STH-DCSG/-C Stereo Head

User's Manual

April, 2005

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1 Introduction

The STH-DCSG is a compact, low-power digital stereo head with an IEEE 1394 digital interface. It consists of two 640x480 (VGA), progressive scan CMOS imagers mounted in a rigid body, and a 1394 peripheral interface module, joined in an integral unit.

The CMOS imagers have a *global shutter* – all pixels are exposed at exactly the same time (the "G" in DCSG). This makes the STH-DCSG suitable for environments with fast movement, such as on an outdoor vehicle.

The CMOS imagers are MT9V022 sensors from Micron Semiconductor.. They are 1/3" format, with a resolution of 640 H by 480 V pixels, and come in either monochrome (STH-DCSG) or colorized (STH-DCSG-C) versions. These imagers have excellent dynamic range, sensitivity, anti-blooming, and noise characteristics. They are fully controllable via the 1394 interface: the user can set exposure, gain, decimation, etc. They have better noise, sensitivity, and crosstalk characteristics than the previous sensors.

The STH-DCSG/-C uses standard C/CS-mount lenses for user-changeable optics. Wide-angle to telephoto options are available, depending on the application.

The variable baseline version of the STH-DCSG/-C uses the same imagers, but has a separate IEEE 1394 interface for each imager. It has similar characteristics to the STH-DCSG/-C; please see the STH-DCSG-VAR/-C manual for more information.

SRI's Small Vision System (SVS) software has an interface to the STH-DCSG/-C, and is included with each stereo head. You can simply and automatically calibrate the stereo head, perform stereo correlation, and view the results as a 3D point set. The SVS software includes software drivers for the STH-DCSG/-C for MS Windows 98SE/ME/2000/XP, and for Linux 2.4.and 2.6 kernels.

1.1 Characteristics

- ***Micron MT9V022 CMOS imagers***
  - ***Global shutter***
  - ***Simultaneous exposure and readout***
  - ***640x480 maximum image size***
  - ***1/3" format***
  - ***High sensitivity, low noise***
  - ***Low pixel cross-talk***
- ***Fully synchronized stereo – left and right pixels are interleaved in the video stream***
- ***Monochrome or Bayer Color***
- ***High frame rates – 30 Hz for 640x480***
- ***On-chip binning (monochrome only) and decimation – full frame 640x480 and 320x240 modes***
- ***Electronic zoom mode – center 320x240 subwindow***
- ***Extensive control of video parameters***
  - ***Automatic or manual control of exposure and gain***
  - ***Automatic control of black level***
  - ***Manual control of color balance***
- ***50 Hz mode – reduces indoor light interference in countries with 50 Hz electrical line frequency***
- ***Stereo calibration information can be stored on the device, and downloaded automatically to the PC***
- ***IEEE 1394 interface to standard PC hardware – carries power and commands to device, data to PC***
- ***Standard C/CS mount lenses, interchangeable – standard focal lengths 2.8, 4.0, and 8.0 mm***
- ***Fixed 9 cm baseline***
- ***Anodized aluminum alloy chassis, high rigidity***

1.2 Global Shutter

The STH-DCSG has a global shutter (the "G" designation in STH-DCSG). Almost all other CMOS imagers have a *rolling* shutter. With rolling shutter, each row of pixels is exposed just before it is read out. So each row is exposed at a different time from other rows. This leads to *motion blur* – a skewing of moving objects from top to bottom.

Global shutter, on the other hand, exposes every pixel at the same time. The charge on exposed pixels is then transferred to a set of storage bins, and read out to give an image. Because the pixels are exposed at the same time, there is no motion blur. With its high sensitivity, the STH-DCSG allows for very short exposure times, even under moderate lighting conditions. So it is appropriate for high-motion applications, such as outdoor robotics, motion capture, etc. Figure 1-1 shows an example of motion capture using the device. Notice the stop-action motion of the model plane.

Although there are a small number of global-shutter CMOS imagers, most of them are *sequential*, that is, the pixels are exposed, then read out. The pixels cannot be exposed again until readout finishes. With sequential readout, either the framerate or the maximum exposure is limited. The STH-DCSG has *simultaneous* exposure and readout, that is, while the pixels are being exposed, the previous image is being read out.

Figure 1-1 Sequence taken by the MT9V022. Exposure 0.7 ms, 30 Hz, 640x480 video stream. Sequence shows about every 4th frame.

2 Quick Start

The STH-DCSG/-C normally comes assembled with the lenses mounted. If you need to change the lenses, or if you are supplying your own, please see Section 6.1.

To set up and test the STH-DCSG/-C, you will need the following:

1. Pair of C-mount lenses, for 1/2" or larger imager (normally included and mounted with the STH-DCSG/-C kit).
2. Host computer with an IEEE 1394 PCI (desktop) or PCMCIA (laptop) card, OHCI compliant; or a built-in IEEE 1394 port.
3. IEEE 1394 6-pin to 6-pin cable.
4. Small Vision System installed on the host computer.

Install the IEEE 1394 host card, if necessary, according to the directions in Section 4.1. Install the Small Vision System software (see Section 4.2).

If the lenses are not mounted on the device, follow the directions in Section 6.1 for installing them.

Plug one end of the IEEE 1394 6-pin video cable into the 1394 jack on the back of the STH-DCSG/-C, and the other into an IEEE 1394 port on the host PC.

Note: The STH-DCSG draws power from the IEEE 1394 bus. PCI cards, or built-in ports for desktop machines, normally supply this power. For PCMCIA cards (PC Cards), and laptops with a built-in port, no power is available. In this case, external power must be supplied – see Section 5.3.

The PC operating system will normally recognize the STH-DCSG, and install the correct system drivers. Please see the Videre support web pages (www.videredesign.com/support.htm) for specific information about installation for your OS. At this point, you should check to see that the STH-DCSG has been recognized by the system.

Start the SVS main program, `smallv(.exe)` or `smallvcal(.exe)`, on the host computer. You should see a screen as in Figure 2-1. The message window should indicate that the "DCS Digital Stereo Interface" is present. If not, go back to software installation (Section 4.2), and follow the instructions for configuring the correct capture library.

Pull down the Input chooser, and select the `Video` option. If everything has been set up correctly, the SVS interface will recognize and configure the stereo head, and a success message will appear in the info text window. If not, the Input chooser will go back to `None`, and an error message will appear in the info window. Please see Section 4 for troubleshooting.

To view stereo video, press the `Continuous` button. Left and right images should appear in the application windows. If the message "Image timed out" appears, then there is a problem with the IEEE 1394 drivers; please see Section 4. If the images are too light or too dark, you can open the manual iris of the cameras, or change the exposure and gain settings

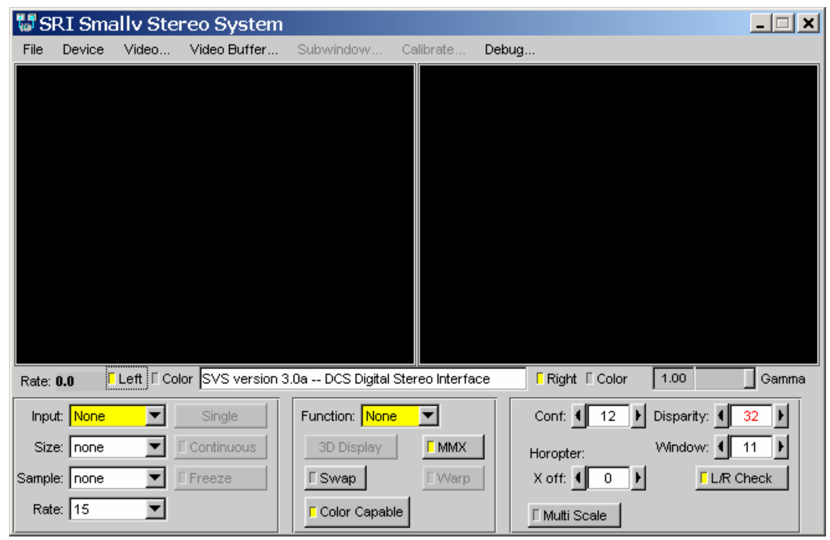


Figure 2-1 SVS main program window.

(Section 7.3). Images can be saved using the File menu.

A more complete description of the video capture program is in Section 7. The SVS programs are described in the SVS User's Manual, and the SVS Calibration Addendum, documentation that comes with that software. It is helpful to review Section 7 in conjunction with the SVS documentation.

3 Hardware Overview

Figure 3-1 shows the hardware configuration of the STH-DCSG/-C.

The imager module has a milled aluminum alloy frame that rigidly holds two megapixel imagers, separated by a fixed distance of 9 cm. Lens mounts are an integral part of the frame, and standard C or CS-mount lenses are screwed into these holders. There is an IR cutoff filter, with a knee at approximately 680 nm, permanently mounted inside the lens holder. See Section 6 for appropriate lens characteristics.

The interface module is mounted on the back of the stereo head. One IEEE 1394 port is placed at the back of the module; it is inset so that the IEEE 1394 plug does not stick out from the device.

A status LED indicates video imager activity. It will turn on when the device is powered and connected to an IEEE 1394 card on the host computer. The LED will begin flashing as soon as images are being acquired by the host computer, at ½ the frame rate. Changing the video modes (frame size, decimation) will cause the frame rate to change, and this will be reflected in the LED flash rate.

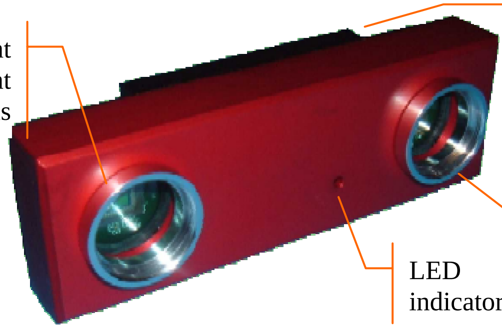


Figure 3-1. Physical layout of the STH-DCSG/-C stereo head.

There are no user-settable switches on the STH-DCSG/-C.

3.1 Hardware Schematic

Figure 3-2 shows the design of the internal hardware of the STH-DCSG/-C. In the stereo imager module, two CMOS imagers, each of size 640x480 pixels, digitize incoming light into a digital stream. The imagers operate in progressive mode only, that is, each line is output in succession from the full frame.

The maximum video rate is 12 megapixels per second from each imager. The imagers are synchronized to a common clock, so that the corresponding pixels from each imager are output at precisely the same time. Special interlace electronics convert the individual streams into a single pixel-interlaced stream at 24 MHz. The interlaced stream contains one byte from the left imager, then the corresponding byte from the right imager, then the next byte from the right imager, and so on.

The interlaced video stream is transferred to the IEEE 1394 interface module, which communicates to the host PC over an IEEE 1394 digital cable. The module also accepts commands from the host PC over the cable, and uses these commands to control imaging modes such as exposure or subwindowing.

The IEEE 1394 interface module can communicate at the maximum IEEE 1394 data rate, 400 MBps.

3.2 Frame Formats and Rates

The IEEE 1394 interface electronics on the STH-DCSG supports a maximum rate of 32 megapixels per second. At this rate, there is no need for large buffer memories to hold video data on the stereo device. The STH-DCSG/-C conforms to the IIDC version 1.30 camera specification. Frame rates and frame sizes are set by this standard. The STH-DCSG/-C implements the formats shown in Table 1.

The Digital Camera Specification was set up with monocular cameras in mind. To conform to this specification, the STH-MDS/-C uses the YUV

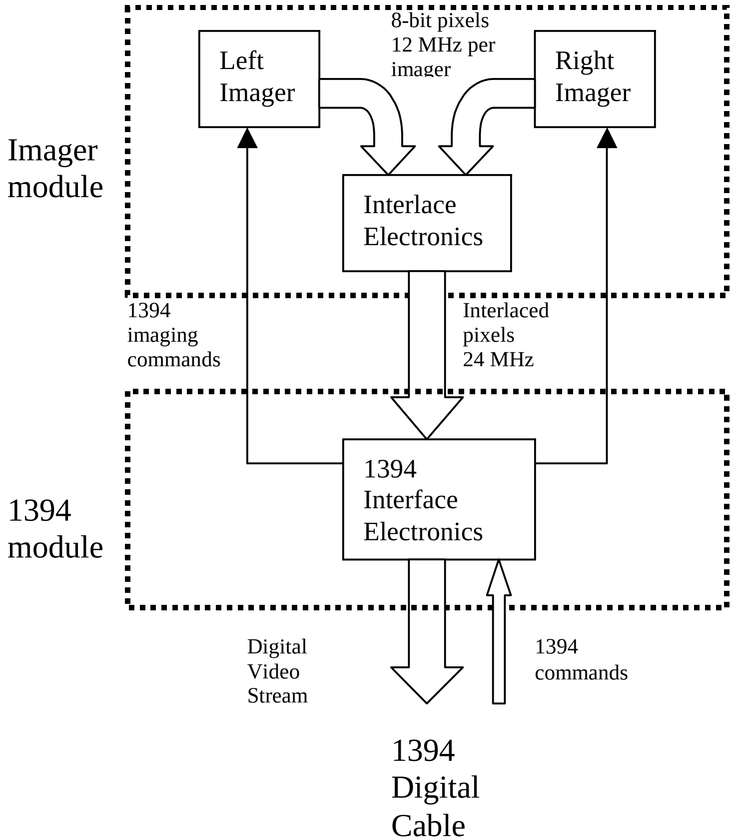


Figure 3-2 Schematic of the STH-DCSG/-C electronics.

data type, sending the left stereo image in Y, and the right image in the UV pixels.

Each image from the stereo camera has 8-bit pixels. In the case of the color version (STH-DCSG-C), the color information is encoded as a Bayer pattern in the same 8-bit pixel image.

Format	**Frame size**	**Frame rate, 60 Hz (default)**	**Frame rate, 50 Hz option**
Format 0, Mode 3 YUV 16 bits Left image on Y, right image on UV	640x480	3.75, 7.5, 15, 30 Hz	3.125, 6.25, 12.5 25 Hz
Format 0, Mode 1 YUV 16 bits Left image on Y, right image on UV	320x240	7.5, 15, 30, 60 Hz	6.25, 12.5, 25, 50 Hz

Table 1 Frame formats and sizes for the STH-DCSG/-C.

On the host computer, the SVS interface software takes the YUV stream and parses it into the left and right images, making them available as separate images in computer memory. It also performs color processing, for the STH-DCSG-C, converting the Bayer pattern into full-color RGB images.

The STH-DCSG also has a *subwindow* mode, in which only the center portion of the image is returned. See Section 7.4 for full information on the modes and resolutions for the STH-DCSG.

For the monochrome device only, smaller frame sizes are also available using on-chip *binning*. Binning averages neighboring pixels to produce a smaller image with improved noise characteristics.

3.3 50 Hz Operation

Indoor lighting, especially from fluorescent fixtures, can oscillate at the frequency of the electrical supply. If the image frame rate does not divide evenly into this frequency, there can be moving horizontal bands of alternating light and dark moving in the output.

For countries with 60 Hz power such as the United State, the frame rates in the third column of Table 1 are ideal. In many other countries, the electrical line frequency is 50 Hz. For these countries, there is a mode to change the frame rates of the STH-DCSG to sub-multiples of 50 Hz. These frame rates are shown in the last column of Table 1.

The frame rate mode of the STH-DCSG device can be changed by using the Firmware Parameter dialog – see Section 7.6.

3.4 Multiple Devices

Multiple STH-DCSG devices can be attached to the same IEEE 1394 bus. When streaming video at the same frame rate, they are synchronized, so that they capture images at the same time.

Each IEEE 1394 PC Card or PCI Card defines a separate IEEE 1394 bus. The two or three ports on the card all belong to the same bus, as does any IEEE 1394 hub connected to these ports. Separate PC Cards and PCI Cards cannot be connected to each other.

The number of devices that can simultaneously send video is determined by the maximum bandwidth of the bus for isochronous transfers: 32 MB/s. This rate cannot be exceeded by the combined video streams on the bus.

Table 2 shows the bandwidth requirements for the STH-DCSG in various modes and for various frame rates. Using this table, it is possible to determine the maximum number devices that can stream video simultaneously. For example, at 15 Hz and 640x480 resolution, a maximum of 3 STH-DCSG devices can send video information at the same time.

The bus bandwidth consumed by a device is more than would be expected from just counting the number of bytes in each frame, because there are blank cycles on the bus, when no data is being transmitted, even though the bandwidth is reserved. Thus, it makes no difference whether the rate is 30 Hz or 25 Hz, the bus bandwidth consumed is the same.

Frame size	**Bus MB per frame - stereo**	**30 / 25 Hz**	**15 / 12.5 Hz**	**7.5 / 6.25 Hz**	**3.75 / 3.125 Hz**
640x480	0.683 MB	20.5 MB	10.2 MB	5.12 MB	2.6 MB
320x240	0.171	5.12 MB	2.56 MB	1.28 MB	N/A

Table 2 Bus bandwidth requirements at different frame rates.

4 Installing the 1394 Host Card and Capture Software

The STH-DCSG/-C connects to a host computer via a digital 1394 interface. The host PC must have a 1394 port, and software to interface to the video stream from the camera. This interface software presents the video stream from the 1394 hardware as a set of stereo frames to the user program (see Figure 4-1). The STH-DCSG/-C comes with interface software for either MS Windows 98SE/ME/2000/XP or Linux.

4.1 1394 Hardware and Drivers

Before installing the software interface, the PC must be equipped with a 1394 port. If there is one already present, a built-in port, then you can skip this section. Otherwise you have to install a PCI or PCMCIA card. The card must be OHCI compliant, which all current cards are.

4.1.1 MS Windows Hardware Installation

For the most up-to-date information about installation, please see the Videre Design website (www.videredesign.com/support_svsmsw.htm).

MS Windows 98SE, ME, 2000, or XP is required.

For a PCI card, insert the card into a free PCI slot with the computer power off, and start the computer. With a PCMCIA card, insert it into the PCMCIA slot. In either case, the New Hardware wizard will walk you through installation steps for the low-level drivers. You may need your MS Windows OS CD to install some files.

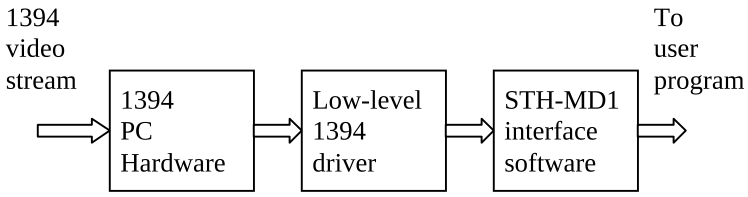


Figure 4-1 Host PC low-level software structure.

The STH-DCSG must be powered from the IEEE 1394 bus. Desktop PCs supply power to the bus; laptops do not. See Section 5 for information about cabling and power for the IEEE 1394 bus.

4.1.2 Linux Hardware and Driver Installation

Linux kernels 2.4 or 2.6 kernels are required for operation. Please see the Videre Design website (www.videredesign.com/support_svslnx.htm) for current information. GCC 3.x is recommended as the compiler; there is a separate SVS distribution for GCC 2.95.x, but it is not as reliable.

4.2 STH-DCSG Software

The STH-DCSG/-C comes with the SVS stereo software, and several sample applications, including the GUI application described in this manual.

For the most up-to-date information about installation, please see the Videre Design website (www.videredesign.com/support_svsmsw.htm).

To install the software under MS Windows, execute the file `svsXXX.exe`. If you have installed a previous version of SVS, the installation wizard will ask you if you want to un-install the old version. It is best to uninstall the old version, then start the installation file again and install the new one.

The installation process will add the relevant interface and application software.

To install the software under Linux, untar the file `svsXXX.tgz` in a new directory, which will become the top-level directory of the software. You should also set the environment variable SVSDIR to this directory, and add `bin/` to your LD_LIBRARY_PATH variable.

`libsvscap.so` and `svsgrab.lib/dll` are the capture libraries for Linux and MS Windows, respectively. These libraries must be set to the correct ones for the STH-DCSG.

In MSW Windows, execute the file `bin\setup_dcs.bat`. This will copy `svsdcs.dll/lib` as the interface libraries.

Under Linux, copy the following file in the `bin/` directory:

```
dcscap.so -> libsvscap.so  (Linux)
```

You can check that the correct interface library is installed, by looking at the information text when the capture application is started. It should say "DCS digital stereo interface". If not, the wrong interface library is installed in `svsgrab.dll` or `libsvscap.so`.

The directory structure for the software is:

```
bin/
   smallv(.exe)
   smallvcal(.exe)
   smallvmat(.exe)

   svsgrab.dll/lib
   libsvscap.so
   interface libraries
   stereo calculation libraries
src/
   flwin.cpp
   image_io.cpp
   svsclass.h
   svs.h
   flwin.h
samples/
   smallv.cpp
   fldispx.cpp
   *.dsw, *.dsp, makefile
```

There are several applications – see the SVS User's Manual for more information. The source code for all applications is included in the distribution. The stereo calculation libraries are also included, so that user applications can link to them. The calibration libraries are *not* included; the only way to run the SVS calibration procedures is through the `smallvcal(.exe)` application.

`smallv(.exe)` is a GUI-based application that allows the user to exercise the capture and stereo functions of the STH-DCSG/-C. It is described in earlier sections of this document.

`smallvmat(.exe)` is similar to `smallv`, with the addition of a MatLab interface for sending images and stereo information to MatLab. You must have installed the R13 release of MatLab to run this program. There is also a version of SVS that can be invoked directly from MatLab – again, see the SVS User's Manual.

`smallvcal(.exe)` is the same as `smallv`, with the addition of a calibration package for calibrating a stereo rig. Use this application to perform calibration on your stereo system.

`stcap(.exe)` is a simple application that connects to the stereo head and displays images. It can serve as a template for user programs that integrate stereo capture from the STH-DCSG/-C.

`stdisp(.exe)` is a simple application that connects to the stereo head, grabs images and performs stereo analysis, and displays the results. It can serve as a template for user programs that integrate stereo capture and computation from the STH-DCSG/-C.

5 IEEE 1394 Interface

Digital image information is transferred from the STH-DCSG/-C to the host PC via a 1394 cable. The cable sends a video stream from the imagers to the PC, and sends commands from the PC to the stereo head to control exposure, subsampling, etc. The cable also supplies power to the stereo head.

5.1 IEEE 1394 Cable

The STH-DCSG/-C must be connected to the host PC via a 6-pin male-male IEEE 1394 cable. The maximum length for such a cable is 4.5 m (about 15 feet). The cable supplies both signals and power to the stereo head. The port on the STH-DCSG is recessed, so that the IEEE 1394 cable plug will not stick out from the camera.

The distance between the stereo head and the PC can be extended by using a 1394 repeater.

Several 1394-enabled devices can be connected together, as long as the connection topology doesn't have any loops. The STH-DCSG/-C can be connected at any point in such a topology. At a maximum, it will need about 60% of the bandwidth of a 400 MBps connection.

5.2 IEEE 1394 Host Interface

The host computer must have an available 1394 port. Some portables and desktops come with built-in ports. If these are 6-pin ports, they can be connected directly to the STH-DCSG/-C. Sony laptops also support an alternative 4-pin 1394 cabling, which has the signal pins but no power. There are adapters that convert from 4-pin to 6-pin styles; these adapters use an external power supply transformer.

If the host PC doesn't have a built-in 1394 port, one can be added by installing a 1394 PCI card or PCMCIA card for laptops. 1394 PCI cards have 6-pin ports, and supply power. PCMCIA cards do not have the capability of supplying power, and come with an adapter for supplying power to the 1394 cable through a wall transformer.

Any 1394 card is suitable, as long as it conforms to OHCI (open host controller interface) specifications. All current cards do, but some older cards may not.

5.3 Supplying Power

Power to the STH-DCSG is supplied through the IEEE 1394 cable. The IEEE 1394 system must supply this power, about 1 Watt.

There are two typical PC systems: desktops and laptops.

- Desktop PCs have either a built-in IEEE 1394 port, or a PCI card with IEEE 1394 ports. In both cases, the desktop should supplysufficient power to run the STH-DCSG.
- Laptop PCs have either a built-in IEEE 1394 port, or a plug-in PC Card (sometimes called a PCMCIA card) with several IEEE 1394 ports. In both cases, the laptop does *not* supply power to the IEEE 1394 bus, and a source of external power must be used – see below.

External power to the IEEE 1394 bus must have the following characteristics:

7 to 16 VDC, > 1.5 W

The IEEE 1394 spec allows up to 40 VDC on the bus, but in practice many devices such as PC Cards will fail if a voltage higher than 16 VDC or so is used. We recommend using a 12 VDC source.

Power can be supplied to the bus through an IEEE 1394 hub or PC Card with an external port. Most hubs have such a port; most PC Cards do not. The PC Card supplied by Videre has a power port.

The format of the power plug can vary with the hub or PC Card, so please check the specifications for the device. Generally, the positive terminal of the plug is on the inside, and the negative is the outside cylinder.

Figure 5-1 shows the two configurations for supplying power. A wall transformer converts line voltage to 12 VDC, and is plugged into a hub or the PC Card.

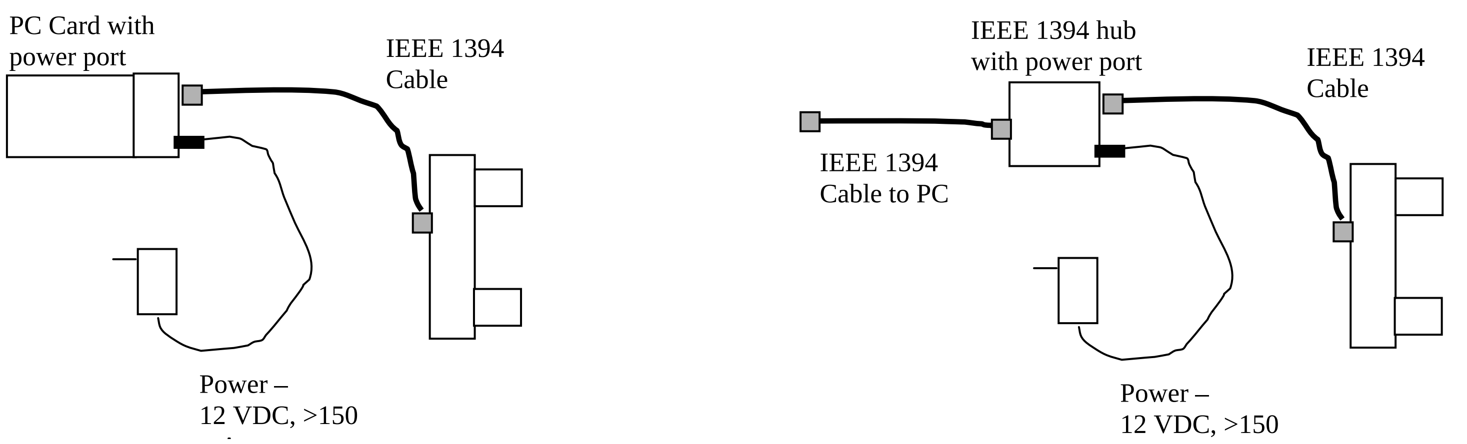


Figure 5-1 External power supply connections. On the left is power supplied to a PC Card with a power port. On the right, power is supplied through a hub with a power port. Power should be 7 to 16 VDC, at > 1.5 W. Check the PC Card or hub for the type of power connector.

6 Lenses

The STH-DCSG/-C uses standard C or CS-mount lenses. Good-quality, fixed-focus lenses with low distortion and high light-gathering capability are best.

Lenses are characterized optically by imager size, F number, and focal length. Following subsections discuss the choice of these values.

6.1 Locking Lenses

Some lenses come with thumbscrew locks for holding the focus and iris settings. We recommend these locking lenses for all applications in which the device is moving, or in which people or objects may touch the lens. For the STH-DCSG, locking lenses are standard (2.8, 4.0, and 8.0 mm).

6.2 C and CS-Mount Lenses

The STH-DCSG will accommodate either C or CS-mount lenses. CS-mount lenses have a mounting distance of 12.5 mm from the imager. C-mount lenses have a mounting distance of 17.5 mm. Normally, 1/3 format lenses are of the CS-mount variety. To use C-mount lenses, add a 5mm spacer behind each lens. Spacers are available from Videre.

6.3 Changing Lenses

Standard C/CS-mount lenses have a 1" diameter, 28 threads-per-inch screw on their back end. The screw mates with the lens holder opening. To insert a lens, place its back end on the lens holder opening as straight as possible, and gently turn it clockwise (looking down at the lens) until it engages the threads of the lens holder. If you encounter a lot of resistance, you may be cross-threading the lens. Forcing it on will damage the lens holder or lens threads.

Once the threads are engaged, continue screwing it on until it seats firmly. You can snug it down, but do not tighten it excessively, since this can damage the lens and the lens holder threads.

Removing the lens is the reverse process: unscrew the lens counter-clockwise. There will be some initial resistance, and then it should unscrew smoothly.

Normal care should be used in taking care of the lenses, as with lenses for any good-quality camera.

6.4 Cleaning the Imagers

It should not be necessary to clean the imagers, since they are sealed off by an IR filter inside the lens mount.

If dirt and dust are present on the IR filter surface, they can be cleaned in the same manner as a lens. Wet a non-abrasive optic cleaning tissue with a small amount of methyl alcohol or similar lens-cleaning solvent, and wipe the imager glass surface gently. Dry with a similar tissue.

6.5 Imager Size

The *imager size* is the largest size of imager that can be covered by the lens. For the STH-DCSG, the lens must be 1/3" or greater.

6.6 F Number

The *F number* is a measure of the light-gathering ability of a lens. The lower the F number, the better it is at pulling in light, and the better the STH-DCSG will see in low-illumination settings. For indoor work, an F number of 1.8 is acceptable, and 1.4 is even better. For outdoors, higher F numbers are fine. In any case, it is useful to have a manual iris for high light situations. While the imagers can have electronic exposure and gain control to automatically compensate for different light conditions, the acceptable illumination range can be extended by mechanical adjustment of the lens opening.

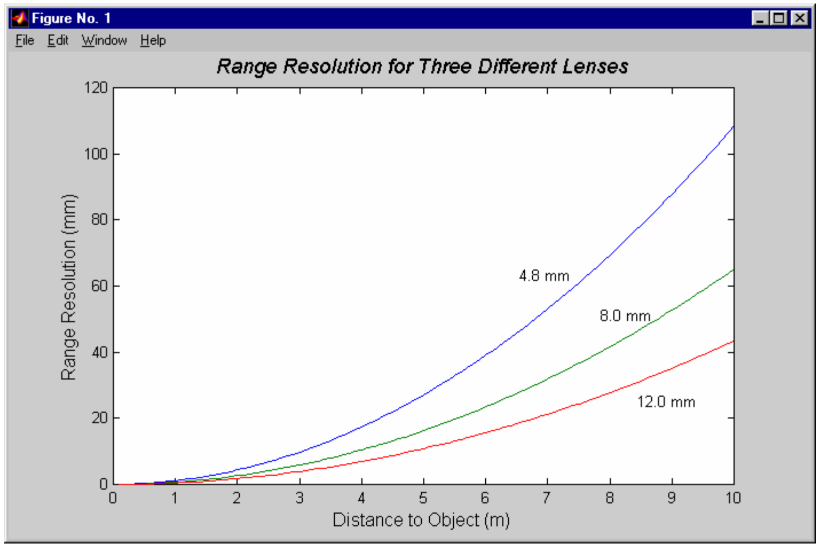


Figure 6-1 Range resolution in mm as a function of distance, for several different lens focal lengths.

6.7 Focal Length

The *focal length* is the distance from the lens virtual viewpoint to the imager. It defines how large an angle the imager views through the lens. The focal length is a primary determinant of the performance of a stereo system. It affects two important aspects of the stereo system: how wide a field of view the system can see, and how good the range resolution of the stereo is. Unfortunately there's a tradeoff here. A wide-angle lens (short focal length) gives a great field of view, but causes a drop in range resolution. A telephoto lens (long focal length) can only see a small field of view, but gives better range resolution. So the choice of lens focal length usually involves a compromise. In typical situations, one usually chooses the focal length based on the narrowest field of view acceptable for an application, and then takes whatever range resolution comes with it.

6.8 Range Resolution

Range resolution is the minimum distance the stereo system can distinguish. Since stereo is a triangulation operation, the range resolution gets worse with increasing distance from the stereo head. The relationship is:

$$\Delta r = \frac{r^2}{bf}\Delta d \,,$$

where b is the baseline between the imagers, f is the focal length of the lens, and Δd is the smallest disparity the stereo system can detect. For the STH-DCSG/-C, b is 90 mm, and Δd is 0.325 um (pixel size of 5.2 um, divided by the interpolation factor of 16).

Table 3 plots this relationship for several focal lengths. At any distance, the range resolution is inversely proportional to the focal length.

6.9 Field of View

The field of view is completely determined by the focal length. The formulas for the FOV in horizontal and vertical directions are:

$$HFOV = 2\arctan(1.92/f)$$

$$VFOV = 2\arctan(1.44/f)$$

where f is in millimeters. For example, a 2.8 mm lens yields a horizontal FOV of 87 degrees.

The following table shows the FOV for some standard focal lengths.

Lens focal length	**Horizontal FOV**	**Vertical FOV**
2.8 mm	69 deg	54 deg
4.0	51	40
8.0	27	20
16	14	10

Table 3 Horizontal and vertical field of view for different lens focal lengths.

7 User Controls

The CMOS imagers are fully controllable via the 1394 interface. User programs may input color images (STH-DCSG-C only), set video digitization parameters (exposure, gain, red and blue balance), and subsampling modes. All of these parameters can be set with the SRI Small Vision System. They are also accessible to user programs through the capture API (Section 8).

User controls for frame size and sampling modes are on the main capture window dialog. Video digitization controls are accessed through a dialog invoked with the *Video…* menu item. Figure 7-1 shows the dialog.

7.1 Color

Color information from the stereo digital head (STH-DCSG-C only) is input as raw colorized pixels, and converted by the interface library into two monochrome and one or two RGB color channels. The primary color channel corresponds to the left image, which is the reference image for stereo. The right image color channel is also available. The color images can be de-warped, just like the monochrome images, to take into account lens distortion (see the Small Vision System User's Manual).

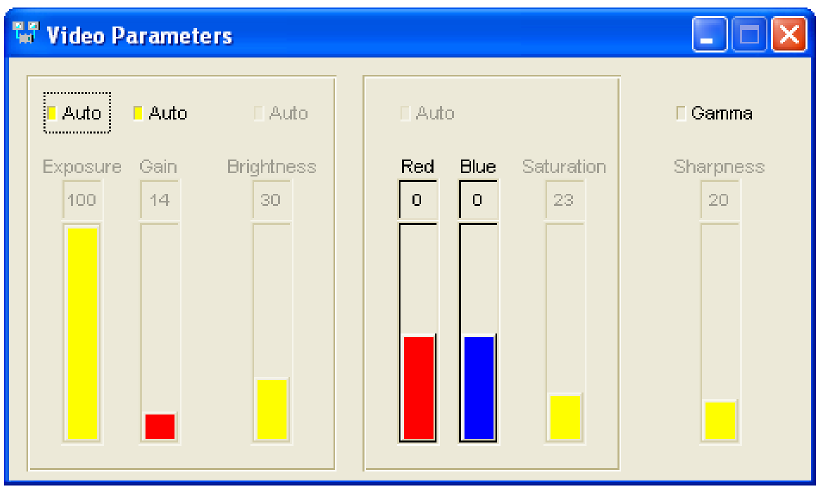


Figure 7-1 Video Parameters dialog.

Color information from the camera is input only if the `Color` button is pressed on the main window (Figure 2-1).

Because the typical color camera uses a colorizing filter on top of its pixels, the color information is sampled at a lower resolution than a similar non-colorized camera samples monochrome information. In general, a color camera has about ¼ the spatial resolution of a similar monochrome camera. The cameras have on-imager binning from 640x480 to 320x240 (monochrome only). Full-frame images at 320x240 use the binning mode.

The relative amounts of the three colors, red/green/blue, affects the appearance of the color image. Many color CCD imagers have attached processors that automatically balance the offsets among these colors, to produce an image that is overall neutral (called *white balance*). The STH-DCSG-C provides manual color balance by allowing variable gain on the red and blue pixels, relative to the green pixels. Manual balance is useful in many machine vision applications, because automatic white balance continuously changes the relative amount of color in the image.

The manual gain on red and blue pixels is adjusted using the *Red* and *Blue* controls on the *Video Parameters* dialog. For a particular lighting source, try adjusting the gains until a white area in the scene looks white, without any color bias.

7.2 Gamma Correction

To display properly for human viewing, most video images are formatted to have a nonlinear relationship between the intensity of light at a pixel and the value of the video signal. The nonlinear function compensates for loss of definition in low light areas. Typically the function is x^{γ}, where γ is 0.45, and the signal is called "gamma corrected."

The STH-DCSG has on-chip gamma correction that can be turned on or off. When on, it compresses the 10-bit output of each pixel into 8 bits. The compression occurs mostly in the higher light levels. With on-chip gamma correction, the STH-DCSG can handle larger dynamic ranges of light, such as occur outdoors with bright sunlight and deep shadow.

Without on-chip gamma correction, the display looks very dark in low-light areas. You can add gamma correction to the displayed image by choosing an appropriate gamma value in the slider under the right display window (Figure 7-2).

7.3 Video Digitization Parameters

The CMOS imagers have electronic exposure and gain controls to compensate for varying lighting conditions. The exposure can vary from a maximum of a full frame time to a minimum of one line time. Gain is an additional amplification of the video signal, for low-light situations. It is settable from 0 to 12 dB (1x to 4x).

Both imagers are treated in exactly the same manner. It is not possible to set a different exposure or gain on each imager.

Digitization control can operate in either manual or automatic mode. Refer to Figure 7-1 for the controls in the video capture program. Both manual and automatic modes are available for the STH-DCSG(-C) devices.

In manual mode, the user program sets the exposure and gain. The exposure and gain are based on a 0 to 100 scale. Here are some tips for setting exposure and gain.

- In general, keep the gain as low as possible, since it introduces additional noise into the system. Use it only if the exposure is set to maximum, or if the exposure must be kept low to minimize motion blur. Indoors, the gain is usually set higher because of the lower light levels.
- Adjust the manual iris of the lens to as small an opening as possible for your application, without having to use gain. This will increase the depth of field and give better optical performance. Indoors, the iris usually is fully open. Outdoors, in bright conditions, the iris can be partially closed.

There are automatic modes for both exposure and gain. In auto mode, gain and exposure are controlled by the imager, which samples the incoming image and sends changes the exposure and gain parameters. The auto algorithm will try to reduce gain as much as possible, while still maintaining overall light levels in the image.

Auto mode for gain and exposure can be set separately. For the STH-DCSG, if there is relatively slow motion, it is recommended to use a manual mode for gain, and auto mode for exposure. Indoors, set the gain to a higher value; outdoors, set it to a low value. With exposure in auto mode,

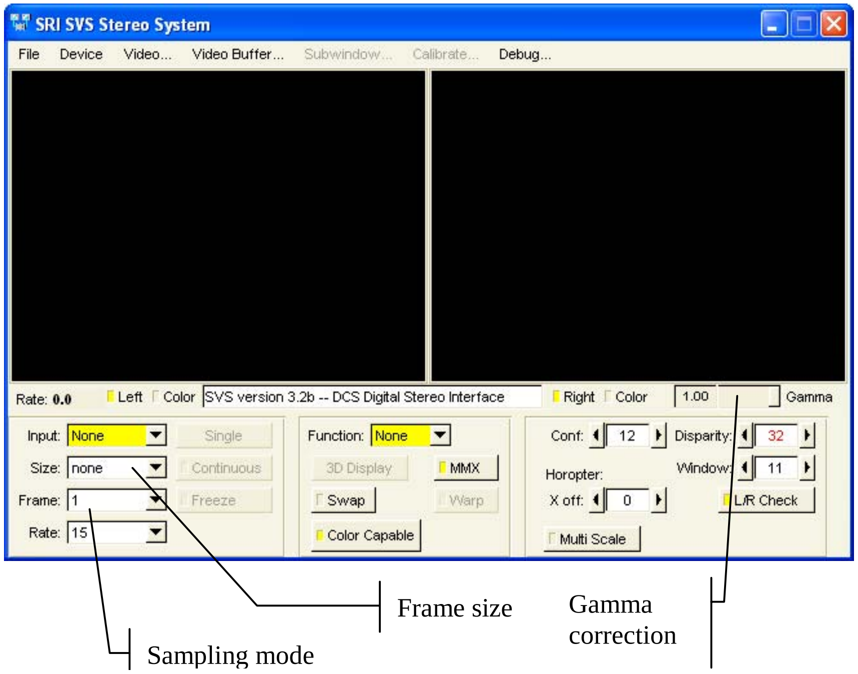


Figure 7-2 Frame size and sampling controls in the main capture window.

the light on the image will be adjusted by changing the exposure.

For high-speed motion, it is better to set the exposure to a fixed, low value, and then use auto-gain to keep reasonable light levels on the imager.

7.4 Subsampling

In many applications it is not necessary to work with the full 640x480 image. The CMOS imagers are capable of sampling the pixels in the array. Sampling allows the video stream to send less data, for faster frame rates or less bus activity. A sampled image shows the same scene as the original image, but it uses fewer pixels to do so, and has less detail.

Binning is a subsampling technique in which several adjacent pixels are averaged into one. Binning reduces video noise, sometimes quite substantially. Binning is available on-chip (monochrome only) and on the host PC – the larger image is first transferred on the IEEE 1394 bus, then binned down.

Sampling differs from *subwindowing*, which picks a rectangular portion of the image, but doesn't change its resolution. The STH-DCSG has one subwindow mode, in which the center 320x240 subwindow of the imager is chosen. Using the subwindow has the effect of zooming the image by a factor of 2.

Figure 7-2 shows the frame size and subsampling controls on the video capture application. With SVS version 3.2b, the sampling control has been changed to a simple Frame Division control. For the STH-DCSG, there are two possible values, 1 (full image) and 1/2.

Refer to Table 4 for a complete list of allowed modes, and how the frame size and sampling setting affect the output image. Explicit control over the sampling mode is accomplished with the `SetSample()` function from the SVS API.

The first two lines of the table are for full-frame images. At 640x480, the full image is sent to the host PC, and there is no binning. At 320x240, there are two choices: binning on the imager (monochrome only), or binning on the host; the default for monochrome is binning on the imager, and for color, binning on the host PC. Using `SetSample(2,1)` means that binning will take place on the imager, which then transmits a 320x240 imager. Using `SetSample(1,2)` means that binning will take place on the host. In this case, the imager transmits all 320x240 pixels, so the maximum frame rate is lower. This is the greyed-out line in the table.

For 1/2 frame images, the resolution is 320x240. In this case, the STH-DCSG transmits a 320x240 image.

7.5 Frame Rates

Frame rates from the STH-DCSG/-C depend on the frame size. Table 4 shows the frame rates available for each of the frame sizes. Note that a 50 Hz option is available – see Section 3.3

7.6 Firmware Parameters

There is one firmware parameter that affects the overall behavior of the STH-DCSG.

- 50 Hz operation

This parameter can be changed by using the Firmware Parameter dialog, accessible from the `smallv` menubar. Choosing this menu brings up the dialog, which is shown in Figure 7-3.

The dialog lists many of the internal parameters of the device, which are

Resolution	**Frame**	**Bin on imager**	**Bin on PC**	**Frames per Second**
640 x 480	Full	no	no	3.75, 7.5, 15, 30
Monochrome only 320 x 240	Full	yes	no	3.75, 7.5, 15, 30, 60
320 x 240	Full	no	yes	3.75, 7.5, 15, 30
320 x 240	1/2	no	no	3.75, 7.5, 15, 30, 60

Table 4 Subsampling modes and frame rates for the STH-DCSG.

fixed in the firmware. The one changeable parameter is for 50 Hz or 60 Hz operation (Section 3.3).

The Firmware Parameter dialog is only available after the STH-DCSG has been opened by pulling down the `Video` item of the `Input` chooser. To

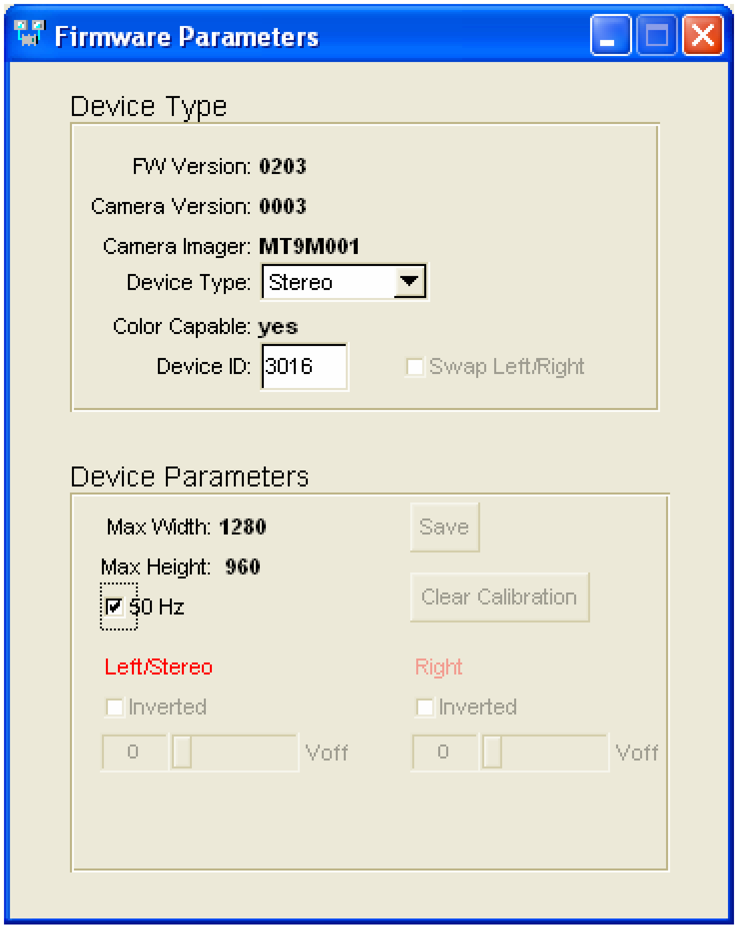


Figure 7-3 Firmware parameters dialog.

use 50 Hz operation, check the box, and then press the `Save` button. This choice is downloaded and stored in the device, and will cause 50 Hz operation every time the STH-DCSG is accessed. To change back to 60 Hz, uncheck the box and again save it to the device.

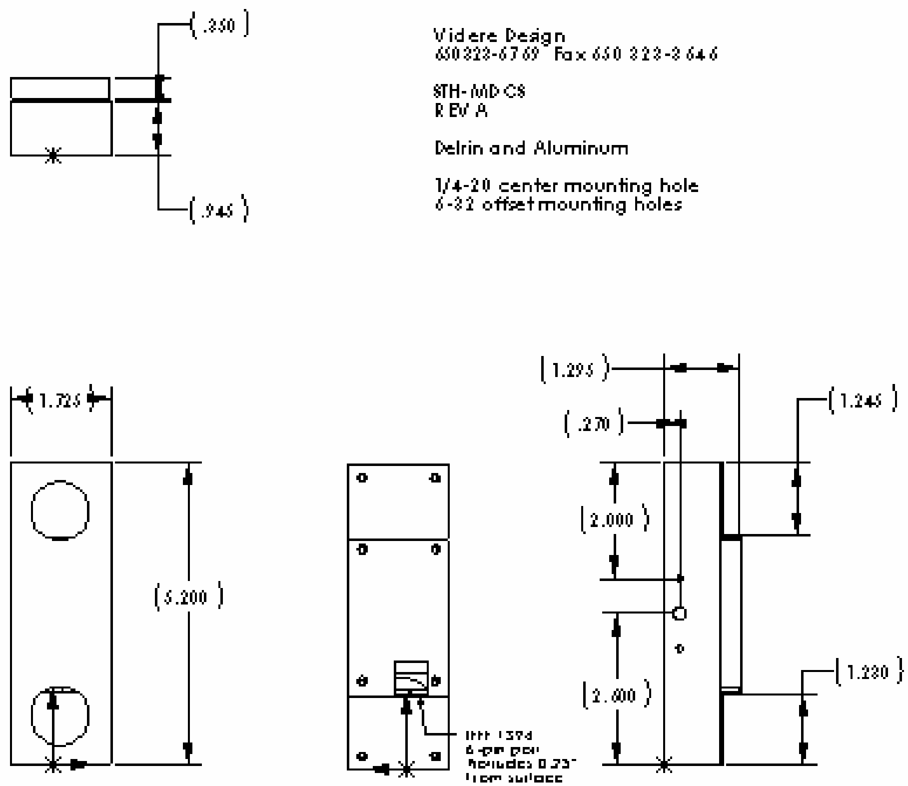
It is also possible to clear any calibration parameters that are saved on the STH-DCSG firmware. If the calibration parameters are present, the Clear Calibration button will be activated. Pressing this button will clear the parameters. See the SVS Users' Manual for information on saving and loading calibration parameters on the device.

8 Interface Software API

Please see the Small Vision System manual for information about the software API for capturing and saving images.

9 Physical Dimensions and Mounting Diagram

The diagram below shows the physical dimensions for the STH-DCSG/-C.



The larger hole is threaded for a ¼-20 machine screw (standard tripod mounting screw). The two smaller holes are threaded for 6-32 machine screws.

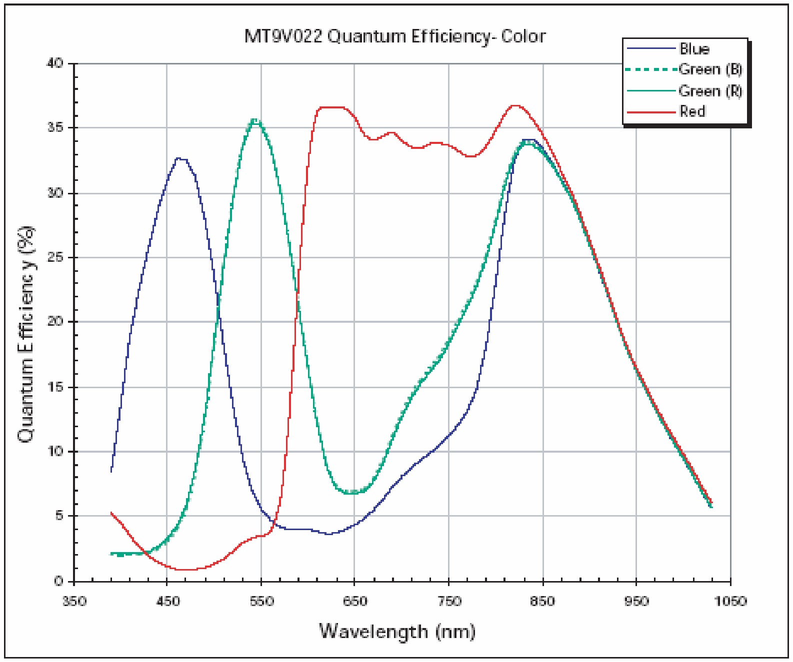
10 Technical Specifications

10.1 Specifications

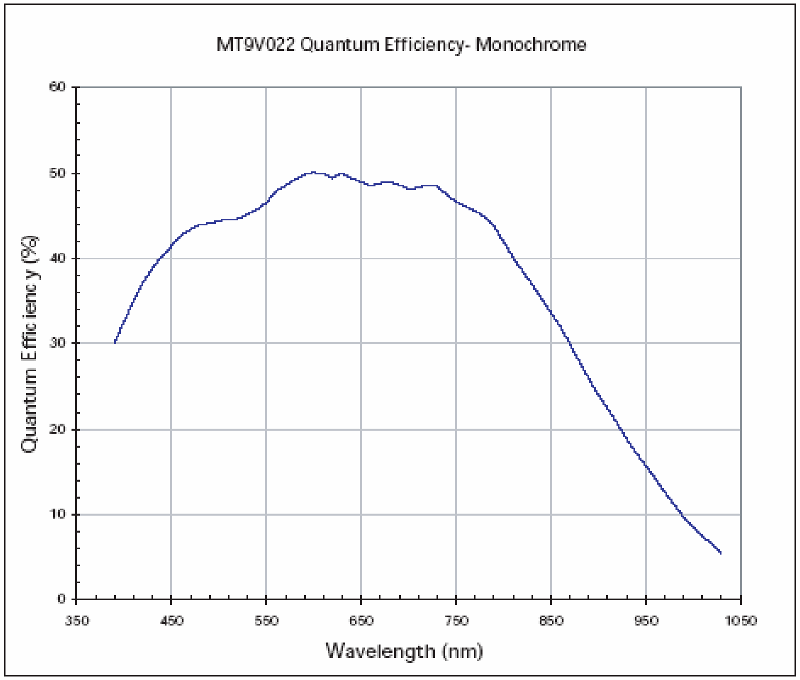
Imagers	1/3" format CMOS (Micron MT9V022) 640x480 active area Progressive scan Color or monochrome
Digital Camera Specification	Version 1.30
Formats	640x480, 320x240 8 bit monochrome or Bayer color pattern
Frame Rates	3.75, 7.5, 15, 30, 60 Hz 3.125, 6.5, 12.5, 25, 50 Hz Max 30 Hz at 640x480
Exposure	1 line time to full frame
Gain	0 – 12 dB (1x – 4x)
Sensitivity	4.8 V/lux-sec (monochrome)
S/N	> 60 dB, no gain
Power	< 1 W
Synchronization	Internal: pixel-locked External: 60 us
Lens	4.0 mm F 1.2 CS mount included 2.8 mm and 8 mm lenses optional

Size	1.725" high x 5.2" long x 1.3" deep (excluding lenses)
Weight	190 g (6.7 oz), without lenses 71 g (2.5 oz) for 4.0 mm lenses
Stereo Baseline	9 cm
SVS software	Linux kernel 2.4, 2.6 MSW 98SE, ME, 2000 and XP
Environmental	0-40^{o} C, < 90% humidity (noncondensing)

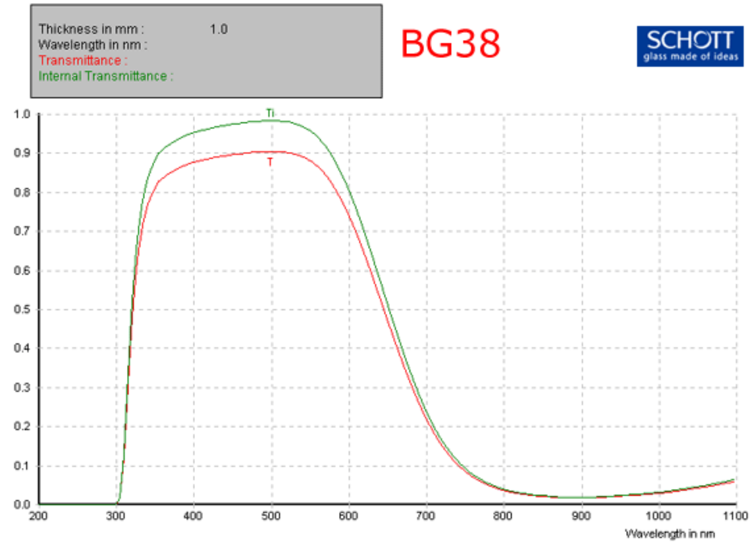
10.2 Imager Response - Color



10.3 Imager Response – Monochrome



10.4 Filter Transmittance



11 Technical Support

For technical support, please contact Videre Design by email or FAX.

Videre Design
865 College Avenue
Menlo Park, CA 94025
Fax: (650)323-3646

Email: support@videredesign.com

Technical information about stereo algorithms and stereo calibration can be found at `www.ai.sri.com/~konolige/svs`.