LEICA FOTOGRAFIE INTERNATIONAL

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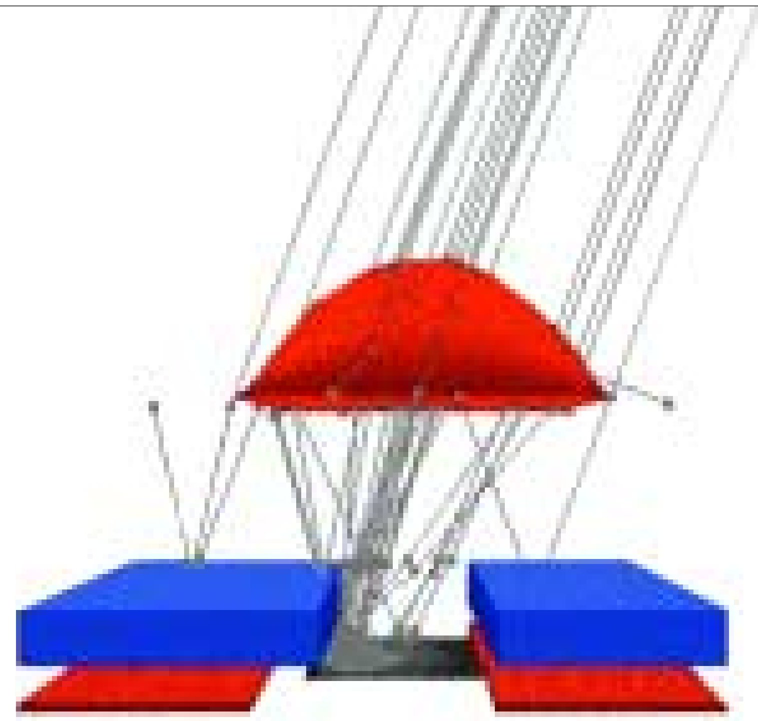
POSITIVE TRANSFORMATION

So far Leica's Digital Module R merely exists on paper, but first prototypes for the CCD image sensor are currently being developed by Eastman Kodak Company in Rochester, USA. We spoke to Brian Benamati from Kodak's Image Sensor Solutions (ISS) division about the development approach and the current state of affairs.

BY HOLGER SPARR

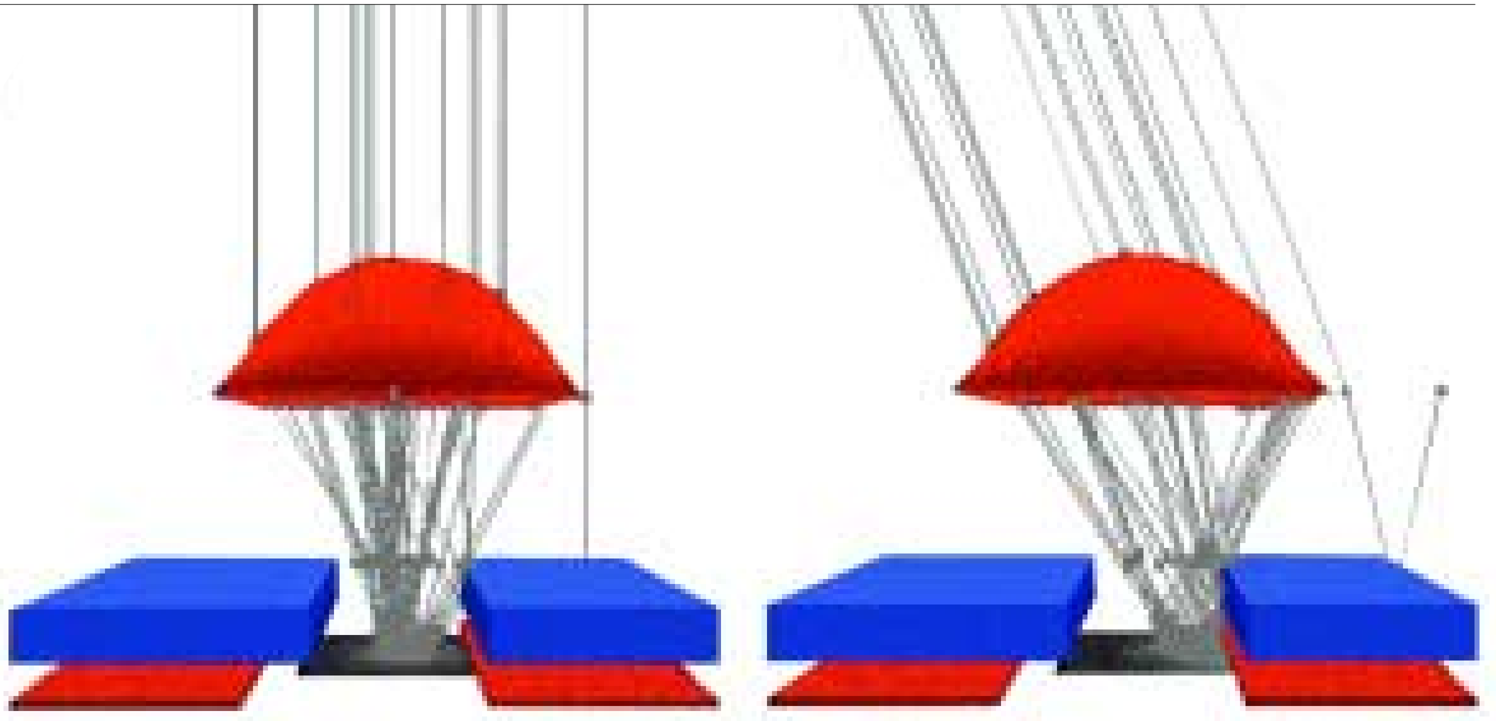


Waiting for a product such as Leica's R8/R9 digital back – the Digital Module R – is not easy. Leica initially announced that they would not be introducing a market ready product before autumn 2004, though now there is hardly an R user who would not love to know about the picture quality from the promised 10 mega pixels in combination with the R camera and lenses. Anyhow, there is one good thing about the early Digital Module-R announcement: we have been permitted to look over the shoulders of Leica's project partners, accompanying the project from start to finish.

For the ambitious project – being the first camera manufacturer to develop a digital back for a small format camera – Leica teamed up with two partners. Danish Imacon has years of experience developing and producing digital backs for medium format cameras. But before the Danes get going, Kodak needs to provide samples of the CCD image sensor, and this is just what the development team is busied with in Rochester. Though Kodak may be using one of their already established CCD architectures as a foundation, additional work and innovation was necessary for the Leica variant. Essentially, the 'KAF-10010CE' image sensor is based on an existing architecture with 6.8 µm pixels, and 'stretched' into a larger format. For example, this technology is used for the 5-million pixel, 4/3-type image sensor that is designed for new 'Four Thirds System' digital cameras such as the Olympus E-1. Kodak also builds image sensors for digital camera backs with noticeably larger light sensitive surfaces for medium format cameras, and here, too, Imacon is one of their customers.

Leica's digital camera back for the R8/R9 had several challenges in store for

Optical model of incident light rays through micro-lenses into pixel near the center and edges of the image sensor



the Kodak Image Sensor Solutions division, as product marketing engineer Brian Benamati elaborates in our interview on page 45. For example, the light sensitive area of the image sensor needed to be as large as possible, while being able to fit within the existing film plane of the Leica R8/R9 cameras. Also, there is only little space between the shutter and the film plane, so great care was taken in the CCD package and cover glass design. Since the user themself can mount and dismount the digital back, the top surface of the chip's glass cover needed to be particularly abrasion resistant in order to withstand the occasional cleaning.

HOW THE IMAGE SENSOR WORKS

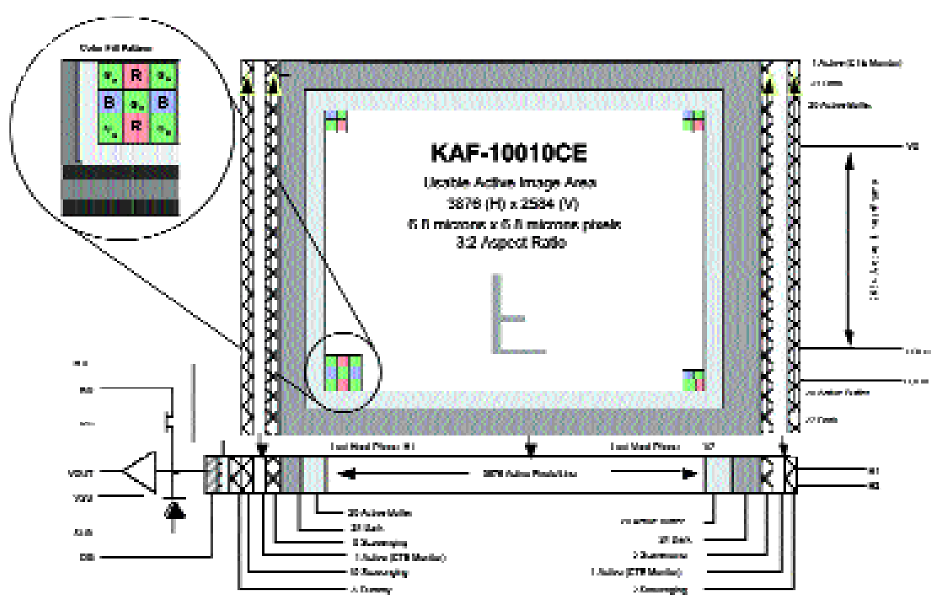
Imagine the light sensitive cells (pixels) like small detectors, which generate signal charge when the light photons are introduced from a scene through the camera lens. The cells convert these photons into electrons. A colour filter array with red, green and blue filters is integrated on the image sensor surface to ensure that colours are recognized. Additionally, an infrared cut-off filter is coated on the cover glass to eliminate wavelengths beyond the visible light. Since not all of the area within each cell is light sensitive microlenses are used over each cell to collect light for increased sensitivity. After exposure has taken place, the signal charge is stored and transferred in the vertical and then in the horizontal CCD register. This signal charge is converted to a voltage at the output amplifier and transferred to an analogue-digital converter in the camera, which transforms the information into a raw, digital image. At this point only one colour has been registered for each pixel. This is when the digital signal processor comes into play. It interpolates the missing colour information from the neighbouring pixels and performs other algorithms to improve image quality. The result is an image file that is saved on the memory chip inside the camera.

CRITICAL TECHNOLOGY DECISIONS

When developing an image sensor for a digital camera, one needs to take several things into consideration. Pixel size for example: smaller pixels on the same surface area may increase resolution, but they also collect less light, which leads the sensitivity of the sensor to decrease. With a pixel size of 6.8 µm, the sensor developed for Leica has very high spatial frequency providing high resolution images and uses micro-lenses to provide high sensitivity. Smaller pixels – often used for consumer digital cameras – generally decrease sensitivity and may be prone to have higher noise in low light conditions. This can be corrected through complex image processing, which may have a negative effect on picture quality.

Another landmark decision concerns the moiré filter, supposed to avoid false interpretation of fine details exceeding the resolution of the sensor. This can be an anti-aliasing filter attached directly on the chip's cover glass, or – what Leica and Imacon have planned – software imitating the process. Since moiré does not arise with most subjects, Leica's solution can be switched on and off, it is flexible, but still needs to prove itself in practice. However, Kodak's sensor is definitely being constructed without a moiré filter.

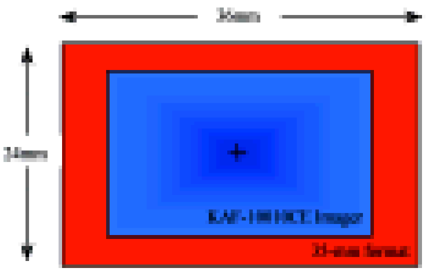
These technology selections will be demonstrated when Kodak delivers the first sensor test samples to Leica and Imacon, scheduled in December. That's when first digital back prototypes will begin assembly. What ever comes to pass, we will continue to follow the development of this exciting project.



Functional block diagram of the Kodak KAF-10010CE image sensor. Red, green and blue filters integrated on the image sensor surface ensure that colours are recognized

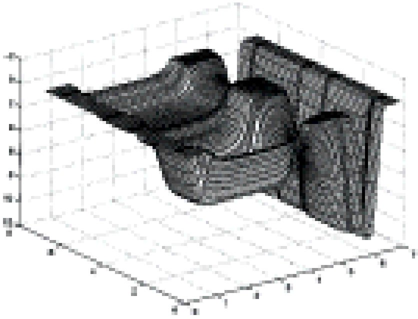
INTERVIEW WITH BRIAN BENAMATI

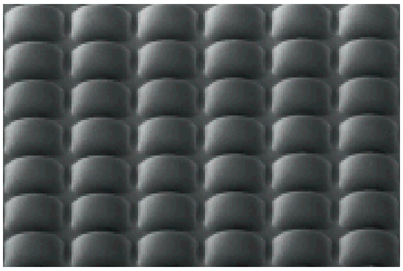
Product Marketing Engineer at Eastman Kodak Company, within the Image Sensor Solutions Division (ISS) in Rochester, USA



Photoactive area of the KAF-10010CE imager used in the Digital Module-R relative to the 35-mm film format

Below: three-dimensional model of Kodak 6.8 µm FF-CCD pixel illustrating the two-phase CCD and lateral overflow drain (LOD) architectures. Beneath: scanning electron micrograph (SEM) of micro-lenses over a many pixels





Brian Benamati joined Kodak in 1980. He has been involved with the development of CCD image sensors, manufacturing semiconductors, and since 2000, he has been a Product Marketing Engineer, concentrating on imager applications in the digital still camera marketplace.

LFI: How did Kodak, Leica and Imacon join together in a partnership to develop the Digital Module-R for Leica R8/R9 cameras?

Benamati: Leica selected Kodak ISS as the image sensor partner for this product because of Kodak's experience in the professional digital camera marketplace. Kodak ISS has proven experience in delivering high-performance image sensors into medium-format digital back and digital SLR camera applications, successfully partnering with a variety of camera makers. We strongly believed that our image sensor technology would be a perfect match for the Leica digital camera back product.

Were you surprised that Leica decided to pursue a digital back rather than designing a new digital camera from scratch?

Benamati: Actually, we thought that this approach made a lot of sense for Leica and their clients, who seek to have compatibility with their existing assets of camera equipment and lenses. We also observed that Leica was implementing design provisions in the R8 and R9 camera designs, such as electrical interconnects, which would enable interfacing with a digital back. We're excited to be a partner with the Leica and Imacon development teams to provide the photographic industry with this interchangeable digital back product.

What technology did Kodak ISS use for this new Leica camera product and why?

Benamati: We assessed this application with regard to the image quality and functionality, and we understood that photographers using Leica equipment are accustomed to very high image quality. For this purpose, we selected FF-CCD (full-frame charge coupled device) technology, based on our experience in the professional SLR camera market. We fully expect this customized FF-CCD will meet the customers' requirements for photoresponsivity, dynamic range (bit depth), and noise, among other key parameters.

What kind of challenges does this digital back present to the chipmaker?

Benamati: The interface of an image sensor into existing camera bodies places constraints on the chip design that must be engineered in terms of the optical, mechanical, and electrical disciplines. These constraints present problems that must be methodically assessed and solved with the chip design. This was especially challenging for the Leica Digital Module-R product because requirements include the interchangeability of the film and digital backs. For example, precautions must be taken for contamination (dust) control to ensure that the imager's focal plane remains clean.

You categorised the three design disciplines as optical, mechanical and electrical. Can you break down the key challenges that needed to be overcome and some of the unique approaches that were used? For instance, what were the key issues related to the optical design?

Benamati: The Leica requirements for the optical design were based on providing the largest photographic image that would work within the Leica R8/R9 cameras and lenses.

The film gate in the Leica R8/R9 is the size of a 35-mm film negative. Therefore the chip, including the package and cover glass assembly, determines the largest possible photographic area. The perimeter circuitry on the chip was designed to maximize the optically active photographic area of the imager and thereby minimize the photographic magnification factor. The photoactive area of the 3:2 aspect ratio imager is 26.4 mm x 17.6 mm. This results in a 32.2 mm diagonal, which is a 1.37 photographic multiplier relative to the 43.3 mm diagonal of a 35-mm format field.

Leica required a resolution that would provide the photographic detail that their customers have come to expect using the Leica lenses. Given the size of the imager's photographic area, Kodak ISS selected the use of a 6.8 µm pixel, which yielded a pixel count of 3,976 x 2,584. This provides 10-million pixels of resolution, enabling finished file sizes of 30 MB and assuring 300 pixels per inch for 8 x 12-inch image sizes.

Because the Leica R8/R9 cameras are highly portable and used in various illumination conditions, a wide range of photosensitivity (effective ISO) was required from the image sensor. In order to accomplish this, micro-lenses were incorporated over each of the pixels. These micro-lenses serve to improve the pixels' quantum efficiency by refracting incoming light rays from less sensitive areas of the pixel to more highly sensitive areas of the pixel. As such, more light is collected from the scene, which improves the photosensitivity. In an imager architecture used for the Kodak KAF-10010CE Image Sensor for the Leica Digital Module-R, a factor of 2x, or one photographic stop, is accomplished.

To meet Leica's strategy for compatibility, the image sensor was required to work with the entire set of Leica R lenses. Of key importance was the angle of the incidence for light rays introduced to the imager surface. This ranges from 9 degrees to 15 degrees for the primary ray at the extreme corners of the KAF-10010CE Image Sensor. Care must be taken with regard to optimizing the micro-lenses for these effects.

Since the Leica R8/R9 cameras have focal plane shutters, there is minimal distance in the 'z' direction between the image sensor and the shutter blades. As such, all optical filters after the taking lens must be incorporated on the imager sensor cover glass. This includes a topside anti-reflective (AR) coating to minimize optical flare and a bottom-side infrared (IR) cut-off filter to extinguish unwanted illumination in the wavelengths beyond 700 nm. In addition, the AR coating was required to meet optical coating standards for abrasion resistance to ensure its integrity for cleaning procedures.

What were the major challenges involved with the mechanical design of the imager assembly?

Benamati: Because the 'film gate' of the Leica R8/R9 cameras was already established as an absolute constraint, care was taken into the design of the imager assembly, including the silicon chip, the ceramic package, and the cover glass. For example, the optical focal plane of the imager must be assembled with precision relative to the mechanical focal plane in the 'z' direction within the camera. This requires tight control of the silicon surface flatness and placement.

The photoactive area of the image sensor must also be precisely placed in the translational directions of 'x' and 'y' relative to the optical center of the camera as well as having minimal rotational error 'theta'.

Once the imager has been positioned precisely, relative to the focal plane and optical center of the camera, there must be sufficient clearance to ensure that no interference results for all conditions in which the camera will be used. This required significant design cooperation between all partners involved.

Finally, in order to minimize the undesired effects of heat generation within the camera, passive cooling design solutions were implemented that require thermal contact to the backside of the imager package assembly.

What were the critical electrical design considerations to be addressed?

Benamati: In order to achieve the stated frame rate of two frames per second at a resolution of 10-million pixels, the operating conditions of the vertical CCD, horizontal CCD, and output amplifier had to be optimized. This was accomplished in a manner that provides high image quality and minimizes power consumption. While multiple outputs could achieve higher frame rates, the product requirements for best-possible image quality resulted in the decision to use a single output, thereby avoiding readout concerns from multiple outputs.

To minimize power consumption and horizontal clock noise, a low-voltage design and process was implemented.

An operating frequency of 24 MHz is used for the horizontal CCD and output amplifier circuits to provide two frames per second continuous burst rate. This requires precise analog front-end circuits for readout. All circuits around the photoactive area, including bond pads, electrostatic discharge (ESD) circuits, metal routing, and amplifier stages were designed to minimize the chip size without compromising performance.

How were all of these requirements managed in the sensor design process?

Benamati: A series of conceptual design reviews, followed by preliminary and final design reviews were held in cooperation with Kodak ISS, Leica and Imacon. The resulting action items were methodically addressed until all parties were jointly satisfied.

How will the digital back compare to traditional film material in terms of picture quality? And how was a resolution of 10-million pixels chosen for this product?

Benamati: Kodak generally refrains from making comparisons between digital and film because this is very difficult to quantify. Based on our experiences, we can say that a sensor with 10-M pixels of resolution, coupled with the imager's high photoresponsitivity, wide dynamic range, and low noise will result in stunning , professional image quality for prints as large as 20 by 30 inches. The Leica Digital Module-R camera system will host the highest resolution CCD image sensor of any 35-mm SLR camera available in the marketplace today.

What is the progress report and what are the next stages for the image sensor development?

Benamati: The progress report is favorable with initial silicon wafers that have been completed through the fabrication process and wafer-probe yielding devices that meet the preliminary product specs. The next stage is to assemble these chips into packages with cover glass and fully characterize their performance. The parts will then be ready for building the first prototype camera systems.

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