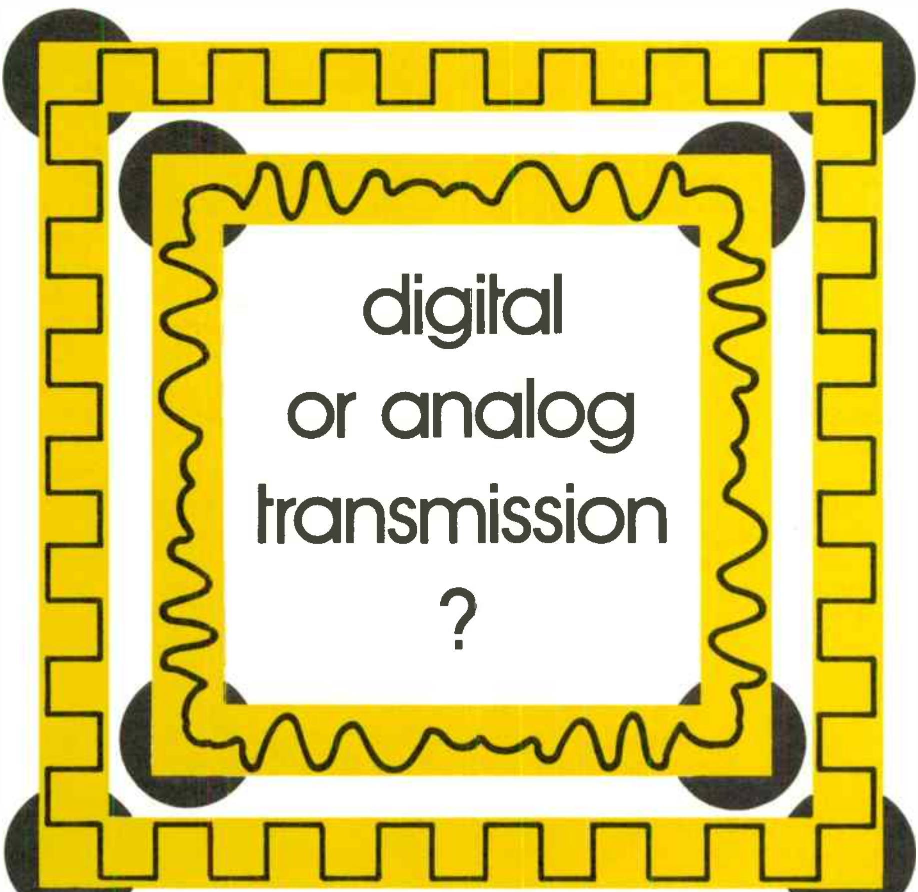
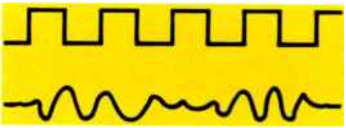
GTE LENKURT

DEMODULATOR

OCTOBER 1973





Is it digital, digitized-analog, or analog? These distinctions need to be understood when designing and using telecommunications equipment.

An abacus with its two-position beads represents a digital system; while a slide rule, with its infinitely variable slide positions, is considered an analog device. The non-digital answer that results from using a slide rule becomes quantized and digitized as soon as the slide rule product is conceived as a discrete numerical value.

Digital data is defined simply as information expressed by a set of discrete values or symbols. These can be based on various systems – if in a computer, on the binary numbering system with "ones" and "zeros"; if a printed page, a set of 26 letters and 10 numbers. Analog data, by contrast, can theoretically assume an infinite number of values within a prescribed range. Analog examples include the loudness of a talker's voice, the varying velocity of the wind, and the result of a slide-rule calculation. However, all measurements of analog information imply approximations. For example, if a result from a slide rule is read as "628" while a more correct result really is 627.95, the eye has made an approximation because it cannot detect the difference. Rounding off to the nearest number in a set of discrete values is called "quantizing" and effectively converts analog data into digital data. In a digital system, these approximations are built into the initial coding scheme. The greater the number of possible codes (or quantizing levels), the more accurate the approximation.

Furthermore, while a printed word is digital, the same word when spoken, with its frequency and amplitude variations, becomes analog, and will represent a different analog signal when spoken by two different people (although the written information being conveyed through speech will generally be the same). This analog signal can be electronically sampled and then quantized into a set of discrete amplitudes for transmission over a digital communications system. At the other end of the communications link, this digitized signal can be converted back into a speech signal. Although still digital in the sense that only a discrete number of choices are available for reconstruction of the speech signal, it closely resembles the original analog voice, especially at low speech volumes. If further desired, a speech recognition system can be employed to convert this reconstructed speech signal into a written or printed word. If errors have been kept to the required minimum, this final reconstructed word should convey the same information as the original.

Another way to transmit this printed page would be to use an all-digital transmission system such as telegraph. But, if analog voice signals of transmission or reception are desired along the way, it may be necessary to use both digital and analog means of information transmittal.

Digital

Digital communication involves the transmission of discrete coded symbols over a transmission channel which has a potential for a high noise level. A digital receiver must be capable of correlating the received signal with this finite set of digital values or symbols, and if necessary, converting to an analog signal. Generally, if the S/N (signal-to-noise) ratio is below a certain threshold, the reproduced digital signal will be free of errors. With an analog signal, the noise, regardless of its level, will distort the signal proportionately to the S/N ratio. If there are any repeaters in the transmission system, the digital signal will be regenerated, free of any noise, at each repeater; while the noise associated with an analog signal accumulates at each repeater.

In digital machines, information is expressed in digital form and the digits are represented by the states of certain physical parts in the machine which can assume one of a finite set of possible states such as the "on" or "off" states of switches. Typical digital machines are the abacus, ordinary desk calculators, telegraph, and typewriters. The precision of a binary digital machine increases exponentially with the number of digits or possible states (see Figure 1). and hence the machine's complexity. Small noise levels in a digital system have no detrimental effect and do not accumulate unless they are significant enough to change the signal to another state.

Binary digital machines are ideal for transmission systems that can tolerate very few errors, and they have the design advantage that there are a variety of two-state components available. Since there are only two states that need to be distinguished in a binary-coded message, the noise level in the transmission system can be quite high before it causes errors in reception of the message. The value of a physical form expressed as a binary digital word is determined by the presence of a one or a zero in each of the digits of the word. Therefore, expressed in terms of voltage levels, a binary digital system requires only two discrete voltage levels. The greater the difference between these two levels, the greater can be the noise in the system before any errors are introduced.

Analog

An analog signal is simply a signal that is continuously variable within a range of values. The signals from such equipment as telephone, radio, and television are generally analog in nature. These transmission systems have traditionally been analog because digital circuit technology has only become practical within the last 25 years.

It is interesting to note that Samuel Morse's digital telegraph (1832), which preceded Bell's analog telephone system (1874) by more than 40 years, was the inspiration for Bell's invention. And, digital transmission is now gaining importance for telephone systems.

In an analog system, data is represented by measurements on a continuous scale, so that the accuracy of the machine is determined by the accuracy of the scale. An analog signal is usually represented as a voltage, phase, current, or frequency, the magnitude of which gives the value of some physical quantity like temperature or time. Analog signals are also represented by such things as color shades or saturations, height of an indicator, angle of a plumb-bob, or the deflection of a compass needle.

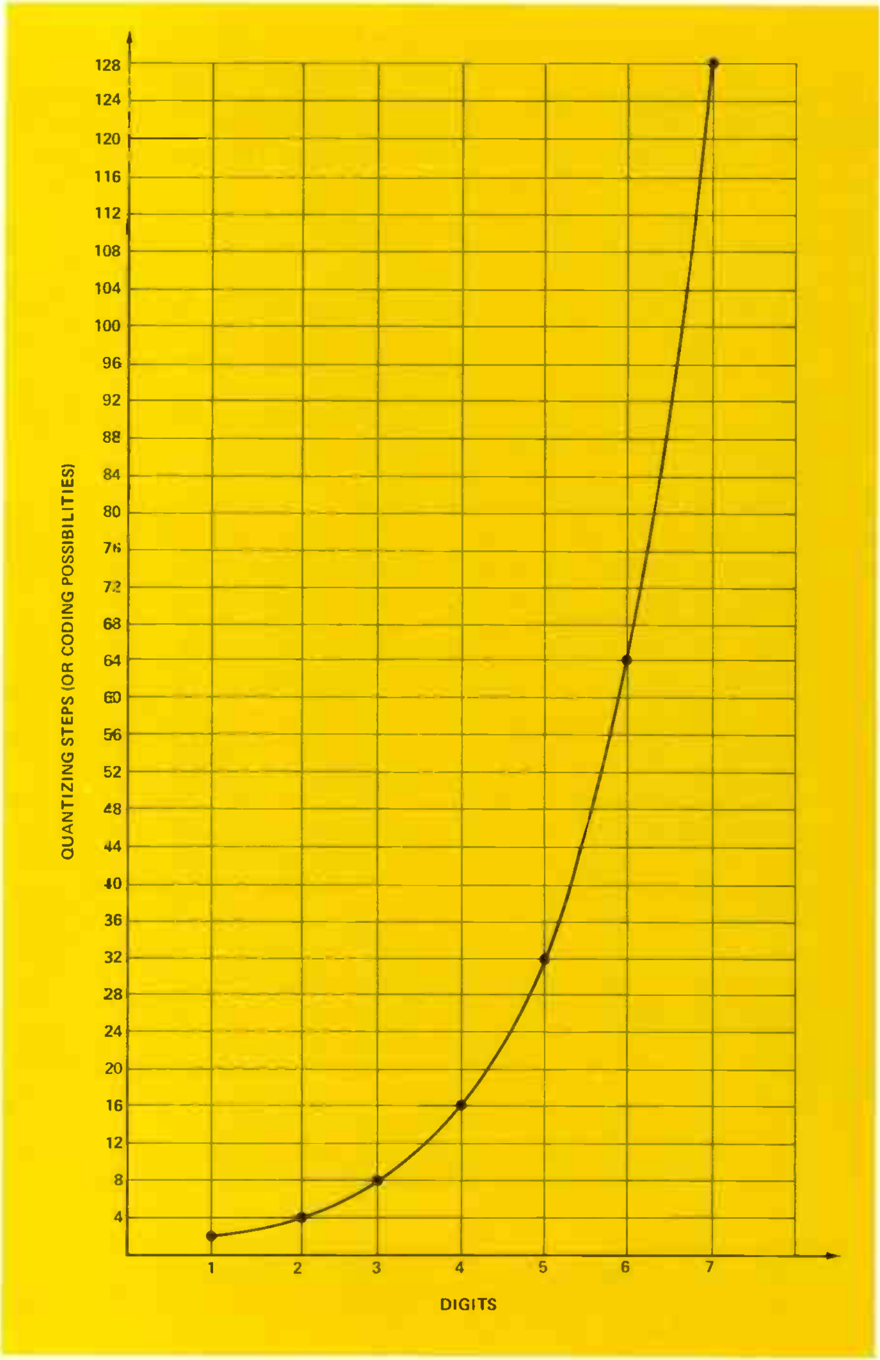


Figure 1. The accuracy of binary digital coding schemes increases exponentially with the number of digits available for coding.

In analog machines, the outputs represented are proportional (that is, analogous) to some physical quantity capable of continuous variation. Typical examples are the slide rule, thermometer, and D'Arsonval meter movement. An increase in precision generally requires a propotional increase in the range of physical variables used to represent the numbers. Furthermore, small errors tend to accumulate, and cannot be eliminated. Consequently, in an analog system, to decrease noise susceptibility by 2 to 1 requires roughly a 2 to 1 increase in the swing of the frequency or the amplitude, which causes an increase in the signal bandwidth by an even larger factor, because more higher-order sidebands become significant.

Digital on Analog

Eyes and ears are analog receptors of information. These receptors can also be used for digital information. Eyes can recognize discrete states and distinguish between these states. They are also receptors for infinitely variable color shades and hues. Ears can distinguish between individual tones and at the same time fully appreciate continuously varying tones such as found in musical compositions.

The same is true of analog telecommunications equipment. As long as the digital signal being transmitted is within the spectrum – frequency or amplitude – of the analog system, there is no difficulty in transmitting the digital signal on the analog channel.

The reverse is not true without some additional steps. An analog signal cannot be transmitted and received on digital equipment unless the analog signal is first sampled, quantized, and then coded according to some predetermined standards. Then at the receiving end, this digitized signal is restored to its analog state.

Data modems are generally used when transmitting a digital signal over an analog channel. The modem is responsible for making sure the digital signal is in the proper part of the spectrum for transmission, and also for making sure that both ends of the transmission system are properly synchronized so that the data received corresponds with the data sent. What happens to digital information when it goes through a data modem is analogous to what happens to an analog signal when it is placed in the proper frequency spectrum and sent over a multiplex channel. In fact, many data modems are also multiplexers so that the function of a data modem and a voice multiplexer can be considered the same. If the modem is not a multiplexer, the output signal from the modem can then be put through a multiplexer the same as an analog signal.

The function of a data modem is not to perform analog-to-digital conversions or digital-to-analog conversions. If a digital signal is put into a modem, a digital signal will be the output of the modem. The same is true of analog systems – analog in, analog out.

Therefore, it should be remembered that when an analog channel is used for transmission of digital data by the use of a modem, the digital data is not really "made into analog", but is rather remade into a shape and format *looking much like* analog (see Figure 2). The purpose is to utilize a system that was originally designed for analog transmission (like the telephone network) for digital transmission. Since, at the receiving end, the intent is to distinguish between a finite number of discrete states for decoding of the digital signal, the signal is, in effect, still digital when transmitted over the system. The fact that a train of

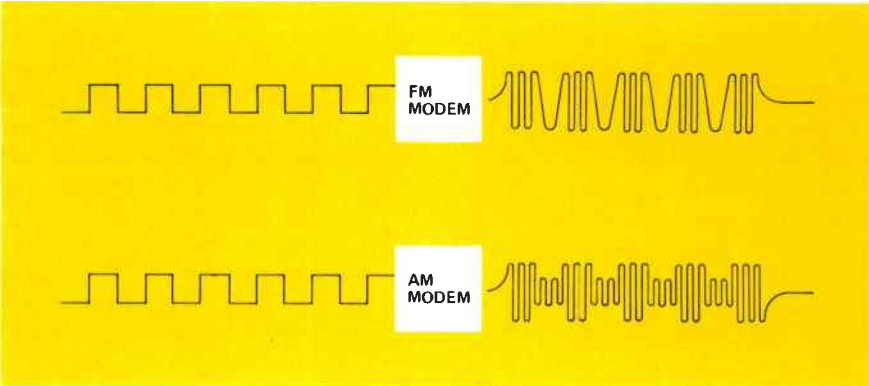


Figure 2. A data modem transforms a digital signal into an "analog" looking signal that is made up of two discrete frequencies or amplitudes.

"square" looking pulses is made into a more rounded shape or a set of frequencies, phases, or amplitudes does *not* make it into analog – it just looks more like analog. It is still a digital signal.

Differentiation Between Analog and Digital

A circuit designer with the requirement to transmit the number 100 has a choice to make between digital and analog. One way to transmit this information is to send a voltage of 100 volts and measure the voltage at the other end with a voltmeter. This would be analog transmission. This same number 100 can also be sent by using a seven-bit binary code to represent 100 (1-1-0-0-1-0-0). By going from a seven-bit binary code to an eight-bit binary code the accuracy of the system is doubled, but the bandwidth need only be increased by 15 percent since only one additional digit is needed. Figure 3 shows the increased accuracy versus bandwidth for a binary digital system.

By recognizing the differences between analog and digital transmission the designer can make the best possible use of the commodities that he has – money, bandwidth, and time – and best satisfy his needs for accuracy. There are definite trade-offs that can be made between digital and analog transmission when considering bandwidth and data rate. Since spectrum conservation is highly important these days, it is imperative to design transmission equipment to make the most efficient use of the available spectrum.

Just because a system is digital doesn't mean that the available spectrum has been used in the most efficient manner. An example of this is the difference between a rotary dial telephone and a tone dial telephone. The rotary dial is a digital signaling scheme and for each digit that is dialed it is necessary to step off the correct number – for the digit seven, step switches are required to step seven times. This is a relatively slow process compared to tone dialing. Tone dialing is a digital signaling scheme in which five different tones (single frequency signals), working in pairs, represent the ten digits used in telephone dialing.

Interoffice signaling has used a similar two-out-of-five digital scheme for some time due to the speed of digital

NO. OF DIGITS	NO. OF QUANTIZING STEPS	APPROXIMATE BANDWIDTH INCREASE (%)
1	2	100
2	4	50
3	8	34
4	16	25
5	32	20
6	64	17
7	128	15
8	256	13
9	512	11
10	1024	10

Figure 3. Maintaining the same noise threshold for a binary digital system, quantizing accuracy can be increased substantially with a diminishing bandwidth, or data rate, increase.

signaling. In the North American telephone industry, the saving of one second of equipment set-up time could result in a multi-million dollar saving.

Common Misconception

In the telephone industry, it is commonly thought that PCM (Pulse Code Modulation) is the only form of digital transmission. This is a misconception since a digital signal can be sent over a frequency modulated or amplitude modulated channel after passing through a modem to make the digital signal "look" analog so that it is compatible with the transmission channel.

Finally, it is often thought that if the signal is digital, the transmission media is digital. But, regardless, of the signal form – digital or analog – the transmission media, whether wire, cable, or radio frequency, is simply a highway over which the signal travels. If the signal is regenerated at repeater points, the channel could be classified as digital: if the repeater simply amplifies, it is analog. But the transmission media itself doesn't care.

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