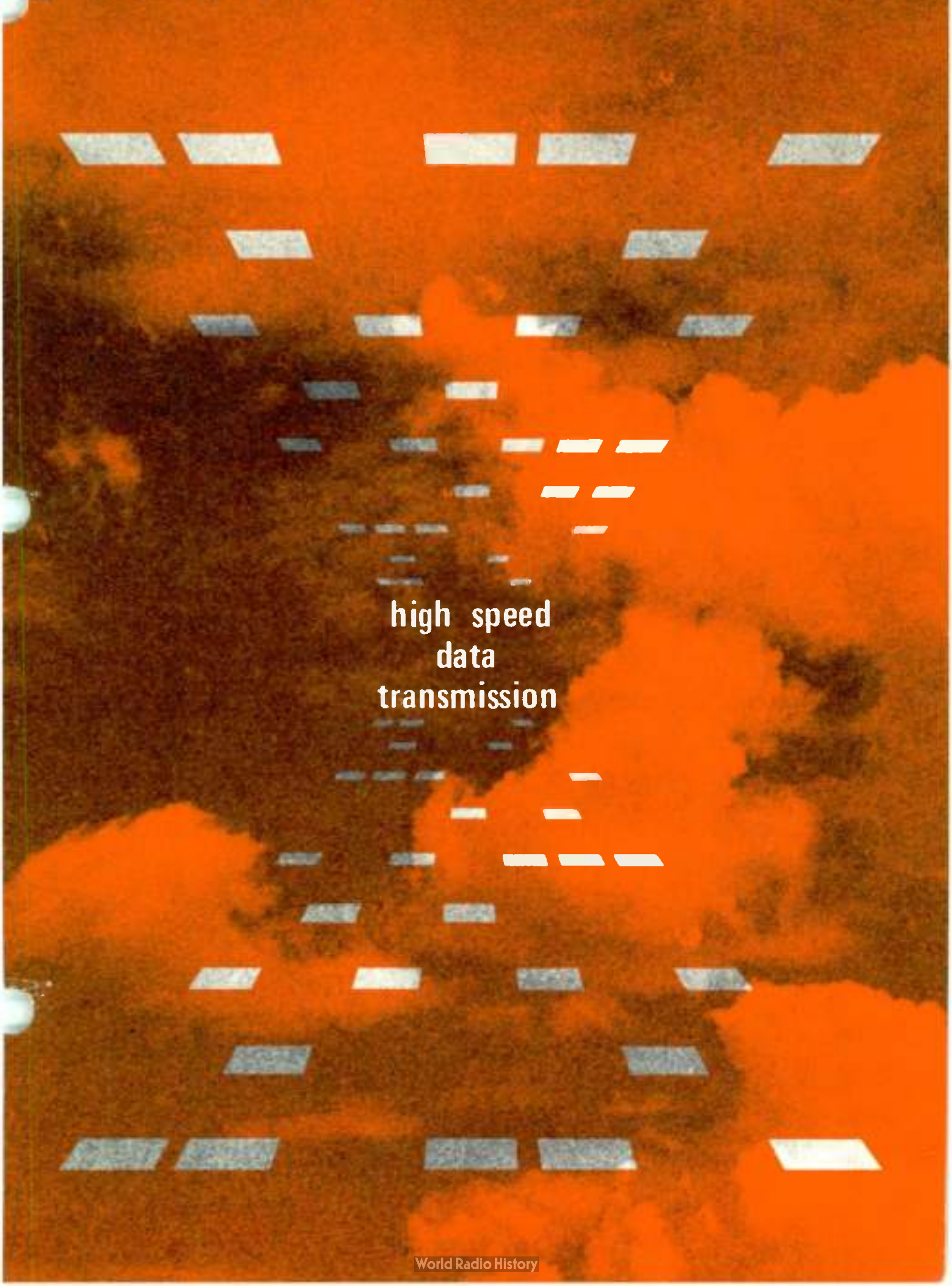
The Lenkurt DEMODULATOR

SEPTEMBER 1970



The large volume of data being transmitted today is relatively small compared to what is forecast for the future. Low-speed data is well understood and will undoubtedly handle a major portion of this future growth. However, the problems associated with high speed data transmission must be more fully understood before its potential can be achieved.

The use of higher data transmission speeds means a complete re-evaluation of transmission methods. But, just as computer technology has advanced from its first days of struggle, so too will the communications industry provide a wide range of reliable data transmission services and equipment. Since there are as many possible ways of transmitting data as there are types of communication channels, the challenge is to determine the best scheme for a particular application.

Using data transmission speeds of 2400 bits/second and higher, large volumes of data can be handled, but situations are also encountered which require thorough compensation techniques to reduce errors and provide high reliability. Ordinary circuit disturbances, normally disregarded by the human ear, must now be taken into account, because transmission impairments can seriously interfere with the discrete levels and frequencies associated with high-speed data transmission.

How are data signals affected by high-speed transmission?

Effect on Data

When a tone or carrier is keyed rapidly by data pulses, sideband frequencies are created. These sidebands carry all the information conveyed by the pulse. Therefore, shifting these sidebands in relative amplitude (attenuation) or position (delay) causes errors in pulse reconstruction.

As data keying rates increase, the sidebands are more widely spread in frequency and the maximum pulse duration is reduced. The extra frequency range of the sidebands moves them to band-edge frequencies of increased delay and attenuation, thus reducing the chances of the pulse being reconstructed accurately at the receiver. With shorter pulse durations, slight shifts in time have a greater effect in degrading the pulse and increasing the possibility of losing it.

Both attenuation distortion and delay distortion have been recognized and successfully corrected for years through the use of equalizers. What, then, makes them so interesting now? The answer is that the old standards of equalization are not good enough for the current high data rates. These high rates demand greater usable band width. And further, they require equalization that is tailored to the particular circuit in use during any one random connection. This is beyond the capability of fixed equalizers.

Considerable research has resulted in the development of equalizers that change their characteristics automatically to fit those of the communications channel. Lenkurt, among others, has developed such an adaptive equalizer for digital signals. Lenkurt's equalizer contains a miniature special-

 ● VOL. 19, NO. 9

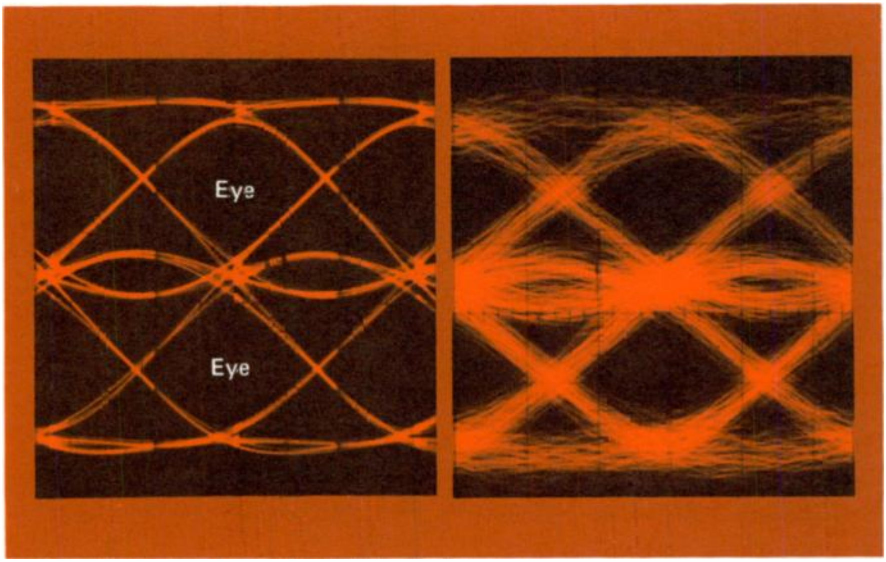


Figure 1. Eye patterns are used to measure the channel's overall performance. The pattern on the left represents a well-equalized duobinary signal, while the right pattern represents a slightly impaired duobinary signal.

purpose computer which adjusts signals to compensate for rapidly changing loss and delay characteristics. Such an equalizer is expected to permit previously unattainable reliability at data transmission rates as high as 9,600 bits/second.

When trying to determine the quality of a data channel, it is imperative to look at the total effect of all transmission impairments. For example, delay and attenuation distortion may be low, but if there are other distortions, the channel may not be satisfactory for data transmission. The eye pattern shown in Figure 1 is often used to determine overall channel quality, because any distortion will tend to close the eye — the larger the opening the better the channel.

Foremost on the list of transmission impairments is *attenuation distortion*, in which the fixed magnitude relationships of the various frequency components of any information-carrying signal are disturbed.

Attenuation Distortion

In an ideal communications channel, all frequency components of the signal experience the same attenuation. In other words, the channel has a flat, loss-frequency response from end to end. Such an ideal channel unfortunately does not exist; therefore, some frequencies are attenuated more than others — resulting in attenuation distortion (see Figure 2).

Attenuation distortion most commonly appears as band-edge roll-off. The causes of this distortion include capacitive and inductive reactances, filters in carrier systems, loaded cable that acts as a lowpass filter, and transformers and series capacitors that act as highpass filters.

Channel design can compensate for a reasonable amount of attenuation distortion. Additionally, linear compensating networks can be constructed to equalize attenuation to some degree. Such networks operate by introducing more loss into the low-loss portions of the band to smooth the channel's attenuation characteristic. However, if the loss variation is great, there may be difficulties in equalizing the high-loss part of the band. Consequently, a limitation on useful bandwidth and signal rates occurs.

Compromise equalization is quite effective against band-edge roll-off because all channels experience a somewhat similar roll-off, regardless of how a channel selection is made through a switched network. Thus, an equalizer can be adjusted to compensate for typical roll-off characteristics. The resulting equalized response will not, however, be exact for every circuit connection, but will generally extend throughout the usable bandwidth.

Delay Distortion

While attenuation distortion disturbs the relative magnitude of the various frequency components in a transmitted signal, *delay distortion* upsets the time relationship between these components. This condition is manifested by some frequency components being delayed more than others during transmission.

A voice circuit acts like a bandpass filter. As the filter cutoff frequency is approached, delay distortion increases rapidly. This delay is produced by the inductive and capacitive reactances in the system; the various inductances and capacitances require a finite time to charge up and then discharge in response to a signal.

Such delay is not objectionable if it is constant for each signal frequency, in which case, all the components of the signal are then delayed by similar amounts. However, if the delay varies with frequency, the components are delayed by unequal amounts and the data pulse shape becomes distorted. In a typical voice channel, the frequency of minimum delay is approximately 1700 Hz, with the relative delay symmetric about this frequency for carrier systems.

As in the case of attenuation distortion, delay distortion can be reduced by adding delay to selected portions of the transmission band. Ideally, delay equalizers should modify the delay characteristic without appreciably changing the loss. As shown in Figure 3, a properly selected equalizer can produce nearly uniform delay across a limited band without affecting the selectivity of the filters responsible for this type of delay distortion.

Noise

Another detriment to error-free data transmission is noise. It is generally classified into two types. One type is often called simply *noise*, or sometimes *white noise* – implying that it is distributed uniformly throughout the frequency band of interest; the other type is *impulse noise.* White noise is the background "hiss," composed largely of thermal noise occasionally noticeable on voice connections. This kind of noise interferes with speech much more than it does with data. The pulsed nature of digital data transmission makes it possible to avoid impairment by setting the amplitude above the background noise level.

It is primarily impulse noise that causes trouble in data transmission. Impulse noise takes the form of sharp clicks or bursts of energy arising from such sources as electrical storms or other electrical systems. Figure 4 illustrates the effect of impulse noise on data signals.

Figure 2. The attenuation characteristic of a telephone channel will assume this general form. The values of F_1, F_2, and F_3 are a function of the type channel used.

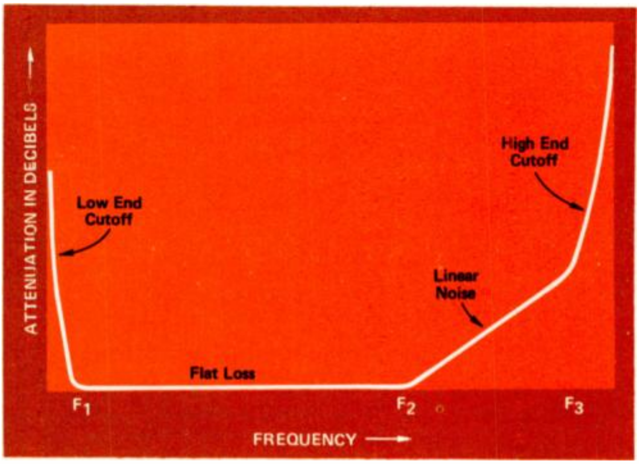
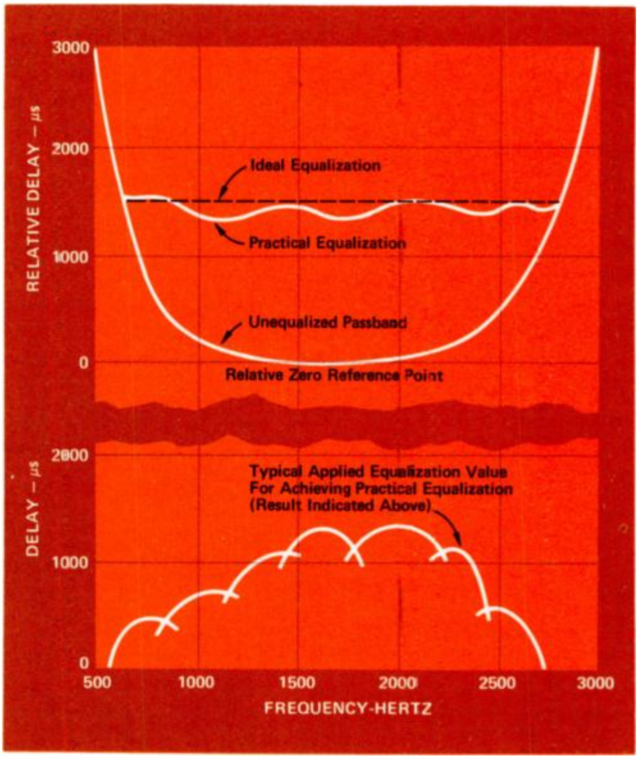


Figure 3. Equalization is provided by adding delay at specified points in the passband.



A large portion of impulse noise comes from switching and signaling equipment, power sources, and other electrical systems. Often these noise spikes have such a short duration that the human ear, with its slow response time, does not hear them. But, data transmission equipment can "hear" them. To a receiver, an impulse spike may "sound" like a data pulse, or cause severe distortion of an actual data pulse.

Here again, the effect is more pronounced in high-speed transmission, when data pulses are of shorter duration and more nearly approximate the duration of noise impulses. Furthermore, a prolonged burst of impulse noise can obliterate more pulses at high speed than at low speed.

Electronic switching systems presently being developed are expected to reduce one prevalent source of impulse noise.

Crosstalk caused by coupling between channels is another form of noise interference on data channels.

Phase Jitter

With the coming of higher data transmission speeds, certain other types of transmission impairments have become more apparent. They are not really new, but have had little effect at low speeds.

For example, the term *phase jitter* was rarely heard in communication circles a few years ago. However, it is now a matter of concern to the industry because it is more critical at data speeds above 2400 bits/second.

Phase jitter causes a pure tone to have an associated FM spectrum at the output of a transmission system. In some cases this spectrum is random, similar to the noise associated with carrier generation. At other times, phase jitter takes the form of discrete spectral lines – often multiples and submultiples of AC power frequencies – caused by coupling through power supplies or from power-line-associated equipment such as ringing generators. Industry guidelines for allowable phase jitter are in a transitional stage.

Other Impairments

A great many minor problems can cause momentary disturbances, or *hits*, on data transmission channels. Individually, they may be only annoying. Collectively, they can seriously increase error rates.

Faulty amplifier components, switching of broadband facilities, and operation and maintenance errors on communication channels can cause sudden changes in signal amplitude. These changes are rarely more than 6 dB, but this is severe enough to disturb some AM data transmission.

Sudden phase changes cause amplitude transients when the signal returns to steady state. These phase changes can result from the switching of out-of-phase carrier supplies or the substitution of a broadband facility having a different propagation time.

Accidents, storms, construction work, or maintenance activity can cause a short-duration signal loss. Such a loss, when it occurs during data transmission is called a *dropout.*

The Outlook

From the viewpoint of transmission quality, the demands for increased data speed and reliability could possibly be met best by building an entirely new world-wide network using special channels designed or conditioned specifically for data. This would mean working with costly, state-of-the-art equipment developed by the existing telecommunications industry. These special high-speed data transmission networks are already being planned. However, many of the

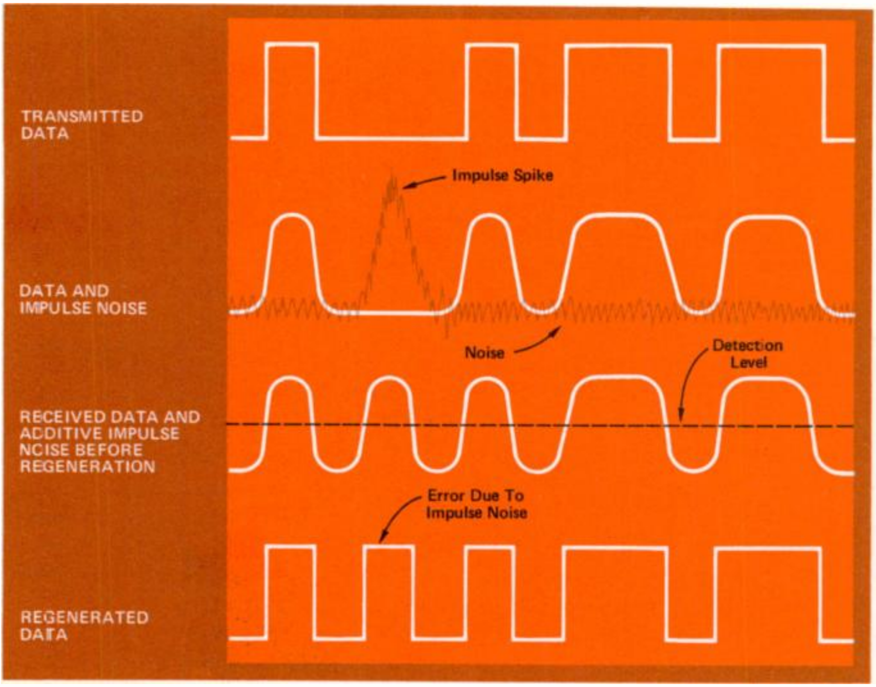


Figure 4. Data transmission is relatively unaffected by noise below the signal detection level; therefore, errors are quite likely to be caused by impulse noise, while white noise has little effect on the signal.

same transmission problems may be present in these new networks as well.

The switched telephone network has availability and flexibility in its favor. It can provide almost instant communication to any location that has a telephone. For some point-to-point data transmission applications, dedicated channels seem to offer the best solution. However, the inherent flexibility of switched networks means they will be called upon to carry more data in the future.

The result is increasing pressure for more stringent control of all the parameters that affect data transmission. Rarely is one parameter a controlling factor, in data speed or reliability. Rather, it is a combination.

There is no shortcut to improving high-speed data transmission. The first step might be summed up as: more engineering attention to data when new facilities are being planned; the installation of equipment designed with data in mind; and more maintenance attention to data-transmission parameters. While these special high-speed systems are being improved, the existing low-speed systems will continue to handle the bulk of data transmission.

LENKURT ELECTRIC CO., INC.
SAN CARLOS, CALIFORNIA 94070

Bulk Rate
U.S. Postage
Paid
San Carlos, Calif
Permit No. 37

ADDRESS CORRECTI
REQUESTED

MR. PHILIP E. FRAZIER 567
UNIV. OF CALIF. RADIATION LAB.
BLDG. 88, ROOM 113
BERKELEY, CAL 94720

LENKURT ELECTRIC
GENERAL TELEPHONE & ELECTRONICS

SAN CARLOS, CALIFORNIA, U.S.A.
VIDEO, VOICE & DATA
TRANSMISSION SYSTEMS

Lenkurt Offices
San Carlos
Atlanta
Falls Church, Va.
Chicago
Dallas

The **Lenkurt Demodulator** is circulated monthly to technicians, engineers and managers employed by companies or government agencies who use and operate communications systems, and to educational institutions. Permission to reprint granted on request.