Symmetric Serpents

You may or may not have a read a delightful children's book titled *Mr. Slow*. The "problem" with poor Mr. Slow is that he does everything, well, slowly. He's a kindly man who can't find his proper place in the world due to his unusual trait, until he finds out that he's ideally suited for the patience-demanding task of driving a steam roller.

Mark Spong of the University of Texas at Dallas, Jacob Apkarian of Quanser, and Dennis Bernstein on the beach before the CDC in Cancun.

Elena Zattoni and Dennis Bernstein visit Italy through a special exhibit at the Detroit Institute of Art.

Unlike the low-frequency world of Mr. Slow, in the control world we've learned to beware of high frequencies. If a Bode plot were drawn like an antique map of the world, everything above a few hundred radians per second would be replaced by sea monsters with their serpentine bodies protruding through the waves.

High frequency means fast. A discontinuous function, such as a step, has harmonic content at all frequencies, infinite bandwidth, so to speak. Fear of the discontinuous is warranted: How can you prepare against something that strikes with no warning? This is the earthquake scenario, where the stresses build up but there is no way to know that something is about to slip. Even without discontinuities, capturing high-frequency behavior is difficult since we need fast sensors and fast data acquisition.

Physical systems tend to be less responsive at high frequencies, which makes modeling more difficult since sensor and ambient noise often mask the dynamics—hence the postulated sea monsters. This natural rolloff at high frequency is bad for command following but good for disturbance rejection for the simple reason that a system that doesn't respond to commands that you give it will also not respond to disturbances that nature throws at it. Finally, something for nothing.

If we insist on command following at high frequency, then we need high gains to pump up the naturally rolled off portion of the plant. This is risky business, however, if we don't know the phase well—Nyquist is clear on this point—so we usually just add more rolloff, hoping to safely avoid the critical point going 'round the bend, sending the high-frequency response and its menacing serpents to the netherworld of really negative decibels.

Beyond this fear, it has occurred to me that the low-frequency end of the response can be just as—if not more—dangerous. You might have noticed that a typical Bode plot has no zero frequency; instead, the frequency axis continues indefinitely to the left, never reaching the quiescent land of constants. To identify this low-frequency portion, you would need to test the system with very, very low-frequency inputs. For example, you might apply a 0.00001-rad/s input, which would require a full week for one cycle to be completed.

Why bother with the low-frequency end of the spectrum? What serpents lurketh in quasi-dc waters? Surely, a plant can roll off at low frequencies just as it can at high frequencies. If you don't believe me, try using your personal optical sensors

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to watch your lawn grow. But what is there to fear about the low frequencies that could be any worse than the high frequencies?

Creep. I've noticed that if I were to gain a mere 0.2 lb per month, then that weight gain would be extremely hard to measure much less regulate. Each day my weight would fluctuate by an order of magnitude beyond that monthly delta. Viewing that fluctuation as noise, the signal—weight gain—would be extremely difficult to detect. But consider the effect of the signal: In a mere 20 years, I would gain 48 lb, which, obviously, is a substantial amount. This isn't exactly "creep" in the sense of structural mechanics, but you get the point.

Now imagine that, say, the climate were to change imperceptibly for decades or centuries. The noise in the signal would mask the trend to the extent that it would be easy to doubt—and cast doubt on—the overall trend.

Creep and its ramifications, such as weight gain and climate change, suggest that we might need to worry about what happens at low frequency. Finding out takes time and patience, something I don't have a lot of. On the other hand, I know the perfect person for the job.

Dennis S. Bernstein

Energy Amplification

In resolving the problem of the mechanical chess player, Ashby had shown that a machine could output more information than was input through its design, by making use of other, random, information. This was a kind of amplification—information amplification—like the amplification of power that utilizes an input of power plus a source of free energy to output much more power than was originally supplied:

Let us remember that the engineers of the middle ages, familiar with the principles of the lever and cog and pulley, must often have said that as no machine, worked by a man, could put out more work than he put in, therefore no machine could ever amplify a man's power. Yet today we see one man keeping all the wheels in a factory turning by shoveling coal into a furnace. It is instructive to notice just how it is that today's stoker defeats the mediaeval engineer's dictum, while being still subject to the law of the conservation of energy. A little thought shows that the process occurs in two stages. In Stage One the stoker lifts the coal into the furnace; and over this stage energy is conserved strictly. The arrival of the coal in the furnace is then the beginning of Stage Two, in which again energy is conserved, as the burning of the coal leads to the generation of steam and ultimately to the turning of the factory's wheels. By making the whole process, from stoker's muscles to factory wheel, take place in two stages, involving two lots of energy whose sizes can vary with some independence, the modern engineer can obtain an overall amplification.

—*Mechanisms of Adaptation to Intelligence Amplifiers: The Philosophy of W. Ross Ashby*,
by Peter M. Asaro. Excerpted from *The Mechanical Mind in History*,
edited by Philip Husbands, Owen Holland, and Michael Wheeler,
The MIT Press, Cambridge, MA, 2008, p 170.