What's All This Time-Domain Stuff, Anyhow?

Last night, I was attacking a thorny problem and thought about the time domain. I think about circuits, as an engineer, in the time domain. When something happens, or changes, then something else can happen—or may start to happen. Is that something that I like? Or is it something I don't like?

I have used this analysis many times, as in "What's All This Fuzzy-Logic Stuff, Anyhow? (Part 4)" *(Nov. 6, 2000;* www.electronicdesign.com, *ED Online 4915)* and "What's All This Ball-On-Beam Balancer Stuff, Anyhow?" *(Nov. 20, 1995, ED Online 6126).*

I know some engineers who like to work in the time domain and some guys who like to work in the frequency domain. We have different kinds of heads. We may each be able to solve a problem, but from completely different angles. Different strategies. And sometimes we have to collaborate. That can be fun! I mean, I am not completely ignorant of the F domain, but I rarely find it helpful.

I know a lot of good engineers who work primarily in the time domain. Often we can solve some problems that the frequency-domain guys have trouble with, such as the ball-on-beam balancer (BOBB) and the fuzzy controller for steam boilers. I get insights that the fuzzy-logic guys and the F-domain guys don't.

KEY QUESTIONS

Several years ago, a guy asked me, "When an LM308 has its dc gain increase, don't you get in trouble when its ac gain increases proportionately?" I asked him where he got that notion from. He said he read it in a book. I told him to drag out that book and X out that idea.

I explained that the gain-bandwidth of any modern op amp (designed in the last 40 years) is invariant of the dc gain. He said his simulations did not show that. I told him his simulations and models were just wrong. The book was wrong.

Then I asked him if he ran a simulation of an LM108 with high gain (–500,000), another one with low gain (–50,000), and another one with reversed gain (+500,000), what if the simulation told him some of them would not work well? What if he ran the amplifiers and they all worked well (as I am sure they would)? Which would he believe, the simulation or the silicon?

He did not know how to answer my questions. He went away. He never came back. I hope he believed the real amplifiers. A few weeks ago, I bumped into another guy who still believed that:

$$A_V = A_{VO} \times 1/(1 + s \times F_O)$$

where F_O is the purported "low-frequency rolloff" frequency. Even at Philbrick, we used to say that. Even when we were wrong. Even when we should have known better. For him, I cooked up a better expression. For mid-frequencies, it is fair to say:

$$-V_O = 2\pi f_H \int V_{IN}\, dt$$

which is the same as saying:

$$-V_{IN} = p \times V_{OUT}/2\pi f_H$$

where f_H is the gain-bandwidth product or the unity-gain frequency. Or if you want to add a second high-frequency rolloff near f_H, that's easy. But for the low-frequency rolloff, the correct way to look at it is:

$$-V_O = 2\pi f_H \int V_{IN}\, dt \times \frac{(p \times fA_{VO} / 2\pi f_H)}{(1 + (p \times fA_{VO} / 2\pi f_H))}$$

The default value of gain when f gets very small becomes $A_V = {\sim}A_{VO}$, as the other terms cancel out. But the low-frequency "break frequency" moves around as A_{VO} changes. It's $F_O = 2\pi f_H/A_{VO}$, and that's okay.

The frequency domain guys can analyze this any way they want to. The fuzzy-logic guys can analyze it any way they want to. But I have a bunch of friends who have sold several *billion* op amps, and we are *right*, and most frequency-domain guys are *wrong*, about how to describe an op amp.

If the dc gain goes up to 10 million, or more, that's not really bad. The f-3dB could fall to 0.1 Hz, or lower, but that does not mean that the amplifier's response will have long settling tails at 0.1 Hz—as I pointed out in "What's All This Output Impedance Stuff, Anyhow? (Part 2)" *(Aug. 28, 2008; ED Online 19555).*

Am I any expert on poles and zeros? Uh-uh. The frequency-domain guys have those tools. They like to use those to solve some problems that I would probably have trouble with. I prefer to solve those problems in the time domain. I like to use p = d/dt. The derivative operator. In linear systems, in the frequency domain, $p = s = 2\pi j(f)$, but I won't waste much time with that. How can I sell you on the time domain? Where can you learn more? I dunno. More later.

Comments invited! rap@galaxy.nsc.com —or:
Mail Stop D2597A, National Semiconductor
P.O. Box 58090, Santa Clara, CA 95052-8090

BOB PEASE obtained a BSEE from MIT in 1961 and is Staff Scientist at National Semiconductor Corp., Santa Clara, Calif.