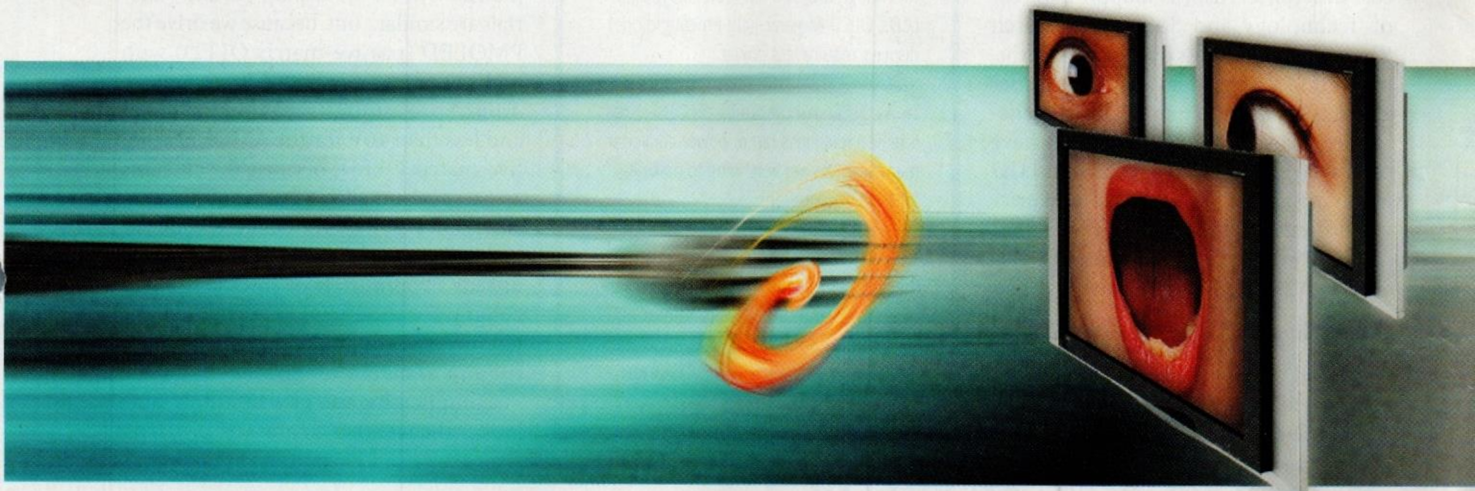


Powering OLEDs: the care and feeding of organic displays

ORGANIC-LED GRAPHICS DISPLAYS ARE TAKING ON LCDs FOR IMAGE QUALITY AND LOW-POWER OPERATION.

IMPROVING YIELDS and declining manufacturing costs are contributing to a steady ramp in OLED (organic-light-emitting-diode) display usage. In response, several semiconductor manufacturers have begun to offer power-converter ICs for OLED- and LCD-bias supplies that give OEM designers flexibility in how they implement the display power subsystem. Though IC makers have not strictly optimized these power controllers for OLEDs, these devices do help preserve the OLED's superior energy efficiency and take advantage of the economies of scale that the LCD segment of the display market offers.

Among the first commercial applications for monochrome OLEDs were small, low-resolution, front-panel displays in portable measurement instrumentation and in entertainment devices. Since manufacturing processes have matured, the technology has enjoyed greater commercial success as secondary displays in clam-shell mobile phones.

Color OLEDs first found homes in analog and digital camcorders and in digital cameras as eyepiece viewfinders, in which they fit well with OEMs' trends toward smaller, higher resolution cameras. Since those first color OLEDs, display manufacturers have been improving fabrication processes and display designs to reduce cost, improve performance, and increase robustness.

Unlike LCDs, which behave like voltage-controlled translucent shutters, OLEDs are light emitters and so do not need a backlight. Current OLED displays offer better energy efficiency, image quality, ruggedness, and low-temperature performance than do LCDs. For the time being, they are also more expensive, but continuing yield improvements and market penetration are narrowing the cost difference. Also, as iSuppli Director of Technology and Strategic Research Kimberly Allen points out, "Kodak's original [OLED-technology] patents are beginning to expire." The associated licensing-fee load that OLED vendors have been bearing is likewise expiring. LCD manufacturers have responded, and pricing differences continue to favor their displays, whereas image quality and efficiency go to the OLED displays.

DRIVING MILLIWATTS WITH MICROWATTS

Not all OLED displays are created equal; their power-supply requirements reflect their differences. The two fundamental display structures are passive matrix and active matrix (see **sidebar** "The matrix: OLEDs on display"). "The materials are similar...but, because we drive the PMOLED (passive-matrix OLED) with higher current, we have higher voltage drops. So [PMOLEDs require] up to 20V and less than 10V for the AMOLED (active-matrix OLED) because the currents are so much smaller," observes STMicroelectronics OLED Product Line Manager Joel Roibet. "The currents are in the range of tens or hundreds of microamps per column for the PMOLED display; some tens or even single-digit microamps per column in the AMOLED."

Complicating the power-supply outlook is the fact that "many active-matrix

AT A GLANCE

- ▷ Though they remain more costly than LCDs, OLED (organic-light-emitting-diode) displays require less power.
- ▷ As OLED manufacturing processes mature and quantities ramp, power-converter manufacturers are beginning to make ICs for OLED applications.
- ▷ One size does not fit all: Depending on the type of OLED display, the required supply voltages and currents vary. The word "OLED" on a power converter's application list does not guarantee that the device is appropriate for your display.

E MATRIX: OLEDs ON DISPLAY

There are fundamentally two ways of forming an OLED (organic-light-emitting-diode) pixel array: passive matrix (PMOLED) and active matrix (AMOLED). The two share similar LED structures (**Figure A**) but address each cell differently. Electrons flow from the cathode to the anode, and holes account for a counter-current. Recombination releases photons in an organic emission-material layer. The light output is, therefore, proportional to current, subtracting for optical losses.

The advantage of such a pixel structure is striking when you compare it with other thin-display technologies, such as LCDs. The LCD requires a backlight and uses shutterlike pixels to locally valve the display's optical transmission. From an energy perspective, this approach is analogous to driving with the gas pedal pushed to the floorboard while you modulate your speed with the brake. Instead, the OLED display produces the light needed to form an image, analogous to opening the throttle of your car's engine only as much as needed to drive at the speed you want. OLEDs and LCD backlights do not produce photons with equal efficiency. However, most photons an LCD backlight emit never see the light of day anyway, so OLED displays are more energy-efficient overall.

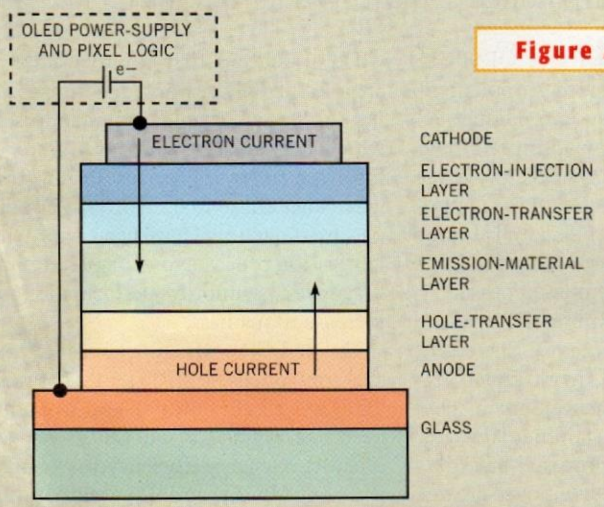
The two kinds of OLED displays differ in how they address pixels. In a passive display, conductive rows and columns form a matrix. The manufacturing process forms OLED structures in the spaces between the matrix conductors at each intersection. As the display controller scans the rows, current flows to columns containing a lit pixel. The pixel is lit, however, only as long as the controller addresses the row its in, so the current duty cycle is inversely proportional to the number of rows, and the peak current is directly proportional to the same number. The perceived brightness is proportional to the time integral of the current over the frame interval. During the next frame, the controller can refresh the pixel, giving the viewer the impression of a persistent image.

AMOLED displays use TFTs (thin-film transistors) at each pixel to latch a drive signal for the duration of the frame interval. The controller scans the rows as in the PMOLED case, but here it programs the pixel with a gate-drive voltage that persists between refreshes. The TFT-pixel control sets and maintains the OLED current. The peak and average current are the same throughout the frame. Since the AMOLED current is 1/nth of the PMOLED current for an n-row device, the resistive losses in the cathode, anode, and matrix are reduced by like proportion.

Enhanced energy efficiency is not the only benefit of the AMOLED structure. Because of the shrinking duty cycle with larger displays, PMOLEDs are limited to about 200 rows. This figure is neither precise nor even fixed; it can increase as process technologies and light-emitting polymer chemistries improve. However, for any given process and chemistry, the maximum practical number of rows is limited. Active-matrix devices are not limited in this way, and many manufacturers hold out the prospect of arbitrarily large displays limited by manufacturing-defect density and controller capability.

The other advantage of AMOLED displays is that the pixels enjoy a unity peak-to-average current ratio instead of the PMOLED pixel's n-to-one ratio. This difference drives an aging effect that is proportional to current density.

Figure A



A two-dimensional schematic of a basic OLED structure shows the diode formed with a light-emitting polymer (courtesy Samsung).

LCD [and] OLED...subsystems in cell phones, digital cameras and other portable devices require positive and negative low-current bias supplies," observes Advanced Analogic Technologies Vice President Jan Nilsson. The AAT3190 from Advanced Analogic Technologies addresses this requirement by generating both positive and negative supplies with one chip using a self-clocking dual-charge-pump architecture that operates at a nominal 1-MHz switching frequency (**Figure 1**). The charge pump develops adjustable outputs to a maximum of ±25V from a unipolar input supply of 2.7 to 5.5V.

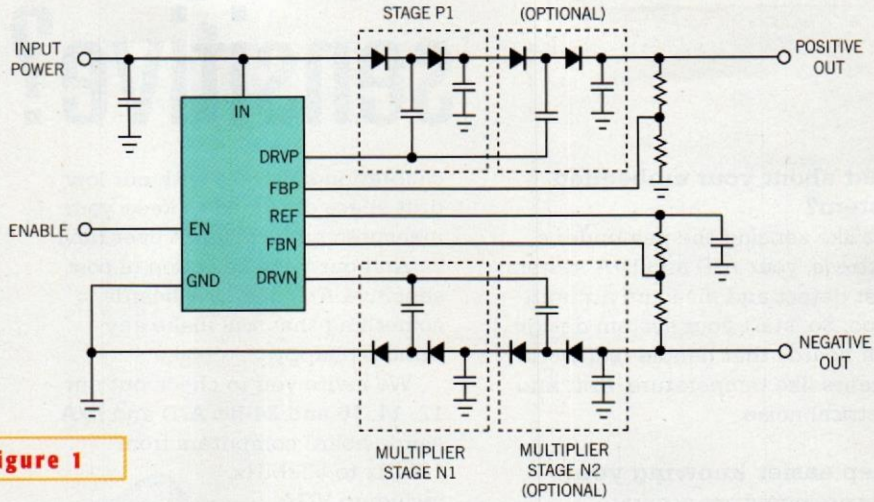


Figure 1

The AAT3190 from Advanced Analogic Technologies has two charge-pump outputs that drive diode/capacitor multiplier stages. You can scale the output voltage by cascading multiple stages.

The voltage controller requires no inductors, which often challenge board-height limits in small, portable devices. Instead, each pump drives external diode/capacitor multiplier stages. You can cascade multiplier stages to scale the output voltages. An external resistive divider on each output provides a feedback signal to the converter. The tolerance on the feedback regulation voltage is 50 mV, or about 4% for the positive supply and 100 mV for the negative. The chip's pump-drive pins can each deliver an absolute maximum 200 mA, and Advanced Analogic Technologies characterizes the part's efficiency and load regulation to 40 mA. Because the two drive pins pump all of the stages for their given polarity, the load current the multiplier cascade can deliver scales inversely with the number of stages.

The $1.73 (1000) AAT3190 provides soft-start, undervoltage lockout, and a shutdown mode that reduces the converter's quiescent current from a maximum of 800 μA to no more than 1 μA. Advanced Analogic Technologies offers the AAT3190 in MSOP-8 and TSOP-12 packages.

GIVING OLEDs A BOOST

For unipolar-display applications, Fairchild Semiconductor offers the FAN5331 boost converter. Like the AAT3190, the FAN5331 operates at a high switching rate—in this case, 1.6 MHz, to reduce the size of external reactive components, so, although the boost topology requires an inductor, this converter requires only 10 mH. The small SOT23-5 package and comparatively few external parts help minimize your display's power supply.

The FAN5331 can deliver a minimum of 35 mA at 15V over its full input range in steady state. With inputs of 3.2V or more, the current capability rises to 50 mA under similar operating conditions. Additionally, the converter's fractional-ohm output switch can deliver a 1A peak current; a cycle-by-cycle current-limit monitor ensures that the peak output current stays within this limit.

The 50-cent (1000) IC draws 2 μA in shutdown mode. A resistive divider allows you to set the output voltage to between the input voltage and the converter's 20V maximum. The nominal 1.23V feedback voltage has a tolerance of 25 mV.

Fast clock rates and correspondingly small inductors indicate a trend in boost converters for thin portable devices, whereas traditionally lower clock speeds have called for larger magnetics, which posed layout- and mechanical-design challenges. Despite these and other challenges, small-supply designers have long appreciated the boost converter's performance advantages. As Linear Technology's Senior Design Engineer Eddy Wells points out, "A traditional boost converter offers more efficient operation and a greater range of step-up ratios, but boost-[converter supplies] typically take more space, and systems issues, such as inrush current and short-circuit protection, are often solved with added external circuitry."

Linear Technology's LTC3459 exemplifies a group of boost converters that address these application concerns. The 3459 provides a burst mode that maintains the converter's efficiency with light load currents and features inrush current limiting, short-circuit protection, and load isolation during shutdown. Despite the feature list, a typical application circuit requires only three capacitors, two resistors, and a boost inductor in the switching circuit (**Figure 2**). Wells observes that, because "the converter operates with a low peak current of approximately 75 mA, an 0805 miniature inductor...[facilitates]

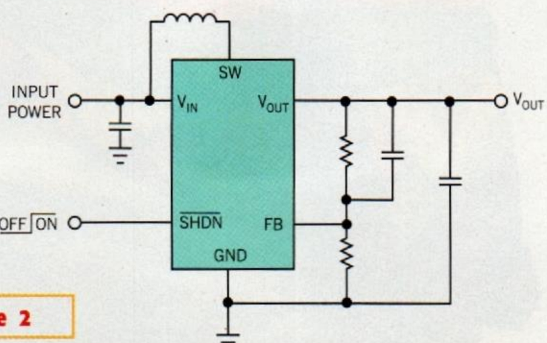


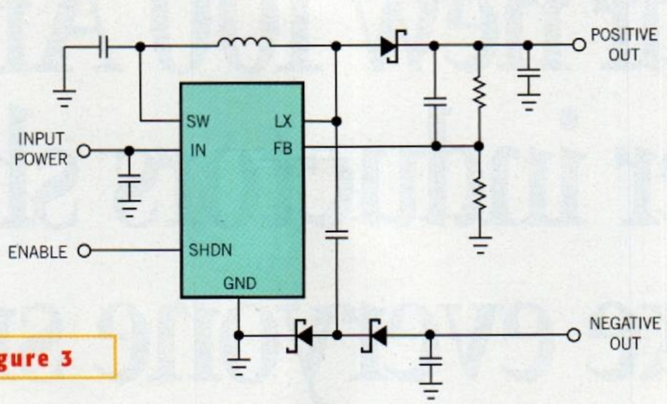
Figure 2

The AAT3190 from Advanced Analogic Technologies has two charge-pump outputs that drive diode/capacitor multiplier stages. You can scale the output voltage by cascading multiple stages.

a footprint similar to an [integrated] charge pump."

The SOT23-6 IC can operate on a 1.5 to 5.5V input and provide a 2.5 to 10V output—appropriate for active-matrix OLED displays. Unlike many other low-power converters that operate with a fixed clock frequency, the 3459 uses a variable switching rate that self-adjusts depending on the input-output differential from about 0.6 to more than 2.6 MHz. The feedback reference is 1.22V with a tolerance of 30 mV. The $1.95 (1000) converter requires a maximum 20-μA quiescent current. When the device is in shutdown mode, the residual operating current reduces to less than 1 μA.

Figure 3



Boost converters that give you access to the inductor's switching signal allow you to build a coarse negative supply at the cost of only a few external components (courtesy Maxim Integrated Products).

Maxim's MAX8570 is one of a quintet of boost converters for low-current applications, including OLED displays and LCDs. The 8570 features an adjustable output voltage, and Maxim characterizes the converter at load currents as large as 5 mA. They characterize the other members of the family, which include the 8571 and 8573 to 15 mA and the 8574 and 8575 to 25 mA. They offer models with either adjustable or fixed 15V outputs at the two larger currents. The boost controllers operate on input supplies of 2.7 to 5.5V; the adjustable models offer an output range of 3 to 28V and have a reference tolerance of 19 mV. The 857x family of converters provide soft start, undervoltage lockout, and current limiting. An active-low shutdown pin reduces the device's quiescent current from 50 μA to 1 μA. Maxim offers the $1.25 (1000) 857x family in SOT23-6 packages.

Comparing the three boost converters from Maxim, Linear Technology, and Fairchild reveals subtle benefits to both greater and lesser levels of integration, depending on your application and again shows that, even in products as conceptually simple as a boost converter, there's no such thing as one best approach to the topology. The LTC3459 isolates its output from the boost inductor with an on-chip PMOS device that has a typical channel resistance on the order of 4Ω. As a result, the application circuit does without the Schottky diode common to many boost-converter circuits, and correspondingly reduces layout area and the bill-of-materials and assembly costs, if only incrementally.

The Fairchild FAN5331 and the Maxim MAX8570 and its kin use an external Schottky, which imposes a junction-voltage overhead on the order of 400 mV as well as an incremental forward resistance of several ohms. The advantage of the external Schottky diode, however, is that it brings the switching waveform off chip where you can use it, for example, to charge-pump a coarse negative supply as Maxim points out in one of its application circuits (**Figure 3**).

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The TPS65130 boost controller/inverter from Texas Instruments can develop ±15V output rails from a 2.7 to 5.5V input. The control topology uses a fixed-frequency, 1.25-MHz PWM switching signal. A low-power mode uses pulse skipping to supply light load currents. The TPS65130 can deliver load currents as large as 200 mA, and the converter's 500-μA quiescent current falls to 1.5 μA in shutdown mode.

The $2.95 (1000) IC is a more "pinny" device than most others, residing as it does in a QFN-24, but the extra connections also provide extra features, such as independent positive- and negative-supply enable inputs that allow you to control supply sequencing. An output to control an external PMOS device can isolate the battery from the boost circuit. In addition to the external PMOS device, however, the application circuit includes two inductors, two Schottky diodes, five resistors, and eight capacitors. These external parts may seem like a lot, particularly in comparison with the lower current single-output boost converters, but the parts count is on the same order as that for the dual charge pump.

The variety of power converters for OLED applications is bound to continue expanding, particularly in current capability and features as OLEDs establish a stronger market position in the overall display-technology mix. "The market for OLED displays is expected to top $1 billion by 2006, with rapid growth driven by a shift from monochrome to color," predicts iSuppli's Allen. In addition to the shift toward color displays, the clear trend is toward active-matrix OLEDs that can support much larger screens than can passive-matrix displays.□

FOR MORE INFORMATION

For more information on products such as those discussed in this article, contact any of the following manufacturers directly, and please let them know you read about their products in *EDN*.

Advanced Analogic Technologies
www.analogictech.com

Fairchild Semiconductor
www.fairchildsemi.com

iSuppli
www.isuppli.com

Linear Technologies
www.linear.com

Maxim Integrated Products
www.maxim-ic.com

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of a 65-nm half-pitch is in development and expected to be available for volume production in 2007.

ENGINEERING CHALLENGES

As semiconductor technology has progressed from 2 microns, to today's 90-nm processes, and on to 65 nm, the number of design elements that have gone from being fixed or "given" to being variable has been increasing. In many cases, this situation requires a trade-off among speed, area, power, and yield. Designers make these trade-offs following design rules that the foundry provides. As the half-pitch decreases, the number of rules increases by several factors. When working with 90-nm geometries, an engineer must consider more than 500 rules when making a design decision. **Reference 2** discusses the issues involved in DFM (design for manufacturing).

Engineers need circuit-design expertise to make correct decisions when dealing with such multidimensional problems. Unfortunately, the industry has convinced the US education system that logic designers need to understand little, if any, physics and electronics theory to develop good designs. In fact, some EDA companies are even advertising that software engineers can create good electronic circuits. Such an assertion is credible only for simple circuits that designers implement on FPGAs or structured ASICs. Engineers cannot confront problems at 90 nm and below without understanding circuit design, and design teams often require an engineering expert in semiconductor-manufacturing issues.

Many problems stem from the need to use lithography equipment that uses a 193-nm wavelength as the illuminating source when the half-pitch of the resulting geometries is 65 nm. To produce a good circuit using the 90-nm process, manufacturers must use RET (reticle-enhancement technology) and OPC (optical phase correction). Both techniques modify the pattern of light to expose the photoresist layer, with dimensions almost half the size of the wavelength of the light source.

What designers see when they look at the prefabrication layout of a chip is no longer what they get. **Figure 1** shows an intended pattern in green, an actual pattern without RET/OPC corrections in purple, and a couple of actual geometries using different combinations of corrections. The circuitry in purple would result in nonworking silicon. Even with the best feasible corrective measures, designers can only approximate the desired shapes. The choice of various corrective measures impacts speed, power, and yield, and the amount of OPC impacts the area. Making the correct decision is generally the critical contribution to product profitability. Stone Pillar Technologies offers products that interconnect the process and mask details with subsequent electrical-test or yield data to provide engineers with insight into the likely cause of failure.

Iroc Technology maintains that reliability is becoming the fifth element to consider in the design process. Soft errors are the dominant causes of reliability failures. Cosmic rays impacting the silicon circuitry cause most of these failures. Iroc has established that the average soft-error FIT (failure-in-time) rate on 130 nm or less is around 500 per megabyte of memory. This value is almost 100 times the classic reliability numbers and 10 times the general market requirements. To ensure continued proper functioning, engineers must design error-correction circuitry into each design.

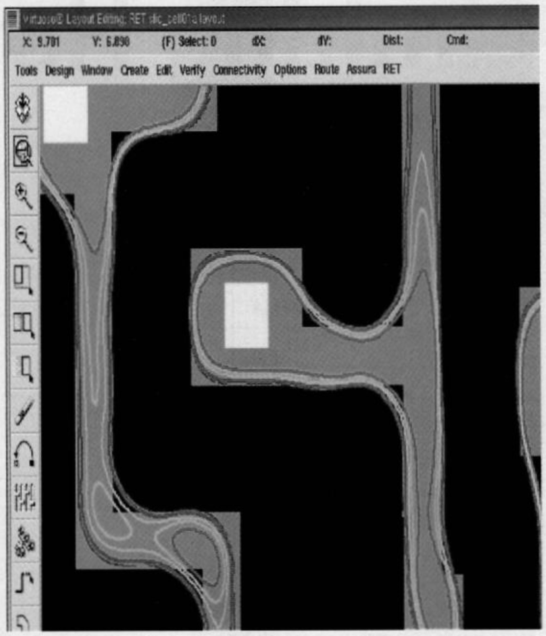

Figure 1 RET/OPC techniques at 90 nm improve the results of optical exposure on the die.

Although Mentor's early understanding of the lithography problem and decision to dedicate engineering resources to work with foundries before the situation became critical has given it a commanding lead in the RET/OPC market, both Cadence and Synopsys are investing significant resources in the area. Synopsys has obtained much-needed knowledge of the required technology following its acquisition of Numerical Technology, and Cadence is working closely with MaskTools, an ASML company.

Designers can no longer limit themselves to understanding the problem and lingo of digital design. When working with 65-nm processes, they will need to work closely with and understand mask designers, manufacturing engineers, and even process-development technologists. It will no longer be sufficient to understand the terminology; team members will need to appreciate the nature and seriousness of each problem they encounter.

Andrzej Strojwas, chief technologist at PDF Solutions contends, "DFM rules must complement design rules in nanotechnology," noting that DFM rules intrinsically differ from design rules but not necessarily sufficiently to achieve good yields. "For example, typical 90-nm DFM rules recommend doubling vias as well as spreading wires to minimize critical area. However, adding the metal needed for doubling vias will increase the critical area of the metal. For technologies with low-k dielectrics, this [step] may lead to an increase in stress and eventually cracking of the dielectric, causing the yield to drop. With so many rules, designers are facing contradictory directives and cannot be sure that they have [made] the correct choice until the ASIC is produced. At this point, correcting the design [becomes] quite expensive."

MANAGEMENT CHALLENGES

Although the engineering challenges are severe, managers also face a serious increase in job complexity (**Figure 2**). In a presentation at September's Chartered Semiconductor Technology Forum in San Jose, CA, Walter Lange, PhD, a field