Digital data: play it like it is

Distortion and noise in tape-playback amplifiers often give you false data. An improved peak detector for NRZI amps rejects both low- and high-level noise, and responds only to the true peak of the playback signal.

By Frank C. Marino, Sr. Dev. Engr.
Digitronics Corp., Albertson, N. Y.

In high density NRZI **(nonreturn-to-zero inverted)** data recording systems, playback signal amplitude variations of 20 to 30 dB are not uncommon. Thus, the peak detector in the playback amplifier of such systems must respond to full-wave rectified signals that range from a few tenths to several volts peak amplitude.

The sensitivity of such a detector poses two problems. One is that at low levels, you must prevent noise signals from reaching the detector. You usually do this by mixing a dc voltage with the rectified input, so that only signals exceeding this threshold-voltage level reach the peak detector.

The second problem is that of high-level noise signals, which the detector must also reject. Most peak detectors consist of a differentiator followed by a nonlinear amplifier. Now, a differentiator is a high-pass network. So unwanted high-frequency noise that exceeds the dc voltage level mixed with the rectified input signal will be passed along by the peak detector.

To prevent this, first remember that most unwanted high-frequency noise—which may be larger in amplitude than wanted low-level signals—is narrower in width than the desired signals. This fact tells you that if you place a pulse-width discriminator after the peak-detector stage, you can get high-level noise rejection. The pulse-width discriminator usually takes the form of an integrator at the input of a shaper amplifier such as a Schmitt-trigger.

Signal distortions

A peak detector made of a differentiator followed by an amplifier is, basically, a zero-slope detector. Such a detector will work properly only for good NRZI playback signals as shown in Fig. 1a, where the signal peaks, P, are the only points at which $dv/dt=0$. The detector will have difficulty with the distorted waveforms of Fig. 1b. Here, a distorted signal shows additional points of zero-slope, or near zero-slope, at points A of the waveform.

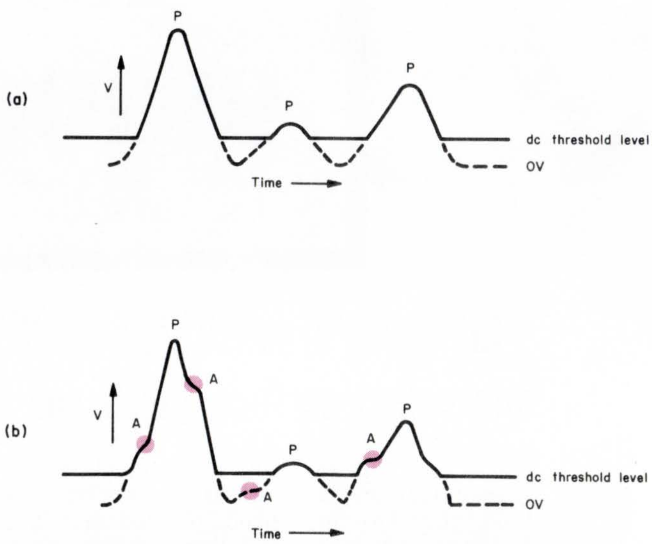


Fig. 1. The upper waveform, (a), is a good **NRZI** playback signal, after rectification. Note that zero-slope points, P, occur only at the true peak of the waveform. Waveform (b), on the other hand, shows spurious zero-slope points, A, from vibration, crosstalk, and dropouts. These cause unwanted outputs from conventional peak detectors.

At unconventional tape speeds (under 3 ips), mechanical vibrations caused by vacuum motors, rotating pulleys, idlers, and so forth, become significant. They move along the tape to the playback head and help produce the distortions shown in the figure. Such

Digital data and magnetic tape

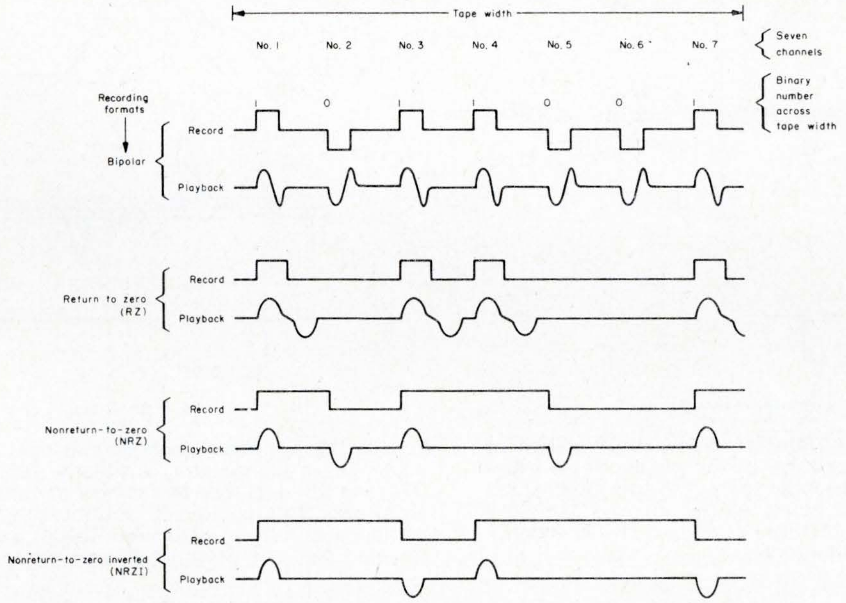
There are several formats for recording digital data on magnetic tape. And a feature common to all such recording modes is that the recording head produces sufficient flux to saturate the tape's magnetic oxide. The direction of magnetization depends upon the direction of the write current, and the length (on the tape) of a particular magnetized section is a function of the tape speed and the write-current time.

Because the tape's oxide is saturated, the playback head gives you an output only at those times that the tape magnetization changes direction.

The various recording modes use the playback head's output pulses to represent the one's and zeroes of digital data. Some common recording formats are shown.

The *nonreturn-to-zero inverted* (NRZI) mode is one of the most common formats. It has a high packing density (you can put lots of data in a small length of tape): it is the least demanding format with respect to the frequency response of the tape and transport mechanism; and accidental polarity reversals do not affect the accuracy of the data (because the flux direction is of no significance: a *1* is represented by a transition in either direction).

To recover the recorded data, you must linearly amplify the playback signal, full-wave rectify it (because in the NRZI mode, binary ones are bipolar), and peak-detect it. Peak detection is desirable because the peak of the playback signal is least affected by pulse crowding and dropout on the tape.



Obviously, proper operation of the peak detector is important to the accuracy of the recovered data. One vital aspect of detector performance is its ability to generate an output that corresponds in time to the true peak of the rectified playback signal. Another is the detector's ability to accurately peak-detect signals in the presence of noise and large input-amplitude variations.

If you satisfy these criteria, you'll have a good detection system. This article describes one way of doing it.

distortions are also common with relatively inexpensive IBM-compatible read/write heads, where write-to-read and read-to-read crosstalk levels are greater than 3%.

The effects of crosstalk are especially noticeable at the base of the waveforms, where signal-to-noise ratios are low. But because it is desirable to use dc threshold voltage levels much less than 15% during playback (to recover extreme dropout signals), the peak detector must tolerate the type of waveform distortion shown in Fig. 1b.

A close look at these waveforms shows you that the peak-points, P, are distinguished from the distortion points, A, by the first derivative of the waveforms. The derivative changes polarity only at the points P, the desired peaks of the waveform. An improved peak detector, therefore, is one which is responsive only to a *change in the polarity of the first derivative* of the playback signal. Such a peak detector consists of a differentiator, followed by a bistable amplifier.

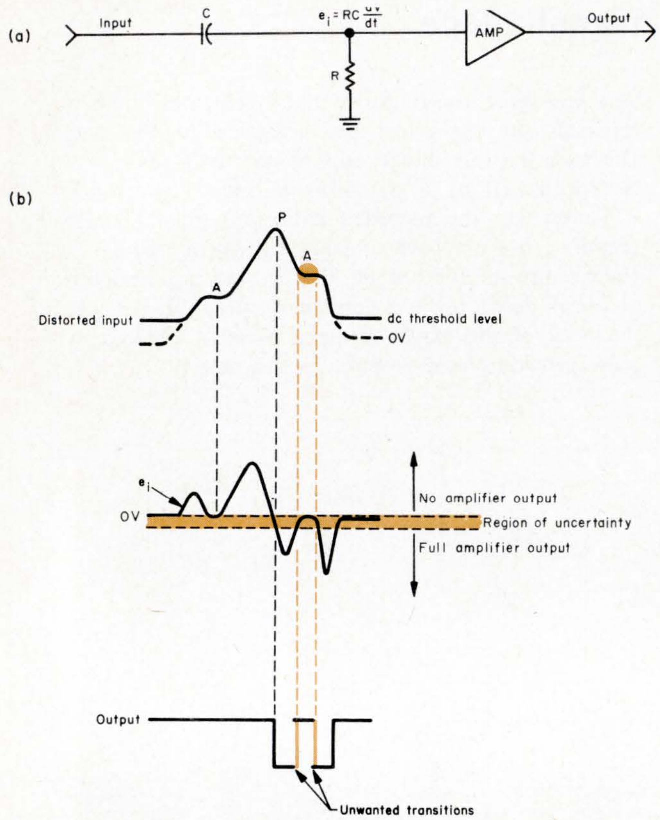


Fig. 2. A conventional peak detector, as in (a), consists of a differentiator, RC, followed by an amplifier. False zero-slope points, A, cause unwanted output transitions which are equivalent to erroneous binary **ones.** There is a limited dynamic range, and the amplifier's region of uncertainty causes spurious output transitions.

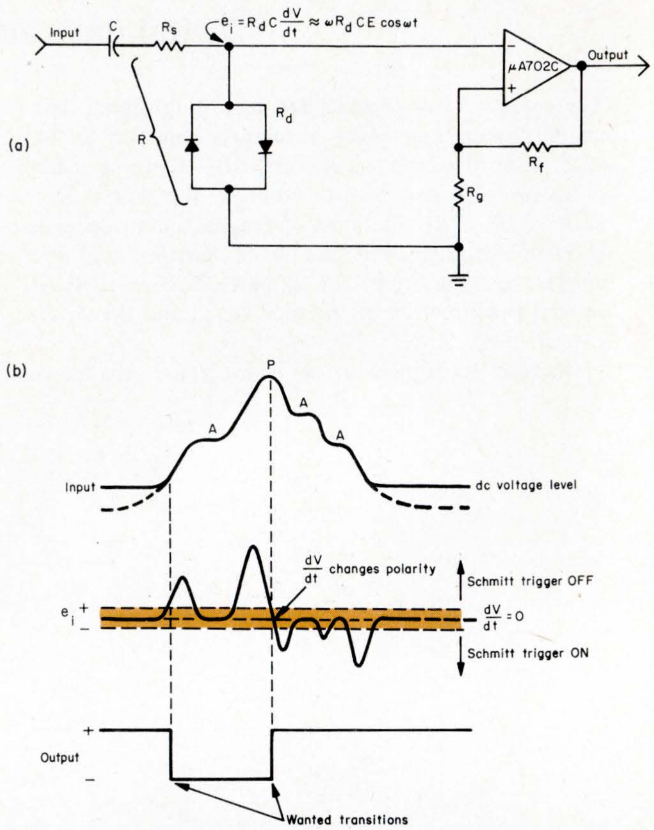


Fig. 3. The improved peak detector (a) is an op amp connected as a comparator. A clearly defined region between OFF and ON replaces the region of uncertainty in ordinary amplifiers. This eliminates spurious triggering, even in the presence of severe distortion. Diodes protect the comparator, and give the detector a large dynamic range.

An op amp to the rescue

Figure 2b shows you how a conventional peak detector fails when presented with a distorted waveform. Another type of failure, not shown, is that of an oscillatory or unstable amplifier output that occurs at the point of distortion which approaches zero-slope. This happens because the resulting input-voltage to the amplifier, $RC\,dv/dt$, may be in the region of uncertainty common to all amplifiers because of their inherent lack of hysteresis.

The combination of any bistable amplifier preceded by an ordinary RC differentiator gives you improved peak-detection. That is, the circuit will respond only to a change in the polarity of the first derivative of the input waveform. But the improved detector of Fig. 3 goes one step further. Its bistable amplifier is a Fairchild μA702C op amp arranged in the form of a comparator with pre-determined hysteresis.

In Fig. 3a, the total differentiator resistance R includes the non-linear resistance of the two diodes. These diodes protect the comparator from the excessive input voltages of signals with large peak amplitudes (say, 5 V), and with sharp rising and decaying slopes. Conversely, for very weak input signals (100 mV) most of the differentiated voltage appears across the now relatively-large diode resistances. Consequently, the peak detector operates accurately with input signal variations greater than 30 dB.

Some analysis

If you assume the rectified input signal approximates a sine wave, you can write this first-order differential equation for the differentiator:

$$RC\frac{dv}{dt} + V = E\sin\omega t \qquad (1)$$

The general solution for the voltage V developed across the capacitor is:

$$V = \epsilon^{-\int\frac{dt}{RC}}\left[\frac{E}{RC}\int \epsilon^{\int\frac{dt}{RC}} \sin\omega t\, dt + K\right] \qquad (2)$$

From which,

$$V = \epsilon^{-\frac{t}{RC}}\left[\frac{E\,\epsilon^{\frac{t}{RC}}(\sin\omega t - \omega RC\cos\omega t)}{(\omega RC)^2 + 1} + K\right] \qquad (3)$$

Since $V = 0$ at $t = 0$, $K = \dfrac{\omega RCE}{(\omega RC)^2 + 1}$

and the particular solution of eq. (1) is:

$$V = \frac{E\left[\sin\omega t + \omega RC\left(\epsilon^{-\frac{t}{RC}} - \cos\omega t\right)\right]}{(\omega RC)^2 + 1} \qquad (4)$$

these values into eq. (9), you can approximate the capacitance as a function of frequency:

$$C_{pF} \approx \frac{2250}{f_{kHz}}$$

For example, at 800 bpi and a tape speed of 40 ips, $f \approx (1/2)\ (800)\ (40) = 16$ kHz, and $C = 2250/16 \approx 140$ pF. At 556 bpi and the same tape speed, $C = 203$ pF. Because it is impractical to change the value of this capacitor to compensate for a change between these two popular packing densities (556 and 800 bpi), you can choose 180 pF as a compromise value for the tape speed. You should pick a value for R_s that is relatively small compared to R_d for weak input signals, but large enough to avoid dynamic overloading of the driving stage during nominal strength input signals.

A complete amplifier

Figure 4 shows a playback amplifier for tape speeds from 10 to 40 ips and packing densities of 556 and 800 bpi. At 40 ips, the best value of the peak detector's differentiator capacitor is 180 pF. At 10 ips, you should increase its value by the factor of 40/10, to about 750 pF.

The first-stage linear amplifier has a balanced input for common-mode rejection, and a closed-loop gain of 40 dB. The second-stage linear amplifier gives you the needed phase-splitting function, and an additional gain of about 20 dB. A full-wave, balanced bridge rectifies the playback signals. The overall frequency response of the linear portions of the amplifier is flat to about 33 kHz, and rolls-off at 12 dB/oct. from this point. Note that the dc voltage that sets the low-level noise is added at the bridge, through D_5.

Following the improved peak-detector circuit are the integrator and Schmitt-trigger stages. These two circuits comprise a pulse-width discriminator for high-level noise rejection. Figure 5 shows how it works. The Schmitt-trigger is, again, an op amp arranged as a comparator with pre-determined hysteresis threshold levels.

You can apply the general amplifier configuration of Fig. 4 to high-density NRZI tape systems with tape speeds from one to more than 100 ips. But at speeds below 10 ips, you must add linear gain. At speeds above 40 ips, you must appropriately extend the upper-corner frequencies by lowering the capacitor values of the various lag networks. And you must also modify the RC time constant in the integrator, as a function of the tape speed.

During read-only operations, you can safely use low-level noise-threshold voltages as low as 3%. This is due mainly to the improved peak detector circuit. And the added use of pulse-width discrimination following the detector eliminates high-frequency noise that exceeds this low threshold-level. Further, the improved detector lets this amplifier perform reliably with less expensive IBM-compatible read/write heads, because it can tolerate increased levels of write-to-read and read-to-read crosstalk.

INFORMATION RETRIEVAL:

Amplifiers, Digital design,
Data acquisition and processing