GTE LENKURT

# DEMODULATOR

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# Data Modem Developments

Also in this issue: Energy Conservation in the Telecommunications Industry

**The purpose of all communication systems is to transmit intelligence from one place to another. The intelligence may originate in many different ways, but before transmission it must be in a form suited to the medium over which it will travel.**

Transmission of information by electrical means requires that intelligence be converted from its original form into either continuous- or pulse-type electrical signals. Continuous-type signals carry information in the form of waves, which are functions of time that are continuously variable over a range of values. Pulse-type signals transmit information by successively assuming various electrical states, usually related to instantaneous values of voltage, phase, or frequency.

The telephone system evolved on the basis of continuous-type, or analog, signals, and improvement has historically centered on providing better voice communication by minimizing the effects of such undesirable transmission medium characteristics as attenuation, echo, singing, crosstalk and noise. In this system, a telephone instrument converts acoustical messages into electrical signals by modulating a steady-state electrical force, which may be supplied by a dc battery or an ac carrier facility (see Figure 1); carrier transmission is most commonly used today, because it more efficiently utilizes the bandpass characteristics of the communications channel. The result of this modulation is a sinusoidal wave whose amplitude, frequency or phase varies in accordance with the audible sound waves producing it.

In the early days of telecommunications, all that was required of the telephone system was voice communication between individuals. It was enough, then, for a telephone instrument to be connected by a wire facility to a central office which supplied switching for connection with other instruments, and electrical energy for transmission of voice-frequency signals. On this basis, the telecommunications network spread to allow almost instantaneous voice communication between practically any two places in the world. Today, however, population density and modern business practices have brought about massive changes in the type of demand placed on the telephone system.

The growth of the digital computer and application of data processing principles to almost every area of society have been perhaps the greatest influences on the telecommunications network. The information exchanged by computers and other data terminals is generally in binary, or pulse-type, form, consisting of a simple voltage on-off pattern. Transmission media linking data processing equipment should, ideally, be capable of handling this pulse-type signal format. In an effort to provide such media, networks are now being placed in service which are intended solely for transmitting digital signals. Presently, however, the analog voice telephone system offers the most readily accessible, widespread communications facility. While



 

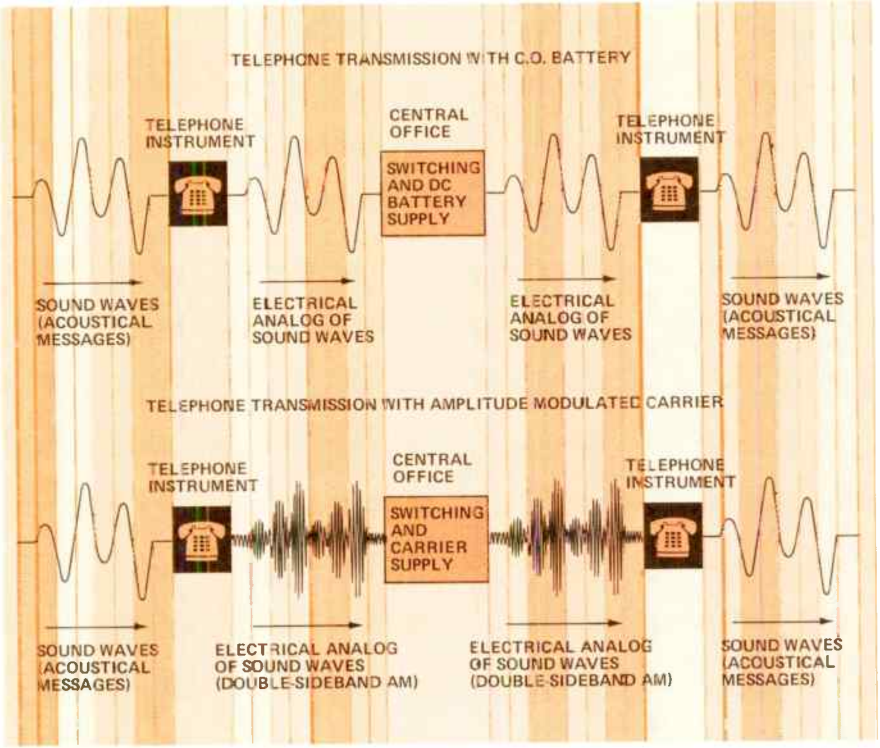


*Figure 1. A voice-channel telephone facility converts acoustical messages into an electrical analog suitable for transmission on the telecommunications network.*

these telephone circuits were originally designed to accommodate a limited quantity of low-speed telegraph traffic, they were not meant to carry high-volume, high-speed digital data: to make transmission of such data possible on voice-channel facilities, the binary language of data processing must be translated into the analog language of voice communication.

A modem, or data set, is a device which provides this translation. It accepts digital data from a computer or terminal and performs a modulation process to produce a continuous-wave analog signal which is suitable for transmission over a voice-channel communications facility. The voice signals normally carried by the telecommunications network are electrical analogs of acoustical messages, while the continuous-wave signal transmitted by a modem is an analog of a pulse-type data stream. A modem also accepts analog signals from other modems and returns them to digital form.

## Modulation

Three basic techniques are used to convert digital data into analog signals (see Figure 2), depending upon specific application: amplitude shift keying (ASK), in which the data control the amplitude of a sine wave carrier; frequency shift keying (FSK), which uses the data signal to vary the frequency of the carrier; and phase shift keying (PSK), wherein the phase angle

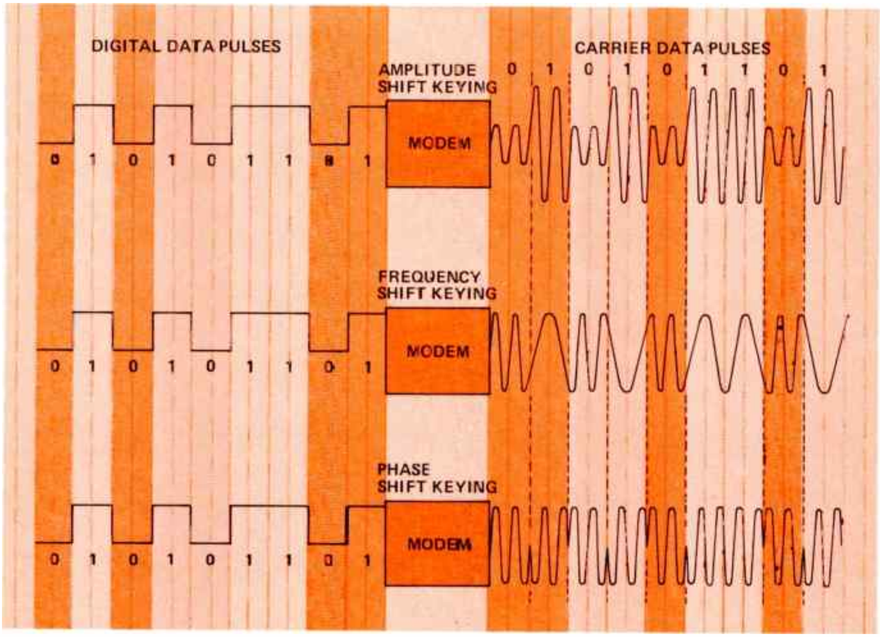


*Figure 2. Three basic modulation techniques are available for translating digital data into a form more compatible with telephone system transmission facilities.*

of the carrier is changed. It has become common practice to refer to those changes in carrier state identifying data signals as pulses, regardless of modulation technique. Thus, although the carrier signal is nominally a constant-frequency source, there can be amplitude, frequency or phase carrier pulses resulting from modulation by digital data signals.

When data are transmitted at relatively low rates, the modulated sine wave can carry information in a binary form; for example, an ASK wave may be at either a high or low level, an FSK signal may be one of two distinct instantaneous frequencies, and the phase of a PSK wave pulse could be either unchanged or shifted by 180°. The information content of these signals is one binary digit, or bit, per pulse. Expressed in bits, information content is determined by the formula:

$$H = \log_2 m$$

where

H = the number of bits
m = the number of choices.

Because there are two choices in the binary format, one bit ($\log_2 2 = 1$) of information can be conveyed.

## Transmission Rate

The rate at which it is possible to transmit a data signal can be expressed in terms of the baud, which is a measure of carrier modulation rate in pulses per second (1 baud = 1 pps). The baud is strictly a statement of signaling speed – that is, it tells how many carrier pulses are available to convey information during each second of transmission – and does not refer to information or its flow; bits and bits per second (bps), however, are units of information and information flow, and do not refer to signaling speed. In a true binary system, each pulse happens to contain one bit of information, so the bit and baud rates are the same – that is, a modem operating at 600 bauds would transmit information at 600 bps – but the terms are not interchangeable where pulses contain more than one bit, as they do in most modems operating at speeds greater than 1200 bps.

In data transmission systems operating up to about 1200 bps, economy and simplicity of operation are generally of greater concern than maximum bandwidth utilization. The process of FSK modulation in binary format is well understood and can be easily accomplished with inexpensive components so, despite its inefficient use of the available frequency spectrum, it has become the usual method by which low-speed data are transmitted. Modems of this type are frequently used in applications where rapid exchange of high-volume data is not required, such as inventory control and computer-assisted instruction.

In industries such as news reporting and stock brokerage, however, there is an obvious need for the most rapid possible transmission of large quantities of information. This need could be met by simultaneous utilization of several low-speed facilities, but a more logical – and less expensive – method is by increasing the rate at which the information is handled. In such situations, binary systems are totally inadequate. This is due in large part to the limited bandwidth of the available communication channels.

Studies have shown that the maximum number of carrier pulses that an ideal channel can accommodate is equal to the channel bandwidth in hertz. Voice-frequency telecommunications channels, having a nominal 3-kHz bandwidth, could thus theoretically transmit at 3000 pulses per second (3000 bauds). Real channels, however, contain several types of noise and distortion, and the bandwidth available for accurate data transmission is significantly reduced; practically, signaling speed is limited to a maximum of approximately 2400 bauds. When the baud and bit rates are identical, as they are in binary systems, the amount of information that can be transmitted is thus severely restricted. Non-binary coding techniques, making each baud contain more than one information bit, must therefore be used to achieve the necessary higher bit rates.

## Coding

Each pulse in a data stream can be made to convey more than one bit if more than one of its characteristics is varied. The amplitude and frequency of a signal could both be changed to indicate data state, with an increase in amplitude representing a logic 1 and a decrease in frequency a logic 0. In this case, two bits per baud would be transmitted, since four choices – two amplitude and two frequency – are possible, and $\log_2 4 = 2$.

Another way to pack more data into a signal is for one characteristic to assume several states. Multiphase PSK modulation is perhaps the most common technique used for high-speed modems (operating at 2400 bps or more) because PSK is relatively insensitive to noise in the transmission facility. In its simplest form, multiphase PSK shifts the phase angle of a signal in reference to a constant phase. As shown in Figure 3, dividing the digital data stream into blocks of two bits each (dibits) and relating every possible 2-bit combination to a particular phase shift angle allows transmission of 2 bits per pulse. If the system were to operate at a 1200-baud rate, this coding process would result in 2400-bps transmission.

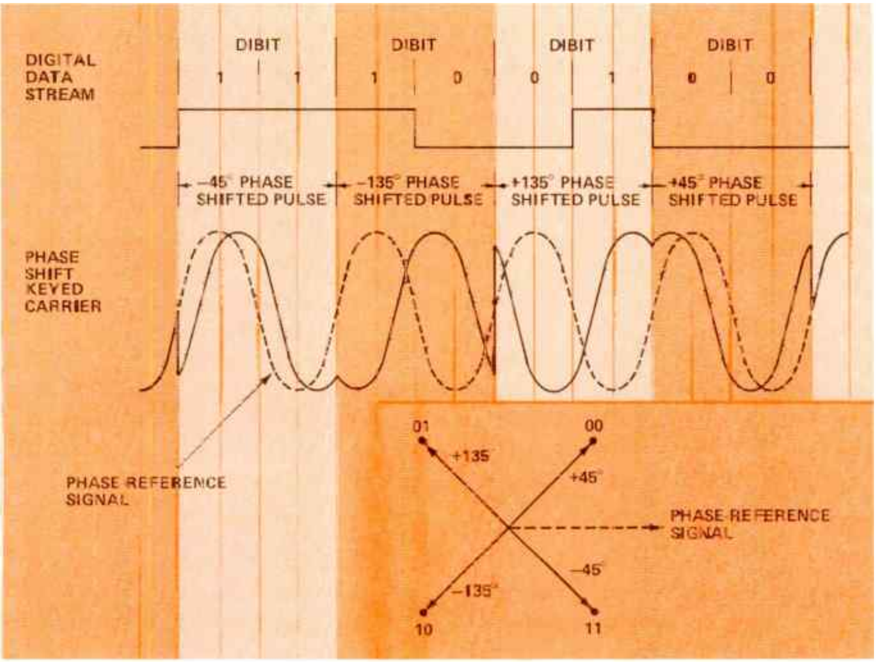


*Figure 3. In multiphase PSK, each shift represents more than one information bit.*

A refinement of the basic PSK technique is differential phase shift keying (DPSK). In DPSK, the phase shift of a pulse is determined by comparing it with the previous pulse, rather than with an absolute phase reference. This avoids the necessity of providing a precise phase-reference signal.

An example of this type of multiphase modulation coding is the 8-phase DPSK format used by many modem manufacturers to achieve a 4800-bps data transmission rate. Essentially, this technique utilizes an 1800-Hz carrier frequency with a 1600-baud signaling rate in which each pulse can assume one of eight phases in relation to the preceding pulse. Because there are eight possible choices, three bits ($\log_2 8 = 3$) of information are contained in every pulse. Two phase relation patterns are most commonly used — one in which phase changes are all some multiple of 45°, the other in which all changes are odd multiples of 22-1/2° (see Figure 4). With the former, there is a possibility that a series of pulses could be produced without a phase change, while the latter pattern always provides a phase shift and, as the format originally selected by the Bell System for use in its modems, is the one found in all Bell-compatible 4800-bps modems.

In either case, the stream of digital pulses from a data terminal is divided into blocks of three bits each (tribits) and encoded according to a "Gray code" (see Figure 5). These tribits then serve as a source of information for modulating the phase of the carrier signal, with each tribit representing a different phase shift. In Figure 4A, for example, the tribit 001 would produce

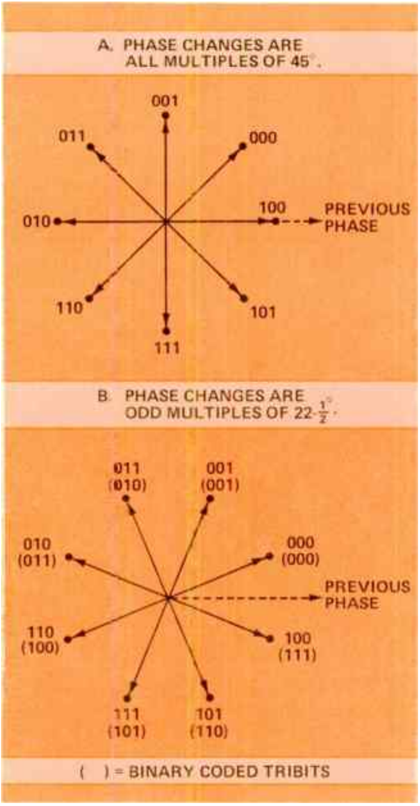


*Figure 4. In 8-phase DPSK modulation, a data pulse can assume one of eight phase angles with respect to the phase of the preceding pulse. Each phase represents a different group of three binary digits (tribits).*

a +90° shift in the carrier phase angle. A receiving modem would detect this shift and decode it to provide the proper bit sequence to a data processor.

The Gray code is used to reduce the effects of undesirable channel characteristics on a data signal. Referring to Figure 4B, a +22.5° phase shift, representing the tribit 000, could be transmitted. If the channel were sufficiently noisy, however, the receiving modem might actually detect a −22.5° shift. Using straight binary coding, this shift would represent the tribit 111, and a 3-bit error would result. With Gray coding, −22.5° identifies 100, so only a 1-bit error is produced and the greater part of the transmission is preserved.

| BINARY NUMBER | GRAY-CODED NUMBER |
|---|---|
| 0 0 0 | 0 0 0 |
| 0 0 1 | 0 0 1 |
| 0 1 0 | 0 1 1 |
| 0 1 1 | 0 1 0 |
| 1 0 0 | 1 1 0 |
| 1 0 1 | 1 1 1 |
| 1 1 0 | 1 0 1 |
| 1 1 1 | 1 0 0 |

*Figure 5. In the Gray code, successive numbers differ by only one digit. With straight binary coding, anywhere from one to all of the digits must change in order to produce the next number in a sequence.*

Data transmission at 9600 bps using voice-frequency channels is the latest accomplishment of modem designers. This is generally achieved with a 2400-baud signal packing 4 bits into each pulse through a quadrature amplitude modulation (QAM) technique. The technique can be described as a combination of phase and amplitude modulation, in which twelve values of phase and three values of amplitude are combined to provide 16 possible signal states, allowing $\log_2 16$, or 4, bits to be transmitted per pulse. As shown in Figure 6, a signal pulse may assume any one of twelve phase angles – each representing a 4-bit, Gray-coded binary number – in relation to an absolute phase reference. Additionally, four of the phases are associated with two amplitude levels which are

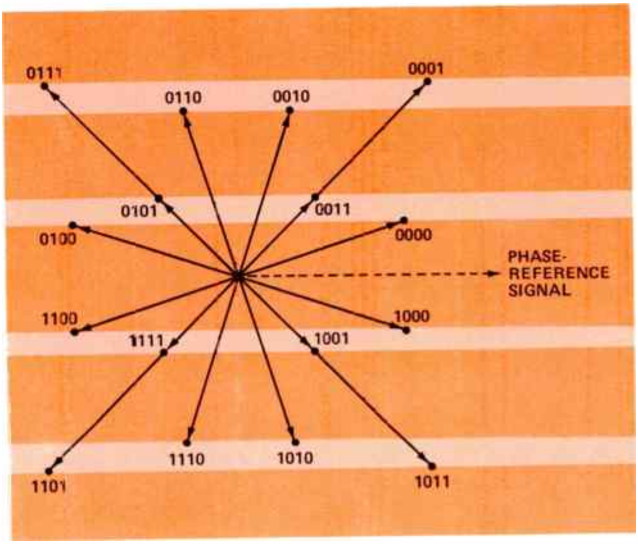


*Figure 6. Quadrature amplitude modulation combines phase and amplitude shifts to produce a complex set of signal state choices, each of which represents a different 4-digit binary number.*

different from that of the others, so that if a pulse assumes one of these phases, its amplitude either increases or decreases.

## Signal Detection

Besides modulating digital data into an analog form, a modem must demodulate the carrier signals to reproduce the data. In general, this is accomplished by comparing the signal pulses with a known reference, detecting the difference, and generating the proper sequence of digital pulses. A high-speed modem using 8-phase DPSK, for example, receives a signal, compares its phase with that of the preceding pulse (information which is stored in a modem's memory facility), and produces a 3-bit binary number corresponding to the difference.

A new technique, recently developed by GTE Lenkurt and used in the 262B (208B) 4800 bps Data Set, allows the phase detection to be done using binary numbers rather than analog carrier waves. In this process, each analog pulse is first separated into two components by a broadband phase splitter. A time-shared successive approximation converter — consisting of two sample-and-hold circuits, a digital-to-analog converter, a comparator and control logic — converts each component into an 8-bit binary number. Successive pairs of 8-bit numbers are further processed by digital circuitry to produce the proper 3-digit binary output. While the process is somewhat more complex than simple analog phase comparison, its end result is a much more accurate — and much more rapidly obtained — phase shift detection.

## Transmission Facilities

The transmission facilities provided by the telephone network fall into two categories: dial-up, or switched, network service and private-line, or dedicated, service. In the switched network, users share common switching equipment and channels, while private-line facilities are leased by a user to provide a permanent, individualized link for his stations.

Private-line circuits are selected to meet certain minimum performance standards, and afford the user a certain degree of control over such error-producing line characteristics as attenuation and phase distortion. Because the facility is relatively permanent (the telephone company may change actual routing, but the circuit is always for the sole use of the lessor), its characteristics can be ascertained and assumed to be reasonably consistent over a period of time. When necessary, telephone companies can provide equalization, or "conditioning," to counteract the effects of distortion. Several levels of conditioning are available, with the selection depending primarily upon data bit rate, modem self-equalization capability, and the quality of the original line. Most high-speed modems now offer automatic self-equalization that reduces the level of conditioning required. In many cases, these modems can operate without conditioning the private lines.

Although the dial-up network provides only 3-kHz voiceband channels which are marked by such imperfections as noise, distortion, echo and nonlinearities, it is nonetheless a very attractive alternative to private lines in many cases. If, as an example, a user intends to transmit data eight hours a day to just a few locations, private lines would be the least expensive facility; if, however, data are to be sent for only half-an-hour per day, or are to be exchanged with a variety of different locations, the greatest economy and maximum versatility would be realized with utilization of the switched network.

Unlike private-line facilities, which can be selected or conditioned to meet predetermined requirements, channels provided by the dial-up network are selected by switching equipment from among those normally used to connect voice conversations. Only by conditioning all of the telephone lines in the country could the telephone companies guarantee that a specific grade of channel would always be available for data transmission. The cost of such treatment is prohibitive, so data modems intended for operation over the switched network must be able to minimize the deleterious effects of the channel characteristics without the benefit of special line conditioning.

Noise in a transmission line is typically dealt with by filtering techniques, some of which are described in the April and May, 1975, *Demodulators*. In the most successful high-speed modem designs, distortion is counteracted with automatic self-equalization (the August, 1974, *Demodulator* contains a discussion of recent developments in equalization).

## Echo

Echo results when a change in line impedance "reflects" a transmitted signal so that it travels back over the line at a reduced amplitude; this is especially likely to occur in long communication circuits. This is not a major problem in data transmission, even at high speeds, but it does make voice communication awkward, so telephone companies install devices called echo suppressors on circuits which are prone to produce echoes. An echo suppressor places a high amount of attenuation in either the transmitting or receiving line, depending upon which speaker is talking the loudest. Because a data user making use of the switched network has no control over what facilities will be available, it is likely that suppressors will be on at least some of the long-distance lines.

Because the dial-up network provides only two-wire facilities, modems must alternately transmit and receive over the same line. This half-duplex operation requires a constant, rapid "turnaround" from transmit to receive mode, usually in about 50 milliseconds. An echo suppressor, however, takes considerably longer than this to reverse itself and can thus seriously hamper data communication. The problem has been solved by designing the suppressors so that they can be disabled before data transmission starts. To accomplish this, a 2025-Hz tone is transmitted for two seconds. The only requirement after that is that no gaps in energy longer than about 50 ms appear on the circuit. To ensure that this does not occur during data transmission, a constant 600-Hz tone — which doesn't interfere with the data signal — is sent by a modem when its transmitter is off.

The difficulties associated with use of the 3 million circuit miles of the switched network within the United States have been adequately resolved for data transmission at rates up to about 4800 bits per second. Beyond this point, problems arise which are not especially significant at lower rates. For example, the large number of states per pulse required to pack many bits into a signal makes that signal very susceptible to noise within the transmission channel. More important, however, is the problem of harmonic and non-linearity distortion introduced by companders (devices installed by telephone companies to achieve greater voice reproduction fidelity by compressing and expanding the signal). Of little concern at lower bit rates, these types of distortion at high transmission rates cannot be removed by normal equalization methods, and will require new technological developments to counteract their effects. Until such problems can be overcome, very high bit rates will be limited to use on private lines.

All-digital networks like Bell's Digital Data Service (DDS) are becoming available for data users and will most certainly be the major arteries for high-speed data transmission in the future. Even this widespread system of private lines specifically designed to meet the needs of data signals will not, however, be the total answer to the world's data communication needs. There will always be situations where only the switched network can provide lines, so there will always be a need for data modems that can operate over it.

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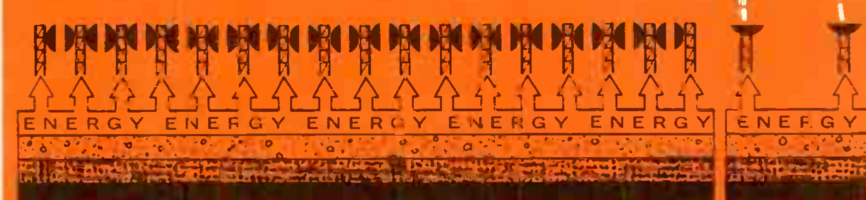
# Energy Conservation in the Telecommunications Industry

Throughout the country there is a growing concern over the availability of energy. Many industries are, for the first time, instituting measures to reduce power consumption. Even before it was in vogue, however, the telecommunications industry was striving for more efficient energy utilization.



The ability to exchange information is a cornerstone of modern technological societies, and the world-wide telecommunications network represents a rapid, energy-conserving facility for such exchange. It allows individuals to converse, and even business conferences to take place, without expending large amounts of fuel and other resources to arrange face-to-face encounters. Likewise, telecommunications can link computers and other data processors, reducing the need for transportation of magnetic tape, punched cards, and other data storage elements.

In addition to providing such energy savings to users of its systems, the telecommunications industry — including both communications service suppliers like the telephone companies, and the suppliers of their equipment — has consistently sought ways to reduce power consumption within its own operations. As with many other industries, it is now concentrating on such tactics as reducing lighting and temperature control in buildings, and using more economical automobiles for business travel. Over the years, however, the increasingly energy-efficient nature of the equipment used to provide services has made the most consistent contribution to energy conservation.

## Open-Wire and Cable Carrier Systems

Typical of this change in energy usage is the equipment used to provide multi-channel carrier transmission on open-wire and cable facilities. Among the first of GTE Lenkurt's products for these applications was the 33A Carrier Telephone System, which provided three channels on open-wire. Introduced in the late 1940's, this system was followed in the early 1950's by type 45 carrier equipment. All of these systems used what was then state-of-the-art technology, including miniaturized vacuum tubes. Power was supplied in either of two ways: through the combination of a 24- or 48-Vdc filament supply battery and a 130-Vdc plate supply battery, or directly from a 115-Vac source.

As shown in Table 1, the power requirements of these early systems were very high, reflecting the energy drain of tube-type circuitry. Compared to this, GTE Lenkurt's fully transistorized 46B cable carrier, introduced in the mid-1960's, had markedly reduced power requirements.

Just as striking is the reduction of power necessary for operation of microwave radio systems.

## Microwave Radios

Relying as they did upon klystrons,

| GTE LENKURT EQUIPMENT TYPE | APPLICATION | CHANNEL CAPACITY | POWER REQUIREMENT (IN WATTS) | POWER REQUIREMENT PER CHANNEL (IN WATTS) |
|---|---|---|---|---|
| 33A | OPEN-WIRE | 3 | 160* | 53 |
| 45A | OPEN-WIRE | 12 | 350** | 29 |
| 45BN | CABLE | 24 | 513** | 21 |
| 46B | CABLE | 24 | 134*** | 5.6 |

* Provided by combination of 24-Vdc filament and 130-Vdc plate supply batteries.
** Provided by combination of 48-Vdc filament and 130-Vdc plate supply batteries.
*** Provided by 48-Vdc supply battery.

*Table 1. Power requirements of several generations of open-wire and cable carrier equipment.*

conventional vacuum tubes and such other large-scale discrete components as RF coils, electrolytic capacitors and high-power resistors, early microwave radio transmitter-receivers were prodigious consumers of electrical energy. GTE Lenkurt's type 72B radio, for example, appeared in 1952 and accommodated up to 72 voice-frequency channels, transmitting them in the 900-MHz frequency band. To accomplish this, it drew 435 watts of power from a 115-Vac source.

As technological advances were made, they were incorporated into radio designs, not only improving overall performance, but also reducing power requirements and making more efficient use of the energy consumed. Table 2 shows this evolution in four of GTE Lenkurt's radio products.

| GTE LENKURT MICROWAVE RADIO TYPE | CHANNEL CAPACITY | POWER REQUIREMENT (IN WATTS) | POWER REQUIREMENT PER CHANNEL |
|---|---|---|---|
| 72A | 72 | 435* | 6 W |
| 74B1 | 480 | 300** | 625 mW |
| 76A2 | 960 | 240** | 250 mW |
| 78A2 | 1500 | 90** | 60 mW |

* Provided by 115-Vac source.
** Provided by 24-Vdc supply battery.

*Table 2. Evolution of power requirements through four generations of modulating-demodulating (baseband) microwave radios.*

The type-74 radio appeared in the early 1950's, and was one of the first to utilize a combination of vacuum tube and transistor circuitry; the type-76 systems that were introduced in the early 1960's contained only two tubes — the transmit and local oscillator klystrons — and had substantially lower power needs than the 74 type. In the late 1960's, the need to supply power for any tube operation was completely eliminated by introduction of the all-solid-state type-78 radio systems.

## Solid-State Technology Impact

These figures, while relating specifically to equipment furnished the telecommunications industry by GTE Lenkurt, are generally representative of the reduced power consumption resulting from advances in equipment and component design over a period of years. As has been indicated, a major portion of the advancement was in the area of solid-state technology and the replacement of tubes and other large-scale discrete components with transistors and semiconductors of various types. Indeed, this replacement was the original goal of transistor developers, and it has not only been realized, but has been surpassed; today, integrated circuits having even lower energy requirements and greater versatility are assuming many of the functions once envisioned for the transistor.

Recently, for example, the Bell System developed a set of hybrid integrated networks (HIN's) that are direct replacements for vacuum tubes in the type-N1 carrier repeater, which was introduced in the early 1950's and is still in use in many areas. With its original tubes, a remotely powered N1 repeater requires about 170 milliamps (mA) of current from a 260-Vdc supply (approximately 44 watts). When equipped with the new HIN's, the same repeater needs only 50 mA at 130 Vdc (about 6.5 watts). This reduction is essentially due to elimination of tube filament voltage and does not degrade repeater performance.

Solid-state devices have resulted in size reduction and energy conservation in all types of telecommunications equipment. This includes everything from radio multiplex equipment to pulse code modulation carrier, data modems and telephone office switching facilities.

Reducing equipment operating power requirements is not the only way in which solid-state technology has aided the telecommunications industry achieve energy conservation. For example, it has also led to high-density, integrated packaging of circuits and decreased the number of components necessary to implement a communications system. With fewer components consuming power – and those that are, doing so at a relatively low level – less heat is produced. Heat itself represents wasted energy, and the problem is compounded when additional energy must be used to remove it.

The heat generated as a waste product by electronic equipment must be dissipated to reduce its harmful effects on the equipment. In most cases, this is accomplished by cooling the surrounding atmosphere, which typically means air conditioning the interior of a building. This is a task that can consume a great deal of power if large increases in temperature must be avoided. Since equipment composed of integrated circuits produces significantly less heat than the discrete-component type, the amount of power wasted by the equipment itself is reduced; in addition, cooling requirements and, consequently, total power consumption can be cut.

Opening up new areas of development is another way in which the telecommunications industry seeks to further improve its services and lower the level of its energy consumption.

## Earth Satellite Communications

The length of an individual microwave radio link is limited by the curvature of the Earth to about 30 miles, assuming that there are no obstacles between terminal locations. Transmission over greater distances requires the installation of repeaters at line-of-sight intervals. Each repeater is composed of complete reception and transmission facilities so that a signal can be received, amplified or regenerated, and transmitted to the next repeater or terminal site; the power requirement of a terrestrial microwave system thus lies not only in the terminal equipment, but is significantly increased by the number of repeaters in the network. In long systems, this can mean a very substantial energy consumption.

A communication satellite, however, can relay messages over the same distance as an extensive terminal-repeater network with only the power requirements of the earth-station terminals to be met, since the orbiting "repeaters" derive their power directly from the sun. Incorporation of satellites into the world's communication systems has begun, and it has been projected that they will assume an even greater role in telecommunications, and further aid in attaining the goals of energy conservation.

## Optical Communications

Although it is still experimental, the transmission of information by use of light is being investigated as a means of establishing extremely energy-efficient communication networks (see the November, 1975, *Demodulator* for a complete discussion).

The light in an optical system will serve essentially the same purpose as the carrier in other systems, but will require a fraction of the power. For example, the primary light sources now under consideration are the light emitting diode (LED) and the laser; a typical LED can produce a 5-milliwatt (mW) optical power output, and the latest semiconductor lasers as much as 50 mW, from a 200-mW electrical input. The input power required by carrier sources in conventional systems is measured in watts rather than milliwatts, so the reduction possible with optical facilities is little short of phenomenal. When it is also noted that capacities of up to 50,000 channels per fiber are forecast, the reasons for seeking to perfect the technology are obvious.

## Alternate Sources

Research is under way to determine the feasibility of developing energy sources other than those which, like commercial electricity and diesel generators, consume valuable resources in the generation process.

One of the most promising fields is that of solar power. Converting the sun's rays to electrical energy, solar panels can generate sufficient power to operate many of the new solid-state devices now available for telecommunications applications, and could simultaneously keep electro-chemical batteries charged for nighttime and standby operation; this is precisely what happens in earth satellites. It is entirely possible that this process could be adapted to use with such equipment as telephone station terminals and earth-bound microwave radio repeaters to further reduce the energy consumption, and the dependence on conventional energy sources, of the telecommunications industry.

Because it has been accomplished mostly at a hardware level, and is not as glamorous as other developments, the fact that the telecommunications industry has been progressively decreasing its energy needs – both by cutting equipment power requirements where possible, and by making more efficient use of energy in general – has received little recognition. While the motivation has more often been economic than ecological, the importance of this fact is not to be underestimated. It is sufficiently important that the savings have been made, and that the efforts to increase them are continuing.

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