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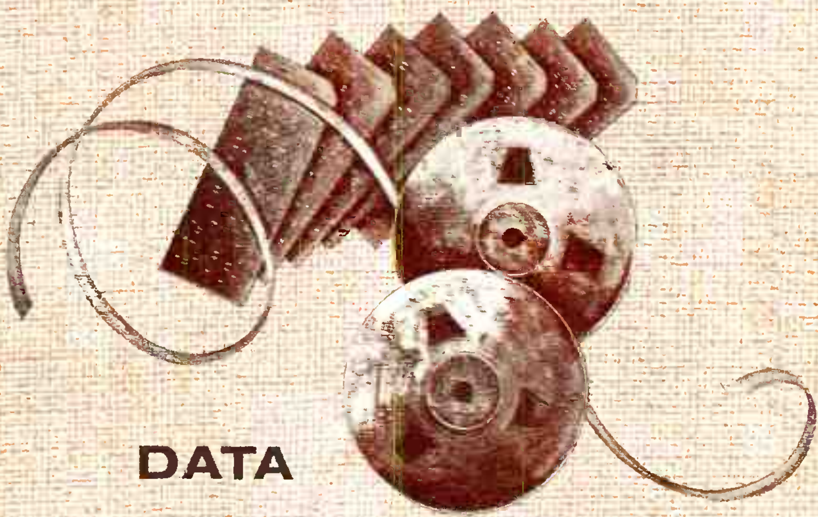
the Lenkurt Demodulator



DATA COMMUNICATIONS

Part 1

Data communications is today a dynamic and rapidly expanding field stimulated by the increasing need to link electronic computers and other business machines across great distances. The resultant union of the data processor and the communicator has provided a vital service to the everyday operation of business, industry, and government.

This is the first of a two-part article which presents an introduction to data communications technology, and offers some insight into the future of this progressive field.

LESS than one percent of the computers in service today are interconnected through a communications network. However, it is estimated that ten years from now at least half of the computers in operation will be working together on a real-time basis. It is also anticipated that the volume of digital data transmitted over communications facilities will eventually equal and perhaps exceed the volume of voice traffic.

A little over a century ago the first data message was transmitted on wire lines by Morse Code. But this was not the beginning of the realization that the spoken word could be represented by some analogous language. Ancient records confirm that semaphore-type data or information transmission systems using the visual sense for perception existed even before the Greek and Roman empires.

But what is data? It might be described as factual information required as the basis for making decisions. Thus, statistical reports, engineering documents, and historical records all contain data. Data covers a broad range of information and plays an important part in the decision-making processes of our everyday lives. In this discussion, however, the meaning of data is limited to digital forms of information used in machine-to-machine communication.

The economics of computers and other types of business machines are based on moving information to achieve optimum use of what are usually expensive facilities. Some of the large-scale computers now in service are capable of input rates as high as 10,000,000 bits per second (b/s). Bit, a contraction of *bi*nary digi*t*, expresses a unit of information in a two-element binary code. The elements are called "mark" and "space", and indicate the choice between two equally possible events.

The requirement for data communications arises because modern business machines and computers can record and store information more efficiently, more accurately, and significantly faster than can humans. At present, thousands of data messages are transmitted over telephone networks at speeds many times faster than could be achieved by human speech.

Communicating with Data

Data signals are transmitted over various types of telephone circuits. They travel on wire from telephone pole to telephone pole, through underground cables, from mountain top to mountain top over microwave facilities, on the ocean floor in submarine cables, and via communications satellites from continent to continent. Some type of data conversion equipment is required to change the digital machine signals to a form suitable for transmission over these facilities.

The data machine which provides an input to the transmit section of the conversion equipment, or *modulator*, can be a keyboard, printer, card reader, paper tape terminal, computer, or magnetic tape terminal. The output from the receive section of the converter, or *demodulator*, can be applied to a tape punch, printer, card punch, magnetic tape unit, computer, or visual display terminal. Typically, both the modulator and demodulator sections of the converter are combined into a two-way data transmitter-receiver, commonly called a *data modem* or *data set*.

Figure 1 illustrates a typical full-duplex data transmission system including the originating data processing equipment and the interface assembly which consists of buffer and control units. The interface assembly at the transmitter accepts data at a rate determined by the operating speed of the data processor, stores the data temporarily, and regenerates it at a rate compatible with that of the data modem. At the receiving terminal the interface assembly accepts the received data, stores it, then feeds it to the data processor at the appropriate rate.

Timing signals from the interface assembly at the transmitter are applied to the data modem to synchronize the computer and the data set. At the receiver, synchronization pulses are derived from the data stream to synchronize the computer.

When more than one data set feeds into a computer, the capacity of the interface equipment is of major concern since it must determine the time slot allocation for each line. Various types of interface assemblies are employed, such as magnetic core memories, shift registers, and delay lines. Not all data communications terminals employ an interface between the data processor and the data modem. Without an interface the input, data transmission, and output functions proceed simultaneously and at the same rate of speed.

Since data signals are rarely in suitable form for transmission over the various types of transmission facilities, a signal coding process is normally performed. Ideally, the transmission medium should have linear attenuation and delay characteristics, but this is never so in practice, and transmission impairments are always present to disturb the data signals. As a comparison, in voice communications a high degree of transmission irregularities can be tolerated. If a voice circuit has a heavy loss or is noisy, the speakers compensate automatically by increasing the intensity of their voices. If words are missed because of transmission difficulties, they are often understood anyway because of the redundant nature of speech. In contrast, there is no inherent redundancy in data signals unless purposely inserted and, therefore, trans-

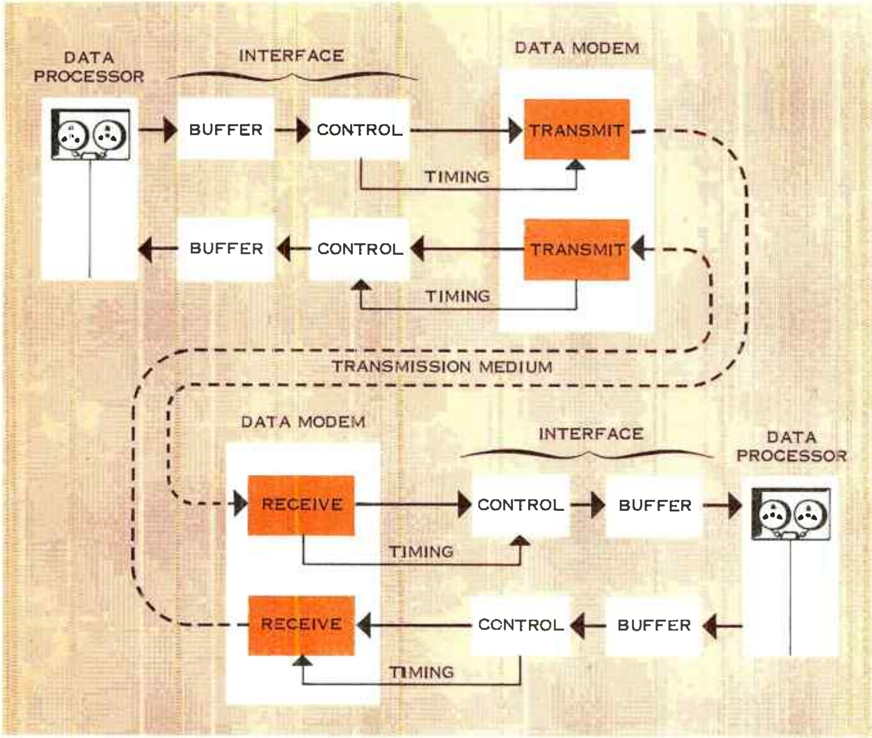


Figure 1. Typical full-duplex data transmission system arrangement. Timing signals from control unit synchronize data transmitter with data processor. At receiver, the element of time is important in reconstructing the original digital representation of the data. This is accomplished by deriving sync pulses from the data stream.

mission variations can only be compensated for over a very small range. In addition, data signals are sensitive to other transmission impairments which have little effect on speech.

Coding is undertaken to alleviate transmission irregularities, to increase the information capacity of the system, to enable error detection, and to provide message security. The coding process in the data transmitter (usually called *encoding*) simply rearranges the applied data machine signals into some other format. At the receiving end the reverse process *(decoding)* is performed to recover the original machine signals.

The diagrams in Figure 2 show the two types of information signals that are applied in digital form to a data modem. Shown in *A* is a binary *non-return to zero* (NRZ) signal. In *B* the same signal is shown in the *return to zero* (RZ) format. The difference between *A* and *B* is that in *A* successive marks or spaces follow one another, whereas in *B* there must be a return to the space level between successive marks. The voltage values of marks and spaces are arbitrary and may be positive, negative, or both.

Telephone Facilities

When data communications developed, a long established voice transmission facility already existed, and logically included service to those locations that would be the terminal ends of a data communications network. To provide economical data communications service, consideration must be given to using existing transmission facilities. It would be financially impractical to establish a completely new data communications network where existing voice facilities could satisfy the need.

An example of the use of voice facilities is the "time sharing" of a computer by several users for different purposes. Although the computer serves each user in sequence, it appears that all users are handled simultaneously because of the high-speed of the computer. A typical time sharing system uses a keyboard printer to connect to a remote computer via a data set. Eventually, data transmission over voice facilities might allow the automatic payment of bills, ordering of groceries, and a variety of other household tasks.

There are times when the nature of the data to be transmitted may prevent using normal voice facilities because of such factors as speed, quality, and compatibility. In this case, the use of a microwave wideband communications facility or a narrow band telegraph channel — but not a voice channel — might be required. At present, however, telegraph and public telephone line facilities are most commonly used for data transmission because of their wide availability and economy.

Data generated at such speeds that transmission requires part or all of a 3-kHz voice channel is normally referred to as *voice-band data.* Within this classification, data rates of 200 bits per second or less are called *low-speed* data. Data rates from 2000 to 2400 bits per second are referred to as *high-speed*. Between the two, data is called

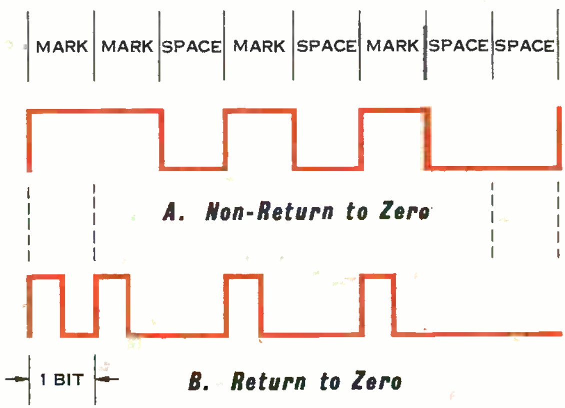
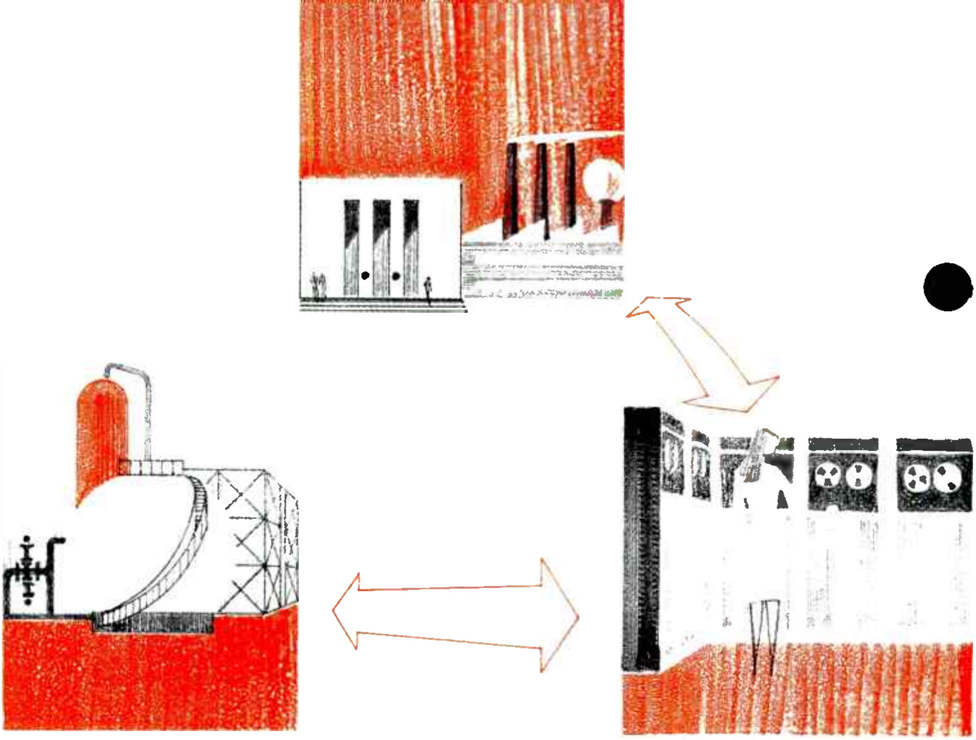


Figure 2. Digital representations of basic information signals.

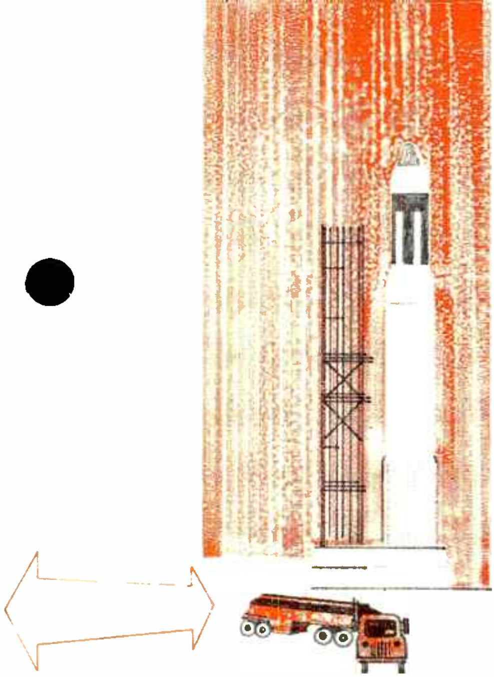


medium-speed. For typical speeds and uses of voice-band data, refer to Table A.

Data signals at speeds requiring more bandwidth than a single voice channel are called *wideband.* The most popular use of wideband data terminals is for remote access in real time to high-speed digital computers. Many of the present wideband data communications systems

TABLE A. Typical Speeds and Uses of Voice-Band Data

Speed	Classification	Use	Number of Circuits Per Voice Channel
75 b/s (120 Hz channel spacing)	Low-speed	5 level 100 wpm teletype 5 level 60 wpm teletype Variable frequency telemetering Pulse duration telemetering Alarm and control	25
110 b/s (170 Hz channel spacing)	Low-speed	8 level 100 wpm ASCII coded teletype All applications of 75 b/s speed	18
200 b/s (340 Hz channel spacing)	Low-speed	Data collection networks (remote to computer)	7
1200 b/s 2400 b/s	Medium-speed High-speed	Computer to computer Secure voice vocoders Pipeline telemetry and control	1



With the increased decentralization of business and industry, and with the need for a worldwide government digital network, data communications extends the services of data processing equipment far beyond the confines of a single office.

operate with 48- and 240-kHz bandwidths, which are the group and supergroup allocations of common multiplex systems. These multi-voice channel allocations may be used for regular voice traffic during busy periods, and during normally slack times used as a single wideband channel for data transmission.

Because cost and not speed ordinarily determines what type of system can be used efficiently, data rates within the voice-band and wideband classifications can vary to a broad extent. Why produce a highly complex and expensive wideband data set when an economical lower speed system will serve equally well? There are over 160 different types of data sets now being manufactured. These operate with approximately 16 different transmission codes, at least 12 different transmission speeds, and numerous methods of error detection and correction.

Transmitting Information

During the past fifty years several investigations have been made concerning the theoretical digital signal capacities of communications channels. In the late 1920's, H. Nyquist, a mathematician at Bell Telephone Laboratories, established a relationship between the bandwidth of an ideal *rectangular* distortionless communications channel and the speed of digital transmission. (Rectangular refers to the bandpass characteristic of a channel — linear throughout the band, with sharp attenuation at the ends.) Nyquist showed that the signaling rate in bits per second is equal to twice the bandwidth in hertz of a lowpass ideal rectangular channel. For example, using Nyquist's criterion, the normal 3000-Hz bandwidth telephone transmission channel could handle a maximum of 6000 bits per second. However, it was realized that the distortionless conditions laid down by Nyquist were ideal and could not be achieved in practice.

Later, C. E. Shannon, then at Bell Telephone Laboratories, examined how much information a channel of given bandwidth would pass in the presence of noise. Shannon's analysis yields a rate of nearly 30,000 b/s for an average telephone channel with a good signal-to-noise ratio. Shannon did not provide a practical means of achieving such transmission capacity, and Nyquist's rate has not been attained in modern data communications. In contrast to the idealized rectangular model of Nyquist, the actual physical channels are not rectangular but have gradual cutoff characteristics and, therefore, require about twice the Nyquist bandwidth, or approximately 1 cycle per bit for optimum binary transmission. (For more detailed information concerning Nyquist's and Shannon's formulas, refer to the April and May 1965 issues of *The Lenkurt Demodulator*.)

Bits and Bauds

The speed of signaling, measured in terms of the amount of information transmitted per unit time, depends on the transmission path and its associated apparatus. Bits per second expresses the total number of *information* pulses in one second and includes redundant bits used for checking errors. If the pulses are of varying length, or if start and

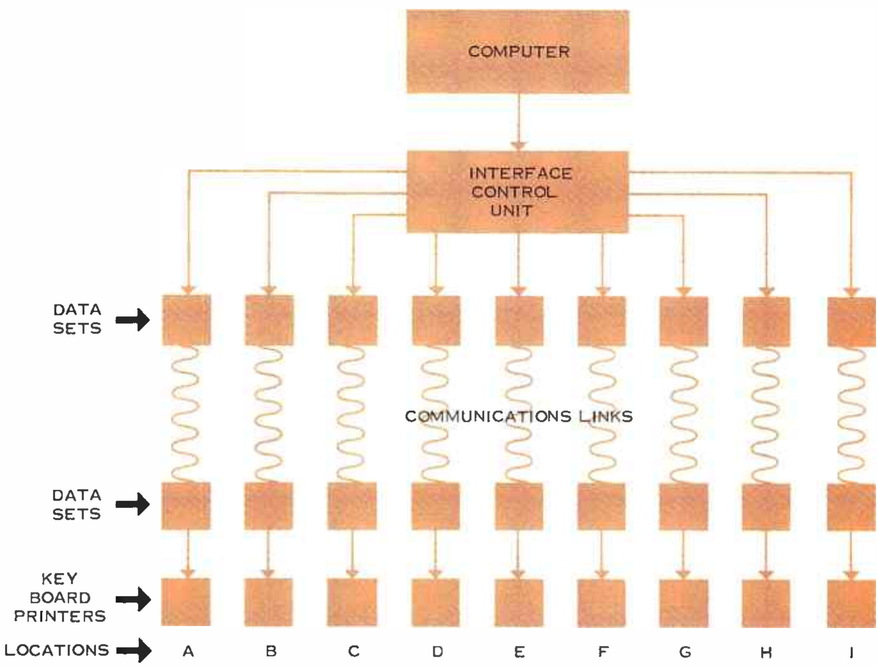


Figure 3. A typical time sharing computer employs an interface control unit to apportion its time among many users at different locations.

Figure 4. Data communications terminal (arrow) permits fast and reliable transmission at 2400 bits per second from a central computer.

stop pulses between each character are added that are not part of the message, the bit rate tells nothing of their number or duration. On the other hand, baud — from Jean Maurice Emile Baudot, an officer in the French Telegraph Service who contributed to early telegraph principles — is defined as the reciprocal of the time of the shortest signal element in a character. The term baud is often misinterpreted as a synonym for bits per second. However, the number of bauds equals the number of bits per second only when all time intervals are constant, and all signal pulses are information pulses, such as in binary transmission.

An example of the relationship between bits and bauds is in ordinary teletypewriter transmission, which makes use of a five-bit code, each bit being 13.5 milliseconds in length. The baud rate is therefore the reciprocal of 13.5 milliseconds, or approximately 74.2 bauds. A single character consists of a start pulse and the five information pulses or bits, each of 13.5 milliseconds duration, for a total of 81 milliseconds. A stop pulse of 19 milliseconds ends the character. The total time for a character is then 100 milliseconds.

Since the bit speed depends on the number of *information* pulses transmitted per unit of time, the equivalent rate for this type of transmission is 5/100 ms, or 50 bits per second.

Now, if a lapse period of 20 milliseconds is arbitrarily inserted between the stop pulse of this character and the start pulse of the next, the bit rate would be reduced to $\frac{5}{100\text{ ms} + 20\text{ ms}}$

or 41.7 bits per second. However, the teletype speed would remain at 74.2 bauds, because the baud rate depends only on the time length of the shortest pulse (13.5 milliseconds) in the character.

The number of words per minute can be determined using the ordinary telegraph definition of a word, which is 6 characters. The speed in bits per second is converted into bits per minute by multiplying by 60; hence, 50 bits per second equals 3000 bits per minute. Since there are 5 bits per character and 6 characters per word, there is a total of 30 bits per word. Dividing 3000 bits per minute by 30 bits per word equals 100 words per minute. Here again, the transmission rate in words per minute could be reduced by a slow teletypewriter operator, but the signal speed remains at 74.2 bauds.

It can be concluded that the baud rate is very important to the telephone engineer, since this rate establishes the type of telecommunications channel to be used. To a lesser degree the computer engineer is concerned with baud rate, but economics and speed of information flow are uppermost in this technology. Hence, to him the bit rate is the major concern, and is the more common expression used in dealing with binary data transmission.

Serial and Parallel Data

The terms *serial* and *parallel* are often used in descriptions of data transmission techniques. Both refer to the method by which information is processed. Serial indicates that the information is handled sequentially, similar to a group of soldiers marching in single file. In parallel transmission the information is divided into characters, words, or blocks which are transmitted simultaneously. This could be compared to a platoon of soldiers marching in ranks.

The output of a common type of business machine is on eight-level punched paper tape, or eight bits of data at a time on eight separate outputs. Each parallel set of eight bits comprises a character, and the output is referred to as *parallel by bit, serial by character*. The choice of either serial or parallel data transmission depends, of course, on the customer's data processing equipment and the transmission speed requirements.

Business machines with parallel outputs, however, can use either direct parallel data transmission or serial

TABLE B. Standards Organizations for Data Communications

Organization	Data Subdivision	Scope
International Telephone and Telegraph Consultative Committee (CCITT)	Study Group A	Data Communications including standards
Electronic Industries Association (EIA)	Committee TR30	Data transmission electrical standards
American Standards Association (ASA)	Subcommittee X3.3	Data transmission electrical standards
Institute of Electrical and Electronics Engineers (IEEE)	Data communications and telegraph systems committee	Electrical Information exchange

transmission, with the addition of a parallel-to-serial converter at the interface point of the business machine and the serial data transmitter. Similarly, another converter at the receiving terminal must change the serial data back to the parallel format.

Both serial and parallel data transmission systems have inherent advantages which are somewhat different. Parallel transmission requires that parts of the available bandwidth be used as guard bands for separating each of the parallel channels, whereas serial transmission systems can use the entire linear portion of the available band to transmit data. On the other hand, parallel systems are convenient to use because many business machines have parallel inputs and outputs. Though a serial data set has the added converters for parallel interface, the parallel transmitter requires several oscillators and filters to generate the frequencies for multiplexing each of the side-by-side channels and, hence, is more susceptible to frequency error.

Standards

Because of the wide variety of data communications and computer equipment available, industrial standards have been established to provide operating compatibility. These standards have evolved as a result of the coordination between manufacturers of communications equipment and the manufacturers of data processing equipment. Of course, it is to a manufacturer's advantage to provide equipment that is universally acceptable. It is also certainly apparent that without standardization intersystem compatibility would be almost impossible.

Organizations currently involved in uniting the data communications and computer fields are the CCITT, Electronic Industries Association (EIA), American Standards Association (ASA), and IEEE. (See Table B.)

A generally accepted standard issued by the EIA, RS-232-B, defines the characteristics of binary data signals, and provides a standard interface for control signals between data processing terminal equipment and data communications equipment. As more and more data communications systems are developed, and additional ways are found to use them, the importance of standards will become even more significant.

The second part of this two-part article will appear in the October issue of the Demodulator. Subjects to be covered include error detection and correction, transmission methods, and signal impairments.

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