CIRCUIT CELLAR

ANSWERS for Issue 242

Test Your EQ

an error-free transmission, and typically within a few tens of frames in the presence of bit errors. All modern 1394 line interface chips use parallel framers.

Answer 3—When the transmission system has bit errors (and they all do, at some level), it is necessary for the framing algorithm to be robust in terms of recognizing the frame pattern even if a few bits are wrong. However, care needs to be taken so that random data patterns aren’t accepted as true frame patterns.

The usual approach is to have two different thresholds for the number of erroneous bits, depending on whether the framer is currently “in frame” or “out of frame.” When out of frame, the framer wants to be very conservative about going into frame—fewer bit errors allowed. However, once in frame, the framer wants to be more liberal—more bit errors allowed—before declaring itself out of frame. This approach creates a system that is relatively robust in the face of error bursts that may last for several frames. In digital telephony systems in particular, it’s generally more acceptable to have a burst of noise in each channel rather than to have the whole system go mute for a while.

Answer 4—Absolutely! A radio time signal such as WWVB is highly predictable—in fact, except for a few bits relating to the UTC offset and leap seconds, it’s completely predictable. Therefore, even with the rather high bit error rate seen on these signals, a robust framing algorithm should be able to lock in on the signal—and the time of day—within a few minutes.

Given the low data rate (1 bps), even a rather modest microcontroller would have plenty of CPU cycles and memory to implement a very robust framing algorithm. It’s just a matter of taking the techniques learned in the high-speed hardware framers and implementing them in software.

Contributed by David Tweed

What’s your EQ? — The answers are posted at www.circuitcellar.com/eq/
You may contact the quizmasters at eq@circuitcellar.com

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Filters, Filters Everywhere

There's no lack of information about filters and filter design on the Internet. But you need to know specifically how filters figure in embedded control systems. This means you must be familiar with low-pass, anti-aliasing filters.

It's hard to imagine a system where a filter of some sort would not be used. Communications, signal processing, controllers, power supplies: filters permeate all electronics. Based on their frequency response, we know low-pass, high-pass, band-pass, and band-reject filters. These can be further subdivided by the specifics of their frequency response—such as Butterworth, Chebyshev, Bessel, elliptic—and can be realized in the frequency domain as analog or in the time domain as digital.

Analog filters, passive and active, utilize resistive and reactive components: resistors, capacitors, and inductors. A gain block, usually an op-amp, is added to make the filter active. There are many advantages to active filters, but their usefulness is limited to a few megahertz and relatively low-power applications. All filters generate a gain-versus-frequency slope of 20 dB/decade for each order (e.g., 40 dB/decade for the second-order filter).

Digital filters perform their task by computations and, therefore, process digital signals only. The three basic digital types are the finite impulse response (FIR), infinite impulse response (IIR), and fast Fourier transform (FFT). The switched capacitor filter is a hybrid, which should be more appropriately called "discrete time filter" rather than digital. It samples its input in discrete time intervals but processes analog signals.

Many books have been written on the subject of filters and their design. This month, I want to look at filters found in every embedded control system: the low-pass, anti-aliasing kind. Figure 1 is a block diagram of a simple closed-loop control system.

**LOW-PASS FILTERS & ALIASING**

We see low-pass filters preceding the ADCs on the command and feedback analog input signals. Their purpose is to limit the bandwidths.
of those signals before digitization to prevent aliasing.

What is aliasing? You can see it in movies when the movement of propeller blades or a wagon wheel’s spokes exceeding the frame rate can appear to move slower, even backwards. Nyquist’s criterion tells us that the sampling frequency must be higher than twice the highest time-continuous sampled frequency in order to faithfully convert it to a time-discrete signal. Otherwise, a phantom frequency, equal to the difference of these frequencies, will become an integral part of the resulting digital signal.

**CONTROLER DESIGN**

Let’s say we are building a controller as in Figure 1 for a system to position an aircraft control surface. A typical control bandwidth of such a system would be around 5 Hz. We decide to digitize the control and feedback analog signals at 50 samples per second. In flight, the surface will be exposed to perturbations by air movement which the position feedback transducer is picking up as 51-Hz vibrations. If the 51-Hz signal is not sufficiently attenuated by the low-pass filter, a new 1-Hz control signal will appear. Because 1 Hz is within the system control bandwidth, it will cause unwanted, erratic movement of the control surface.

The data acquisition part of the design will be a trade-off between the sampling rate and the order of the filter required to attenuate all out-of-the-band frequencies to an acceptable level. I personally like to use no more than the fourth-order filters. With the sampling frequency 10x the bandwidth, the resulting 60-dB attenuation of the third-order filter in Figure 2 should be sufficient. The system designer, however, not you, must specify the magnitude and the spectrum of out-of-the-band signals to be encountered.

You can use analog filters, passive or active, or switched capacitor. It is my personal preference to use a passive first-order filter followed by a buffer, followed by a Sallen-Key second-order filter, as shown in Figure 2, for the –60 dB/decade slope. R1 being typically 100 kΩ can ensure lightning Level 5 (the highest) and electro-static discharge (ESD) are sufficiently suppressed by inexpensive signal diodes D1, D2, and capacitor C1. Make sure R1 can survive the high voltage without flash-over. Sallen-Key filters are simple to design and the setup has always satisfied my requirements. I try to keep my circuits simple for robustness, to achieve high reliability, and to minimize defects in manufacturing.

A low-pass Sallen-Key filter and its derivatives do not continue to attenuate at the same slope forever. Depending on the op-amp’s bandwidth and its open-loop gain, the output will begin to rise at some point. This can be compensated for by the preceding first-order filter and the buffer’s bandwidth. The result is shown in Figure 3.

With increasing popularity of delta-sigma ADCs, antialiasing filters can be reduced to simple RC, while internal digital filters do the rest. Choosing a digitizer is a matter of analyzing the trade-offs between performance, resolution, component count, reliability, cost, obsolescence, and other engineering considerations.

Once the signals have been digitized, digital filters can be employed. In the closed-loop controller, they usually are a part of the processor software, typically performing the PID (proportional, integrating, derivative) compensation. PID is still the most common compensation in use, but
more sophisticated filters—such as adaptive and Kalman—are gaining in popularity.

**UNDERSAMPLING**

Since I touched upon Nyquist’s criterion, I’d like to finish with a few words about undersampling, which some call a violation of the criterion. The name is misleading. Harry Nyquist postulated that the sampling rate must be greater than twice the bandwidth. Also being the highest frequency is only a special case. Undersampling is of great use in digital communications.

Imagine that we have a 70-MHz intermediate frequency (IF) carrying data within bandwidth $B = 4$ MHz. To satisfy Nyquist’s criterion, we can sample at $2.5 \times$ the bandwidth—that is, at 10 MHz. The 70-MHz IF and the 10-MHz sample rate will alias, fold back, and recover the data in a DC-to-less-than-5-MHz baseband.

“There are many ways to skin a cat,” goes a popular saying. Engineering is about choosing the best way. Your engineering duty is to consider all the often contradictory requirements, make the trade-offs, and come up with the best design.

George Novacek (gnowacek@texas.com) is a professional engineer with a degree in cybernetics and closed-loop control. Now retired, he was most recently president of a multinational manufacturer for embedded control systems for aerospace applications. George wrote 26 feature articles for Circuit Cellar between 1999 and 2004.

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**NEED-TO-KNOW INFO**

**Knowledge is power.** In the computer applications industry, informed engineers and programmers don’t just survive, they thrive and excel. To learn more about some of the topics covered in George Novacek’s 243 article, the Circuit Cellar editorial staff recommends the following:

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**No Fear with FIR**

**Put a FIR Filter to Work**

by Robert Lacoste

*Circuit Cellar* 207, 2007

Working with finite impulse response (FIR) filters isn’t black magic. Robert covers the basics and touches on the mathematical concepts you’ll need to understand in order to put a FIR filter to work.

Topics: Filters, FIR Filter, Fourier, DFT, IDFT

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**Time-Triggered Technology**

by Robert Lacoste

*Circuit Cellar* 231, 2009

With cascaded integrator-comb (CIC) filters, you can tackle signal-processing problems. With them and some multirate signal-processing techniques, you have an option when a FIR filter doesn’t fit the bill. Topics: Filters, CIC, FIR, Sampling Rate, Digital Mixing

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