WHITE PAPER

Beyond Selfies: How Frame Grabbers Help Develop High Performance CSI-2 Sensors

E SERIES

Published in Canada on February 25, 2020
MK-W005-E-20056

INTROSPECT.CA

Table of Contents

Introduction

Image sensors have been used prolifically in many industrial, vision, and imaging applications, and this was traditionally achieved through the use of high-resolution optical sensing arrays that were coupled with wide-bandwidth digital transfer links. At the same time, consumer-grade sensors based on the MIPI Alliance® CSI-2^{SM} specifications started to offer a rich set of features that made them especially attractive for other high-performance applications. For example, CSI-2 sensors now include high dynamic range support, brightness control, contrast control, variable frame rate, and many other features that have been made possible by the latest MIPI Alliance C-PHY^{SM} and D-PHY^{SM} physical layer standards. They are even used for sensing non-optical inputs such as radar signals.

The new breed of CSI-2 sensors now need to be tested and validated for real-life situations involving continuous (high frame rate) captures and continuously variable stimulus conditions — not just single-frame analysis. To address this, a frame grabber is needed that supports:

- Live streaming to a host computer
- Capturing large sequences of contiguous images from a single video stream
- Dynamically controlling the sensor parameters while continuously modifying input and environmental conditions

This white paper shows how the SV4E-CPRXG MIPI C-PHY Frame Grabber solution from Introspect Technology can be used to address all the above requirements. We will illustrate concepts related to physical attachment, sensor power-up and turn-on sequencing, live video streaming, and bulk frame capturing. We will also describe the all-important subject of dynamically controlling sensor parameters during live streaming operations.

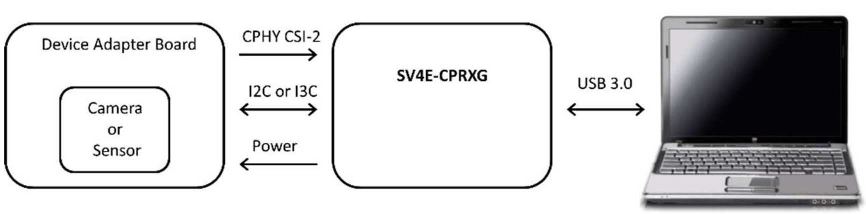
Sensor Testing and Calibration Steps

PHYSICAL ATTACHMENT TO A SENSOR BOARD

The SV4E-CPRXG MIPI C-PHY Frame Grabber is pictured in Figure 1(a). As can be seen, a CSI-2 sensor is integrated onto a device adapter board (DAB) which connects directly to the SV4E-CPRXG. Importantly, a single standard Samtec board-to-board connector is used to provide power rails, control bus, and high-speed data lanes to/from the sensor under test.

A block diagram of an entire test setup is shown in Figure 1(b). The SV4E-CPRXG controls the sensor directly via an I2C or I3C[SM] bus and receives the CPHY CSI-2 data stream from it. The SV4E-CPRXG has six independent programmable power supplies which can address all power requirements for the sensor, and these power supplies can be turned on or off at arbitrary times through software as will be described later in this white paper. The entire setup is controlled through the Introspect ESP Software, running on a host PC connected to the SV4E-CPRXG via a USB 3.0 connection.

(a)



(b)

Figure 1: Frame Grabber Test Bench (a) SV4E-CPRXG test platform, (b) block diagram of entire test setup

POWER UP AND INITIALIZATION IN THE INTROSPECT ESP SOFTWARE

Initialization of the sensor can be automated through the Introspect ESP Software. Python-based scripts are used to manage the sensor power bring-up as well as monitor current dissipation during operation. All initialization of the sensor (for example, setting image resolution, brightness, or setting proprietary parameters) may be performed via the built-in I2C / I3C bus. A screen shot of a Frame Grabber GUI is shown in Figure 2(a) and (b). Context help is always available, as shown in Figure 3, which shows a screen shot of the Frame Grabber GUI. Both RGB888 and RAW formats are supported, as in the figure.

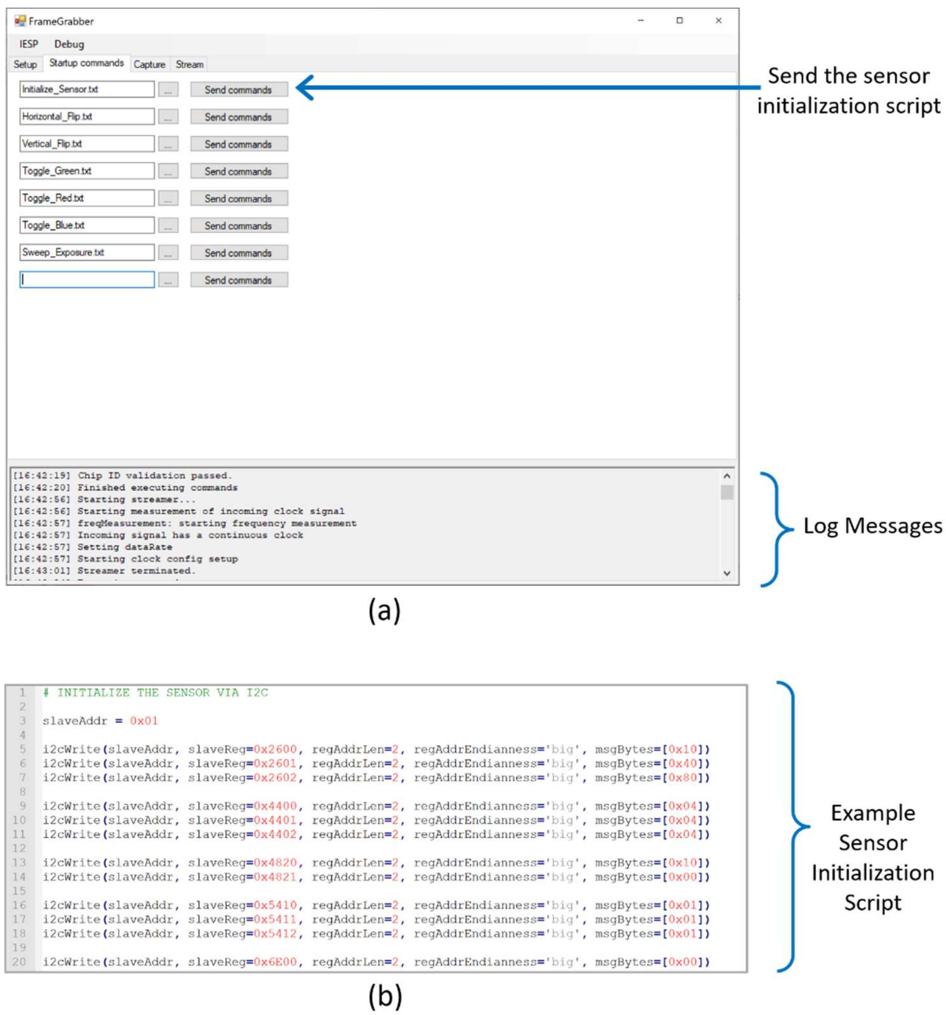


Figure 2: Frame Grabber software (a) example script selection, (b) example Initialization script

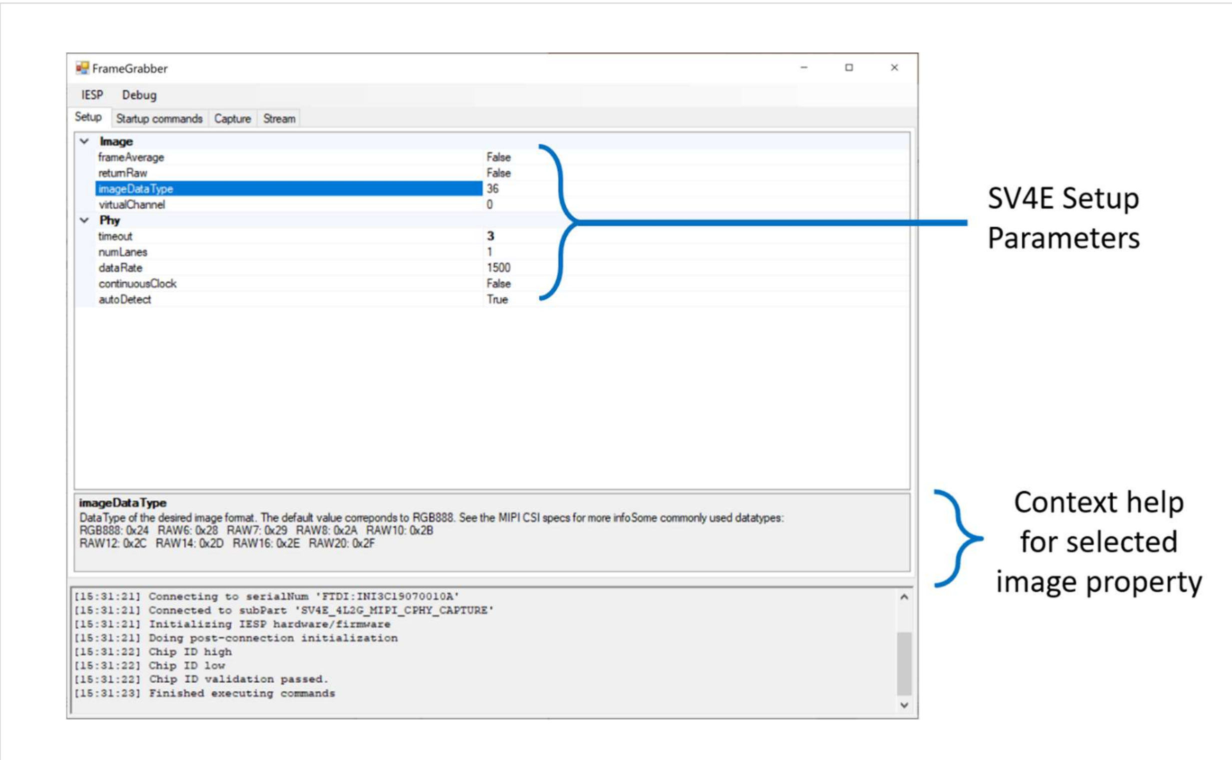


Figure 3: Frame Grabber software – setting the SV4E-CPRXG parameters

STREAMING AND CAPTURING WITH FRAME GRABBER SOFTWARE

Once configured, the Frame Grabber can be used to stream or capture images from the CSI-2 sensor under test. Figure 4 shows an example of Frame Grabber streaming a live scene: in this case, an Introspect Technology test module, a flower, and a spinning top. For this selected image size and image format, the GUI live streams the images to the viewer at 36 fps.

Figure 5 shows an example of the Frame Grabber capturing contiguous frames at the full sensor rate of 60 fps. The number of frames to capture and the file save location can be configured. Note the displayed frame numbers in the four images shown. The motion of the spinning top can be observed across the different frames.

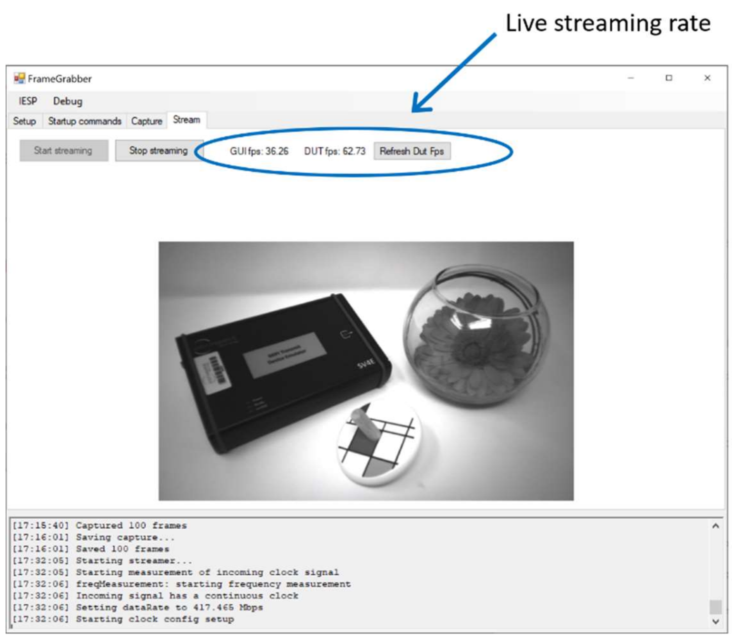


Figure 4: Streaming live images and measuring sensor frame rate

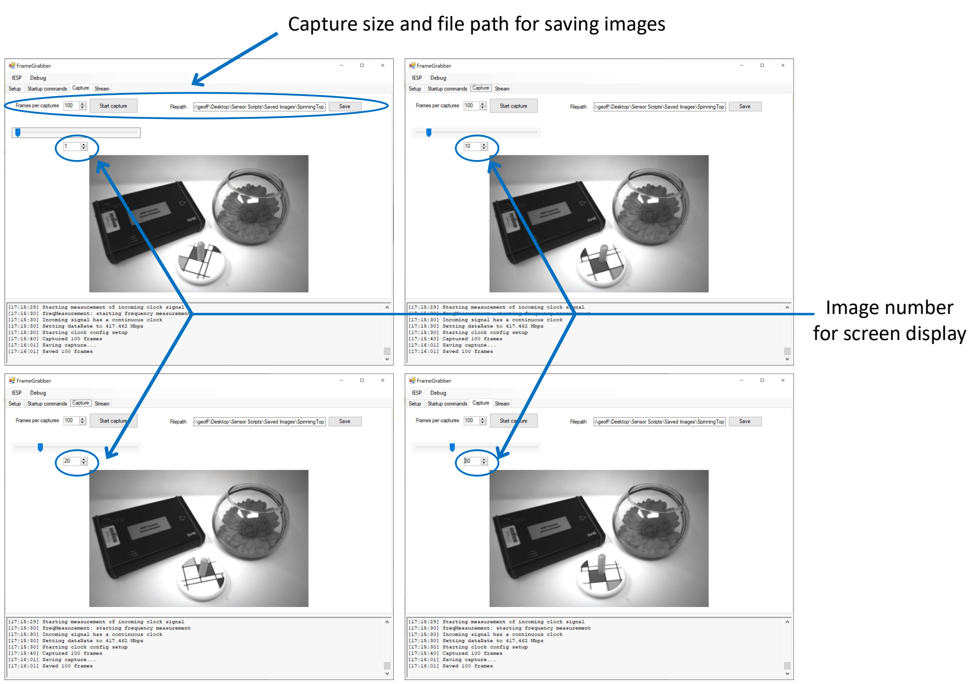


Figure 5: Capturing contiguous frames at the full sensor frame rate

DYNAMICALLY CONTROLLING THE SENSOR PARAMETERS

The Frame Grabber software allows for dynamic control of sensor parameters through the I2C or I3C bus. For example, modifying the gain of red, green or blue color channels can be performed during a live stream or during a contiguous frame capture. This is demonstrated during live streaming in Figure 6 below.

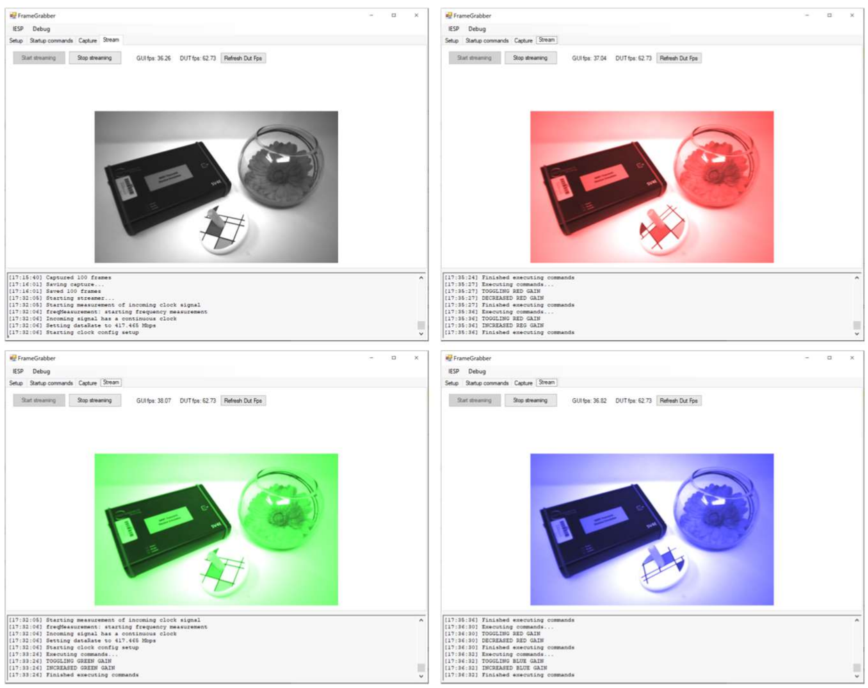


Figure 6: Controlling the gain of the individual color channels in a sensor

Similarly, parameters such as the exposure level of the sensor can be modified during a live stream or contiguous frame capture, as shown in Figure 7 on the following page. Test patterns – if supported by the sensor manufacturer – may be programmed and captured by the SV4E-CPRXG MIPI C-PHY Frame Grabber, as shown in Figure 8.

Figure 7: Adjusting exposure time and lighting parameters

Figure 8: Programming sensor test pattern generators

PUTTING IT ALL TOGETHER

The Frame Grabber software allows for full integration of SV4E-CPRXG MIPI C-PHY Frame Grabber high-speed data acquisition with the full sensor feature set for a completely automated sensor system-level test. As with all Introspect ESP Software applications, scripting is performed in Python. A simple example Python script shown below in Figure 9.

```
# FULL SENSOR SYSTEM LEVEL TEST

# SET PROGRAMMABLE POWER SUPPLIES
setProgrammableVoltages([1], 1800) # in mV
setProgrammableVoltages([2], 5000) # in mV
setProgrammableVoltages([3], 3300) # in mV
enableProgrammableVoltagePins([1,2,3])
sleepMillis(500)

# INITIALIZE SENSOR VIA I2C
slaveAddr = 0x01
i2cWrite(slaveAddr, slaveReg=0x2600, regAddrLen=2, regAddrEndianness='big', msgBytes=[0x10])
i2cWrite(slaveAddr, slaveReg=0x2601, regAddrLen=2, regAddrEndianness='big', msgBytes=[0x40])
i2cWrite(slaveAddr, slaveReg=0x2602, regAddrLen=2, regAddrEndianness='big', msgBytes=[0x80])
i2cWrite(slaveAddr, slaveReg=0x5410, regAddrLen=2, regAddrEndianness='big', msgBytes=[0x01])
i2cWrite(slaveAddr, slaveReg=0x5411, regAddrLen=2, regAddrEndianness='big', msgBytes=[0x01])
i2cWrite(slaveAddr, slaveReg=0x5412, regAddrLen=2, regAddrEndianness='big', msgBytes=[0x01])

# SET DEFAULT EXPOSURE
i2cWrite(slaveAddr, slaveReg=0x4400, regAddrLen=2, regAddrEndianness='big', msgBytes=[0x04])
i2cWrite(slaveAddr, slaveReg=0x4401, regAddrLen=2, regAddrEndianness='big', msgBytes=[0x04])
i2cWrite(slaveAddr, slaveReg=0x4402, regAddrLen=2, regAddrEndianness='big', msgBytes=[0x04])

# START STREAMER
mipiCphyCsiStreamer1.start()

# CAPTURE TEST PATTERN
print("TEST PATTERN ENABLE")
i2cWrite(slaveAddr, slaveReg=0x6E00, regAddrLen=2, regAddrEndianness='big', msgBytes=[0x08])
sleepMillis(50)
testPatternFrame1 = mipiCphyCsiStreamer1.getFrame()
i2cWrite(slaveAddr, slaveReg=0x6E00, regAddrLen=2, regAddrEndianness='big', msgBytes=[0x00])
sleepMillis(50)

# ENABLE VERTICAL AND HORIZONTAL FLIP
i2cWrite(slaveAddr, slaveReg=0x4820, regAddrLen=2, regAddrEndianness='big', msgBytes=[0x10])
print("VERTICAL FLIP ON"); sleepMillis(100)
verticalFrameFlipOn = mipiCphyCsiStreamer1.getFrame()
i2cWrite(slaveAddr, slaveReg=0x4820, regAddrLen=2, regAddrEndianness='big', msgBytes=[0x00])
print("VERTICAL FLIP OFF"); sleepMillis(100)
verticalFrameFlipOff = mipiCphyCsiStreamer1.getFrame()
i2cWrite(slaveAddr, slaveReg=0x4821, regAddrLen=2, regAddrEndianness='big', msgBytes=[0x04])
print("HORIZONTAL FLIP ON"); sleepMillis(100)
horizontalFrameFlipOn = mipiCphyCsiStreamer1.getFrame()
i2cWrite(slaveAddr, slaveReg=0x4821, regAddrLen=2, regAddrEndianness='big', msgBytes=[0x00])
print("HORIZONTAL FLIP OFF"); sleepMillis(100)
horizontalFrameFlipOff = mipiCphyCsiStreamer1.getFrame()

mipiCphyCsiStreamer1.stop()

# START CONSECUTIVE FRAME CAPTURE
mipiCphyCsiBulkCapture1.numFrames = 100
mipiCphyCsiBulkCapture1.run()

# SWEEP THE SENSOR EXPOSURE SETTINGS
print("SWEEPING EXPOSURE")
...
...
#---------------------------
```

Figure 9: Frame Grabber software – complete automation script

Summary of SV4E-CPRXG MIPI C-PHY Frame Grabber Features

Introspect Technology's C-PHY frame grabber leverages many generations of hardware and software tools for MIPI, and it is optimized for the C-PHY physical layer. The following is a list of its main features:

- Any rate operation from 80 Msps to 3.5 Gsps
- Any CSI-2 lane configuration
- Support for all CSI-2 data types and pixel formats, including RAW16 and RAW20
- Automatic isolation of all CSI-2 virtual channels according to the latest revision of the CSI-2 specifications
- Integrated I2C master for controlling sensors under test
- Integrated I3C master for controlling sensors under test
- Support for contiguous frame capture at the maxim frame rate supported by the CSI-2 specifications
- Advanced exposure features including frame start and line start trigger I/O's
- Built-in frame rate monitors
- Built-in programmable power supplies for automating the turn-on and turn-off of sensors under test

Conclusion

With the deployment of MIPI CSI-2 based sensors into a wider range of applications, there is a strong need for flexible and robust frame grabber solutions that can handle the latest physical layer characteristics of these sensors. Introspect Technology's unique analog front-end technology for both C-PHY and D-PHY means that users can achieve high-confidence sensor validation without worrying about physical attachment issues. This white paper has provided an overview of the typical steps that are required to calibrate, optimize, and validate modern sensor devices based on the MIPI CSI-2 standard. The focus of this paper was on the C-PHY physical layer, but the same concepts apply to D-PHY image sensors and to the SV4E-DPRXG MIPI D-PHY Frame Grabber solution from Introspect Technology.

Revision Number	History	Date
1.0	Document Release	February 25, 2020

The information in this document is subject to change without notice and should not be construed as a commitment by Introspect Technology. While reasonable precautions have been taken, Introspect Technology assumes no responsibility for any errors that may appear in this document.

Published in Canada on February 25, 2020
MK-W005-E-20056

INTROSPECT.CA