how it works

FILM-SIZED IMAGING SUBSYSTEMS ENABLE PHOTOGRAPHERS TO USE THEIR CAMERAS, OPTICS, AND OTHER EQUIPMENT INVESTMENTS IN THE NEW DIGITAL ERA. BUT MIMICKING FILM IS NO TRIVIAL CHALLENGE.

Electronic film focuses on low power, high image quality

By Brian Dipert, Technical Editor

YOUR DESIGN OBJECTIVE: Create a sensor, processor, and storage system that turns a 35-mm camera into a digital-image-capture device. Seems pretty simple at first. The market opportunity is tempting, too; more than 10 million "prosumer" (high-end-consumer) SLR (single-lens-reflex) cameras have been sold to date, along with more than 55 million consumer SLRs and more than 250 million point-and-shoot cameras. Irvine Sensors (www.irvine-sensors.com) envisioned near-term success in 1997 when it spun off Imagek (now Silicon Film Technologies, www.siliconfilm.com) as a separate company and began electronic-film-system development. After four long years, the company last month began shipping its first-generation $699 EFS-1 system, based on a fundamental patent filed in 1991 (**Figure 1**). Along the way, Silicon Film Technologies' engineers, in partnership with a plethora of hardware and software vendors, have surmounted numerous design hurdles, and the company has filed additional patents on its innovations.

To understand why this seemingly straightforward design objective became so complicated, consider a few basic characteristics of silver-halide-based film. It costs only a few dollars per roll and a few extra dollars for processing. You can squeeze as many as 36 pictures onto a single roll of film, and you can take multiple pictures per second if the camera contains an autowinder or motor drive. Film is always on, ready for exposure whenever the camera's shutter opens, but its presence doesn't increase the drain on the camera's batteries, nor does it require its own batteries. Depending on the film's ISO (International Standards Organization, formerly ASA (American Standards Association)) rating (therefore its grain pattern) and how large you want to make the prints or projected slides, an image sen-

Figure 1 The EFS-1 system includes (e)film for image capture, (e)port for image transfer to a PC, and (e)box for temporary bulk-image storage (courtesy Silicon Film Technologies).

sor might need to deliver 10-megapixel or higher resolution to match the film's detail potential.

Figures 2 and **3** show EFS-1's (e)film cartridge, which, in contrast, holds as many as 24 1.3-megapixel images, captures an image every 2 sec, and fits inside the (e)port module to transfer the images to a computer over PC-card or USB interfaces. If you've filled up (e)film and don't have a computer handy, you can insert the (e)film/(e)port combo into the (e)box storage device, whose interface logic controls a Type 1 or 2 CompactFlash-mass-storage device, such as a flash-memory card or IBM (www.ibm.com) MicroDrive. With USB ports now prevalent in both notebook and desktop PCs, Silicon Film Technologies is considering combining (e)port and (e)box in a single next-generation unit with USB and CompactFlash connections. The result would be the elimination of the PC-card interface, the simplification of the now-redundant logic in both units, and perhaps the addition of an LCD for image viewing and file management.

PARTITIONING PUTS A DAMPER ON POWER

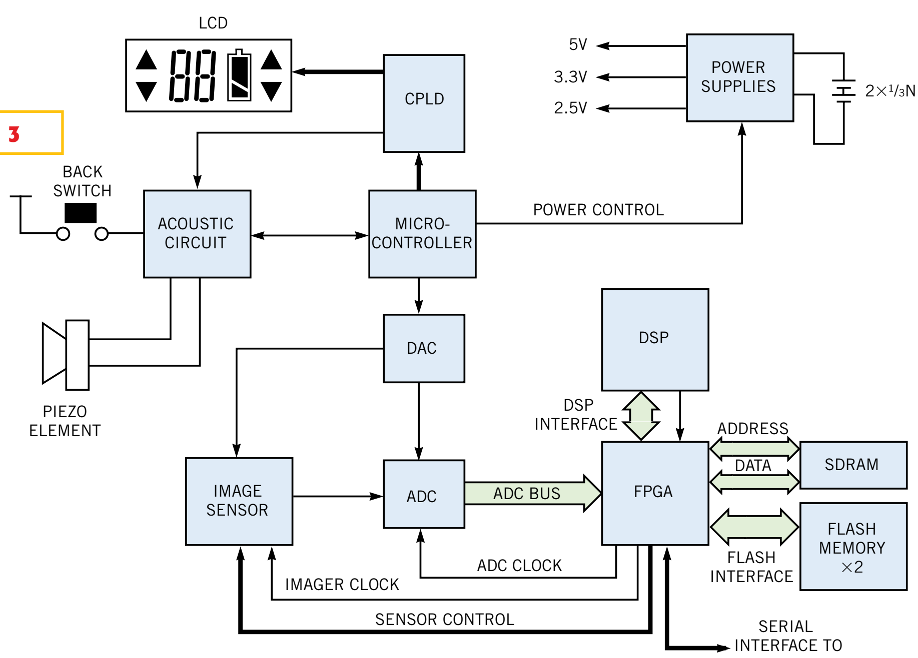
Because (e)film's goals are low cost and long battery life, its built-in image-processing capabilities are limited. Analog Devices' (www.analog.com) ADSP-2186 DSP creates a thumbnail image that supplements the raw CMOS-sensor data, at 12 bits per pixel, in each stored file. Most image processing, including the conversion from a Bayer color pattern to per-pixel RGB, takes place via a twain driver once you move the files onto your PC. This approach harkens back to the one used in Kodak's (www.kodak.com) DC120 digital camera and the one Intel (www.intel.com) advocated with its digital-camera-design guidelines of a few years ago (**Reference 1**). Because the 64 Mbytes of NAND flash memory inside (e)film constitute a disproportionately high percentage of its cost, 12- versus 24-bit-pixel or higher storage minimizes the cost per image without requiring JPEG or another lossy-compression scheme.

Power-consumption along with ease-of-integration concerns drove Silicon Film Technologies' selection of a 1280×1024-pixel CMOS sensor instead of today's more common CCD (charge-coupled device) (**Reference 2**). The company estimates that you

Figure 2

Silicon Film Technologies designed (e)film to drop into a 35-mm SLR camera.

Figure 3



Careful hardware and software partitioning, including reliance on the PC for most of the image processing, optimizes (e)film cost, battery life, and picture quality (courtesy Silicon Film Technologies).

can shoot approximately 300 pictures with each set of two CR1/3N batteries. EFS-1 uses 1997-lineage CMOS-sensor technology from VLSI Vision, now part of STMicroelectronics (www.st.com). To eliminate dark current noise, (e)film buffers two images to its 16 Mbytes of DRAM, one taken with the shutter open and the other taken with the shutter subsequently closed, and then subtracts the latter from the former. Still, you can't use a shutter speed slower than $^1/_{15}$ sec with (e)film.

The sensor is approximately 2.85 times smaller than a 35-mm negative (**Figure 4**). This variance means that the focal length of any lens mounted on the camera body is multiplied by a factor of 2.85. For landscape photographers using wide-angle optics, this focal-length transformation is undesirable. Conversely, sports and wildlife photographers, or anyone who needs a telephoto lens, would welcome the fact that, for example, a 100-mm lens becomes a 285-mm lens when coupled with (e)film. The company provides stickers that you apply to the camera's focusing screen, indicating the percentage of the viewfinder that the (e)film sensor covers.

Figure 4

The small image sensor, compared with a 35-mm film negative or slide, multiplies the effective focal length of any lens by a factor of 2.85 (courtesy Silicon Film Technologies).

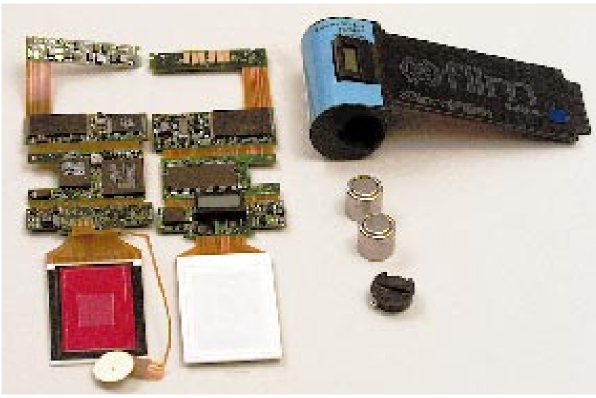
Until the camera's film-pressure plate depresses a switch on the back of (e)film, the unit is turned off. With (e)film properly installed, its batteries would drain in short order if all of its circuitry were constantly on, awaiting a picture-taking opportunity. Unlike with the customized digital SLR cameras that companies such as Canon (www.canon.com), Fuji (www.fujifilm.com), Kodak, and Nikon (www.nikon.com) make, no electrical means exist for the camera to tell (e)film to "wake up." Initially, Silicon Film Technologies investigated using optical sensors at the edges of the (e)film module to detect an opening shutter. However, different camera companies, brands, and models used shutters with different directions of motion (left-to-right, right-to-left, top-to-bottom, and bottom-to-top), and Silicon Film Technologies was also unable to wake up (e)film with optical sensors in time to respond to fast shutter speeds.

Instead, (e)film employs a transducer, which does double duty as an acoustic sensor to detect the sound of a rising SLR mirror prior to the shutter's opening and a speaker to communicate valid-exposure and other status "beep" indications to the user. The 40-msec or slower delay between mirror rise and shutter opening in the numerous cameras that the company tested is sufficient time to transition (e)film from its 15-µA sleep mode to a fully-on mode ready to capture the image. Currently, Silicon Film Technologies advocates the use of (e)film only with newer auto-film-advance cameras. Manual film advancing to reset the shutter may cause noise that the transducer would incorrectly interpret as a rising mirror, resulting in unintended blank pictures. Highest operating current, roughly 200 mA, occurs in the 300-msec interval when (e)film reads data off the sensor. After (e)-film shuts off its analog subsystem, current draw drops to 100 mA for image processing and interleave writing to flash memory. Whenever you insert (e)film into (e)port, the combo powers itself using the USB or PC-card connections or via (e)box's AA batteries.

Silicon Film Technologies' power-prioritized trade-offs extended to a decision not to include an RTC (real-time clock) inside (e)film. The RTC would have provided a time and date stamp for each image when captured but would have decreased the number of shots per battery set by roughly 25%. The company gives particular praise to Actel (www.actel.com) and Xilinx (www.xilinx.com) for their respective low-power, single-chip 54SX08 antifuse FGPA and CoolRunner CPLD. Signal Processing Technologies' (www.spt.com) SPT7935 ADC delivered a unique blend of 12-bit precision at video-performance rates, along with low 3.3V power consumption, according to Silicon Film Technologies' engineers. To handle general system-housekeeping tasks, (e)film also includes an Atmel (www.atmel.com) AVR microcontroller.

ELECTRO-ORIGAMI

If you have seen a 35-mm film canister, you know how small it is. Subtract roughly 75% of the internal volume to comprehend (e)film's two batteries, and you have little space left for the remainder of the electronics. Therefore, (e)film uses a flexible circuit board, whose nonideal ground plane created no shortage of design headaches (**Figure 5, left**). Folding the pc board several times and manually inserting it into the housing achieved the required form factor (**Figure 5, right**). Silicon Film Technologies employed chip-scale packaging whenever available; Actel, in fact, accelerated its BGA-packaging schedules for this design. To keep costs down, bare die wasn't a feasible option.



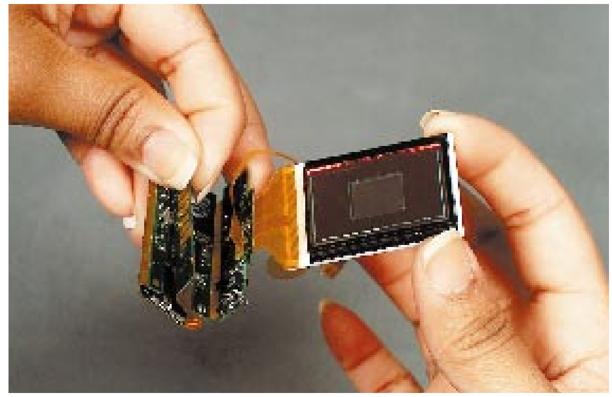


Figure 5 Squeezing two batteries and most of the (e)film's electronics (left) into a film-cartridge-sized form factor requires a mechanical-engineering magic act and manual dexterity (right). The left photo shows views of the pc-board top and bottom; each system requires only one circuit board (courtesy Silicon Film Technologies).

ISO 100 film has equivalent light sensitivity to (e)film. Silicon Film Technologies could have communicated this fact to the camera via an industry-standardized contact pattern on the canister. But the company found that if it chose this approach, the camera would automatically engage the auto-advance motor which, not sensing tension on the take-up spool, would subsequently indicate a "film-loading error." Fortunately, for demonstration and troubleshooting purposes, nearly all cameras operate without film, and they either default to ISO 100 or you can manually set them to this value.

Another (e)film challenge the company had to surmount dealt with TTL (through-the-lens) metering, a camera feature that adjusts the flash output during exposure to comprehend ambient-lighting conditions. Silicon Film Technologies ensured that the sensor-plus-surrounding-chassis combination, like film, reflected an average of 30% of light shining on it. Module thickness also required attention; the sensor-plus-protective-glass combination couldn't interfere with shutter operation. The company, in conjunction with Optical Coating Laboratory (www.ocli.com), applies an ultrathin infrared-filter coating between glass and sensor, and it implements a DSP-based, rather than optical, blur filter. Thickness tolerances even precluded the application of conventional epoxy-paint labeling for the product name; the company instead used laser marking.

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Different cameras have different cartridge-to-focal-plan spacings, an issue that necessitates multiple (e)film variants. In addition, (e)film must meet tight manufacturing tolerances to ensure that it's centered between the film rails and is almost perfectly coplanar. Of all the film-imitation challenges facing (e)film, perhaps the most vexing deals with image quality. How do you make a 1.3-megapixel sensor approximate conventional silver-halide film and match or exceed digital cameras that claim higher pixel counts?

Future products from Silicon Film Technologies, due out by year-end, will include both larger format and higher resolution sensors. For now, the company is making do with careful hardware and software design to maximize sensor and ADC dynamic range and minimize the effects of sensor-fixed pattern noise, pixel-to-pixel offset, and gain variations. A lot of "black magic" in the twain driver extracts maximum quality out of the captured image. Partner LizardTech's (www.lizardtech.com) Genuine Fractals technology employs intelligent interpolation to upscale the image resolution (**Reference 3**). And, unlike with "pure" digital cameras, an (e)film-equipped SLR can still use silver-halide film when you need the absolute highest quality.□

References

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Author's biography

Technical editor Brian Dipert is a photography hobbyist who uses Pentax 35-mm and 6×7 medium-format gear, Microtek flatbed and Polaroid film scanners, Adobe Photoshop and Hamrick Software VueScan, a Kodak digital camera, and a Canon large-format inkjet printer. Check out his Web site http://members.aol.com/bdipert (where you can see some of the pictures he's taken).