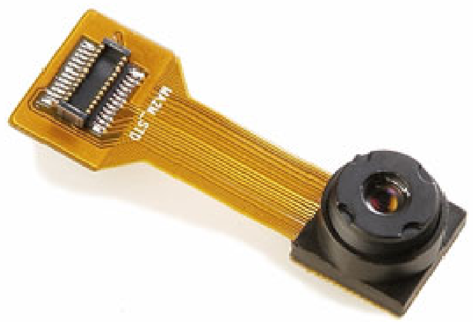
CMOS Image Sensor Testing
An Intetrated Approach

CMOS image sensors and camera modules are complex integrated circuits with a variety of input and output types many inputs and outputs. Engineers working with CMOS image sensor and camera module components have been hampered by the lack of an affordable, integrated, off-the-shelf solution for interface, control, and testing.

Test and Production Engineers at image sensor, camera module, and end-product manufacturers need a low cost, simple and fast way to interface, control, and test CMOS image sensors/camera modules to insure they are working properly.

Product Development Engineers who use CMOS image sensors or camera modules within their end-products need an integrated, comprehensive solution to fully exercise and evaluate image sensors and camera modules from competing suppliers.



Traditionally, engineers have had three approaches available for CMOS image sensor and camera test. At the high end, there are automated production machines, from companies such as Agilent and Teradyne, each costing several hundred thousand dollars. At the low-end, chip-makers, like Aptina, OmniVision and Kodak, sell specific demo/evaluation boards that work with just their chip and provide limited functionality.

In the middle have been “do-it-yourself” combinations in which an engineer pieces together several off-the-shelf instruments with custom designed circuitry in order to support a new sensor type. This process often becomes a project in itself, requiring time, staff and relatively significant cost and technical risk.

In addition to acquiring sensor hardware interface equipment for the “do-it-yourself” approach, a considerable amount of software is required to integrate the various instruments and components; to support and convert the many image output formats, and testing; and to perform the standard image quality measurements. In short, building a system to communicate with and test CMOS image sensors can be a costly and time-consuming endeavor.

An off-the-shelf, integrated solution, which would work with most chips or camera modules, would significantly reduce both the price and the time necessary to complete a CMOS image sensor interface and test system.

For **Quality/Test Engineers**, the solution would provide interface, control and characterization testing for image sensors/camera modules, and have a generic interface to accommodate differing image sensors and modules from many vendors.

For **Product Development Engineers**, the solution would supply easy, GUI-based sensor/camera control and evaluation that is customizable and has a generic interface that works with sensors made by multiple chip vendors, including functionality for baseline comparisons.

The **Image Sensor Lab ISL-3200** from Jova Solutions was designed to solve this problem. The ISL-3200 is a CMOS image sensor and camera module test solution that provides a full range of CMOS image sensor interface, control, test, evaluation and comparison capabilities in one low-cost, small-footprint solution. The fully integrated hardware/software solution supports testing on a wide variety of CMOS image sensors, with a full complement of evaluation and test functionality, for needs ranging from early design and development all the way to end-product development and the automated manufacturing line.

Out of the box, the **ISL-3200** offers a fully integrated interface, control and test electronics, and advanced analysis and characterization software. It provides product development engineers sophisticated software to fully exercise and evaluate image sensors/modules. The **ISL-3200** is a universal engineering solution for the full evaluation of CMOS image sensors and can interface to and test any of the hundreds of image sensor designs, regardless of the chip or module manufacturer.

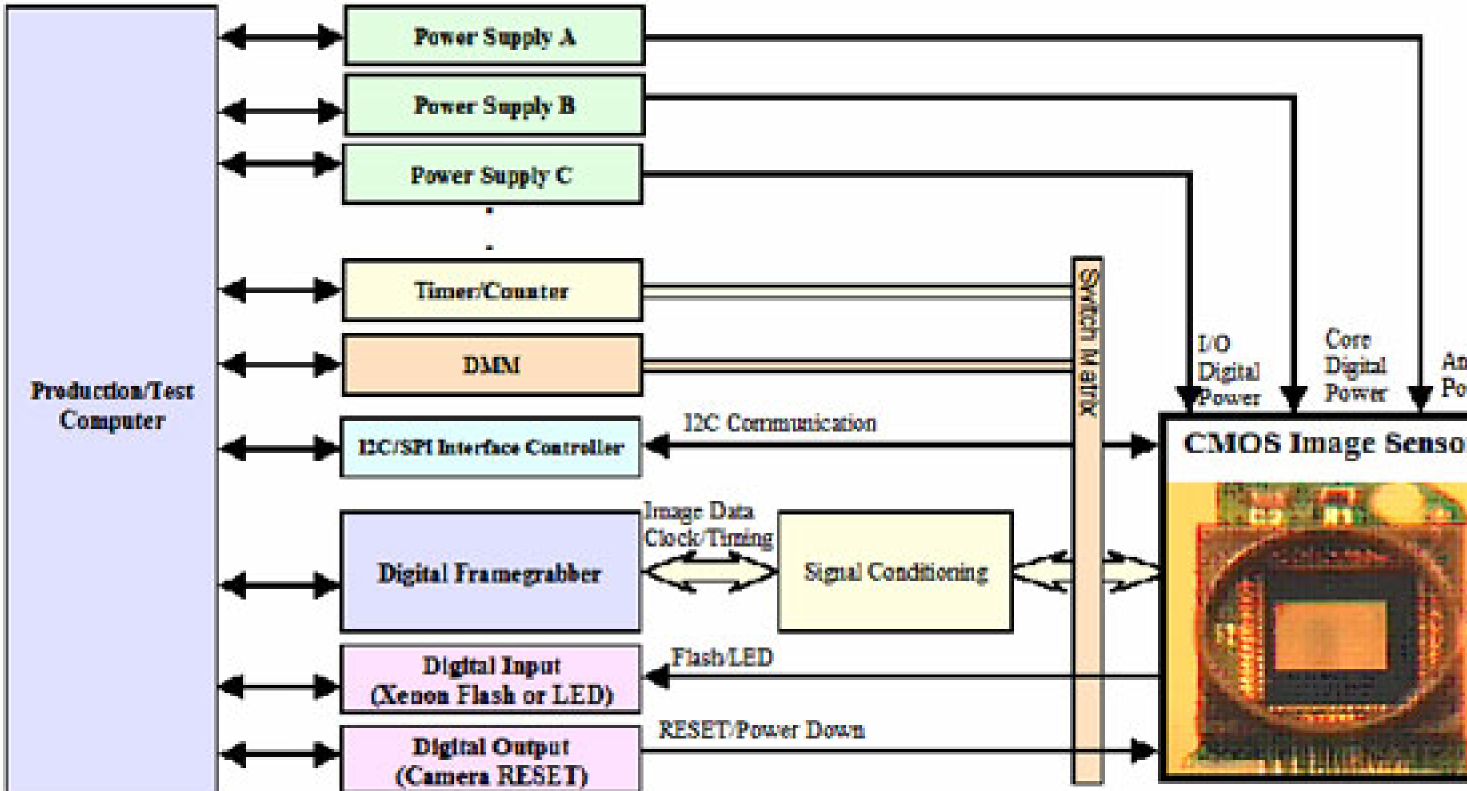
CMOS Image Sensor Test - Challenges with the Current Approaches

Image sensors often require multiple low-noise power sources and a variety of digital control lines. Digital image data and associated synchronization signals are output by image sensors, as are additional status and control lines that allow functions such as reset, standby, flash or

LED control. The majority of CMOS image sensors use a 2-wire communication protocol, such as the I2C Bus protocol, or the 3-Wire/4-Wire SPI/Microwire Bus protocol. Since the signal voltage levels of the digital I/O lines of an image sensor often differ from one sensor model to another, variable signal level translation is needed.

Most off-the-shelf test equipment cannot be connected directly to a sensor due to the very low voltage and current signal levels of CMOS image sensors. Design, production, and test engineers wanting to fully communicate with, and exercise, the image sensor must first assemble several pieces of expensive off-the-shelf test equipment and then design and produce custom circuits for signal conditioning and interfacing.

Some vendors of CMOS image sensors provide demonstration boards that interface to their specific image sensors, but these may not be commercially available and may not provide true frame capture, nor do they provide adjustable voltage levels or clock frequencies. Image sensors cannot be installed or removed on these devices unless the USB cable is unplugged, which further limits their use in a production or manufacturing environment.



Total	**$26,140**

In addition to the sizeable task of putting together an initial system in a timely manner and at a reasonable cost, there are additional challenges, many often hidden (or often unforeseen) to companies just starting to work with image sensors. An effective and efficient CMOS image sensor and camera module test solution must address the following challenges.

CMOS Image Sensor Mounting, Positioning, and Proximity Challenges

Even though a significant amount of image sensor test and development work can be performed at a desk or lab bench, some engineering or production level testing may require the use of accurately positioned sensor and targets and controlled uniform lighting.

When working with camera modules, the device must be accurately positioned in front of specialized test targets in order to accurately measure image sensor to lens alignment and other characteristics. To accomplish this, custom test fixtures need to be designed for accurate positioning of the camera module.

CMOS image sensors are IC components intended to be in close proximity to the control and processing electronics that make up the end product. Image sensors are low voltage low current devices, which cannot typically drive long wires or cables therefore interface and test electronics are best located as close to the image sensor as possible. If not, additional custom signal driving and conditioning circuitry must be designed, produced, and maintained. This can be difficult with large numbers of separately boxed test instruments and frame-grabbers installed in PC enclosures and creates additional challenges to manufacturing and test engineers developing test fixtures and test cells.

CMOS Image Sensor Communications Challenges

Most CMOS image sensors use a 2-wire serial protocol such as the SPI or I2C communication protocols. These communications protocols, and the devices that use them, are intended for inter-chip communications on a printed circuit board, and are not intended for transmission over wires longer than two inches. PC plug-in cards are not suitable for this function - a custom circuit or a small remote device placed close to the image sensor is preferable.

Communicating with, configuring and controlling a CMOS image sensor involves writing and reading many low level registers. These registers control the various operating modes, exposure and gain controls, output image formats, and a variety of other options. There are usually several hundred registers used, and many of these registers contain compound configurations, with each individual bit of the register controlling a specific parameter.

It may be a challenge for developers and engineers who use image sensor devices to fully understand the myriad of logic programmed into the device. This logic ties together and restricts the combinations of allowable register settings available to the user. It is not unusual for image sensor specifications to run several hundred pages in length in order to document the complex, yet rudimentary, raw register-level programming required. Gaining an understanding of device operation can be painfully slow and non-intuitive.

Full characterization testing requires a thorough exercise of many operational modes and output formats. A typical CMOS image sensor contains several hundred configuration registers, and a single characterization test may write and read several hundred-register settings.

Requirements for Powering CMOS Image Sensors

Typical CMOS image sensors have several separate power inputs. The analog and digital circuitry are usually separated. Newer sensors may have additional separate power supply inputs (Analog, Digital Core, Digital I/O, etc). Application circuits, into which the image sensor is placed, might require additional power sources for such functions as Flash, LED, or an auto-focus motor.

For characterization or acceptance testing, ultra-low noise power supplies are appropriate because they better simulate the batteries that are used in most end products. It is important to note that image sensor power supply noise can directly contribute to image noise and adversely affect the accuracy of a functional characterization or acceptance test.

Because cell phone battery life is an important specification for consumers, a common characterization test performed by engineers, or during manufacturing, is a measurement of the sensor current draw when in low-power standby mode. The very low current draw in standby mode mandates a high-resolution meter.

CMOS Image Sensor Signal Conditioning Challenges

Often, the voltage levels of CMOS image sensor signals are not the same as the signal levels of off-the-shelf digital frame-grabbers that are used for image acquisition. Voltage level buffers are often employed to address this voltage mismatch. Additional signal conditioning may be required if the test cabling and wiring is of a length exceeding several inches. This custom signal conditioning circuitry must be developed, tested, and maintained, which impacts schedules and total cost.

Measurement Instrument Considerations

There are several pieces of standard test equipment that are used during the initial development phase and during fault isolation testing in the production process. Oscilloscopes, DMMs, and counter/timer instruments are the most common. Oscilloscopes are used to check or verify signal quality and can be used to detect signal problems due to manufacturing errors or test fixture wiring problems. Timer/counters are used in a variety of ways including bringing up new sensors as well as troubleshooting and fault isolation testing. Timer/counters can quickly and accurately measure parameters such as: frame rate (VSync/sec), Rows/Frame (HSync/Vsync), Clock rates, Clocks/Row, and others.

During the production process, fault isolation capability may become necessary in order to understand poor yields. The basic measurements for shorted or open signal lines between the test setup and the sensor require the use of a basic test instrument such as a DMM. Unfortunately, a standard DMM can cause damage to a CMOS image sensor, because the voltage levels from the DMM during a resistance measurement often exceed the absolute maximum voltages allowed by the sensor input or output lines. Special instrument circuitry is therefore required to measure shorted or open signal lines.

CMOS Image Sensor Digital Frame-capture Challenges

Digital image frame-capture is the most complex part of the entire image sensor interface and test system. Until recently, off-the-shelf frame grabber cards or custom designed electronics were the only solutions available for capturing image data from the image sensors. The challenges design and test engineers face in this area include: output clock limitations; limited synchronization and timing options; PCI plug-in card solutions requiring long expensive cables and custom signal conditioning circuitry; and the need for advanced frame capture options that are not typically found in off-the-shelf frame grabber cards.

Frame-capture electronics must be very flexible with programmable clock rates, configurable triggering, and timing signal settings. CMOS image sensor clock rates of up to and exceeding 100 MHz are now becoming common, while frame capture devices are typically limited to 50 MHz. Most CMOS image sensors can operate at a variety of clock rates, depending on the operation mode selected, and it is common to change the clock rate several times during a single characterization test.

Most frame grabber board solutions have limited synchronization options, as they target the scientific camera market and typically interface complete camera systems with only the standard HSync and VSync signal outputs. Image sensors often contain or support additional synchronization and pixel qualification signals that must be accommodated in order to properly capture the image data, forcing many companies to abandon conventional frame grabber cards and develop their own custom circuitry.

The use of a frame grabber plug-in card also implies long cable lengths between the image sensor mounted in a test fixture and the back of the computer that contains the frame grabber card. In this case, the image sensor signals must be conditioned (usually with custom developed circuitry) and then fed down a bulky expensive cable to the frame grabber card. This adds considerable expense and complexity to any test or production setup.

Throughput is fast becoming one of the top challenges facing design and test engineers. As pixel counts balloon and multi-mega pixel cameras become common in cell phones, test and production equipment must also advance and be able to accommodate these high-density images and then process and analyze them at rates similar to today’s VGA and 1.3 Megapixel sensors. Manufacturing and production will push hard to not have their throughput impacted by the increased test times required by the larger and larger images.

Proper characterization of image sensors can include the need to capture consecutive images, in order to verify that certain functions are occurring at specified rates. For these tests, the frame capture electronics must be able to reliably capture every single frame over a specified time-period, without missing a single frame generated by the image sensor. Systems utilizing the demonstration boards from the sensor vendors cannot meet this requirement. Most sensor demonstration (demo) boards/kits are designed to be just that – a small inexpensive demonstration unit. They do not have the ability to perform many of the advanced functions needed in most design, test, and production environments. Most demo boards have limited clock-rate frequencies, are not true frame-capture devices, and are limited to streaming video over the USB bus. This produces frame synchronization errors at the host computer end, and in split-frames or in frames made up of data from different frame captures, and results in inaccurate and misleading test data.

CMOS Image Sensor Additional I/O Support Challenges

Modern CMOS image sensors offer a rich feature set, including additional I/O to support such functions as a Flash or LED output, shutter outputs, motor control outputs, RESET and power down inputs, capture inputs, and many more. Since some of these additional I/O lines are not optional, but required in order to operate the sensor, an interface and test system must be able to accommodate the additional digital and analog I/O required by the image sensors being tested. It should also be noted that these I/O line voltages could vary from one sensor type to another. If the development or test environment must support a variety of sensor types, then the additional circuitry supporting this additional I/O, must also have the ability to operate at a variety of voltage levels.

Challenges in Supporting a Variety of CMOS Image Sensors from Multiple Vendors

Design and development engineers often need to work with and evaluate a variety of image sensors from multiple vendors. All these image sensors generate image data, but the control and I/O lines, operating modes and parameter settings most likely differ. The output data format will probably vary from one type to the next. Data width and depth can vary, as can the byte order, clock frequency, etc. In addition, the physical connection to the devices may vary, further complicating the goal of one common test interface to support all types of sensors. Currently, at most companies working with image sensors, a completely different set of interface electronics is used for interfacing to different vendors' image sensors. This adds development, training, and logistics efforts. Support for multiple vendors' sensors has traditionally resulted in adding a considerable amount of new equipment with high cost and extra delays. Having to design, develop, produce, and maintain separate image sensor test systems for each type of sensor not only adds considerable cost but also makes it very difficult to compare the performance of one sensor against the next.

Integration and Software Challenges

Integrating the variety of equipment described above can present additional challenges to developers and engineers. The vendor supplying the power supplies is not the same as the frame-grabber vendor. The supplier of the I2C interface is most likely not going to be either of the other vendors. Not only does the needed test equipment come from many different vendors, it also employs different host computer connections. Digital frame-grabbers are commonly PCI plug-in cards, which require complicated installation procedures. The power supplies, DMM's, and counter/timers are often GPIB or RS-232 based instruments. The I2C interface is most likely a USB device. Additional I/O is typically provided by another PCI plug-in card or possibly by a USB device.

Once the developer or test engineer has integrated the hardware, they need to gather the individual low-level drivers for each of these instruments or devices, and must program a test or prototype application with the various pieces. The developer must choose a programming language or environment that allows not only low-level control, but also supports high-level GUI and image processing and analysis capabilities. Although the combination of hardware described above allows communication to, and raw digital pixel data acquisition from, the image sensor, a substantial amount of custom software, on top of these basic operations, is needed to fully analyze, test or even display the data in any meaningful way.

There are image processing libraries and suites available that provide the basic building blocks needed to construct image sensor specific test algorithms. The imaging software needs the ability to process data from 8- and 16-bit images and perform all the basic image conversions between formats such as Bayer, YUV, RGB (565, 555, 444), JPEG, etc. The imaging tools should also include good filtering libraries, because custom background corrections and other sensor specific compensations are often desirable. The standard tests commonly found in product testing specifications include: focus scoring, photo response uniformity, shading, distortion, modulation transfer function (MTF), dead and defective pixel detection, cluster defects, dust and particle detection and color accuracy.

Coding and validating these tests and analysis algorithms is no small task. Often additional imaging algorithms such as background correction or subtraction and edge detection and steepness measurements are required. Standardized test suites that provide these types of tests are not commercially available and the developers and engineers must provide this layer of functionality.

Manufacturing and Production Challenges

Of all the types of electronics devices being produced today, CMOS image sensors are among the most complex.

In addition to the challenges in providing a basic CMOS image sensor interface listed above, challenges exist in manufacturing and production environments where high-throughput and full characterization testing is of greatest concern.

In production environments, the test operator must be able to quickly mount and connect the image sensor to a test fixture or setup. Hot swap capability (connecting or disconnecting devices without first removing power to the test fixture and equipment) is desired in this scenario. This requirement is often overlooked. Demo boards from sensor vendors do not support hot swap and are therefore difficult to use in a production environment. These devices must have the USB cable disconnected before installing or removing an image sensor under test, and then, when the USB cable is plugged back in, the host computer OS must re-enumerate the USB device, adding a considerable delay to the process. Hot swap image sensor connection capability can dramatically improve production throughput.

Production testing requirements also drive the need for programmable, variable-voltage power supplies and clock rates, so that margin testing can be performed. Most demo boards do not have these capabilities.

The ability to test for image sensor connection ‘opens’ and ‘shorts’ is also valuable in a production environment. Measuring ‘shorts’ would normally require a separate test fixture with resistance measuring and switching circuitry. Measuring ‘opens’ is even more difficult and involves complex software in addition to hardware switching circuitry. These shorts and opens tests can add significant cost, and for that reason, are not typically performed during production by most companies, thereby affecting the ultimate product quality.

Manufacturing and production environments demand software that is robust, secure, and easy to use. The complexity of CMOS image sensors translates into longer and more complicated testing suites in order to guarantee performance.

The final and probably greatest challenge for volume production is the cost and complexity of the interface and test solution. Production volumes have demanded a fan-out of test equipment with a high individual system cost, which, when multiplied by a large number of units, significantly compounds the overall cost.

Summary of Challenges

Developers and engineers face considerable challenges when interfacing, testing and working with CMOS image sensor devices. Providing all the I/O and logic required to simply interface with the device is time consuming and costly and requires expensive instruments and customized interface circuitry. Image sensor characterization and testing requires extensive, sophisticated image sensor specific software on top of the basic interface.

These challenges present significant hurdles for companies needing to design or develop products that utilize CMOS image sensors.

For **Quality/Test Engineers**, a low-cost, integrated, off-the-shelf solution would simplify and accelerate the interface, control, and testing process; evaluate chip failure; and improve product quality.

For **Product Development Engineers**, a low-cost, integrated, off-the-shelf solution would enable fast, comprehensive image sensor/camera module evaluation as well as end product camera algorithm development, cutting considerable time off of the product development schedule.

The Image Sensor Lab Solution

The Jova Solutions **Image Sensor Lab™** is a low-cost, off-the-shelf, integrated solution that addresses many of the challenges described above and can significantly reduce the cost and time associated with interfacing to, controlling, testing, evaluating and comparing CMOS image sensors.

The ISL-3200 provides all the power and I/O required by the image sensor, in a compact package. Multiple power supplies, I2C and SPI sensor communication, digital frame capture, additional I/O, and test and measurement instrumentation are included.

The ISL-3200 includes the Image Sensor Lab application software, a fully featured image sensor interface and testing software application, which provides flexible image sensor interface configuration allowing support for a large variety of image sensor models from a variety of vendors. The software also provides a standard characterization and test suite of image processing algorithms including standards such as: focus accuracy, dark/light field dead and defective pixel detection, photo response uniformity, color accuracy and SFR/MTF.

The Image Sensor Lab hardware and software were designed with automation and production in mind. The application software includes a powerful scripting and sequencing engine that automates many tedious setup tasks and repeated configuration changes. LabVIEW drivers and a DLL interface are also available to ease integration into test and production systems.

Image Sensor Lab Reduces Costly Integration and Development

The ISL-3200 is a fully integrated solution that eliminates complicated installations, plug-in cards, expensive heavy cables, multiple vendors and hours of integration effort. It connects to a host computer via a single USB 2.0 high-speed interface. The ISL-3200 includes: both I2C and SPI sensor communications; multiple programmable sensor power supplies; programmable master clock; flexible digital frame capture capability; additional I/O for extra sensor control and status lines; built in counter/timer instrumentation; and an optional built in DMM.

Image Sensor Lab Simplifies Development

The ISL-3200 comes with both LabVIEW drivers and a DLL driver library, both of which include all the basic and specialized functions needed to fully communicate with and test CMOS image sensors. An image test suite is available that performs many of the common production tests in use today.

Image Sensor Lab allows design and test engineers to immediately get started designing and testing the image sensor or the end product, and eliminates the need to design and build expensive test equipment before starting the real task at hand.

Image Sensor Lab Speeds Time to Production with New Sensors

The ISL-3200 interfaces to a wide variety of CMOS image sensors and camera modules from various vendors including: Micron, Philips, OmniVision, Toshiba, Hynix and others. This flexibility allows users to avoid costly hardware variations and duplications. The ISL-3200 allows multiple vendors' image sensors to be tested on the same equipment, reducing setup and breakdown times and giving flexibility to the production line planner. This flexibility can also significantly increase equipment utilization rates.

The work required to support new image sensors is reduced to building a cable or interface board that routes the sensor pins to the standard I/O on the ISL-3200 I/O connector. (Jova Solutions offers custom adapter development services.)

Image Sensor Lab Increases Throughput, Resulting in Reduced Cost

Image Sensor Lab is a fully integrated solution with a unified driver that allows for optimum coordination in executing a test or measurement sequence. The ISL-3200 hardware, combined with the highly efficient image processing algorithms, provides an excellent platform for high-throughput testing and processing.

Image Sensor Lab Improves Test Coverage

The programmable power supplies of the ISL-3200 allow for improved test coverage with the addition of margin testing. The master clock is also programmable and can be driven by the FPGA, allowing the possibility of complex test scenarios.

The built-in timer counter allows additional test coverage including accurate framing rates, clock frequency verifications, and frame and row timing, among others.
An upcoming, built-in DMM option will provide additional capabilities including the ability to perform pin-to-pin ‘short’ and ‘open’ connection tests.

Image Sensor Lab Reduces Overall Costs

Image Sensor Lab is a much lower cost solution than the alternatives: considerable customization and integration on top of a collection of independent pieces of test equipment from a variety of vendors or very expensive automated production test equipment. More significant than the already impressive hardware cost savings, is the development time saved in interfacing and testing new image sensors. Even more savings will be realized from the increased production throughput and test coverage enabled by the ISL-3200.

Image Sensor Lab

The ISL-3200 Image Sensor solution is an integrated off-the-shelf solution for quickly interfacing to and testing CMOS image sensor devices. The ISL-3200 provides a full range of CMOS image sensor interface, control, test, evaluation and comparison capabilities in one low-cost, small-footprint test solution. The fully integrated hardware/software solution supports testing on a wide variety of CMOS image sensors, with a full complement of evaluation and test functionality, for needs ranging from end-product development to manufacturing line final test.

Most importantly, the ISL-3200 significantly reduces the overall cost of working with CMOS image sensors.