

REPRINT

Title: The DA Time Bomb

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My teaching activities require that I spend a fair amount of time with experiment and measurement practitioners who are using digital data acquisition (DA) as a tool for solving a wide variety of technical problems. Since my courses are aimed largely at those who consider themselves beginners, I am fortunate enough to catch a few investigators before they make any really grave errors. However, more often than I would like (almost every session) I meet one or more practitioners who are acquiring data that are seriously corrupted. Worse, they are completely unaware that this is happening! The cause of the corruption is insidious. And it is lurking nearly everywhere, ready to catch even sophisticated users of digital DA systems. The villain is aliasing.

System Wrong, Analysts Right

The basic theory of discrete sampling was developed by Claude Elwood Shannon (b. 1916), the American mathematician who found that if a signal is acquired that has no frequency components above $1/2$ the sample rate (called the Nyquist frequency), then the signal can be completely reconstructed. The converse is equally straightforward: If there are any components of the signal whose frequencies are at or above the Nyquist frequency, the theory is violated and the data will be corrupted. In the real world, there will always be components above this critical boundary. However, we have found that, if we can be assured that the interfering components are sufficiently small, the errors will be equivalently insignificant. But if the required precautions are not exercised, the data may be significantly corrupted (i.e., wrong!).

A particularly onerous example surfaced a few years ago. The story is paraphrased to protect the innocent.

A large company built more than 100 DA systems to collect field data. The objective of the measurements was to characterize a pressure phenomenon whose frequencies of interest were below 50 Hz. Using an often-accepted rule of thumb, the DA system was designed to use a sample rate of 500 sps, producing 10 points/cycle at the highest frequency of interest. It was assumed that higher-frequency components were unimportant, and no provision was made to limit the bandwidth of the signal. These systems were used for several years (over thousands of recording hours) to produce data that the analysts often questioned. But since the data were acquired with a computerized DA system, the analysts found it difficult to

dispute the results.

The measurement, however, was not so straightforward. As normally happens, the actual signal to be characterized was made up of much more than the response of interest. A piezoelectric transducer that responded to excitations up to and above its 25 KHz resonant frequency was used. Pressure fluctuations and other excitations in the system caused significant transducer response at frequencies well above the 250 Hz Nyquist frequency.

Shannon's theorem was violated and the acquired data were wrong. The analyst's suspicions were correct.

But how large were the errors? One of the problems with aliasing is that the error level is impossible to ascertain. In this case, the data sets were probably in error by more than 100%.

This mishap resulted in two obvious repercussions, each of them serious:

- Bad data were used for several years to make engineering decisions.
- The data had to be re-acquired with systems that were enhanced with anti-alias filters. The cost of the bad data/decisions and the retesting is hard to quantify but it is certainly huge compared to the cost of doing it right in the first place.

What caused the problem in the first place? Innocence (or to put it less gently, ignorance) on the part of the user/system designers. They either didn't appreciate or didn't understand the concept of aliasing. The question is: Where does this ignorance come from? And what must be done about it?

Where Does Ignorance Come From

I believe this ignorance comes from the DA hardware/system manufacturers, who are usually the first (and often the only) DA theory instructors that the end users ever see.

So, what do DA manufacturers do when they appear in your workplace to demonstrate their wares?

Every demonstration I've ever seen uses a sine wave generator as an excitation source. (Who doesn't love sine waves?) The demonstrator sets up the demo to sample at some nominal rate (let's assume 1000 sps here). Then the sine generator is set to 1 V at 10 Hz or 20 Hz. The system faithfully records and displays the result.

Smith, "The DA Time Bomb," 1997.

What's Missing? Let's sweep the frequency up. What happens when the frequency is 400 Hz (still well under one half of the sample rate)? The data appear to be a very poor representation of the real sine wave, but they can be reconstructed. But let's keep increasing the frequency to 995 Hz (really violating the 500 Hz Nyquist limit).

If the system has been correctly designed, we will see essentially nothing.

If not, the system will report a 1 V signal at 5 Hz... the wrong result.

The solution is straightforward. Frequency components above the Nyquist frequency must be reduced to an "insignificant" level.

To do this, a low pass (anti-alias) filter must be applied before digitization. For most applications, an analog filter with significant attenuation characteristics (as indicated by lots of "poles") is needed.¹

Who Needs Brakes?

Why don't the manufacturers include discussions and/or demonstrations of this critical effect? I've been trying to figure that out for years.

Several reasons are possible:

- Demonstrators don't fully understand the problem in the first place.
- Manufacturers know that adding the required features will increase the cost and complexity of any system, thereby making the system less attractive.
- Some customers don't want to be bothered by problems they don't understand. Others are reluctant to risk the embarrassment of asking questions.
- Many manufacturers simply don't offer a solution, even though they know that forcing users to solve the problem with another manufacturer's add-on may make their product less appealing and thus inhibit future sales to that customer. I am often surprised (appalled, actually) to find that manufacturers who do offer appropriate hardware often don't promote it.
- Manufacturers sometimes don't realize that part of their job is education.

Imagine shopping for a new car, one that will start, run, and stop. You find one you like and buy it. Driving it home, you feel like a smart shopper indeed, until you try

to stop and find your face planted in a fully inflated air bag. Peeling yourself from the wreckage, you return to the dealer, who explains that to keep costs down and pass the savings on to you, the manufacturer has opted to omit brakes from this model, but that you can purchase a retrofit brake system from an aftermarket manufacturer if you

- (1) know you need brakes,
- (2) want them, and
- (3) are willing to pay for them.

Like our hypothetical car dealer, some manufacturers are leading unwary customers into near-certain disaster.

Anti-aliasing: Don't Leave Home Without It

Aliasing protection must be included in any machine that purports to be a general-purpose system. There are, however, a large number of home-built (and a shocking number of turnkey) systems that don't have this feature. With these systems, the validity of the data acquired is always in question.

If you have an unprotected system, the time bomb in your site may already have gone off and your system is cranking out corrupted data virtually as we speak. Aliasing errors don't leave a signature. Their detection and characterization is not straightforward unless you know what to look for (as we did in our experiment, above).

There are countless examples of very costly testing programs wherein the acquired data sets are irretrievably corrupted. At best, these data sets must be re-acquired with a proper system: at worst, the bad data are being used to make engineering/design decisions. Any system that doesn't have adequate aliasing protection is a time bomb.

What must be done? We educators are doing our best to spread the warning.

But the onus must be put on the manufacturers, who are, after all, the front-line warriors who see the users first, and may in fact be the only "educators" that the end user ever sees. The manufacturers must offer some form of hardware that provides aliasing protection and must help the purchaser in the configuration of a viable system. Any other approach invites disaster for the user and, in the long run, for the manufacturer.

¹ Systems using the new SD oversampling process offer an alternative, and often better solution but at this point their use is limited to a small number of applications.