THE FOUR DEES OF ANALOG, *circa* 2025

By Barrie Gilbert [barrie.gilbert@analog.com]

The young woman standing at the BlueBoard, wearing the least-casual consumables she could find on the cybermall for this important occasion, is Niku Yeng. Aware that every aspect of her interview is being net-vetted—via this fusion of the old whiteboard, HDTV plasma display, two-way mirror, noncontact stress monitor and data link—she is looking a little concerned; but not because of this familiar tool. At the outset, she felt very confident. Her curriculum at Nova Terra University had covered all the major topics of the day. But after an hour of grilling, she felt her hopes of employment at Analog Devices fading, as question after probing question had been so unexpectedly related to fundamental issues.

She'd been asked: "Why are resistors noisy?"; "State the noise-spectral-density of a 50-Ω resistor."; "Show me how the forward voltage of a PN junction varies with temperature."; "What are the essential differences between bipolar transistors—such as today's 25 THz HBTs—and, say, a 10-nm MOS transistor?"; "What causes shot noise?"; "Where do you think the designer of this amplifier got the idea for its topology?" Rather than testing her knowledge of advanced signal processing, modern tools for the rapid realization of microsyms, or even the standard circuit cells in the realm of continuous-value analog (CVA) techniques, the questions seemed aimed at assessing her ability to *invent* circuit solutions—on the spot!—from *fundamental* properties of circuit elements.

This way of thinking about analog design differed greatly from what she'd learned at Nova Terra. Advised of today's extreme emphasis on quick-turn delivery and totally reproducible performance, Niku's emphasis in her Ph.D. thesis was concerned with design and routing tools for F-cell re-use, by developers of microsyms called *Fusers*. (An *F-cell* is a simple functional unit of less than, say, a thousand elements.) Nowadays, the word "transistor" is rarely heard among the Fusers, since the mazes of devices in today's products are merged to the degree that individual elements are indistinguishable. Few Fusers know—or *need* to know—anything about the physical properties of an isolated element. But she was aware that this cannot be said of the *originators*—those who design basic cells from ground zero. It seemed that Analog Devices was currently interested in hiring people of that sort.

Fortunately, her electives had covered the concepts of binary-value analog (BVA—or "binanalog") circuits quite well. She was clear about how the broad class of sigmadel cells work, and familiar with what used to be called "Class-D" amplifiers, using fully switching output devices and duty-cycle modulation—the basis of the sigmadel paradigm—to efficiently deliver generous amounts of audio power. Nowadays, using highly elaborated forms, almost indistinguishable from digital VLSI, binanalog products are ubiquitous. Since about 2010, Class-D amplifiers have been regarded, even by audiophiles, as the most accurate load-driving elements. Sigmadel products using similar output stages now power antennas well into the gigahertz range, thanks to the extremely low inertia of modern transistors and the use of low-loss resonators to convert all the power to the fundamental carrier frequency.

The LEIF (Local E-net Interview Facilitator) turned to probing her perception of how invention and innovation occur in modern companies. Like her fellow students, Niku used the CyberLearn™ system to access an abundance of information. But she's learning from Dr. Leif (coincidentally eponymous) that accumulating information cannot be equated with acquiring knowledge, which is far more profound. Knowledge is about knowing the value of information, skimmed from numerous sources; then filtered, distilled, adapted, extended, assimilated and finally sublimated into a whole, with a set of contextual hooks, in each individual mind, each holding a peculiar world view—a highly differentiated and unique model of reality. "*Knowledge is information activated by thought*," he had told her.

Job interviews aren't usually intended to be mentoring experiences; but Niku was already seeing the prospect of a career in analog design in a new and invigorating light. The old mantra "Analog means antiquated" had emerged from subliminal messages in wave after wave of ads, proclaiming the benefits of "going digital," which conveniently neglected to mention the continued importance of challenges in the real world of analog processors.

"Analog design," said Dr. Leif, "requires one to think in the many dimensions that characterize physical elements and signals. It calls for meticulous attention to minuscule details, always bound by the Fundaments." She'd learned that meant all of the physics of materials and the ground rules governing what can and (probably) cannot be realized in practice. "Analog design can be summed up by the Four Dees, which I briefly mentioned earlier."

Although she'd forgotten what "Four Dees" referred to, the insights gained during the past hour were now illuminating Niku's vision of an exciting future in analog, as an originator. As the interview drew to a close, her eyes twinkling with genuine enthusiasm, she said: "Dr. Leif, thank you for being so generous with your time. I've learned a great deal, and it's apparent you have a deep knowledge of what you call 'The Fundaments.' I'm sure you also have many recollections of the analog world at the beginning of the century. If you'd allow me to buy you coffee at Galaxybux, I'd love to continue this conversation just a little longer."

Leif's smile broadened. Her sincerity and evident zeal fueled his impression that here was more than a talented young lady. She had shown by her answers to many tough questions that she was one of those rarities—a keen problem analyzer and an independent thinker—who compels a manager to give forethought to which of the incentives available to him in acquiring exceptionally talented people he should pick.

"I'd be delighted! I promise not to order anything over $25 a cup!" As they strolled across the campus, he chatted about the microsym business. "That name was suggested by one of the old-timers at ADI decades ago, to capture the notion that the 'ICs' of his time were becoming little cities—microcosms of bustling electronic activity," Leif said. "Today's microsyms have a lot in common with the old silicon ICs, but they no longer depend on the exclusive use of monolithic solutions—which we once thought to be the only way to keep the cost down; that, and the belief that it was imperative to use so-called 'deep submicron CMOS,' which used to mean channel lengths of the order of 100 nm.

"Increasingly, these processes became so severely optimized for binary applications that we needed to re-examine the wisdom of relying on them for high-performance analog signal processing. We realized the flaw in this popular dictate, and went a different way. As you know, our products have for many years combined the unique advantages of a variety of technologies spread out over several smaller chips, each optimally suited to serve the local processing objectives, pre-tested and assembled on tiny substrates entirely automatically using microbots, as you saw earlier today, endowed with a dexterity, speed, and autonomy unimaginable in 2000. Here we are," he said, on reaching the coffee shop.

As they entered, the autowelcomer interrogated the 72-GHz transponder in Leif's pocket. After checking his biometrics, it selected its U.S.-English female voice.

"Hello, Dr. Leif. I heard your team just released another microsym. Congratulations! By the way, have you tried SplendoMix.......?"

Generated by fully analog neural networks, integrated with a local database of customer profiles, these greetings varied intelligently; but the adpops got tiresome after a while. Ordering a Galaxy Express for Leif and a Hitchhiker for herself, charging them via her own transponder, Niku said, "I've read that the price of a coffee has increased 10% per year over the past 20 years, but the price of microsyms continues to decline. Why is that?" Leif smiled with secret pride.

"An astonishing aspect of our industry is that the products keep getting cheaper, in relative terms; and that fact continues to be the key driving force behind today's endless electronic innovations and all the high-tech products they enable. Some of the reasons for this are to be found in the way today's flat-world economy works. But let's just stick to technical matters for now."

"Alright," said Niku, "You briefly mentioned the 'Four Dees of Analog.' I'd like to hear more."

Savoring his espresso, Leif explained, "The Dees are the distinctive differences between the nature of analog and digital design, the products, the components they utilize, and the signals themselves."

"The 'Dees' are the Four Differences, then?" she responded.

"Well, you could say that, but that's not what I have in mind." He took a PDA from an inside pocket. "Let me show you a few slides from a lecture I have on the NovaWeb ... here ... The Dees are mnemonics for capturing these crucial distinctions in four words starting with that letter. They're equally important, but let's start with one that touches on that issue of economy.

"Analog microsyms are DURABLE. Very successful products can have a lifetime of over thirty years."

"I'm surprised!" she replied. "From what I learned at college, a lifetime of a few years is generally the case for VLSI, before they're outdated by a new technology. Why doesn't that impact analog in the same way?"

"A good question, one not easy to answer. It's partly because analog functions still tend to be generic in spite of many examples of very complex and specialized analog products designed for a specific service. But while the latter may include scores of amplifiers, there are still uses for single units. A good all-rounder, well-designed in an older technology, eventually becomes so cheap—a penny or two—that it continues to find applications in many places. Unlike, say, a binary AND gate, which is far too primitive a function to make as a standalone part, an amplifier actually serves each application differently, and there's no need for the fastest technology in many of them. It's also a reflection of the three other Dees."

"This is fascinating! I've never thought about analog design at such a basic level as you've presented. I thought it was all re-use, now," said Niku, with evident delight. "What's the second Dee?"

Touching the screen of his PDA, Leif retrieved another slide. Underneath a row of notes on a music staff, it said DIVERSE.

"What does that mean?"

It was Leif's turn to show signs of delight. Speaking with boyish glee, "Analog design is all about writing new tunes. You see this row of just 16 notes, equal in duration? Suppose each has one of 20 allowable pitches. How many tunes can you write?"

"Hundreds, I imagine!"

"How about 655 billion-billion? The notes are your components; but today's tunes—that is, the cell topologies—use many more than 16 components, and each can have far more than 20 'pitches'—the parametric variations. Not all these combinations are useful, of course, just like the tunes; but in practice there are still endless opportunities for invention."

"That's a wonderful metaphor, Dr. Leif." Suddenly, the coffee-shop lights flickered and died. "Well!" she laughed, "*that's* a digital problem!"

"You're probably right—I've heard that the control systems for these latest white emitters have some software bugs. But you can still see my PDA, right?" The screen showed the word DIMENSIONAL, above which was a list of several signal parameters—voltage, current, frequency and so on; and below, component parameters, including resistance, capacitance, and inductance. All were defined in terms of just four dimensions in the modified MKS system: mass, time, length, and charge. "Now, this is the most profound difference." Then teasingly, Leif said "Tell me: What is the dimension of a logical variable?" Niku was not to be caught off-guard.

"Well, it doesn't have any dimension!"

"Right! So given that latitude, why are we still using very similar elements for digital processors as we use for analog?"

"Well, they are very cheap, very tiny, and very fast."

"Right again! But why haven't all those other nanodevices stepped in, to replace silicon?"

"Economics?"

"Exactly! Even though digital processors are only incidentally electronic, silicon is a very serviceable medium. On the other hand, analog circuits are fundamentally dimensional: their performance depends on the quality, actual physical size, and absolute value of the components, so the designer must be constantly aware of the consequences of misjudging such factors."

"Well, component matching is important too."

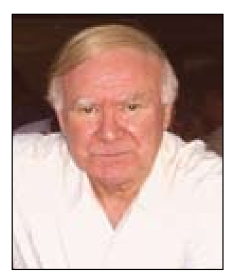
"Yes, that's true; but matching like against like is a dimensionless proposition. You see, there are two kinds of sensitivity in an analog circuit: aspects of performance that are *dependent on* absolute parameter values, and those that are *tolerant of variations* in absolute values." At that moment, the lights came back on, and Niku asked whether Dr. Leif would like another Galaxy Express.

"Thank you, but I have to get back to the lab."

Disappointed, she said, "But aren't you going to tell me what the Fourth Dee is?"

"No, not right now. Let's continue this conversation at our website: <www.analog.com/library/analogdialogue/leif1.html>. You must excuse me. By the way," he said, as he started from the table, "I would be honored if you should wish to join my team."

And Niku felt sure the white emitters flickered.



Barrie Gilbert, the first-appointed ADI Fellow, has "spent a lifetime in pursuit of analog excellence." Barrie was born in Bournemouth, England, in 1937. Before joining ADI, he worked with first-generation transistors at SRDE in 1954. At Mullard, Ltd. in the late '50s, he pioneered transistorized sampling oscilloscopes, and in 1964 became a leading 'scope designer at Tektronix. He spent two years as a group leader at Plessey Research Labs before joining Analog Devices in 1972, where he is now director of the Northwest Labs in Beaverton, Oregon. Barrie is a Life Fellow of the IEEE and has received numerous service awards. He has about 70 issued patents, has authored some 50 papers, is a reviewer for several professional journals, and a co-author or co-editor of five books. In 1997, he was awarded an honorary doctorate of engineering from Oregon State University.