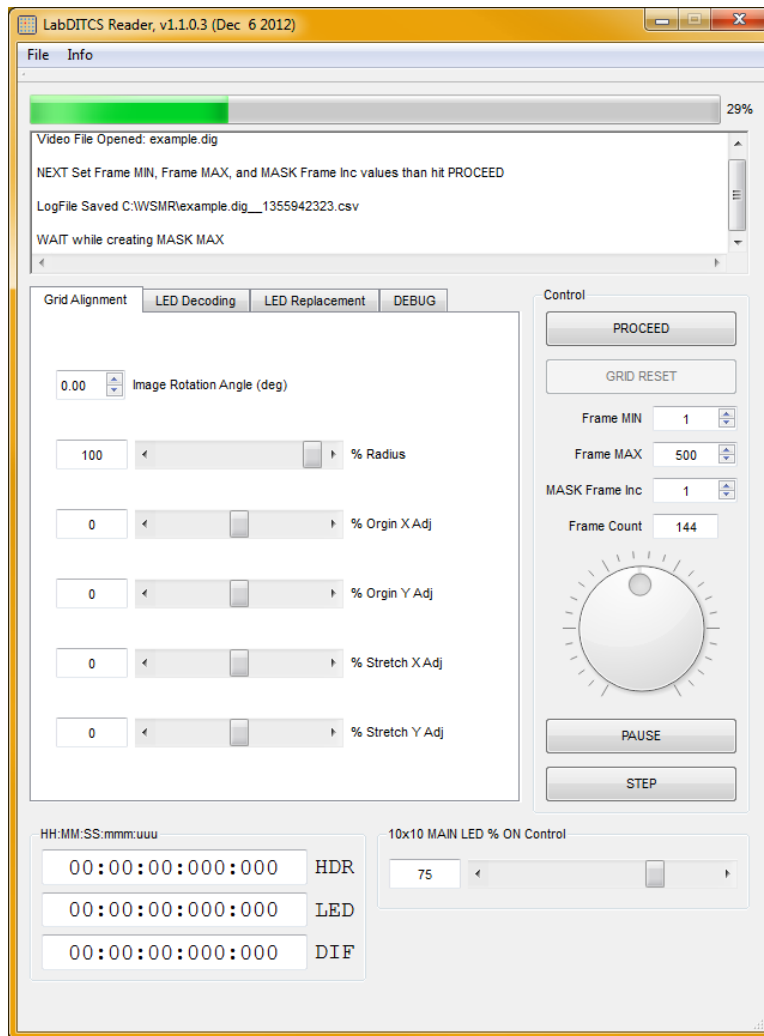


Figure 18 Create the MASK MAX GUI

Upon clicking the proceed button the LabDITCS Reader GUI Process Bar and Frame Count will display the current status of the MASK MAX creation process as shown in Figure 18.  It will also spawn a real time display window called MASK MAX frame creation as shown in Figure 7. Once the MASK MAX creation is complete the user has to verify that all 100 LEDS of the 10x10 MAIN are illuminated, as shown in Figure 7. Note in some cases (not this example) not all 100 LEDS of the 10x10 MAIN are illuminated , as shown in Figure 8, at which point the user would have to make use of the LED 10x10 Replacement option described in section 2.5.

### 3.3    Step 3 : Select the Four Alignment LEDS

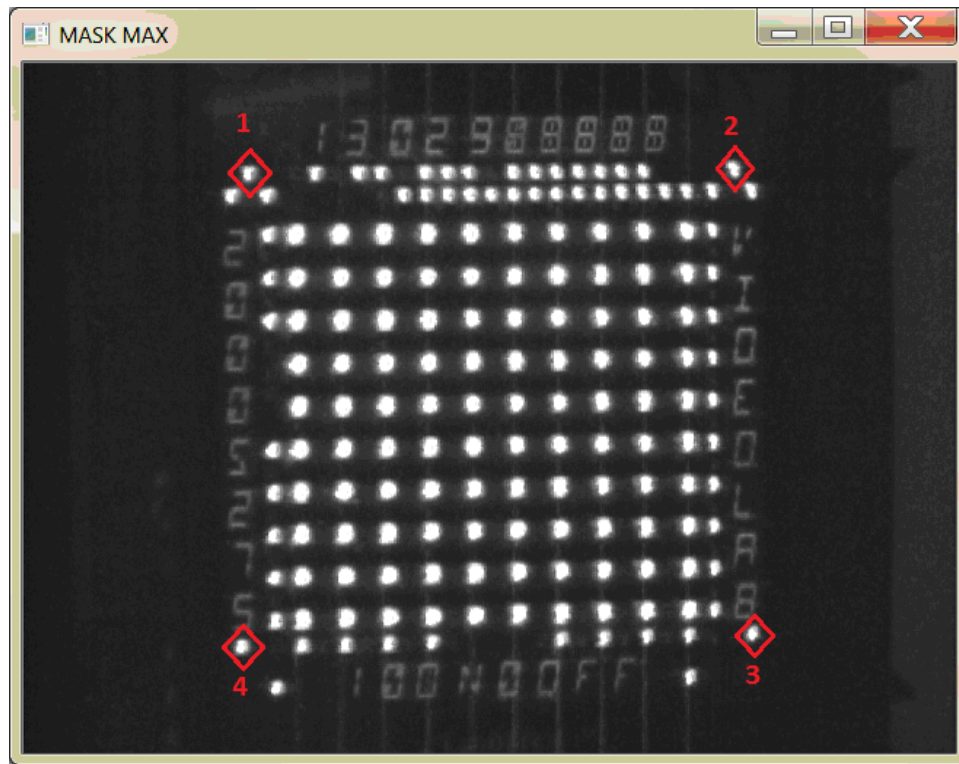Next step click on the four alignment LEDS, in order, of the MASK MAX show in red in Figure 19.



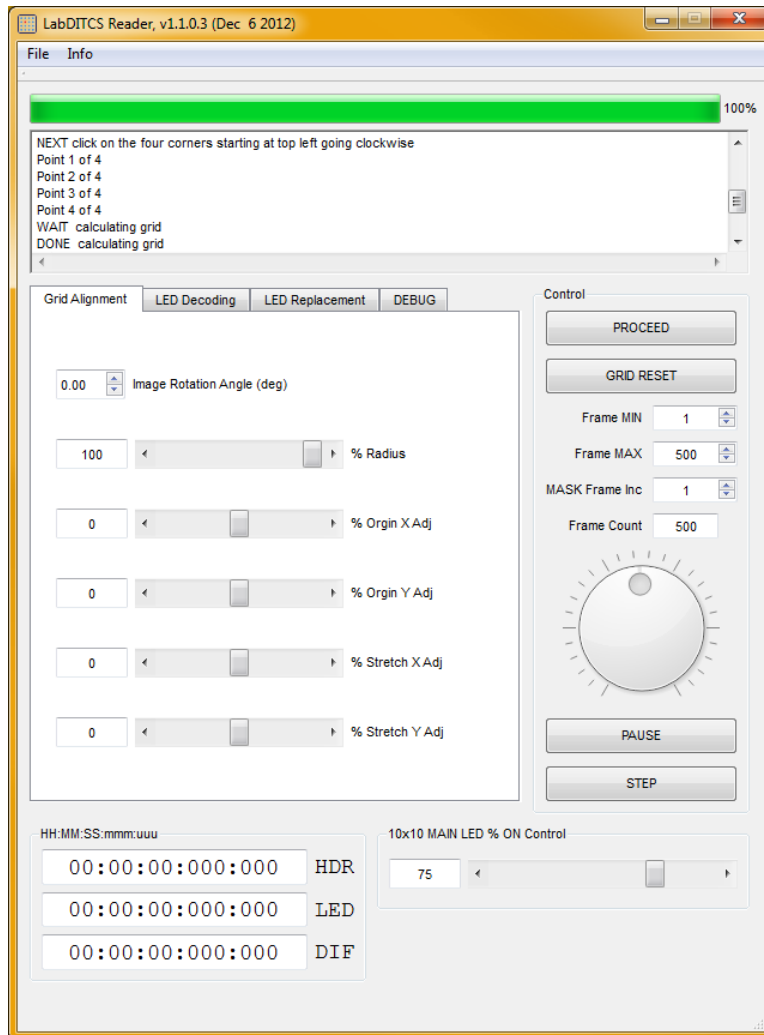Figure 19 MASK MAX Four Alignment LEDS

Figure 20 Click on Four Corners GUI

As you click on each of the alignment LEDS the LabDITCS Reader Status window will update with the corresponding LED point count as shown in Figure 20. Note after clicking on the four alignment LEDS the MASK MAX video frame is closed and the Adjust Grid video frame is displayed as shown in Figure 21.
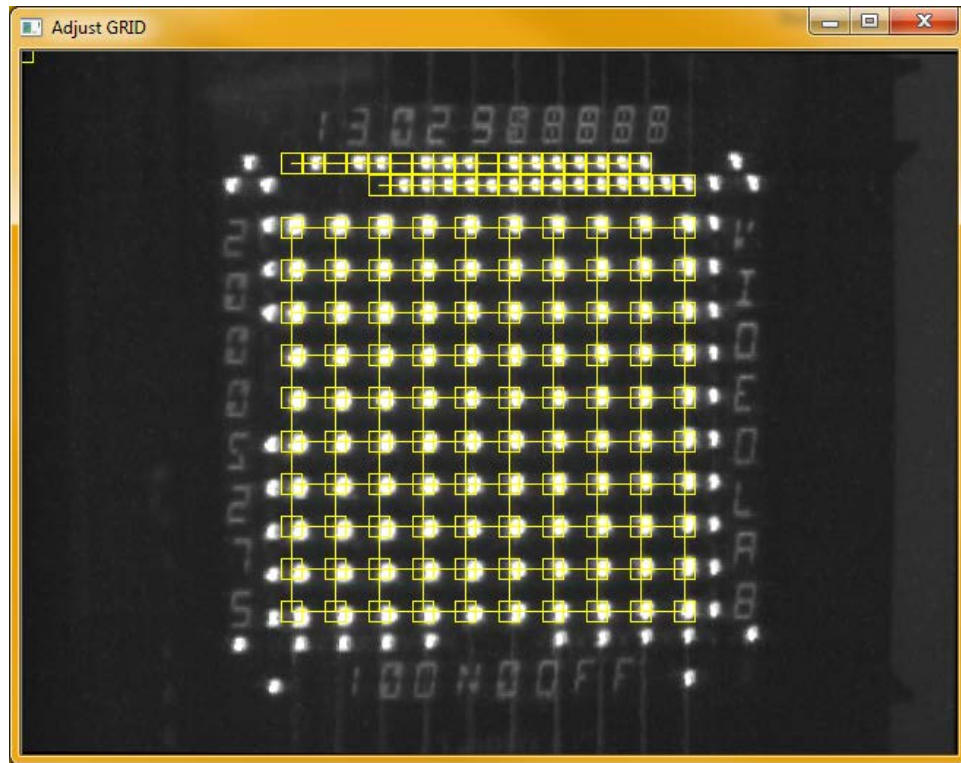
Figure 21 Adjust Grid Display

The alignment of the grid relative to the LEDS depends on how well the user clicked on the four corners and the corresponding grid calculations. As you will see in the next step, tools are provided to adjust the location and size of the grid relative to the LEDS.

### 3.4    Step 4 : Adjust Grid

Next step, if necessary, use the LabDITCS Reader tools under the Grid Alignment Tab to adjust the grid overlay location and size.
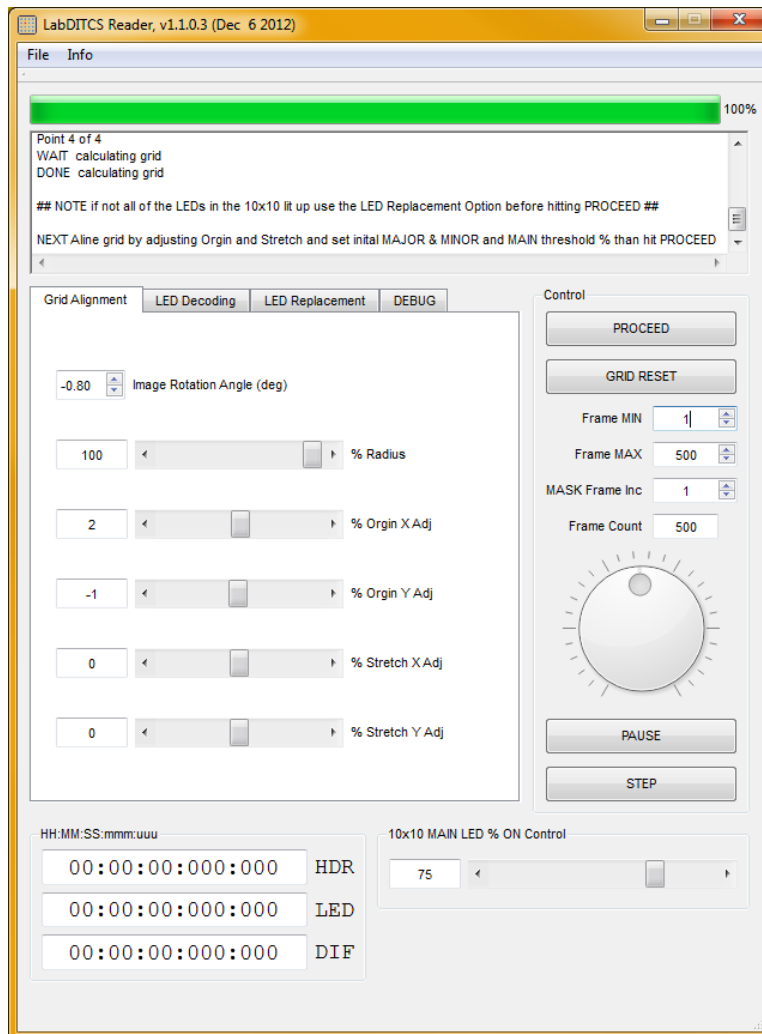


Figure 22 Adjust Grid GUI

For example compare Figure 23 to Figure 24. You should notice the grid in Figure 24 is aligned better than the grid in Figure 23.  This improved grid alignment was accomplished by setting the rotation angle to -0.80 which causes the image behind the grid to rotate relative to the grid. Next the whole grid is moved slightly to the right (positive) by setting the '% Origin X Adj' to 2. Next the whole grid is moved slightly up (negative) by setting the '% Origin Y Adj to -1. The size of the grid appears to be fine therefore the '% Stretch X Adj' and the '% Stretch Y Adj' are left at their default values. If necessary the size of the grid can be made bigger (positive) or smaller (negative) by in X or Y by adjusting these values. Also note the size of the grid boxes drawn around the LEDS appear to be fine and therefore the '% Radius' is left at it's default value of 100%. If necessary the size of the box can be reduced by lowering this value, which in turn will affect the intensity summation value in that the summation value is depended on the pixels inside this box for each LED.
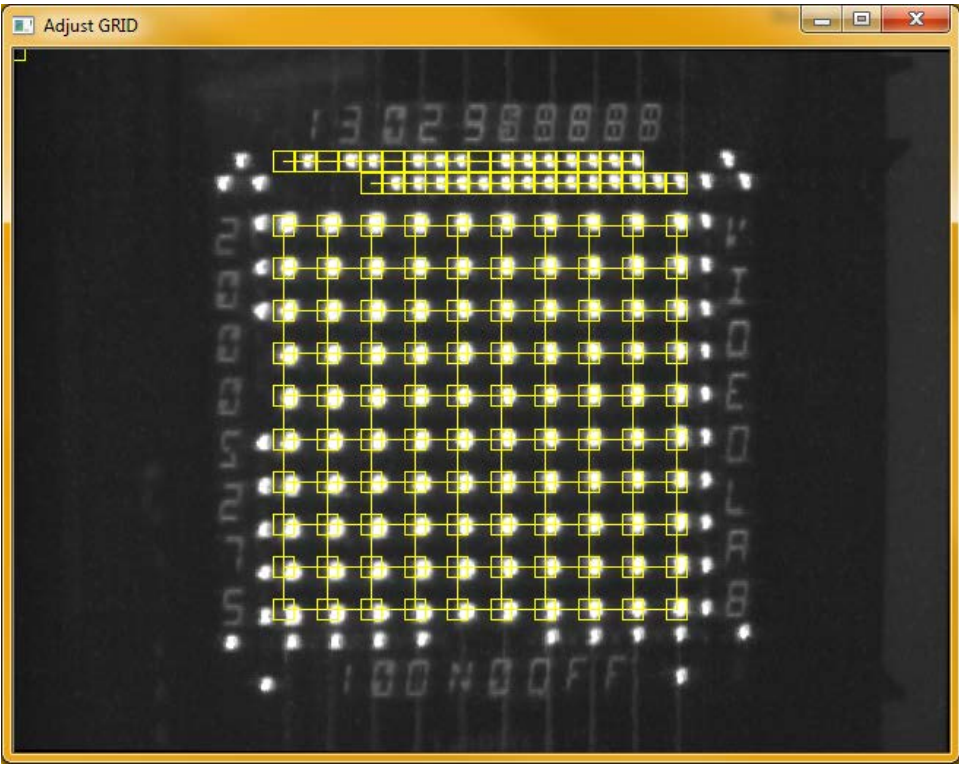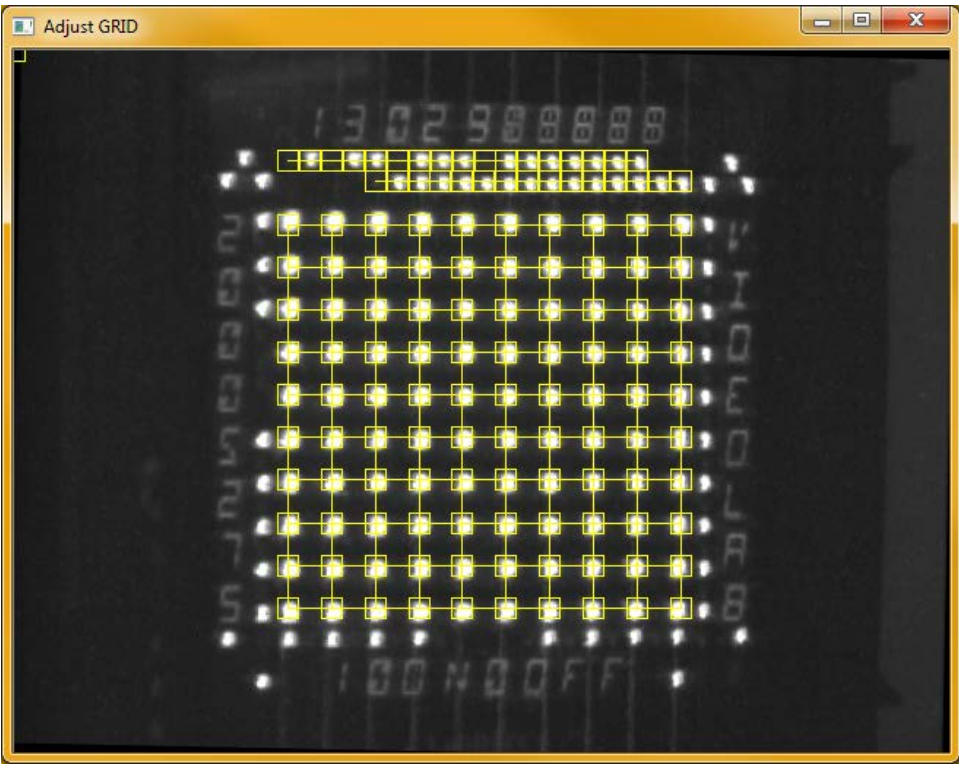
Figure 23 Adjust Grid display before adjustments



Figure 24 Adjust Grid display after adjustments

## 3.5 Step 5 : Processing Video

Next step click the proceed button to process the video

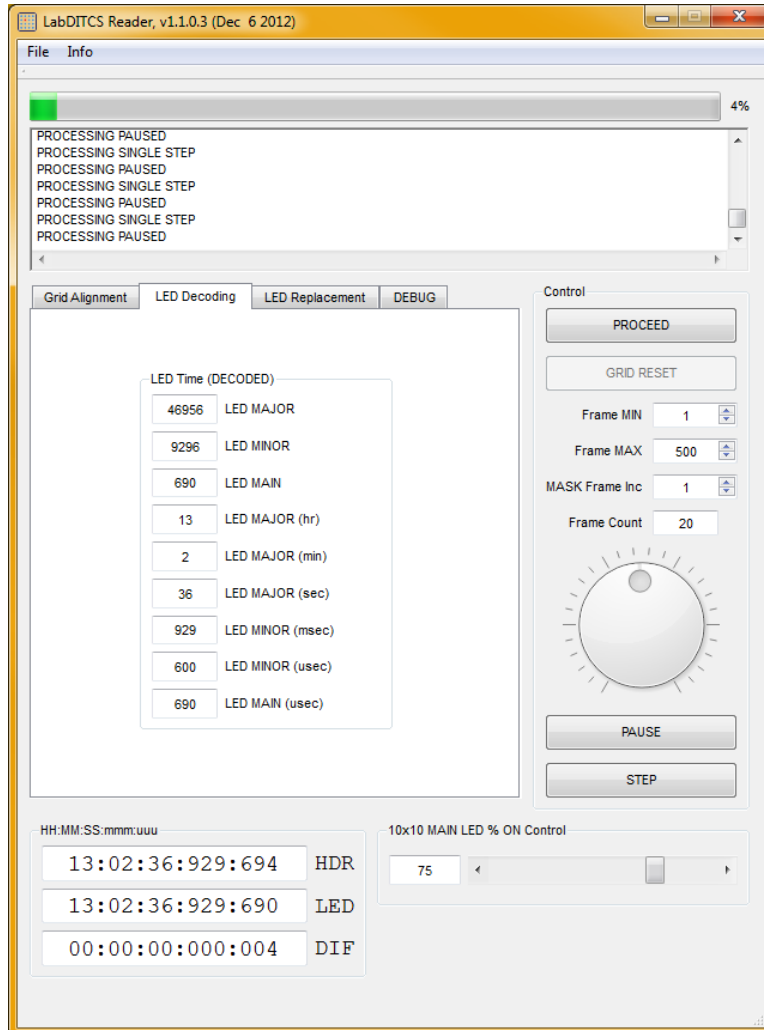### 3.5.1. Processing Video Pass Case


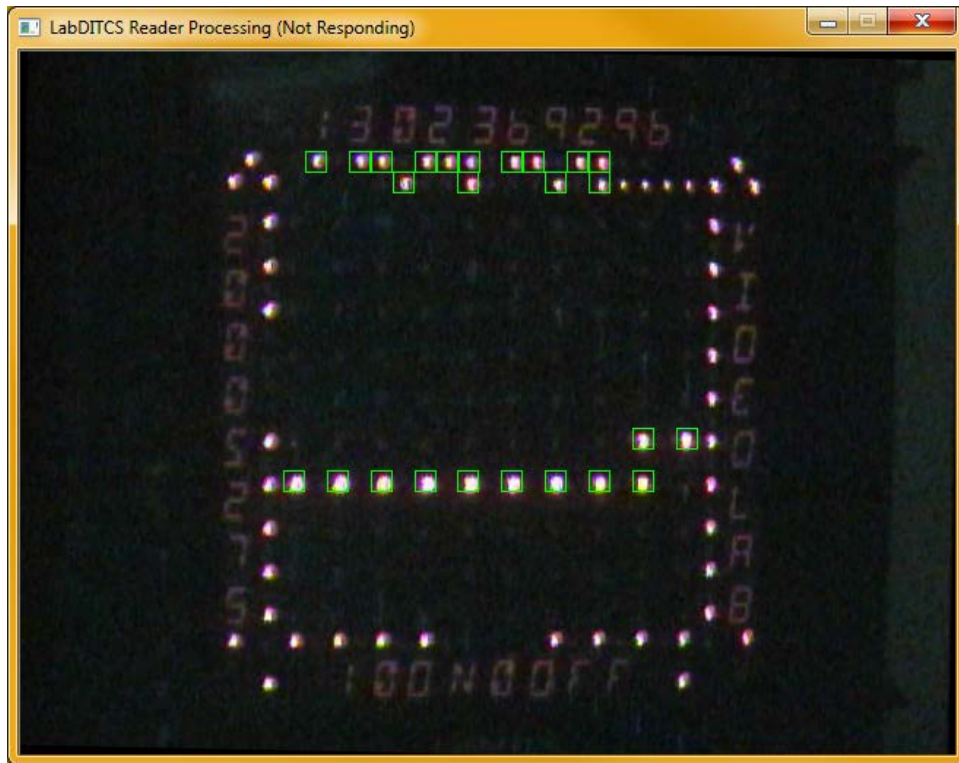Figure 25 Processing Video GUI Passed example

Figure 26 Processing Video Frame Passed example

Note Figure 26 shows green squares around the LEDS that are considered to be on. The green indicates a passed comparison. Look at the Header Time vs. LED Decoded Time Display in Figure 25 we can see the hours, minutes, seconds, milliseconds and microseconds comparisons between the header time and the decoded LED time. In this case the difference is 4 microseconds. Also note the LCD display shown in Figure 26 matches the values header and LED decoded values down to the millisecond, where the microsecond display of the LCD is limited to the hundreds display of the microsecond value in the header.
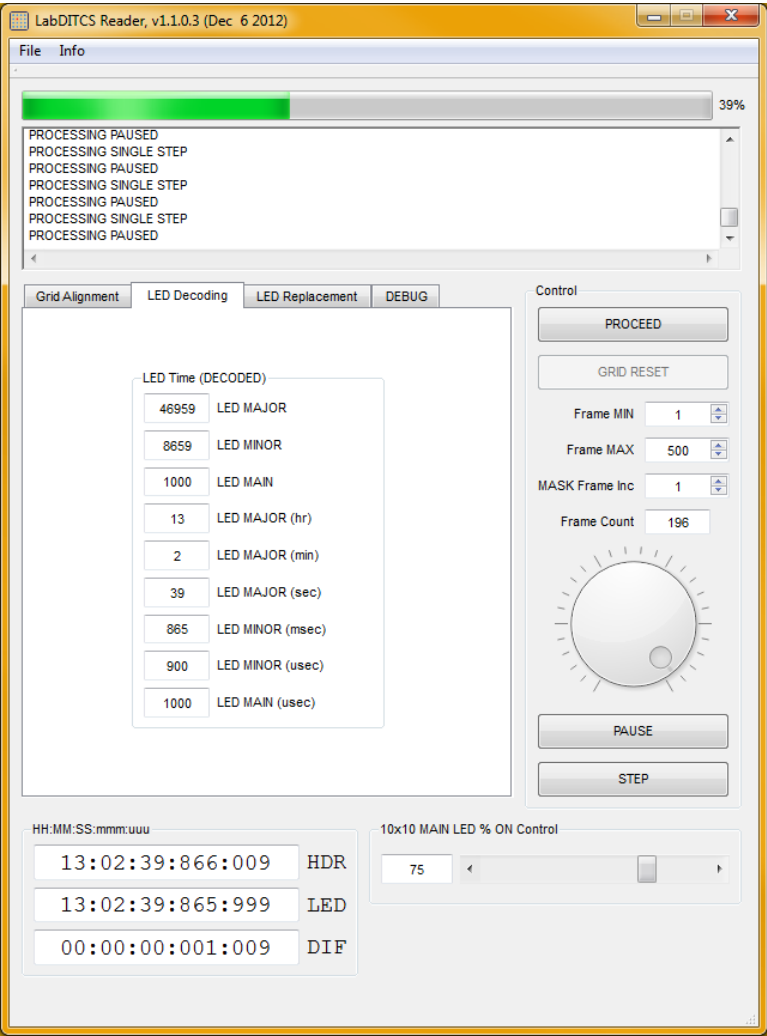
### 3.5.2. Processing Video Fail Case



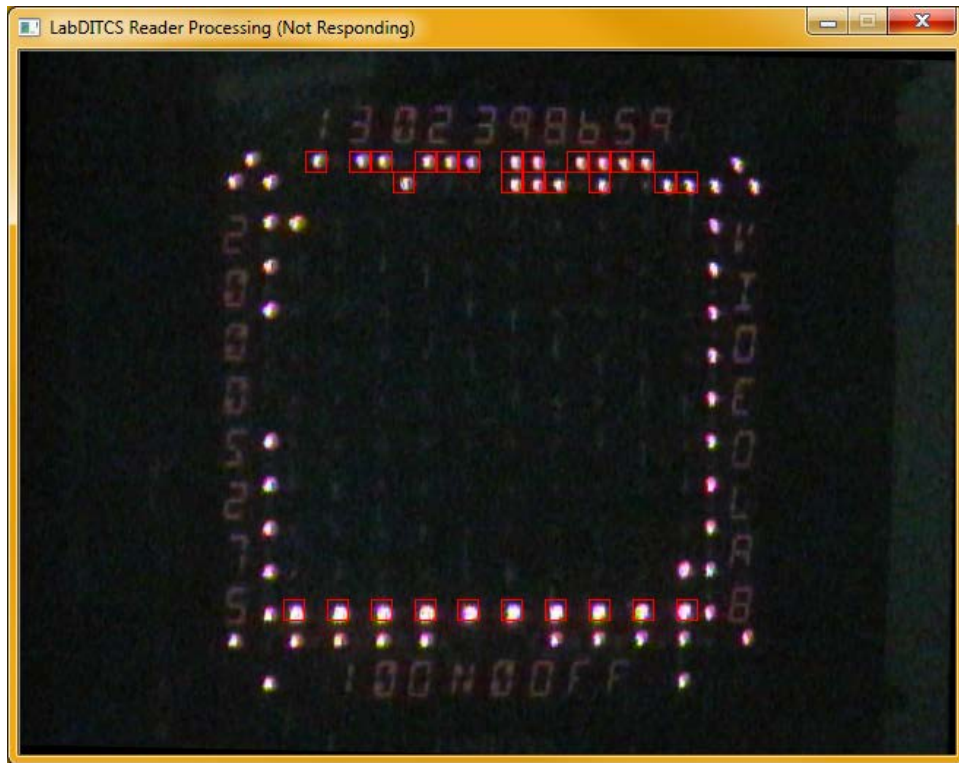Figure 27 Processing Video GUI Failed example

Figure 28 Processing Video Frame Failed example

Note Figure 28 shows red squares around the LEDS that are considered to be on. The red indicates a failed comparison. Look at the Header Time vs. LED Decoded Time Display in Figure 27 we can see the hours, minutes, seconds, milliseconds and microseconds comparisons between the header time and the decoded LED time. In this case the difference is 1 ms and 9 µs. Also note the LCD display shown in Figure 28 matches the values header and LED decoded values down to the millisecond, where the microsecond display of the LCD is limited to the hundreds display of the microsecond value in the header. Note this is considered a fail, in that the milliseconds didn't match, but there is actually nothing wrong with this decode. This is just a case where the LED decode time is slightly ahead of the header time such that the milliseconds has incremented with regards to the LED decode time before the header time. The real time failure logic is simplified, where as the MATLAB script provided has more failure logic such that this type of roll over failure would not occur.

### 3.5.3. Processing Video Log File

Note the log file is saved in the C:\WSMR directory.

## 4. Current Status and Future Development

This section list proposed options for future versions of the LabDITCS Reader. Please feel free to pass along your wishes to Grant C. Senn at grant.c.senn.ctr@mail.mil.

### 4.1.1. Random Four Corner Selection

Currently you have to click on the four corners in the order shown in Figure 13. Otherwise the grid will not be calculated correctly.

### 4.1.2. Log File Playback

Where log file from a previous process will be read in allow the user to jump-to bad data (error code based) to visually see if it was an error in the LED decoding, or a true error.

### 4.1.3. Auto pause on error

Add an auto pause on error option so user can verify errors in real time.

### 4.1.4. Export LED intensities

Export the LED summation intensity for each LED to a file. In essence a LabDITCS specific cal file.

### 4.1.5. Add Statistical Processing to Log File.

Currently the mean and standard deviation are done post processing via EXCEL or MATLAB, but could be added to the program.

### 4.1.6. Add LED Decode Logic

Currently the LabDITCS Reader real time LED Decode logic is simplified. All of raw data and LED Decode logic results are save to the log file frame by frame. The intent here is so the user can apply post processing LED Decode logic algorithms. A MATLAB script has been developed and provided for this purpose. Taking this approach will enable the end user to adjust and or apply new algorithms for their specific cases.

# APPENDIX D

## Citations

Howard Waldie. "Laboratory Digital Imager Timing Certification System (LabDITCS), User's Manual." Rev R0. September 2013. May be superseded by update. Available on request to support@protectedlogic.com.

Jim Beurrier, Vision Research/Ametek Materials Analysis Division. "Procedure for adjusting the time shift that can occur using modulated IRIG on V1610/1210 cameras." 23 August 2013. Retrieved 27 July 2016. Available at http://www.wsmr.army.mil/RCCsite/Documents/468-16_Testing_Validation_Properties_High_Speed_Digital_Cameras/Modulated_IRIG_phase_adjustment.pdf.

John Eidson. *IEEE-1588 Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems - A Tutorial*. Agilent Technologies. 10 October 2005. Retrieved 11 February 2016. Available at http://www.nist.gov/el/isd/ieee/upload/tutorial-basic.pdf.

Institute of Electrical and Electronics Engineers. *IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems*. IEEE 1588-2008. Geneva: International Electrotechnical Commission, 2008.

National Institute of Standards and Technology. *NIST Time and Frequency Services*. NIST Special Publication 432. January 2002. May be superseded by update. Retrieved 11 February 2016. Available at http://tf.nist.gov/timefreq/general/pdf/1383.pdf.

Range Commanders Council. *IRIG Serial Time Code Formats*. RCC 200-04. September 2004. May be superseded by update. Retrieved 11 February 2016. Available at http://www.wsmr.army.mil/RCCsite/Documents/200-04_IRIG_Serial_Time_Code_Formats/.

This page intentionally left blank.

# APPENDIX E

# References

## ADDITIONAL RESOURCES

LabDITCS Reader Software - Contact Mr. Grant Senn.  (575) 678-3667.
grant.c.senn.ctr@mail.mil.

Timing Check Software Utility - Contact Mr. Larry Alejo.  (575) 678-4317.
larry.w.alejo.civ@mil.mil.

**\* \* \*  END OF DOCUMENT  \* \* \***