The World Is Analog

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The world we live in is analog. We are analog. Any inputs we can perceive are analog. For example, sounds are analog signals; they are continuous time and continuous value. Our ears listen to analog signals and we speak with analog signals. Images, pictures, and video are all analog at the source and our eyes are analog sensors. Measuring our heartbeat, tracking our activity, all requires processing analog sensor information.

Computers are digital. Information is represented with discrete time and amplitude quantized signals using digital bits. Such representation lends itself to efficient processing and long-term storage of signals and information. But information and signals come from the physical world and need to move back into the physical world for us to perceive them. No matter how "digital" our electronic devices get, they always require interfaces that translate signals from the physical world into the digital world of electronics.

Even when computers talk to computers, analog interfaces are required. To transmit information over long distances (e.g., over a high-speed bus between the memory and the processor or over a wired network connection), the digital information needs to be moved into an analog format at the transmitter to drive the communication channel. At the receiver, the signals typically picked up from the channel do not look anymore like digital signals and need to be processed in the analog domain before they can be converted back into digital information. This is even more so if we consider wireless communications, where the digital information needs to be modulated on a high-speed radio-frequency (RF) carrier in the transmitter and demodulated at the receiver. RF electronics are also analog in nature.

The semiconductor industry has lived through tremendous advances fueled by what is known as Moore's law: about every two years, thanks to increasing device miniaturization, the number of devices on a chip doubles. This exponential scaling has led to unprecedented advances in computing and software and has made the digitization of most information possible. Our literature, music, movies, and pictures are all processed and stored in digital format nowadays. Digital chips make up most of the volume of chips fabricated and it is thus economically desirable to fine-tune CMOS technologies for digital circuits. But electronic systems need analog interfaces to connect the bits to the world and most consumer products now rely on System-on-Chip (SoC) solutions where one integrated circuit contains the whole system function, from interfaces to digital signal processing and memory blocks. SoCs need a lot of analog interfaces, but their area is mainly composed of digital blocks (often over 90%). As technology scales, the performance of the digital core improves and this in turn increases the requirements of the analog interfaces.

Today's analog designers are thus asked to design more interfaces with higher performance but using circuits that are as compatible with digital circuits as possible. This trend emerged a few decades ago and has grown stronger and stronger driven by the continuing increase of the functional density of SoCs. Not only do SoCs need more interfaces and better interfaces, the analog performance of highly miniaturized devices like nanometer CMOS transistors has steadily degraded.

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Making nanoscale transistors is great to increase the functional density, but has its drawbacks when designing analog circuits. Nanoscale transistors can only withstand small supply voltages. For example, circuits designed with the latest CMOS transistors can only work with a supply voltage of up to 1 V or so. Traditionally analog circuits operated from voltages as large as +5 V/–5 V, but steadily their supply voltage was forced to reduce to 5 V, to 3.3 V, to 1.8 V, to 1.2 V and projections for future devices are as low as 0.5 V or even 0.2 V since reducing supply voltages also helps digital designs reduce energy consumption. However, for analog circuits, reducing the supply voltage increases their susceptibility to noise or interference and degrades signal quality. To add to the difficulties, nanoscale transistors also exhibit more mismatches, leading to random offset errors, more flicker (1/f) noise, and have poor gain performance.

But analog designers always like to rise up to a challenge. Research in academic and industrial groups has devised a number of novel analog design techniques to build better analog circuits while relying less and less on the performance of an individual device. In my group, for example, we have developed a set of design techniques to design analog circuits that operate with supplies as low as 0.5 V.

Scaling also offers new avenues for designing analog circuits. In nanoscale processes transistors are not able to handle large voltages, but they can intrinsically switch very fast. That allows us to introduce different signal representations at the transistor level for analog functions. Instead of using the traditional voltages or currents, we can now use time delays to represent analog information. This opens a whole range of opportunities to explore new circuits. Technology scaling is driving a paradigm shift in analog design away from the transistor used as a current source or voltage-controlled current source towards the transistor used as a fast switch even when processing analog information. In fact, analog circuits are being built out of what traditionally are digital blocks like switches or ring oscillators. But with the appropriate signal representation and circuit arrangements, they can process analog information to provide interfaces between the real world and the digital world.

The analog electronics field is going through very exciting times. The digital revolution in electronics has made analog even more necessary. And the future is looking bright. Mobile devices are packed with analog interfaces and a host of analog sensors, whose count increases with each new generation. The Internet of Things is all about massively gathering sensor information in one form of another, under strict power-consumption and cost constraints. All this while the traditional analog design techniques are clearly showing their limitations in the face of aggressive device scaling. This makes for a very challenging but a very interesting time for analog designers with plenty of opportunities to make an impact. Analog is the future!

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