



ThermoVision[®] SC4000/SC6000

User's Guide



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1 Introduction

Thank you for choosing the ThermoVision® SC4000/6000 camera!

The ThermoVision® SC4000/6000 camera is the most advanced commercial infrared camera in the world, and was designed with the high-end infrared camera user in mind.

1.1 Camera System Components

The ThermoVision® SC4000/6000 infrared camera and its accessories are delivered in a box which typically contains the items below.

Description	Indigo Part Number
Power supply, 24V, 4A	306-0001-00
AC line cord	208-0004-02
Analog video 75 ohm molded BNC cable	208-0004-21
Gigabit Ethernet Cat-6 cable, 2m length	208-0004-28
USB cable, 2m length	208-0004-31
Bayonet Mount Plug	322-0100-01
BNC Jack to RCA Plug adapter	202-0011-04
Laboratory Calibration Plate	307-0003-01
Water-resistant Hardigg Storm case	307-0003-01
SC4000/6000 User's Manual	420-0044-00
SC4000/6000 Quick Start Guide	420-TBD
SC4000/6000 GUI Installation CD	TBD

- There may also be additional items that you have ordered. Refer to the **SC4000/6000 Camera Shipping Checklist** included with the camera system for the complete list of items shipped.

1.2 System Overview

The ThermoVision® SC4000/6000 infrared camera system has been developed by FLIR Systems Indigo Operations to meet the needs of the research, industrial and ruggedized OEM communities. The camera makes use of Indigo's standard readout integrated circuits (ROICs), mated to a variety of infrared detector materials to cover the full range of the infrared spectrum. SC4000/6000 cameras utilize large format, 640 x 512. The architecture of the camera system fully exploits the rich palette of features available in these standard ROICs to support the specialized needs of basic research.

- The SC4000/6000 is a stand-alone imaging camera that interfaces to host PCs using some of the latest interface standards, including Gigabit Ethernet and Camera Link. The SC4000/6000 is designed to work with the Indigo common SDK for command and control. This SDK is available from Indigo Operations and makes it possible for the system designer to write their own control GUI and acquire image data with their own custom application.

- Key features of the SC4000/6000 camera:
- Fast Frame Rates
- The SC4000/6000 camera features extremely fast frame rates – 50 Megapixels per second, which enables 126 frames per second for 640 x 512 FPAs, or 420 frames per second for 320 x 256 FPAs.
- 14-Bit Digital Image Data


The SC4000/6000 camera system is built around high performance 14-bit A/D converters, preserving the full dynamic range of the FPA.

- Windowing Capability
- Higher frame rates are available by windowing down at the Focal Plane Array (FPA) level. Arbitrary size and location of windows are available, limited only by the intrinsic characteristics of the readout.
- NUC Presets
- Up to four NUC tables and their associated parameters such as integration time, frame rate and window size, are available for instant selection with a single command.
- Independently Controllable Analog and Digital Image Streams
- The SC4000/6000 camera provides independent streams for both analog and digital data. For example, this allows corrected thermal imagery to be sent to a video monitor while uncorrected data is sent to a digital acquisition/recording system. This capability also works during a windowing (sub-sampling) mode with a black bar or box surrounding the thermal image when in the video display, and in preset cycling mode (Superframing).
- Independently Adjustable Frame Rates
- A continuously variable frame rate is user selectable from 1 Hz up to the maximum allowed in increments of 0.1Hz for any window size.
- Multiple Triggering Modes and Synchronizing Interfaces
- The SC4000/6000 camera provides different interfaces to support maximum flexibility for synchronizing the camera to external events, as well as synchronizing external events to the camera.
- Sync In (TTL and CMOS)
- Built-in IRIG timing card
- Genlock input for analog video syncing of multiple cameras
- Sync Out – a buffered replica of the Sync In signal
- Adjustable Digital Gains and Offsets
- The SC4000/6000 allows the user to adjust digital gains and offsets, making it possible to map the linear portion of the FPA to the full range of digital count values.
- Multiple Control Options
- The SC4000/6000 can be controlled with a user GUI or optional SDK through:
 - Gigabit Ethernet port
 - USB port
 - Camera Link serial channel
 - Traditional RS-232 asynchronous serial port
- Multiple Video Outputs
- The SC4000/6000 camera features multiple video outputs that are fully independent and simultaneous data paths. Output paths include:
 - Analog – Composite (NTSC or PAL)

- Digital – Camera Link
- Digital – Gigabit Ethernet
- File Based Storage System
- The SC4000/6000 camera software is hosted on a real-time operating system that has internal storage capability on flash memory. The saved camera state, NUC tables, and bad pixel maps are stored as named files that support multiple user camera states.
- Ruggedized Construction
- The SC4000/6000 camera is packaged as a semi-sealed enclosure with an integral forced air heat exchanger.
- Standard Lenses
- The SC4000/6000 camera system is compatible with industry standard bayonet-mount IR lenses, such as the lenses manufactured by Janos, Diop and Optimum Optical Systems.
-

2 Warnings and Cautions

For best results and user safety, the following warnings and precautions should be followed when handling and operating the camera.

 Warnings and Cautions:

- Do not open the camera body for any reason. Disassembly of the camera (including removal of the cover) can cause permanent damage and will void the warranty.
- Great care should be exercised with your camera optics. Refer to Chapter 9 for lens cleaning.
- Operating the camera outside of the specified input voltage range or the specified operating temperature range can cause permanent damage.
- The camera is not completely sealed. Avoid exposure to dust and moisture and replace the lens cap when not in use.
- Do not image extremely high intensity radiation sources, such as the sun, lasers, arc welders, etc.
- The camera is a precision optical instrument and should not be exposed to excessive shock and/or vibration. Refer to the Chapter 7 for detailed environmental requirements.
- The camera contains static-sensitive electronics and should be handled appropriately.
-

3 Getting Started

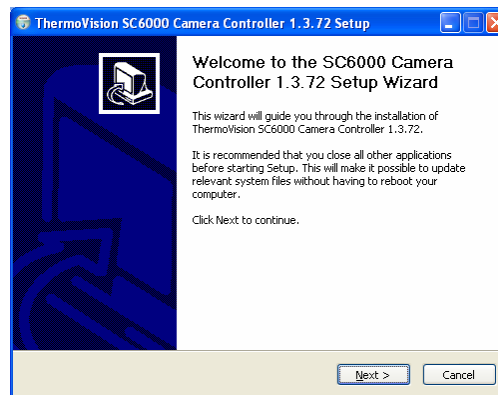
3.1 Installing the SC6000 Camera Controller



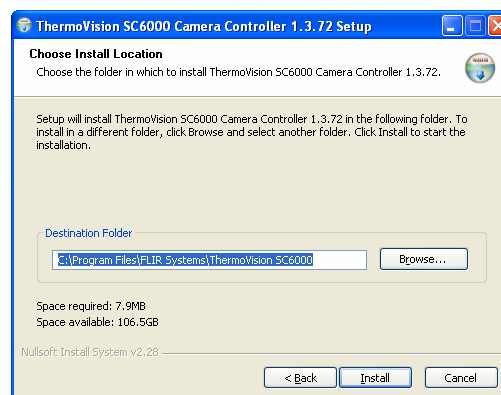
If you are going to use RTools you do not need to install this camera controller. The camera controller is installed with RTools, please follow the RTools installation instructions.

NOTE: The SC6000 Camera Controller is also used for the SC4000.

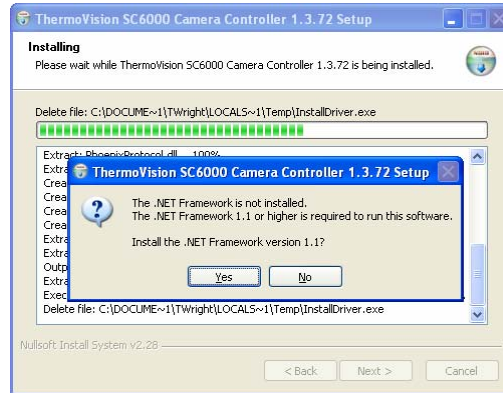
After inserting the SC4000/SC6000 GUI CD, the Setup Wizard will be displayed. If AutoPlay is off and the Setup Wizard is not automatically displayed, run Setup.exe from the CD.



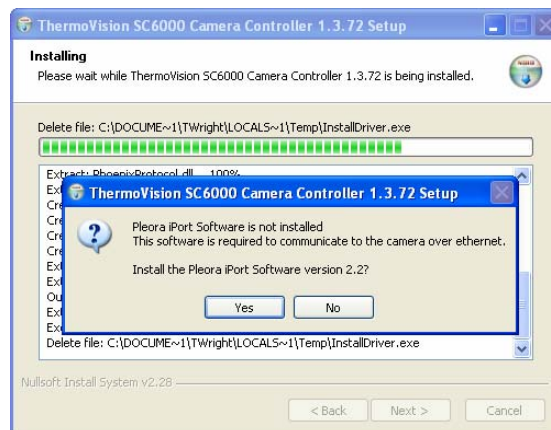
The next page selects the installation directory. The default should work for most users. Click Install to install the camera controller.



The .NET Framework version 1.1 or higher must be installed for the camera controller to run. Version 1.1 is provided on the SC6000 GUI CD. During the installation process you may be asked if you want to install the .NET Framework or the Pleora iPORT software if these components are not already installed. It is recommended that you click Yes when asked to install these components. The Setup Wizard will install these components for you. If you choose not to install these components at this time you can install them later with the installers located on the SC6000 GUI CD in the DotNetFramework and Pleora directories.

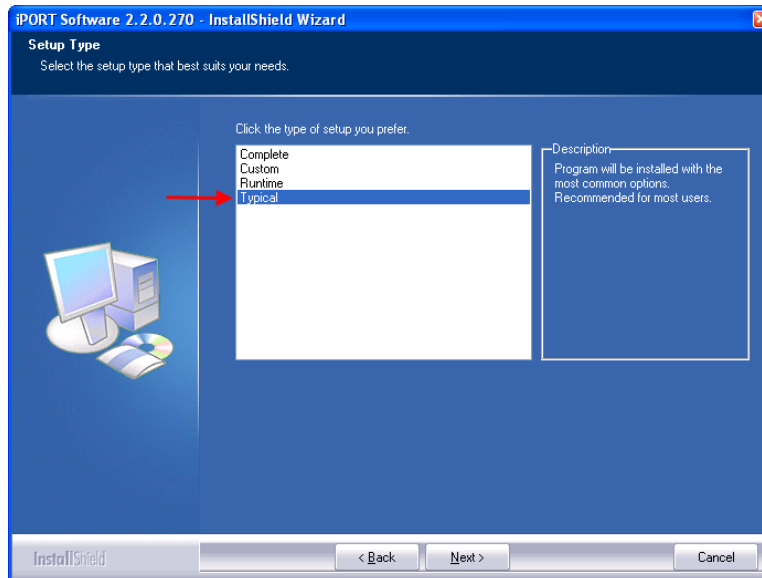


The Pleora iPORT Software version 2.1.4 or 2.2 must be installed for the camera controller to connect to a camera over Ethernet. (If you plan to run RTools v2.2 or later you need iPORT software v2.2.) Version 2.2 is provided on the SC6000 GUI CD.

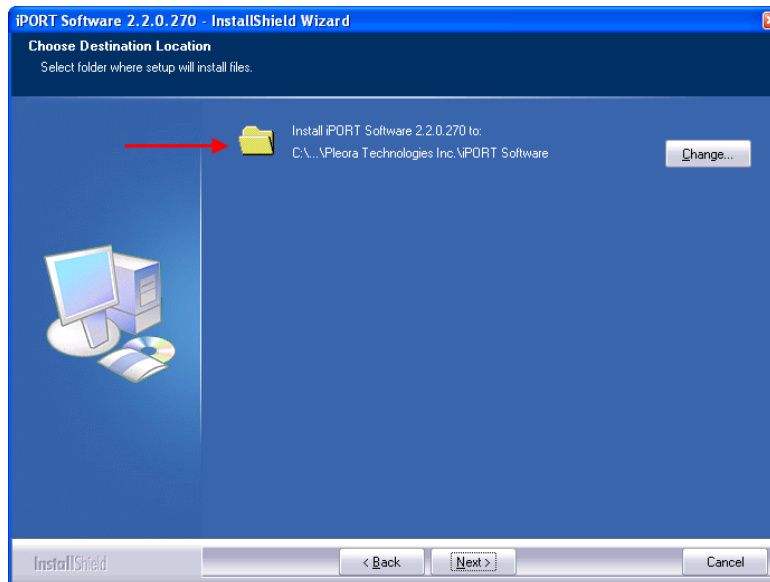


3.2 Installing the Pleora iPORT GigE drivers

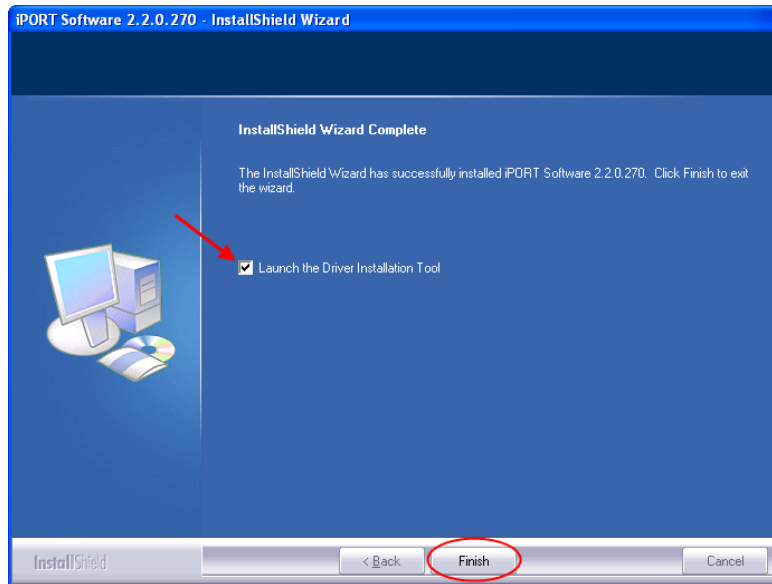
Choose Typical Install.



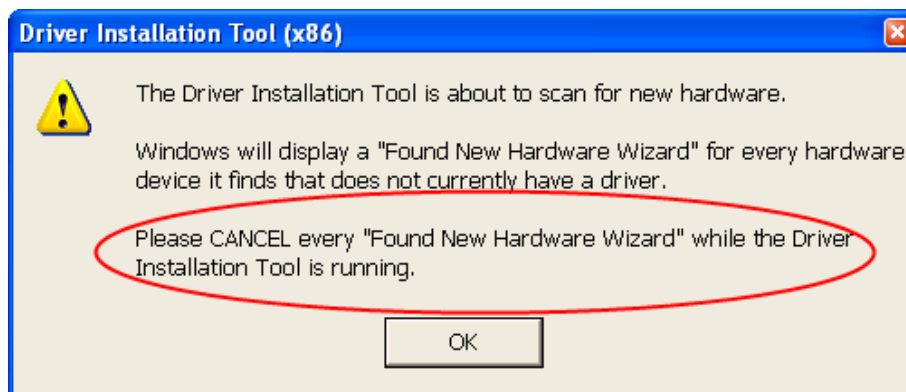
Choose the default installation location.



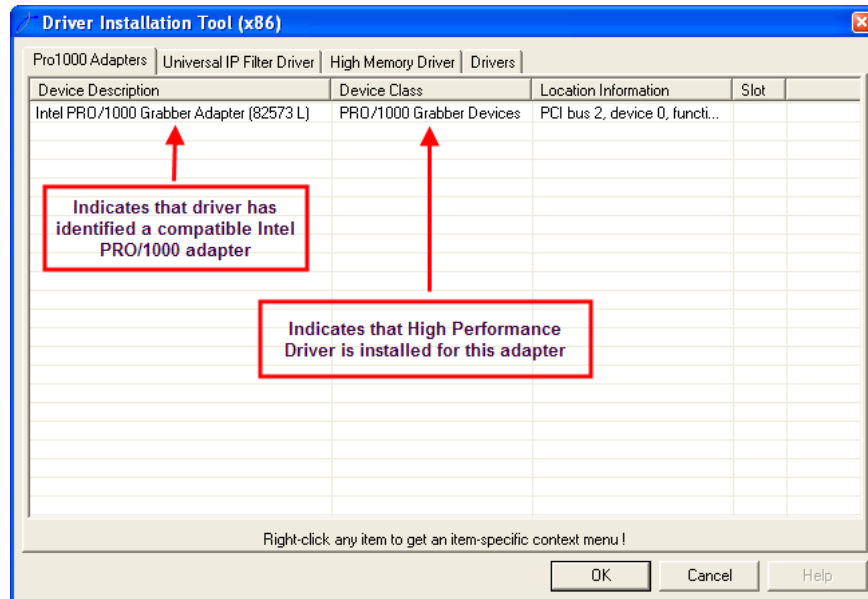
Check the box to “launch the Drive Installation Tool”. Click Finish.



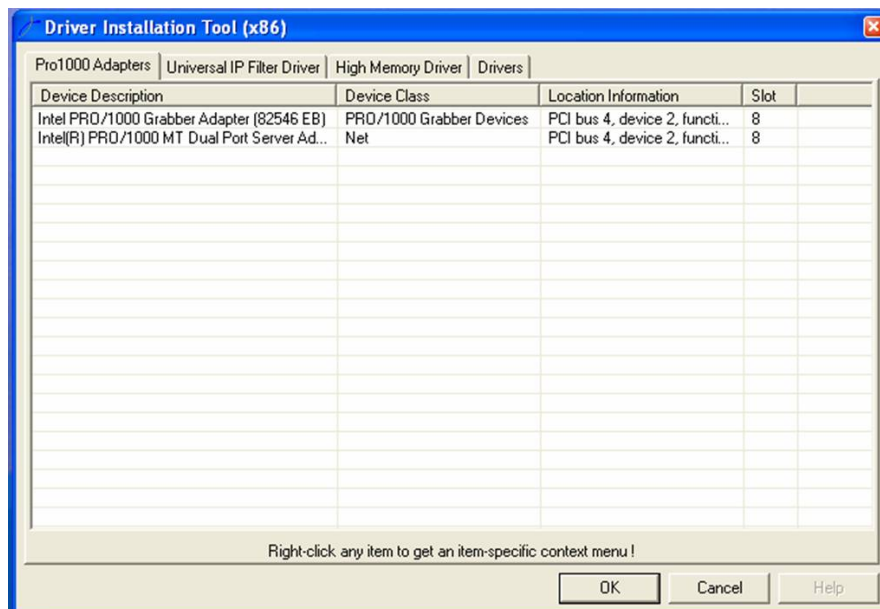
A dialog will appear advising you to Cancel all “New Hardware Found” wizards that appear while the Driver Installation Tool is running. Click OK.



The Driver Installation Tool will appear. It has four tabs. If you have a system with an Intel PRO/1000 adapter you should see something similar to the picture below. This shows that the High Performance driver has been installed.

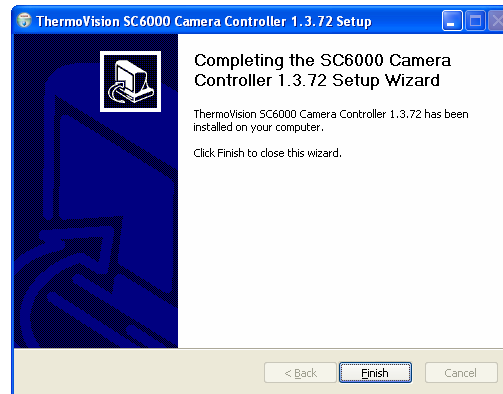


Below is an example of a dual network adapter system with one adapter using the High Performance driver and another adapter using the standard network driver.



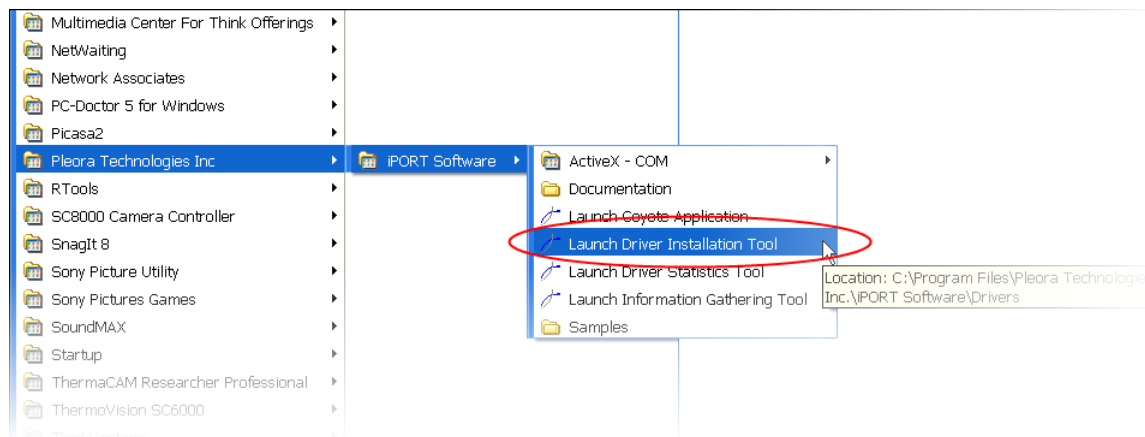
The camera controller installation is now complete; the camera controller can now be run. To uninstall the camera controller use the Uninstall link in the Start Menu under ThermoVision SC6000 or the Add/Remove Programs item in Control Panel.

Software Installation is now complete.



3.3 Configuring the Pleora iPORT driver

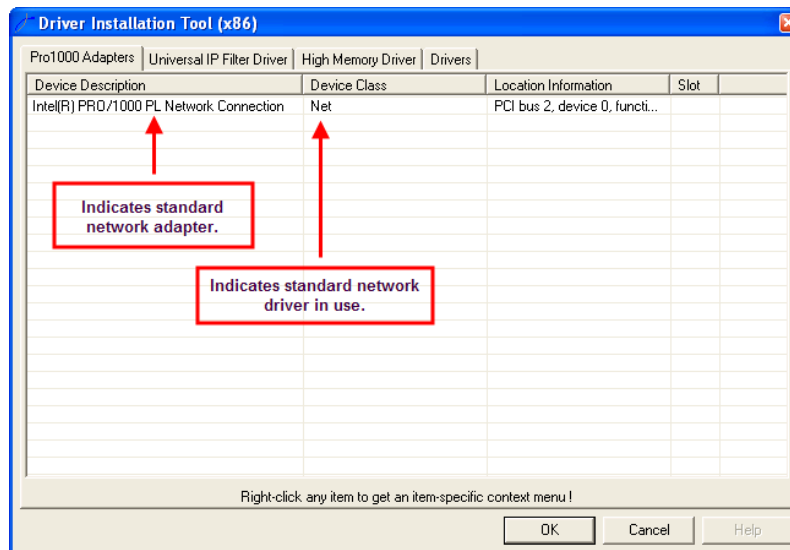
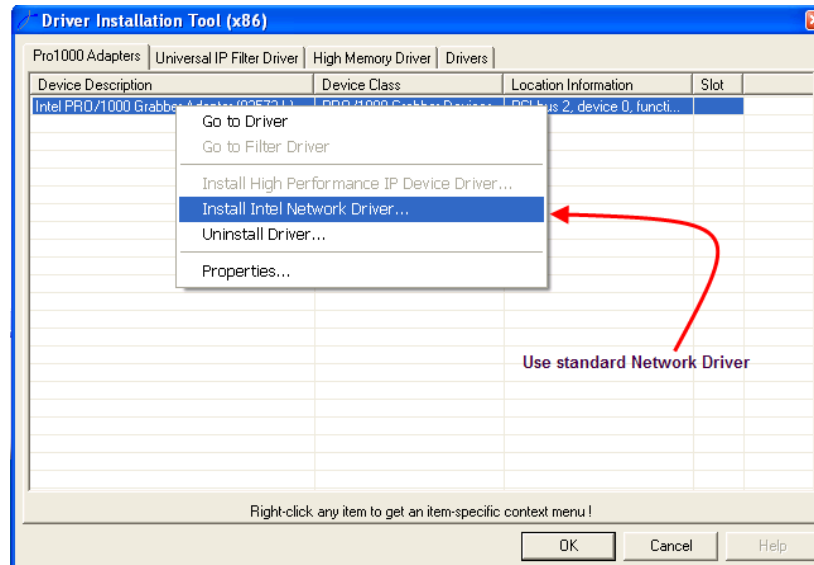
Launch the Driver installation Tool



3.3.1 If you have an Intel PRO/1000 adapter

To install the standard Network Driver:

On the Pro1000 Adapters tab, right click on the network adapter and choose the Intel Network Driver.



To switch back to High Performance Driver

Launch Driver Installation tool.

Right click Intel Pro/1000 Network Connection

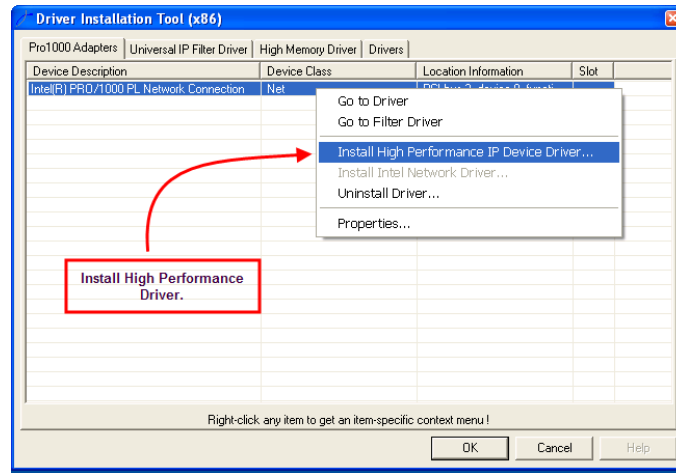
Choose “Uninstall Driver...”. The Device will change to Intel Pro/1000 Grabber Adapter. The Device Class will change from Net to Ethernet Controller.

NOTE: If you skip this step, and install the High Performance Driver directly, you may have problems where the driver does not seem to install.

Right click on the Intel Pro/1000 Grabber Adapter.

Choose “Install High Performance IP Device Driver”.

Device Class should change to Pro/1000 Grabber Device. (Note: This is your indication the high performance driver is installed on this adapter. On the Driver tab, the Pro1000 should be “in use”).



3.3.2 If you don't have an Intel PRO/1000 adapter

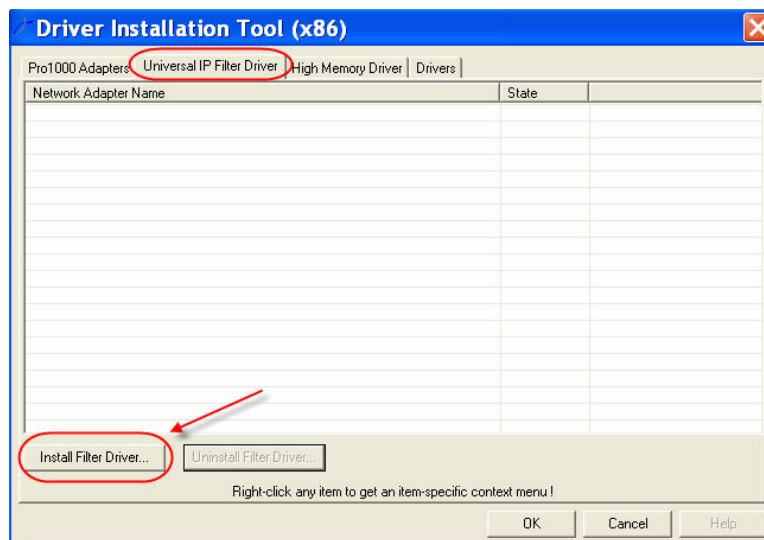
We strongly recommend that you use an Intel PRO/1000 adapter if at all possible. For a very small cost you will be able to take advantage of greatly improved performance and easier configuration. If this is not possible, you have two options. Either simply run with the Windows network driver or install the Pleora Universal Filter Driver. The Filter Driver works with virtually all network adapters. It provides significantly better performance than the Windows driver but not nearly as good as the High Performance driver. If you run the Filter Driver you can use this driver to connect you PC to either the camera or to a regular IP network.

Using the Windows driver requires no further configuration of the Pleora Driver Installation tool. Proceed to section 2.2.2.3 for instructions to configure you PC's network adapter.

To install the Pleora Universal Filter Driver:

Start the Pleora Driver Installation Tool.

Go to the "Universal IP Filter Driver" tab. The table should be blank. Click the button labeled "Install Filter Driver..."



The first time you do this the system will recommend a restart. (After installing this once you can uninstall and reinstall the driver without rebooting.) This driver will let you use the adapter on your computer either as a regular network port or to connect to a camera. After installing the driver (and rebooting) you should see this...



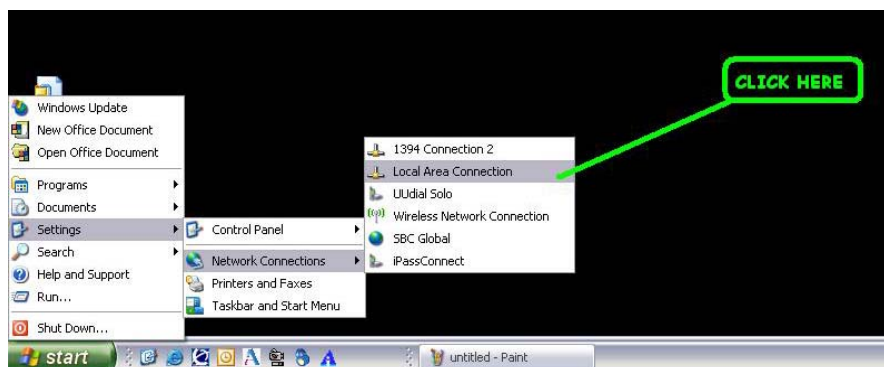
3.3.3 Configure the PC's Ethernet Port (Non Intel PRO/1000 Only)



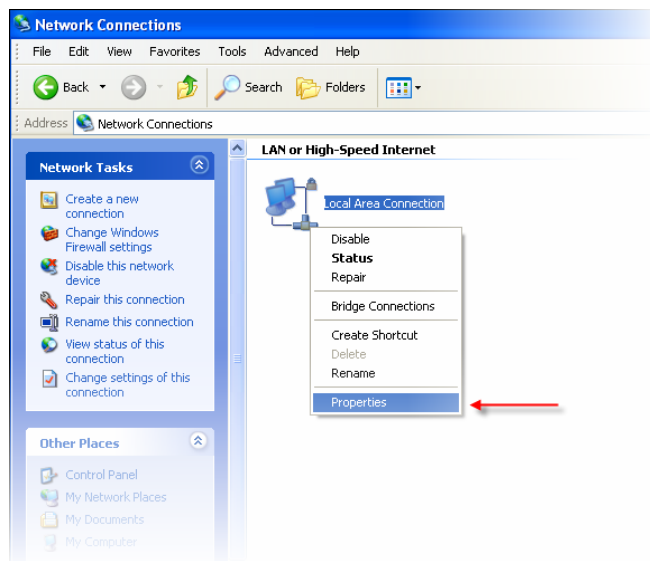
Skip this section if you DO HAVE the Intel Pro 1000 and are using the High Performance Driver

It is highly recommended that you use a dedicated clean install PC or at the least a dedicated Ethernet port for interfacing to your camera. This will reduce time used to configure and re-configure your Ethernet port. It also insures there are no firewall settings that could block data transmission between your PC and the Camera.

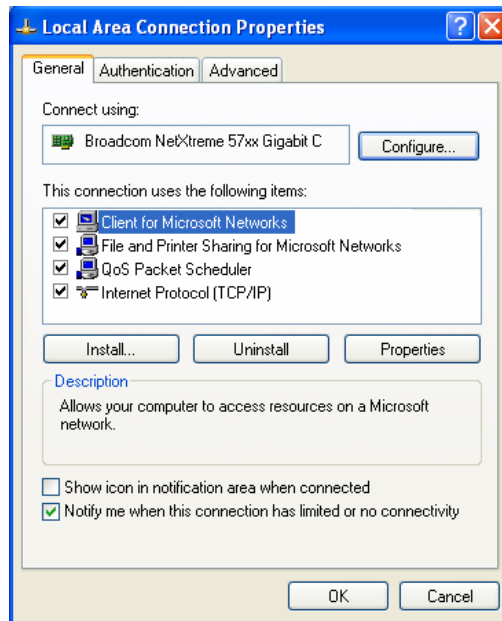
First you will need to change the network IP address from a dynamic IP to a static IP. To do this will make networking the Camera to the PC much easier.



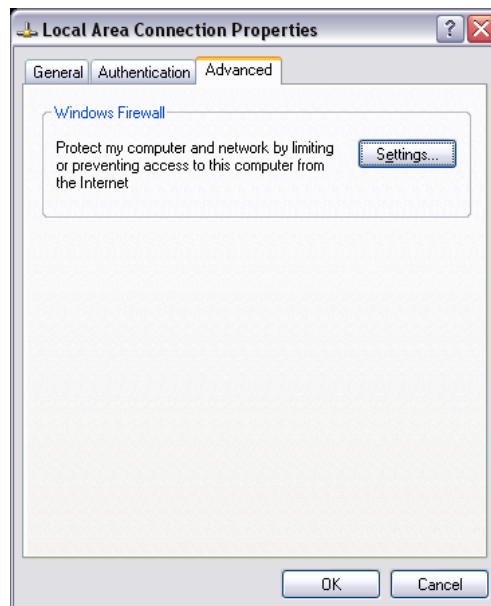
Step 1. Go to My Network Places and click on “View Network Connections”. Right click on the connection for the adapter you wish to use to connect to the camera. Choose “Properties”.



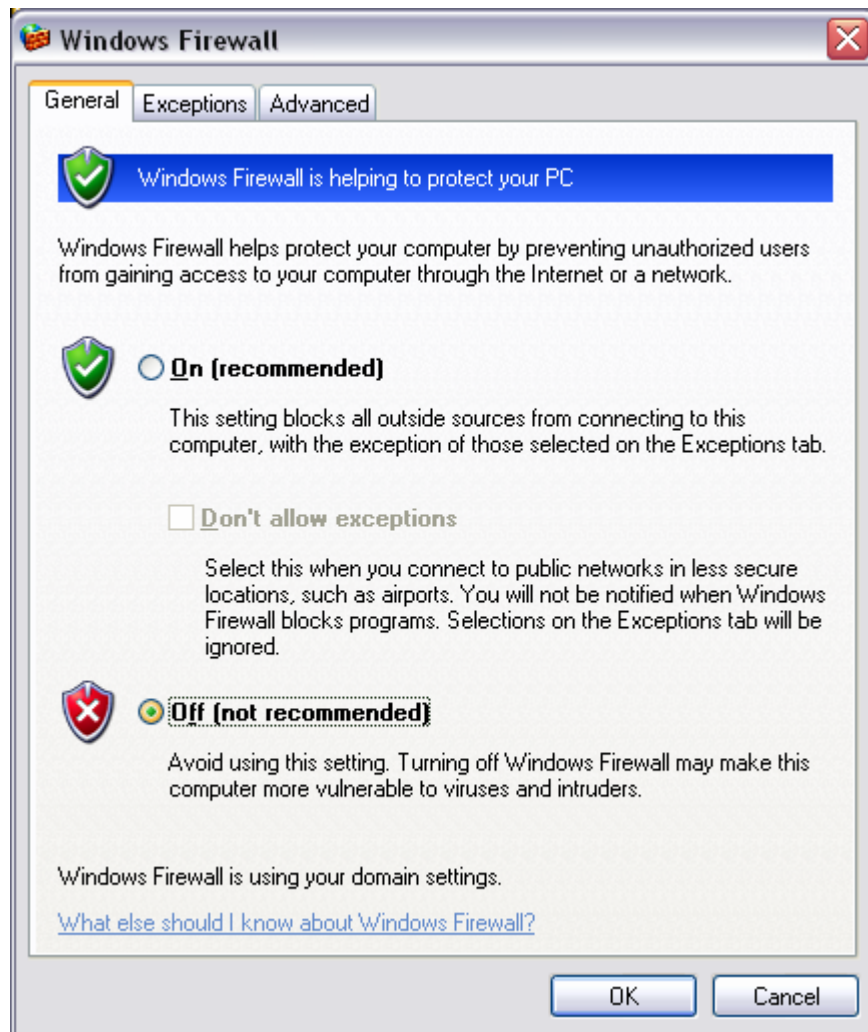
Step 2. On the Properties window, click on the Advanced tab.



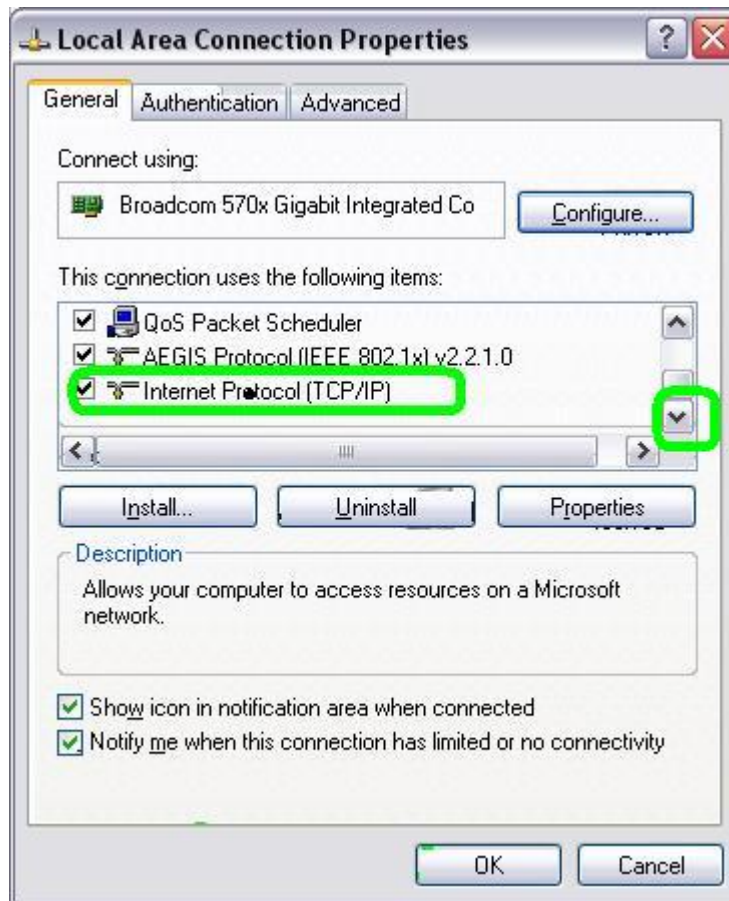
Step 3. Click on Settings.



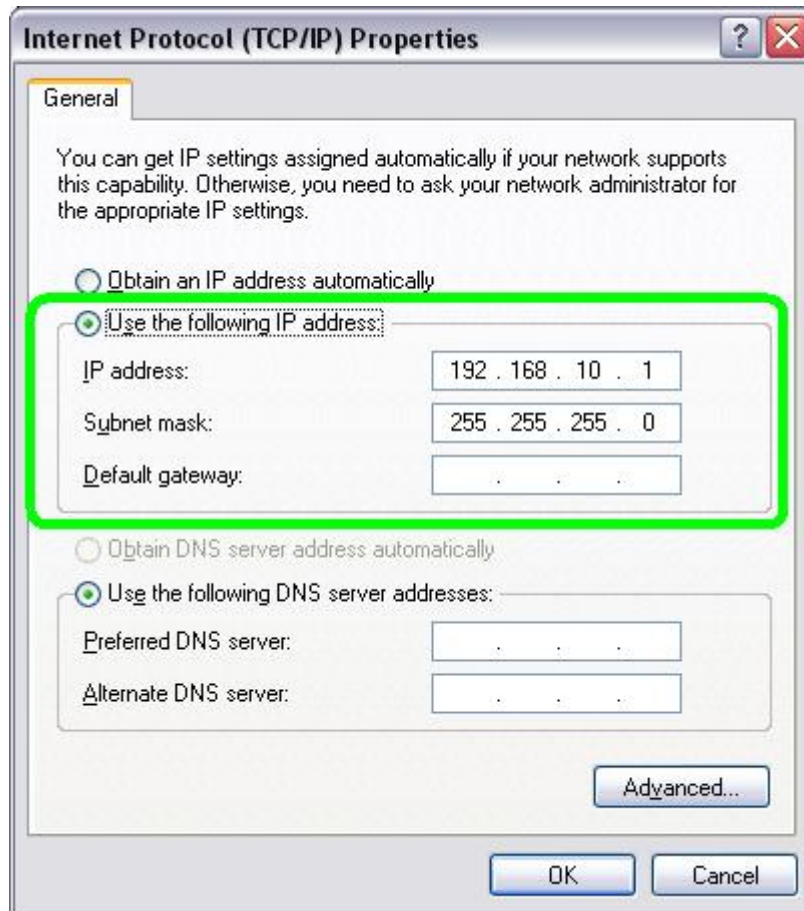
Step 4. Here you want to disable the Firewall settings by clicking on **Off (not recommended)**. Then click **OK**. If you are not using Windows XP Service Pack 2, then this screen is not there; so skip this step.



Step 5. Click back to the **General** Tab. The properties page will allow you view the properties of the Local Area Connection (LAN Connection). Scroll down until you see the **Internet Protocol (TCP/IP)**, and double click on this item.



Step 6. Here your IP is likely set to Obtain an IP address automatically. Since we're creating our own local network with the camera, we want to assign a static IP. So click on **Use the following IP address** and type in **192.168.10.1**. The subnet mask should handle itself, but you can fill in 255.255.255.0 if it doesn't default to this address. Then **click OK** until you closed all windows and are back to your desktop. A side note, you can choose almost any IP address you wish, just so long as you set the camera to have an IP address within the same subnet.



If you wish to talk to the camera over a network, you can leave you PC set to get its IP address automatically. Go to Start->Run... and Enter "cmd" to open a command window. Run "ipconfig" at the prompt to see the current network configuration as shown below.

```

C:\WINDOWS\system32\cmd.exe
Microsoft Windows XP [Version 5.1.2600]
(C) Copyright 1985-2001 Microsoft Corp.
C:\Documents and Settings\rmartine>ipconfig

Windows IP Configuration

Ethernet adapter Local Area Connection:

    Connection-specific DNS Suffix  . : bos.flir.net
    IP Address. . . . . : 10.11.4.8
    Subnet Mask . . . . . : 255.255.0.0
    Default Gateway . . . . . : 10.11.1.1
C:\Documents and Settings\rmartine>

```

You will need to set the camera's IP address to an address in the same subnet, but that doesn't conflict with another computer on the network.

3.4 Connecting to the camera

The camera's rear panel is shown in Figure 3-1.

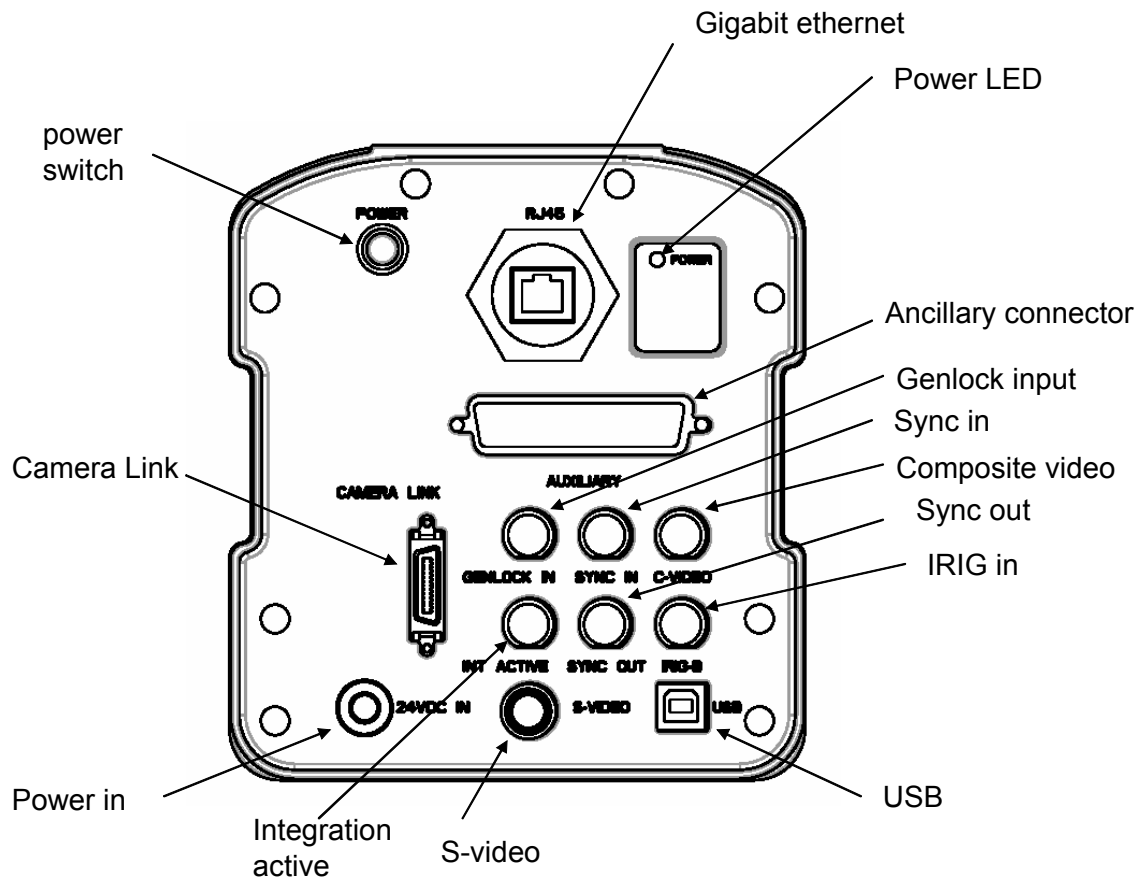


Figure 3-1: Rear Panel of SC6000

3.4.1 Power

Connect the power cable.

3.4.2 Analog Video Output

Connect the C-video to your monitor using the BNC cable provided.

Note

This is **optional**.

Analog video is available in all camera modes, at all times.

3.4.3 Command Control / Digital Output Ports

Connect the USB cable between the camera and your PC.

Connect the Ethernet cable between the camera and your PC.

Connect the Camera Link cable between the camera and your PC (Only for HSDR or custom data systems).

Note

You can choose either USB or Ethernet as your command interface port. The command interface port and digital output can be different. If the command interface port is set to Ethernet then you do not need to connect the USB cable.

3.4.4 Setting the camera communication port

The camera can be set to communicate with the GUI via three paths: USB , Gigabit Ethernet or RS-232. You can configure the camera to communicate on the desired port by follow the steps.

There are two steps to setting the communications port:

Step 1. Tell the camera on which port to listen for commands

- Connect the PC to the camera's USB port
- Launch the SC6000 GUI
- Select the **Tools** menu, and click on **Camera Port**
- Choose the desired port (Figure 3-2 shows USB) and click **Select**.

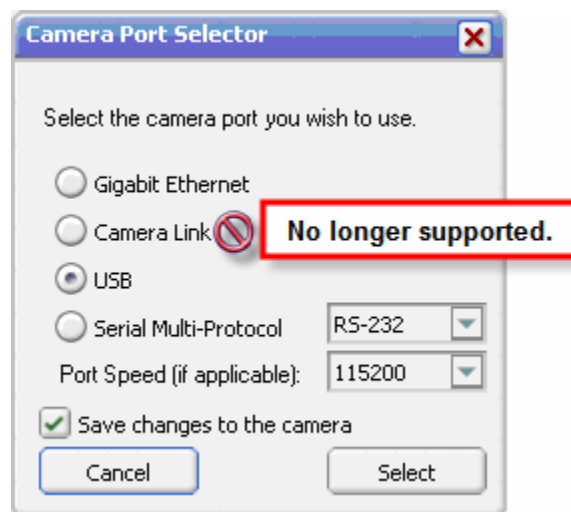
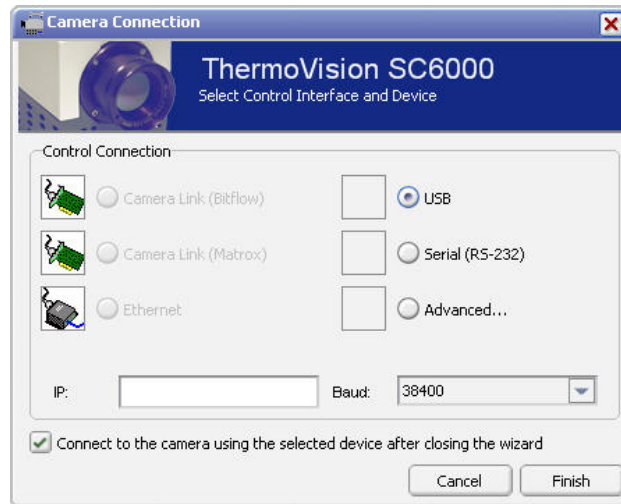


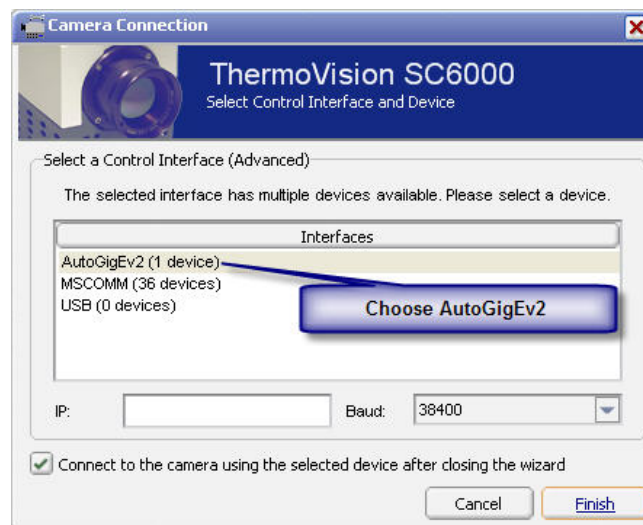
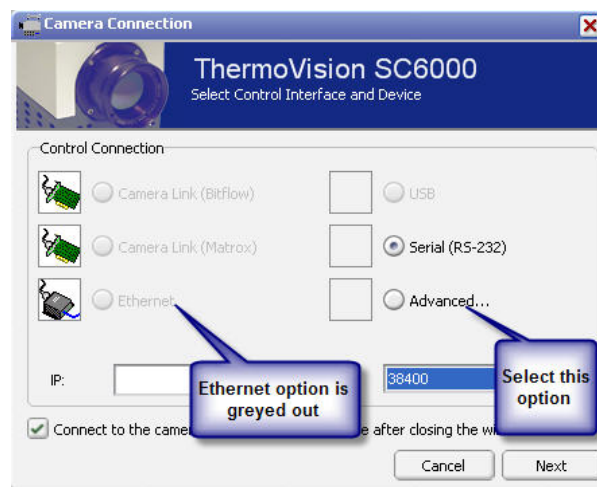
Figure 3-2: Set the Camera Communication Port

Step 2. Tell the Camera Controller on which port to send commands

- In the GUI, select the **Tools** menu, and click on **Connection**
- Choose the same port you chose in Step 1 and click **Finish**.



NOTE: The current version on the GUI (1.3.72) does not properly recognize the Pleora 2.2 drivers. This causes the Ethernet connection option to be greyed out. (This will be addressed in the next GUI release.) To connect via Ethernet, choose the “Advanced...” option and click **Next**. On the following dialog choose “AutoGigEv2” and click **Finish**.



- The system status will show **Ready for acquisition.**

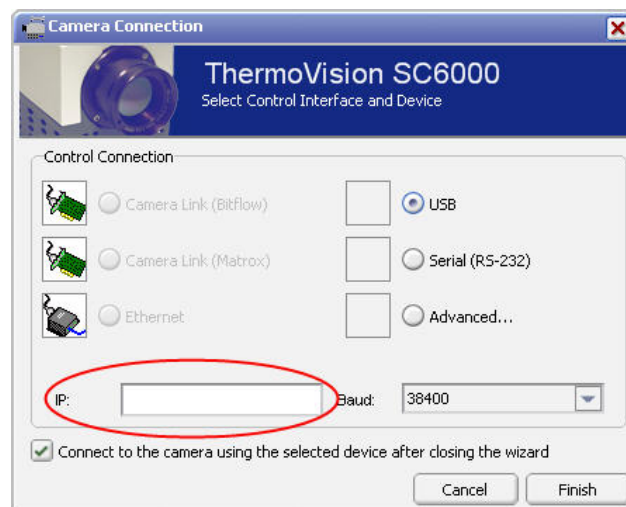


Figure 3-3: System is Ready

If you wish to change the communications port in the future, use these same steps but you will need to make sure that the Controller is disconnected from the camera before you will be able to access the menu options. In the GUI, Select **Camera->Disconnect.**

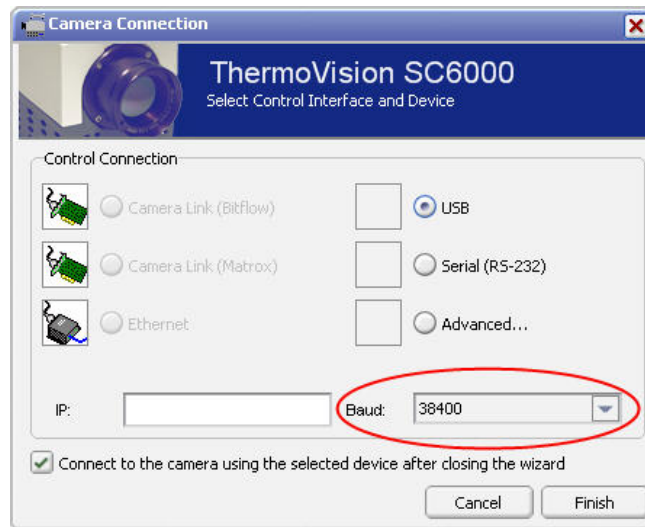
3.4.5 Additional connection options

3.4.5.1 Ethernet IP Address



This option sets the IP address for the camera. If you are using the Pleora High Performance Driver you do not need to set the IP address. If you are using the Windows network driver or the Pleora Filter Driver you need to give the camera an address in the same subnet as your PC. If the camera is on a network then you need to make sure that the address does not conflict with another device on the network.

3.4.5.2 Baud Rate



This option only applies if you are communicating with the camera over RS-232.

3.5 Troubleshooting

3.5.1 Can't communicate over USB

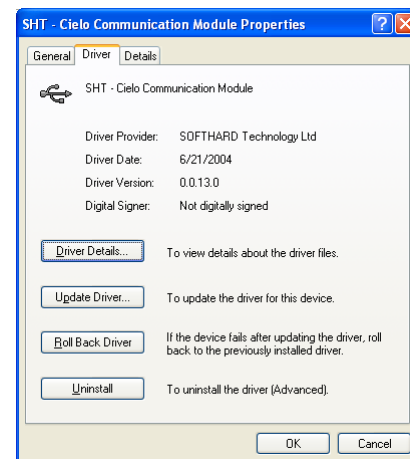
Symptoms: Camera Port dialog fails to set the camera port. Cannot connected to camera over USB.

Solution: Re-install the USB driver (Cielo driver).

Open device manager you should see “SHT – Cielo Communications Module” under “USB I/O Controlled Devices”. It will probably have an exclamation mark next to it as shown below.



Double click on “SHT – Cielo Communications Module”, the properties dialog should be displayed. Click the Driver tab.

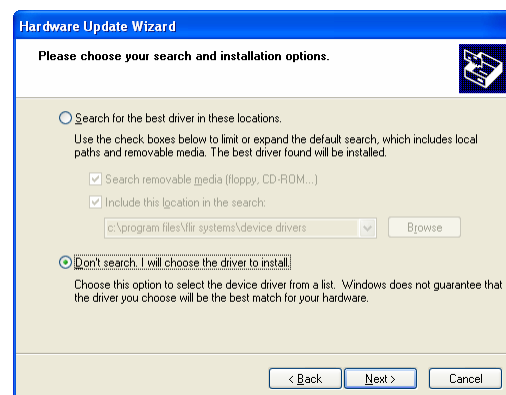


Click Update Driver, the hardware update wizard should be shown. If the hardware update wizard asks to connect to windows update select no, not this time.

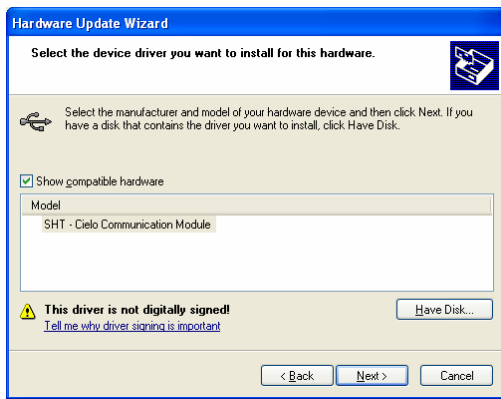


Select “Install from a list or specific location” and click “Next”.

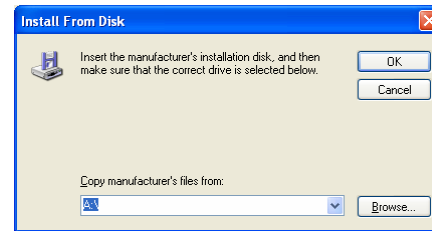
Select “Don't search, I will choose the driver to install” click “Next”.



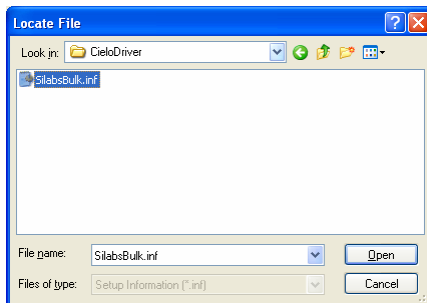
and



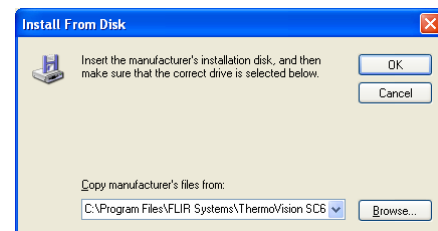
Click “Have Disk”.



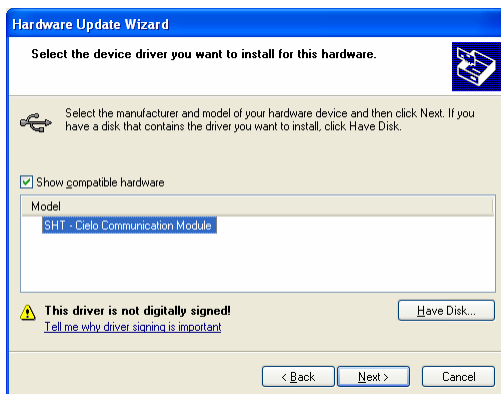
Click “Browse”.



Locate SilabsBulk.inf in the CieloDriver subfolder of the installation folder. This is usually C:\Program Files\FLIR Systems\ThermoVision SC6000\CieloDriver. Click “Open”.



Click “OK”.



Click “Next”. Windows will install the driver.

Click “Finish”. The Cielo diver has been re-installed.



4 Camera Architecture and Functionality

4.1 Functional Description

The SC4000/6000 is a 50 mega pixel per second infrared camera that fully exploits the features inherent in Indigo's standard ROICs. Figure 4-1 shows the functional block diagram of the camera.

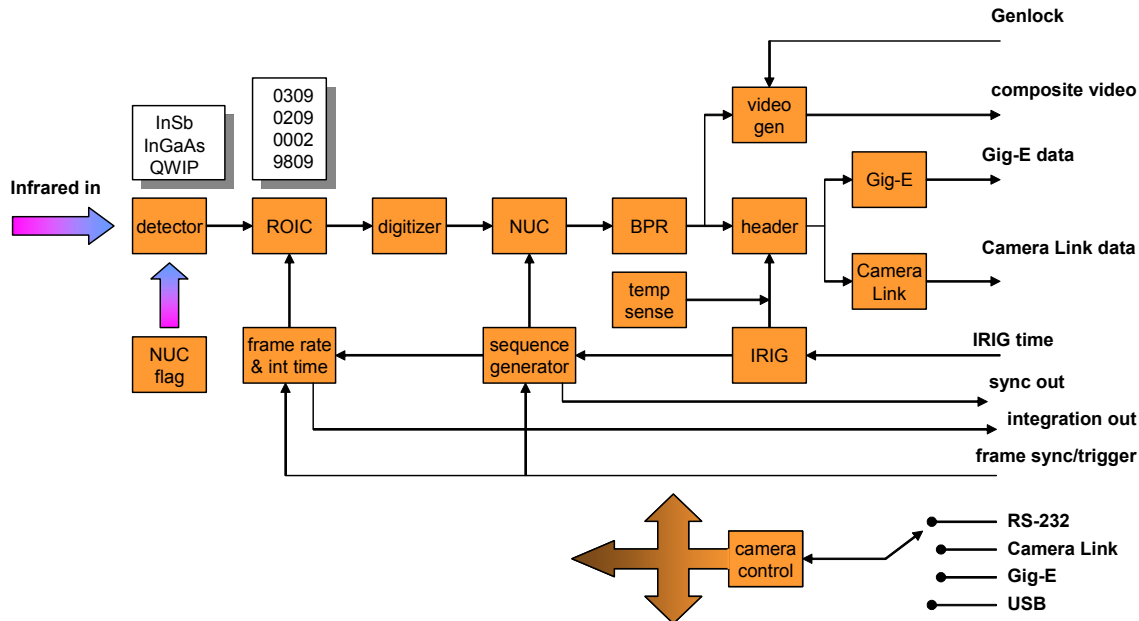


Figure 4-1: Major functional blocks of the Thermovision® SC4000/6000

The major blocks are:

Detector. InGaAs for the near IR (0.9 – 1.7 μm) or VisGaAs for the visible to near IR (0.4 – 1.7 μm) region; InSb for the midwave IR (3 - 5 μm) region and Quantum Well Infrared Photodetectors (QWIP) for the far IR (8 – 9 μm) region.

ROIC. The ROICs used in SC6000 and SC4000 cameras are: SC4000: **ISC9705**, **ISC0209**, and **ISC9809**, SC6000: **ISC9803**, **ISC0309** and **ISC0002**.

Digitizer. 14 bit digitization of the full dynamic range of the FPA at a total data rate of 50 mega pixels per second.

Non Uniformity Correction (NUC) stage. Gain and offset correction on a per pixel basis for uniform imagery and data output.

Bad pixel replacement (BPR). Bad pixels are replaced in the data stream with the average of the nearest 4 neighboring pixels; both this stage and the NUC stage can be selectively overridden by the user.

Header insertion. The row immediately preceding valid data in each frame has a header inserted with IRIG time, camera temperature information, a rolling frame counter and a variety of current camera parameters to simplify the archiving and distribution of data.

Data output stages. Parallel output of digital video is available using gigabit Ethernet and Camera Link base LVDS output. Full 14 bit data can be output in raw, NUC'd and NUC'd with bad pixel replaced format.

Video generation. This section generates NTSC or PAL compatible composite video output asynchronously to the digital signal flow. Video is available regardless of selected FPA frame rate or window size. For FPA frame rates greater than the video frame rate, the most current frame of data is

output; for FPA frame rates slower than the video frame rate, the most recent video field is repeated until newer scene data is available.

Genlock input. The camera accepts a composite sync signal that overrides the composite timing in the video generation block; this does not affect the FPA timing but allows the camera to be gen locked to external sources to the video pixel level.

IRIG-B decoder. The camera accepts an optional IRIG input that can be used for time stamping as well as the initiation of data acquisition sequences.

Frame rate and integration control. An internal sync generator allows the camera to run at any frame rate from 1 Hz to the maximum allowed by the currently selected window size. It supports integration times up to greater than 99% of the frame time. It can also accept external syncs in place of camera generated syncs to sync the FPA to external events and provides logic to “lock out” syncs at inappropriate times to prevent the corruption of data.

Sequence generator. This generates sequences of syncs as well as sequential switching of NUC presets to profile events that exceed the single integration time dynamic range of the camera. This section can also accept an external trigger to start the sequence as well as an IRIG time trigger.

NUC flag. For InSb and QWIP cameras, a dual temperature calibration flag provides both hot and cold temperature sources to internally update NUC tables.

Camera control. The camera is controlled with a DSP that can communicate through four different user selectable serial ports.

There are of course other components and blocks that are required for camera operation that the user never interacts with: power supply generation, detector cooling subsystems, and detector vacuum packages.

4.1.1 Detector

Near Infrared Sensor Assembly (NIR)

The FPA consists of a thermoelectric-cooled Indium Gallium Arsenide (InGaAs) detector fabricated on an Indigo ROIC using an indium bump hybridization process. The FPA can be either a 320x256 or 640x512 array of detectors, sensitive in the 0.9 to 1.7 μm range. The thermally stabilized FPA is enclosed in a sensor assembly cooled by a thermoelectric cooler.

Mid-Wavelength Infrared Sensor Assembly (MWIR)

The FPA is fabricated by hybridizing an Indium Antimonide (InSb) detector array to an Indigo ROIC using an indium bump hybridization process. The FPA can be either a 320x256 or 640x512 array of detectors, sensitive in the 1.0 μm to 5.7 μm range. The standard camera configuration incorporates a cold filter that restricts the camera's spectral response to the 3.0-5.0 μm band.

The MWIR sensor assembly is an all-metal evacuated dewar assembly cooled by a closed-cycle Stirling cryogenic cooler to a temperature of approximately 77 Kelvin. The Stirling linear cooler is a sealed refrigeration unit that uses helium as the working gas. It is thermally coupled to the FPA via a cold finger. The cooler uses a compression step, followed by an expansion step to remove heat from the cold finger. The compression and expansion process is repeated at a rapid rate, resulting in a low humming noise. The typical time to cool down the FPA to 77 K is 5-6 minutes, but the cooling may take longer if the camera temperature is elevated. For instance, if the camera is enclosed in a gimbaled housing on a land vehicle operating in hot weather, the camera case temperature may be 45°C, requiring additional cooling time.

Long-Wavelength Infrared Sensor Assembly (LWIR)

The FPA is fabricated by hybridizing a Quantum Well Infrared Photodetector (QWIP) array to an Indigo ROIC using an indium bump hybridization process. The FPA is available in either a 320x256 or 640x 512 format. The spectral response is 8 μm to 9.2 μm .

The LWIR FPA is cooled to a temperature of approximately 70 Kelvin using a Stirling-cycle linear cryogenic cooler that is thermally coupled to the FPA via a cold finger. The Stirling cooler is a sealed refrigeration unit that uses helium as the working gas. It does not require you to refill the camera with cryogenics such as liquid nitrogen, and it is designed for long life and high reliability. The cooler uses a compression step, followed by an expansion to remove heat from the cold finger. The compression and expansion process is repeated at a rapid rate, resulting in a low humming noise. As with the MWIR, the typical time to cool down the FPA to 70 K is 5-6 minutes, but the cooling may take longer if the camera temperature is elevated. In hot weather, the camera case temperature may be 45°C, requiring additional cooling time.

4.1.2 ROIC

The ROICs used in SC6000 and SC4000 cameras are: **ISC9705**, **ISC0209**, **ISC9809**, **ISC9803**, **ISC0309** and **ISC0002**. Note that the ISC9705 and ISC0209 as well as the ISC9803 and ISC0309 are completely functionally equivalent, the 0209 and 0309 are just later versions. The direct injection readouts feature large integration wells (18 and 11 million electrons respectively) for high sensitivity application with InSb and QWIP detectors. The high gain CTIA unit cell ROICs are for low background applications using InGaAs.

4.1.2.1 Direct Injection Unit Cell Readouts

The unit cell shown in Figure 4-2 uses a direct injection topology with an anti-blooming transistor. The output from each unit cell is addressed to a column amplifier. The columns are multiplexed down to two outputs. A skimming function is provided to globally offset the output signal.

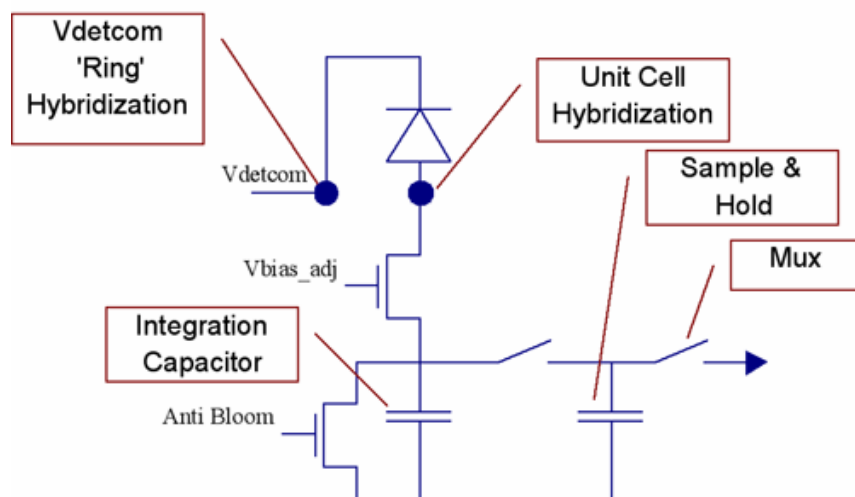


Figure 4-2: Simplified Schematic of Standard Direct Injection Unit Cell

Detector current flows through the input gate transistor and charges up the integration capacitor. The anti-bloom gate keeps the input circuit from saturating. The voltage on the integration capacitor is sampled and multiplexed to the column amplifier.

The column amplifier, shown in Figure 4-3, provides sample/hold, amplification and skimming functions. The signal from the unit cell is sampled and held onto the column amplifier. A global offset, or skimming, function is implemented with the column amplifier, which also drives the output multiplexer.

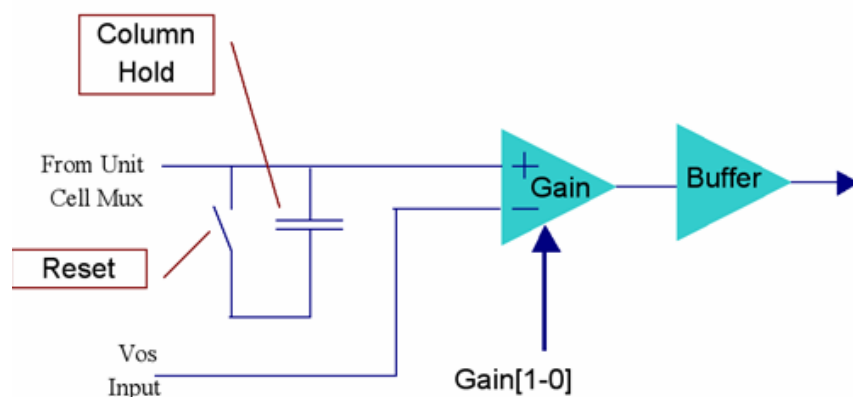


Figure 4-3: Column Amplifier Block Diagram

ISC9705/ ISC0209

This 320 x 256 mid format array has 30 μm pixel pitch and direct injection with a well capacity of up to 18 million electrons. Additional specifications include snapshot readout with an *integrate while read* capability, four selectable gain stages, four video outputs (down selectable to two or one) with a maximum total data rate of 40 MHz in the DTS-based system. Windowing capability includes a minimum window size of 2 rows by 128 columns. This ROIC is available with either InSb or QWIP detector material and can be installed in either a permanently sealed, closed cycle dewar or pour filled, laboratory unit.

ISC9803/ ISC0309

The 9803 is a 640 x 512 large format array with 25 μm pixel pitch, and direct injection with up to an 11 million electron well capacity. Similar to the 9705, it includes snapshot readout with an *integrate while read* capability, four selectable gain stages and four video outputs (down selectable to two or one) with a maximum total data rate of 40 MHz with the DTS-based system. The minimum window size is 4 rows by 128 columns. This ROIC is available with InSb or QWIP detector material, and can be installed in either a permanently sealed, closed cycle dewar or pour filled, laboratory unit.

4.1.2.2 CTIA Unit Cell Readouts

For this unit cell, a capacitive trans-impedance amplifier (CTIA) provides a low noise front end including an anti-blooming transistor. The CTIA has two selectable integration capacitors. The output from each unit cell is addressed to a column bus and sampled onto a column amplifier. The column amplifier is multiplexed to two output channels. A skimming function provides a global offset for the output signal. A simplified schematic of a CTIA unit cell input circuit is shown in Figure 4-4.

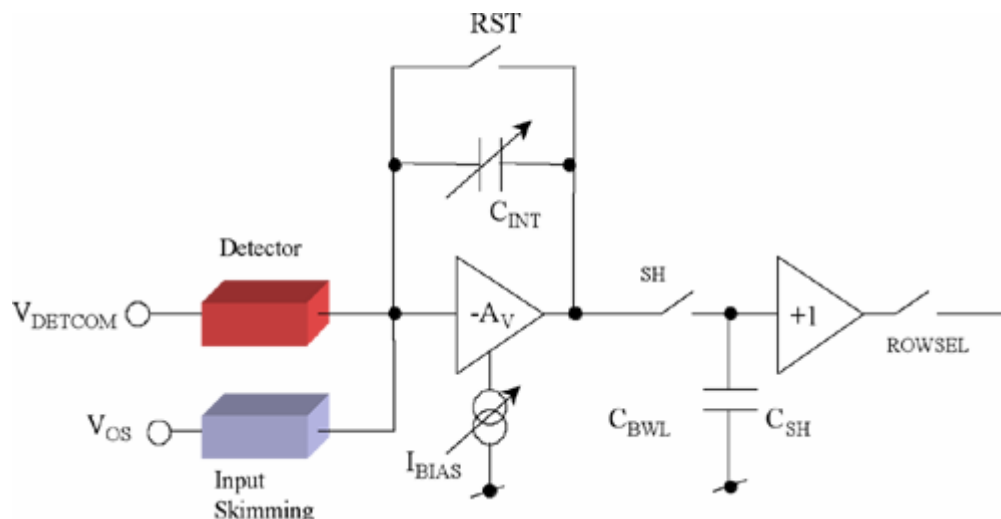


Figure 4-4: Schematic of a CTIA unit cell input circuit

Input Circuit

The CTIA input circuits of the ISC9809 and ISC002 have minimal readout noise. The detector signal is integrated onto the CTIA feedback capacitor. The voltage on the integration capacitor is sampled and multiplexed to the column amplifier. The CTIA has two selectable integration capacitors. Specific well capacities in units of electrons are shown in 7.6 Detector/FPA on page 72. You can select the amount of time that integration takes place through the camera control software. Offset adjustment in the signal chain allows skimming of the signal on top of a fixed background or leakage current. A sample-and-hold capacitor is in each unit cell for full frame snapshot integration while reading out the previously integrated frame (IWR).

The unit cell signal is buffered in each cell by a source follower for voltage multiplexing to each column. The column output voltage is buffered, sampled, and multiplexed to high bandwidth output amplifier(s).

Output Multiplexer and Buffers

Both the ISC9809 and ISC0002 can be run using from one to four outputs. The SC6000 and SC4000 camera system is always in four output mode. Routing of a given column amplifier to a given output buffer is accomplished through the output multiplexer. Pixels are assigned to a specific output channel, and are read out only through that channel regardless of the invert/revert and/or windowing modes selected. Every other column of pixels that are readout uses the same output channel.

Selectable Gain

All of the Indigo ROICs incorporate user selectable gains. For the CTIA readouts, this is implemented by including two integration capacitors (C_{INT}) in each of the unit's cells. There is switching logic that can parallel both capacitors to effectively act as one larger capacitor. The direct injection readouts adjust gain by changing the gain of the column amplifiers. As the name implies, there is a column amplifier for each column of the readout.

ISC9809

This 320 x 256 mid format, 30 μm pixel pitch array includes capacitive trans-impedance amplifier (CTIA) input circuit with up to 3.5 million electron well capacity. The snapshot readout has an *integrate while read* capability, two selectable CTIA gains and four video outputs with a maximum total data rate of 50MHz. Windowing capability includes a minimum window size of 2 rows by 128 columns. This ROIC is optimized for low background and high-speed imaging. In the high gain mode, read noise is on the order of 60 electrons. When utilized in the special *integrate then read* mode (special ITR), integration times as short as 500 nSec are possible (compared with 9 and 17 microseconds for the 9705 and 9803 respectively). This ROIC is available with either InSb or InGaAs detector material. The InSb FPA can be installed in either a permanently sealed, closed cycle dewar or pour filled, laboratory unit while the InGaAs detector is supplied in a permanently sealed thermoelectric (TE) cooled package.

ISC0002

The 640 x 512 large format array with 25 μm pixel pitch and CTIA input circuit has a well capacity of up to 2.5 million electrons. It includes snapshot readout with an *integrate while read* capability, two selectable CTIA gains, selectable bandwidth, four video outputs (down selectable to two or one) with a maximum total data rate of 50MHz. This ROIC is optimized for low background and high-speed imaging. In the high gain mode, read noise is less than or equal to 45 electrons. There is input skimming capability and when utilized in the special *integrate then read* mode (special ITR), integration times as short as 3 μs are possible (compared with 9 and 17 μs for the 9705/0209 and 9803/0309 respectively). This ROIC is available with either InSb or InGaAs detector material.

4.1.2.3 Readout settings

Table 4-1 lists typical settings and possible adjustments for the SC4000/6000 ROICs.

Table 4-1: User Accessible Voltage Settings for SC4000/6000 ROICs

ROIC	Detector	FPA Gain	Typical Skim Voltage	Possible Skim Adjustment	Typical Detector Common Voltage	Possible Detector Common Voltage	Typical FPA Bias Voltage	Possible FPA Bias Adjustment
Direct Injection 9705 320x256 and 9803 640x512	QWIP	0 (lowest)	Normally not used (Off)		6.0V		0.0V	
		1	Normally not used (Off)		6.0V		0.0V	
		2	Possibly Used 1.6 to 5.5V	More V => More Skimming	6.0V		0.0V	
		3 (highest)	1.6 to 5.5V	More V => More Skimming	6.0V		0.0V	
0002 640x512 CTIA	InGaAs	0 (lowest)	5.5V	Skim V > Det Com => More Skimming	3.2V	2.7 to 5.5V	Not applicable	Not applicable
		1 (highest)	3.5V	Skim V > Det Com => More Skimming	3.2V	2.7 to 5.5V	Not applicable	Not applicable

ROIC	Detector	FPA Gain	Typical Skim Voltage	Possible Skim Adjustment	Typical Detector Common Voltage	Possible Detector Common Voltage	Typical FPA Bias Voltage	Possible FPA Bias Adjustment
Direct Injection 9705 320x256 and 9803 640x512	InSb	0 (lowest)	Normally not used (Off)		Not connected	Not applicable	0.05 to 0.15V	Lower V for very high flux
		1	Normally not used (Off)		Not connected	Not applicable	0.05 to 0.15V	Lower V for very high flux
		2	Possibly Used 1.6 to 5.5V	More V => More Skimming	Not connected	Not applicable	0.05 to 0.15V	Lower V for very high flux
		3 (highest)	1.6 to 5.5V	More V => More Skimming	Not connected	Not applicable	0.05 to 0.15V	Lower V for very high flux
9809 320x256 CTIA	InGaAs	0 (low)	5.5V	Skim V > Det Com =>reverse Skimming	4.8V	Up to 5.5V for high flux (e.g. $T_{int} < 0.05mS$)	Not applicable	Not applicable
		1 (high)	5.0V as delivered; Can Skim Off.	Skim V > Det Com =>reverse Skimming	4.8V		Not applicable	Not applicable
	InSb	0 (lowest)	Skim Off (Skim = Det Com) Typical range if used: 4.2V-0.0V	Skim On Lower V=>More Skimming (0.0V for maximum Skimming)	4.2V		Not applicable	Not applicable
		1 (highest)	Skim off (Skim = Det Com) Typical range if used: 4.2V-0.0V	Skim On Lower V=>More Skimming (0.0V for maximum Skimming)	4.2V		Not applicable	Not applicable

4.1.3 NUC and BPR

Infrared detectors vary in their individual response to thermal or photon energy. This is commonly referred to as *detector non-uniformity*. Unless some type of compensation is performed, this variation in response of the individual detectors will result in a non-uniform and unusable image. Non-uniform images appear grainy and unclear with possible black and/or white pixels apparent. The non-uniformity correction process requires uniform temperature source. InSb and QWIP cameras are equipped with a dual temperature calibration flag that provides both hot and cold temperature.

Non uniformity correction is performed on a pixel by pixel basis; it includes gain and offset as well as the function of bad pixel replacement. The following types of NUC update are supported:

- One point offset, internal or external source
- Two point (offset and gain), internal or external source

During the NUC process, imaging continues with the current NUC while the data is being accumulated for the generation of the new coefficients. During actual accumulation, the 'freeze frame' function is utilized to prevent the image from displaying unusual artifacts. For internal NUC's where the core controls the flag, the 'freeze frame' function is used during the flag transitions periods.

NUC's are permanently stored in non-volatile FLASH, maintained when the camera is in the off state. During operation, up to four NUC coefficient sets are loaded into the active, volatile NUC memory and are available for use. The camera has sufficient volatile memory for four 1024 x 1024 coefficients sets and sufficient non-volatile storage for the same. Presets (active, volatile NUC's) are limited to four; non-volatile NUC's are only limited by the size of memory – that is, smaller arrays or window sizes allow for the permanent storage of more NUC's.

Bad pixel substitution is accomplished using the algorithm of average of the 4 nearest good pixels. The replacement algorithm is applied independently to each defective pixel. Bad pixels are stored independently of the NUC coefficients.

User can upload and down load NUC coefficient sets to a host system. A NUC coefficient set is defined as the following:

- The table of gain coefficients
- The table of offset coefficients
- Any bad pixel lists associated with that NUC
- All associated camera/FPA settings such as window size, integration time etc.

4.2 Signal Chain

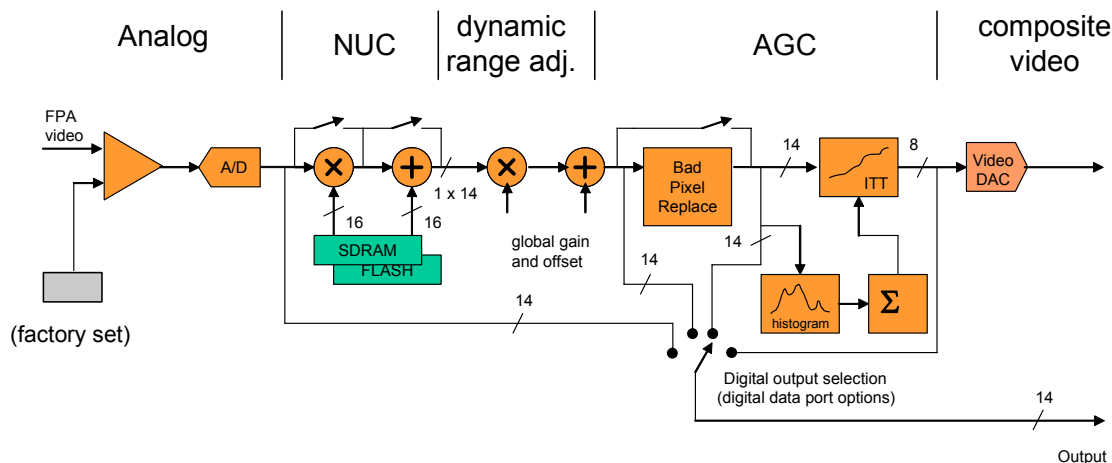


Figure 4-5: Signal path for the SC4000/6000

Figure 4-5 illustrates a simplified diagram of the signal processing chain. The actual implementation of this signal path is fully parallelized up to the AGC stage to allow for the independent use of the controls for the video and digital outputs. The signal flow is from left to right:

The output of the FPA is locally buffered at the dewar with an analog stage. Factory set offset and gain is used to ensure that full analog range of the FPA is entirely captured within the range of the 14 bit A/D converter

The signal is digitized at the earliest stage possible in the signal path. Four 14 bit A/Ds run in parallel at a sample rate of 12.5 MHz for a composite multiplexed rate of 50 MHz.

NUC is applied on each pixel with a 16 bit gain coefficient followed by a 16 bit offset coefficient. The 16 bit gain can ranges from 0.5 to 1.99997. The 16 offset has a range of -16384.5 to 16383.5.

Global gain and offset are applied. This stage allows for the user to select a *portion* of the FPAs dynamic range and map it to the full 14 bit output range of the camera. This is useful for situations such as radiometry where a 'clean', simultaneous digital saturation of all pixels is desired. The gain

has the same range and resolution as the NUC gain coefficients; the offset can shift the full 14 bits up or down and has a resolution of one digital count.

Bad pixels are replaced using a best available algorithm: if the four nearest neighbors are good, they are averaged; if not, nearest 2 in the line; nearest 1 if not 2 nearest.

AGC stage. The purpose of the AGC stage is to convert 14 bit data to 8 bit displayed video. A variety of algorithms are available to do this, but all are based on collecting the histogram of the scene. This histogram is then used to generate a 14 x 8 *Image Translation Table* which compresses the 14 bits to a displayable format. When the user desires manual control over this function, brightness and contrast controls are used to fill the ITT with a linear transfer function. The automatic algorithms available are:

Plateau equalization – a better balanced version of histogram equalization

Logarithmic equalization – a method of logarithmically compressing the histogram before it is converted to an ITT

Linear AGC – traditional linear AGC with inputs based on percentage of scene included (“95-5”) or number of standard deviations included (“mean sigma”)

Video DAC. The 8 bit output of the AGC stage is converted back to analog for display on a conventional NTSC or PAL monitor.

Digital data taps. Any portion of the signal chain from raw uncorrected FPA data to AGC compressed 8 bit video can be sent to the digital output. The analog output has the same, independent selections available except that AGC is always applied to the data.

4.3 Camera Behavior

4.3.1 Frame Rate and Integration Time

The standard mode of camera operation is the Asynchronous Integrate While Read (AIWR) mode. This mode allows for semi-independent control of the camera’s frame rate and integration time. The frame rate is the number of snapshots taken per second; the integration time is the length of time that each snapshot actually views the scene. As the name implies, the camera is able to integrate scene signal while simultaneously reading out the previous frame.

The frame rate may be controlled by the camera (free run) or may be externally synchronized to off-camera events. It is arbitrarily adjustable up to a maximum rate that is limited by the window size. The maximum integration times are in turn, controlled by the selected frame rate. Refer to figure x1 below for the following points:

Frame rate limited by readout time. In the top of figure x1, the time required to readout all of the pixels limits the maximum frame rate (frame time is the inverse of frame rate). At the end of each integration period, the readout sequence is seen to start; at the appropriate time, the camera starts the next integration period – this is determined by what the user has selected. The maximum frame rate is dependent on the window size; for a full frame 640 x 512 window, this is 126 Hz.

The camera can take either frame rate priority when integration time is automatically adjusted to conform, or integration time priority when frame rate is automatically adjusted to conform. Camera will not allow conflicting values between frame rate and integration time.

Data Latency

The latency between the start of integration and start of data output on the digital port is

SC4000 – integration time + about 37 μ sec

SC4000/6000 – integration time + about 78 μ sec

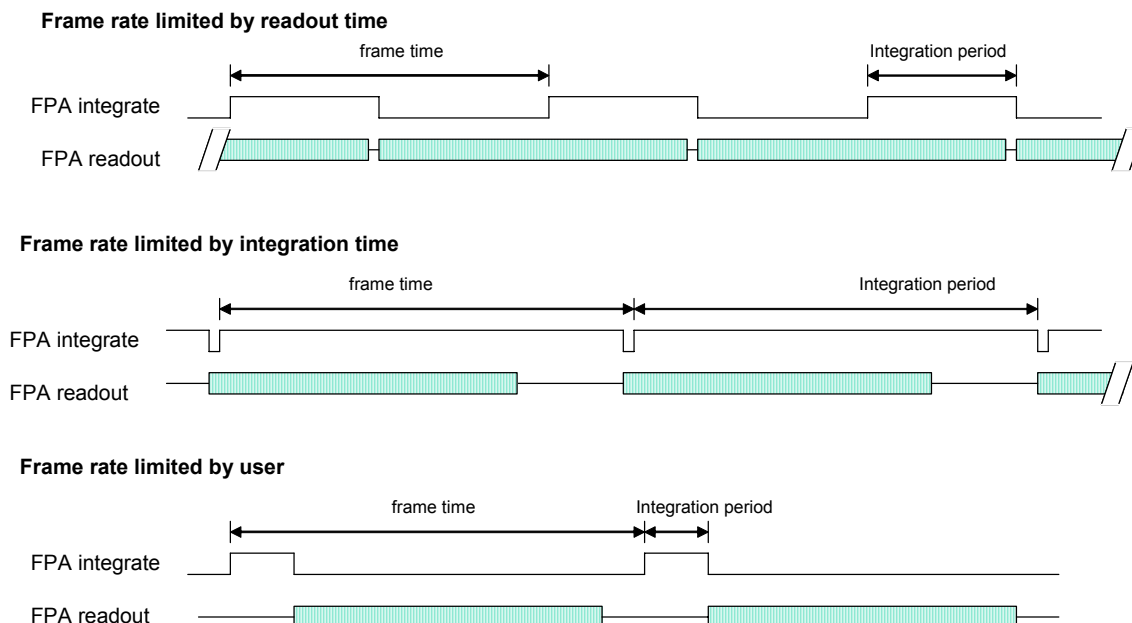


Figure 4-6: Frame rate and integration time interactions in the AIWR mode

Frame rate limited by integration time. When the user desires a longer integration time than the frame period allows, a slower frame rate (longer frame period) is first selected and the longer integration period can then be chosen. The frame rate must be reduced to:

$$\text{framerate} < \frac{1}{\text{integration time} + \tau_{\text{overhead}}}$$

This scenario is depicted in the middle of Figure 4-6. The camera starts the integration period almost immediately after the start of the pixel readout period. τ_{overhead} is an ROIC dependent overhead parameter that limits the maximum integration time. Its value for each ROIC type is:

ROIC	τ_{overhead} _____
9803	6.9 μsec
9705	5.4 μsec
0002	8.3 μsec
9809	5.4 μsec

The camera has internal limitations to prevent it from accepting integration periods longer than these ROIC imposed maxima. The minimum integration time is limited to 10 μsec for 0309 and 5 μsec for 0209.

Frame rate limited by user. The bottom scenario in Figure 4-6 shows the frame rate set at lower than the maximum allowed by the readout window, and the integration time set at less than the frame time. In this case, the user has selected a frame rate for other reasons. When set in internal, free run mode, the user can select any frame rate from 1 Hz to the maximum allowed by the window size. Frame rates less than 1 Hz may be selected by using an external sync source.

Special considerations for external sync. The AIWR mode works with an external sync; this is useful for synchronizing the camera to external events. In this mode, the start of the integration period is controlled by the external sync. The same maximum frame rate restrictions apply; if the sync signal arrives too early, then it will be ignored.

4.3.2 Windowing

The SC4000/6000 supports semi-arbitrary windowing of the FPA. Location and size can be selected within the constraints of the FPA type in the camera. Windowing is primarily used to obtain faster frame rates but can also be used to limit the amount of data collected for a particular acquisition.

Table 4-2 below summarizes the FPA restrictions on granularity of size and location.

Table 4-2: Resolution restrictions for window size and position

Windowing parameter	640 x 512 FPAs	320 x 256 FPAs
Location resolution – column direction	16	16
Location resolution – row direction	4	2
Size resolution – column direction	16	8
Size resolution – row direction	4	2
Minimum window size (column x row)	128* x 4	128 x 2

*9803 FPAs can accept a minimum of 64

NUC considerations. There are two ways to use non-uniformity correction coefficients with windows. The simplest is to use an existing, full-frame NUC and select the desired window size and location. With no change in integration time this will produce an acceptable image and is very useful for setting up tests. Since one of the principle reasons for selecting a smaller window is to run at higher frame rates, the integration time must frequently be reduced (discussed below). Changing the integration time generally will result in a less than optimum correction and for the best uniformity, it is best to perform a NUC on the selected window, frame rate and integration time.

Frame rate and integration time considerations. The selection of a smaller window allows the maximum frame rate to increase; this in turn *limits* the maximum integration time available; use of slower than the maximum frame rate is required if a longer integration time is needed.

The maximum frame rate achievable for a given window size is:

$$\dot{F} = \frac{50000000}{(\text{rows} + 3)(\text{columns} + 128) + 8} \quad \text{for 640 x 512 FPA sizes}$$

$$\dot{F} = \frac{50000000}{(\text{rows} + 2)(\text{columns} + 128) + 8} \quad \text{for 320 x 256 FPA sizes}$$

The integration time is then limited to slightly less than the inverse of the frame rate (see section 4.3.1 – frame rate and integration time).

4.3.3 External Synchronization of the Camera

The camera provides multiple options for external synchronization and triggering. Options for the synchronized event (integration, data readout, video output) as well as the synchronization source (TTL pulse, composite video, IRIG) are available in various combinations and are discussed below.

Asynchronous Integrate While Read (AIWR). Probably the most common synchronization task is to control the start of the FPA integration period with an external signal. The AIWR mode offers the most flexibility for accomplishing this.

Figure 4-7 illustrates the camera level timing of this mode. The externally provided frame sync controls the start of the integration period, which causes scene charge to be collected for the length of time that has been programmed by the user. At the end of the integration period, the FPA readout process begins. This is shown in the lower part of the figure which includes the Camera link frame and line valid signals.

The duration of the readout process is determined by the user selected window size – all pixels in this window must be read out. At a time that is approximately the selected integration time *prior to the end*

of read out it is possible to start the next integration period (i.e. *integrate while read*). This is indicated in the figure by the end of the lockout period; at that point the camera will accept another frame sync input. As illustrated here, the user waits a short period before issuing the sync – at that time, the integration period and lockout period begin again. During the lockout period, the camera will ignore any external sync pulses.

4.3.3.1 Data Latency

The latency between the external synchronization input and the start of integration is $400 \text{ nsec} \pm 80 \text{ nsec}$.

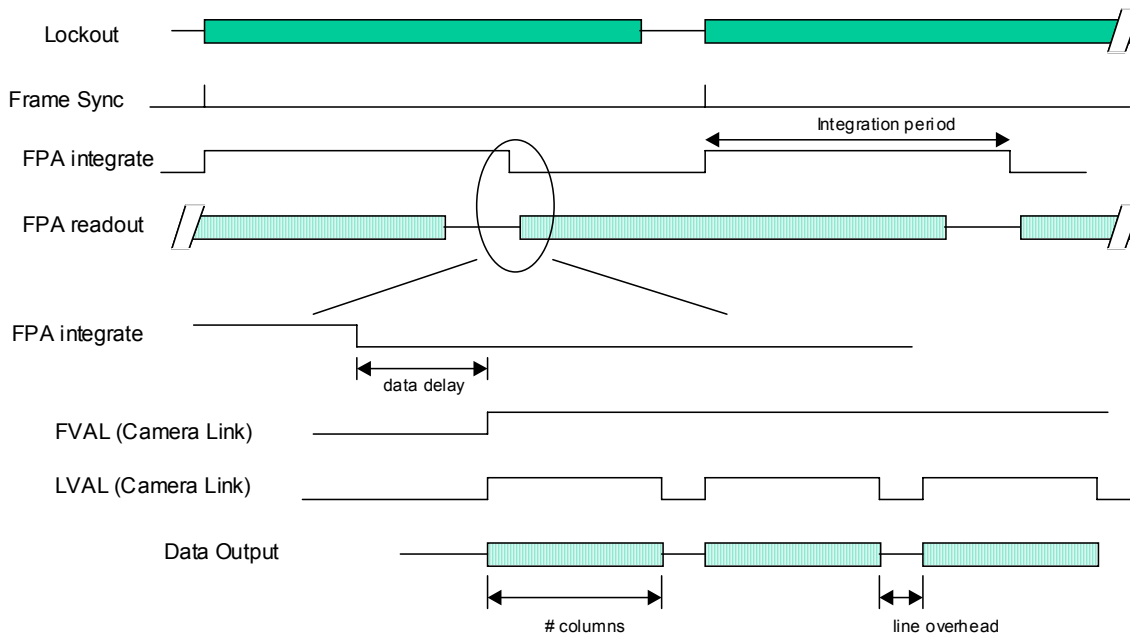


Figure 4-7: AIWR mode synchronizes the start of integration to an external source

Asynchronous Triggered FPA Read (ATFR). The ATFR mode is used to synchronize the *readout* of scene information. This mode is useful for any downstream signal processing elements that either need control of when data is sent, or need a fixed relationship between the sync and when data is available.

Referring to Figure 4-8 below, the external frame sync initiates the readout period of the FPA. While not immediately apparent, it also initiates the start of the integration period at a time calculated by the camera which is approximately the time required for readout, less the user selected integration time.

At the end of the integration period, the FPA readout process is automatically started but the camera halts this *immediately prior to the appearance of the first valid pixel*. At this point, the lockout period ends and the camera will accept another sync pulse. When the sync is received, the data readout process continues with the readout of the first valid pixel, the lockout period begins, and at a later time, the integration period starts again.

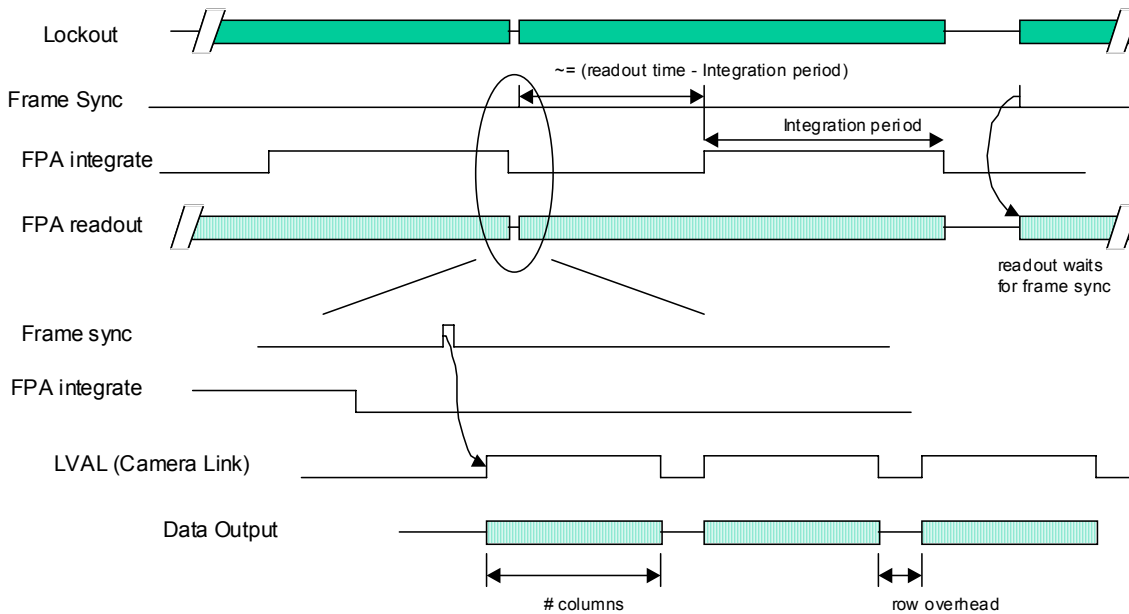


Figure 4-8: ATFR mode synchronizes the data read period to external events

IRIG synchronization. The camera has an IRIG input and on-board decoder. There is an option for setting a future time that is used to trigger a sync pulse. When the IRIG time matches the setting, a single sync pulse is generated and the camera will output a single frame. When used in conjunction with the preset sequence controls, multiple frames can be triggered at the programmed time.

Synchronization to a composite video input – Genlock. In the genlock mode, the composite video output section of the camera is locked to an externally provided composite video signal. It is important to understand that this genlock is in the analog video portion of the camera only; that is, the FPA continues to operate at its selected frame rate and the digital output (Camera Link, Gig-E) is not synchronized to the composite input.

Synchronization to video source. This makes use of the video vertical signal to synchronize the FPA – that is, the FPA will be operated at 59.994 Hz, synchronized to the video analog video section of the camera.

4.3.4 Global Gain and Offset

The global gain and offset stages are digital features of the camera that allow the corrected digital output of the camera to be mapped to different output ranges. Figure 4-9 illustrates the position of these stages in the signal path:

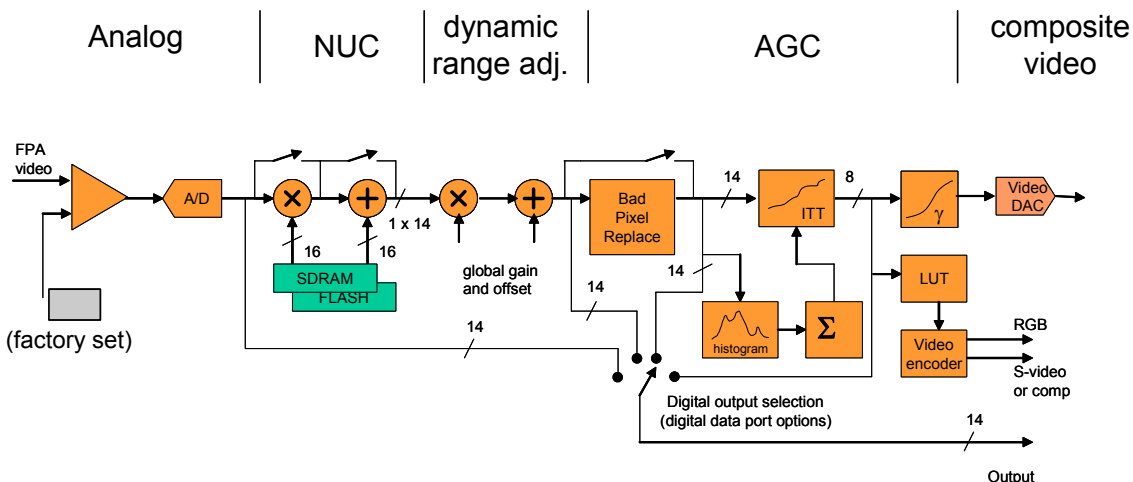


Figure 4-9: SC4000/6000 signal processing chain

The FPA is passed through an analog gain and offset stage that are both factory-set to ensure that the entire range of the FPA well is digitized. Pixel by pixel gain and offset coefficients are applied to correct the video for fixed-pattern noise (NUC). User selectable gain and offset are applied.

Setup and use. The camera (as set up at the factory) will digitize the entire range of the FPA. This is shown in Figure 4-10 which plots the digital output of a typical camera against *background photon flux*. The actual scale of the flux depends on integration time setting.

The figure shows an example where the user desires to operate the camera between two flux points such that these two limits use the entire 14 bit range. With no global gain and offset adjustment these two points correspond to 3200 counts and 15800 counts for the low and high flux ranges respectively. Having obtained these numbers during a calibration procedure, we set the gain to use the full 14-bit range:

$$gain = \frac{16383}{15800 - 3200} = 1.30$$

Since the offset stage is *after* the gain stage we calculate the offset value using the gain:

$$offset = -3200 \times gain = -4160$$

These values are then entered into the global gain and offset controls and the linearized (red curve) transfer function shown in Figure 4-10 is the result.

The available gain range is 1.999 to essentially zero; the available offset range is ± 32767 . The default values are a gain of 1 and an offset of zero – that is, the factory transfer function. Because the system sensitivity (NE Δ T) is set prior to the A/D stages, there is no detrimental effect on performance from the use of the global gain and offset controls.

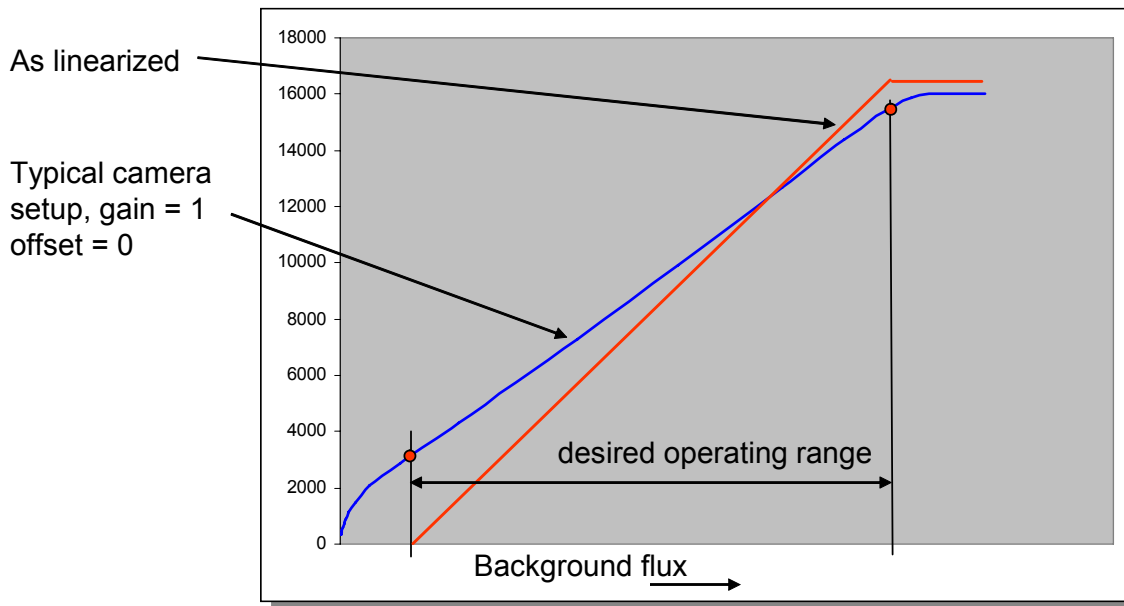


Figure 4-10: Use of global gain and offset to linearize the camera

5 SC4000/6000 Camera GUI

The SC4000/6000 camera Graphic User interface (GUI) is used to control the camera over the USB port, Gigabit Ethernet port or Camera Link serial port.

5.1 Menu

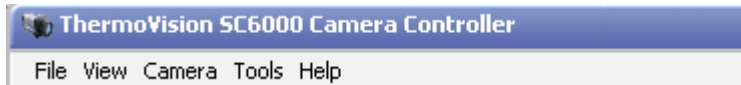


Figure 5-1: Top Menu

5.1.1 File

File->Load State

Loads a complete camera state from the computer (can only be used when the camera is connected)

File->Save State

Saves a complete camera state to the computer (can only be used when the camera is connected)

File->Exit

Closes the application

5.1.2 View

View->Log

Shows or hides the log window

View->Refresh

Refreshes the current pane, all information on the current pane is read from the camera. This can also be accomplished by pressing the F5 key.

5.1.3 Camera

Camera->Connect

The GUI will connect to the camera using the current communications settings

Camera->Disconnect

The GUI will disconnect from the camera if connected

Camera->Load State

Loads a previously saved global camera state from a file in the camera, reading the global camera state also reads all the preset states that the global state refers to. The loaded state will be used when the camera boots (can only be used when the camera is connected).

The camera has two kinds of state information: global state and preset state. Global state includes AGC settings, sync source, and other preset independent information. The global state also includes the names of all the NUC used for each preset. In order for the camera to boot using a new set of NUCs the global state must be saved. Any information that is dependent on preset (integration time, frame rate, integration mode, window size, calibration setup) is stored in the preset state. Preset state information is associated with NUCs so in order to save the preset information you must save the NUC for a given preset.

Camera->Save State

Saves the global state (and optionally each NUC) information to a file in the camera. The file is the current state file (shown in parentheses). The save state will be used when the camera boots (can only be used when the camera is connected).

Camera->Save State As

Saves the global state (and optionally each NUC) information to a file in the camera. The file is picked by the user. The save state will be used when the camera boots. (can only be used when the camera is connected)

Camera->Update

Starts a camera software update process (can only be used when the camera is connected) as shown in Figure 5-2.

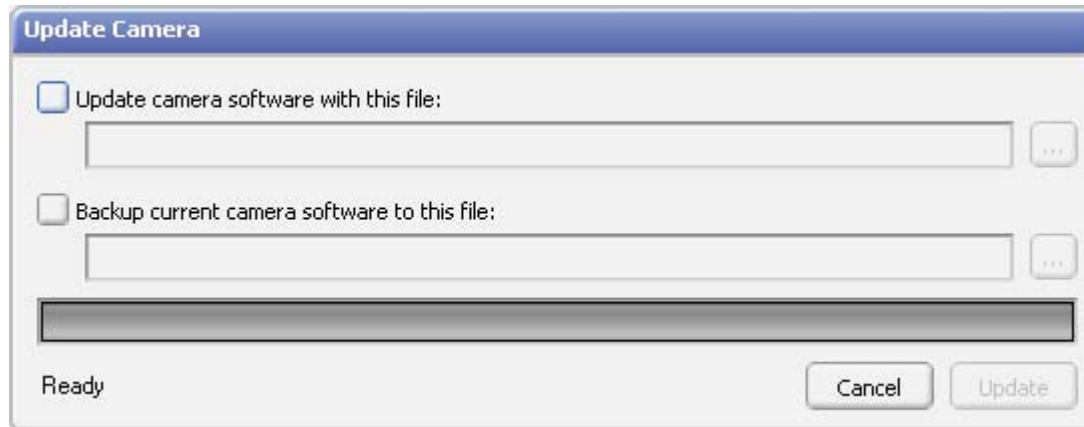


Figure 5-2: Update Camera Window

Check **Update camera software with this file** to update camera software. The browse ... button is used to find the camera software file.

Check **Backup current camera software to this file** to backup camera file. The browse ... button is used to select a destination camera software file.

5.1.4 Tools

Tools->Clear Log

Removes all text from the Log

Tools->Connection

Displays the connection wizard (can only be used when the camera is **NOT** connected)

Tools->Settings

Displays the settings window as shown in Figure 5-3

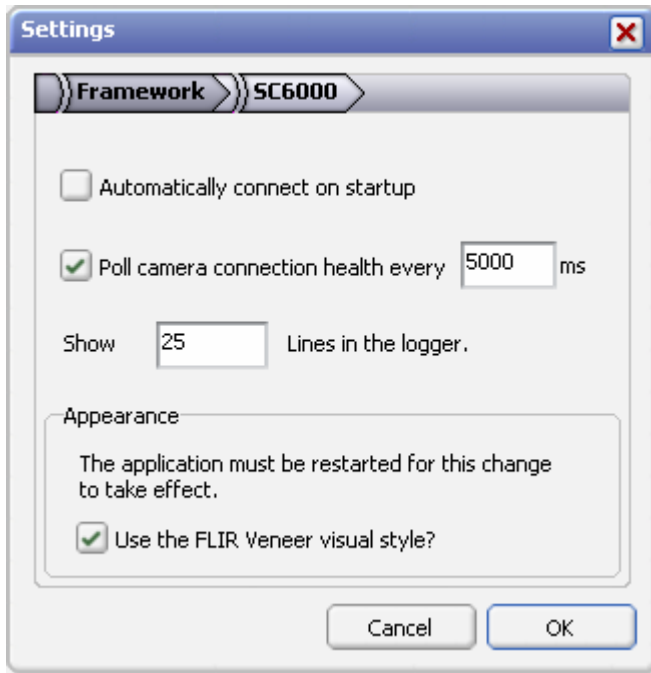


Figure 5-3: Settings Window -Framework

Automatically connect on startup attempts to connect the GUI to the camera whenever it is running.

Poll camera connection health will send a nop message to the camera at the given interval, if the nop message fails the connection is assumed to have been broken and the GUI disconnects. This polling does not occur while files are transferring.

Show X lines in the logger determines how many lines of text are displayed in the logger at any give time. All text is logged to a file named SC6000CameraController.exe.log in the same directory as the camera controller executable. The log file is cleared when the application starts.

Use FLIR Veneer visual style turns the FLIR look-n-feel on and off.

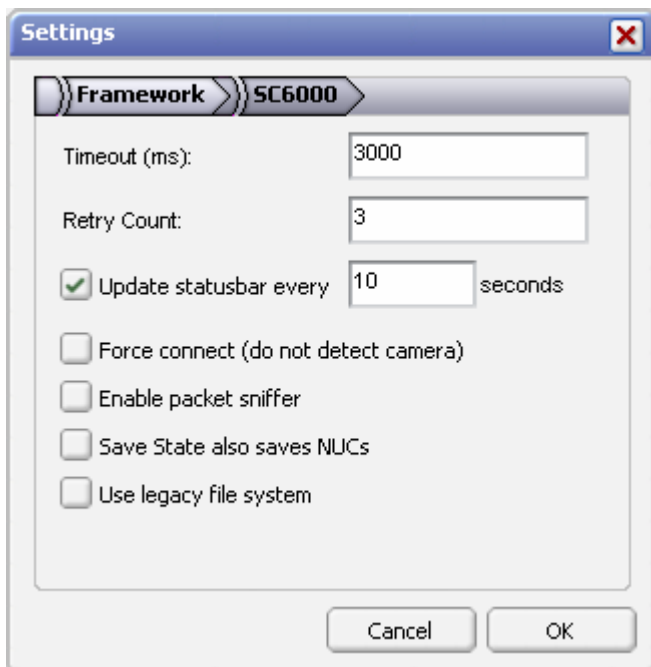


Figure 5-4: Settings Window –SC4000/6000

Timeout (ms) is the number of ms to wait for a response to a message before giving up.

Retry count is the number of times to try to re-send the message after a failure.

Update statusbar every X seconds determines how often the status bar is refreshed. This only pertains to FPA temperature.

Force connect allows the GUI to “connect” to the camera even if the camera isn’t there. This should only be used for troubleshooting purposes.

Enable packet sniffer logs the contents of all messages sent to and received from the camera. Communications are slower when this is enabled. This should only be used for troubleshooting.

Save Sate also saves NUCs determines if each NUC is saved in response to a global save state.

Use legacy file system is provided for updating older cameras and troubleshooting.

Tools->Camera Port

Displays the camera port selector (can only be used when the camera is **NOT** connected)

Tools->Real Time Clock

Displays the real time clock window as shown in Figure 5-5 (can only be used when the camera is connected)

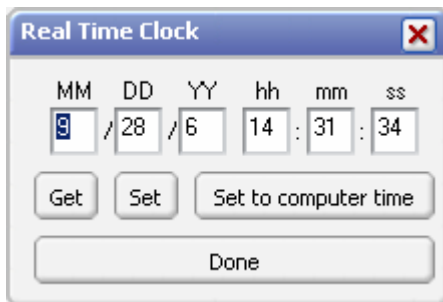


Figure 5-5: Real Time Clock Window

Real Time Clock (RTC) is used to timestamp camera files

Click **Get** to get the current RTC

Fill out the text boxes with a date and time and click **set** to set the RTC

Click **Set to computer time** to set the RTC to the computers current time

Click **Done** to close the dialog.

Tools->IRIG Time

Displays the IRIG time window as shown in Figure 5-6

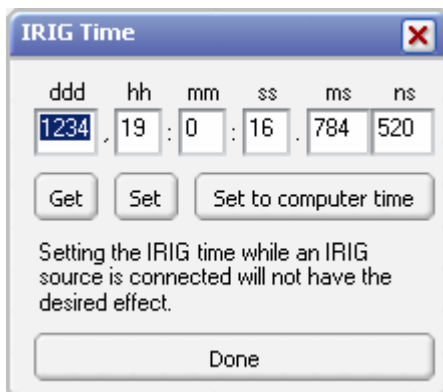


Figure 5-6: IRIG Time Window

IRIG Time is used to set the IRIG time when no IRIG input is present. The camera will automatically generate time when no IRIG input is present (can only be used when the camera is connected).

Click **Get** to get the current IRIG time

Fill out the text boxes with a date and time and click **set** to set the IRIG time

Click **Set to computer time** to set the IRIG time to the computers current time

Note

The computer time is not as precise as IRIG time. Therefore, zeros are used for nano-second.

Click **Done** to close the dialog.

5.2 Control Screens

There are six control screens: **Status**, **Setup**, **Correction**, **AGC**, **Video** and **Advanced**. The various control screens of the GUI are accessed by pressing the button on the left side.

5.2.1 Status Screen

Once the camera and PC are connected, you will see an initial status screen like the one shown in Figure 5-7.



Figure 5-7: Status Screen

The **Status** screen displays the current status of the SC4000/6000 camera.

Information on the **Status** screen includes:

- A summary of the system status which will notify you of whether or not the camera is ready
- Communication path
 - Figure 5-7 shows the system is communicating via USB.
- Detector material and readout circuitry of the FPA

- The current focal plane array (FPA) temperature
- The FPA temperature will be refreshed every 5 seconds while the **Status** Screen is visible.
- The current active preset
- The active preset integration time, frame size and frame rate

Note

The current active preset and active preset integration time will be replaced with Multi Seq in preset sequencing mode.

5.2.2 Setup Screen

Many of the primary camera adjustments and settings can be accessed by Setup screen.

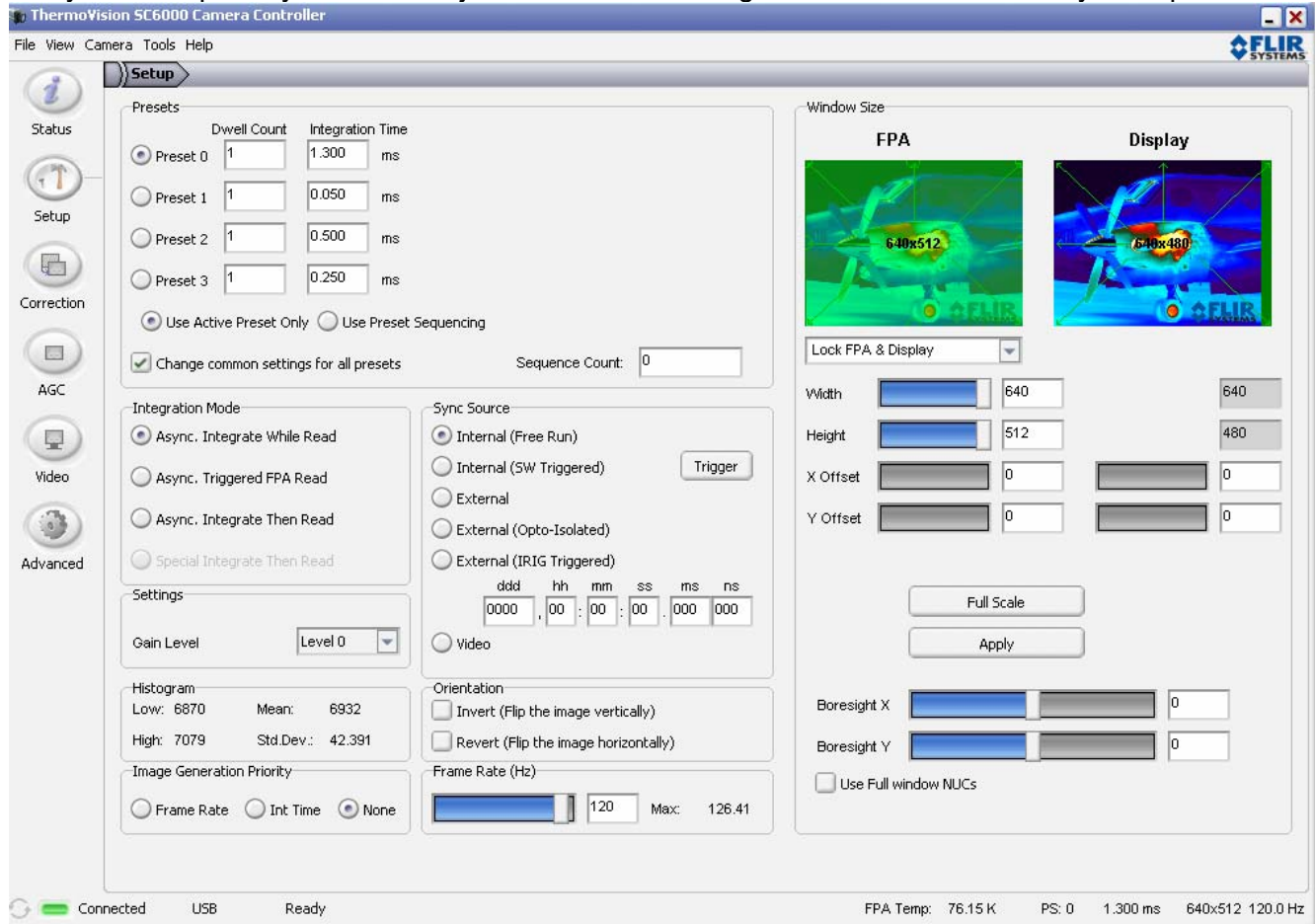


Figure 5-8: SC4000/6000 GUI – Setup Screen

Many settings can be set on a per preset basis, but are typically set to the same value (especially for preset sequencing). These settings will have a single set of controls that will modify the values for any one, or all presets. Change common settings for all presets determines if the settings change for all presets or just for the active preset. Common settings are: Window Size, Frame Rate, Image Generation Priority, Invert/Revert, Gain, FPA enable, and Integration Mode.

When in preset sequencing mode the preset 0,1,2,3 radio buttons determine what preset is displayed on the analog video

When in active preset only mode the preset 0,1,2,3 radio buttons determine what preset is used.

When in preset sequencing mode the dwell count for a preset determines how many frames are generated in that preset before moving to the next preset.

The integration time can be entered for each preset using the textbox or the slider.

Use active preset only enters active preset mode

Use preset sequencing enters preset sequencing mode, this mode can only be used if at least one preset has a frame count greater than zero.

Use triggered preset sequencing enters triggered preset sequencing mode (not available with internal sync mode), this mode can only be used if at least one preset has a frame count greater than zero and the sequence count is greater than zero.

Sequence count determines the number of sequences to trigger

Integration mode sets the active integration mode. Not all integration modes will be supported by all cameras; if an integration mode isn't supported, it will be grayed out.

A frame in the following refers to an image

A sequence in the following refers to generating frame count frames in each preset starting at 0

Sync source along with the preset sequencing mode determine how images are generated.

Internal (free run)

Active Preset

The camera automatically generates frames in the active preset

Preset sequencing

The camera automatically generates sequences

Triggered Preset Sequencing

Not useful in this mode, almost identical to preset sequencing

Internal (SW Triggered)

Active Preset

Clicking the Trigger button generates a frame in the active preset

Preset sequencing

Clicking the Trigger button generates a sequence

Triggered Preset Sequencing

Clicking the Trigger button generates sequence count sequences

External, External (Opto-Isolated), and External (IRIG Triggered)

External

The external sync input is the sync in BNC on the back of the camera.

External (Opto-Isolated)

The external sync input is optically isolated. The sync source and camera do not use the same ground, which prevents the sync source from generating any noise in the camera. The optically isolated sync in uses an LED and a light sensor and as such the frequency is limited by the response of the LED. The sync input is located in the AUX connector OPTODEC+ and OPTODEC-.

External (IRIG Triggered)

The external sync input is the output of an IRIG time comparator. A sync is generated whenever the current IRIG time matches the given time. The time entered can be an exact time or it can contain a match any digit ("X"). If a match any digit is used any time value at that digit will match. For instance if the time "XXXX,XX:XX:X0.XXXXXX" is given the time will match whenever the low digit of seconds is 0 (i.e. 00, 10, 20, 30, 40, 50). Using this method the time can match every second, 10 seconds, minute, etc. Since match any is per digit, repeated matches can only be done at digit boundaries.

This means time can NOT match every 5 seconds, 40 seconds, or in general any 2-9 of any 10 base increment of time. Combining exact time method and match any digit method is possible. For instance the string “0032,16:XX:0X.XXXXXX” will match every minute on the 16th hour on the 32nd day in the year.

Time String	Matches	Width
XXXX,XX:XX:XX.XXXXXX	Always	inf
XXXX,XX:XX:XX.XXXXX0	Every 10 microseconds	1 us
XXXX,XX:XX:XX.XXXXX0X	Every 100 microseconds	10 us
XXXX,XX:XX:XX.XXX0XX	Every millisecond	100 us
XXXX,XX:XX:XX.XX0XXX	Every 10 milliseconds	1 ms
XXXX,XX:XX:XX.X0XXXX	Every 100 milliseconds	10 ms
XXXX,XX:XX:XX.0XXXXX	Every second	100 ms
XXXX,XX:XX:X0.XXXXXX	Every 10 seconds	1 s
XXXX,XX:XX:0X.XXXXXX	Every minute	10 s
XXXX,XX:X0:XX.XXXXXX	Every 10 minutes	1 m
XXXX,XX:0X:XX.XXXXXX	Every hour	10 m
XXXX,X0:XX:XX.XXXXXX	Every 10 hours*	1 h
XXXX,0X:XX:XX.XXXXXX	Every day	10 h

*When matching every 10 hours the matches are from the start of the day and are reset every day. When matching every 10 or 100 days the matches are from the start of the year and are reset every year.

Width refers to the pulse width, that is the amount of time the sync is asserted. Exact matching additional digits can affect the pulse width. The pulse width can be ignored if the external sync polarity is set to rising edge.

Active Preset

When a sync is received the camera generates a frame in the active preset

Preset sequencing

When a sync is received the camera generates a sequence

Triggered Preset Sequencing

When a sync is received the camera generates sequence count sequences

Video operates like external sync. Video Sync synchronizes to the video rate.

Gain level selects the FPA’s analog gain.

Enable the FPA enables and disables the FPA, when the FPA is disabled it will not output an image, it will output something more like a constant.

Invert and Revert flip the image data vertically and horizontally respectively.

The image generation priority determines how to bound frame rate and integration time. Integration time and frame rate are interdependent, in order to have a high frame rate you have to have a low integration time and in order to have a high integration time you have to have a low frame rate. When frame rate has priority the integration time is bounded by the frame rate. When integration time has priority the frame rate is bounded by integration time. When there is no priority neither frame rate nor integration time have a maximum bound. In this mode integration time is bounded if you set the frame rate higher than the current integration time can handle and frame rate is bounded if you set the integration time higher than the current frame rate can handle.

The histogram group contains the low (min), high (max), mean, and standard deviation of the image data.

The frame rate determines the rate at which frames are generated, it can be modified with the text box or the slider.

Window size controls the size of the window in the FPA and on the display. The window can be modified in the FPA or in the display or in both by using the update window in selection.

The window can be modified by

Entering width, height, xoffset, yoffset into the appropriate text boxes dragging the sliders associated with width, height, xoffset, and yoffset;

Clicking the green portion of the window display and dragging it to a new position (changes xoffset and yoffset);

Clicking the dark green size handles at the corners and sides of the window display and dragging it to a new position (changes width and height);

Clicking the Apply button sends the window to the camera.

When use full window NUCs is checked the camera will NUC the entire FPA when performing a NUC. When it is not checked the camera will NUC just the window when performing a NUC. The advantage to this option being checked is that you can change the window size after doing a full window NUC without having to reNUC, but if it isn't checked you will have to reNUC.

5.2.3 Correction Screen

The **correction** screen shown in Figure 5-9 is used to perform non uniformity correction (NUC) and manage stored NUCs.

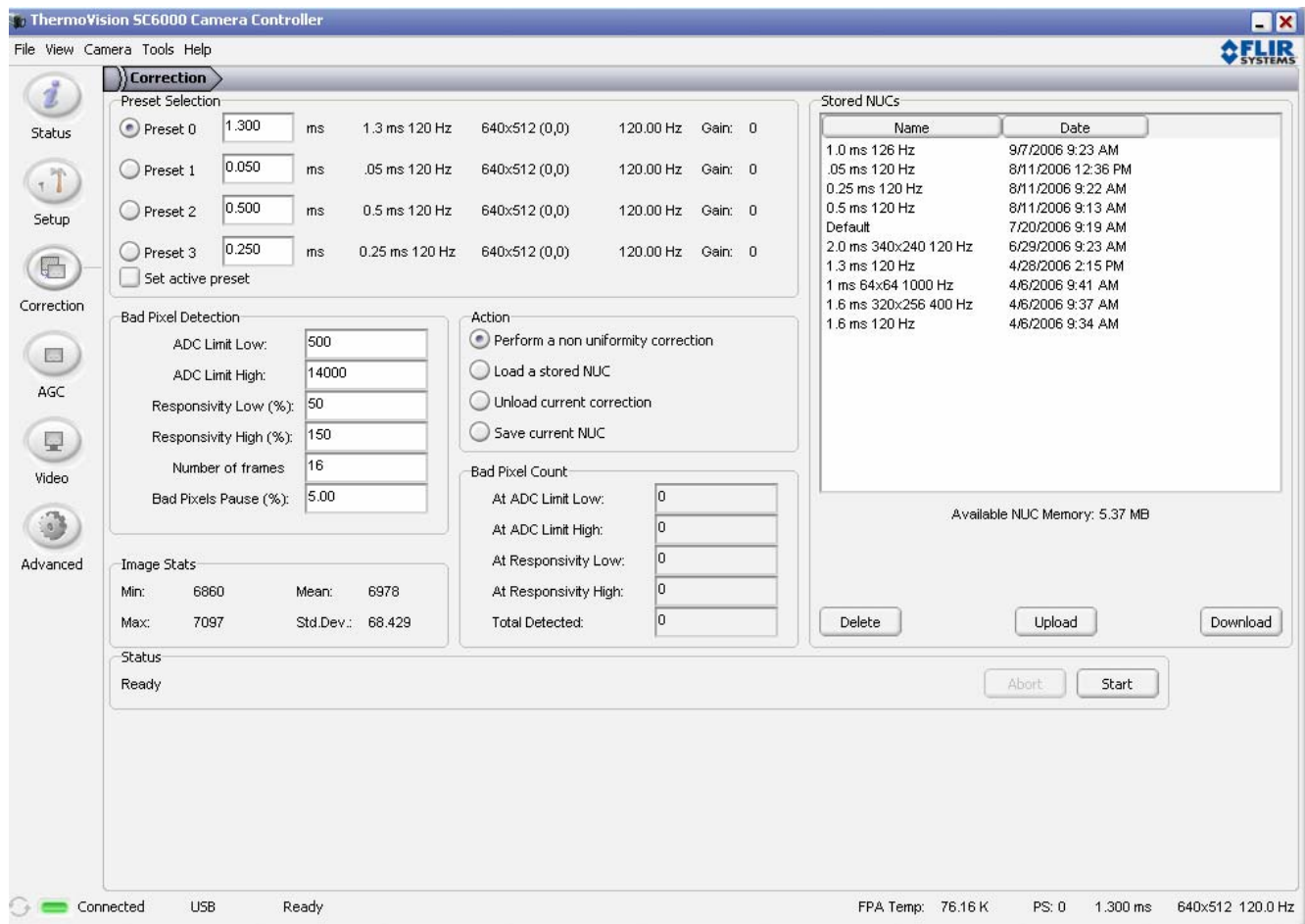


Figure 5-9: SC4000/6000 GUI – Correction Screen

In general this pane is used by first selecting the preset to modify, selecting an action, setting up the configurations, then clicking the button at the bottom right of the pane.

The preset 0,1,2,3 radio buttons determine what preset is used when performing an action.

The set active preset checkbox determines if the active preset will be change to the preset you select for an action. This is useful for previewing the preset before performing an action.

The integration time can be entered using the text box next to the preset radio.

Several values are displayed for each preset in the following order

The Filename currently used for the NUC.

The window size and origin “widthXheight (xoffset,yoffset)”

The frame rate.

The gain.

The image stats displays the current min, max, mean, and standard deviation of the image.

The bad pixel detection group contains parameters for bad pixel detection, that are applied when performing a NUC.

Bad pixels are detected if detect bad pixels is checked

Bad pixels are replaced with the nearest good pixel if replace bad pixels is checked

ADC limit low: if a pixel value is less than the A/D counts limit low then it is considered bad

ADC limit high: if a pixels value is greater than the A/D counts limit high then it is considered bad

Bad pixels pause %: if the percentage of bad pixels reaches this level the NUC is paused

Number of frames: number of frames to average when collecting a sample frame

Responsivity low %: if a pixel has a responsivity below this percent of the mean responsivity then it is considered bad. Responsivity low minimum is 50% (max gain <1.99999).

Note

Abort during NUC process may cause hang. If so, cycle power and restart.

Responsivity high %: if a pixel has a responsivity above this percent of the mean responsivity then it is considered bad

The bad pixel count group displays the number of bad pixels detected.

At ADC Low: number of pixels bad because of ADC low rule

At ADC High: number of pixels bad because of ADC high rule

At responsivity low: number of pixels bad because of resp low rule

At responsivity high: number of pixels bad because of resp high rule

Total detected: total number of bad pixels

The stored NUCs group contains a list of NUCs that are stored on the camera.

The available NUC memory is also displayed.

To delete a NUC select it and click delete.

To upload a NUC from the computer click the upload button.

To download a NUC to the computer select it and click the download button.

The action determines what action to perform

Perform a NUC

Perform a new NUC, click start

A dialog will be displayed

After setting up the NUC options the NUC will proceed

The current NUC status will be displayed in the ready line next to the abort button.

Click Abort to stop the NUC process

Click Continue when prompted

Load a stored NUC

The selected NUC will be loaded into the selected preset. Select the NUC with the stored NUCs list, click load

Save current NUC

The correction currently loaded into the selected preset will be saved to non-volatile memory, click save

Unload current NUC

Not supported

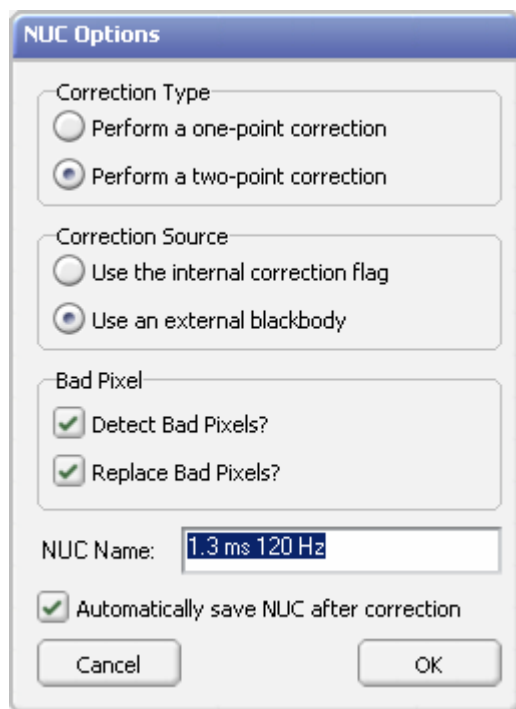


Figure 5-10: NUC Options

Select a correction type

One point performs an offset correction

Two point performs an offset and gain correction

Select a correction source

Internal correction flag uses the temperature controlled flag mounted in front of the FPA to automatically perform a correction.

External uses a black body that the user is responsible for setting up.

The NUC name is the filename to save the NUC to.

If automatically save NUC is checked the NUC will be saved to flash after performing a correction, if it isn't checked then the NUC will have to be saved manually.

Clicking **OK** will proceed with the NUC; clicking Cancel will cancel the NUC.

5.2.4 AGC Screen

AGC (Automatic Gain Control) pertains only to the analog video imagery. Digital data is not affected by these controls.

There are two sub-panels AGC and ROI in the AGC screen.

5.2.4.1 Automatic Gain Control (AGC)

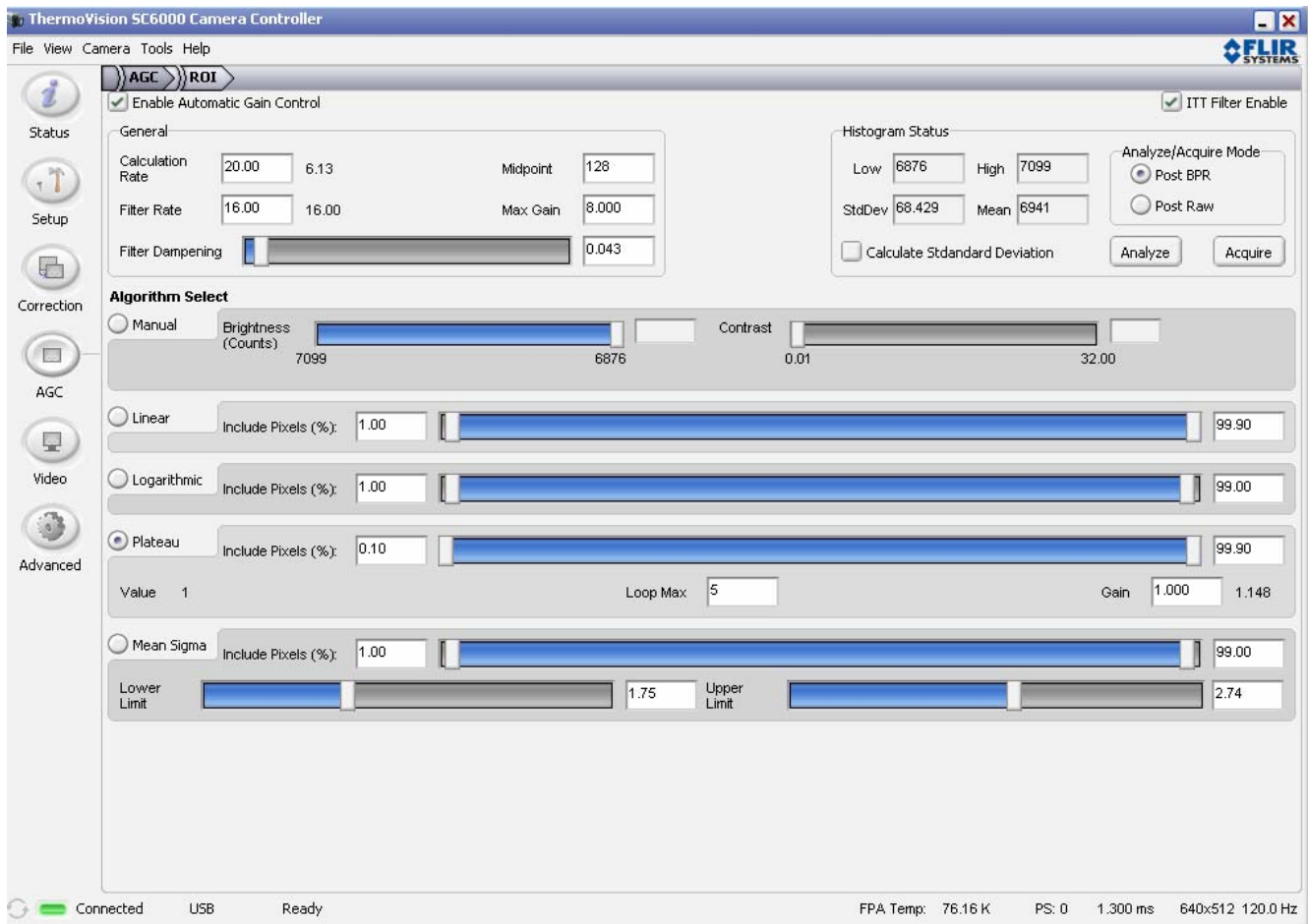


Figure 5-11: SC4000/6000 GUI – AGC

Checking Enable Automatic Gain Control will turn on AGC.

ITT stands for Intensity Transform Table, an ITT is a table mapping pixel values (counts) into display colors.

If ITT filter enable is checked a filter dampening will be applied to the ITT, if it is not checked then the AGC ITT will be used directly. ITT dampening effects how fast scene changes take effect and tends to give a smoother display.

Note

If enable AGC is checked the ITT will update constantly, if this isn't checked the ITT will stay fixed.

The **calculation rate** is how often the ITT is to be calculated in Hz, the rate entered is a target rate, the camera will attempt to match the target rate as best it can. The actual rate is displayed next to the requested rate.

The **filter rate** is how often to apply damping to the ITT is to be applied in Hz, the rate entered is a target rate, the camera will attempt to match the target rate as best it can. The actual rate is displayed next to the requested rate.

The **midpoint** is the grayscale color value that is associated with the middle of the ITT.

The **max gain** is an upper bound on the maximum gain to apply. If a given AGC algorithm produces a gain higher than the max it will be bounded to the max.

Filter damping controls how quickly scene changes effect and how smooth the transition is. The ITT used is the new ITT * damp + (1-damp) * old ITT.

The **histogram status** contains the current min, max, mean, standard deviation of the image.

The **analyze** button analyzes the histogram immediately and updates min, max, mean, std dev.

The **Acquire** button immediately captures the histogram and stores it on the camera.

The **acquire mode** is determines the histogram status and acquire source. Post BPR is after bad pixel replacement, Post Raw is raw data.

If the calculate standard deviation checkbox is checked then standard deviation will always be calculated whenever the min, max, and mean are calculated.

Each AGC algorithm has a group of controls associated with it; these are shown by a shaded group box.

AGC Types available:

Manual

Linear

Logarithmic

Plateau

Mean Sigma

To select an AGC algorithm use the manual, linear, logarithmic, plateau, or mean sigma radio button.

Manual uses two controls to scale image data. Brightness is an offset in counts and contrast is a gain.

Linear uses a linear scale, colors are evenly distributed across the minimum and maximum of the image. The include pixels control determines what pixels are included when determining the min and max value used for scaling. Including 0% to 100% of pixels includes all pixels. Including 5% to 95% of pixels includes all pixels except for the lower and upper 5%.

Logarithmic uses a linear scale on the log of the data, colors are evenly distributed across the log of the minimum and log of the maximum of the image. The include pixels control determines what pixels are included when determining the min and max value used for scaling. Including 0% to 100% of pixels includes all pixels. Including 5% to 95% of pixels includes all pixels except for the lower and upper 5%.

Plateau performs plateau equalization, histogram data is evenly distributed into bins, a bin determines the color. The gain is a pseudo gain. The algorithm will attempt to distribute colors such that the gain is as close to the requested gain as possible. The actual gain is displayed beside the requested gain. The loop max is the maximum number of iterations to perform before converging on the requested gain. The value is the value of the plateau and is displayed for informational purposes. The include pixels control determines what pixels are included when performing the AGC algorithm. Including 0% to 100% of pixels includes all pixels. Including 5% to 95% of pixels includes all pixels except for the lower and upper 5%.

Mean sigma uses a linear scale between mean - lower limit * sigma and mean + upper limit * sigma, colors are evenly distributed across the computed range. The include pixels control determines what pixels are included when performing the algorithm. Including 0% to 100% of pixels includes all pixels. Including 5% to 95% of pixels includes all pixels except for the lower and upper 5%.

Note

It is recommended to make changes slowly and incrementally giving the GUI time between changes so that the fields have time to get updated.

5.2.4.2 Region of Interest (ROI)

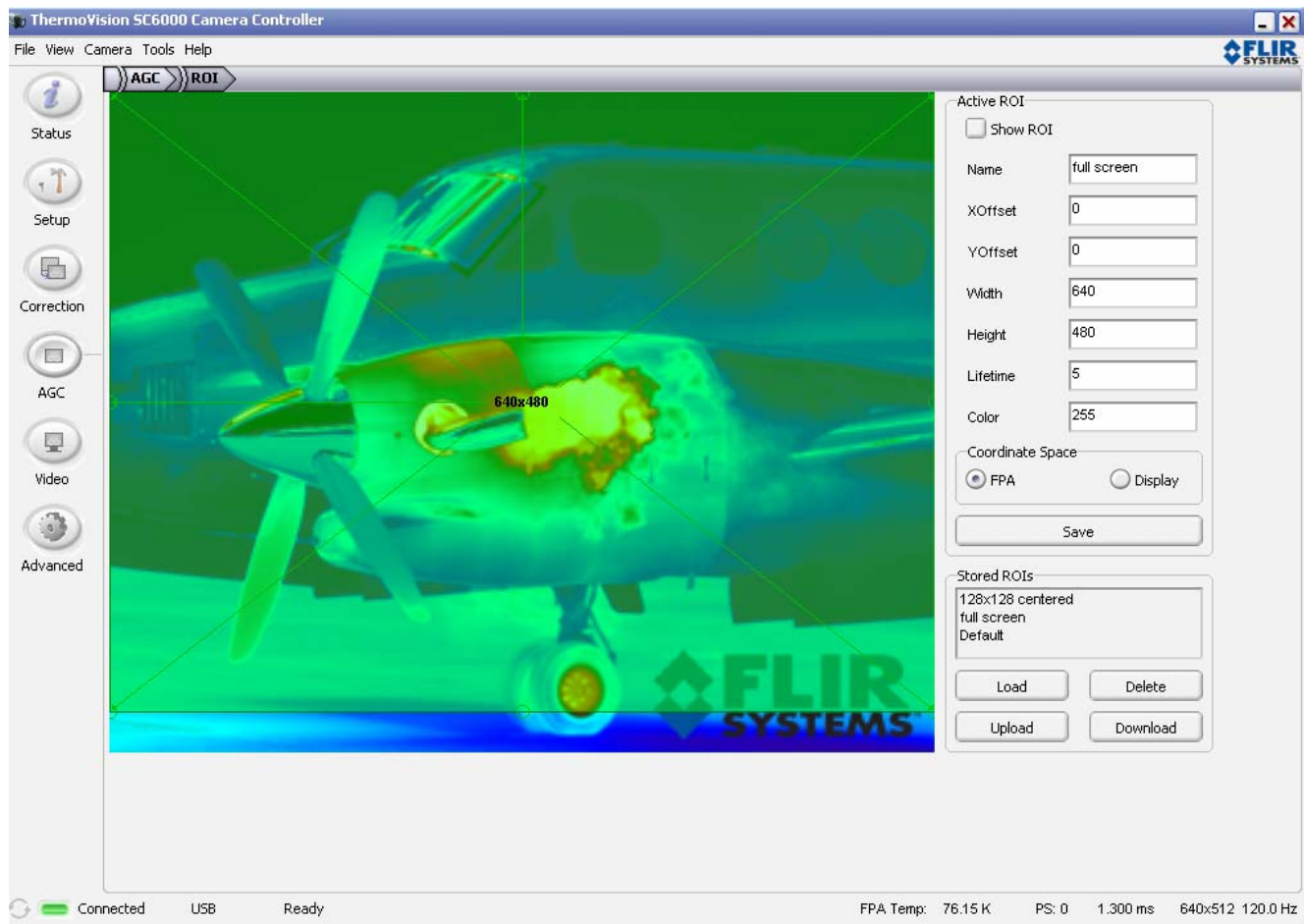


Figure 5-12: SC4000/6000 GUI – AGC ROI

The ROI is a region of interest. It determines what pixels are used for AGC. Only the pixels inside the ROI will be used for AGC scaling.

If show ROI is checked the ROI will always be shown on the analog video.

The name of the ROI is the file name used to store it, after a save state the ROI listed in the active ROI name will be loaded when the camera boots.

The ROIs position and size is modified by entering values into the xoffset, yoffset, width, and height fields. The ROI can also be modified visually similar to the way a window can be edited.

The lifetime determines how long the ROI is shown on bootup.

The color is a grayscale color used to display the ROI in.

The coordinate space determines what the ROI's position/size are relative to. FPA uses the FPA space, Display uses the display space.

Stored ROIs are also displayed. A stored ROI can be loaded or deleted by selecting it and the clicking load or delete respectively.

A stored ROI can be downloaded to the computer by selecting the ROI and then clicking download; an ROI on the computer can be uploaded by clicking the upload button.

5.2.5 Video Screen

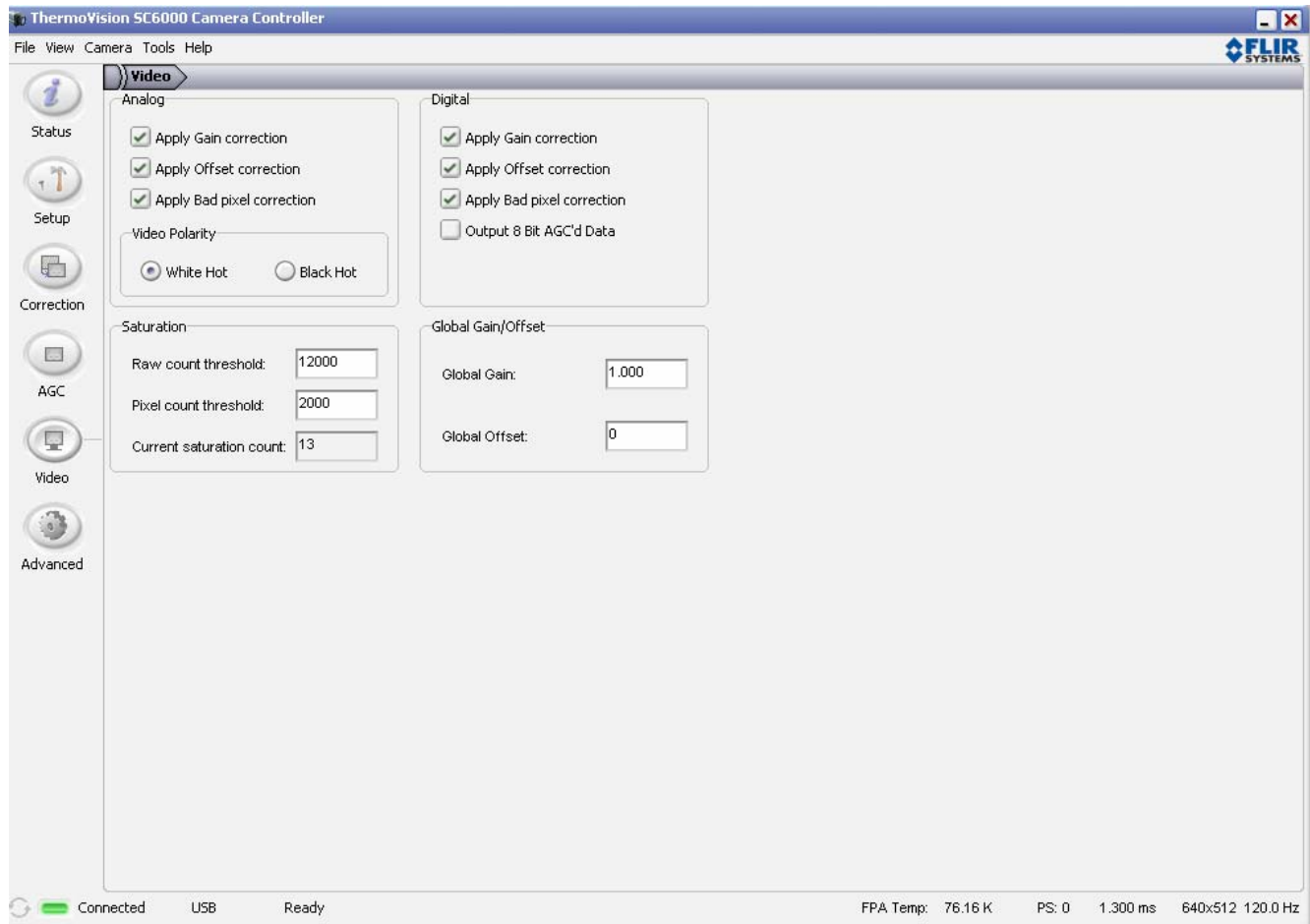


Figure 5-13: SC4000/6000 GUI – Video Screen

The analog group contains settings for the analog data path.

Apply gain correction determines if the NUC gain is applied.

Apply offset correction determines if the NUC offset is applied.

Apply bad pixel correction determines if the NUC bad pixels are replaced.

Video polarity controls the color scale (white hot or black hot).

The digital group contains settings for the digital data path.

Apply gain correction determines if the NUC gain is applied.

Apply offset correction determines if the NUC offset is applied.

Apply bad pixel correction determines if the NUC bad pixels are replaced.

The saturation group contains settings for the saturation flag.

If a pixel is over raw count threshold it will be considered saturated. If the number of saturated pixels is over the pixel count threshold the saturation flag in the image header will be set. The current number of saturated pixels is displayed in the current saturation count.

The digital gain and offset are the gain and offset applied to the digital image data.

5.2.6 Advanced Screen

5.2.6.1 Advanced

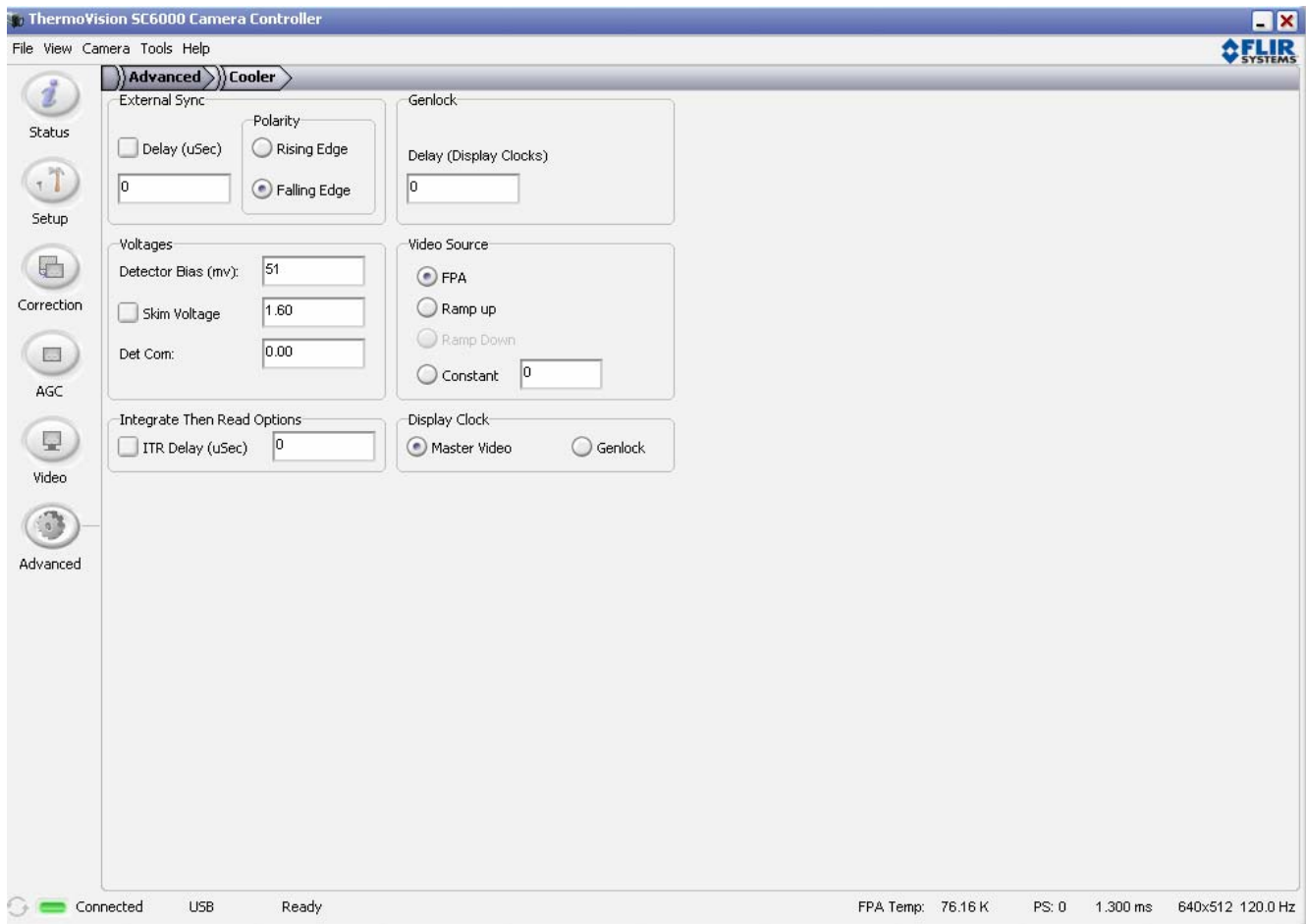


Figure 5-14: SC4000/6000 GUI – Advanced Screen

The external sync group controls external sync.

If Delay is checked a delay will be inserted between when the sync is received and when it is acted upon.

The text box determines the delay

The polarity determines when a sync is registered, it can be either rising edge or falling edge.

The genlock group controls genlock.

If enabled is checked genlock will be enabled.

A delay between when the sync is registered and when it is acted upon is always used, this delay can be entered via the textbox.

The voltages group contains voltages (fancy that).

Detector bias can be set.

Skim voltage and Det com voltage can be set for 0002.

Skim enable determines if the skim voltage is used.

Integrate then read options allows you to optionally specify an ITR delay.

Display clock selects the clock source for the analog video, this can be either the internal master clock or the genlock input.

Video source selects where the video is coming from. This can be the FPA, a ramp up pattern, or a constant.

5.2.6.2 Cooler

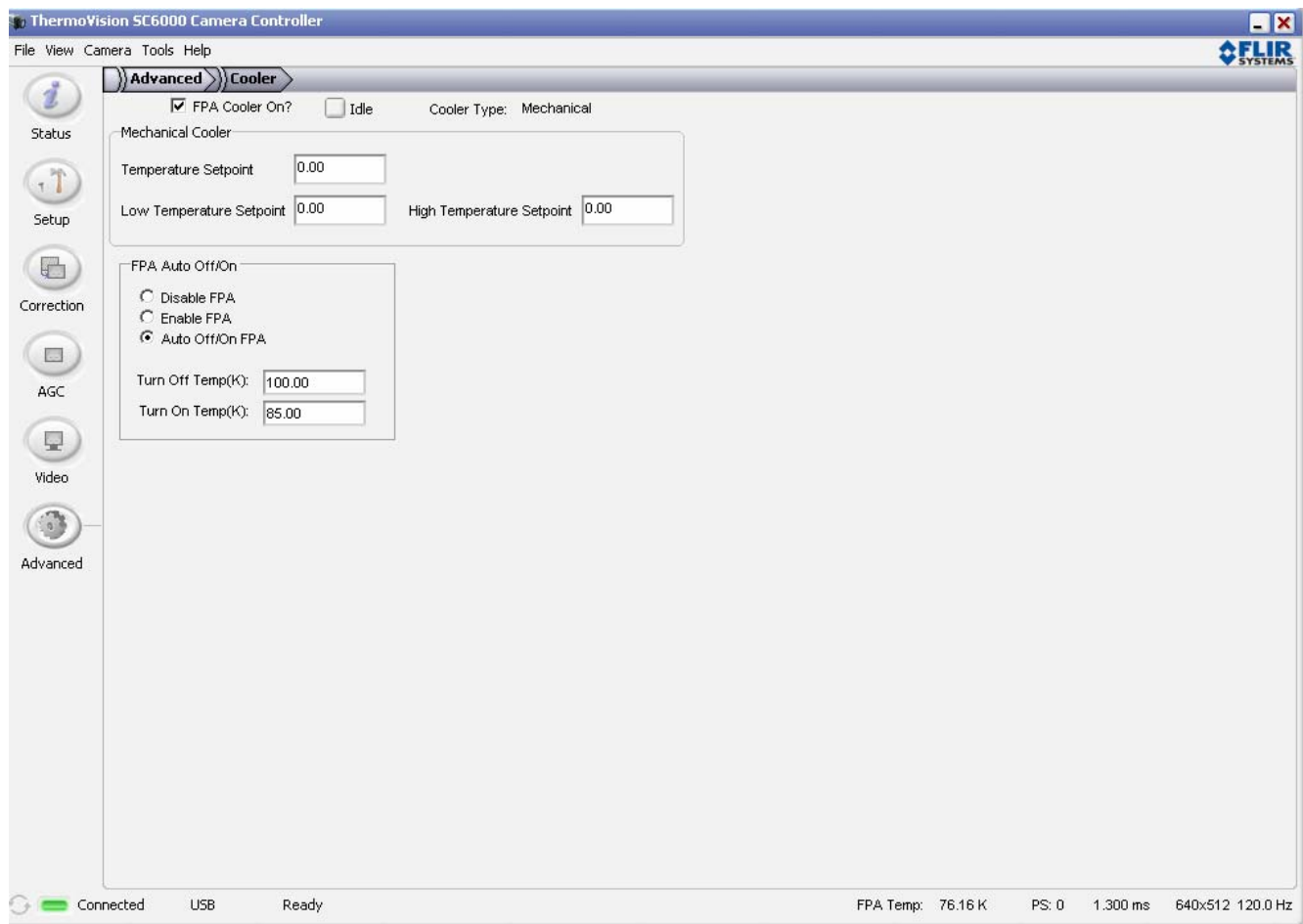


Figure 5-15: SC4000/6000 GUI – Advanced Screen - Cooler

The cooler page controls the cooler in the camera.

The cooler can be enabled with Enable FPA cooler or put into idle mode with the Idle checkbox.

The mechanical cooler group contains options for the mechanical cooler

The temperature setpoint is the temperature to shoot for, the low temperature setpoint is the min temperature to allow, the high temperature setpoint is the max temperature to allow.

6 Interfaces

6.1 Mechanical and Optical

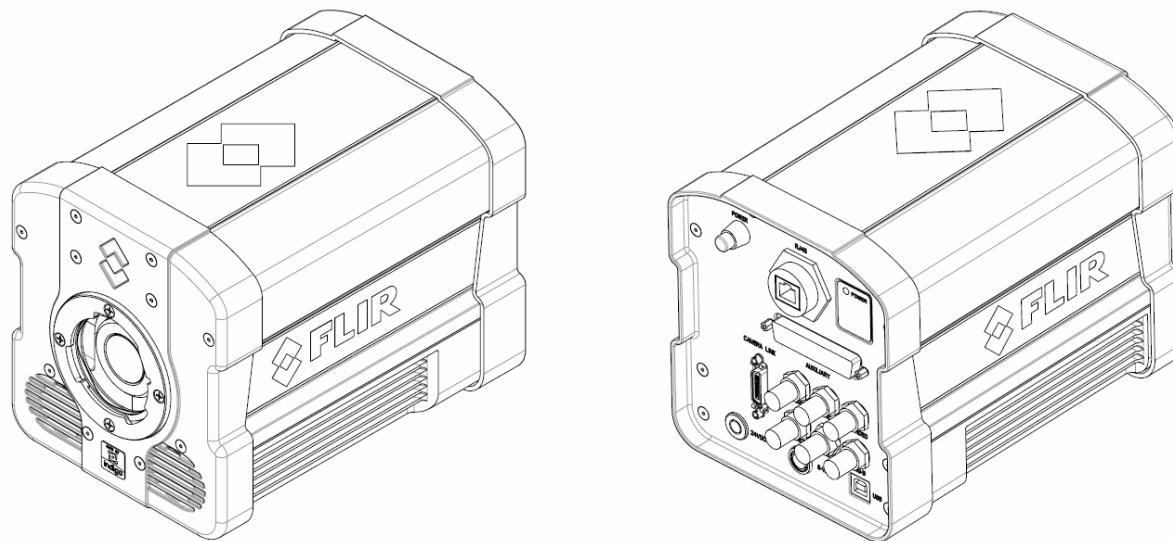


Figure 6-1: Isometric view of SC4000/6000 camera with bayonet lens interface

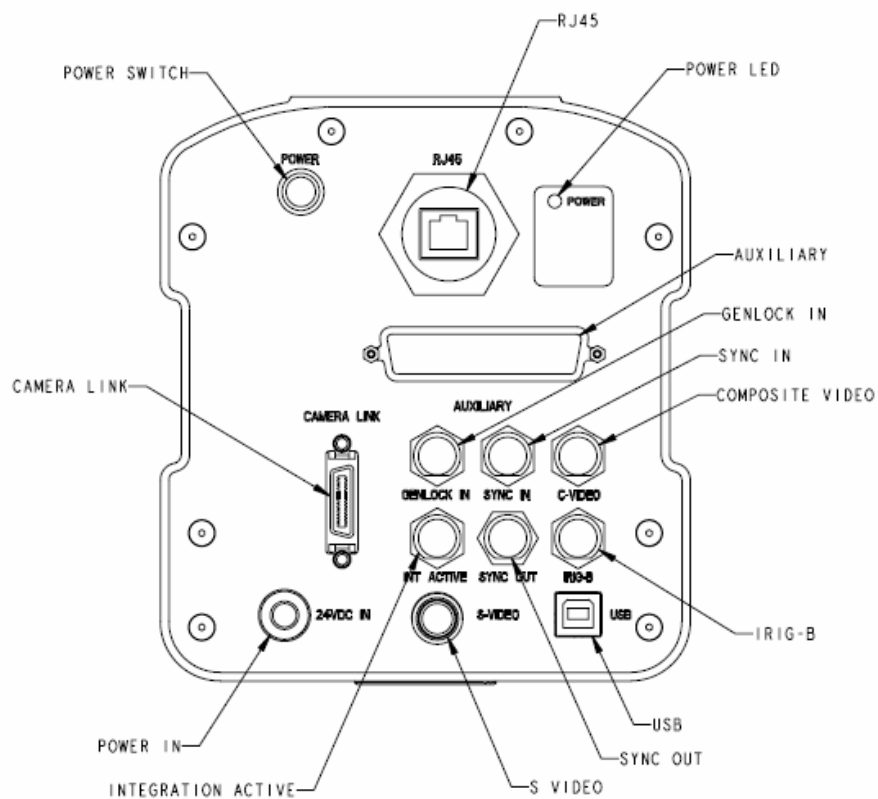


Figure 6-2: Back end of SC4000/6000

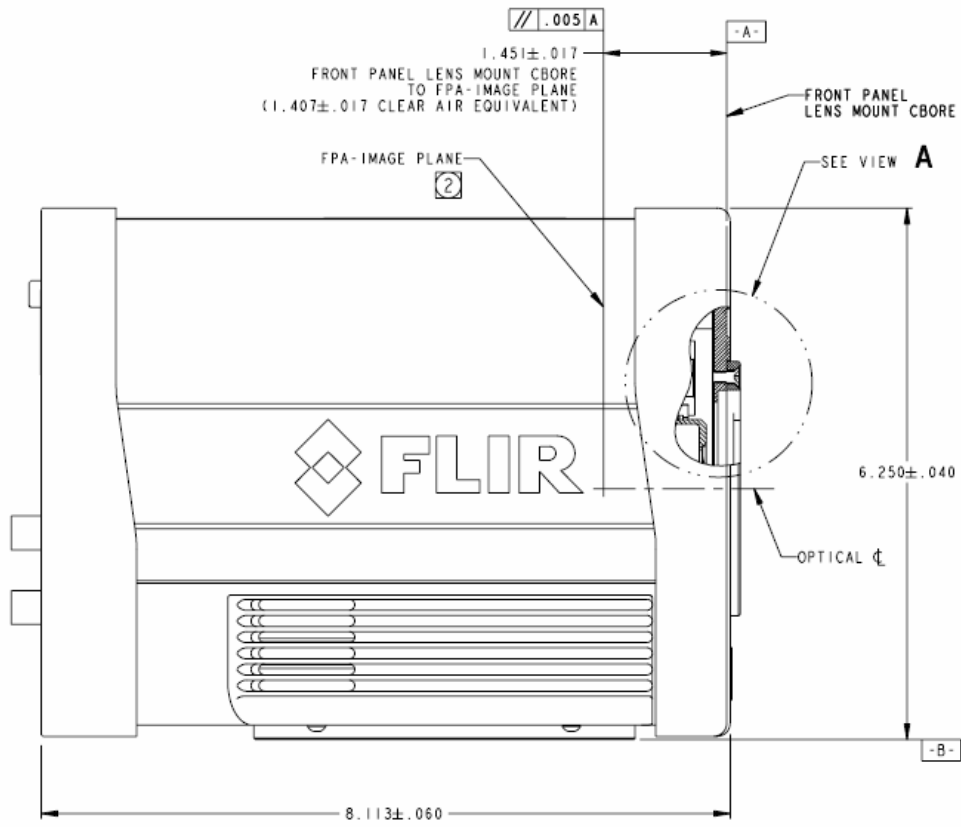


Figure 6-3: Side view of SC4000/6000

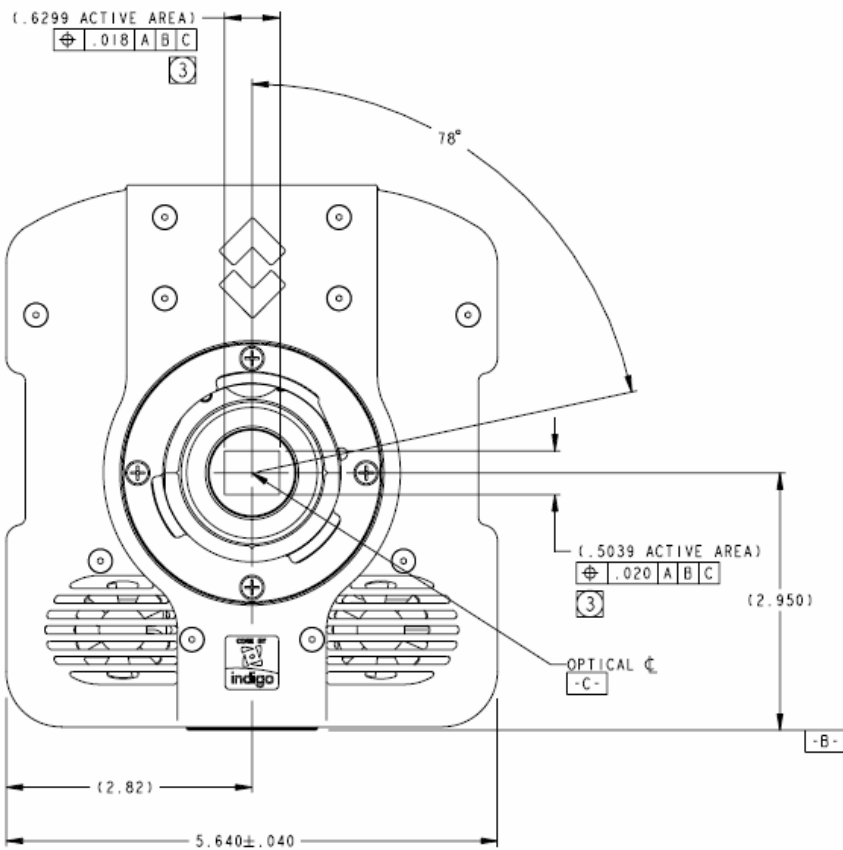


Figure 6-4: Front view of SC4000/6000

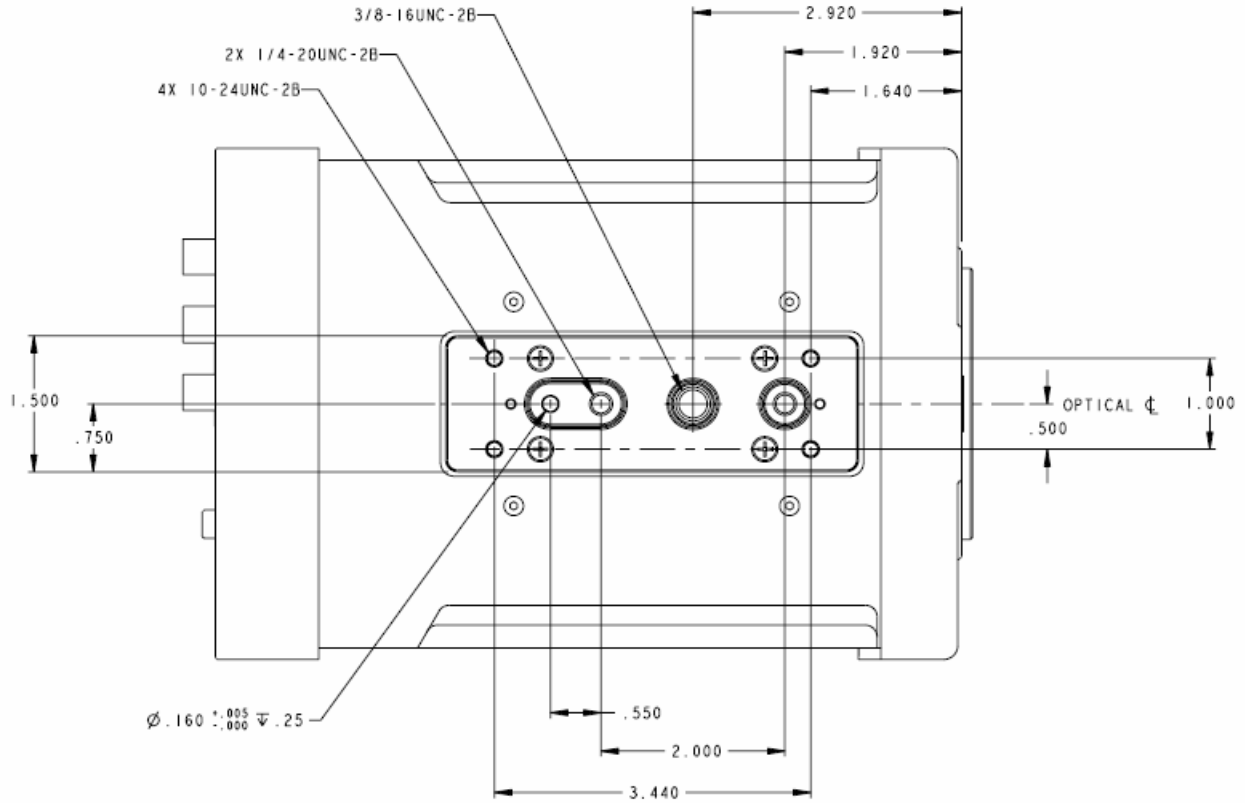


Figure 6-5: Bottom view of SC4000/6000

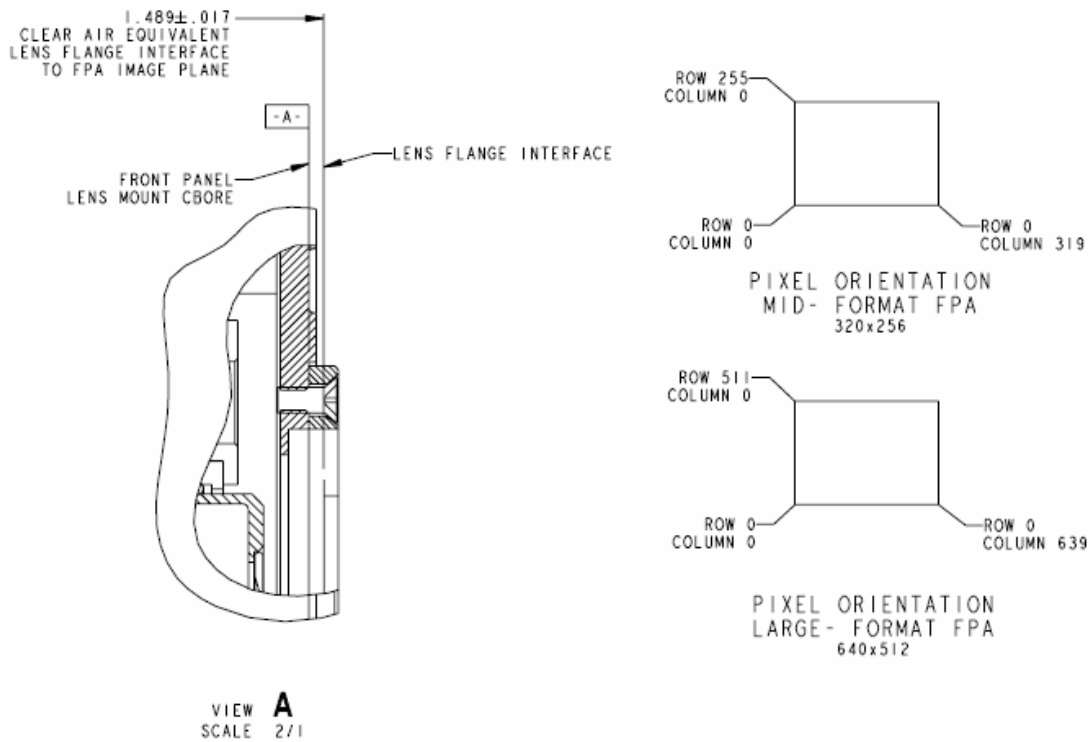


Figure 6-6: FPA orientation

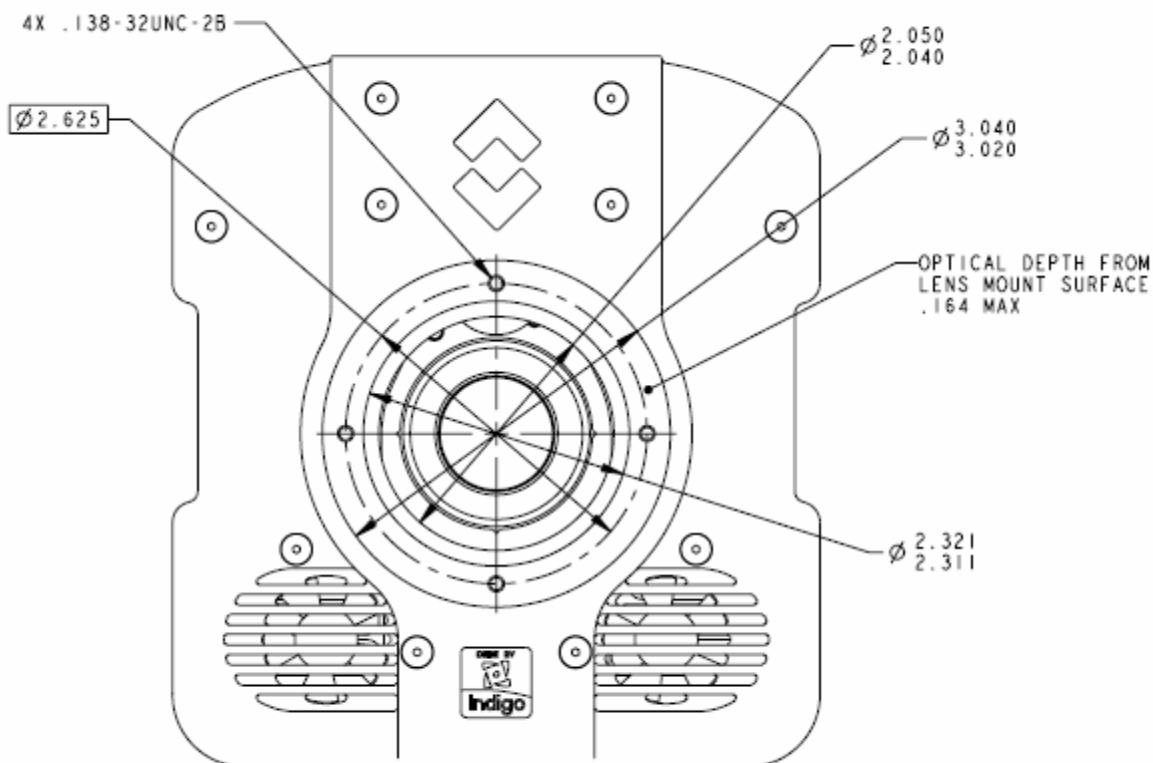


Figure 6-7: SC4000/6000 optical interface dimensions

6.2 Electrical

SC4000/6000 camera interfaces to the host user through a variety of industry standards and camera specific signals. Except for the auxiliary connector, all pinouts and connector types are commercial standard types. All connection is on the back panel of the camera, as shown in Figure 6-2.



6.2.1 Power Interface

An 18 to 36 VDC(24V nominal), external AC-DC power converter is provided with the SC4000/6000 camera system as a standard accessory. Power supply specifications are:

- Input voltage range: 100-250VAC 50/60Hz
- Current draw: 24 VDC at up to 4.0 amps input to the camera
- Converter dimensions: 6.25 inches x 3.5 inches x 2.75 inch (L x W x H)
- Converter weight: approximately 1 lb

The power input pinouts are shown in Figure 6-8.

Pin1: +Power input
Pin2: Power return
Pin3: Chassis ground

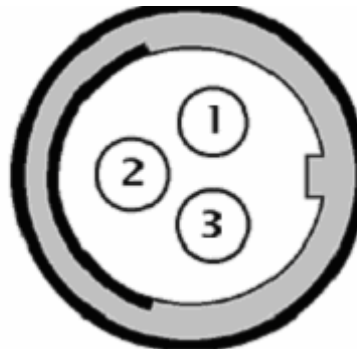


Figure 6-8: SC4000/6000 Power Input Pinouts

When using your own DC power supply, you should take note of the following information:

- Mating connector is FISCHER Cable Connector (p/n S103 A052-60) and FISCHER Cable Clamp (p/n E3 103.5/6.7).
- Input voltage range: 18 to 36 volts, with 24 VDC optimum value
- Current draw: 1.5 amps nominal steady state, 2.0 amps peak
- Raw input power: supplied to SC4000/6000's Power Supply PCB electronics and then distributed to the other PCBs
- SC4000/6000 power dissipation is <50 Watts steady state at nominal ambient temperature

6.2.2 Control Interface

6.2.2.1 USB

USB Stands for Universal Serial Bus. It is a standard found on most computers made after 2000.

6.2.2.2 Gigabit Ethernet

Gigabit Ethernet (GigE) is a common interface found in most PC's. The GigE interface of SC4000/6000 which is compatible with an Intel® Pro/1000 MT Desktop adapter or equivalent can transmit the full data of the SC4000/6000 camera. The Ethernet port has to be setup to accept the camera data. The Ethernet port is no longer a port for other Ethernet uses once it is set up to accept camera data.

6.2.2.3 Camera Link

Camera link is the new standard for high end visible and IR cameras. It was developed to create a standard interface for all frame grabber and camera companies to make products more compatible with each other.

Only one standard Camera Link cable shall be required between the Cumulus and the host PC. Camera link cables are commercial off the shelf and common to all camera link frame grabber cards (with the exception of Camera link Medium and Full). The standard Camera link cable shipped in the package is 3 meter. However, camera link cable can be up to 10 meters long. Camera link is considered more robust and reliable than GigE. The downfall is that it is more expensive and is not available for use with a Laptop.

The 5 differential LVDS pairs on the Camera Link connector (X0 +/- through X3 +/- and Xclk +/-) are a channel link transmission set, configured to operate with any Camera Link frame grabber conforming to the standard. Details are provided here for those users with non-standard frame grabbers or custom receiving electronics.

The interface is designed to be terminated by a National Semiconductor DS90CR286 part. When received, the channel link output is a 28 bit parallel interface with a received clock. A total of 17 of the 28 bits are used for the data link: 14 for digital video data and 3 for data “qualifiers”. The use of these qualifiers conforms to the Camera Link standard and is illustrated in **Error! Reference source not found.**

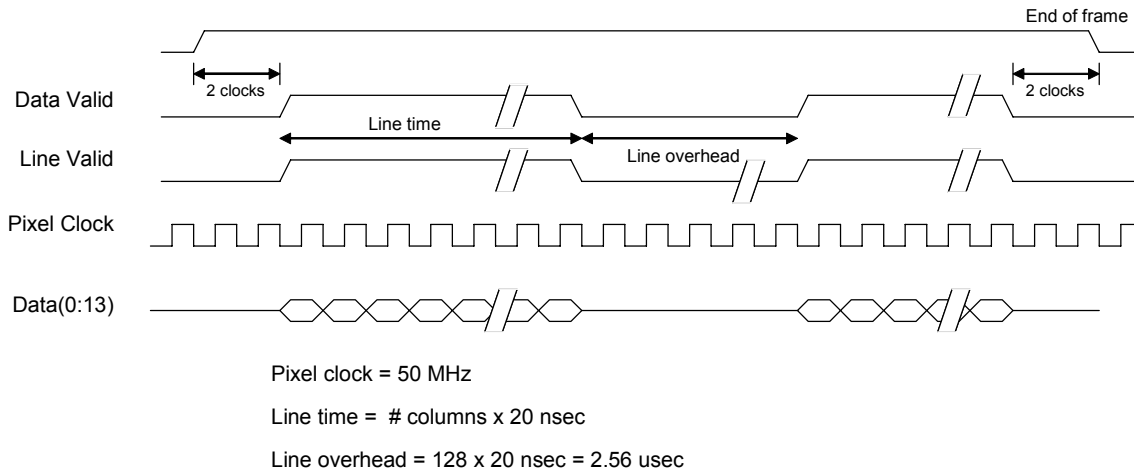
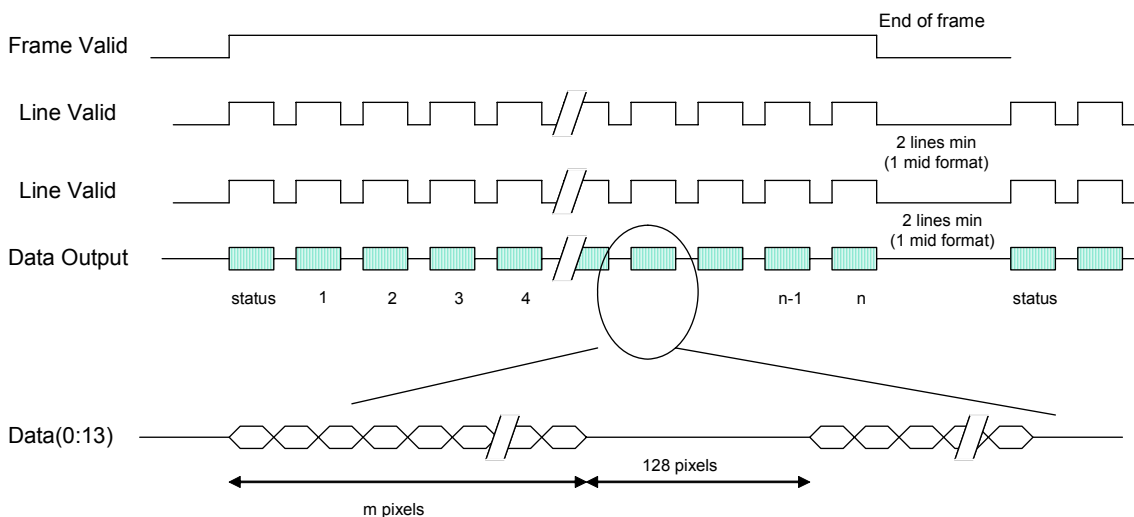


Figure 6-9: Channel Link as received timing diagram

Figure 6-10 shows the details of the frame timing. For an m column by n row frame, there will be a total of at least n + 2 rows for mid format ROICs and n+3 rows for large format:

- n rows of valid pixel data
- 1 row of status immediately prior to the first valid image data
- 2 rows minimum dead time (1 for mid format); this applies if the camera is set to its maximum frame rate. For frame rates less than maximum, extra dead time will appear in this position of the data

For each row that is output, there are m valid pixels (e.g. 640 for the full frame readout) and 128 pixels of dead time.



Timing for an m column by n row data frame
 2 dead lines minimum (1 for mid format)
 n + 1 rows of valid data
 m pixels valid video + 128 pixels overhead per line

Figure 6-10: Details of Channel Link frame, row and pixel timing

Table 6-1 tabulates the bit assignments of the Channel Link chip, which as with the data qualifiers, conform to the Camera Link standard. The parallel data is received at a rate of 50 MHz.

Table 6-1: Channel Link receiver bit assignments by camera function

Channel Link	Camera Data	Channel Link	Camera Data
RX 26	Data Valid	RX 12	Bit 11
RX 25	Frame Valid	RX 13	Bit 12
RX 24	Line Valid	RX 14	Bit 13
RX 0	Bit 0	RX 10	Not used
RX 1	Bit 1	RX 11	Not used
RX 2	Bit 2	RX 15	Not used
RX 3	Bit 3	RX 16	Not used
RX 4	Bit 4	RX 17	Not used
RX 6	Bit 5	RX 18	Not used
RX 27	Bit 6	RX 19	Not used
RX 5	Bit 7	RX 20	Not used
RX 7	Bit 8	RX 21	Not used
RX 8	Bit 9	RX 22	Not used
RX 9	Bit 10	RX 23	Not used

6.2.3 Synchronization Interface

A variety of interfaces are available for synchronizing the camera to external events as well as synchronizing external events to the camera.

6.2.3.1 Sync In

The Sync In input is used to synchronize the camera to the rising edge of external events. There is a single ended TTL compatible BNC input on the Sync In connector. The edge-triggered input allows the camera to synchronize its integration time and frame rate to an external signal. Sync IN is only functional in ITR mode.

6.2.3.2 IRIG In

An IRIG-B decoder is built into the camera to allow for time stamping of each frame as well as support triggered data acquisition at user programmed times.

6.2.3.3 Genlock Input

The Genlock mode is only enabled by the presence of a signal. In a Genlock synchronization mode, a composite sync signal is input to the camera and the FPA output is locked to it on a line-by-line basis. The camera is configured to accept the same type of composite sync signal as the video output (NTSC or PAL).

6.2.3.4 Sync Out

This TTL single ended signal is normally synchronous with the camera Sync In and can be used to synchronize other events to the camera when the camera is in a free run mode. It is also used in conjunction with the clock out signal to synchronize two SC4000/6000 cameras in master-slave fashion. When used in this way, the camera acting as the master makes appropriate adjustments to the camera sync out signal to assure that the data output of the two cameras is synchronized at the pixel level. This output is available in both ITR and IWR mode.

6.2.3.5 Integration Active

The camera has a signal that is true when the FPA is actively integrating charge (“shutter open”). The Integration Active provides a synchronizing signal output corresponding to the time the detector signal is actually being acquired.

6.2.4 Analog Video

The SC4000/6000 camera is capable of generating composite video in NTSC or PAL format. The video signal is brought out to a BNC connector. The selection of NTSC or PAL video is enabled in the electronics hardware configuration at the factory. Standard video levels of 1.0 V peak-to-peak are obtained when the camera video output is terminated with 75ohms to ground. A 75-ohm BNC cable is provided with the camera. The center pin (pin 1) is the encoded NTSC or PAL video and the connector body (pin 2) is the video ground (shell).

6.2.4.1 NTSC Format

The NTSC (National Standards Television Committee) analog composite video format provides 480 active lines per frame, and 240 lines per field. The SC4000/6000 camera's NTSC analog video is defined by the following specifications:

- Output: 29.97 frames per second
- Interlaced fields: two per frame of video data
- Field rate: 59.94 Hz
- Effective size of the actual video image: 640 x 480 at 29.97 Hz
- Large format: 640x512 FPA pixels mapped one-to-one to analog video pixels
- Medium format: 320x256 FPA pixels replicated in both horizontal and vertical direction mapped into the video display format

The voltage levels for the analog video output signal span a range of one volt as seen below:

- Sync portion range: 0.000 volts to 0.286 volts
- Video portion range: 0.286 volts for black level to 1.000 volts for white level

These voltages assume a standard 75 ohm termination. Even though the voltage range of the SC4000/6000 analog output is different in absolute terms than the NTSC standard, which is -0.286 volts to +0.714 volts, the vast majority of monitors and other video equipment should have no problem. The actual voltage swing range is identical to the NTSC video standard.

6.2.4.2 PAL Format

PAL (Phase Alternation by Line) is a television signal standard used in most of Europe, some Middle Eastern and Asian countries, several African countries, Australia, New Zealand, and other Pacific island countries. The PAL analog composite video format provides 576 active lines per frame, and 288 lines per field. The SC4000/6000 camera's PAL analog video output is defined by the following specifications:

- Output rate: 25.00 frames per second
- Interlaced fields: two per frame of video data
- Field rate: 50.000 Hz
- Effective size of the actual video image: 768x576 at 25.000 Hz

- Large format: 640x512 FPA pixels mapped one-to-one to analog video pixels
- Medium format: 320x256 FPA pixels replicated in both horizontal and vertical direction mapped into the video display format

Unlike the NTSC analog video, all lines of the FPA are displayed. The lines and columns are centered in the PAL video output. The Bore Sight controls can be used to move the video, if desired.

The voltage levels for the PAL analog video output signal span a range of one volt as seen below:

- Sync portion range: 0.000 volts to 0.286 volts
- Video portion range: 0.286 volts for black level to 1.000 volts for white level

These voltages assume a standard 75 ohm termination. Even though the voltage range of the SC4000/6000 analog output is different in absolute terms than the PAL standard, which is -0.286 volts to +0.714 volts, the vast majority of monitors and other video equipment should have no problem. The actual voltage swing range is identical to the PAL video standard.

6.2.5 Auxiliary Connector

Table 6-2: Definition of Auxiliary Connector Pinouts

Pin	Signal	Level	Description
1	ANALOG_IN0+		Differential analog input – general purpose
2	ANALOG_IN2+		Differential analog input – general purpose
3	SYNC_CLK_OUT+	LVDS	Differential pixel clock out
4	SYNC_CLK_IN+	LVDS	Differential pixel clock in
5	GND		Ground
6	UART_IN_LEN2+	232/422/485	Lens serial in number 2
7	UART_IN_LEN1+	232/422/485	Lens serial in number 1
8	GND		Ground
9	HS_RX_FRM-	LVDS	Not currently supported
10	HS_RX_DAT-	LVDS	Not currently supported
11	HS_RX_CLK-	LVDS	Not currently supported
12	I2C_CLK	3V CMOS	I ² C clock
13	GND		Ground
14	DIG_IN2	3/5V CMOS	Discrete digital input – general purpose
15	DIG_IN4	3/5V CMOS	Discrete digital input – general purpose
16	DIG_IN6	3/5V CMOS	Discrete digital input – general purpose
17	DIG_IN8	3/5V CMOS	Discrete digital input – general purpose
18	I2C_CLK	3V CMOS	I ² C clock
19	NC		
20	NC		
21	ANALOG_IN0-		Differential analog input – general purpose
22	ANALOG_IN2-		Differential analog input – general purpose
23	SYNC_CLK_OUT-	LVDS	

24	SYNC_CLK_IN-	LVDS	
25	GND		
26	UART_IN_LEN2-	232/422/485	Lens serial in number 2
27	UART_IN_LEN1-	232/422/485	Lens serial in number 1
28	HS_RX_FRM+	LVDS	Not currently supported
29	HS_RX_DAT+	LVDS	Not currently supported
30	HS_RX_CLK+	LVDS	Not currently supported
31	GND		
32	I2C_DAT	3V CMOS	I ² C data
33	DIG_IN1	3/5V CMOS	Discrete digital input – general purpose
34	DIG_IN3	3/5V CMOS	Discrete digital input – general purpose
35	DIG_IN5	3/5V CMOS	Discrete digital input – general purpose
36	DIG_IN7	3/5V CMOS	Discrete digital input – general purpose
37	GND		
38	I2C_DAT	3V CMOS	I ² C data
39	NC		
40	ANALOG_IN1+		Differential analog input – general purpose
41	ANALOG_GND		Analog ground for differential inputs
42	OPTDEC-		Opto-isolated sync input
43	SER_RX_PT-	232/422/485	Legacy serial port
44	SER_TX_PT-	232/422/485	Legacy serial port
45	UART_OUT_LEN2+	232/422/485	Lens serial in number 2
46	UART_OUT_LEN1+	232/422/485	Lens serial in number 1
47	GND		Ground
48	HS_TX_FRM-	LVDS	Not currently supported
49	HS_TX_DAT-	LVDS	Not currently supported
50	HS_TX_CLK-	LVDS	Not currently supported
51	I2C_CLK	3V CMOS	I ² C clock
52	GND		Ground
53	DIG_OUT3	3V CMOS	Discrete digital output – general purpose
54	DIG_OUT5	3V CMOS	Discrete digital output – general purpose
55	DIG_OUT7	3V CMOS	Discrete digital output – general purpose
56	GND		Ground
57	I2C_DAT	3V CMOS	I ² C data
58	NC		
59	NC		

60	ANALOG_IN1-		Differential analog input – general purpose
61	OPTDEC+		Opto-isolated sync input
62	SER_RX_PT+	232/422/485	Legacy serial port
63	SER_TX_PT+	232/422/485	Legacy serial port
64	GND		Ground
65	UART_OUT_LEN2-	232/422/485	Lens serial in number 2
66	UART_OUT_LEN1-	232/422/485	Lens serial in number 1
67	HS_TX_FRM+	LVDS	Not currently supported
68	HS_TX_DAT+	LVDS	Not currently supported
69	HS_TX_CLK+	LVDS	Not currently supported
70	GND		Ground
71	I2C_DAT	3V CMOS	I ² C data
72	DIG_OUT2	3V CMOS	Discrete digital output – general purpose
73	DIG_OUT4	3V CMOS	Discrete digital output – general purpose
74	DIG_OUT6	3V CMOS	Discrete digital output – general purpose
75	DIG_OUT8	3V CMOS	Discrete digital output – general purpose
76	I2C_CLK	3V CMOS	I ² C clock
77	NC		
78	NC		

7 Specifications

FLIR Systems reserves the right to change specification at any time without prior notice.

7.1 Interfaces

	InSb	InGaAs	QWIP
AC power	90 - 230 VAC, 50-60 Hz		
Control	Gigabit Ethernet (10/100/1000), USB, Camera Link serial or RS-232/422		
NTSC/PAL video out	BNC connector, 75 Ohm composite output 1 V pk-pk		
Frame synchronization in	3.3 volt TTL single ended, opto-isolated differential		
Frame synchronization out	3.3 volt TTL single ended frame rate sync signal		
Integration valid	3.3 volt TTL single ended, true when detector is integrating		
Genlock in	Composite sync input, field and line sync of video output		
IRIG-B in	BNC connector		
Digital video out	14 bit Camera Link, Gigabit Ethernet		
Optical interface	f/2.5 coldshield Industry standard bayonet F/4.1 optional	c-mount Canon F (large format)	f/2.5 coldshield Same as InSb
Thermal interface	Sealed enclosure with integral forced air heat exchanger; bottom mounting surface provides direct heat path for low atmospheric pressure environments		
Mechanical Interface	2 ¼-20 tripod screws , 3/8-16 professional tripod screw, 4 10-24 mount holes		

7.2 Windowing Capacity

		InSb	InGaAs	QWIP
Minimum Size	Mid Format	2 rows x 64 cols	2 rows x 128 cols	2 rows x 64 cols
	Large Format	4 rows x 64 cols	4 rows x 128 cols	4 rows x 64 cols
Resolution (size)	Mid Format	2 rows x 16 cols	2 rows x 16 cols	2 rows x 16 cols
	Large Format	4 rows x 16 cols	4 rows x 16 cols	4 rows x 16 cols
Resolution (location)	Mid Format	2 rows x 16 cols	2 rows x 16 cols	2 rows x 16 cols
	Large Format	4 rows x 16 cols	4 rows x 16 cols	4 rows x 16 cols

7.3 Acquisition Modes and Features

		InSb	InGaAs	QWIP
Frame rate Full window	Mid format	432 Hz		
	Large format	126 Hz		
Frame rate Minimum window	Mid format	48.45 kHz		
	Large format	36.98 kHz for 9803, 27.78 kHz for 0002		
Pixel rate (burst)		50 MHz		
Integration time control	Maximum	Greater than 98 percent of selected frame time (1 / frame rate)		
	Minimum	9705: 5 μ sec 9803:10 μ sec 9809: 0.5 μ sec 0002: 2 μ sec		
Synchronization modes		<ul style="list-style-type: none"> - Genlock to synchronize video output to composite video sync sources - Video sync to synchronize the FPA to internal or external video sync - Asynchronous Integrate While Read to synchronize the start of the <i>integration</i> period to an external source - Asynchronous Triggered FPA Read to synchronize the start of the FPA <i>readout</i> period to an external source - Special Integrate Then Read supports integration times between 5 and 0.5 microseconds (9809) and between 8 and 3 microseconds (0002) - IRIG triggered acquisition sequence at pre-programmed time 		

Preset sequences	- 4 presets programmable for 1 to 4095 frames each - Preset sequence programmable for up to 1023 sequence repeats
Digital video output selection	Raw digital video (14 bit) Gain and offset (NUC) corrected (14 bit) NUC with dead pixel replace (14 bit) NUC, dead pixel replace, AGC (8 bit)
Global gain and offset	Variable global gain (0.5 – 2) and offset (full A/D range) allow the mapping of any portion of the FPA range to the output range
AGC	Histogram based automatic gain and level, plateau based equalization, logarithmic equalization
Manual brightness and contrast	User selectable, increment and decrement controls
Video boresight	NTSC window can be placed on FPA to at one pixel increments

7.4 Performance Characteristics

		InSb	InGaAs	QWIP
Power Consumption	Steady state typical (25°C)	40 watts	25 watts	50 watts
	Max during cooldown	75 watts	30 watts	75 watts
Cooldown time (max, high ambient)		10 minutes	30 seconds	10 minutes
Sensitivity (without optics)				
NE Δ T ¹	9705, 9803	18 mK, 20 mK	---	
NEI ²	9809 high gain	---	$3 \times 10^{-10} \text{ W/cm}^2$	---
	9809 low gain	---	$1.5 \times 10^{-7} \text{ W/cm}^2$	---
	0002 high gain	---	$1.5 \times 10^{-9} \text{ W/cm}^2$	---
	0002 low gain	---	$3 \times 10^{-10} \text{ W/cm}^2$	---

System gain ^{3,4}	9705 low gain - 1100 e ⁻ /lsb 9803 low gain - 670 e ⁻ /lsb 9809 low gain - 220 e ⁻ /lsb 9809 high gain - 11 e ⁻ /lsb 0002 low gain – 143 e ⁻ /lsb
System noise floor ^{3,5}	9705 low gain - 2500 e ⁻ 9803 low gain - 2200 e ⁻ 9809 low gain - 550 e ⁻ 9809 high gain - 140 e ⁻ 0002 TBA

7.5 Non Uniformity Correction

		InSb	InGaAs	QWIP
NUC Types		One point (offset) Two-point (offset and gain) non-volatile Two point with dead pixel detection All NUC types can be performed with internal (InSb, QWIP) or external sources		
NUC source (internal)		TE controlled flag (InSb and QWIP)		
Dead pixel replacement		Averaging of 4 nearest neighbors		
Number of NUC's		4 loaded NUC's in preset selectable form 10 saved NUC's for large format 20 saved NUC's for mid format		
Bad pixel lists		Bad pixel lists are stored as files, up to three lists may be used together		
NUC time		< 10 seconds for single point refresh, < 40 seconds for 2 point		
NUC performance	Mid Format	0.1%	0.35% (high gain) 0.2% (low gain)	0.25%
	Large Format	0.1%	0.5% (high gain) 0.25% (low gain)	0.25%

7.6 Detector/FPA

	InSb	InGaAs	QWIP
Spectral response	3 – 5 microns (standard)1.5 – 5 microns (special)	0.9 – 1.7 microns 0.4 – 1.7 microns (VisGaAs)	8.2 – 9.2 microns

Detector type		Indium Antimonide	Indium Gallium Arsenide	Quantum Well
FPA's supported	Mid Format	9705, 9809, 0209	9809	9705, 0209
	Large Format	9803, 0309	0002	9803, 0309
Integration mode		snapshot	snapshot	snapshot
Format (H x V)	Mid Format	320 x 256	320 x 256	320 x 256
	Large Format	640 x 512	640 x 512	640 x 512
Operability	Mid Format	99.8% typical) (99.95	99.5% (99.8 typical)	99.5% typical) (99.8
	Large Format	99.8% typical) (99.95	99.5% (99.8 typical)	99.5% typical) (99.8
Charge handling capacity ³	Mid Format			
	Gain 0	18 x 10 ⁶ carriers (9705)	3.5 x 10 ⁶ carriers	18 x 10 ⁶ carriers
		3.5 x 10 ⁶ carriers (9809)	--	--
	Gain 1	13.5 x 10 ⁶ carriers(9705)	170 x 10 ³ carriers	13.5 x 10 ⁶ carriers
		170 x 10 ³ carriers(9809)	--	--
	Gain 2	9 x 10 ⁶ carriers (9705)	--	9 x 10 ⁶ carriers
	Gain 3	4.5 x 10 ⁶ carriers (9705)	--	4.5 x 10 ⁶ carriers
	Large Format			
	Gain 0	11 x 10 ⁶ carriers	2.5 x 10 ⁶ carriers	11 x 10 ⁶ carriers
	Gain 1	8.3 x 10 ⁶ carriers	45 x 10 ⁶ carriers	8.3 x 10 ⁶ carriers
	Gain 2	5.5 x 10 ⁶ carriers	--	5.5 x 10 ⁶ carriers
	Gain 3	2.8 x 10 ⁶ carriers	--	2.8 x 10 ⁶ carriers

Detector pitch	Mid Format	30 microns	30 microns	30 microns
	Large Format	25 microns	25 microns	25 microns
Detector cooling		Sterling cycle Optional lab (LN ₂)	TE cooler	Sterling cycle

7.7 General Characteristics

	InSb	InGaAs	QWIP
Size(LxWxH):	.5 x 5.7 x 6.3 in (215 x 145 x 160 mm) not including lens		
Weight:	10lbs	8lbs	10lbs
Operating temperature	-40°C to +71°C	40°C to +40°C	-40°C to + 55°C
Storage temperature	-55°C to +80°C	-55°C to +80°C	-55°C to +80°C
Shock	40 g's, 11 msec half sine pulse		
Vibration	4.3 g's RMS random vibration, all three axes		
Humidity	< 95% relative humidity, non-condensing		
Altitude	0 to 40,000 feet operational, 0 to 70,000 feet non-operational		
Operating orientation	No restriction in orientation except for lab (LN ₂) dewar		

- 1) NE Δ T is at 50% nominal bucket fill, 298K background, $\pm 5^\circ\text{C}$ signal
- 2) NEI is at measured at 16 msec with 320 °C source for high gain, 0.2 msec with 850 °C source at low gain
- 3) Typical numbers not separately tested or guaranteed.
- 4) Gains are $\pm 20\%$
- 5) Noise floor is zero flux equivalent, and includes all other noise sources. Integration times per sensitivity measurement conditions

8 Infrared Technology

8.1 History of Infrared

Less than 200 years ago the existence of the infrared portion of the electromagnetic spectrum wasn't even suspected. The original significance of the infrared spectrum, or simply 'the infrared' as it is often called, as a form of heat radiation is perhaps less obvious today than it was at the time of its discovery by Herschel in 1800.



Figure 8-1: Sir William Herschel (1738–1822)

The discovery was made accidentally during the search for a new optical material. Sir William Herschel – Royal Astronomer to King George III of England, and already famous for his discovery of the planet Uranus – was searching for an optical filter material to reduce the brightness of the sun's image in telescopes during solar observations. While testing different samples of colored glass which gave similar reductions in brightness he was intrigued to find that some of the samples passed very little of the sun's heat, while others passed so much heat that he risked eye damage after only a few seconds' observation.

Herschel was soon convinced of the necessity of setting up a systematic experiment, with the objective of finding a single material that would give the desired reduction in brightness as well as the maximum reduction in heat. He began the experiment by actually repeating Newton's prism experiment, but looking for the heating effect rather than the visual distribution of intensity in the spectrum. He first blackened the bulb of a sensitive mercury-in-glass thermometer with ink, and with this as his radiation detector he proceeded to test the heating effect of the various colors of the spectrum formed on the top of a table by passing sunlight through a glass prism. Other thermometers, placed outside the sun's rays, served as controls.

As the blackened thermometer was moved slowly along the colors of the spectrum, the temperature readings showed a steady increase from the violet end to the red end. This was not entirely unexpected, since the Italian researcher, Landriani, in a similar experiment in 1777 had observed much the same effect. It was Herschel, however, who was the first to recognize that there must be a point where the heating effect reaches a maximum, and those measurements confined to the visible portion of the spectrum failed to locate this point.



Figure 8-2: Marsilio Landriani (1746–1815)

Moving the thermometer into the dark region beyond the red end of the spectrum, Herschel confirmed that the heating continued to increase. The maximum point, when he found it, lay well beyond the red end – in what is known today as the 'infrared wavelengths'.

When Herschel revealed his discovery, he referred to this new portion of the electromagnetic spectrum as the ‘thermometrical spectrum’. The radiation itself he sometimes referred to as ‘dark heat’, or simply ‘the invisible rays’. Ironically, and contrary to popular opinion, it wasn’t Herschel who originated the term ‘infrared’. The word only began to appear in print around 75 years later, and it is still unclear who should receive credit as the originator.

Herschel’s use of glass in the prism of his original experiment led to some early controversies with his contemporaries about the actual existence of the infrared wavelengths. Different investigators, in attempting to confirm his work, used various types of glass indiscriminately, having different transparencies in the infrared. Through his later experiments, Herschel was aware of the limited transparency of glass to the newly-discovered thermal radiation, and he was forced to conclude that optics for the infrared would probably be doomed to the use of reflective elements exclusively (i.e. plane and curved mirrors). Fortunately, this proved to be true only until 1830, when the Italian investigator, Melloni, made his great discovery that naturally occurring rock salt (NaCl) – which was available in large enough natural crystals to be made into lenses and prisms – is remarkably transparent to the infrared. The result was that rock salt became the principal infrared optical material, and remained so for the next hundred years, until the art of synthetic crystal growing was mastered in the 1930’s.



Figure 8-3: Macedonio Melloni (1798–1854)

Thermometers, as radiation detectors, remained unchallenged until 1829, the year Nobili invented the thermocouple. (Herschel’s own thermometer could be read to 0.2 °C (0.036 °F), and later models were able to be read to 0.05 °C (0.09 °F)). Then a breakthrough occurred; Melloni connected a number of thermocouples in series to form the first thermopile. The new device was at least 40 times as sensitive as the best thermometer of the day for detecting heat radiation – capable of detecting the heat from a person standing three meters away.

The first so-called ‘heat-picture’ became possible in 1840, the result of work by Sir John Herschel, son of the discoverer of the infrared and a famous astronomer in his own right. Based upon the differential evaporation of a thin film of oil when exposed to a heat pattern focused upon it, the thermal image could be seen by reflected light where the interference effects of the oil film made the image visible to the eye. Sir John also managed to obtain a primitive record of the thermal image on paper, which he called a ‘thermograph’.



Figure 8-4: Samuel P. Langley (1834–1906)

The improvement of infrared-detector sensitivity progressed slowly. Another major breakthrough, made by Langley in 1880, was the invention of the bolometer. This consisted of a thin blackened strip of platinum connected in one arm of a Wheatstone bridge circuit upon which the infrared radiation was

focused and to which a sensitive galvanometer responded. This instrument is said to have been able to detect the heat from a cow at a distance of 400 meters.

An English scientist, Sir James Dewar, first introduced the use of liquefied gases as cooling agents (such as liquid nitrogen with a temperature of $-196\text{ }^{\circ}\text{C}$ ($-320.8\text{ }^{\circ}\text{F}$)) in low temperature research. In 1892 he invented a unique vacuum insulating container in which it is possible to store liquefied gases for entire days. The common ‘thermos bottle’, used for storing hot and cold drinks, is based upon his invention.

Between the years 1900 and 1920, the inventors of the world ‘discovered’ the infrared. Many patents were issued for devices to detect personnel, artillery, aircraft, ships – and even icebergs. The first operating systems, in the modern sense, began to be developed during the 1914–18 war, when both sides had research programs devoted to the military exploitation of the infrared. These programs included experimental systems for enemy intrusion/detection, remote temperature sensing, secure communications, and ‘flying torpedo’ guidance. An infrared search system tested during this period was able to detect an approaching airplane at a distance of 1.5 km (0.94 miles), or a person more than 300 meters (984 ft.) away.

The most sensitive systems up to this time were all based upon variations of the bolometer idea, but the period between the two wars saw the development of two revolutionary new infrared detectors: the image converter and the photon detector. At first, the image converter received the greatest attention by the military, because it enabled an observer for the first time in history to literally ‘see in the dark’. However, the sensitivity of the image converter was limited to the near infrared wavelengths, and the most interesting military targets (i.e. enemy soldiers) had to be illuminated by infrared search beams. Since this involved the risk of giving away the observer’s position to a similarly-equipped enemy observer, it is understandable that military interest in the image converter eventually faded.

The tactical military disadvantages of so-called ‘active’ (i.e. search beam-equipped) thermal imaging systems provided impetus following the 1939–45 war for extensive secret military infrared-research programs into the possibilities of developing ‘passive’ (no search beam) systems around the extremely sensitive photon detector. During this period, military secrecy regulations completely prevented disclosure of the status of infrared-imaging technology. This secrecy only began to be lifted in the middle of the 1950’s, and from that time adequate thermal-imaging devices finally began to be available to civilian science and industry.

8.2 Theory of Thermography

8.2.1 Introduction

The subjects of infrared radiation and the related technique of thermography are still new to many who will use an infrared camera. In this section the theory behind thermography will be given.

8.2.2 The Electromagnetic Spectrum

The electromagnetic spectrum is divided arbitrarily into a number of wavelength regions, called bands, distinguished by the methods used to produce and detect the radiation. There is no fundamental difference between radiation in the different bands of the electromagnetic spectrum. They are all governed by the same laws and the only differences are those due to differences in wavelength.

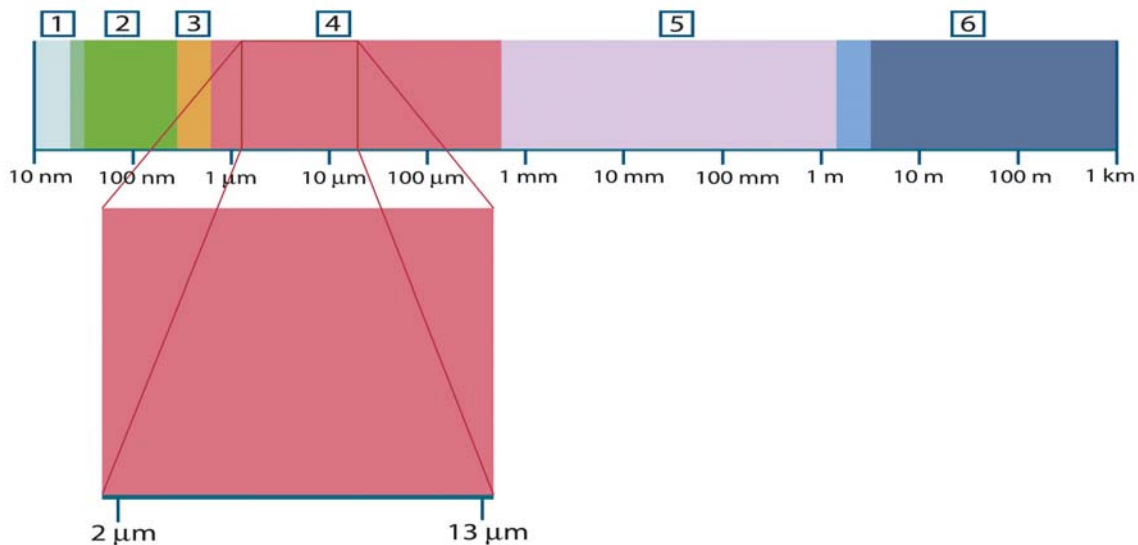


Figure 8-5 The Electromagnetic Spectrum

1: X-ray; 2: UV; 3: Visible; 4: IR; 5: Microwaves; 6: Radiowaves.

Thermography makes use of the infrared spectral band. At the short-wavelength end the boundary lies at the limit of visual perception, in the deep red. At the longwavelength end it merges with the microwave radio wavelengths, in the millimeter range.

The infrared band is often further subdivided into four smaller bands, the boundaries of which are also arbitrarily chosen. They include: the near infrared (0.75–3 μm), the middle infrared (3–6 μm), the far infrared (6–15 μm) and the extreme infrared (15–100 μm). Although the wavelengths are given in μm (micrometers), other units are often still used to measure wavelength in this spectral region, e.g. nanometer (nm) and Ångström (Å). The relationships between the different wavelength measurements is:

$$10\,000\ \text{Å} = 1\,000\ \text{nm} = 1\ \mu = 1\ \mu\text{m}$$

8.2.3 Blackbody Radiation

A blackbody is defined as an object which absorbs all radiation that impinges on it at any wavelength. The apparent misnomer black relating to an object emitting radiation is explained by Kirchhoff's Law (after Gustav Robert Kirchhoff, 1824–1887), which states that a body capable of absorbing all radiation at any wavelength is equally capable in the emission of radiation.



Figure 8-6: Gustav Robert Kirchhoff (1824–1887)

The construction of a blackbody source is, in principle, very simple. The radiation characteristics of an aperture in an isotherm cavity made of an opaque absorbing material represents almost exactly the properties of a blackbody. A practical application of the principle to the construction of a perfect absorber of radiation consists of a box that is light tight except for an aperture in one of the sides. Any radiation which then enters the hole is scattered and absorbed by repeated reflections so only an

infinitesimal fraction can possibly escape. The blackness which is obtained at the aperture is nearly equal to a blackbody and almost perfect for all wavelengths.

By providing such an isothermal cavity with a suitable heater it becomes what is termed a cavity radiator. An isothermal cavity heated to a uniform temperature generates blackbody radiation, the characteristics of which are determined solely by the temperature of the cavity. Such cavity radiators are commonly used as sources of radiation in temperature reference standards in the laboratory for calibrating thermographic instruments, such as a FLIR Systems camera for example.

If the temperature of blackbody radiation increases to more than 525 °C (977 °F), the source begins to be visible so that it appears to the eye no longer black. This is the incipient red heat temperature of the radiator, which then becomes orange or yellow as the temperature increases further. In fact, the definition of the so-called color temperature of an object is the temperature to which a blackbody would have to be heated to have the same appearance. Now consider three expressions that describe the radiation emitted from a blackbody.

8.2.3.1 Planck's Law



Figure 8-7: Max Planck (1858–1947)

Max Planck (1858–1947) was able to describe the spectral distribution of the radiation from a blackbody by means of the following formula:

$$W_{\lambda b} = \frac{2\pi hc^3}{\lambda^5 (e^{hc/\lambda kT} - 1)} \times 10^{-6} \left[\text{Watt/m}^2 \mu\text{m} \right]$$

Where:

- **W_{λb}** = Blackbody spectral radiant emittance at wavelength λ.
- **c** = Velocity of light = 3 × 10⁸ m/s
- **h** = Planck's constant = 6.6 × 10⁻³⁴ Joule sec.
- **k** = Boltzmann's constant = 1.4 × 10⁻²³ Joule/K.
- **T** = Absolute temperature (K) of a blackbody.
- **λ** = Wavelength (μm).

Note

The factor 10⁻⁶ is used since spectral emittance in the curves is expressed in Watt/m²m. If the factor is excluded, the dimension will be Watt/m²μm.

Planck's formula, when plotted graphically for various temperatures, produces a family of curves. Following any particular Planck curve, the spectral emittance is zero at λ = 0, then increases rapidly to a maximum at a wavelength λ_{max} and after passing it approaches zero again at very long wavelengths. The higher the temperature, the shorter the wavelength at which maximum occurs.

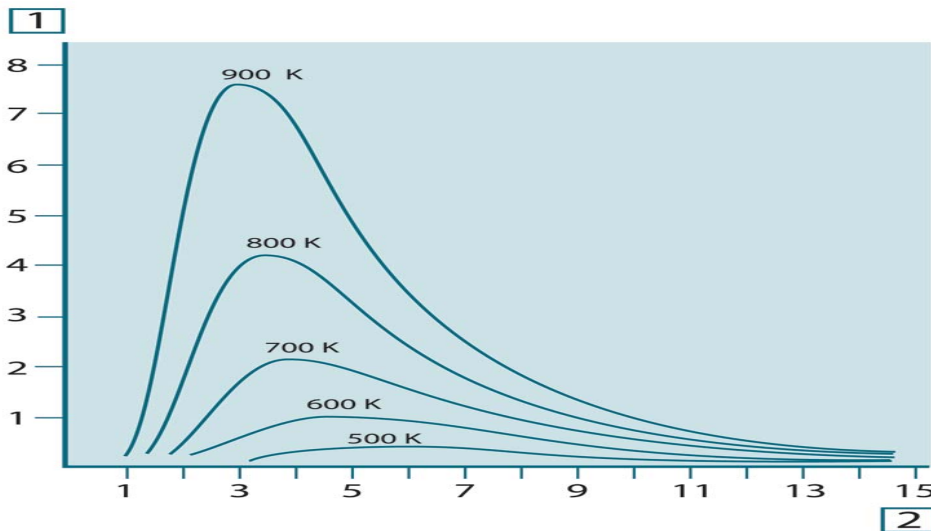


Figure 8-8: Blackbody spectral radiant emittance according to Planck's law, plotted for various absolute temperatures. 1: Spectral radiant emittance ($W/cm^2 \times 10^3(\mu m)$); 2: Wavelength (μm)

8.2.3.2 Wien's Displacement Law

By differentiating Planck's formula with respect to λ , and finding the maximum, we have:

$$\lambda_{\max} = \frac{2898}{T} [\mu m]$$

This is Wien's formula (after Wilhelm Wien, 1864–1928), which expresses mathematically the common observation that colors vary from red to orange or yellow as the temperature of a thermal radiator increases. The wavelength of the color is the same as the wavelength calculated for λ_{\max} . A good approximation of the value of λ_{\max} for a given blackbody temperature is obtained by applying the rule-of-thumb $3\,000/T \mu m$. Thus, a very hot star such as Sirius (11 000 K), emitting bluish-white light, radiates with the peak of spectral radiant emittance occurring within the invisible ultraviolet spectrum, at wavelength $0.27 \mu m$.



Figure 8-9: Wilhelm Wien (1864–1928)

The sun (approx. 6 000 K) emits yellow light, peaking at about $0.5 \mu m$ in the middle of the visible light spectrum.

At room temperature (300 K) the peak of radiant emittance lies at $9.7 \mu m$, in the far infrared, while at the temperature of liquid nitrogen (77 K) the maximum of the almost insignificant amount of radiant emittance occurs at $38 \mu m$, in the extreme infrared wavelengths.

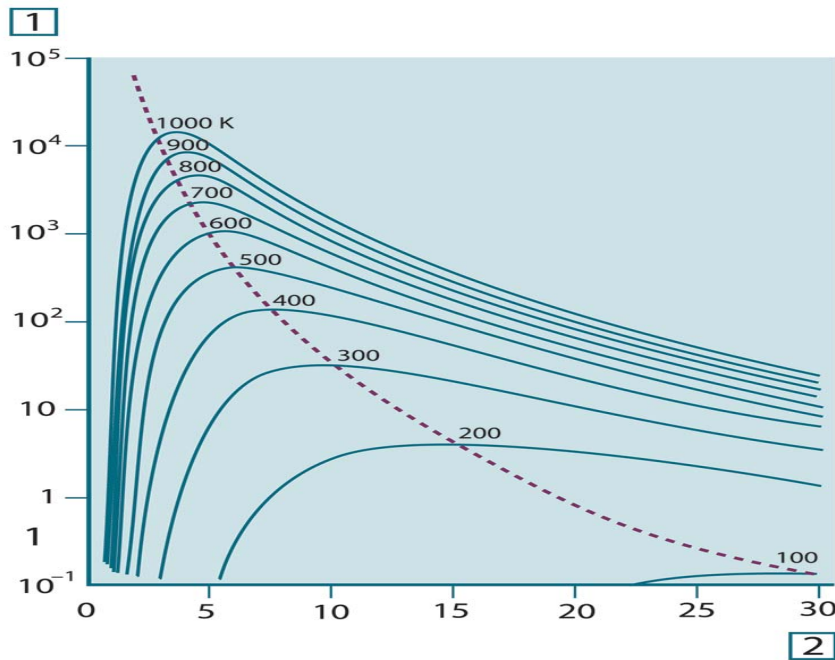


Figure 8-10: Planckian curves plotted on semi-log scales from 100 K to 1000 K. The dotted line represents the locus of maximum radiant emittance at each temperature as described by Wien's displacement law. 1: Spectral radiant emittance (W/cm² (μm)); 2: Wavelength (μm).

8.2.3.3 Stefan-Boltzmann's Law

By integrating Planck's formula from $\lambda = 0$ to $\lambda = \infty$, we obtain the total radiant emittance (W_b) of a blackbody:

$$W_b = \sigma T^4 \text{ [Watt/m}^2\text{]}$$

This is the Stefan-Boltzmann formula (after Josef Stefan, 1835–1893, and Ludwig Boltzmann, 1844–1906), which states that the total emissive power of a blackbody is proportional to the fourth power of its absolute temperature. Graphically, W_b represents the area below the Planck curve for a particular temperature. It can be shown that the radiant emittance in the interval $\lambda = 0$ to λ_{max} is only 25 % of the total, which represents about the amount of the sun's radiation which lies inside the visible light spectrum.



Figure 8-11: Josef Stefan (1835–1893), and Ludwig Boltzmann (1844–1906)

Using the Stefan-Boltzmann formula to calculate the power radiated by the human body, at a temperature of 300 K and an external surface area of approx. 2 m², we obtain 1 kW. This power loss could not be sustained if it were not for the compensating absorption of radiation from surrounding surfaces, at room temperatures which do not vary too drastically from the temperature of the body – or, of course, the addition of clothing.

8.2.3.4 Non-Blackbody Emitters

So far, only blackbody radiators and blackbody radiation have been discussed. However, real objects almost never comply with these laws over an extended wavelength region – although they may approach the blackbody behavior in certain spectral intervals. For example, a certain type of white paint may appear perfectly *white* in the visible light spectrum, but becomes distinctly *gray* at about 2 μm , and beyond 3 μm it is almost *black*.

There are three processes which can occur that prevent a real object from acting like a blackbody: a fraction of the incident radiation α may be absorbed, a fraction ρ may be reflected, and a fraction τ may be transmitted. Since all of these factors are more or less wavelength dependent, the subscript λ is used to imply the spectral dependence of their definitions. Thus:

- The spectral absorptance α_λ = the ratio of the spectral radiant power absorbed by an object to that incident upon it.
- The spectral reflectance ρ_λ = the ratio of the spectral radiant power reflected by an object to that incident upon it.
- The spectral transmittance τ_λ = the ratio of the spectral radiant power transmitted through an object to that incident upon it.

The sum of these three factors must always add up to the whole at any wavelength, so we have the relation:

$$\alpha_\lambda + \rho_\lambda + \tau_\lambda = 1$$

For opaque materials $\tau_\lambda = 0$ and the relation simplifies to:

$$\alpha_\lambda + \rho_\lambda = 1$$

Another factor, called the emissivity, is required to describe the fraction ε of the radiant emittance of a blackbody produced by an object at a specific temperature. Thus, we have the definition: The spectral emissivity ε_λ = the ratio of the spectral radiant power from an object to that from a blackbody at the same temperature and wavelength. Expressed mathematically, this can be written as the ratio of the spectral emittance of the object to that of a blackbody as follows:

$$\varepsilon_\lambda = \frac{W_{\lambda o}}{W_{\lambda b}}$$

Generally speaking, there are three types of radiation source, distinguished by the ways in which the spectral emittance of each varies with wavelength.

- A blackbody, for which $\varepsilon_\lambda = \varepsilon = 1$
- A graybody, for which $\varepsilon_\lambda = \varepsilon = \text{constant less than } 1$
- A selective radiator, for which ε varies with wavelength

According to Kirchhoff's law, for any material the spectral emissivity and spectral absorptance of a body are equal at any specified temperature and wavelength. That is:

$$\varepsilon_\lambda = \alpha_\lambda$$

From this we obtain, for an opaque material (since $\alpha_\lambda + \rho_\lambda = 1$):

$$\varepsilon_\lambda + \rho_\lambda = 1$$

For highly polished materials ε_λ approaches zero, so that for a perfectly reflecting material (*i.e.* a perfect mirror) we have:

$$\rho_\lambda = 1$$

For a graybody radiator, the Stefan-Boltzmann formula becomes:

$$W = \varepsilon\sigma T^4 \text{ [Watt/m}^2\text{]}$$

This states that the total emissive power of a graybody is the same as a blackbody at the same temperature reduced in proportion to the value of ε from the graybody.

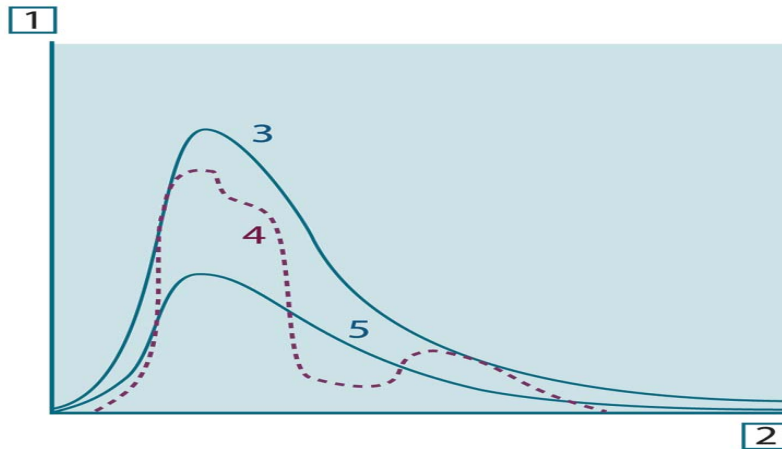


Figure 8-12: Spectral radiant emittance of three types of radiators. 1: Spectral radiant emittance; 2: wavelength; 3: Blackbody; 4: Selective radiator; 5: Graybody.

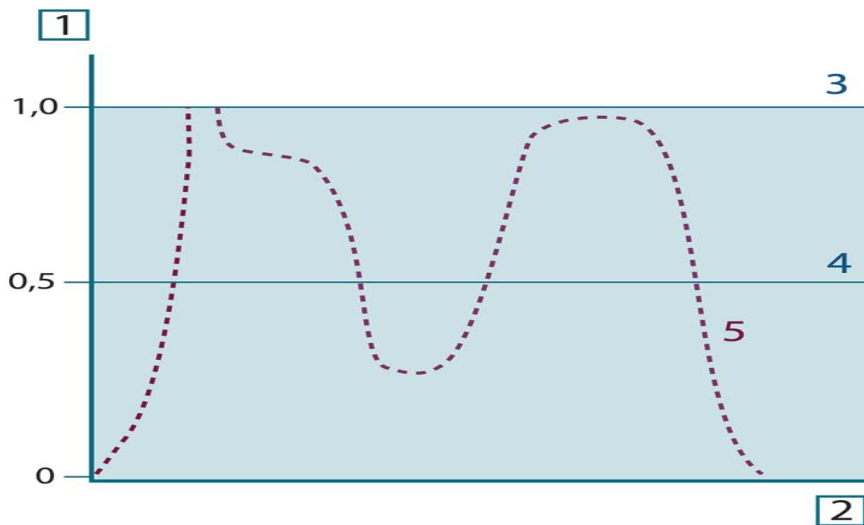


Figure 8-13: Spectral emissivity of three types of radiators. 1: Spectral emissivity; 2: Wavelength; 3: blackbody; 4: Graybody; 5: Selective radiator.

8.2.4 Infrared Semi-Transparent Materials

Consider now a non-metallic, semi-transparent body – let us say, in the form of a thick flat plate of plastic material. When the plate is heated, radiation generated within its volume must work its way toward the surfaces through the material in which it is partially absorbed. Moreover, when it arrives at the surface, some of it is reflected back into the interior. The back-reflected radiation is again partially absorbed, but some of it arrives at the other surface, through which most of it escapes; part of it is reflected back again. Although the progressive reflections become weaker and weaker they must all be added up when the total emittance of the plate is sought. When the resulting geometrical series is summed, the effective emissivity of a semi-transparent plate is obtained as:

$$\varepsilon_\lambda = \frac{(1 - \rho_\lambda)(1 - \tau_\lambda)}{1 - \rho_\lambda \tau_\lambda}$$

When the plate becomes opaque this formula is reduced to the single formula:

$$\varepsilon_\lambda = 1 - \rho_\lambda$$

This last relation is a particularly convenient one, because it is often easier to measure reflectance than to measure emissivity directly.

8.3 The Measurement Formula

As already mentioned, when viewing an object, the camera receives radiation not only from the object itself. It also collects radiation from the surroundings reflected via the object surface. Both these radiation contributions become attenuated to some extent by the atmosphere in the measurement path. To this comes a third radiation contribution from the atmosphere itself.

This description of the measurement situation, as illustrated in the figure below, is so far a fairly true description of the real conditions. What has been neglected could for instance be sun light scattering in the atmosphere or stray radiation from intense radiation sources outside the field of view. Such disturbances are difficult to quantify, however, in most cases they are fortunately small enough to be neglected. In case they are not negligible, the measurement configuration is likely to be such that the risk for disturbance is obvious, at least to a trained operator. It is then his responsibility to modify the measurement situation to avoid the disturbance e.g. by changing the viewing direction, shielding off intense radiation sources etc.

Accepting the description above, we can use the figure below to derive a formula for the calculation of the object temperature from the calibrated camera output.

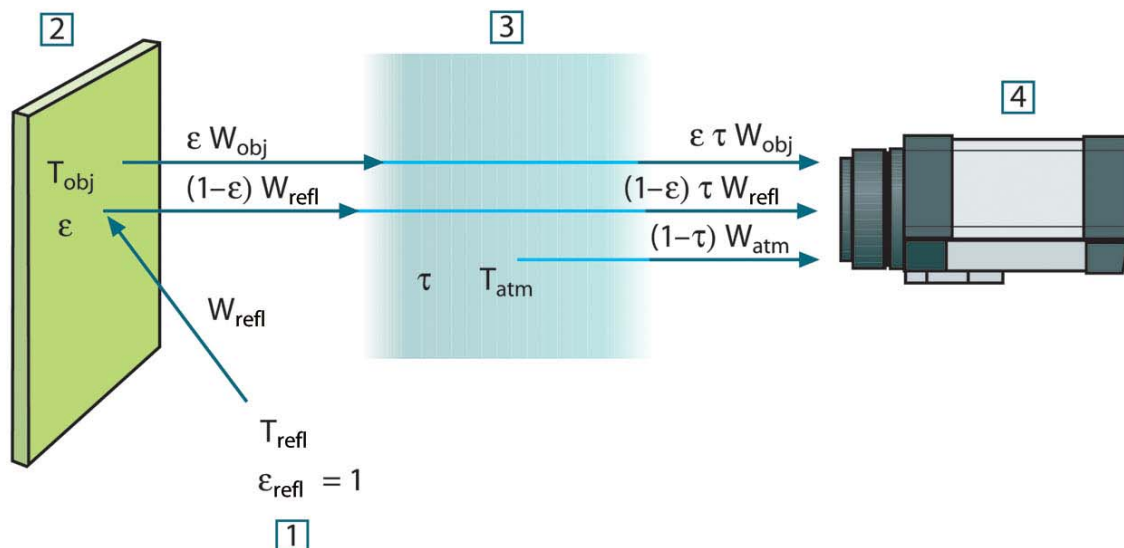


Figure 8-14: A schematic representation of the general thermographic measurement situation. 1: Surroundings; 2: Object; 3: Atmosphere; 4: Camera

Assume that the received radiation power W from a blackbody source of temperature T_{source} on short distance generates a camera output signal U_{source} that is proportional to the power input (power linear camera). We can then write (Equation 1):

$$U_{\text{source}} = CW(T_{\text{source}}), \text{ or with simplified notation: } U_{\text{source}} = CW_{\text{source}}$$

Where C is a constant.

Should the source be a graybody with emittance ε , the received radiation would consequently be $\varepsilon W_{\text{source}}$.

We are now ready to write the three collected radiation power terms:

- Emission from the object = $\varepsilon\tau W_{\text{obj}}$, where ε is the emittance of the object and τ is the transmittance of the atmosphere. The object temperature is T_{obj} .
- Reflected emission from ambient sources = $(1 - \varepsilon)\tau W_{\text{refl}}$, where $(1 - \varepsilon)$ is the reflectance of the object. The ambient sources have the temperature T_{refl} .

It has here been assumed that the temperature T_{refl} is the same for all emitting surfaces within the hemisphere seen from a point on the object surface. This is of course sometimes a simplification of the true situation. It is, however, a necessary simplification in order to derive a workable formula, and T_{refl} can – at least theoretically – be given a value that represents an efficient temperature of a complex surrounding.

Note also that we have assumed that the emittance for the surroundings = 1. This is correct in accordance with Kirchhoff's law: All radiation impinging on the surrounding surfaces will eventually be absorbed by the same surfaces. Thus the emittance = 1.

Note

Though that the latest discussion requires the complete sphere around the object to be considered.

- Emission from the atmosphere = $(1 - \tau)\tau W_{\text{atm}}$, where $(1 - \tau)$ is the emittance of the atmosphere. The temperature of the atmosphere is T_{atm} .

The total received radiation power can now be written (Equation 2):

$$W_{\text{tot}} = \varepsilon\tau W_{\text{obj}} + (1 - \varepsilon)\tau W_{\text{refl}} + (1 - \tau)W_{\text{atm}}$$

We multiply each term by the constant C of Equation 1 and replace the CW products by the corresponding U according to the same equation, and get (Equation 3):

$$U_{\text{tot}} = \varepsilon\tau U_{\text{obj}} + (1 - \varepsilon)\tau U_{\text{refl}} + (1 - \tau)U_{\text{atm}}$$

Solve Equation 3 for U_{obj} (Equation 4):

$$U_{\text{obj}} = \frac{1}{\varepsilon\tau} U_{\text{tot}} - \frac{1 - \varepsilon}{\varepsilon} U_{\text{refl}} - \frac{1 - \tau}{\varepsilon\tau} U_{\text{atm}}$$

This is the general measurement formula used in all the FLIR Systems thermographic equipment. The voltages of the formula are:

- **Uobj** = Calculated camera output voltage for a blackbody of temperature T_{obj} i.e. a voltage that can be directly converted into true requested object temperature.
- **Utot** = Measured camera output voltage for the actual case.
- **Urefl** = Theoretical camera output voltage for a blackbody of temperature T_{refl} according to the calibration.
- **Uatm** = Theoretical camera output voltage for a blackbody of temperature T_{atm} according to the calibration.

The operator has to supply a number of parameter values for the calculation:

- The object emittance ε ,
- The relative humidity,
- T_{atm}
- Object distance (D_{obj})

- The (effective) temperature of the object surroundings, or the reflected ambient temperature T_{refl} , and
- The temperature of the atmosphere T_{atm}

This task could sometimes be a heavy burden for the operator since there are normally no easy ways to find accurate values of emittance and atmospheric transmittance for the actual case. The two temperatures are normally less of a problem provided the surroundings do not contain large and intense radiation sources.

A natural question in this connection is: How important is it to know the right values of these parameters? It could though be of interest to get a feeling for this problem already here by looking into some different measurement cases and compare the relative magnitudes of the three radiation terms. This will give indications about when it is important to use correct values of which parameters.

The figures below illustrates the relative magnitudes of the three radiation contributions for three different object temperatures, two emittances, and two spectral ranges: SW and LW. Remaining parameters have the following fixed values:

- $\tau = 0.88$
- $T_{refl} = +20\text{ }^{\circ}\text{C} (+68\text{ }^{\circ}\text{F})$
- $T_{refl} = +20\text{ }^{\circ}\text{C} (+68\text{ }^{\circ}\text{F})$
- It is obvious that measurement of low object temperatures are more critical than measuring high temperatures since the ‘disturbing’ radiation sources are relatively much stronger in the first case. Should also the object emittance be low, the situation would be still more difficult.

We have finally to answer a question about the importance of being allowed to use the calibration curve above the highest calibration point, what we call extrapolation. Imagine that we in a certain case measure $U_{tot} = 4.5$ volts. The highest calibration point for the camera was in the order of 4.1 volts, a value unknown to the operator. Thus, even if the object happened to be a blackbody, i.e. $U_{obj} = U_{tot}$, we are actually performing extrapolation of the calibration curve when converting 4.5 volts into temperature.

Let us now assume that the object is not black, it has an emittance of 0.75, and the transmittance is 0.92. We also assume that the two second terms of Equation 4 amount to 0.5 volts together. Computation of U_{obj} by means of Equation 4 then results in $U_{obj} = 4.5 / 0.75 / 0.92 - 0.5 = 6.0$. This is a rather extreme extrapolation, particularly when considering that the video amplifier might limit the output to 5 volts! Note, though, that the application of the calibration curve is a theoretical procedure where no electronic or other limitations exist. We trust that if there had been no signal limitations in the camera, and if it had been calibrated far beyond 5 volts, the resulting curve would have been very much the same as our real curve extrapolated beyond 4.1 volts, provided the calibration algorithm is based on radiation physics, like the FLIR Systems algorithm. Of course there must be a limit to such extrapolations.

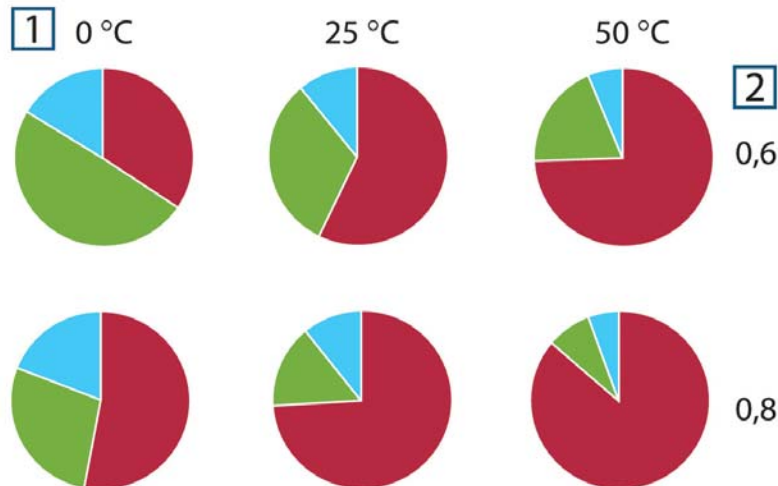


Figure 8-15: Relative magnitudes of radiation sources under varying measurement conditions (SW camera). 1: Object temperature; 2: Emittance; RED: Object radiation; BLUE: Reflected radiation; GREEN: atmosphere radiation. Fixed parameters: $\tau = 0.88$; $T_{refl} = 20\text{ °C}$ (+68 °F); $T_{atm} = 20\text{ °C}$ (+68 °F).

8.4 Emissivity tables

This section presents a compilation of emissivity data from the infrared literature and FLIR Systems own measurements.

Table 8-1: T: Total spectrum; SW: 2–5 μm ; LW: 8–14 μm , LLW: 6.5–20 μm ; 1: Material; 2: Specification; 3: Temperature in °C; 4: Spectrum; 5: Emissivity; 6: Reference

- Mikael A. Bramson: Infrared Radiation, A Handbook for Applications, Plenum press, N.Y.
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1	2	3	4	5	6
Aluminum	anodized, black, dull	70	LW	0.95	9

Aluminum	anodized, black, dull	70	SW	0.67	9
Aluminum	anodized, light gray, dull	70	T	0.97	9
Aluminum	anodized, light gray, dull	70	T	0.61	9
Aluminum	anodized sheet	100	T	0.55	2
Aluminum	as received, plate	100	T	0.09	4
Aluminum	as received, sheet	100	T	0.09	2
Aluminum	cast, blast cleaned	70	LW	0.46	9
Aluminum	cast, blast cleaned	70	SW	0.47	9
Aluminum	dipped in HNO ₃ , plate	100	T	0.09	4
Aluminum	Foil	27	3 µm	0.09	3
Aluminum	Foil	27	10 µm	0.04	3
Aluminum	oxidized, strongly	50-100	T	0.2-0.3	1
Aluminum	polished	50-100	T	0.04-0.06	1
Aluminum	polished, sheet	100	T	0.05	2
Aluminum	polished plate	100	T	0.05	4
Aluminum	roughened	27	3 µm	0.28	3
Aluminum	roughened	27	10 µm	0.18	3
Aluminum	rough surface	20-50	T	0.06-0.07	1
Aluminum	Sheet, 4 samples differently scratched	70	LW	0.03-0.06	9
Aluminum	Sheet, 4 samples differently scratched	70	SW	0.05-0.08	9
Aluminum	vacuum deposited	20	T	0.04	2
Aluminum	weathered, heavily	17	SW	0.83-0.94	5
Aluminum bronze		20	T	0.60	1
Aluminum hydroxide	powder		T	0.28	1
Aluminum oxide	activated, powder		T	0.46	1
Aluminum oxide	pure, powder alumina		T	0.16	1
Asbestos	Board	20	T	0.96	1
Asbestos	Fabric		T	0.78	7
Asbestos	floor tile	35	SW	0.94	1
Asbestos	Paper	40-400	T	0.93-0.95	1
Asbestos	Powder		T	0.40-0.60	1
Asbestos	Slate	20	T	0.96	8
Asphalt paving		4	LLW	0.967	1
Brass	dull, tarnished	20-350	T	0.22	9
Brass	oxidized	70	SW	0.04-0.09	9

Brass	oxidized	70	LW	0.03-0.07	2
Brass	oxidized	100	T	0.61	1
Brass	oxidized at 600 °C	200-600	T	0.59-0.61	1
Brass	polished	200	T	0.03	2
Brass	polished, highly	100	T	0.03	2
Brass	rubbed with 80- grit emery	20	T	0.20	1
Brass	Sheet, rolled	20	T	0.06	1
Brass	Sheet, worked with emery	20	T	0.2	5
Brick	Alumina	17	SW	0.68	5
Brick	common	17	SW	0.86-0.81	5
Brick	Dinas silica, glazed, rough	1100	T	0.85	1
Brick	Dinas silica, refractory	1000	T	0.66	1
Brick	Dinas silica, unglazed, rough	1000	T	0.80	1
Brick	firebrick	17	SW	0.68	5
Brick	Fireclay	20	T	0.85	1
Brick	fireclay	1000	T	0.75	1
Brick	fireclay	1200	T	0.59	1
Brick	masonry	35	SW	0.94	7
Brick	masonry, plastered	20	T	0.94	1
Brick	red, common	20	T	0.93	2
Brick	red, rough	20	T	0.88-0.93	1
Brick	refractory, corundum	1000	T	0.46	1
Brick	refractory, magnesite	1000-1300	T	0.38	1
Brick	refractory, strongly radiating	500-1000	T	0.8-0.9	1
Brick	refractory, weakly radiating	500-1000	T	0.65-0.75	1
Brick	Silica, 95 % SiO ₂	1230	T	0.66	1
Brick	sillimanite, 33 % SiO ₂ , 64 % Al ₂ O ₃	1500	T	0.29	1
Brick	waterproof	17	SW	0.87	5
Bronze	phosphor bronze	70	LW	0.06	9
Bronze	phosphor bronze	70	SW	0.08	9
Bronze	polished	50	T	0.1	1
Bronze	porous, rough	50-150	T	0.55	1
Bronze	Powder		T	0.76-0.80	1
Carbon	candle soot	20	T	0.95	2
Carbon	charcoal powder		T	0.96	1

Carbon	graphite, filed surface	20	T	0.98	2
Carbon	graphite powder		T	0.97	1
Carbon	lampblack	20-400	T	0.95-0.97	1
Chipboard	untreated	20	SW	0.90	6
Chromium	polished	50	T	0.10	1
Chromium	Polished	500-1000	T	0.28-0.38	1
Clay	Fired	70	T	0.91	1
Cloth	Black	20	T	0.98	1
Concrete		20	SW	0.92	2
Concrete	Dry	36	SW	0.95	7
Concrete	Rough	17	LLW	0.97	5
Concrete	Walkway	5	T	0.974	8
Copper	commercial, burnished	20	T	0.07	1
Copper	electrolytic, carefully polished	80	T	0.018	1
Copper	electrolytic, polished	-34	T	0.006	4
Copper	Molten	1100-1300	T	0.13-0.15	1
Copper	Oxidized	50	T	0.6-0.7	1
Copper	oxidized, black	27	T	0.78	4
Copper	oxidized, heavily	20	T		
Copper	oxidized to blackness		T	0.88	1
Copper	Polished	50-100	T	0.02	1
Copper	Polished	100	T	0.03	2
Copper	polished, commercial	27	T	0.03	4
Copper	polished, mechanical	22	T	0.015	4
Copper	pure, carefully prepared surface	22	T	0.008	4
Copper	Scraped	27	T	0.07	4
Copper dioxide	Powder		T	0.84	1
Copper oxide	red, powder		T	0.70	1
Ebonite			T	0.89	1
Emery	Coarse	80	T	0.85	1
Enamel		20	T	0.9	1
Enamel	Lacquer	20	T	0.85-0.95	1
Fiber board	hard, untreated	20	SW	0.85	6
Fiber board	Masonite	70	LW	0.88	9
Fiber board	Masonite	70	SW	0.75	9

Fiber board	particle board	70	LW	0.89	9
Fiber board	particle board	70	SW	0.77	9
Fiber board	porous, untreated	20	SW	0.85	6
Gold	Polished	130	T	0.018	1
Gold	polished, carefully	200-600	T	0.02-0.03	1
Gold	polished, highly	100	T	0.02	2
Granite	Polished	20	LLW	0.849	8
Granite	Rough	21	LLW	0.879	8
Granite	rough, 4 different samples	70	LW	0.77-0.87	9
Granite	rough, 4 different samples	70	SW	0.95-0.97	9
Gypsum		20	T	0.8-0.9	1
Ice: See Water			T		
Iron, cast	Casting	50	T	0.81	1
Iron, cast	Ingots	1000	T	0.95	1
Iron, cast	Liquid	1300	T	0.28	1
Iron, cast	Machined	800-1000	T	0.60-0.70	1
Iron, cast	Oxidized	38	T	0.63	4
Iron, cast	Oxidized	100	T	0.64	2
Iron, cast	Oxidized	260	T	0.66	4
Iron, cast	Oxidized	538	T	0.76	4
Iron, cast	oxidized at 600°C	200-600	T	0.64-0.78	1
Iron, cast	Polished	38	T	0.21	4
Iron, cast	Polished	40	T	0.21	2
Iron, cast	Polished	200	T	0.21	1
Iron, cast	Unworked	900-1100	T	0.87-0.95	1
Iron and steel	cold rolled	70	LW	0.09	9
Iron and steel	cold rolled	70	SW	0.20	9
Iron and steel	covered with red rust	20	T	0.61-0.85	1
Iron and steel	Electrolytic	22	T	0.05	4
Iron and steel	Electrolytic	100	T	0.05	4
Iron and steel	Electrolytic	260	T	0.07	4
Iron and steel	electrolytic, carefully polished	175-225	T	0.05-0.06	1
Iron and steel	freshly worked with emery	20	T	0.24	1
Iron and steel	ground sheet	950-1100	T	0.55-0.61	1
Iron and steel	heavily rusted sheet	20	T	0.69	2
Iron and steel	hot rolled	20	T	0.77	1

Iron and steel	hot rolled	130	T	0.60	1
Iron and steel	Oxidized	100	T	0.74	1
Iron and steel	Oxidized	100	T	0.74	4
Iron and steel	Oxidized	125-525	T	0.78-0.82	1
Iron and steel	Oxidized	200	T	0.79	2
Iron and steel	Oxidized	1227	T	0.89	4
Iron and steel	Oxidized	200-600	T	0.80	1
Iron and steel	oxidized strongly	50	T	0.88	1
Iron and steel	oxidized strongly	500	T	0.98	1
Iron and steel	Polished	100	T	0.07	2
Iron and steel	Polished	400-1000	T	0.14-0.38	1
Iron and steel	polished sheet	750-1050	T	0.52-0.56	1
Iron and steel	rolled, freshly	20	T	0.24	1
Iron and steel	rolled sheet	50	T	0.56	1
Iron and steel	rough, plane surface	50	T	0.95-0.98	1
Iron and steel	rusted, heavily	17	SW	0.96	5
Iron and steel	rusted red, sheet	22	T	0.69	4
Iron and steel	rusty, red	20	T	0.69	1
Iron and steel	shiny, etched	150	T	0.16	1
Iron and steel	Shiny oxide layer, sheet	20	T	0.82	1
Iron and steel	Wrought, carefully polished	40-250	T	0.28	1
Iron galvanized	heavily oxidized	70	LW	0.85	9
Iron galvanized	heavily oxidized	70	SW	0.64	9
Iron galvanized	Sheet	92	T	0.07	4
Iron galvanized	sheet, burnished	30	T	0.23	1
Iron galvanized	sheet, oxidized	20	T	0.28	1
Iron tinned	Sheet	24	T	0.064	4
Lacquer	3 colors sprayed on Aluminum	70	LW	0.92-0.94	9
Lacquer	3 colors sprayed on Aluminum	70	SW	0.50-0.53	9
Lacquer	Aluminum on rough surface	20	T	0.4	1
Lacquer	Bakelite	80	T	0.83	1
Lacquer	black, dull	40-100	T	0.96-0.98	1
Lacquer	black, matte	100	T	0.97	2
Lacquer	black, shiny, sprayed on iron	20	T	0.87	1
Lacquer	heat-resistant	100	T	0.92	1

Lacquer	White	40-100	T	0.8-0.95	1
Lacquer	White	100	T	0.92	2
Lead	oxidized, gray	20	T	0.28	1
Lead	oxidized, gray	22	T	0.28	4
Lead	oxidized at 200 °C	200	T	0.63	1
Lead	Shiny	250	T	0.08	1
Lead	unoxidized, polished	100	T	0.05	4
Lead red		100	T	0.93	4
Lead red, powder		100	T	0.93	1
Leather	Tanned		T	0.75-0.80	1
Lime			T	0.3-0.4	1
Magnesium		22	T	0.07	4
Magnesium		260	T	0.13	4
Magnesium		538	T	0.18	4
Magnesium	Polished	20	T	0.07	2
Magnesium powder			T	0.86	1
Molybdenum		600-1000	T	0.08-0.13	1
Molybdenum		1500-2200	T	0.19-0.26	1
Molybdenum	Filament	700-2500	T	0.1-0.3	1
Mortar		17	SW	0.87	5
Mortar	Dry	36	SW	0.94	7
Nichrome	Rolled	700	T	0.25	1
Nichrome	Sandblasted	700	T	0.70	1
Nichrome	wire, clean	50	T	0.65	1
Nichrome	wire, clean	500-1000	T	0.71-0.79	1
Nichrome	wire, oxidized	50-500	T	0.95-0.98	1
Nickel	bright matte	122	T	0.041	4
Nickel	Commercially pure, polished	100	T	0.045	1
Nickel	Commercially pure, polished	200-400	T	0.07-0.09	1
Nickel	Electrolytic	22	T	0.04	4
Nickel	Electrolytic	38	T	0.06	4
Nickel	Electrolytic	260	T	0.07	4
Nickel	Electrolytic	538	T	0.10	4
Nickel	electroplated, polished	20	T	0.05	2
Nickel	Electroplated on iron, polished	22	T	0.045	4

Nickel	electroplated on iron, unpolished	20	T	0.11-0.40	1
Nickel	electroplated on iron, unpolished	22	T	0.11	4
Nickel	Oxidized	200	T	0.37	2
Nickel	Oxidized	227	T	0.37	4
Nickel	Oxidized	1227	T	0.85	4
Nickel	oxidized at 600 °C	200-600	T	0.37-0.48	1
Nickel	Polished	122	T	0.045	4
Nickel	Wire	200-1000	T	0.1-0.2	1
Nickel oxide		500-650	T	0.52-0.59	1
Nickel oxide		1000-1250	T	0.75-0.86	1
Oil, lubricating	0.025 mm film	20	T	0.27	2
Oil, lubricating	0.050 mm film	20	T	0.46	2
Oil, lubricating	0.125 mm film	20	T	0.72	2
Oil, lubricating	film on Ni base: Ni base only	20	T	0.05	2
Oil, lubricating	thick coating	20	T	0.82	2
Paint	8 different colors and qualities	70	LW	0.92-0.94	9
Paint	8 different colors and qualities	70	SW	0.88-0.96	9
Paint	Aluminum, various ages	50-100	T	0.27-0.67	1
Paint	cadmium yellow		T	0.28-0.33	1
Paint	chrome green		T	0.65-0.70	1
Paint	cobalt blue		T	0.7-0.8	1
Paint	Oil	17	SW	0.87	5
Paint	oil, black flat	20	SW	0.94	6
Paint	oil, black gloss	20	SW	0.92	6
Paint	oil, gray flat	20	SW	0.97	6
Paint	oil, gray gloss	20	SW	0.96	6
Paint	oil, various colors	100	T	0.92-0.96	1
Paint	oil based, average of 16 colors	100	T	0.94	2
Paint	plastic, black	20	SW	0.95	6
Paint	plastic, white	20	SW	0.84	6
Paper	4 different colors	70	LW	0.92-0.94	9
Paper	4 different colors	70	SW	0.68-0.74	9
Paper	Black		T	0.90	1

Paper	black, dull		T	0.94	1
Paper	black, dull	70	LW	0.89	9
Paper	black, dull	70	SW	0.86	9
Paper	blue, dark		T	0.84	1
Paper	coated with black lacquer		T	0.93	1
Paper	Green		T	0.85	1
Paper	Red		T	0.76	1
Paper	White	20	T	0.7-0.9	1
Paper	white, 3 different glosses	70	LW	0.88-0.90	9
Paper	white, 3 different glosses	70	SW	0.76-0.78	9
Paper	white bond	20	T	0.93	2
Paper	Yellow		T	0.72	1
Plaster		17	SW	0.86	5
Plaster	plasterboard, untreated	20	SW	0.90	6
Plaster	rough coat	20	T	0.91	2
Plastic	glass fibre laminate (printed circ. board)	70	LW	0.91	9
Plastic	glass fibre laminate (printed circ. board)	70	SW	0.94	9
Plastic	Polyurethane isolation board	70	LW	0.55	9
Plastic	Polyurethane isolation board	70	SW	0.29	9
Plastic	PVC, plastic floor, dull, structured	70	LW	0.93	9
Plastic	PVC, plastic for, dull, structured	70	SW	0.94	9
Platinum		17	T	0.016	4
Platinum		22	T	0.03	4
Platinum		100	T	0.05	4
Platinum		260	T	0.06	4
Platinum		538	T	0.10	4
Platinum		1000-1500	T	0.14-0.18	1
Platinum		1094	T	0.18	4
Platinum	pure, polished	200-600	T	0.05-0.10	1
Platinum	Ribbon	900-1100	T	0.12-0.17	1
Platinum	Wire	50-200	T	0.06-0.07	1
Platinum	Wire	500-1000	T	0.10-0.16	1
Platinum	Wire	1400	T	0.18	1
Porcelain	Glazed	20		0.92	1

Porcelain	white, shiny		T	0.70-0.75	1
Rubber	Hard	20	T	0.95	1
Rubber	soft, gray, rough	20	T	0.95	1
Sand			T	0.60	1
Sand		20	T	0.90	2
Sandstone	Polished	19	LLW	0.909	8
Sandstone	Rough	19	LLW	0.935	8
Silver	Polished	100	T	0.03	2
Silver	pure, polished	200-600	T	0.02-0.03	1
Skin	Human	32	T	0.98	2
Slag	Boiler	0-100	T	0.97-0.93	1
Slag	Boiler	200-500	T	0.89-0.78	1
Slag	Boiler	600-1200	T	0.76-0.70	1
Slag	Boiler	1400-1800	T	0.69-0.67	1
Snow: See Water					
Soil	Dry	20	T	0.92	2
Soil	saturated with water	20	T	0.95	2
Stainless steel	alloy, 8 % Ni, 18 % Cr	500	T	0.35	1
Stainless steel	Rolled	700	T	0.45	1
Stainless steel	Sandblasted	700	T	0.70	1
Stainless steel	sheet, polished	70	LW	0.14	9
Stainless steel	sheet, polished	70	SW	0.18	9
Stainless steel	sheet, untreated, somewhat scratched	70	LW	0.28	9
Stainless steel	sheet, untreated, somewhat scratched	70	SW	0.30	9
Stainless steel	type 18-8, buffed	20	T	0.16	2
Stainless steel	type 18-8, oxidized at 800 °C	60	T	0.85	2
Stucco	rough, lime	10-90	T	0.91	1
Styrofoam	Insulation	37	SW	0.60	7
Tar			T	0.79-0.84	1
Tar	Paper	20	T	0.91-0.93	1
Tile	Glazed	17	SW	0.94	5
Tin	Burnished	20-50	T	0.04-0.06	1
Tin	tin-plated sheet iron	100	T	0.07	2
Titanium	Oxidized at 540 °C	200	T	0.40	1
Titanium	Oxidized at 540 °C	500	T	0.50	1

Titanium	Oxidized at 540 °C	1000	T	0.60	1
Titanium	Polished	200	T	0.15	1
Titanium	Polished	500	T	0.20	1
Titanium	Polished	1000	T	0.36	1
Tungsten		200	T	0.05	1
Tungsten		600-1000	T	0.1-0.16	1
Tungsten		1500-2200	T	0.24-0.31	1
Tungsten	Filament	3300	T	0.39	1
Varnish	Flat	20	SW	0.93	6
Varnish	on oak parquet floor	70	LW	0.90-0.93	9
Varnish	on oak parquet floor	70	SW	0.90	9
Wallpaper	slight pattern, light gray	20	SW	0.85	6
Wallpaper	slight pattern, red	20	SW	0.90	6
Water	Distilled	20	T	0.96	2
Water	frost crystals	-10	T	0.98	2
Water	ice, covered with heavy frost	0	T	0.98	1
Water	ice, smooth	-10	T	0.96	2
Water	ice, smooth	0	T	0.97	1
Water	layer >0.1 mm thick	0-100	T	0.95-0.98	1
Water	Snow		T	0.8	1
Water	Snow	-10	T	0.85	2
Wood		17	SW	0.98	5
Wood		19	LLW	0.962	8
Wood	Ground		T	0.5-0.7	1
Wood	pine, 4 different samples	70	LW	0.81-0.89	9
Wood	pine, 4 different samples	70	SW	0.67-0.75	9
Wood	Planed	20	T	0.8-0.9	1
Wood	planed oak	20	T	0.90	2
Wood	planed oak	70	LW	0.88	9
Wood	planed oak	70	SW	0.77	9
Wood	plywood, smooth, dry	36	SW	0.82	7
Wood	plywood, untreated	20	SW	0.83	6
Wood	white, damp	20	T	0.7-0.8	1
Zinc	oxidized at 400 °C	400	T	0.11	1
Zinc	oxidized surface	100-1200	T	0.50-0.60	1
Zinc	Polished	200-300	T	0.04-0.05	1
Zinc	Sheet	50	T	0.20	1

9 Maintenance

9.1 Camera and Lens Cleaning

9.1.1 Camera Body, Cables and Accessories

The camera body, cables and accessories may be cleaned by wiping with a soft cloth. To remove stains, wipe with a soft cloth moistened with a mild detergent solution and wrung dry, then wipe with a dry soft cloth.

Do not use benzene, thinner, or any other chemical product on the camera, the cables or the accessories, as this may cause deterioration.

9.1.2 Lenses

It is recommended that all optics be handled with care and the need for cleaning is eliminated or at least reduced. If however, cleaning is deemed necessary, the methods herein are accepted industry standards and should yield good results.

Before you BEGIN,

- Identify the type of optic to be cleaned.
- Is it hard or soft material?
- Is it coated & with what?
- How is it contaminated?
- Particulate or film or both.
- Set a standard of cleanliness.
- What is clean enough?
- Establish & document a standard.
- Know your solvent.
- Read the MSDS
- See recommended solvents
- Assemble your supplies:
 - Latex gloves or finger cotts
 - Clean brite work area
 - Inspection light
 - Lens tissue or cloth
 - Dust bulb or filtered air
 - Proper solvent
 - Solvent dispenser

The Drag Wipe Method:

Set-up a clean area to work from with an anti-roll barrier around the edge to prevent anything from leaving the table.

Use a clean, lint free cloth or lens tissue.

Wear latex gloves - clean them with alcohol or detergent before handling optic.

NEVER touch the face of the optic.

Cover the optic and store in a dry - dust free area immediately after cleaning.

- Blow or brush loose particles from surface. Don't let them contaminate your work area. Use air from a can or a filtered source.
- Apply solvent directly to your cloth. Use slow, even, light pressure working from edge to edge across the optic.
-
- Recommended Solvents

Material	Solvent		
Fused Silica	1,2,3,4	Zinc Selenide	1,2,4
BK-7	1,2,3,4	Zinc Sulfide	1,2,4
Optical Crown Glass	1,2,3,4	Sapphire	1,2,3,4
Zerodur	1,2,3,4		
Calcium Fluoride	1,2,4	Coated Optics	
Magnesium Fluoride	1,2,4	Dielectric coating	1,2,3,4
Sodium Chloride	Nitrogen	Interference filters	3
Potassium Chloride	Nitrogen	Soft metallic coating	Air only
Potassium Bromide	Nitrogen	Hard/Protected metallic	1,2,3,4
Thallium Bromiodide	Nitrogen		

1] Water free Acetone

2] Ethanol

3] Methanol

4] Isopropanol

9.2 Thermographic Periodic Recalibration

You can check the camera for temperature measurement accuracy using blackbody simulators. To do this you will need two separate blackbody simulators with known temperatures and known emittances.

If you prefer not to follow the above procedure or if determine that your camera is out of calibration, you will have to return it to the manufacturer for calibration adjustment.

10 Appendix – Lab Camera Information

10.1 Introduction

The Lab Camera consists of:

- InSb focal plane array mounted in a leadless chip carrier (LCC).
- Pour filled LN₂ dewar (F/2.6) configured for the ISC9705 or ISC 9803 device packaged in a leadless chip carrier (LCC).
- Evacuation adapter and funnel.
- Nominal Ge window, bandpass is 1.5 to 5.5 mm.
- 3-5 mm cold filter (typical).
- Enclosure containing the electronics and interface connector to the dewar.
- Bayonet flange lens mount.

Optional accessories include:

- MWIR optics.
- Bandpass filters.
- Dewar with a 4 position filter wheel.
- Customer supplied 1" diameter dewar window.

The Laboratory Camera is delivered completely assembled. The system has been setup to image room temperature scenes and the non-uniformity correction (NUC) table has been preset with integration time, video offset, gain and detector bias adjusted for each NUC. The FPA of the lab camera requires cooling in order to image. The array is cooled with liquid nitrogen, which you add to the dewar.

10.2 Warnings and Precautions

- **Great care should be exercised with your camera optics.** The anti-reflection coating on the germanium optics is very easily scratched. It should only be cleaned when absolutely necessary and only according to the procedures outlined below. A light dusting of air should be enough to dislodge any dust particles; small amounts of dust will not affect image quality noticeably. If it is absolutely necessary to clean the surface, use 75% isopropyl alcohol and a good quality lens tissue. Use extremely light wiping motions to avoid scratching the surface. Use a fresh section of tissue with each swipe so as not to drag a piece of dirt back over the lens surface.
- **Use appropriate safety precautions with liquid nitrogen.** When using liquid nitrogen cooled systems, for example, in the lab Phoenix, appropriate handling measures must be taken to ensure user safety. Liquid nitrogen is a potentially dangerous material owing to its extremely cold temperature and tendency to boil violently when placed in contact with warm objects. It should be handled by trained users wearing safety glasses and protective gloves, and should be stored in containers approved for liquid nitrogen use only.
- **Do not to allow air to enter the dewar vacuum space.** Moisture in the air when the FPA is cooled down with liquid nitrogen will freeze onto the FPA, and can cause permanent damage.
- **Do not to let vacuum pump oil vapor into the dewar.** We recommend using a vacuum pump that does not use oil, such as a turbo or cryo pump. If you do use an oil-type vacuum pump, make sure that the system has an in-line oil vapor trap to prevent contamination of the FPA surface. (A recommended source for vacuum pumps can be found on Kurt J. Lesker Co., www.lesker.com, 1-800-245-1656.)
- **Do not open your camera body for any reason.** The camera should only be serviced by qualified Indigo Systems technicians.

- **Make sure the dewar is under vacuum prior to cooling.** An unevacuated dewar can freeze up and cause damage to the system.

10.3 Dewar Evacuation and Cooling

The Lab Camera uses a vacuum insulated dewar to prevent condensation on the detector and to prevent the rapid loss of liquid nitrogen. The vacuum space must be repumped periodically during use, and always after the dewar has been opened.

The dewar is evacuated to a pressure of $< 6 \times 10^{-5}$ Torr at Indigo, prior to shipping. The vacuum typically holds for a few weeks. If the dewar is not used within the first few weeks after shipment from Indigo it should be pumped prior to cooling.

Note

Do not pour cryogenics into a dewar that has not been evacuated (to $\sim 6 \times 10^{-5}$ Torr, depending on vacuum sensor location). An unevacuated dewar will freeze up and cause damage to the system.

It is difficult to predict how much time is needed to pump the dewar to a suitable pressure, since it depends on factors including the conductance between the dewar and the pump, the cleanliness of the dewar, and how long since the dewar was last opened. Also, the pressure indicated on pump gauges may not be an accurate measure of the dewar vacuum, since there can be a significant pressure drop between the dewar and vacuum gauge. As a dewar ages without being opened, repumping is generally not required as frequently.

A turbo-molecular type pump or a diffusion pump with a cold-trap is recommended. A recommend source for vacuum pumps is:

Kurt J. Lesker Co., www.lesker.com, 1-800-245-1656

Care should be taken to avoid pumps where oil can contaminate the dewar and FPA, mechanical pumps tend to achieve a marginal vacuum and pump oils can be deposited on the detector. Use of this type of pump is not recommended.

10.3.1 Dewar Evacuation Procedure

- Use the evacuation adapter to attach the dewar to a pumping station. The evacuation adapter screws onto the dewar vacuum port. The adapter needs to be only hand tightened onto the dewar as there is an o-ring that compresses to make the seal. There is no need to tighten this with a wrench.
- Power up the pumping station with the dewar evacuation plug closed. Do not open the plug with the dewar at atmospheric pressure and the pump running at full speed, as this could damage the pump, especially diffusion type pumps.
- Once the pump is open use the evacuation adapter to open the dewar plug by screwing the adapter into the plug and pulling it out of the dewar.
- Allow the dewar to pump until the vacuum pressure reaches $\sim 6 \times 10^{-5}$ Torr.
- While the pump is running, close the dewar plug by pushing the plug back into the evacuation port, then close the pump down.
- Carefully unscrew the evacuation adapter from the plug while the plug is in the dewar vacuum port.
- Unscrew the evacuation adapter from the dewar.

10.3.2 Dewar Filling Procedure

- Once the dewar is under vacuum the liquid nitrogen can be poured into the dewar through the port in the top of the dewar.
- Use the factory-supplied funnel to pour the LN_2 into the dewar. Fill the dewar and let the LN_2 boil off until equilibrium is reached.
- Refill the dewar and let it cool for at least 10 minutes and up to 60 minutes for a stable, cold FPA temperature to be reached.

When first filled with LN₂, the dewar wall is cooled by spilled nitrogen and the rapidly evaporated liquid. If the vacuum is sufficient the dewar wall should return to room temperature within about 20 minutes after the dewar is filled.

If, after about half an hour following the dewar being filled with liquid nitrogen, the dewar wall is cold to the touch or condenses water (sweating), then the vacuum is not adequate. In this situation, the dewar should be allowed to warm to room temperature, then repumped. The time required to warm the dewar back to room temperature can be reduced by emptying out the LN₂ and blowing compressed air into the LN₂ reservoir.

10.3.3 Dewar Repumping

If a dewar must be opened for any reason, the repumping time can be minimized by following the precautions below.

Note

Anytime the dewar is opened, the focal plane array (FPA) is vulnerable and at risk of being damaged. Only qualified individuals should attempt this operation. The following steps are only an outline, and it is assumed that anyone attempting this has had adequate training and experience to do so. As an alternative, contact Indigo Systems Corporation, Client Services Department for assistance at a nominal fee.

- **Be sure that the dewar is warmed up to room temperature prior to opening the dewar.** Purging the inside of the LN₂ reservoir with a low flow of air overnight can ensure this.
- **Allow dry nitrogen gas to fill the dewar before opening it to air.** Nitrogen prevents water vapor from collecting directly on the dewar walls. Nitrogen is more easily removed from the walls than is water vapor.
- **Use clean gloves when handling dewar components.** Finger oils and other contaminants cause out gassing which slows the pumping process and may contaminate the vacuum system after the dewar is removed from the pump.
- **Only open the dewar under static safe conditions at a static dissipative workstation.** The FPA is static sensitive. Wear a grounded wrist strap.
- **Use vacuum compatible materials.** Do not use epoxies, greases, or other materials in the vacuum space unless you are sure that they are vacuum compatible, and you are willing to accept their effect upon dewar performance.
- Check o-ring seals for proper seating, and remove any debris that may prevent a good seal when the dewar is closed. O-rings can be cleaned and coated with a light film of vacuum grease to ensure a good seal.

10.4 Filter Wheel Dewars

Filter wheel dewars allow you the ability to rotate four different cold filters into the optical path.

Note

As with other dewar parts, to install or change filters follow all handling precautions and procedures noted in this appendix. Be sure the dewar is fully warmed to room ambient temperature prior to opening the dewar.

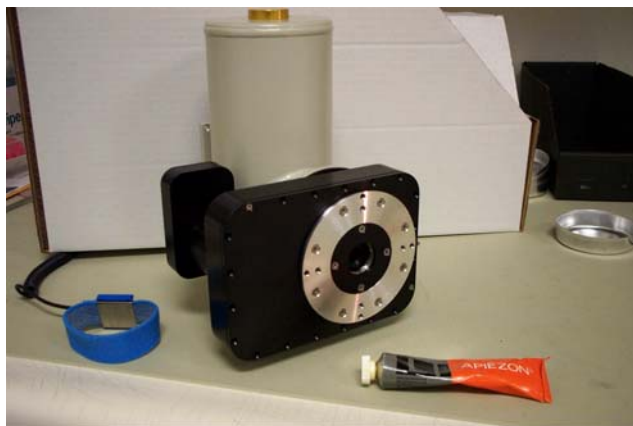


Figure 10-1: Filter wheel dewar with lens mounting ring removed.

10.4.1 Filter Wheel Installation or Removal

- Rotate the filter wheel to position (1) on the index wheel.
- Remove all the perimeter screws of the housing to open the filter wheel dewar.

Housing perimeter screws;
remove all of them.

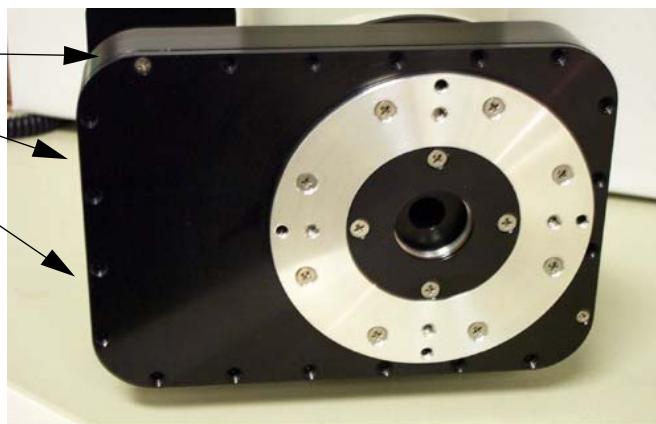


Figure 10-2: Close-up of filter wheel housing.

- Remove the three screws holding the filter wheel cover. Gently pry the cover off.

Remove these three
screws.

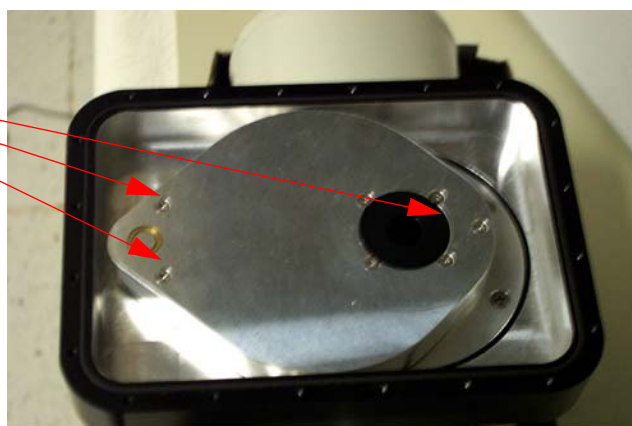


Figure 10-3: Filter wheel housing with outside cover removed.

- Note which filter position is currently in front of the detector array. This is filter position number one. The subsequent positions 2, 3, and 4 are counted counter clockwise. A metal scribe can be used to note these positions as shown below.

Filter position #1.

Center axle.

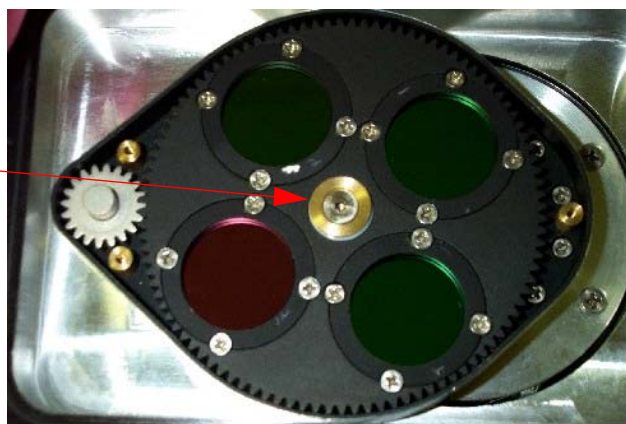


Figure 10-4: Filter wheel housing with filter wheel cover removed.

- Remove the filter wheel by un-bolting the center axle.
- Remove the small drive gear and filter wheel.
- After removing the filter wheel, place it on a clean particulate free surface. Be careful not to damage the Teflon layer on the back of the wheel. Remove the retaining rings by removing the four securing screws, or the thread in retainer depending on the system type you have.
- Install the 1" filter into the holder. Depending on the thickness of the filter substrate, a shim of indium can be used to assure intimate thermal contact between the filter and the wheel.
- Re-install the filter-retaining ring and gently tighten.
- After installing the filters, reinstall the filter wheel. The center axle bolt should only be secured with a very light torque.
- Rotate the filter wheel so that filter position number one is directly over the opening of the FPA. Then reinstall the small drive gear so that it engages with the pin on the selection knob shaft and holds the filter in its current location (position #1).

Note

In the Figure 10-4, the filter wheel is **not** positioned over the FPA.

- Reinstall the filter wheel cover.
- Verify that the O-ring is clean and free of any debris. If necessary, clean and re-grease the O-ring. Assure that the O-ring mating surface is also clean, then attach the outer cover and replace all the perimeter screws.
- Re-pump/evacuate the dewar per the instructions in "Dewar Evacuation Procedure" on page 101.