INVITED PAPER *Special Section on Analog Circuits and Their Application Technologies*

Encouraging Innovation in Analog IC Design

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SUMMARY Recent years have seen a decline in the art of analog IC design even though analog interface and analog signal processing remain just as essential as ever. While there are many contributing factors, four specific pressures which contribute the most to the loss of creativity and innovation within analog practice are examined: process evolution, risk aversion, digitally assisted analog, and corporate culture. Despite the potency of these forces, none are found to be insurmountable obstacles to reinvigorating the industry. A more creative future is within our reach.

key words: *analog, design, semiconductor, industry, trends*

1. Decline

In the mid-1990's, when fully integrated systems were making their debut at the ISSCC, the Program Committee became alarmed at the complete absence of transistor circuitry in many of the papers. Block diagrams seemed to be taking over the conference, which was supposed to be about solid-state circuits. To combat this and encourage sharing of transistor level innovation, a "short paper" category was introduced so that smaller circuits could share the stage with Intel's latest CPU. This was helpful, but it did not stem the tide of block diagrams.

More recently, the Solid-State Circuits Society has established the IEEE Brokaw Award for Circuit Elegance to -once again- encourage transistor level innovation. Unfortunately, the award committee has not found any winners for the last two years of its three-year existence. Clearly, the basic building blocks of analog circuits are not getting the attention they used to.

One explanation offered for the missing transistors at the ISSCC is that analog creativity has "moved on" and that innovation -even in analog signal processing- is taking place at the system level. To be sure, much great analog research and development now concentrates on the architectural domain, tackling such problems as offset cancellation, noise reduction, and linearity correction. Valuable as this work is, it represents a departure from traditional analog thinking which is focused on lower level, transistor circuit topologies. The distinction is important because of the creative process: at the system level, individual functional blocks are chosen from an almost unlimited catalog of possible options. Transistor level design, on the other hand, is severely limited to a handful of transistor types and a couple of passive elements. With few exceptions, transistor innovation can only proceed along topological lines.

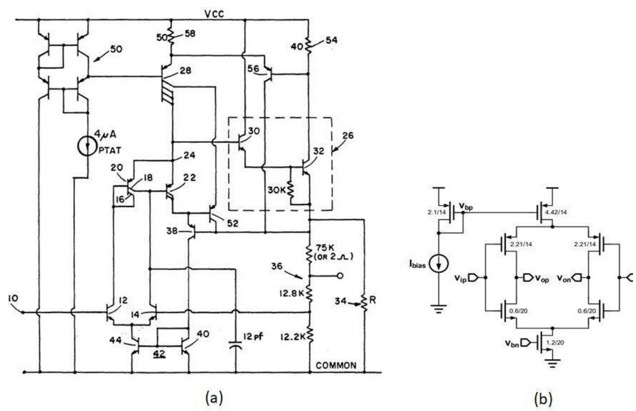

Fig. 1 Progress? (a) 1989 op-amp from Ref [1], (b) 2022 op-amp from Ref [2]. (The system this op-amp sits in is remarkable, but the op-amp itself is not.)

To illustrate the difference between block-level and transistor-level design, recall that flourishes of creative inspiration are the hallmark of traditional transistor design. Transistor gurus are hailed as magicians or artists, because of their ability to blind-side us with their leaps of insight. Engineers flock to conferences to see their latest inventions and sit in rapt attention while the marvels are unveiled. This does not happen with block diagrams. There is a difference.

If more proof of declining innovation is needed, one need look no further than the most fundamental of all functional blocks, the operational amplifier. Figure 1 shows two incarnations of the venerable op-amp that span more than 30 years of so-called progress. Yet the current mirror of the old amp exhibits more complexity than the entirety of the new amp.

So, what is to blame for this loss of circuit sophistication? There has been no decline in the need for interface circuitry, analog processing, or analog/digital conversion over the years. If anything, analog functionality is more widely used than it ever was. The analog content of a "digital TV", for example is way beyond what could be found in an old analog TV. High performance wireline interfaces are the lifeline of all digital systems these days. Radio-based communications have completely transformed our world. Why then, is transistor level analog design in such a neglected state?

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There are many explanations for the current state of affairs, but four of the pressures on our industry are the biggest contributors:

- Process Evolution: changes in transistor and wafer technology.
- Risk: the exponentially rising cost failure.
- Digitally Assisted Analog: hybridization of formerly quite separate realms.
- Corporate Culture: changes in the commercial mindset and work environment.

Each of these pose a unique threat to the creativity and innovation of analog design. Yet, as we shall see, none of them need be fatal.

2. Process Evolution

There is no doubt that the nature of the modern transistor has a limiting effect on what a designer can and cannot do in a circuit. The most obvious problem is simply the dropping supply voltage. The original "monolithic" op-amps were designed to operate in over 30 volts of supply range. This afforded plenty of headroom for elaborate stacks of transistors with all sorts of fancy defect compensation features. Modern supplies, on the other hand, must be less than a volt in order to protect the tiny MOSFETs that they feed. In the same timeframe, the voltage required to operate the transistor has not changed much. The original bipolar Vbe was about 600mV while the modern MOSFET has a Vt on the order of 300mV. That is a factor of two reduction in the minimum operating voltage of the transistor in the same period that saw a 30X decline in the power supply. Such a dramatic loss of operating latitude clearly reduces the topological options available to the circuit designer. So much so, that modern analog designs tend to look more like a collection of CMOS inverters than anything else.

If you believe the endless conference panels on the subject, every advancement in technology endangers the very existence of analog design. Digital threatens to replace analog. Inferior CMOS threatens to replace essential bipolar. Low voltage threatens everything. You get the impression that analog designers feel personally assaulted by any semiconductor progress. They seem to live in an ever-shrinking box of limited choices, in constant fear that the end of their world is at hand. This is ironic because it is precisely the challenge of a constrained environment that drew many to the field in the first place. It is less obvious these days because IC design has grown into a profession distinct from board level design, but older generations of analog designers accepted the limitations of working in a silicon environment exactly because the solution space was so limited compared to board design. Constraints make the puzzle harder. That was what made it fun. Why does that not hold true today? Why do the process limitations of the modern wafer suppress our creativity and not inspire it?

One thing the beleaguered analog curmudgeons forget is that digital designers face many of the same issues that threaten analog design. This creates enough pressure to guarantee that work-arounds will be available. It might well be called the "Little Orphan Annie Effect" after the irrepressibly optimistic heroine who was certain that good things were just over the horizon. For example, at the same time when declining supply voltages were threatening analog design, digital designers found themselves with untenable leakage and drive strength tradeoffs, so dual Vt processes were created. When fragile logic transistors could no longer support connection to the outside world, high voltage transistors options were added. Both of these developments provided welcome solutions to analog problems as well. The much-dreaded end of the world did not happen.

Overall, process evolution is not the threat to analog creativity that it is made out to be. There are new limitations, to be sure, but they are not as debilitating as the pundits would have us believe. Where, then, do we get this pessimism toward new technology? It could be that this attitude springs from a kind of "digital envy" because we view all new process development as being in service of digital, not analog, design. The features and capabilities of each new node are not what analog designers would request if they were in charge. We see ourselves as the victims of progress rather than the beneficiaries. Each new step requires that we abandon old solutions and invent new ones.

The validity of this persecution complex could be debated, but fundamentally, it does not matter. Process development has always followed commercial pressures, and will continue to do so, independently of what analog designer think they want. Analog engineers can either embrace the challenges this presents, or they can wallow the self-pity of the victim mentality. Our future lies in the former, not the latter.

3. Risk

Skyrocketing mask costs and endless development hours have also had a chilling effect on creativity. The stakes of failure have been raised so high as to turn all but the reckless into risk-averse conservatives. Yet it has long been known that real creativity must have a safe environment, free of criticism and tolerant of failure, to thrive. No one ever is going to suggest anything new if they are terrified of disapproval or failure.

Given the astronomical prices of modern process nodes, the tendency toward conservatism is certainly understandable. However, it is less defensible when viewed from a wider perspective. For example, there is some evidence that the typical corporate risk posture is actually causing more harm than good. In one instance, a company continued to re-use an outdated topology for a critical analog block, despite the better judgement of the engineers in charge of the circuit. Management felt more secure clinging to an old circuit -that was not very good to start with- rather than take the risk on something new. What makes this behavior particularly worthy of a Dilbert cartoon, though, is that each new generation of the product was built in a new generation of the process. Since the block in question was an analog circuit, the cell had to be redesigned each time the process changed. It could not just be copied as the management imagined. So, the cell was, in fact, always something new, even though that is precisely what management sought to avoid. Moreover, that "something new" was an inferior topology that needed considerable work to prop it up for each new generation. The risk associated with doing the block in a new, more sensible way was no greater, and probably less, than re-creating the old design over-and-over. Nevertheless, the conservative behavior continued until finally the product failed in the hands of an important customer, threatening huge revenue loss and corporate embarrassment, whereupon a new, sensible design was implemented. So, the moral of the story is that, even when considered from the limited viewpoint of fiscally conservative management, over-zealous, anti-innovation risk avoidance is not a good strategy. It is ultimately not even compatible with corporate self-interest.

The conservative mind-set is so strong that even the expense factor associated with modern process nodes may be blown out of proportion. To appreciate this, recall what life was like when we, as an industry, were facing the daunting prospect of designing in the new 28nm wafers. Mask costs were outrageous. Layout rules were hideously complex and time consuming. Surely this was the end of the world. Serious debates were held among design engineers as to whether we should turn back and retreat to cheaper processes, parting ways with Moore's Law forever. As it turned out, this was not the end of the world, and the semiconductor industry settled quite rapidly into a comfortable status quo at 28nm. Not only was it not the end of the world, but the industry went on to take two more major steps forward since then, to $14 \sim 16$ nm and to $5 \sim 7$ nm, each with an exponential increase in cost and complexity. In retrospect, the move to 28nm seems like a no-brainer. So, what did we get wrong? Why did we approach that 28nm step with such trepidation?

Perhaps the biggest reason for the misplaced anxiety was just engineers failing to understand the magnitude of corporate finance. Although the million-dollar price tag on the masks set seems like a lot to an individual, it is well within the means of a multi-billion-dollar company, especially when prototyping runs can be done for much less using multi-project masks and wafers. Thus, price fears may have been exaggerated by the engineers themselves. Fortunately, projects went ahead in spite of design misgivings. Mistakes were made, and yet, the world did not end. Successful products were launched, and revenue flowed. Ultimately, the creativity-killing conservative posture was not vindicated.

4. Digitally Assisted Analog

There is no shortage of irony to be found in the analog community's response to digitally assisted analog. In many ways, this new flexibility is the answer to the analog designer's prayers. Offset and gain adjustments, linearity tweaks and calibration, suddenly all these are within reach -and unlike old laser-wafer-trim technology- it is available post-packaging and adaptable on the fly. You would expect dancing in the streets. There is none.

In retrospect, the name, digitally assisted analog, was not a good choice. It was bound to lead devaluation of the analog arts. With this label, analog was cast as something weak, inferior, and buggy that needs help. The name is too close to "assisted living", which is the current euphemism for elder care facilities, implying that aging analog now lacks enough vigor to even care for itself. We should have held out for a better label, or maybe we should have just left it at "calibration". Sadly, it is too late. The damage has already been done. The label has stuck.

As if to fuel the denigration of the "digital assist" label, engineers have come to rely on digital tweaks in the same way one might become overly dependent on a prothesis: it has become a crutch. Why sweat all the details of a sensitive design when you can just add a DAC and patch it up later? The biggest danger is that, like a prosthesis, over-dependence leads to atrophy in the abilities of the user. Indeed, one highly respected professor claimed that there is no longer a need to teach the finer points of analog design because digital correction is all the students need know.

The strongest motive behind the overdose of digital assistance medicine could well be coming from project managers. Analog circuits are finnicky. And when they go bad, they are time consuming to debug and fix. They are invariably the project manager's biggest headache. Digital assistance would appear to offer relief: "Let's not waste time fussing over this analog stuff; let's just build it and fix it with software later." Experienced designers know this is a serious mistake because digital correction only works when you know what you are fixing and build the specific correction circuitry to address it. You cannot fix a power supply noise problem, for example, by just adding a DAC. Nevertheless, digital assistance is a seductive paradigm that encourages devaluation of analog skills. Of course, when digital-overuse inevitably fails, it is the analog technology that gets the blame.

Digital assistance, and the pathological mindset it engenders, are thus formidable obstacles to keeping analog innovation alive and healthy. With time, collective experience may temper the tendency to abuse calibration, but such experience is rarely taught in schools, so it may have to be re-learned in every new generation of industrial engineers. And it may be hard for analog practitioners to advocate for sensible digital use without seeming to be retrograde sentimentalists.

We can draw an important object lesson from the software-vs-hardware struggle that electronics faced in previous decades. Like digital assistance in the IC, software was introduced to replace custom hardware in consumer products with much fanfare and optimism. Also, like digital assistance, it was not the panacea that it was supposed to be. Software promised rapid development, flexibility, and ease of modification, and -at first- it delivered on those promises. But as the size and complexity of the software grew, so did its limitations. Soon, the software packages became too complicated to change. To avoid the lengthy and expensive process of re-verifying the entire program after any change, OEMs demanded that the ICs be modified instead. In other words, it was easier and cheaper to fix a bug or make a last-minute feature change in silicon than it was to do it in software, precisely the opposite of what was predicted when software was introduced. Doubtless we will see the same sort of reversal with digital assistance: as the complexity of SOC increase, the expected benefits of digital correction, flexibility, and time-to-market, will begin to evaporate. However, like software, digital assistance is here to stay, and its use -at a sensible level- should be encouraged by analog designers. Of course, we should not allow it to deprecate traditional analog technology, nor should we permit it to suppress analog innovation.

5. Corporate Culture

Many analog veterans will tell you that the aging maturity of the semiconductor industry is to blame for our plight. These days, semiconductors are serious multi-billion-dollar, index fund business. Gone are the wild frontier days of the garage startup and the lone cowboy with the single-designer chip. No more shoot-from-the-hip marketing. No more late-night lab pranks. No more raw, irascible egos. No more fun. The industry -and its gurus- have grown up.

Corporate mergers have consolidated former competitors and blended their unique cultures into a bland homogeneous mush. Armies of professional managers, human resource wranglers, and accountants have swarmed in to support the growing organizations and have quietly taken the reins away from those who knew and loved the technology. Much as they like to think of themselves as innovative, the new corporate masters are anything but. “Innovation” itself is a buzzword copied from other companies, just another corporate fad. This is not an environment that nurtures creativity.

Industry maturity means more than just stuffy, bureaucratic management, though. It also means that multiple companies have figured out how to meet customer’s needs, and -in many arenas- performance is no longer the primary vector of competition. As marketeers will sometimes say, the demand is for “conformance, not performance,” meaning that customers insist on a certain minimum specs for their application, beyond which, they will not pay a single yen for improvements. This leads to interchangeable, commodity products, and the emphasis quickly shifts from design sophistication to manufacturing and cost. Goodbye creativity.

All of this is discouraging to the would-be circuit artist among the single-color corporate paint sprayers. But to be fair, the news is not all bad. Modern corporate life offers a degree of leverage beyond anything the former cowboys could ever have dreamed of. A successful idea in today’s marketplace can put our work in the hands of billions of people, and improve energy efficiency, quality of life and the security of democracy all at the same time. Surely it is worth putting up with a little corporate “Dilbert-ism” for such power. And the modern designer is largely free to concentrate on design while an army of specialists handle the mask making, wafer fab, assembly and testing for us, a luxury our forebears did not have.

It is also useful to remember that engineers have always complained about corporations, no matter how small the organization and how light the bureaucracy. Designers have been known to resent their masters even when working in a tiny company operating out of trailers. It is in our nature to chafe against authority. It has always been considered a matter of pride to maintain a healthy cynicism about all things corporate. It comes with the territory.

6. The Fix

The multiple forces of process evolution, increased risk, digital supremacy and deteriorating corporate culture are constantly at work to dampen our creative urges. These forces are all very real, and sometimes quite powerful. So, it is not surprising that we feel a bit “hemmed in” and experience a decline in creativity in our field. This is, after all, the natural result of these forces taking their toll as time moves forward. But powerful as these forces are, they are neither inevitable nor insurmountable. There are two aspects to these forces that should give us hope that we can prevail against them.

First, these anti-innovation pressures have always been part of the landscape. Although each generation perceives them to be new, they are not. They have been with us all along:

- Process evolution has always been a mixed blessing of opportunity and threat to analog design. Consider the displacement of bipolar by CMOS technology: this was nothing short of an apocalypse for some designers.
- Risk of failure is a universal deterrent to engineering creativity, in all fields of endeavor. The monetary stakes of IC development have risen over time, but when viewed from the bank accounts of multi-billion-dollar corporations, they have not been so bad. Costs have stayed proportional to the potential revenues.
- Since its arrival, digital technology has been a thorn in the side of analog practice. It is an indispensable partner that simultaneously threatens and devalues our work.
- As long as there have been corporations, they have tried to make order out of the creative chaos, and engineers have resented them for it. Expanding corporate size and bureaucracy have not made companies any easier to deal with, but essentially, they present the same creative buzzkill that they always have.

Second, the power of these forces stems from the attitudes they engender. They are not immutable laws of nature. They are merely points of view. Creativity, being a delicate psychological process, is easily derailed by such negative thinking. Anything that boosts morale, stimulates excitement, and fosters a feeling of safety neutralizes whatever power these anti-innovation forces can muster. In other words, restoring creativity to our profession does not require any structural changes, only psychological ones.

When considering the forces arrayed against us, it is tempting to search for something or someone to blame. While this might afford temporary solace, it is counterproductive, because -ultimately- it does not matter where the blame lies. Transistors and wafer processing will continue to evolve. Risk will always be present in what we do, and the stakes will continue to climb. Digital technology will not cease to steal the spotlight away from analog circuits. And corporations will always be... well... corporations.

If change is to be had, it is up to us to make it happen. We must embrace the opportunities and challenges of advancing technology. We must brave the risk of failure to create things that are truly new. We must make sure that digital technology is used wisely. And we must all do what we can to make the corporate environment a hospitable place for new ideas.

Remember why we got involved with analog circuits in the first place. It was not because we wanted to create the same circuits over-and-over using a formula or automated software. No, if that is what we wanted, we could have taken up bridge design. It was because analog circuitry was the canvas upon which the most amazing flourishes of human creativity, the highest plane of engineering, could be seen on a daily basis. Let's not forget that. Let's make it that way again.

References

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