BY DAVID MARSH • CONTRIBUTING TECHNICAL EDITOR

Photosensors brighten consumer and industrial products

ACCURATE DETECTION OF LIGHT LEVELS FINDS LIMITLESS APPLICATIONS IN AUTOMOTIVE, CONSUMER, AND INDUSTRIAL EQUIPMENT. A NEW GENERATION OF PHOTOSENSORS SIMPLIFIES THE DESIGNER'S TASK AND MAKES COLOUR ANALYSIS AVAILABLE AT MINIMAL COST.

As winter recedes and the days lengthen, the power of light is plain to see. Its effect touches everything and everyone, from plants straining to catch the last rays to people whose moods invariably brighten on sunny days. At every school pupil knows, light is essential for life, from tropical corals that thrive on wavelengths close to ultraviolet to arctic plants that flower for the few brief moments that they're free of snow cover. In each case, organisms respond not only to lighting intensity, but also to the illumination's spectral content. Many applications exploit either illumination level or spectral content, or both—from aquarium owners who attempt to synthesise natural light to stimulate marine life to scientific disciplines ranging from material analysis to cosmic exploration. Within the manufacturing industry, processes routinely use colour detection within automatic sorting equipment, while humble illuminance sensors appear in everything from security lighting to children's toys.

These applications and yet many more depend upon photodetectors, an often-overlooked market sector that's currently enjoying fresh impetus from consumer electronics—such as mobile phones and LCD televisions. With consumers' lust for increasing functionality for all things mobile within ever-smaller packages, photodetectors are playing a key role in system-power reduction by helping to adapt current-hungry LED backlights to ambient lighting levels. Other growth areas for relatively mundane photosensors continue within the wider lighting industry, where the need for energy efficiency has greater impact on the planet's health. More sophisticated devices that analyse the RGB (red, green, and blue) parts of the spectrum are making inroads into domestic applications such as mood lighting control, while the high accuracy that these parts can now achieve lowers the cost of systems from industrial automation to medical instruments. So what's available to product designers looking to exploit light-monitoring devices, and what's involved in interfacing these characteristically analogue components with digital systems?

Before considering the gamut of available devices and how to interface with them, it's useful to review the basics of light and the mechanics of photodetection. While this involves a brief return to high school physics theory that engineers normally take for granted, the practicalities of photodetection make this exercise unusually worthwhile. The textbooks state that light is the product of energy release from the atoms within a material "due to heat, chemical, or other reactions". Furthermore, the optical section of the electromagnetic spectrum extends from deep infrared at around 3,000 nm to ultraviolet at around 300 nm, with humans perceiving colours than span red through blue within a relatively small 700- to 400-nm window. While there are no steps between wavelengths within the electromagnetic spectrum, a convention that photographers conveniently apply divides the visible spectrum into blue from 400 to 500 nm, green from 500 to 600 nm, and red from 600 to 700 nm. The eye has very little receptivity to wavelengths beyond these extremes, which, according to the Young-Helmholtz theory of colour vision, is due to three types of conical receptors in the retina that respectively respond to short, medium, and long wave visible radiation. This theory also provides one explanation for the fact that it's possible to synthesise any colour from an appropriate mixture of the three primary colours—that is, red, green, and blue.

Having a direct effect on semiconductor selection, each wavelength has an associated energy level that's expressed in terms of electron volts (eV). In turn, different semiconductor materials possess eV bandgap energies that demonstrate peak photosensitivity at definite and quite limited parts of the spectrum. The energy level and the wavelength of the light to detect thus determine which material best suits an application. Crucially, photodetection is a quantum process—because a photon's energy is inversely proportional to its wavelength, the number of photons per second that arrive at a detector for a given amount of incident light is linearly proportional to the photon's wavelength. Accordingly, the quantum efficiency of a detector increases with wavelength. The raw physics states that the responsivity of an ideal photodiode—the most popular type of detector—expressed in terms of Amps of electrical output per Watt of optical

AT A GLANCE

- Light-dependent resistors enable simple illuminance sensors.
- Photodiodes improve detection accuracy and speed response times.
- Integral amplifiers simplify analogue interfacing issues.
- Digital-output photosensors suit direct connection to logic.
- Colour photosensors achieve new accuracy/low-price points

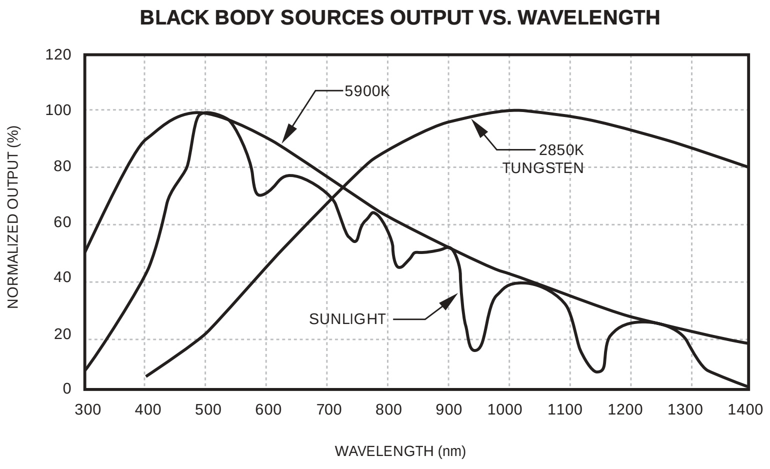

Figure 1 Tungsten sources simulate black-body radiators.

input power is 0.807 times the micron value of the photon's wavelength:

$$R_{ideal} = 0.807\lambda\mu m \text{ mA/mW}$$

In practice, silicon photodiodes working within the 0.4- to 1-μm region only get within around 30% of this ideal. The ratio between ideal responsivity and the device's real response is the quantum efficiency (η) metric that appears on many device datasheets.

LDRS SIMPLIFY PHOTORELAYS

It's easy to forget that photodetectors predate the silicon era by many decades. Exploiting the photosensitive nature of materials, many early experimenters fabricated homebrew photocells using copper-oxide technology. The process involves heating a small area of thin sheet copper to red heat, depositing a droplet of strong saline solution on the copper while it's still incandescent, then pressing a clean copper wire onto the oxidised area to form the second electrode. First made by Siemens using selenium on a mica substrate with platinum electrodes, selenium cells are a more sophisticated photovoltaic device that telephone pioneer Alexander Graham Bell employed as the detector for an optical communications link as early as 1879. Requiring only a microammeter to construct a crude photometer, this relatively bulky and insensitive detector technology persisted in applications such as camera exposure meters until the mid-1970s, when so-called "blue-sensitive" photodiodes with near human-eye responses made compact through-the-lens metering systems possible.

Today, a legacy technology that enjoys widespread use in photo-relay applications from children's toys to streetlights exploits light-dependent resistors (LDRs), which—as the name says—are photoresistive, not photovoltaic. This two-terminal device conventionally comprises a layer of sintered cadmium-sulphide (CdS) element that's vacuum deposited onto a ceramic substrate and etched into shape using photolithographic techniques. It is housed within a variety of packages—from a film of lacquer that drives cost down to around $0.10 in high volume to multidollar hermetically sealed transistor-style cans; ohmic contacts connect the element to its leads. The sensor doesn't have a junction, acting instead as a bulk-effect device whose bulk resistivity falls in proportion to rising levels of incident light. Ideally, the element's resistance K changes according to the law $K = \log(R1/R2) / \log(E2/E1)$, where R represents the resistances of the photocell at light intensity E.

The industry-standard method for describing a photocell's resistance employs a tungsten lamp that has a correlated colour temperature of 2856°K, which datasheets often refer to as "CIE standard light source A" after the Commission Internationale d'Eclairage's convention. The CIE is the reference body for all matters pertaining to light, from street lamps and swimming-pool lighting to the definition of colour rendering and all measurement practices. The output from a 2856°K tungsten source compares with the sun's black-body radiation of around 5900°K in free space (at the Earth's surface, the sun's spectrum shows absorption bands due to atmospheric elements such as carbon dioxide and water vapour—see Figure 1). While a true black-body radiator's spectral output depends exclusively on temperature, tungsten lamps are a practical approximation that usefully

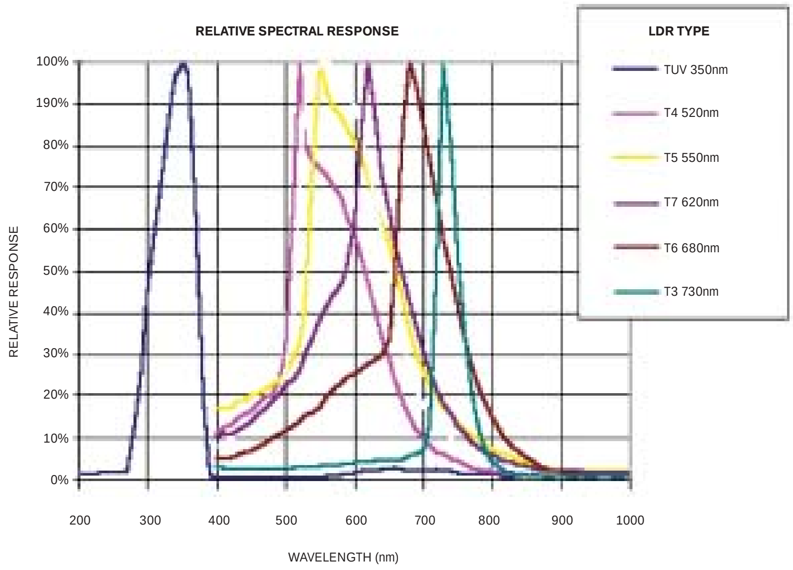

Figure 2 Alternative compounds give Silonex' light-dependent resistors peak responses that span ultraviolet to near-infrared.

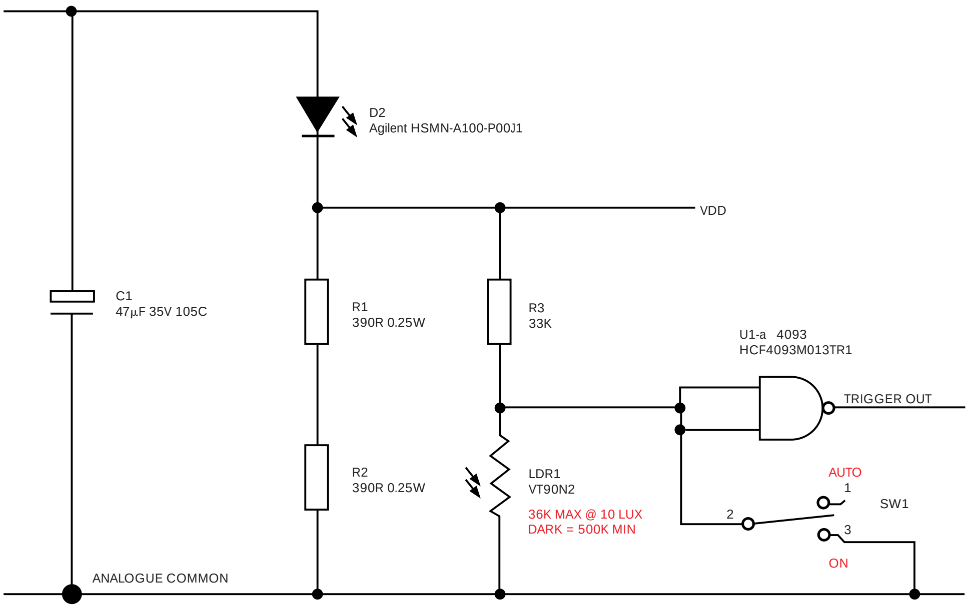

Figure 3 This simple light-level sensor uses a Schmitt-trigger comparator to minimise costs.

contains significant energy across the visible spectrum and well into the infrared. Datasheets describe resistance values at dark conditions and for one or more lux values of lighting intensity. The international standard measure of illuminance, one lux represents one lumen per square metre—hence it's a measure of the radiant energy falling on a surface, with a standard value of 1.46 mW at a frequency of 540^{E12} Hz, or about the 555 nm that's the centre of human-eye response. For comparison, normal room-lighting levels typically lie between about 250 and 400 lux, while direct sunlight exceeds 100,000 lux. Commodity LDRs have a dynamic range of several orders of magnitude that accommodates this moonlight-to-sunlight scenario.

Commodity LDRs are also very linear in the centre of their range, while their resistive nature makes them very easy to apply in voltage-divider circuits. Their low noise and distortion together with stepless response characteristics allow these devices to replace potentiometers in audio and similar gain-control applications. Photoresistive optocouplers from suppliers such as Silonex represent a contemporary choice for this near-forgotten analogue control concept. Other advantages of LDRs include high sensitivity and a spectral response that's broadly similar to that of the human eye. Most devices have their peak responses around 550 nm, but it's possible to adjust the base-material composition to produce well-defined peaks from 515 to 615 nm, while adding a trace of selenium to the mix extends peak sensitivity to 725 nm (Figure 2). But because the sensor's resistance depends on its film microstructure, resistance values for a given condition often span a 3:1 ratio, while temperature-coefficient performance is positive at around +0.4%/°C across a permissible −40 to +75°C operating range. Other disadvantages of this material include response times that can take hundreds of msec to stabilise, together with a memory effect that can take days to recover from exposure to high brightness levels.

Representative LDR suppliers include Hamamatsu, Perkin-Elmer, Silonex, and Tesla Blatna. Example devices include Perkin-Elmer's widely available VT935G that uses a protective epoxy coating to minimise cost in benign environments such as domestic lighting. Its dark resistance is more than 1 MΩ with three bright-light groupings that span average values from 18.5 to 40.5 kΩ at 10 lux. The company also offers photocell ranges in hermetically sealed metal-to-glass packages including TO-5, TO-8, and TO-46 enclosures. Available in durable TO-5 and TO-18 formats, the NSL family from Silonex offers dark-to-light resistance responses that span 50Ω to 20 kΩ under full illumination to 100 kΩ - 880 MΩ when dark, all with several orders-of-magnitude of dynamic range. Suiting applications such as flame detection, the company's NSL-21UV401 features a quartz window that's transmissive at short wavelengths to help tune the device to the near-ultraviolet 350 nm while blocking some 98% of the visible spectrum. While most devices have maximum voltage ratings of between 320 and 600V that permit ac-line applications, Tesla Blatna distinguishes itself by offering its K2553 and P2853 series of devices that withstand as much as 1,500V.

Interfacing LDRs with logic for a typical photo-relay application really couldn't be simpler—see Figure 3, which describes part of a minimum-cost consumer product that uses Perkin-Elmer's VT90N2. Here, the Schmitt-trigger gate U1A continuously compares the level at the junction between bias resistor R3 and the LDR with its own supply voltage to derive a trigger signal that controls a power switch. Replacing R3 with a potentiometer and a limiting resistor adds switch threshold control, as often appears in passive-infrared movement detectors that control halogen floodlights. Another way to assess the ambient light level while providing for an automatic calibration facility is to connect the junction between the bias resistor and LDR to a microcontroller's ADC. For battery-powered operation, connect the

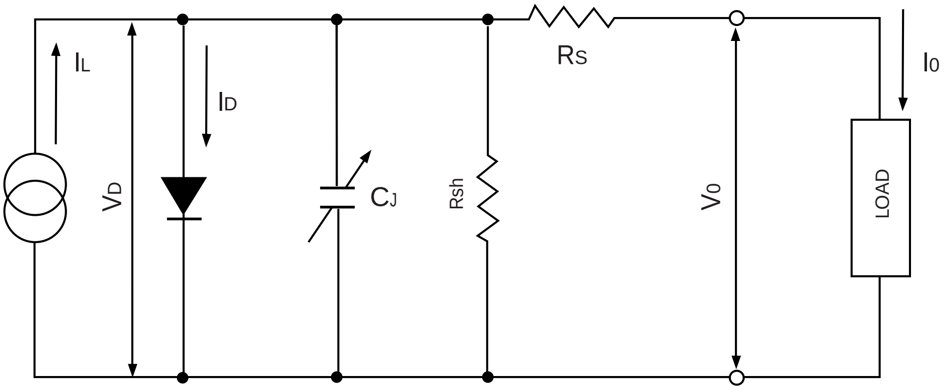

Figure 4 A photodiode's equivalent circuit shows its potential for use in current- and voltage-amplification circuits.

low side of the LDR to an output pin instead of ground. To take a reading, the control software sets this low-side pin to zero level, returning it high immediately afterwards. In this way, no current flows through the sensor except during the measurement. This approach is often superior to that of choosing an LDR with a very high operating resistance that may not satisfactorily drive an ADC input without buffering. It also works equally well with other resistive sensors—such as thermistors—up to the I/O port's maximum sink-current capability.

PHOTODIODES SPEED RESPONSE

Photodiodes are often smaller and always very much faster than LDRs, while general-purpose devices also retain the benefit of low cost. Commodity devices have rise times that normally lie within the microsecond region and have no light-memory problems, but their maximum breakdown voltages of around 15V restrict use to low voltage circuits. Operating as high-impedance photovoltaic current or voltage sources, photodiodes are more difficult to interface with than their photoresistor counterparts, especially for applications that require linear performance and optimum speed over as many as seven decades of output current. But for general-purpose use, a new generation of miniature parts with minimal interfacing issues facilitates new applications, such as adaptive backlights in mobile phones.

All pn-junction diodes are photosensitive—sometimes to the extent that they can wreak havoc in sensitive analogue circuits, such as the front ends of high-resolution multimeters. Here, it's common practice to sleeve glass-encapsulated devices in opaque silicone rubber. Otherwise, photons that have enough energy to penetrate the diode's material band-gap form electron-hole pairs that create an electric field that causes current flow. With their optically optimised packages, LEDs are a good example of diode emitters that also work quite well as detectors, which is easy to show by shining one directly into another diode of the same type and measuring the voltage that develops across the receiver's terminals.

For visible-light photodetector applications, silicon planar structures are easy and cheap to fabricate. The band-gap energy effect means that a photodiode's peak responsivity depends on its construction material, with silicon having its maximum sensitivity at around 880 nm. Better sensitivity and repeatability results from selectively doping the semiconductor structure between the normal p- and n-layers to create a pin junction photodiode. The "i" or intrinsic layer forms a high-resistivity layer that increases the width of the space-charge region by around two orders of magnitude. Because photodetection relies on photons generating charge-pairs in close proximity to the structure's highly depleted region, this layer greatly increases sensitivity and response speed. Either variety of photodiode has an equivalent circuit that comprises a current generator in parallel with a forward-conducting diode, a shunt capacitor and resistance, with a series output resistance (**Figure 4**). Neglecting the effect of illuminance levels, the device's current-versus-voltage characteristic resembles that of a diode. Undemanding applications can often use a simple voltage amplifier to raise the photovoltaic voltage to a level that's suitable for logic. More demanding applications employ the current-generator mode, with the photodiode typically operating with some reverse bias in a transimpedance amplifier configuration.

An industry-standard part for street- and security-lighting applications, Perkin-Elmer's VTB8440B is a planar silicon device in a low-cost epoxy-window plastic package. Its integral infrared rejection filter reshapes the device's 920-nm peak response to the 550-nm region. With a typical open-circuit voltage that ranges from around 150 mV at 0.1 lux to 490 mV at 1,000 lux, this device primarily targets operation in the photovoltaic mode using a high-impedance voltage follower or amplifier. But by applying up to 2V of reverse bias, it's possible to constrain dark current leakage to 2 nA while halving junction capacitance to around 0.5 nF, improving dynamic range and response speed. The transimpedance amplifier uses

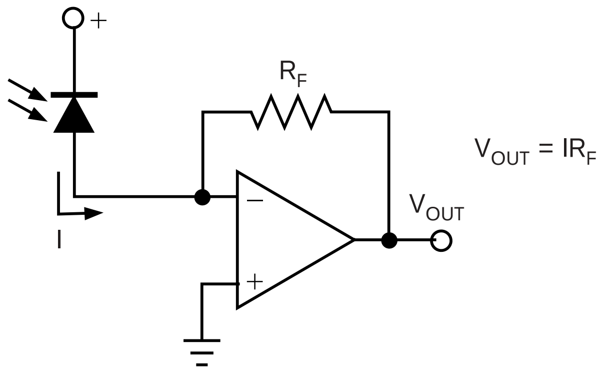

Figure 5 The transimpedance amplifier operates the photodiode as a current generator, often under negative bias.

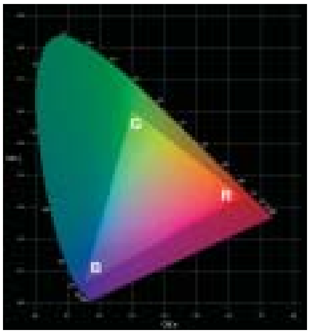

Figure 6 A colour monitor is only capable of reproducing a portion of the colours that humans perceive.

negative feedback to drive the inverting input to ground, forcing any photodiode current—35 µA minimum at 1,000 lux for the VTB8440B—to flow through the feedback resistor (**Figure 5**). The ideal response is $V_{OUT} = I \times R_F$, but as with all high-impedance circuits, it's essential to choose a low-input-current op-amp and to exercise care in component layout and construction. See the excellent article by Linear Technology's Glen Brisebois that appears in this issue of *EDN Europe* (pg 52) for more on high-impedance op-amp circuits.

For engineers with analogue mindsets, experimenting with photodiode circuits is fun, and it's relatively straightforward to build a detector that's capable of decent performance with the help of a practically orientated textbook—see **Reference 1**. Alternatively, one way to minimise analogue-interface concerns is to select a photodiode with an on-board amplifier, such as the EL7900 visible-light sensor from Intersil. A finalist in *EDN*'s 2005 Innovation of the Year Award, this tiny 5-pin, 2×2 mm leadless device closely models human-eye response over a 1- to 10,000-lux range. Operating from a single 2.5 to 5.5V supply, it generates a current output from 150 nA at darkness to 60 µA for 100 lux of fluorescent light. As a result, its current consumption virtually mirrors its output current, but is as low as 1.5 µA when disabled. Its compliance capability enables output voltages within 300 mV of the positive rail, so for a linear response over the range of interest, it's important to choose a resistor value that doesn't cause the output to saturate. Resistor choice also affects response times, but as these still lie within the sub-200 µsec region, there's plenty of bandwidth left from periodically enabling the device to suit its principal application of controlling display backlights in portable electronics. The devices are available now; budgetary pricing lies around $0.70/1,000.

Now appearing under the Avago Technologies trade name, the former Agilent optoelectronics portfolio includes a simple "light-in, digital-out" part, the HSDL-9000. Capable of saving 50 to 70% of backlighting power in typical use, the chip mates its photodiode with a transimpedance amplifier and semiconductor wavelength filter that suppresses peaks in the sidebands around the central 550-nm response area. In particular, the filter rejects harmonics from sources such as fluorescent striplights to better replicate human perception. Operating from 2.7 to 3.6V supplies, the device's six-lead, 1.1-mm high, 4.0×3.2-mm package permits three digitally controlled gain levels that facilitate automatic gain control, as well as device shutdown. An optional analogue gain trim is available using a potentiometer. These gain settings control the threshold level of the digital output that typically controls an external power switch. Related products include the voltage-output HSDL-9001 that shrinks similar analogue circuitry into a two-pin 2×1.5-mm QFN package that's just 0.6 mm high, and the new APDS-9002 that provides a ground-referenced current output in a four-pin outline of comparable footprint. The new part runs from 2.4 to 5.5V supplies and operates over the −40 to +85°C range.

Texas Advanced Optical Systems (TAOS) uses another approach in its TSL2550. This 8-pin SOIC or 4-pin leadless package houses one photodiode that responds to visible and infrared sources with another that's primarily sensitive to infrared. Available for about €3/100 at catalogue-distribution prices, the chip's ADC integrates incoming light readings to suppress flicker from ac-line powered lighting, then subtracts one channel from the other to approximate human-eye response over a 12-bit dynamic range. The device outputs results via its SMBus-compatible serial port. The company's "bit-banger's guide" to microcontroller interfacing provides a succinct explanation of how to handle this two-wire connection (**Reference 2**). For minimal connections at similar cost, consider its light-to-frequency converters, such as the wide-band TSL235R that covers the 320 to 1,050-nm range and peaks at around 760 nm. This device and the similar infrared-responding TSL245R have three-pin side-looking through-hole packages that suit edge-of-board mounting. Operating from 5V supplies, these devices output a TTL-compatible square-wave whose intensity-proportional linearity is within 0.1% up to 10 kHz and ±0.2% to the 500-kHz full-scale value. TAOS also offers several low-cost linear sensor arrays that suit applications from simple edge detection to document scanning. For instance, the TSL1401R (around €6.50/100) packs a 128×1 linear photodiode array together with charge amplifiers, pixel data-hold circuitry, and serial data interface into an 8-pin DIP that runs from 2.7 to 5V rails. Evaluation boards are available for this and many other TAOS parts.

HUES SHARPEN CONTROL LOOPS

The range of colours that equipment and processes can achieve differs widely, as becomes clear when you consider the difference between a PC's monitor and a colour printer. Because the monitor projects red, green, and blue onto a dark surface, it's excellent at reproducing RGB. Conventional printers use cyan, magenta, yellow, and black inks, so they favour reproducing these pure hues. Either RGB or CMYK colour spaces are a subset of human perception, as the CIE-1931 colour-gamut diagram in **Figure 6** shows, where the triangle bounding the "RGB" annotation shows the limits of a colour monitor's reproduction within the spectrum that the eye sees. And as every graphic artist knows, there's no chance of printing a faithful copy of on-screen artwork without calibrating the monitor and adjusting the printer, typically by using a colorimeter and application software. Semiconductor devices that perform this type of spectral analysis comprise multiple photodiodes arranged singly or in arrays beneath filters that separate the visible spectrum into RGB portions. While the ability to detect colour has traditionally enjoyed multiple industrial and scientific uses, it's the advent of LCD screens that stimulates today's mass-market opportunity for colour photosensors—see **sidebar** "Colour Sensors Brighten LCD Screens".

Available in a 16-terminal, 5×5×1 mm QFN package, Avago's HDJD-S722-QR999 colour sensor is sufficiently

COLOUR SENSORS BRIGHTEN LCD SCREENS

As a visit to any electrical superstore shows, LCD screens–and in particular, those for televisions–are one of the consumer success stories of our times. Their low manufacturing cost, flicker-free reproduction, and slimness signals the demise of traditional CRTs, as the recent TV-tube plant closures at Philips–Europe's largest manufacturer of such displays–reflect. The advent of high-definition television (HDTV) from satellite broadcasters is apparent too, with virtually every model sporting the "HD-ready" tag. Issues with first-generation LCD screens such as sluggish response times and poor contrast ratios are now history, yet some problems remain regarding colour rendition and faithfulness, especially over time. Now, manufacturers such as Sharp are including colour-correction circuitry to provide more engaging image rendition. For example, Sharp recently released its HDTV-compatible LC-65GE1 panel to the Japanese HDTV market. This 1,920×1,080 pixel screen includes the company's proprietary four-wavelength backlight that adds a crimson hue to the RGB emitters to better reproduce red tones.

Elsewhere, manufacturers are moving away from cold-cathode fluorescent (CCFL) backlights–which typically render only about 75% of the TV signal's colour gamut–in favour of LED arrays. With a typical lifespan of 15,000 to 25,000 hours, CCFL emitters also fade over time, further compromising visual quality. Of course, LEDs also degrade–many high-power types to around 50% of their initial illuminance after 50,000 hours–but adjusting the ratios between drive currents in RGB devices can largely compensate for this effect. Because the wavelength of a LED's emissions changes with drive current and temperature, it's essential to monitor the white colour-temperature set point using a stable colour sensor before providing compensation via a feedback network. This approach maintains a reasonably constant colour temperature while allowing TV manufacturers selling into international markets to adjust the display's white colour-temperature set point. Conventionally 6,500°K for studio monitors in Europe and the US, this value spans 6,500°K for European TV sets through 7,100°K in the US to 9,300°K in Japan–which is the same bluer tint that most PC monitors display.

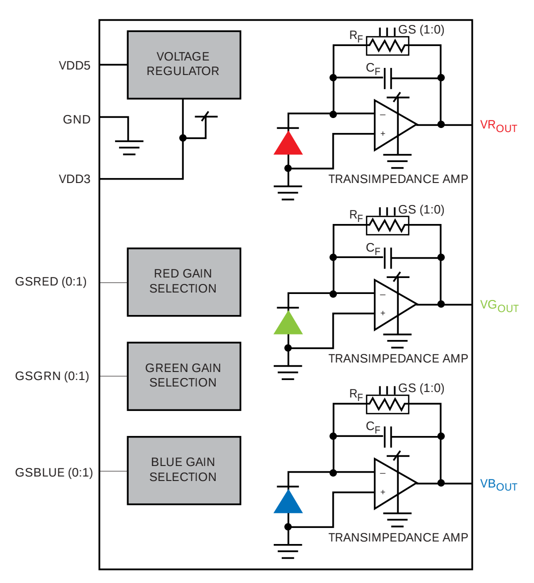

Figure A Avago's photosensor uses a combination of six resistor values to program its transimpedance amplifiers.

One of EDN's Hot 100 products of 2005, Avago's HDJD-JB01 illumination-colour-management system targets flat-panel LCD TVs, while its separately available colour-sensor module finds widespread application in industry and instrumentation (see main text for the broadly similar HDJD-S722-QR999 chip). By controlling an array of Lumiled's Luxeon RGB LEDs in a closed-loop colour-monitoring arrangement at frame rate, the television application continuously controls the colour temperature of an LCD's white backlighting. The system electronics comprise the HDJD-S831-QT333 tricolour photosensor and the companion HDJD-J822-SCR00 colour-management controller that together cost around $35 in low volume. Users can define the white-colour set point and brightness that they prefer, and the system will maintain this setting for the life of the television.

The HDJD-S831-QT333 module is a 27.6×7.1-mm pc board that carries the photosensor and a tiny 5-pin edge connector that mates with a 3-mm wide, 0.5-mm pitch flat flexible cable. Its connections provide 5V power and ground for the photosensor's internal 3.3V regulator, and return three voltage levels. Six unpopulated pads on the module allow setting the individual sensitivities of the 12×12 photodiode array in four increments, courtesy of three on-chip transimpedance amplifiers–see Figure A. In the HDJD-JB01 system, these output voltages connect to ADCs within the colour-management control chip, which includes colour data-processing logic and a 12-bit PWM generator that controls the external LED drivers. According to Soo-Ghee Lee, vice-president and general manager for Avago's optoelectronic products division, the company's engineers "solved the problem of how to achieve 100% of the NTSC colour gamut for a more exciting LCD TV viewing experience. The result, announced at last year's Consumer Electronics Show, was the world's first intelligent LED backlighting system for LCD TVs that dramatically increases the range and depth of colours."

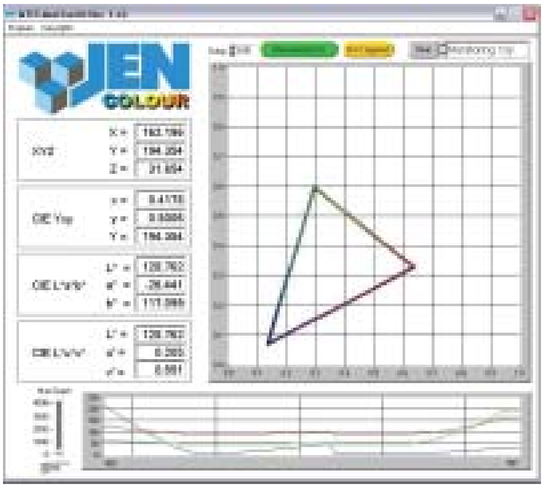

Figure 7 Mazet's true-colour sensor and application software enables colorimeter applications.

accurate to precisely identify a colour's coordinates within the spectrum. Applications that augment LCD-backlighting control range from colour measurement in blood-glucose monitoring for medical instrumentation to pigment matching in paint manufacture. The monolithic CMOS sensor comprises three sets of 3×3 photodiode arrays under integral RGB filters that are uniformly distributed throughout the photodiode's active area, helping to minimise any inaccuracies due to light gradient, optical aperture misalignment, and package-surface irregularities. Interleaving the photodiodes on the chip's substrate further reduces contamination and optical-aperture-misalignment effects. Gain-programmable using resistors, three on-chip transimpedance amplifiers convert coloured light to RGB-channel voltage outputs whose values increase proportionally with increasing light levels. Specified over the −40 to +85°C range, the chip regulates its internal 3.3V power from a 5V rail. The guide price is $10 in low volumes.

German optoelectronics specialist Mazet offers its MCS family that appears under the company's Jencolour trademark. Examples include the MCS3AS, which costs around €30 in low volume. Its 8-pin SOIC package houses three silicon pin photodiodes that have sub-1 μsec rise and fall times. Integral optical filters separate spectral responses into 470-, 570-, and 650-nm peaks with sensitivities that respectively span 0.26, 0.33, and 0.41 mA/mW. Being current-output devices that work best under reverse-bias conditions, the photodiodes require an external transimpedance amplifier to generate output voltages at levels that suit ADCs. Accordingly, Mazet offers its MT104, a four-channel sensor amplifier that features eight digitally-programmable transimpedance gain settings, together with a switchable capacitor within each amplifier's feedback loop that compensates for photodiode capacitances of up to 5 and 80 pF. Powered from a single 5V supply, the MT104 is available in 16-pin SOP and QSOP outlines for less than €10 in low volume. The company's MCS-EB1 evaluation board accommodates various MCS-family devices and features a 10-bit ADC, 8052 microcontroller, and RS232 interface that enable PC connectivity. Four white LEDs illuminate the user's test target, with software controlling gain factors and reporting digitised photocurrent values. The board costs around €700 from catalogue distributors such as Farnell InOne.

For applications requiring a response that models the CIE-1931 profile, Mazet's MTCSiCS/CT true-colour sensor houses a 19×3 array of pin photodiodes within a TO-39 or 8-terminal LCC package. While commodity colour photosensors have widely varying responses to the red, green, and blue parts of the spectrum, the MTCSiCS/CT true-colour sensors have an even peak response for each hue. The complementary MTCS-ME1 evaluation board comprises a baseboard that accommodates a range of application-specific plug-in sensor modules with light sources. The PC-resident modEVA-Software package communicates with the board via USB, analysing results in a range of colour spaces (**Figure 7**). Other products include interface drivers and an application-programming interface in Windows DLL (dynamic-link-library) format that allows users to integrate similar facilities within their own systems.

TAOS uses a colour-to-frequency conversion approach with its TCS230 chip, which—with a guide price below €5/100—suits applications from consumer electronics to industrial process-control equipment (Optek's OPB780 is a device that has suspiciously similar specifications, but comes within a custom plastic enclosure for industrial use). This 8-pin SOIC operates from a 2.7 to 5.5V supply and contains an 8×8 array of photodiodes that are arranged into four groups of sixteen. Each of the photodiodes in a group connects in parallel with its peers. Red, green, blue, and clear filters segregate each group into appropriate wavelengths for analysis, with the clear-filter group being able to return the intensity of wideband white light. The on-chip current-to-frequency converter generates a squarewave output whose frequency is proportional to lighting intensity. Two enable inputs select the photodiode group for a host microcontroller to read, while two more logic inputs control frequency dividers that scale the output frequency range through 2, 20, and 100% of the 500-kHz full-scale output. The fourth logic condition is a power-down mode that cuts consumption from a 3 mA maximum to 15 μA. Stable to within ±200 ppm/°C, the chip's response is typically linear to within 0.2% at 50 kHz.EDN

REFERENCES

1 Johnson, Mark, "Photodetection and measurement–maximizing performance in optical systems," ISBN 0-07-140944-0, McGraw Hill, 2003.

2 Pilgrim, Phil, "Using the TSL2550 with a microcontroller–a bit banger's guide to the SMBus," design note 6, Texas Advanced Optical Solutions, www.taos.com.

AUTHOR'S BIOGRAPHY

You can reach Contributing Technical Editor David Marsh at forncett@btinternet.com.

FOR MORE INFORMATION

Avago Technologies
www.avagotech.com

CIE (International Commission on Illumination)
www.cie.co.at/cie/

Farnell InOne
www.farnellinone.com

Hamamatsu
www.hamamatsu.com

Intersil
www.intersil.com

Lumileds
www.lumileds.com

Mazet
www.mazet.de

Optek
www.optekinc.com

Perkin-Elmer
http://optoelectronics.perkinelmer.com

Sharp Microelectronics
www.sharp-sme.com

Silonex
www.silonex.com

Tesla Blatna
www.tesla-blatna.cz

Texas Advanced Optical Systems
www.taosinc.com