

Digital Data, Digital Signals

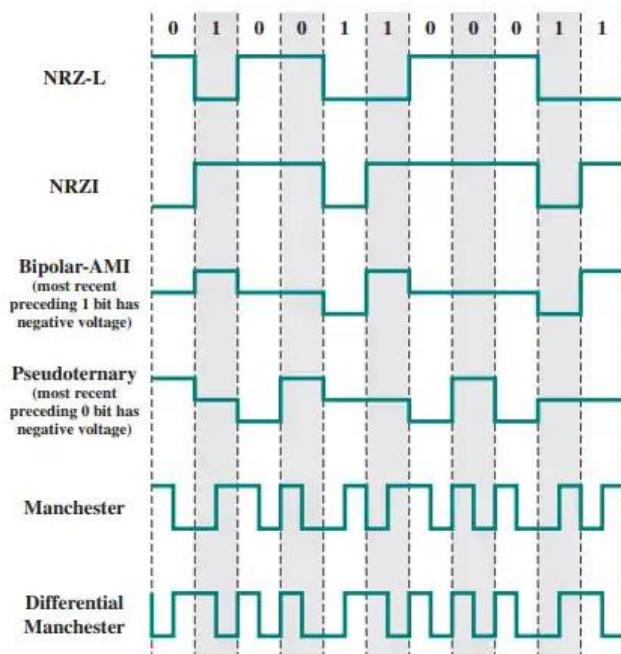
A digital signal is a sequence of discrete, discontinuous voltage pulses. Each pulse is a signal element. Binary data are transmitted by encoding each data bit into signal elements. In the simplest case, there is a one-to-one correspondence between bits and signal elements.

First, we define some terms. If the signal elements all have the same algebraic sign, that is, all positive or negative, then the signal is unipolar. In polar signaling, one logic state is represented by a positive voltage level and the other by a negative voltage level. The data signaling rate, or just data rate, of a signal is the rate, in bits per second, that data are transmitted. The duration or length of a bit is the amount of time it takes for the transmitter to emit the bit; for a data rate R , the bit duration is $1/R$. The modulation rate, by contrast, is the rate at which the signal level is changed. This will depend on the nature of the digital encoding, as explained later. The modulation rate is expressed in baud, which means signal elements per second. Finally, the terms mark and space, for historical reasons, refer to the binary digits 1 and 0, respectively.

First, the receiver must know the timing of each bit; that is, the receiver must know with some accuracy when a bit begins and ends. Second, the receiver must determine whether the signal level for each bit position is high (0) or low (1).

Before describing these techniques, let us consider the following ways of evaluating or comparing the various techniques.

Signal spectrum: Several aspects of the signal spectrum are important. A lack of high-frequency components means that less bandwidth is required for transmission. In addition, lack of a direct-current (dc) component is also desirable. With a dc component to the signal, there must be direct physical attachment of transmission components. With no dc component, ac coupling via transformer is possible; this provides excellent electrical isolation, reducing interference.



Finally, the magnitude of the effects of signal distortion and interference depends on the spectral properties of the transmitted signal. In practice, it usually happens that the transmission characteristics of a channel are worse near the band edges. Therefore, a good signal design should concentrate the transmitted power in the middle of the transmission bandwidth. In such a case, a smaller distortion should be present in the received signal. To meet this objective, codes can be designed with the aim of shaping the spectrum of the transmitted signal.

Clocking: We mentioned the need to determine the beginning and end of each bit position. This is no easy task. One rather expensive approach is to provide a separate clock lead to synchronize the transmitter and receiver. The alternative is to provide some synchronization mechanism that is based on the transmitted signal. This can be achieved with suitable encoding, as explained subsequently.

Signal interference and noise immunity: Certain codes exhibit superior performance in the presence of noise. Performance is usually expressed in terms of a BER.

Cost and complexity: Although digital logic continues to drop in price, this factor should not be ignored. In particular, the higher the signaling rate to achieve a given data rate, the greater the cost. We shall see that some codes require a signaling rate that is greater than the actual data rate.

Nonreturn to Zero (NRZ):

The most common, and easiest, way to transmit digital signals is to use two different voltage levels for the two binary digits. Codes that follow this strategy share the property that the voltage level is constant during a bit interval; there is no transition (no return to a zero voltage level). For example, the absence of voltage can be used to represent binary 0, with a constant positive voltage used to represent binary 1. More commonly, a negative voltage represents one binary value and a positive voltage represents the other. This latter code, known as Nonreturn to Zero-Level (NRZ-L).

A variation of NRZ is known as NRZI (Nonreturn to Zero, invert on ones). As with NRZ-L, NRZI maintains a constant voltage pulse for the duration of a bit time. The data themselves are encoded as the presence or absence of a signal transition at the beginning of the bit time. A transition (low to high or high to low) at the beginning of a bit time denotes a binary 1 for that bit time; no transition indicates a binary 0. NRZI is an example of differential encoding. In differential encoding, the information to be transmitted is represented in terms of the changes between successive signal elements rather than the signal elements themselves. The encoding of the current bit is determined as follows: If the current bit is a binary 0, then the current bit is encoded with the same signal as the preceding bit; if the current bit is a binary 1, then the current bit is encoded with a different signal than the preceding bit. One benefit of differential encoding is that it may be more reliable to detect a transition in the presence of noise than to compare a value to a threshold. Another benefit is that with a complex transmission layout, it is easy to lose the sense of the polarity of the signal. For example, on a multidrop twisted-pair line, if the leads from an attached device to the twisted pair are accidentally inverted, all 1s and 0s for NRZ-L will be inverted. This does not happen with differential encoding.

Multilevel Binary

Multilevel binary encoding techniques address some of the deficiencies of the NRZ codes. These codes use more than two signal levels.

In the case of the bipolar-AMI scheme, a binary 0 is represented by no line signal, and a binary 1 is represented by a positive or negative pulse. The binary 1 pulses must alternate in polarity. There are several advantages to this approach. First, there will be no loss of synchronization if a long string of 1s occurs. Each 1 introduces a transition, and the receiver can resynchronize on that transition. A long string of 0s would still be a problem. Second, because the 1 signals alternate in voltage from positive to negative, there is no net dc component. Also, the bandwidth of the resulting signal is considerably less than the bandwidth for NRZ. Finally, the pulse alternation property provides a simple means of error detection. Any isolated error, whether it deletes a pulse or adds a pulse, causes a violation of this property.

Biphase

There is another set of coding techniques, grouped under the term biphase, that overcomes the limitations of NRZ codes. Two of these techniques, Manchester and differential Manchester, are in common use. In the Manchester code, there is a transition at the middle of each bit period. The midbit transition serves as a clocking mechanism and also as data: A low-to-high transition represents a 1, and a high-to-low transition represents a 0. In differential

Manchester

the midbit transition is used only to provide clocking. The encoding of a 0 is represented by the presence of a transition at the beginning of a bit period, and a 1 is represented by the absence of a transition at the beginning of a bit period. Differential Manchester has the added advantage of employing differential encoding. All of the biphase techniques require at least one transition per bit time and may have as many as two transitions. Thus, the maximum modulation rate is twice that for NRZ; this means that the bandwidth required is correspondingly greater.

On the other hand, the biphase schemes have several advantages:

- Synchronization: Because there is a predictable transition during each bit time, the receiver can synchronize on that transition. For this reason, the biphase codes are known as self-clocking codes.
- No dc component: Biphase codes have no dc component, yielding the benefits described earlier.
- Error detection: The absence of an expected transition can be used to detect errors. Noise on the line would have to invert both the signal before and after the expected transition to cause an undetected error.