Delta Modulation: The Forgotten A/D Converter

A close examination of this often-overlooked bandwidth-compression circuit for use in telephone, cable-TV and digital data-recording

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Data acquition is currently big business. It seems like everyone who has an analog signal wants to digitize it, and everyone who has an 8-bit digital signal wants to convert it into analog form.

Many techniques can be used to convert an analog signal into digital form. Among them are single- and dual-slope integration, successive approximation, voltage-to-frequency (v/f) conversion, flash modulation and, last but not least, delta modulation. (According to the *Datel-Intersil Data Acquistion and Conversion Handbook,* 70 to 80 percent of all analog-to-digital, or A/D for short, converters now in use employ the successive-approximation method.) While each method has its unique advantages and disadvantages, it seems that the world has forgotten *delta modulation*. This is unfortunate because delta modulation offers benefits not obtainable with the other methods popularly used.

Lest you believe that delta modulation is a panacea, let us first state its disadvantages. Delta modulation doesn't have the great bandwidth capabilities characteristic of flash conversion, nor does it have the great accuracy of the dual-slope method. What it does offer, however, is good performance at a low price, with the bonus of bandwidth compression and a serial digital output—all without a voltage reference.

If your data transmission system has more bandwidth than you know what to do with, you can count yourself lucky; you probably aren't interested in bandwidth compression. But if you're into telephone systems or cable TV or digital data recording, you have (or should have) a very high interest in bandwidth compression and the economical way it can be obtained by using delta modulation. With this in mind, let's examine delta modulation methods with an eye to-

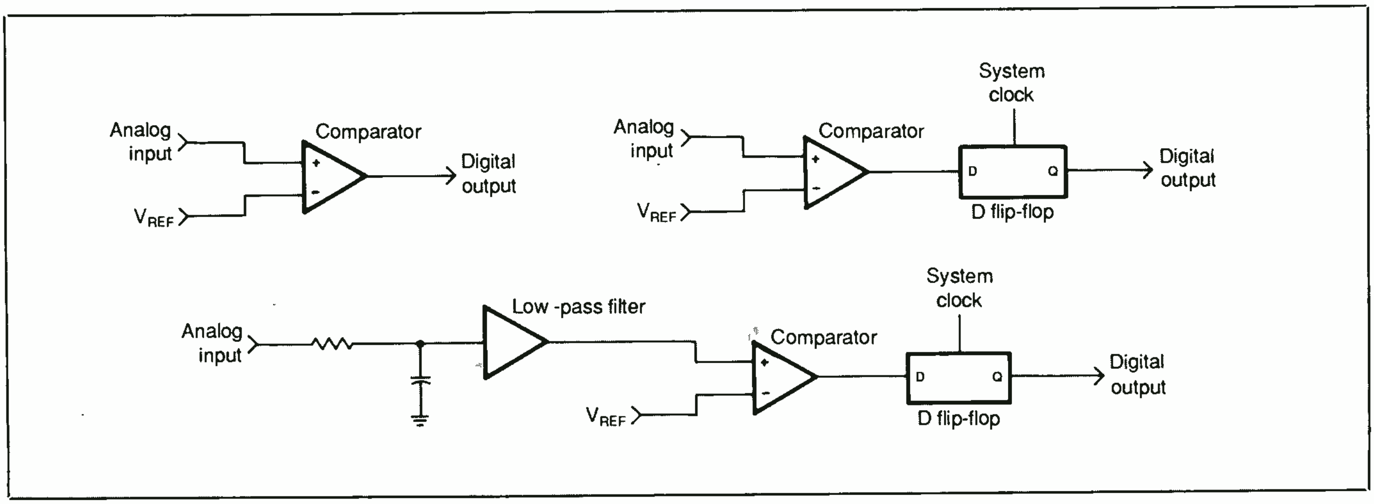


Fig. 1. Comparator (A) is simplest of A/D converters. Adding a D flip-flop (B) synchronizes converter's digital output with rest of system. Low-pass filter (C) climinates state-change problems that can occur between clock pulses.

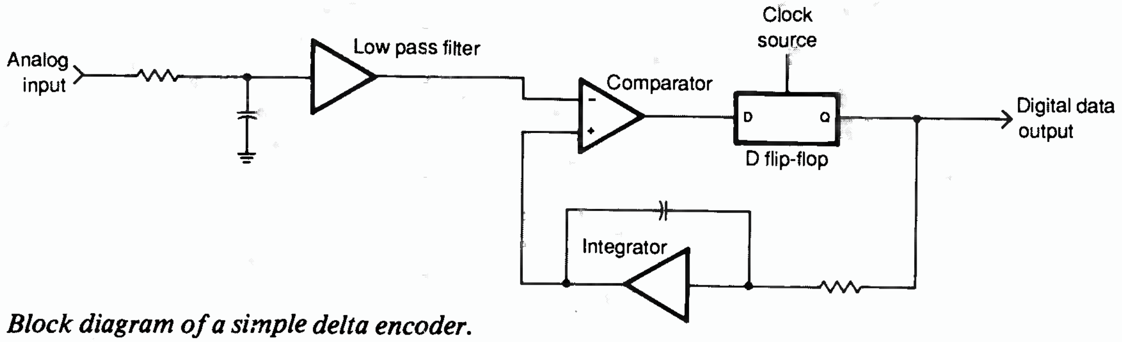


Fig. 2. Block diagram of a simple delta encoder.

ward implementing it in your electronic circuits and systems.

Theory of Operation

To understand the theory behind delta modulation, let's first look at the simplest A/D converter—the comparator shown in Fig. 1(A). In this circuit, if the input potential to the comparator's noninvertering (+) input is greater than the reference voltage (V_{ref}) at its inverting (−) input, the output will be a logic 1. Conversely, if the + input voltage is less than V_{ref}, the output will be a logic 0. This 1-bit A/D converter may not be very fancy, but it finds many uses in electronics where only simple 1/0 results are needed.

If the comparator's response is fast enough, the output can change from a 0 to a 1, or vice-versa, as fast as the analog signal can change. This can cause problems in most digital systems. In order to synchronize the digital output of the comparator with the system, a D flip-flop, shown at the output of the comparator in Fig. 1(B), is added to the basic circuit. However, the problem of a fast comparator and a fast analog signal can still cause the comparator to change states between clock pulses in a digital system. To remedy this, an analog low-pass filter is placed in front of the comparator, as shown in Fig. 1(C), so that the problem of changing states between clock pulses is eliminated.

Delta modulation uses the 1-bit A/D principle just described but with the slight twist that the reference voltage isn't fixed. Instead, V_{ref} is the integrated output from the flip-flop.

The integrator outputs a voltage that is based on the "average" of the last few samples. The next sample will be a 1 if the analog input voltage is greater than this average. In essence, then, the output will be a 1 if the analog input is rising or a 0 if the input is falling. Therefore, the comparator is always looking at the *difference* (or "delta," which is taken from the Greek letter Δ) of the average of the last two samples and the current analog input. As a bonus, no UARTs or shift registers are needed to convert the digital data into a serial-format output—it's already a serial data stream!

A block diagram of a delta encoder is shown in Fig. 2. Notice the feedback loop from the output to the integrator. By integrating the digital data stream, past history is obtained for the comparator. This results in a lower bandwidth for a given signal-to-noise ratio (S/N) and frequency response.

Decoding at the receiving end couldn't be simpler. You simply integrate the digital data stream (the output from the integrator will look exactly like the output from the integrator in the encoder) and low-pass filter the signal to remove the clock edges. A block diagram of the decoder is shown in Fig. 3.

The simple delta modulator/demodulator is built around a fixed-slope integrator. Think of it as a low-pass filter with a fixed-slew-rate operational amplifier that has a fairly slow response. This is okay for signals with a low dynamic range of less than 20 dB. However, for signals with a greater dynamic range, music for example, the fixed-slope integrator can't keep up with the rapidly

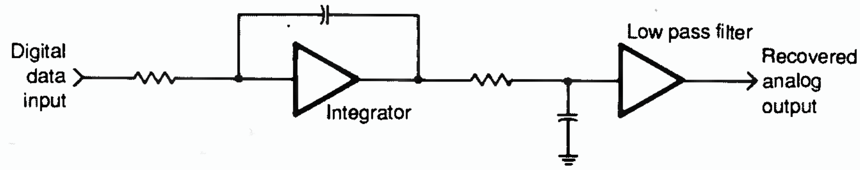
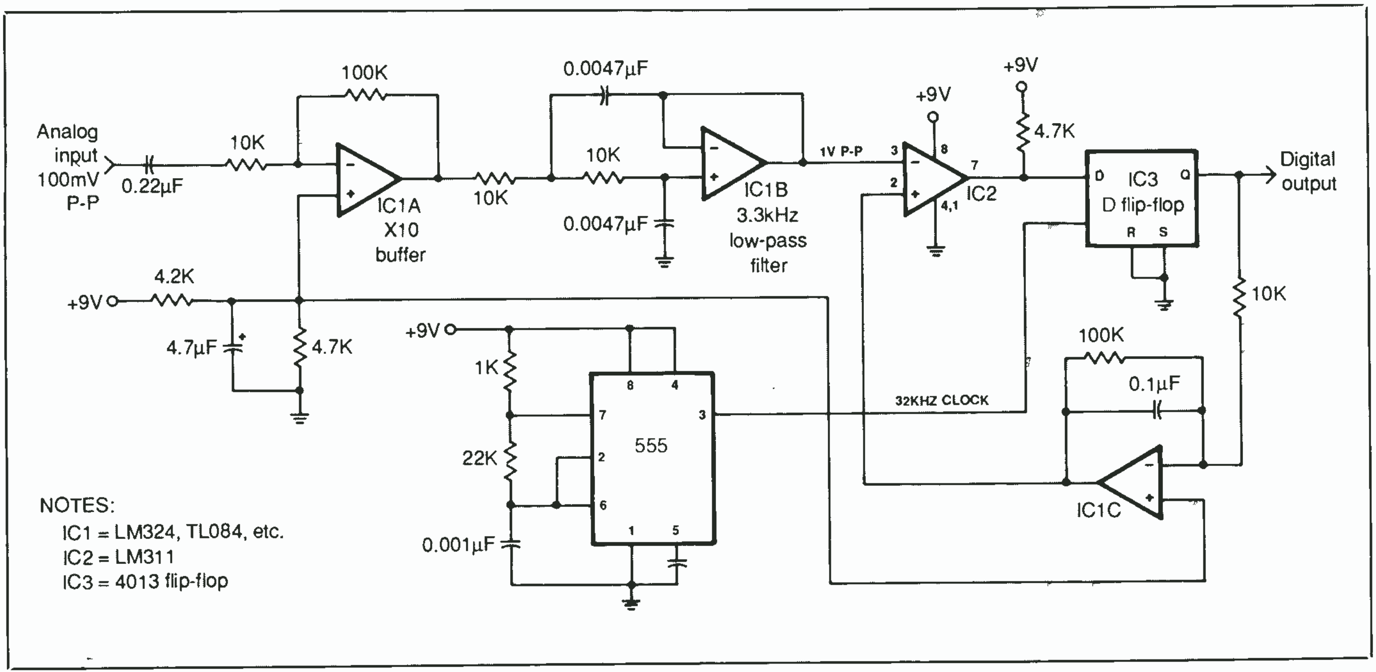


Fig. 3. Block diagram of a simple delta decoder.



NOTES:
IC1 = LM324, TL084, etc.
IC2 = LM311
IC3 = 4013 flip-flop

Fig. 4. A practical delta modulator.

changing input waveform. A higher clock frequency helps by making each change smaller, but at the expense of increased bandwidth.

Two manufacturers—Motorola and Harris—offer a solution to the fixed-slope problem. This is the continuously variable slope delta (CVSD) integrator. Unlike the simple delta integrator, the CVSD integrator slope is variable. In practice, this means that a rapidly changing input signal will cause the integrator to slew faster. Performance specifications include a 30-dB S/N and 50-dB dynamic range. ICs that contain all the circuitry (except passive devices and clock generator) to implement a CVSD modulator/demodulator include the MC3517 and MC3518 from Motorola and HC-55535 (demodulator only) and HC-55564 from Harris.

In addition to a voice or music data link, CVSDs lend themselves to other applications as well:

Secure Communications. Since the output of the delta modulator is a serial data stream, it can be encoded with a pseudo-random noise source to provide data security.

Music Delay Line. Here a simple shift register can be used to delay the data stream. Taps on the shift register can provide echo, reverberation and other special effects. However, to obtain a meaningful delay, the shift register must have a fairly high bit count, perhaps 10K bits or more.

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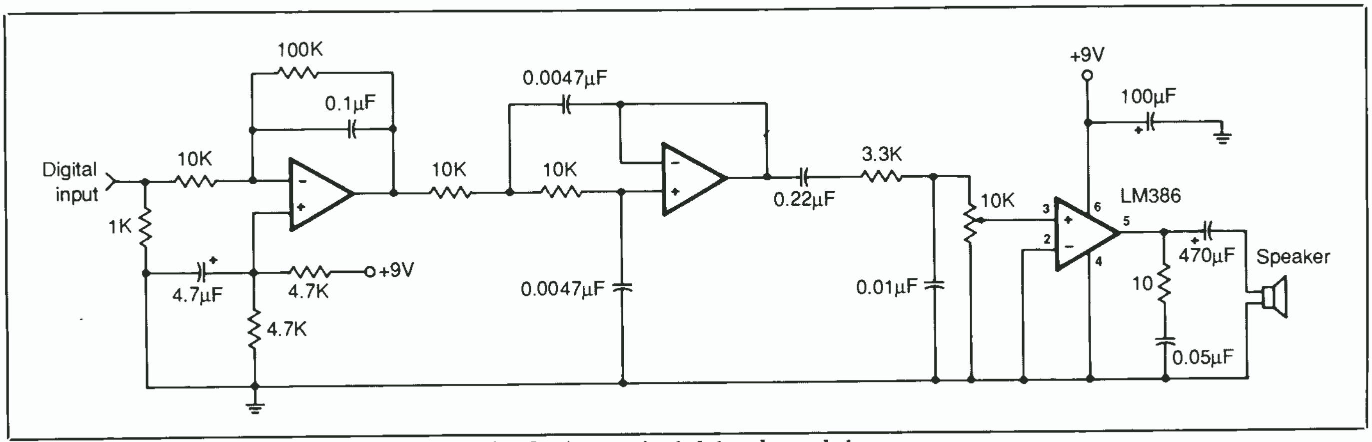

Fig. 5. A practical delta demodulator.

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Computer Input/Output (I/O). In this application, the bandwidth-compression effects of CVSD results in a smaller amount of data storage on-disk or in RAM memory.

Optical Data Links. By driving a light-emitting diode (LED) with the digital signal and using a phototransistor and comparator at the receiving end, you have a data link.

If you wish to know more about delta modulation, the following are just a few publications to which you can refer: *Analog Data Manual* and Application Note 607 ("Delta Modulation for Voice") from Harris; *Transmission* from Dow Jones; Telecommunications Device Manual "Telephone Quality CVSD Codecs Using New Bipolar Linear I^2L I.C." by Stephen H. Kelley and John J. Price from Motorola; and *Data Acquistion and Conversion Handbook* from Datel-Intersil.

Build a Simple Delta Modulator/Demodulator

Perhaps the best way to understand delta modulation (or any circuit, for that matter) is to actually build it. The circuits shown in Figs. 4 and 5 illustrate a simple delta modulator and demodulator, respectively. Although they're adequate for voice communication, don't expect terrific performance. Devices are available that will outperform a simple delta modulator on a single chip. However, hooking up a single chip (which is difficult to find) wouldn't lead to a very good understanding of delta modulation.

Almost any operational amplifier will work in the Figs. 4 and 5 circuits, except for the low-power types whose bandwidths can be measured with a stopwatch. You can experiment with the clock frequency, which doesn't even have to be very stable. However, don't expect too much from a clock frequency of less than about 10 kHz.

Not all pinouts or power-supply pins are shown in the schematics be-

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cause this is not a blow-by-blow construction piece. Rather, it's meant to serve as an introduction to an old idea, and since different op amps can be used, their pinouts would be different. Therefore, you should refer to the data sheet of the op amp selected for pinout and other pertinent information.

Since the circuit is fairly simple in design, you can use perforated-board construction techniques to wire the modulator and demodulator. Feel free to experiment with the circuits. There's no better way to learn how they operate and perform and what their limitations are than by experimenting. **ME**