The *Lenkurt*

DEMODULATOR

1967
ISSUES

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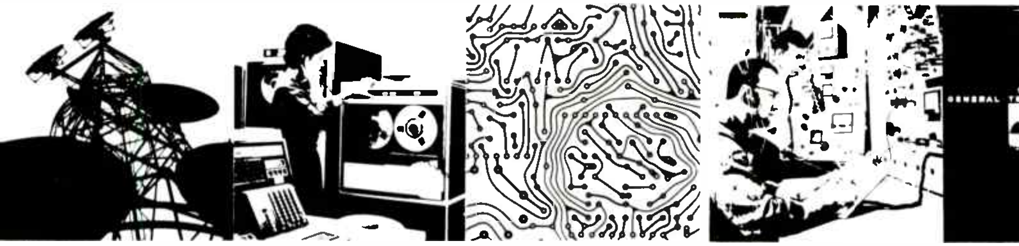
GENERAL TELEPHONE & ELECTRONICS
GENERAL SYSTEM

LENKURT ELECTRIC

... is a major manufacturer of communications equipment used by the telephone industry, government, and commerce. Products include microwave radio, multiplex, carrier, and data transmission systems which find worldwide use. Lenkurt has established a tradition in the telecommunications industry with a reputation of quality products and customer service.



Products a

MICROWAVE RADIO SYSTEMS

Lenkurt microwave systems operate in the various common carrier, government, and industrial frequency bands between 406 and 13250 MHz. Systems provide a wide range of service carrying voice, data, television and control signals for telephone, industrial, and government organizations.

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TELEGRAPH AND DATA SYSTEMS

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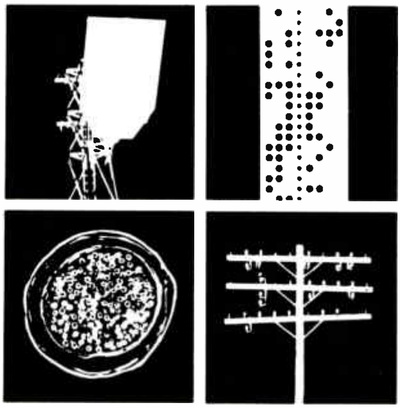

The Lenkurt Demodulator is a technical periodical published monthly and circulated without charge within the telecommunications industry and to educational institutions.

This complimentary volume includes the twelve issues that appeared during 1967. If you wish to receive the *Lenkurt Demodulator* regularly, correspond with our office on company letterhead.

ADDITIONAL INFORMATION about Lenkurt's major systems is available on request. Included are product brochures describing our major communications systems, comprehensive technical publications and drawings containing detailed information on equipment engineering.

For more information about Lenkurt products and services, please contact one of our sales offices or Government engineering representatives, or write directly to our Main Office.

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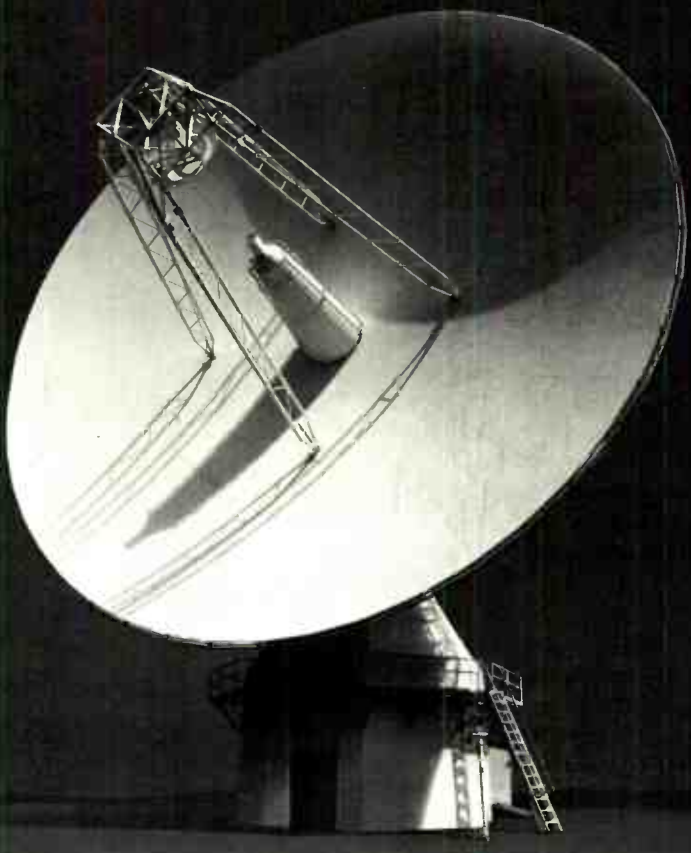
The Lenkurt DEMODULATOR

GROUND STATIONS for Satellite Communications



Necessarily, most of a satellite communications system never leaves the ground. Highly directional antennas and elaborate electronics equipment must be stationed around the world to interconnect the orbiting microwave relay with its terrestrial users.

The techniques of communication through satellites and point-to-point microwave radio systems share conceptual similarities: both receive and transmit the same signals at the same frequencies through directional antennas. Differences are in the areas of power, bandwidth, and access to the system.

Point-to-point microwave transmitters span 30-mile distances with 1 to 5 watts, using dish antennas about 6 feet in diameter. Satellite ground stations must work with a repeater 22,300 miles distant, with 10-kilowatt transmitters driving 85-foot antennas. Moreover, the large antenna must be steerable and have the ability to accurately track a satellite in orbit.

At the same time, the satellite must offer access to many ground station "end terminals" — perhaps dozens of countries wanting to relay messages through the same repeater at the same time.

Bandwidths up to 500 MHz place additional demands on the earth station, which must "scoop in" meager satellite signals while maintaining relatively low noise figures. Large antennas, coupled with super-quiet receivers meet the requirements — but not without a great deal of engineering sophistication.

The commercial satellite system is being established through the International Telecommunications Satellite Consortium (Intelsat), with America's Communications Satellite Corporation (Comsat) as manager. Intelsat is providing the satellite relays for its 54 member nations, plus ground control equipment to keep the satellites properly positioned. The individual countries are responsible for establishing and operating their own ground stations — and will coordinate traffic and and tariffs with local carriers.

Since the summer of 1965, earth stations in Europe and North America have been gateways for international communications through the Early Bird satellite. The launching of improved satellites this year will open more channels across the Atlantic and establish service in the Pacific — spanning nearly two-thirds of the earth. For this service to be useful, many new ground stations must be built.

Locations

In the United States, three ground stations are now in operation for use with the new Intelsat 2 satellites. The

Figure 1. Brewster Flat ground station, with folded-horn and Cassagrain antenna (right, in distance). Microwave antennas are visible above building.

station at Andover, Maine, was built to work with Telstar in 1962, and is now a part of the Comsat system. Two new stations serving the Pacific were recently activated at Brewster Flat, Wash., and Paumalu, Hawaii. Comsat plans other stations at Moorefield, W. Va., and in the Caribbean. A station at Mill Village, Nova Scotia, will connect Canada to the global system.

In Europe, major stations are being operated in England, France, Germany and Italy. New stations are being built on Ascension Island by the United Kingdom; at Madrid and on the Grand Canary Island by Spain; and in Australia. Japan is joining the Pacific system with a station at Ibaraki.

Many other sites are being considered: Hong Kong, Bahrain on the Persian Gulf, Thailand, the Philippines, a number of countries in Latin America, the African Continent, and another location in Australia.

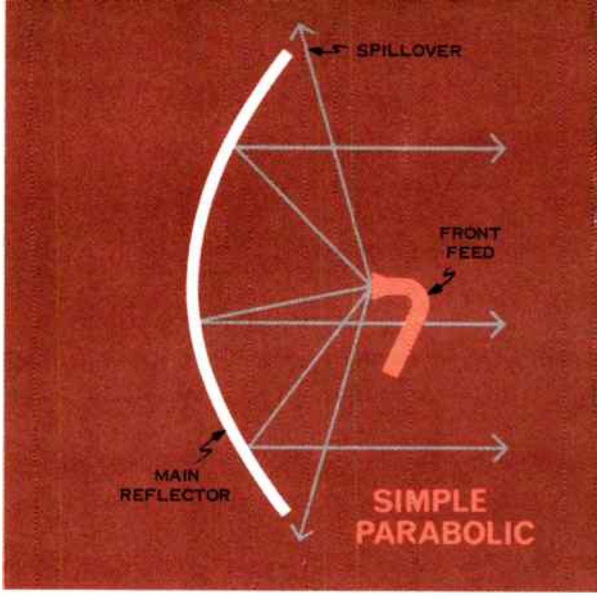
Earth stations must avoid all sources of electromagnetic noise — natural or man-made — if faint satellite signals are to be received satisfactorily. Geographic location, frequency allocations, and antenna design all must be considered if noise is to be reduced. Ideally, ground stations are situated in "radio quiet" locations, distant from sources of interference, yet close to power and telephone network interconnect.

Frequency Choice

The choice of frequencies to be used has a great influence on communications satellite technology. An antenna pointed skyward will "see" two types of noise: that from galactic sources, and that from the atmosphere itself. Galactic noise is relatively high at frequencies under 400 MHz, but falls off rapidly at the higher frequencies; galactic noise is negligible above 1 GHz. On the other hand, atmospheric noise increases above 8 GHz, and is considerable above 10 GHz. Logically, the spectrum between 1 and 10 GHz is considered most favorable for satellite communications.

Operating frequencies now in use were adopted at the 1963 Extraordinary Administrative Radio Conference in Geneva. Uplinks (ground to satellite) for commercial satellite systems are in the 6-GHz frequency range, while returning downlinks are in the 4-GHz

Figure 2. Three versions of the parabolic antenna, showing placement of rf feed and path of reflected energy. The Cassagrain is most practical type for satellite communications.



band. Other bands are used for special purposes, including military communications.

Since many of the satellite allocations are shared with other services, restrictions have been placed on the maximum flux density allowable at the earth's surface. While there are a number of variables, such as angle of arrival and method of modulation, the basic recommendation is for a maximum density of -130 dBw/m^2 in any 4-kHz bandwidth. This restriction limits the power a satellite may radiate, and likewise places greater emphasis on the design of the ground stations that must receive these signals. In many cases, the ground station will be joined to telephone networks by point-to-point microwave radio using the same 4 and 6 GHz bands.

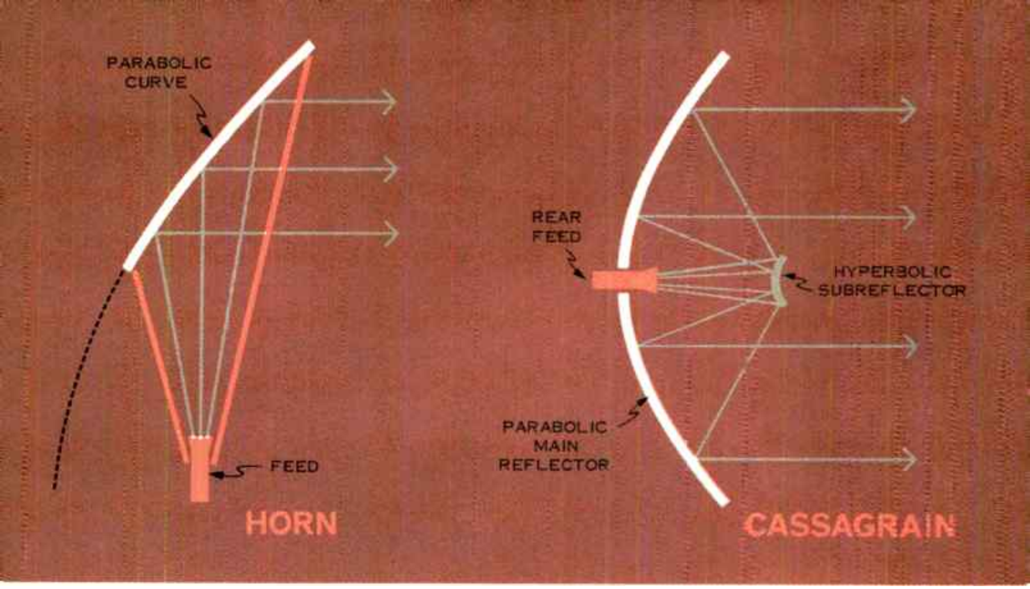
Antenna Gain

Probably the most critical single component in a ground station — and the most costly — is the antenna. It must concentrate transmitter power toward the satellite, and receive communications and tracking signals from the satellite. The desirability of a particular antenna design is directly proportional to the ratio of antenna gain to receiving system noise. Gain is primarily dependent on the physical size of the antenna, and may be defined as the capability of the antenna to concentrate *transmitted* energy in the desired direction. Similarly, gain represents the *reception* of energy from a desired direction and the rejection of energy from other directions.

It is obvious that an effective ground station must have as narrow a beam as possible. While transmitting, the antenna must concentrate most of the radiated power in the main beam, known as the major lobe. Any energy in side lobes is wasted. Conversely, in a receiving antenna the side lobes represent sources of extraneous noise.

Noise Temperature

Noise in antenna-receiver systems is commonly expressed in degrees Kelvin. Since all objects radiate energy — the higher the temperature of the object, the more energy radiated — *noise temperature* is an appropriate unit of measure-



ment for receiving systems. For instance, a highly directional antenna pointed at the sun (surface temperature about 6000°K) will receive a noise power of 8.28×10^{-14} watts, or −101 dBm.

The concept of noise temperature is easily extended to other noise sources. Any device which produces random noise of 4.0×10^{-21} watt (−174 dBm) per cycle of bandwidth, may be said to have a noise temperature of 290°K — even though that may not be its physical temperature. In other words, the noise temperature of a device is the temperature at which a thermal noise source would have to be operated to produce the same noise power. Expressed as temperatures, noise units from antenna and receiver are conveniently added to arrive at a total system noise value.

Antenna Design

Three variations of the basic parabolic reflector can be considered for satellite communications ground stations — with noise performance the constant criterion.

The basic parabolic antenna (Figure 2), like those used in point-to-point microwave transmission, is a highly directional device. However, the center feed at the focal point of the antenna cannot be precisely controlled to illuminate only the reflector. A certain amount of "spillover" occurs in even the best system, adding undesirable lobes at the back and sides of the antenna. With the antenna reflector looking skyward, the feed is pointed back at the relatively noisy ground (approximately 290°K). Spillover from the simple parabolic adds to the antenna's noise temperature. Also, it is mechanically inconvenient to mount needed preamplifiers at the feed of the simple parabolic.

In an attempt to reduce minor lobes, the horn reflector antenna was developed. The antenna is basically a section of a parabola, with sides extended from the feed to the edges of the reflector. The horn is a highly efficient, low-noise antenna, but is large and costly. The first U.S. commercial satellite ground station at Andover uses a horn reflector weighing 380 tons.

The popular choice is the Cassagrain antenna. The double-reflector system incorporates a parabola main reflector, and a hyperbola subreflector. The feed is at the rear of the main reflector and looks, with the antenna, at the sky (noise temperature typically less than 30°K). In operation, rf energy from the feed strikes the subreflector and is bounced back to illuminate the main reflector as if it had come from the focal point of the parabolic.

The Cassagrain antenna (named for William Cassagrain who developed the subreflector method of improving optical telescopes) is superior to the conventional parabolic in a number of ways. The antenna has low spillover, shorter transmission lines, greater mechanical stability in the feed system, and more flexibility in design. Careful engineering eliminates the otherwise serious disadvantage of placing elements that could block radiation in front of the antenna.

The typical commercial ground station uses an 85-foot Cassagrain. Illustrated on the cover is the antenna recently installed by Sylvania Electric Products, Inc. at two Comsat stations.

Variations

Other variations exist, especially in mobile and transportable antennas. A 42-foot transportable folded-horn antenna is being used at some commercial ground stations while the more complex Cassagrains are readied for service.

The smaller the antenna, however, the higher the noise temperature of the system. Likewise, the lower the signal-to-noise ratio, the less bandwidth available for communications. The 42-foot folded horn is designed to provide a limited number of channels for telephone, telegraph, and high-speed data, but the 85-foot Cassagrain must be used for television transmission.

Willing to sacrifice bandwidth for mobility, the military is developing a number of smaller units for field and shipboard use. The smallest antenna system may service only one voice channel, but allow reliable long-range communications to be established at virtually any remote location in hours.

Pointing Accuracy

Large reflectors characteristically have high gain and narrow beamwidths; sophisticated control is required to keep these antennas properly aimed at the small point in the sky.

The accuracy imposed on earth stations is illustrated at Brewster Flat and Paumalu. The movable portion of the antennas at these new stations weighs more than 135 tons, but must be able to rotate 360 degrees in 120 seconds, and track satellites to within 1/500th of a degree!

It should be noted, however, that when commercial satellite systems are fully removed from the experimental stage and configurations are firmly established, little antenna adjustment should be required.

With any narrow-beam antenna, the transmitted signal must be pointed in a precisely known direction. Mechanical vs. electrical alignment is accomplished in much the same way an expert marksman corrects the sights on his rifle — by carefully aiming, firing a shot, and noting where it hits.

A 6-foot "boresight" antenna is the target for the ground station antenna. The boresight facility simulates the satellite's performance by translating a received signal to a different frequency and returning it to the ground station. By pointing the large antenna at the target and plotting returned signals, engineers can calibrate accurately the true direction of the narrow radiated beam.

Amplifiers

In operation, usable signals from the communications satellite are possible because of high-gain, low-noise antennas matched with ultralow-noise preamplifiers. The preamplifier, which might be a maser, parametric amplifier, or other similar device, is placed as near as possible to the antenna feed. A parametric amplifier operating as the initial microwave amplifier, may have a noise temperature of only 15°K. The entire receiving system, including antenna, could be rated at less than 50°K. Compared to the 1200°K temperature of a very good receiver only a few years ago, it is easy to recognize the great technological advances necessary for a practical satellite communications system.

Ground stations must transmit powerful signals to the satellite. Comsat stations use either traveling wave tube or klystron power amplifiers to produce 5 to 10 kilowatts of rf energy. The TWT is generally used for its greater bandwidth, while the more powerful klystron serves tunable narrow-band applications.

Telephone Interface

The national telephone network is connected to remotely located ground stations by point-to-point microwave radio relay. At Brewster Flat, for example, three separate microwave channels in the 11-GHz range — one for voice, one for television, and a protection channel — carry communications to and from the site. A parallel microwave system in the 2-GHz band carries order wire and control signals.

Multiplexed voice channels are interconnected to ground station equipment at the standard group frequency level (60-108 kHz). Comsat equipment further processes these voice signals, along with wideband television signals, to be fed to separate radio transmitters. The outputs of these transmitters, in the 5925 to 6425-MHz band, are combined through the power amplifier before they are supplied to the ground station antenna. Received signals are handled in essentially the reverse manner.

Signaling

Increasing global communication through satellites focuses attention on the technical necessity for agreement between many countries. One of the most difficult technical problems in international telecommunications is signaling. Successful interface with large numbers of unique national switching systems must be achieved.

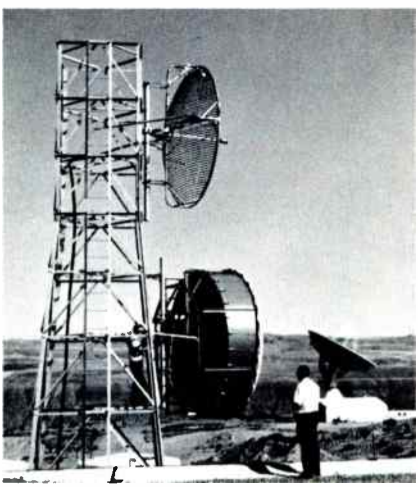
Members of the International Telegraph and Telephone Consultative Committee (CCITT) have agreed on a system to send line or supervisory signals at two in-band frequencies in a link-by-link arrangement. The register or numerical signaling, also link-by-link, uses two out of six in-band frequencies.

A proposed revision, if adopted, will mark the first time a completely new equipment design has been undertaken by international committee action. The new system would transmit signaling over a common channel separated from voice circuits.

Discussion continues on future methods of handling carrier group and supergroup pilots, necessary for level regulation. CCITT recommendations place the pilots near the middle of the group frequency bands, but the Bell System has moved them to the edge to allow for wideband data service. The need for coordination between such varying systems has been accentuated by satellite communications.

Lenkurt Electric Co., Inc.
San Carlos, California

75/76 Microwave for Comsat



The Pacific portion of the Comsat global communications system is being linked to major telephone switching networks with Lenkurt microwave radio.

Ground stations at Brewster Flat, Wash., and Paumalu, Hawaii, are connected to telephone facilities up to 90 miles away with high-density type 75 and 76 microwave radio systems. At Brewster Flat a parallel type 71F radio route provides order wire and control signal transmission.

Other Lenkurt equipment at the ground stations includes 46A and 34A multiplex, 936A alarm, 53C order wire, and 23A telegraph and data transmission systems. For more information on Lenkurt products, write Dept. B720.

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THE LENKURT DEMODULATOR is a monthly periodical circulated to technicians, engineers, and managers employed by companies or government agencies who *use and operate* communications systems, and to educational institutions. Job title, company affiliation, and nature of business must be indicated on subscription requests. Each issue features an instructive article on a subject dealing with the science of telecommunications. Permission to reprint articles may be obtained by writing THE EDITOR.

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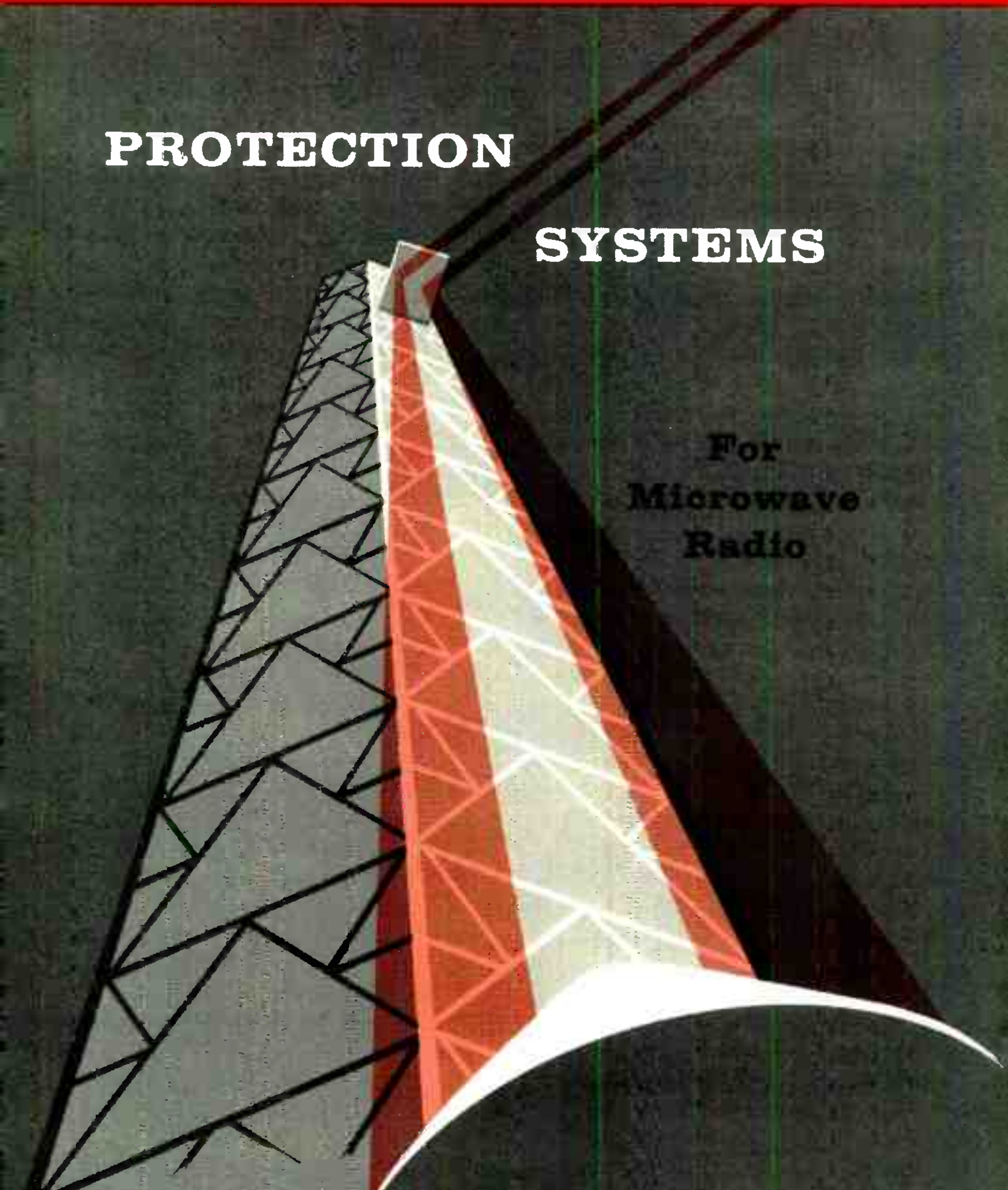


PROTECTION SYSTEMS

For Microwave Radio

Microwave radio systems are playing an extremely important role in the expansion and modernization of fixed communications facilities. The load handling capacity of microwave communications systems has been steadily increasing during the past ten years. This improved capability has made them increasingly useful for telephone traffic, broadcast audio and television, telephotos, and in meeting the rising demand for digital data communications.

The increased usage of microwave radio systems has placed a very high premium on reliability to prevent outages involving perhaps hundreds of communications circuits — especially those carrying vital messages and real-time data. The great importance placed on reliability has brought about several methods of protecting microwave systems against the possibility of interruptions in service.

Loss of primary power, equipment failure, and multiple path (multipath) fading are the three most serious events which can interrupt service on microwave radio communications systems. Primary power failures are counteracted by auxiliary sources of electric power standing by ready to assume the load. High quality components and complete "hot standby" systems that switch into service automatically if the primary system fails are used to protect against equipment failures.

The most troublesome event to guard against is multipath fading. This elusive and random phenomenon unpredictably *drops* the signal level at the receiver of microwave radio systems. Multipath fades occur mostly at night, are frequency selective, and pass very swiftly. They are caused by reflected or refracted energy arriving at the receiver out of phase with the direct beam.

Multipath Fading

Microwave radio beams exhibit many properties of light — they travel in relatively straight lines, are reflected by large flat surfaces, and are refracted by atmospheric conditions. During normal conditions, temperature, humidity and pressure in the lower atmosphere decrease almost linearly with increased altitude. This produces a corresponding linear decrease in the refractive index of the atmosphere. The velocity of microwaves traveling through the atmosphere increases as the refractive index decreases. As the wavefront passes through a normal atmosphere, the increased velocities at the top of the wavefront cause the microwave beam to bend slightly downward in a relatively uniform curve. This curve is about one-fourth the curvature of the earth.

Unfortunately, normal atmospheric conditions do not always prevail. Irregularities in the atmosphere cause energy components of a microwave beam to be reflected or refracted upwards or downwards instead of follow-

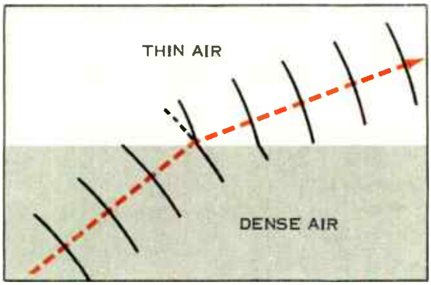


Figure 1. The velocity of microwaves traveling through the atmosphere increases as the refractive index of the air decreases. The increased velocities at the top of the wavefront cause the microwave beam to bend.

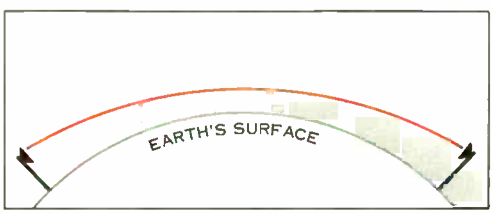
ing the normal slightly curved path to the receiving antenna. As a result, two or more separate wave components may travel to the receiver over slightly different paths. These components will be somewhat out of phase with each other because of the difference in the length of the path each has traveled. Also, at each point of reflection a 180° phase shift normally occurs.

If two equal signal components travel paths that are different by a wavelength, and one signal component has been reflected, they will arrive at the receiver 180° out of phase. Since the signal energy at the receiver is the vector sum of the wave components, the resultant strength of the two signal components will be zero. It is interesting to note that the wavelength of a 6000-MHz carrier is only about two inches. Thus, a one inch difference in the path traveled by two equal signal components (without a reflection) will cause total energy cancellation.

Normally, the information content of a microwave carrier is not disturbed by multipath fading. Differences in path length due to atmospheric refraction and reflection usually vary from a fraction of an inch to perhaps six or seven feet. Such differences cause many opportunities for severe phase separation of carrier wave components at microwave frequencies. However, such differences in path lengths are only a fraction of the wavelength of the information-bearing or modulating component of the microwave carrier. For example, the highest frequency in the baseband modulating signal of a typical 600-channel multiplex system is less than 3 MHz. A 3-MHz signal has a wavelength of about 328 feet. Path length variations of six feet represent a phase difference of only about 6.6 degrees between two 3-MHz components — not enough to cause significant signal distortion. The main problem is to ensure that enough microwave energy reaches the antenna so that the signal can be detected properly in the receiver.

Some multipath fades reduce the signal strength only a few dB, but deep fades may cause it to drop more than

Figure 2. In a normal atmosphere, microwaves beams bend slightly downward in a relatively uniform curve.



40 dB. As already mentioned, multipath fading occurs randomly. Lord Rayleigh showed that random phase cancellations occur in a predictable manner and follow the probability distribution shown in the curve of Figure 3. This curve indicates the probability of microwave fades of various depths. For example, fades of 35 dB or more from the median signal level are shown to occur 0.02% of the time. In a year this would amount to about an hour and 45 minutes during which transmission would be interrupted. This might seem like a relatively short period of time, but it could represent thousands of short term outages. Large numbers of short outages are extremely objectionable when transmititng high speed data.

It should be emphasized that the Rayleigh distribution applies only to the time when multipath fading is occuring. Also, this method of predicting the probability of fades is not precise, but is an expedient that can be used to *estimate* the propagation reliability of a particular system based upon a certain fade margin. The fade margin is the difference in dB between the practical noise threshold (or FM improvement threshold) and the median receiver input signal level selected for the system. Propagation reliability is simply the percentage of time that the receive signal is above the noise threshold point of the receiver. The fade margin required to meet propagation reliability objectives, determined by actual field tests and economic considerations, is a function of output power, receiver input power, antenna gain, and waveguide and free space losses. Typically, fade margins for line-of-sight microwave radio systems operating in the 6-GHz band range from about 30 to 40 dB, usually providing propagation reliabilities greater than 99.9 percent.

Engineering a microwave line-of-sight path with a fade margin that will assure almost 100 percent propagation reliability can be very costly. The expense of shorter hops, with larger antennas, reflectors, and towers needed to obtain extra power to offset deep fades places an economic limit on such an approach.

A more practical approach has been to use *diversity reception* — a means of reducing the effects of multipath fading. Three types of diversity reception commonly used in radio systems are *polarization, space,* and *frequency.* Polarization diversity has been useful in lower frequency radio systems that use sky waves, but it has not provided any significant advantage in line-of-sight microwave systems.

Space and Frequency Diversity

In space diversity, two or more receiving antennas intercept signals from the same transmitter. The receiving antennas are usually separated vertically on the same tower, providing separate direct paths from the transmitter. It is highly unlikely that signals traveling over vertically separated line-of-sight paths will incur deep fades simultaneously because of the vertical characteristic of the phenomenon. Thus, a sufficiently strong signal should usually be present at one of the receivers. The amount of vertical separation required for the receiving antennas may range from a few feet to over 80 feet.

A minimum of one transmitter and two receivers with separate antennas are required at the terminals of a space diversity system. However, a hot-standby transmitter may be required to protect against equipment failures. Since only one frequency is needed, this type of diversity reception is especially useful in conserving frequency allocations.

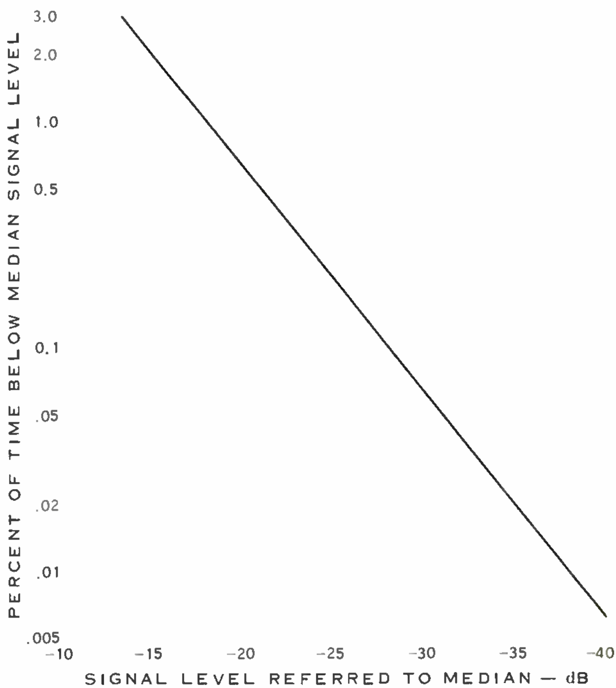


Figure 3. Rayleigh distribution curve shows probability of fades of various depths.

Frequency diversity has been the most popular type of diversity reception where the use of two or more frequencies in one system is permitted. Since multipath fades are frequency selective, microwave signals sufficiently different in frequency are not likely to fade simultaneously due to the different wavelengths of the signals.

This type of diversity reception requires two or more transmitters, each operating at a different frequency, and two or more receivers, generally using the same antenna. The completely redundant system also provides an improvement in overall equipment reliability. Like space diversity, a sufficiently strong signal should usually be present at one of the receivers. Normally, the frequencies selected for this type of diversity reception are within the same band allocation. For maximum propagation reliability, the frequencies should be separated by about 5 percent of the lower frequency. In practice, it is seldom possible to obtain more than about 2 or 3 percent separation because of limited frequency allocations within the band. An extension of frequency diversity, called cross-band diversity, is sometimes permitted using frequencies in different bands (e.g., 6 and 12 GHz).

In any type of space or frequency diversity system some sort of *combining* technique is used at the receive terminal to process the diversity signals. Three forms of combining in use are *variable gain*, *equal gain*, and *optimal switching*. Combining can be accomplished at the baseband level (post detection combining) or at the intermediate frequency level (predetection combining). Post detection combining is the most commonly used method.

Variable Gain Combining

In variable gain combining, the signals from two diversity receivers are amplified then added together to form a combined output. The amount of amplification each signal receives depends on the signal-to-noise ratio. The signal with the highest signal-to-noise ratio receives the largest gain and thus provides a larger portion of the baseband output. The two signals add together on a voltage basis (20 log) while noise in the two circuits is random and tends to add on a power basis (10 log). When the signal-to-noise ratios of the two signals are equal, the signal-to-noise ratio of the combined output, theoretically, will be 3 dB better than that of either receiver.

Figure 6 is a simplified diagram of a typical variable gain combiner circuit that combines the output signals from two diversity receivers. The signals from each receiver are at a fixed level and are adjusted so that they are equal both in magnitude and phase. The filtering and sensing unit bridged onto each receiver leg monitors the channel. A pilot monitor signal and a noise monitor signal (proportional to the noise sensed in the channel) are fed from each receiver leg into a control unit. The control unit continuously compares the noise voltages in the two legs and feeds a gain control signal to the two variable amplifiers. The control signal adjusts the gain of each amplifier (upward or downward) in accordance with the so-called *ratio-squared* principle. For this reason, this type of device is often called a ratio-squared combiner.

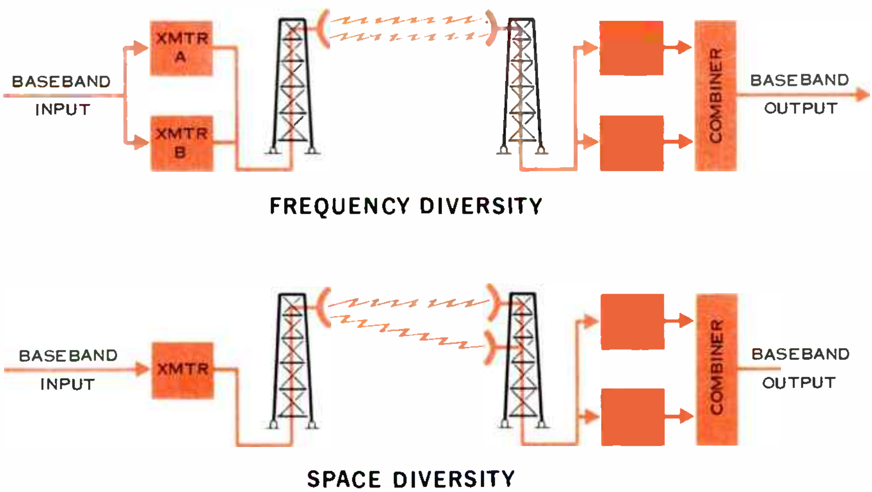
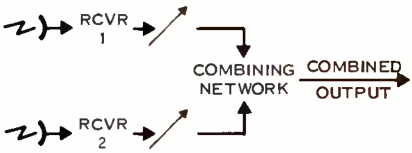
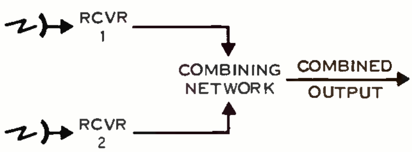


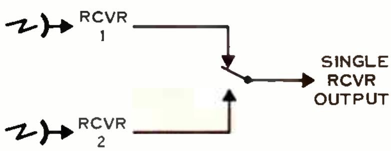
Figure 4. Two types of diversity reception commonly used in line-of-sight microwave systems are frequency diversity and space diversity.



VARIABLE GAIN COMBINING



EQUAL GAIN COMBINING



OPTIMAL SWITCHING COMBINING

Figure 5. Some method of combining the multiple signals is required at the receive terminal of a diversity system. Three forms of combining in use are variable gain, equal gain. and optimal switching.

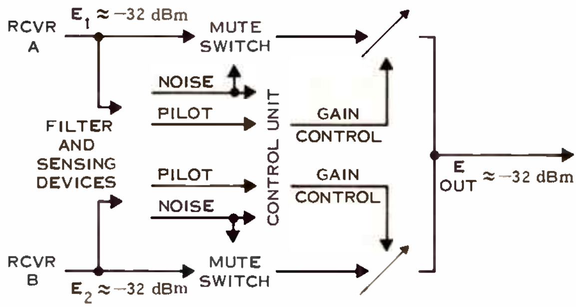
If the signal-to-noise ratio in both receiver legs is equal, the gains in the two amplifiers will be equal and each receiver will be contributing the same amount of signal to the baseband circuit. If the signal in one receiver fades, decreasing the signal-to-noise ratio, the gain of the variable amplifier in that leg will drop by a corresponding amount, while the gain in the other amplifier will be increased. Ideally, the amount of gain changes in the two amplifiers should provide an optimum signal-to-noise ratio for the combined output and maintain the signal at exactly the normal level.

If the continuity pilot in one leg disappears, the gain of the amplifier in that leg will be driven to zero while the gain of the other amplifier will be increased to keep the baseband signal at its normal level. The squelch or mute relays in each receiver leg are controlled by the noise monitor signal from each filtering and sensing device. When the noise in a leg reaches a set level, usually about 49 to 52 dBa0, the switch will open, disconnecting the noisy receiver from the combiner circuit. If the noise in both receiver legs reaches the set level at the same time, both circuits will be disconnected and there will be no output signal.

One of the disadvantages of the variable gain combiner is the gain variations it introduces into the system. Stabilizing a variable gain amplifier is far more difficult than stabilizing the gain of the fixed amplifiers in other parts of the system. Consequently, this type of combiner is inherently a source of unstable gains, a feature not found in the other types of combiners.

Also, variable amplifiers are a source of intermodulation noise. In wideband, high density microwave systems intermodulation noise can be a serious problem. To overcome this problem the combiner output signal level usually must be lower than the standard output levels established for microwave systems. In such cases, additional amplification has to be provided after the combiner. Redundant amplifiers with failure sensing devices may be required in this circuit to maintain a satisfactory degree of equipment reliability. All of the additional *active* devices used in this type of combiner tend to lower the overall equipment reliability of the microwave system.

Figure 6. Simplified diagram of typical variable gain combiner circuit.



Equal Gain and Optimal Switching Combining

In equal gain combining, the two signal voltages and the noise power add together in the same manner as in the variable gain combiner. The signal applied to the baseband circuit, therefore, is the sum of the two receiver signals. When the signal-to-noise ratios of the two separate signals are equal, the signal-to-noise ratio of the combined output theoretically will be 3 dB better. As long as the two ratios remain within several decibels of each other, there will be a noise improvement in the combined output. However, the signal-to-noise ratio of the combined output can never be more than 6 dB better than the signal-to-noise ratio of the worst receiver channel. Consequently, this type of combining cannot overcome tremendous increases in noise from a receiver during a very deep fade. The device used to achieve equal gain combining is often called a *linear-adder combiner*.

Optimal switching combining is not actually a combining technique, although it is generally classified as such. In this type of system an automatic switching device monitors continuity pilots and noise levels from both receivers, determines which signal is best, and connects that receiver to the baseband circuit. The receiver with the weaker signal is disconnected from the baseband circuit.

A very practical and reliable method that has been successfully used is a combination of the optimal switching and equal gain techniques. In this type of system, when one of the diversity signals fades too far below normal, its receiver is disconnected from the combiner circuit and only the good signal from the other receiver is applied to the baseband circuit.

Figure 7 is a simplified diagram of a typical combiner circuit using the combination optimal-switching and equal-gain technique.

This circuit, like the ratio-squared combiner circuit, contains a filtering and sensing device bridged across each receiver leg. Also, the receiver output signals are at a fixed level and are adjusted to be equal in magnitude and phase. However, the fixed levels are typically set at about −15 dBm compared to a lower level of about −32 dBm used in ratio-squared systems.

Under normal conditions, half the signal voltage in each receiver leg is

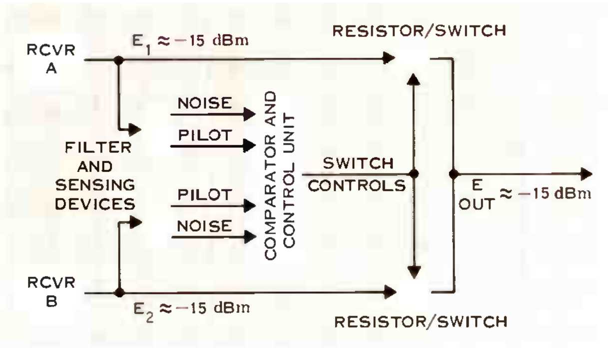


Figure 7. Simplified diagram of typical combination equal-gain optimal-switching combiner circuit.

dropped across a resistive network while the other two halves are combined in phase and applied to the baseband circuit. Because the two signal voltages are in phase, they add directly to produce an output signal voltage equal to that in each receiver leg. As stated previously, the two signals add together on a voltage basis (20 log) while the random noise tends to add on a power basis (10 log).

The comparator and control unit continuously monitors and compares the noise voltages in the two receiver legs. As long as the two voltages are within 5 to 6 dB of each other, the combiner is kept in the *combined* condition. If one signal fades to the point that the noise voltage becomes about 6 dB greater than that in the other leg, the receiver circuit will be automatically disconnected. At the same time, the full signal voltage from the other receiver will be connected to the baseband circuit. The switching time is usually very fast, about 1 to 2 microseconds, to prevent any level or phase changes. The circuit will remain in this *uncombined* condition as long as the noise differential persists. The same switching action will occur if the pilot in one of the receiver legs is lost.

The squelch or noise muting circuit used in the equal-gain optimal-switching type of combiner operates similarly to the one described for the ratio-squared combiner. However, there is no need for extra relays or switches since the function can be performed by the faster-acting solid-state noise differential switches.

Variable gain combining provides a slight advantage over the combination equal-gain optimal-switching type, with respect to receiver front end thermal noise, when the two diversity signals are unequal by a few dB. However, under usual signal conditions front end thermal noise is seldom the controlling noise problem in line-of-sight systems.

Standby Diversity

Frequency diversity systems require twice as much transmitting and receiving equipment as an unprotected system. In large systems, where many radio channels link the same locations, the cost of duplicate equipment for each channel may be prohibitive. Also, there may not be adequate space for all the extra equipment, or the signals might occupy such a large portion of the available frequency band that diversity reception is not feasible.

In such situations it has become practical to use a standby radio channel that is shared by perhaps three or more working channels. The standby channel and the working channels each require a separate frequency assignment. This standby arrangement reduces the cost of providing frequency diversity reception for each channel thereby conserving frequency allocations. Standby diversity, which cannot be used in space diversity systems, provides what is referred to as one-for-two protection, one-for-three protection, two-for-six protection, and so on. The first quantity refers to the number of standby channels and the second to the number of working channels. One-for-three protection, for example, means that one channel is providing standby protection for three operating channels. If one of the operating channels fails, or if its signal fades or contains excessive noise, a sensing mechanism at the receiver switches the signal from the failed channel to the standby channel with little or no interruption in service.

This type of diversity reception has become practical through the development of high-speed solid-state logic and switching circuits that automatically control the transfer of channels, usually on some priority basis. Channel switching can be accomplished at the microwave, intermediate frequency (IF), or baseband signal level, and many types of switching and priority arrangements have been developed to meet the needs of different applications.

Figure 8 illustrates a typical one-for-three protection arrangement. In this arrangement, channel B is operating in frequency diversity with channel A, while at the same time providing hot standby protection for channels C and D. Channel A would normally be carrying higher priority traffic and would have the controlling use of channel B. Thus, if channel A fails and is switched out of service, channels C and

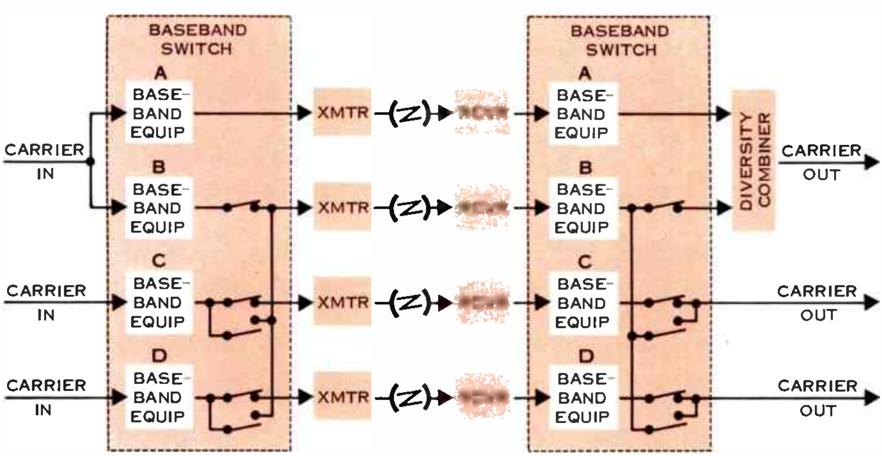


Figure 8. Block diagram of typical standby diversity protection system. Channel B operates in frequency diversity with channel A, while providing backup for channels C and D in the event of a failure.

D will not be protected by channel B until channel A is restored. If channel A is operating, and channel C or D fails, channel B will switch from its frequency diversity arrangement with channel A to support the failed channel. However, if channel A should also fail, channel B will drop channel C or D and restore service to higher priority channel A.

In another type of arrangement, the standby channel might be used to carry low-priority traffic, instead of operating in frequency diversity, while providing protection for perhaps three other channels carrying higher priority traffic. When an equipment failure or excessive fade occurs on one of the regular channels, the standby channel will drop its low-priority traffic and support the failed channel. While the standby channel is supporting a failed channel, the other regular channels are, of course, unprotected.

Conclusions

Frequency diversity systems have a significant advantage over hot standby or space diversity systems since any of the duplicate parallel channels can be completely tested while in service. Also, space diversity systems require additional waveguide runs and more complex antenna arrangements which, of course, increases their cost. However, frequency diversity operation is prohibited in many applications because of the amount of congestion within the allocated frequency band. In these situations the choice of protection systems is limited to hot standby or space diversity arrangements.

The choice of combining techniques used at the receive terminal in diversity systems depends, to a great extent, on the operating characteristics of the particular microwave radio system. Tropospheric scatter microwave systems, for example, are usually characterized by continuous fast fading, low signal levels, low fade margin, and relatively high receiver front end thermal noise. Under these conditions, the ratio-squared combiner generally provides the best noise improvement.

The same is not necessarily true, however, in line-of-sight microwave systems. These systems are characterized by relatively high signal levels, high fade margins, normally low receiver front end thermal noise, and only occasional periods of fading. Under average conditions, intermodulation and intrinsic noise usually are a greater problem in these systems than front end thermal noise. For this type of noise, the equal-optimal gain-switching combiner provides the best combiner noise improvement.

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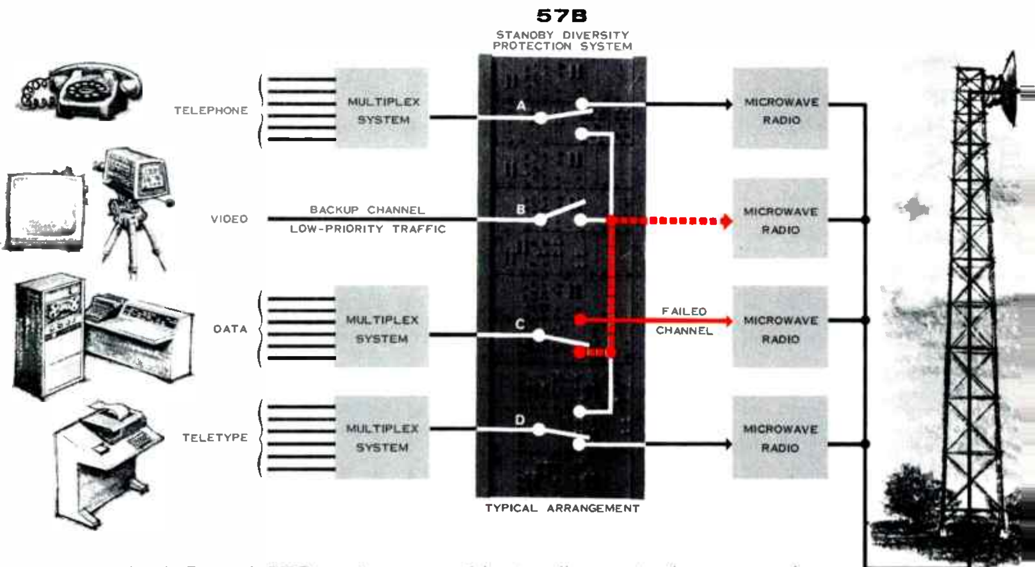

Lenkurt's 57B and 57C systems provide standby protection economically for large microwave systems, where many radio channels link the same locations. The 57B system provides one-for-three standby protection using baseband switching, while the 57C system provides two-for-six standby protection using IF switching. Both systems are capable of protecting microwave radio systems handling up to 1200 message channels or one TV signal.

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THE LENKURT DEMODULATOR is a monthly periodical circulated to technicians, engineers, and managers employed by companies or government agencies who *use and operate* communications systems, and to educational institutions. Job title, company affiliation, and nature of business must be indicated on subscription requests. Each issue features an instructive article on a subject dealing with the science of telecommunications. Permission to reprint articles may be obtained by writing THE EDITOR.

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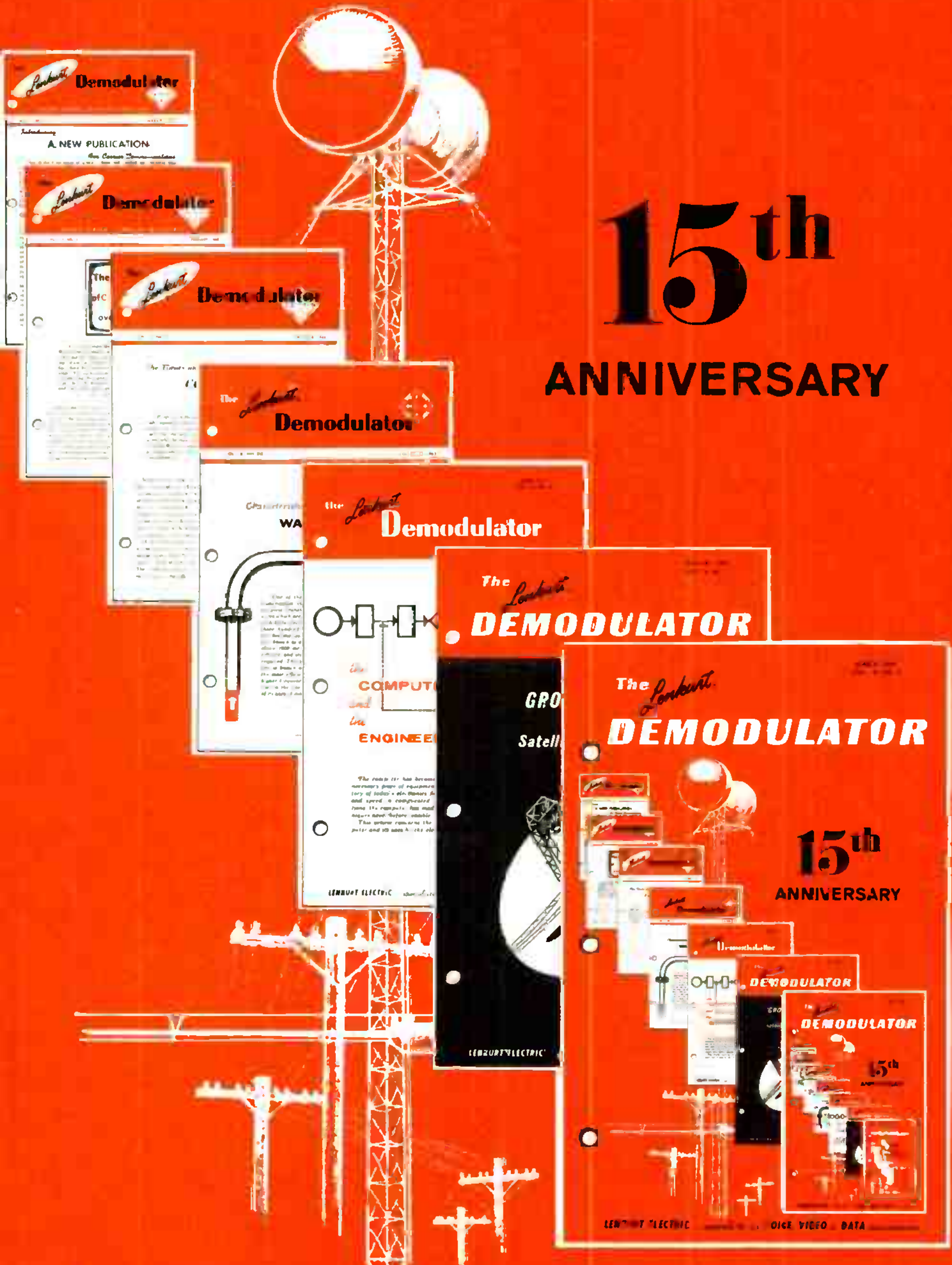
The Lenkurt DEMODULATOR

15th ANNIVERSARY



LENKURT ELECTRIC . . . *specialists in* VOICE, VIDEO & DATA *transmission*

This month the Demodulator *celebrates its 15th anniversary. Over the years, the format and policy of the publication have changed in many ways, just as the industry it serves has changed. This issue is a report to our readers: the current status of the* Demodulator, *and where we expect to go from here.*

Multichannel transmission or carrier telephony was a new technique to the telephone industry in the early 1950's. Operating companies were vitally interested in this new method of sending numerous telephone conversations over a single pair of wires. But reliable sources of information were not readily available.

During those first years the independent telephone industry turned to Lenkurt as the major supplier of carrier equipment—and as an authority on the subject. Accepting the responsibility, the company established the *Demodulator* in March 1952.

Three key sentences appeared on page 1 of the first issue, summarizing the intent of the publication to:

". . . bring you information about carrier systems, related products, and the Lenkurt factory and organization."

". . . provide information for which there has been no regular channel in the past."

". . . tell you about new equipment, special problems of carrier operation, interesting installations, forthcoming products, new literature, current delivery schedules, and price changes."

Policies have changed—you won't find delivery schedules in today's issues—but the goals have remained the same: to regularly inform the readers of important developments in telecommunications with informative and easy to understand articles.

From Carrier To . . .

The monthly periodical has expanded from articles on carrier techniques into many related subject areas. It is now necessary to consider Lenkurt's service to areas outside the telephone industry, including work with the military, public utilities, railroads, broadcasters, and others. Current articles may concern basic components, complete systems, or new techniques in communications.

The first *Demodulator* issues were usually two part: a simple explanation of a technical subject, and an article describing a specific piece of equipment.

The treatment of these subjects was not in a vocational or "how to" treatment, but did attempt to be educational. It was considered important to stress the value of carrier techniques, relating sometimes highly technical information in an understandable way. The articles were written so that the reader need not have specialized knowledge to comprehend the material and to include enough specific information to be helpful to the reader in his daily work.

Another guideline of the early *Demodulator* articles stated that there should be no simple treatment of the subject in readily available standard reference books. In other words, no purpose was served in rewriting material already available to the industry—the *Demodulator* attempted to be an original source of specialized and useful information.

Some of the subjects of that first year indicate how this was achieved. They included: "Transmission of Signals Over Carrier System Channels," "A Brief Discussion of Frequency Division Multiplexing," "A Discussion of 'Levels' and 'Powers' in a Carrier System," and so forth.

It should be noted that microwave radio was gaining interest at about the same time. Lenkurt was the first to introduce telephone-engineered microwave radio systems to the industry, and as the market for these new products widened, so did the scope of the *Demodulator* articles.

Throughout the history of the *Demodulator*, its goals have remained basically the same. Policy has shifted away from direct descriptions of individual products, except as examples of a particular technique or installation. In response to readers' needs, the publication has attempted to stay abreast of the sometimes rapid technological changes in telecommunications, and at the same time keep the industry informed in special areas of interest.

The *Demodulator* reader has always been an active participant. Through letters and personal comments, the staff is made aware of the interests of its readers. Suggestions come regularly for new article subjects, and it is always obvious from the calls for reprints which past articles have satisfied a popular need.

In recent years, the scope has widened considerably. It is not uncommon, for example, to find articles deal-

Figure 1. Demodulator Editor plans illustrations with artist. Lenkurt's art department completes the illustrations for each issue, designs page layouts, and prepares material for two-color offset printing.

ing with laser communications, information theory, or communications satellites interspersed between such expository treatments as the traveling wave tube, the use of compandors, or microwave for TV transmission.

Circulation

Originally, the *Demodulator* was sent to some 4000 selected representatives of the telephone industry. It was fairly easy to know their interests in subject matter. But, as the circulation grew from that first few thousand to over thirty thousand subscribers, the interest levels broadened too. At a point it became necessary to question if such a large and diverse readership could be served satisfactorily by one publication.

In 1965, circulation policies were tightened to include only those individuals employed by companies or agencies operating fixed communications systems, and to educational institutions. At the same time, each reader was contacted by survey card, with a request for more accurate information defining his position in the telecommunications industry.

These two steps not only allowed closer control over distribution, but assured the staff of a specific audience when preparing articles of timely interest.

The accompanying charts illustrate the growth of the *Demodulator* (including the Spanish version, *El Demodulador*, published since March 1956), the status of our readers, and where they work.

There are now more than 31,000 regular subscribers to the *Demodulator* —the English edition goes to over 100 foreign countries; the Spanish version

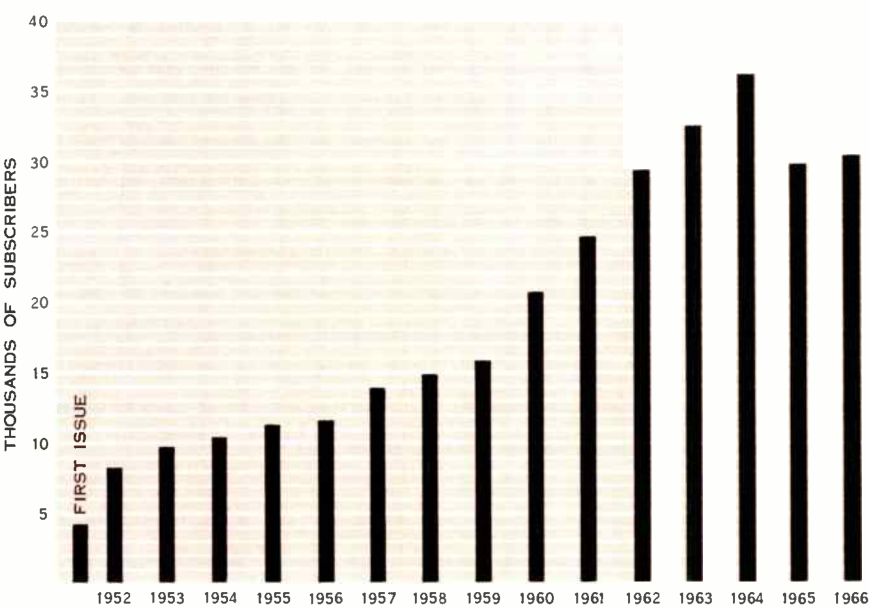


Figure 2. Circulation of the Demodulator grew from 4000 subscribers in 1952 to over 30,000 by the end of 1966. Drop in circulation shown in 1965 resulted from mailing list survey.

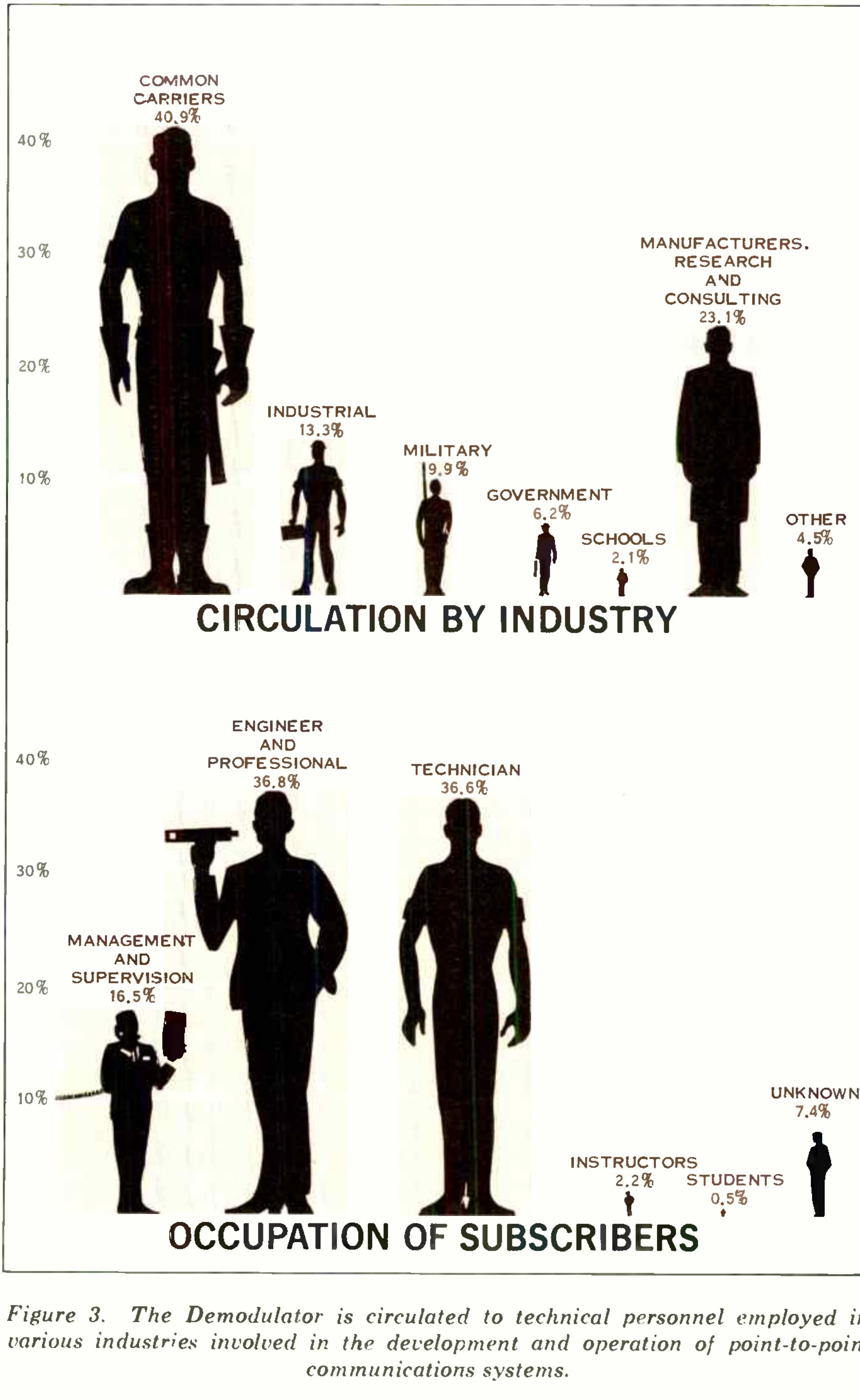


Figure 3. The Demodulator is circulated to technical personnel employed in various industries involved in the development and operation of point-to-point communications systems.

Figure 4. Demodulator staff processes over 4000 additions and 1600 address changes to the Addressograph mailing list each year.

to 30 countries, mostly in Central and South America.

Many Requests

In addition to the regular monthly mailing of the *Demodulator*, hundreds of requests are received yearly for back copies of specific articles. Instructional articles are used extensively by many firms as training aids and text for company-sponsored schools and seminars. Many requests come from university and college instructors, and copies are frequently distributed through public relations offices or handed out at meetings and conventions. Often, bulk orders are received from professional organizations for their members.

File copies of the *Demodulator* are sent regularly to numerous company and educational institution libraries, and binders containing issues going back many years are seen on the desks of many communications engineers.

Many times each year articles from the *Demodulator* are reprinted with our permission in other professional and trade publications both in this country and abroad. In the United States they frequently appear in communication industry periodicals, and other trade magazines with specialized interests in communications.

In addition to the regular Spanish translation done by our staff, articles have been reprinted in Italian, German, French, and Danish.

Attempts are always made to fill requests for back issues, but it is not always possible. This becomes especially acute when a new subscriber wants to establish his own reference file with several *years* of previous editions.

Reprint Books

To fill this need, and to provide a convenient reference source for all readers, the first *Demodulator* reprint book was compiled in 1959. The cloth-bound book included 32 of the best and most popular articles, and was sold at cost. In six years, thousands of these books were bought by readers throughout the world.

A second edition, expanded to over 700 pages and including 74 articles, was

Figure 5. Demodulator staff members spend many hours in Lenkurt's technical library researching material for articles.

published early last year. Intended as a valuable addition to any reader's permanent library, the book includes authoritative information on multiplex technology, microwave radio, digital data transmission, semiconductor devices, and general communications subjects. Over five thousand copies of the popular new reprint book have been purchased by *Demodulator* readers.

Subjects Picked

At least twice a year the *Demodulator* staff meets to discuss subjects for the next six months. Acting on the stimulus of readers' letters, and their own personal contact with the industry, the staff reviews a variety of ideas and potential subjects. Always there is the attempt to integrate the varied interests of thirty-one thousand subscribers (the actual number of *readers* is estimated at two or three times that) into a meaningful schedule.

The *Demodulator* staff writer will take about six to eight weeks to complete an article. The first few weeks are necessary to familiarize himself with the subject, followed by the actual writing. Members of the company's technical staff carefully review each manuscript before it is ready to be set in type. Two-color offset printing is done in Lenkurt's own facility.

The *Demodulator* audience is by no means a passive one: nearly 700 letters are received each year, many involving technical questions and requests for additional information on specific subjects. The office processes over 4000 additions to the mailing list each year, removes some 2500 others of people who fail to notify us of their new addresses, and changes addresses for about 1600 people. Reprint book sales are handled through the office, and orders for other materials such as the *Demodulator* binders are processed.

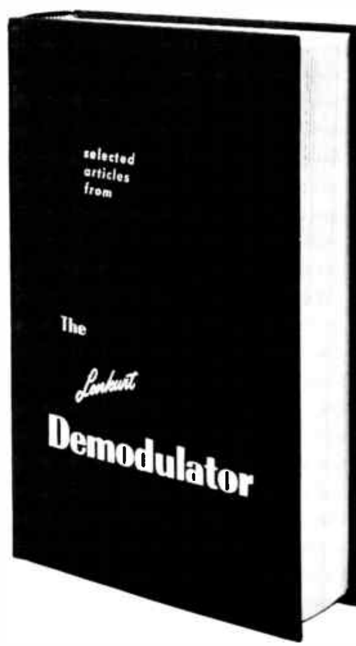
Where Do We Go From Here?

The Lenkurt Demodulator will continue to respond to the needs of the industry, as it has for 15 successful years—ready to report contemporary techniques or follow innovation. The language will be concise and understandable, the information authoritative. By continually promoting better understanding of communications technology, we hope to keep your good will.

Lenkurt Electric Co., Inc.
San Carlos, California

EXCEPTIONAL OFFER!

The new Lenkurt Demodulator Reprint Book—a collection of 74 of the best and most popular Demodulator articles case-bound into an attractive volume. Over 700 pages of authoritative, easy-to-read information about *multiplex technology, microwave radio, digital data transmission, general communications,* and *semiconductor devices*—a valuable book for your reference library.



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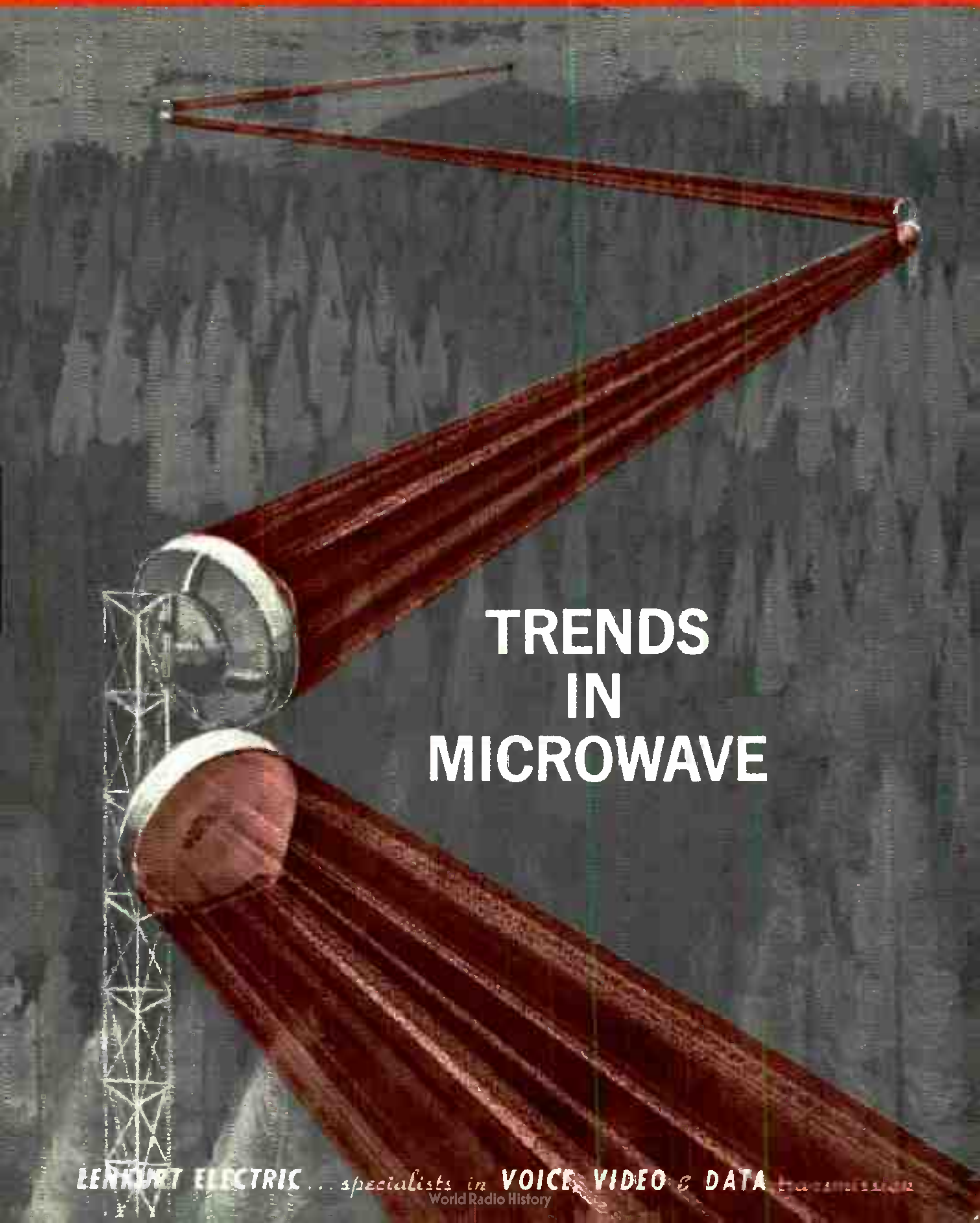
The Lenkurt DEMODULATOR



TRENDS IN MICROWAVE

LENKURT ELECTRIC . . . specialists in VOICE, VIDEO & DATA transmission

Microwave radio transmission systems are becoming increasingly important because of their general utility and economy. Continual improvements in design and performance —especially solid-state advances— will greatly increase the popularity of these systems.

The demand for microwave radio service has steadily increased since its introduction to the communications industry during the 1940's. Much of the technology for microwave radio came from rapid developments in radar made during World War II. A few of the microwave devices that were applied to both radar and to radio systems include high gain reflector antennas, waveguides, klystrons, and traveling wave tubes.

Most early microwave radio systems were limited to carrying multiplexed speech signals over public common carrier or military communications networks. Long-haul, wideband systems, such as the Bell System type TD-2, transmitted network television across the nation. At intermediate points, light-route narrowband systems were used to branch off and distribute small groups of telephone channels to local switching offices. These light-route systems could not carry television which required a bandwidth of 4.2 MHz.

Rapid Growth

Since those early days, the use of microwave radio systems has spread into many areas. Railroads, pipelines, and power utilities were given the authority to operate their own microwave radio systems. In September 1960, the FCC extended this authority to private business.

The growth of microwave radio communications since then has been spectacular. The U.S. Government, independent common carriers (non-Bell System companies), and public and private industrial users of communications systems increased their expenditures for microwave and associated equipment by 150 percent between 1960 and 1966. In comparison, cable carrier systems grew only by half this amount during the same period.

The astonishing growth rate of microwave radio communications systems certainly parallels what has been called the "information revolution." In fact, the use of microwave radio has helped to overcome certain economic and technological problems involved in transmitting large amounts of information. The growing complexities of business, commerce, and military operations have had an enormous impact on the development of microwave communications systems. This impact has been felt not only in the greater number of channels needed for the "information revolution", but also in the types of information signals transmitted over electrical communications systems. Message, video (including high-resolution closed-circuit and broadcast), high fidelity music, supervisory signaling and control, telemetry, teletype, digital data and high speed facsimile are types of signals now being processed over microwave radio communications systems.

Advantage

There is at least one special feature that has made microwave radio extremely useful as a multichannel transmission system—its broad bandwidth. By comparison, open-wire carrier systems have a practical limitation of 12 to 16 voice channels, and multipair cable carrier systems have been limited to about 24 channels. There are many high quality microwave radio systems available today that are capable of handling more than 1200 voice channels or a video channel, and the Bell System TH cross-country system can handle up to 1860 voice channels.

Although coaxial cable transmission systems are also capable of handling large numbers of voice channels or TV, they are not as practical as microwave systems in many situations and locations. Also, delay distortion problems encountered in wideband coaxial systems must be overcome by equalization, and repeater spacing is in the order of 2 to 4 miles. Signals processed over microwave radio systems, on the other hand, do not experience delay distortion to the same extent, and repeater spacing—limited generally by terrain—is in the order of 20-30 miles.

Present Trend

With the rapid expansion of microwave radio into many areas of communications, there has been continual pressure to develop systems that are lower in cost, have greater capacity, are more reliable, and have higher quality.

One of the most prominent developments currently underway in microwave radio equipment is total solid-state electronics. Since 1962, most microwave manufacturers have provided communications equipment with all solid-state circuitry except the klystron tube oscillators and traveling wave tube amplifiers. Completely solid-state IF modulators and up-converter multipliers have been used to convert baseband signals to a frequency range suitable for amplification by these electron tube devices. Operating life and reliability of electron tube systems are extremely satisfactory, and the best performing systems in the 6 GHz and higher frequency bands still use klystrons and traveling wave tubes. However, rapidly evolving semiconductor technology promises new compact mechanics and the use of significantly more efficient power sources.

Total solid-state construction involves more than simply adapting semiconductor components and microwave design principles to meet existing industry standards for stability, noise performance, bandwidth and power. More important considerations are cost and reliability. Cost is very important since a microwave system must be reasonably priced to be of practical use in many applications. Reliability is also important and sometimes outweighs cost considerations.

The continual trend towards improved transmission performance has been exemplified by the expanding use of low-noise IF amplifiers and mixer diodes, as well as new designs with parametric and tunnel diode amplifiers. However, parametric and tunnel diode amplifier designs are not particularly attractive because of high cost, low signal capacity, and marginal noise figure improvement.

Another aspect is increased spectrum use through tighter frequency control. This is becoming possible with more efficient transmitter klystron temperature control and with solid-state microwave sources replacing klystrons as receiver local oscillators. Generation with crystal reference not only will increase frequency stability, but will allow the use of low voltage power supplies at the receiver.

The reason for not immediately extending this approach to solid-state transmitters is because present-day solid-state sources are generally limited in power. To maintain the same net path loss as in tube systems, expensive construction techniques, such as increased antenna size, would have to be used. Solid-state transmitter sources also contribute greater than acceptable system noise levels, particularly at frequencies of 6 GHz and higher, and are somewhat limited in modulation bandwidth. But both difficulties are rapidly being overcome.

Semiconductor device manufacturers are providing packaged multiplier chains for use as solid-state local oscillators at 2, 4, 6, and 8 GHz. But communications equipment designers generally must adhere to stringent noise requirements, and usually have to develop their own frequency sources. Ultimately, of course, suitable low-noise frequency sources will be available "off the shelf" from suppliers.

Klystrons and traveling wave tubes require stable high voltages. Solid-state devices, conversely, do not need such stable high voltages and, with proper circuit design, are not susceptible to parameter changes with variations in voltage or operating temperature. However, at higher frequencies—above 6 GHz—the efficiency of solid-state devices decreases. At powers of 1 watt or more, broad bandwidths and low noise figures are difficult to attain.

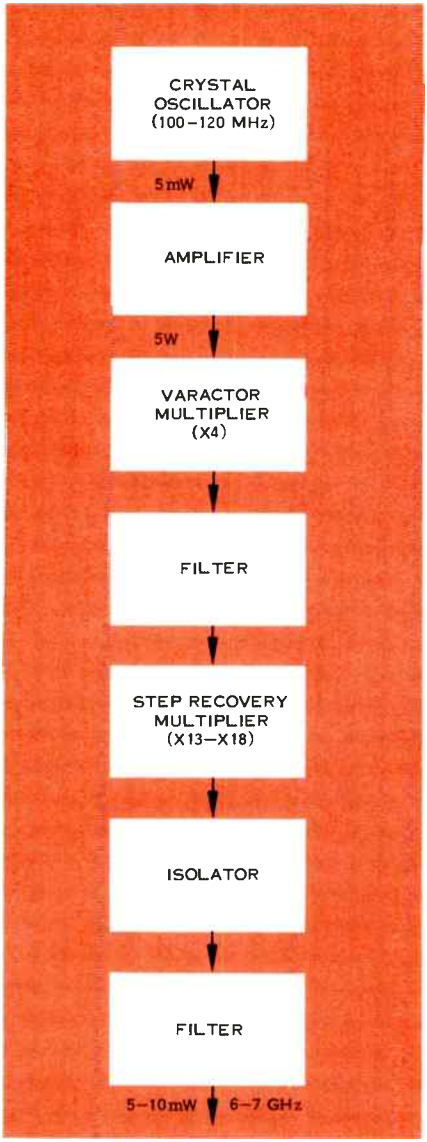


Figure 1. Typical solid-state local oscillator design uses crystal oscillator frequency reference source, varactor diode multiplier for times four multiplication and step recovery diode for times thirteen to times eighteen multiplication. Microwave frequency in the 6 to 7 GHz range, determined by the step recovery multiplication, has from 5 to 10 milliwatts output.

Solid-State Local Oscillator

One method of generating a frequency at 6 GHz (see Figure 1) is to use a very stable crystal reference source operating at 100 MHz. A substantial amount of power can then be provided by amplification. Succeeding varactor and step recovery diode frequency multipliers convert the energy to microwave frequencies in the order of 6 GHz. But efficiency is low. Approximately 5 to 10 watts of power at 100 MHz is reduced to about 10 milliwatts at 6 GHz. Ten milliwatts is adequate power for a local oscillator signal, but much less than needed to drive a solid-state transmitter. However, at lower frequencies, for example 2 GHz, the multiplier efficiency is much higher, and transmitter power outputs of about 2 watts and broad bandwidths for 300 message channels are now available.

Receiver local oscillators, using a crystal reference source, are not generally affected by environment. However, the oscillation frequency of the klystron varies with changes in environment, power supply voltage, the stabililty of the frequency reference cavity, and the AFC loop. The oscillation frequency of a common type of reflex klystron is guaranteed by the manufacturer to have a temperature coefficient of less than 100 kHz per degree change in Centigrade. A temperature change of 10°C could change the klystron frequency as much as 1 MHz.

This is not too important, however, since the conventional klystron local oscillator is normally operated with an AFC loop which makes it not only immune to temperature and power supply variations, but also causes it to track accurately the frequency variations of the transmitter. The microwave discriminator reference cavity has a negligible variation with temperature, and by feeding an error voltage to the power supply, changes are made in repeller voltage to bring the klystron back on frequency. Typically, the repeller modulation coefficient is 500 kHz per volt. Thus, a 12-volt change in repeller voltage will compensate for a shift of about 6 MHz at −30°C. The effects of temperature variations, therefore, can be reduced substantially.

The introduction of a solid-state receiver local oscillator having a fixed and highly stable frequency—without automatic frequency control—requires a corresponding improvement of the transmitter frequency stability. Variations in temperature affect both the power output versus frequency characteristic and the linearity of the frequency modulation characteristic of a transmitter klystron. The klystron must be modulated linearly, and this is especially important with wide baseband signals. Some means must be used to keep the modulation linearity characteristic constant even during ambient temperature changes.

Temperature Control

Conduction heat sinking continues to be highly successful in all microwave systems using klystrons. This method uses a finned aluminum radiator attached to the klystron to dissipate heat —it is economical and requires no maintenance.

Another method of controlling the temperature of a transmitter klystron is called heat value control. Though mechanically more complicated than heat sink dissipators, heat value control devices maintain more stable temperatures and thereby decrease the amount of shift of the modulation linearity curve of a klystron.

Heat value control, also referred to as vapor phase cooling, uses the boiling or vapor point of a liquid to maintain a constant temperature—usually higher than the temperature that would be reached by the surrounding atmosphere. Thus, the name "cooling" could be considered a misnomer when comparing this method with conduction heat sinking.

One technique of heat value control (Figure 2) is to pass water through the bottom of a circular waveguide flange which has an enclosed annular passage surrounding its rectangular opening. The waveguide flange is attached to the output flange of the klystron. At the bottom of the flange water is vaporized and rises through the flange to the top opening where it is passed to a finned radiator heat exchanger. The vapor is cooled to liquid in the radiator and returned to a reservoir for reuse. This process continues indefinitely at atmospheric pressure without any mechanical pumps. Inert chemicals may be used for the "coolant", but distilled water is readily available, more convenient to use, and has a much higher latent heat of vaporization.

The temperature coefficient of a klystron using this device is reduced to about 8 kHz/°C, maintaining modulation linearity for a baseband wide enough for up to 1200 channels.

Benefits

One of the major advantages of completely solid-state transmitter and receiver equipment will be the elimination of high voltage power supplies. Thus, repeaters located at isolated sites can be operated from a 24-volt battery, eliminating the need for engine-driven emergency power genera-

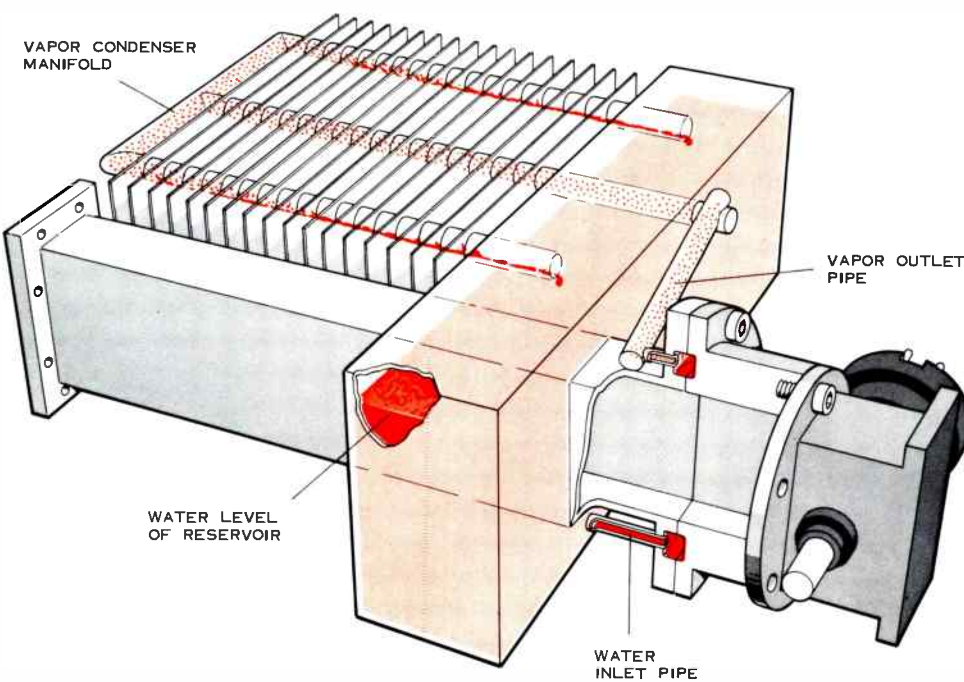


Figure 2. Typical cooling device maintains constant klystron temperature. Water vapor rises through outlet pipe to condenser manifold where it returns to liquid state and drops into water reservoir.

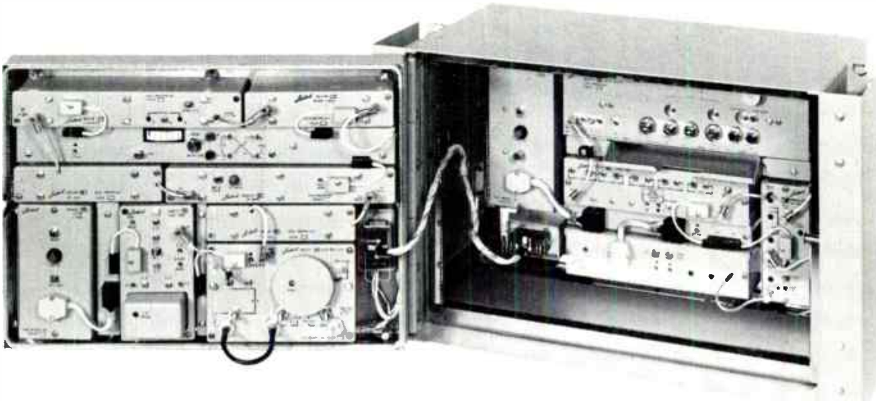


Figure 3. Construction of the Lenkurt 71F 2-GHz Microwave Radio typifies the advanced modular design and high density packaging afforded by total *solid-state construction.*

tors. Also, the low power requirements of solid-state repeaters will permit the use of previously unsuitable power sources, such as solar cells and thermoelectric generators. These devices require very little attention and generally provide uniform efficiencies over a wide range of power outputs at extremely low operating costs.

The development of suitable solid-state devices will greatly influence the mechanical and maintenance features of modern microwave radio equipment. This will be especially noticeable in high density packaging and modular construction techniques. These techniques will allow equipment to be put together in "building block" fashion so that systems can be specially arranged to better fit the needs of each application. These separate modules will usually be placed on shelves mounted in equipment racks, allowing the modules to be removed and replaced very quickly and easily for maintenance purposes.

For the present time and possibly for a long time to come, klystrons will be used predominately in baseband transmitters. It is expected that improvements in power with tube devices will generally provide lower noise and increased baseband capacity, therefore contributing to the overall efficiency of microwave transmission systems. Heterodyne repeater microwave systems also will probably continue to use traveling wave tubes, with solid-state sources for the transmitter up-converter and receiver local oscillator.

Later developments in microwave will certainly continue to decrease the size of the equipment while providing more efficient performance and greater reliability. In the future, miniaturized microwave radios will probably be mounted directly on top of antenna towers, thus avoiding the cost and technical problems of long waveguide runs.

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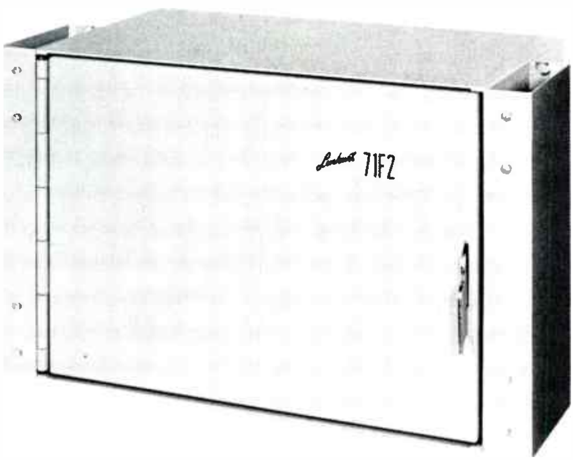
San Carlos, California



Lenkurt's 71F2 is a 300-channel light-route microwave system ideally suited for industrial, common carrier, and government applications in the 1700 to 2300 MHz frequency range. Compact design and superior performance are achieved using all solid-state construction with 2 watts power output. For information, write Lenkurt, Dept. B720.

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MAY, 1967
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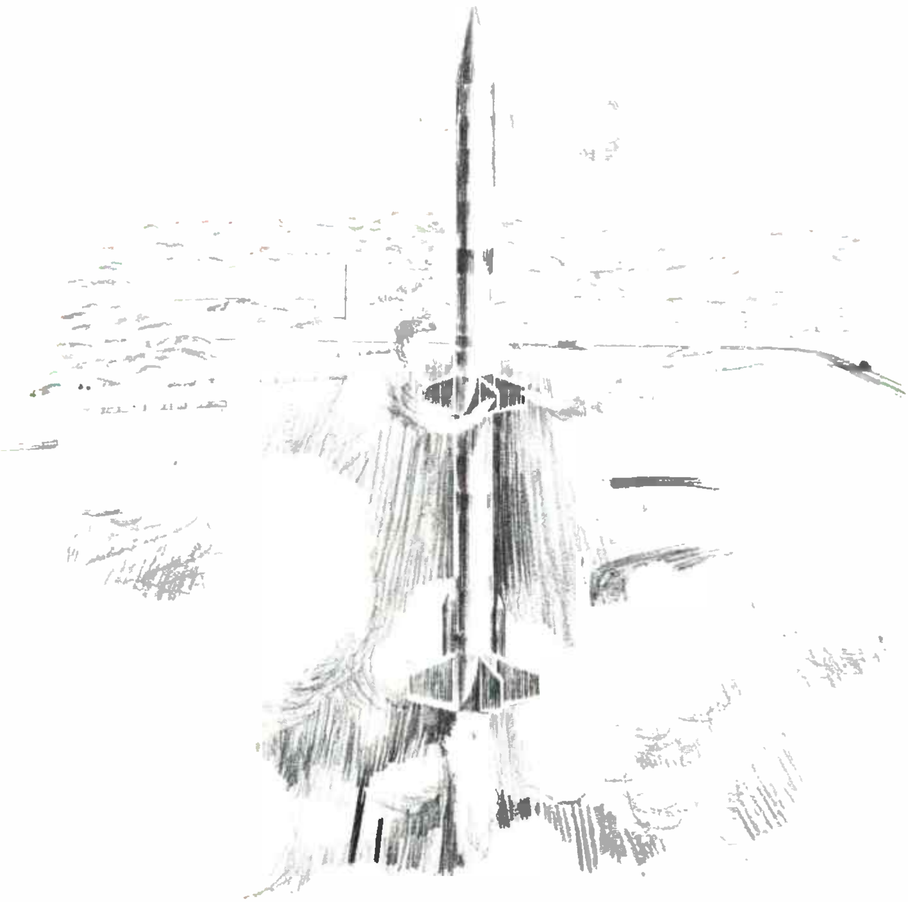
The Lenkurt DEMODULATOR

MISSILE RANGE COMMUNICATIONS



LENKURT ELECTRIC ... specialists in VOICE, VIDEO & DATA transmission

The success and growth of modern rocketry depends heavily on realistic missile range testing. On the range, effective communications has become an increasingly important component, and is called on to carry large quantities of voice and digital data.

Every missile or rocket booster used by the armed forces or other government agencies must be extensively tested under controlled conditions. Like any new product, it must perform in the field to prove it will actually do the job intended. In the case of a missile, this involves a number of ground tests and eventually a series of launches. It is at this final stage that the missile range becomes invaluable.

The testing of missile systems is carried out primarily at five national test ranges. These include the Eastern Test Range at Cape Kennedy, the Western Test Range and Pacific Missile Range on the West Coast, the White Sands Missile Range in New Mexico, and the Kwajalein Islands Test Site. A number of smaller ranges support specific types of investigation and testing.

Large Areas Needed

The missile range may be over land or water—but always requires vast areas. Small tactical weapons necessitate firing over ranges of thousands of yards, or at the most a few miles. The multistage rockets of an intercontinental ballistic missile or the booster of a space probe require hundreds, if not thousands of miles of flying room for realistic testing. The White Sands Missile Range, for example, uses over 4,000 square miles of desert land—yet many of the larger vehicles tested there must be launched from Utah for impact on the range. Large rockets launched from the Pacific and Western ranges may extend out over the ocean nearly to Hawaii—over 2,000 miles away.

However, rocket testing is not just firing a missile from "here to there" and seeing where it lands. Scientific testing demands that as much data as possible be obtained and recorded during every moment of the flight. To do this, the range is equipped with many types of instruments: radar, special cameras, telescopes, and telemetry radio. Some instruments are used to accurately determine the trajectory, while others receive data on physical changes taking place inside the missile itself. Control of the rocket's flight must also be under constant centralized control. Since these functions must be carried out over sometimes vast distances with close coordination, a heavy burden is placed on the communications capability of the range.

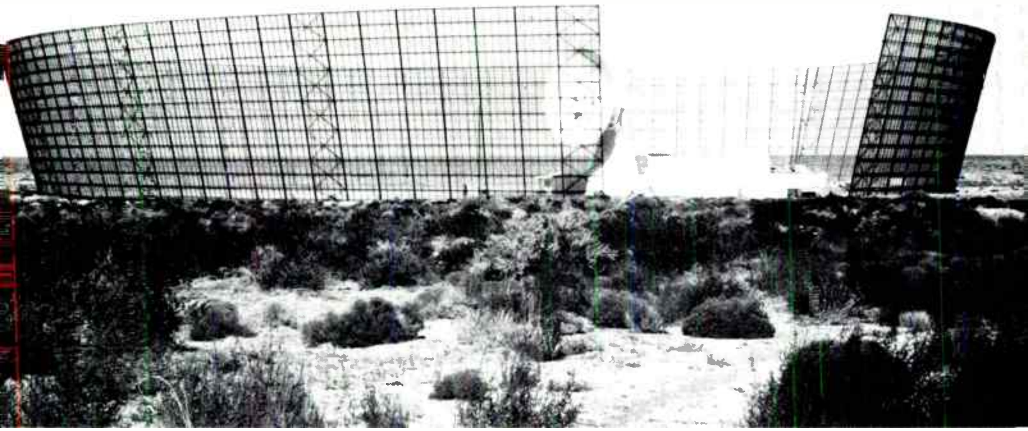


Figure 1. Radar is first range instrument to "see" missile. Installation at White Sands Missile Range is surrounded by clutter shield.

Range Facilities

Range instrumentation is the sensing organ of the test facility. To be in a position to "see" the missile during its flight, these stations must be placed at many locations on the range. The range communications centers provide a nerve system over which flows volumes of tracking and flight performance data.

Two needs appear from the basic mission of the test range: the communication of tracking information to and from many instrument sites, and the reception and handling of performance data direct from the missile. Many instruments are used to determine the trajectory of the missile—an important factor in judging the performance of a new vehicle. Radar installations (Figure 1) are first to "acquire" the missile, and from the radar, pointing information is subsequently supplied to all other instruments on the range.

A variety of optical instruments are used to record the flight. Included are standard still and motion picture cameras, and a number of specially developed telescope-camera combinations. Some are stationary and use a single film plate; multiple exposures accurately trace the path of the missile. Others are adjusted to follow the missile with rapid-sequence photographs, using tracking information obtained from radar through the communications network, and additional manual tracking. For example, a combination telescope and motion-picture camera, the cinetheodolite (Figure 2), is widely used for observation of such parameters as angular velocity, changes in roll, pitch, and yaw, and acceleration. On each frame are recorded the azimuth and elevation angles, and timing information.

Other information on the flight is obtained through telemetry—the radio

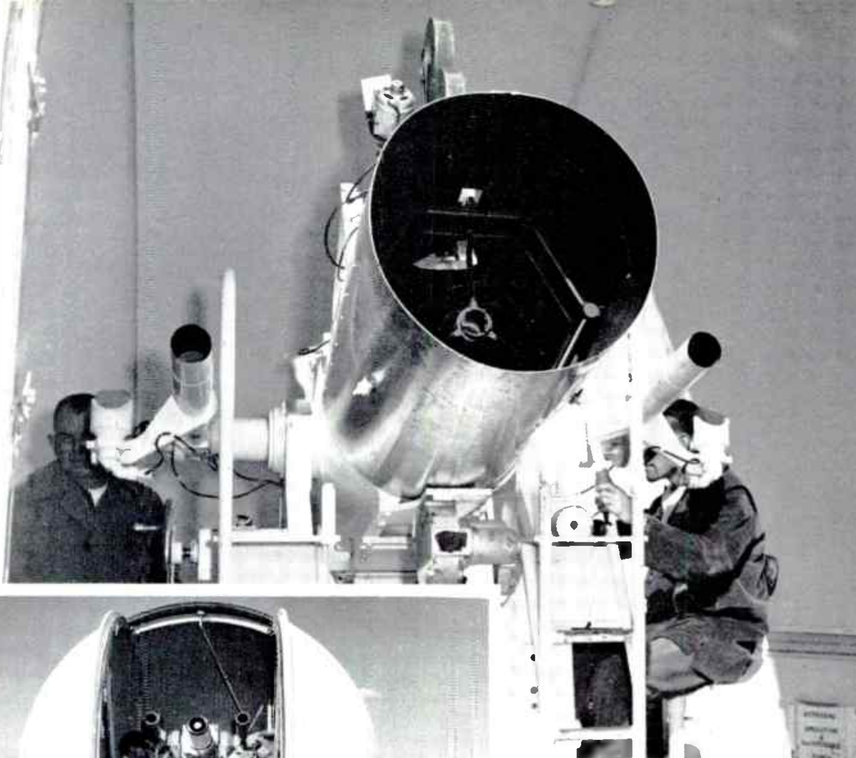
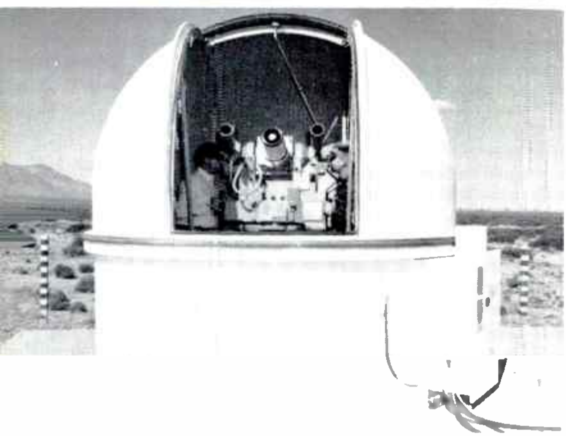



Figure 2. Cinetheodolites optically track missiles for many miles, recording on film changes in trajectory, attitude and other events. After receiving preliminary tracking information over the range communications network, the operators follow the missile manually.

transmission of physical data directly from the missile to the ground.

As a flight progresses over the test range, a great number of functions occur simultaneously: radar supplies tracking information to many sites; optical instruments record trajectory, attitude and events; and telemetry installations receive a constant flow of data from inside the missile. During large tests hundreds of instruments must be in constant coordination with the range control center. At this central point, tracking information is digested and relayed in proper form to each other station, and telemetry data is accepted for immediate or future analysis.

Two distinct functions of missile testing, range tracking and control, and telemetry acquisition, may share the same communications links, or have specialized systems designed for their unique requirements. This article will treat them separately, realizing that either choice may be made at a particular range.

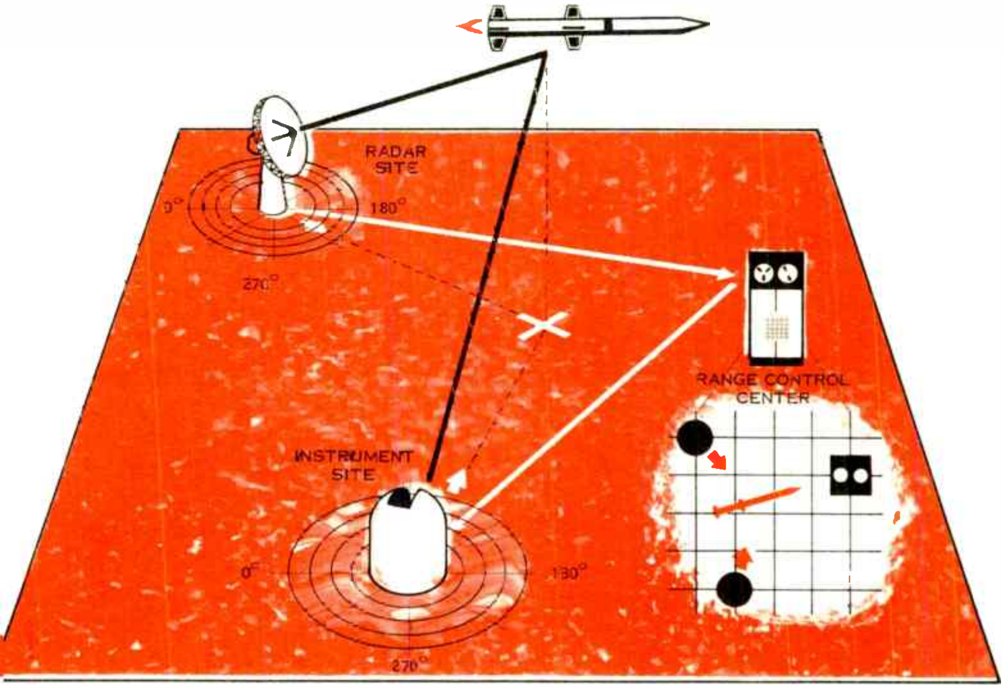


Figure 3. Radar picks up missile after launch, sends polar coordinate tracking information to the range control center. Computer translates to Cartesian system, sending pointing information to other instrument sites.

Instrumentation and Data Control

As a missile is launched and begins its flight over the range, the first requirement of all instrumentation is to find the object, know its trajectory, and be able to track it. Whether the instrument is a camera, telescope or a telemetry antenna, it must know where to look for the missile. Each site will receive guidance from an instrument control system.

Radar tracking stations acquire the missile shortly after launch. Azimuth, elevation and range are transmitted from these sites, through the range communications network, to the range control center. Data from the radar will be sampled 100 times a second, and transmitted in real time at 24 kilobits per second in some applications.

The radar positioning information, in polar coordinates, places the missile in reference to the individual site. Along with azimuth, elevation, and range figures, a quality check signal is included. At the range control center a computer complex analyzes the incoming signals from a number of radar sites on the range, and selects the one installation having the best "fix" on the missile. Once this is done, the computer converts the polar coordinates sent by the radar into a Cartesian (straight line) coordinate system to accurately place the missile over the range (see Figure 3). This Cartesian information is sent

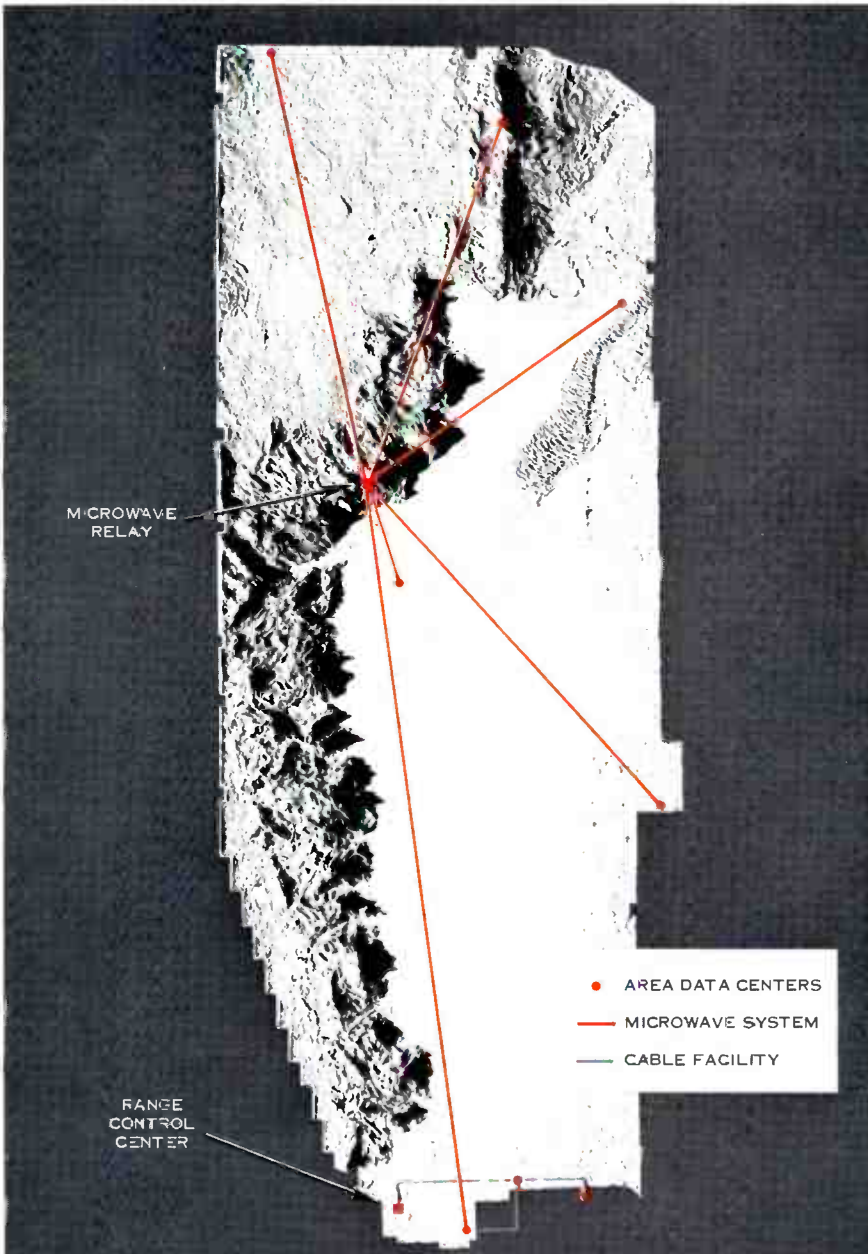


Figure 4. Microwave system recently installed at White Sands Missile Range by Lenkurt relays instrumentation and data control information between area data centers and range control center. Many instruments surround each site, linked by hard line facilities.

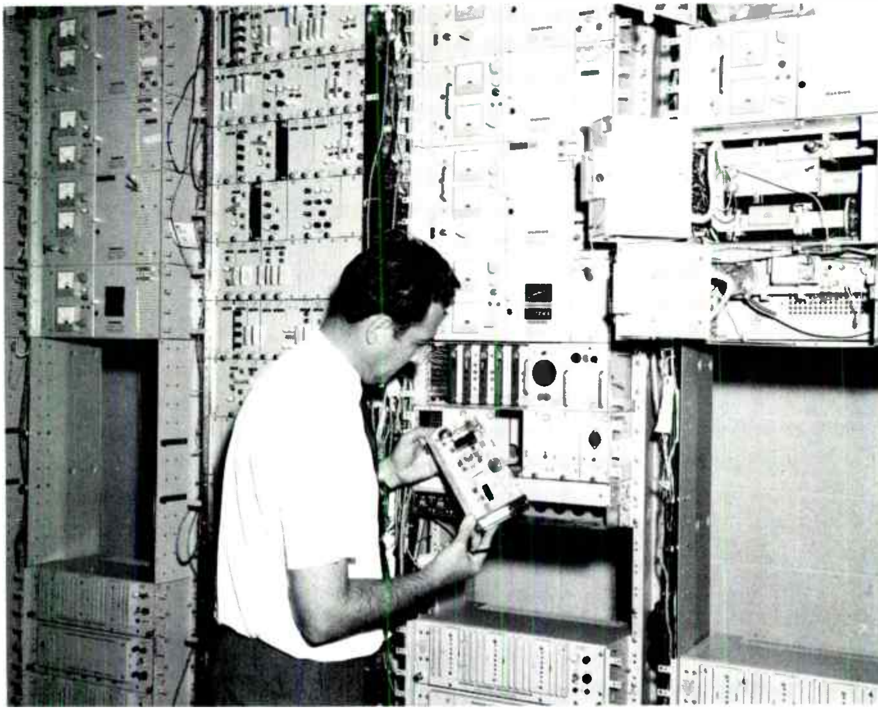


Figure 5. Lenkurt 76 microwave radio system provides updated communications capabilities at White Sands Missile Range. To left of radio is 57B path protection system.

back to observation stations throughout the range where it is translated back to separate polar coordinates to position each station. Tracking signals leave the range control center at 2400 b/s, with typical sampling rates of 10 per second.

Through this sharing of data, each range instrument is coordinated in tracking the missile and can follow it throughout the flight. Control signals from the command center also cue camera shutters and announce start times for certain recording devices.

As the missile continues over the range, other radar stations will become better sources of tracking data, and by continuous analysis the computer will switch these into the system as primary guidance sources.

A number of other functions must be monitored before and during the test flight. Range readiness, the progress of the countdown, and other important prelaunch situations must be collected from the downrange sites, assimilated, and displayed to range control sites. During the test, range safety control is in constant need of tracking information; if a missile is badly off course, command destruct immediately must be put into effect.

Continuous operational status reports must be available to all stations, indicating the conditions of *scheduled, run,*

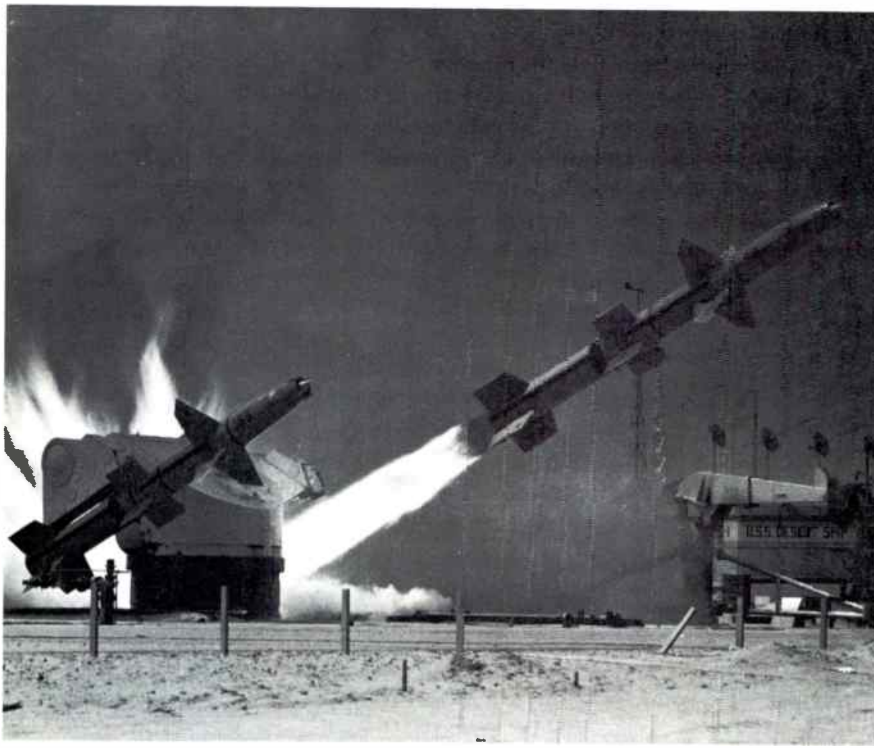


Figure 6. Short and long range missiles must undergo the same demanding tests before they become operational. Here, the TALOS is fired from a simulated ship at White Sands. The missile is under constant surveillance as it passes over the range.

hold, standby, cancelled, rescheduled, and completed missions. All of these functions utilize the range communications system in a heavy flow of traffic between remote sites and the range control center.

Frequent Tests

Activity will vary considerably depending on the nature of the range. An over-water range may be called on more for ICBM tests, resulting in less frequent missions than a range involved with smaller, tactical weapons. White Sands Missile Range, for example, conducts approximately 3,000 firings a year—sometimes as many as 40 in one day. These may extend all the way from small, hand-held weapons and field artillery missiles, to surface-to-air rockets and intermediate range multistage missiles.

The range control center—and in direct support, the range communications system—will at times be in control of perhaps 10 separate operations at one time. And between tests, the turnaround time must be very short. Tracking facilities may have only 30 minutes between operations to readjust to new circumstances. Reliable communications is a necessary component in the overall function of the missile range.

To connect the area data centers with the data processing center at White Sands, Lenkurt has installed an instrumentation data transmission system to update the present network (Figure 4). Multiplexed voice channels and high speed data signals to and from the sites are transmitted through a network of microwave radio stations. When completely operational, the system will have a capacity of 1200 channels. Approximately 100 data sets will be used at the range control center to receive and transmit tracking information. As many as 600 data sets at remote instrument sites will allow all phases of the test program to operate in real time—each in constant communication with the master control consoles. Data at 2400 b/s can be transmitted on a single voice channel; high-speed, wideband data requires a group of 12 channels.

Telemetry

Once most stations have the information needed to accurately track the vehicle under test, the result is the continuous observation and recording of test data. External observations of the missile by radar and specially built telescopes and cameras supply trajectory

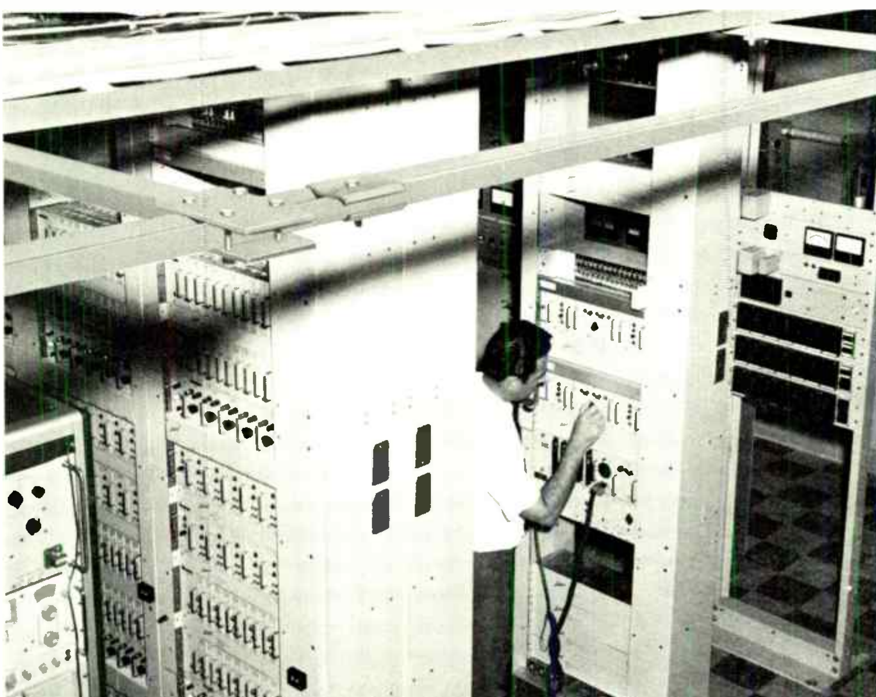


Figure 7. Row upon row of communications equipment fills key stations in the instrumentation and data control system. Here, technician checks Lenkurt multiplex and signaling equipment at White Sands.

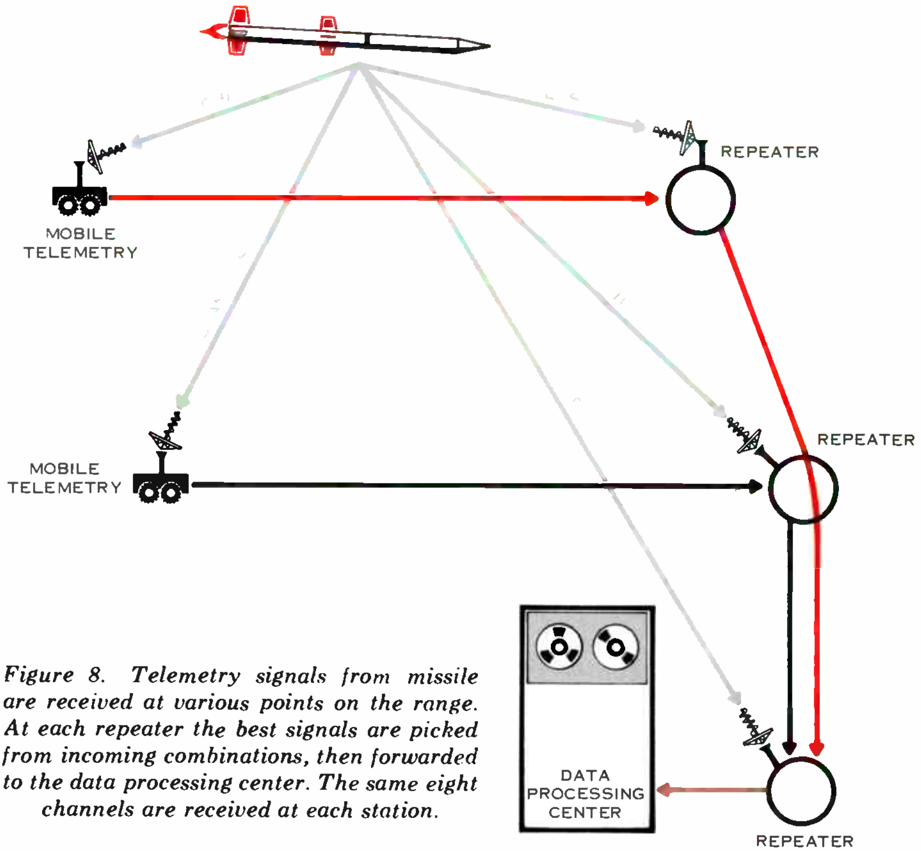


Figure 8. Telemetry signals from missile are received at various points on the range. At each repeater the best signals are picked from incoming combinations, then forwarded to the data processing center. The same eight channels are received at each station.

and other measurements. The observation of dynamic physical phenomena is done by small sensing devices carried on the missile itself and relayed to earth by telemetry radio transmitters.

A number of telemetry acquisition sites, many of them mobile, are placed at appropriate locations on the range. For a landlocked range such as White Sands, these stations may be anywhere within and outside the 100 x 40 mile area. At ranges firing over water, tracking and telemetry stations will be concentrated along the coast, with additional units aboard ships and on islands along the flight path.

Telemetry data from these stations is transmitted to the central data processing installation in real time. Simultaneously, the information is recorded at the site. If a transmission path should fail, data is not lost and can be evaluated at a later time.

Telemetry signals from the missile may be received at a number of sites concurrently. Quality checks are made at each relay point and only the best of several redundant signals received are forwarded.

Figure 8 illustrates how eight channels of data received from the missile might be handled on a typical mission at White Sands. Where two sources come together, the channels are analyzed and compared. The better signal is the one passed on. In this example five different stations are receiving data. The telemetry data center ultimately receives only the best combination of eight channels.

Telemetry data from internal instruments on the missile comes from such variables as temperature, pressure, force, acceleration, and vibration, allowing engineers to survey the operation of the vehicle under actual flight conditions.

By commutation, a number of separate pieces of data may be time division multiplexed onto one channel. The sampling rate and the number of separate inputs will be determined by bandwidth requirements and the rate of change of the particular parameter. A slow-changing characteristic need not be sampled as often as one with rapid variations.

At the telemetry data center, multiplexed signals are separated and recorded. Many also appear in visual form for immediate use.

Accurate Timing

Individual pieces of test data are of limited value unless they can be precisely correlated with all other data. To make this possible, a highly accurate system of timing is made available to each instrument on the range. Where good communication is available, timing signals are generated from a single location and forwarded to all installations. These generators are so stable that they remain within 50 milliseconds of Greenwich Mean Time. In some cases, for instance where tracking ships are thousands of miles away, real time communication is not always possible. It is then necessary to hand carry atomic timing clocks to the remote instruments.

Timing information is included with all telemetry data sent from area data centers. In this way all data inputs may be synchronized for comparison. Radar pulses are also controlled so that measurements at many locations can be made simultaneously. Even camera shutters can be triggered together. And in the communications system data modem clocks are locked to the range timing system for accurate coordination.

The communications system on a missile test range is much like the telephone exchange of an average city. It must provide subscriber loops to a number of individual points, and have the capability to switch these circuits for various applications. The most dramatic difference is the amount of digital data carried by the range system. While the communications system must always have voice circuits for coordination between sites, the great percentage of circuits are dedicated to carrying data signals between remote instruments and the range control center.

Large quantities of information must flow smoothly and reliably through the communications network before and during a flight. Centralized control is thus maintained over the missile itself and numerous instrumentation sites. The physical boundary of control and the actual ability of the test range to satisfy its mission is to a great extent limited by the effectiveness of its communications system.

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Lenkurt Electric Co., Inc.
San Carlos, California

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JUNE, 1967
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The Lenkurt DEMODULATOR

Coaxial Cable

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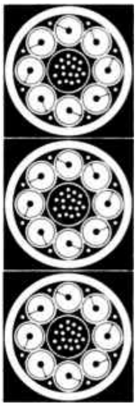

Coaxial cable transmission systems have played an extremely important role in the phenomenal growth of the telephone industry in the U. S. and abroad. This article plots the history of the coaxial cable in communications, and describes some of the characteristics of the cable, the system, and its uses.

The heart of any communications system is the transmission medium over which the information signals pass. The makeup of the transmission medium places constraints on the design of the terminal communications equipment, such as multiplexing method, channel density and performance. These mediums include simple wire conductors, multipair cable, coaxial cable and microwave radio. Each medium has its own peculiar application advantages, and each plays an important role in our day-to-day communications.

The evolution of the coaxial cable in the 1920's—a significant structural innovation of a two-wire transmission line—has made possible the wideband, high-capacity communications of today.

Growth

In 1941, Bell System L1 coaxial cable routes were established between major metropolitan areas in the eastern United States. By 1948, a complete transcontinental coaxial cable facility was in operation. The L1 had a capacity of 600 message channels—an enormous amount compared to the few channels that could be transmitted over an open wire or multipair cable. Since microwave radio was not generally in use at that time, the coaxial cable medium was considered — and certainly was — the ultimate in multichannel communications.

As television became popular and network programming began to fill the airwaves, the coaxial cable seemed to be the ideal answer for conveying network broadcasts between stations. Although the L1 had only a 2.8-MHz bandwidth, performance was found entirely acceptable. The first TV application of the L1 was to transmit the Army-Navy game in 1945.

During the ensuing years the Bell System continued to develop multiplexing equipment and repeaters for more efficient use of the coaxial transmission line. In 1953, the L3 system went into service with an increased capacity of 1860 message channels, or 600 message channels and a 4.1-MHz TV signal on the same type of cable used for the L1.

More recently foreign systems have been developed with capacities up to 2700 message channels, and the Bell System L4 with 3600 channels is meeting the need for better utilization of existing and newly plowed-in cable routes in the U.S.

The coaxial cable has played an important part in long distance communications, accounting for about 25% of long distance services crisscrossing the country. Presently, about 13,000 miles of coaxial cable routes exist. An additional 10,000 miles is planned for the next five years.

The development of microwave in the late 1940's soon tended to stem expansion of coaxial cable systems. Microwave radio eliminated costly construction, right-of-way acquisition, maintenance, and other problems associated with establishing land lines. However, the relationship of microwave and coaxial cable proved to be valuable, mainly because the same basic multiplex equipment developed for coaxial cable could also be applied to the microwave baseband. Now, a second look is being given to coaxial cable in areas where allocations for microwave frequencies are not available.

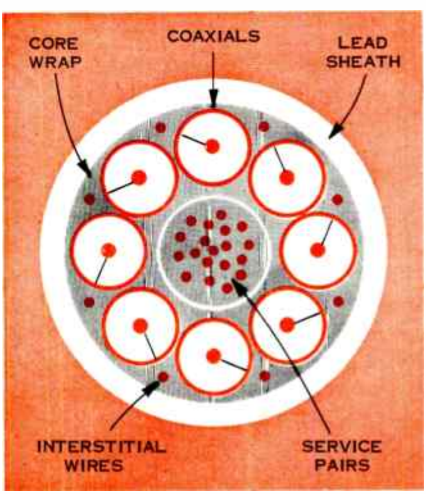

Figure 1. Typical communications coaxial cable consists of a number of "pipes" or "tubes" together with interstitial wires and service pairs inside a single sheath. Each pipe or tube provides one-way transmission for a large number of message channels or a TV signal.

Cable Construction

The communications coaxial cable consists basically of a single wire suspended in the center of a cylindrical conductor. The wire is held in the center of the tube by small disc-shaped dielectric or nonconducting insulators spaced closely together. Usually a number of these "pipes" or "tubes" (see Figure 1) are combined inside a single sheath.

Coaxial cable has a very low attenuation factor coupled with extremely good shielding from interference. In addition to its importance in the communications industry, other important uses of coaxial cable are associated with CATV and ETV, radar, navigation aids, aircraft, and test equipment.

Construction of the communications coaxial cable differs from the other types of cable which have the area between the inner and outer conductors separated by solid dielectric material. In addition, these types of cable normally have a braided copper outside conductor instead of the rigid copper tube, providing the needed flexibility for their particular use.

Disc insulated coaxial lines have much lower losses than the solid dielectric lines, but are more difficult to manufacture because of the mechanical problem of keeping the conductors concentric. The communications coaxial line with its spaced insulators approaches the ideal condition of having air as a dielectric, and is often referred to as air dielectric cable.

Included in the typical communications cable sheath with the coaxial tubes are interstitial wires and a cylindrical core containing service pairs. These added wires "round out" the cable. Around the cables is a layer of heavy insulation and a lead sheath. Interstitial wires may be used typically for v-f order wire between attended repeater stations, and for monitoring and control functions at unattended repeaters.

The service pairs, if provided, may be used as physical v-f circuits or with a cable multiplex facility.

Coaxial tube dimensions (see Figure 2) are usually described in terms of diameters of the inner and outer conductors. For example, when dimensions of 0.102/0.375 inches are given for a coaxial tube, this means that the outside diameter of the inner conductor is 0.102 inches, and the inside diameter of the outer conductor is 0.375 inches. More commonly, only the outer diameter is given; for example, 0.375 inches.

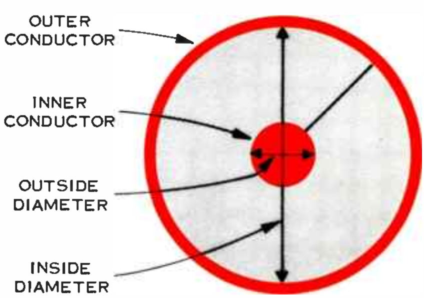

Figure 2. Coaxial tube dimensions are specified by the outside *diameter of the inner conductor, and the* inside *diameter of the outer conductor.*

Cable Sizes

The first cable installations in the U. S. were of coaxials having an outer diameter of 0.27 inches. Later installations were 0.375 inches, and this has become standard for long distance circuits. Other size cables in use include a 0.290 inch foam-filled dielectric cable used in Canada, and a "pencil gauge" cable of 0.174 inches.

The International Telegraph and Telephone Consultative Committee (CCITT) has established recommendations concerning the characteristics and performance of coaxial cable systems employing two standard size cables, the pencil gauge and 0.375 inch. According to their recommendations, the pencil gauge systems have a maximum bandwidth of about 6 MHz or 1260 voice-frequency channels, while the 0.375 inch systems have a capacity of 12 MHz or 2700 voice-frequency channels. Bell System technology has effectively exceeded this limit with the 3600 channels on 0.375 inch cable provided by the L4.

Characteristics

Electrically, what makes a coaxial cable attractive for communications is that it provides more conducting surface area than a two-wire transmission line and therefore suffers less resistance losses at higher frequencies. In addition, the electromagnetic energy propagation in a coaxial line is confined within the tube and isolated from outside interference or crosstalk because of its structure.

Generally, the effective bandwidth of a coaxial cable communications system is limited only by the required gain needed to maintain good signal quality. Spacing cable repeaters closer together makes it possible to increase the effective bandwidth by providing more amplification, and this approach has been used to increase the capacity of existing coaxial cable. However, economics and transmission reliability dictate certain limitations to such an approach.

Although a coaxial line will transmit signals down to zero frequency or dc, the lower practical frequency limit for communications is about 60 kHz. This is because the coaxial line does not provide good shielding at low frequency and because of equalization frequency limits.

The upper frequency limit for transmission in a given system is determined by cable dimensions, cable construction, and permissible attenuation. All three characteristics interact in such a manner that a compromise is usually made by giving appropriate attention to such factors as acceptable noise, repeater spacing, and amplification limits. The attenuation of a coaxial cable is given by the formula:

$$A = 40.1 \times 10^{-6} \frac{\sqrt{f}\left(\frac{1}{a} + \frac{1}{b}\right)}{\log \frac{b}{a}}$$

where:

A = attenuation in dB/1000 ft.

a = radius of inner conductor in centimeters

b = inner radius of outer conductor in centimeters

f = frequency in hertz

It can be seen from the equation that the attenuation of the cable varies directly with the square root of frequency and inversely with the size of the cable. Mathematically it has been proven that the minimum attenuation per unit length is accomplished with a ratio between the diameters of the inner and outer conductors of 3.6. With this particular ratio the impedance of a coaxial line, ignoring the losses of the dielectric, is obtained from the formula:

$$Z_0 = 138 \log \frac{b}{a} \text{ ohms}$$

Using $b/a = 3.6$, Z_0 is 77 ohms.

The insulating discs that support the center conductor of a coaxial cable represent shunt capacitive loading for the cable, and, therefore, lower the characteristic impedance and the velocity of propagation.

A coaxial cable having dimensions of 0.102 inches for the diameter of the inside conductor and 0.375 inches for the outside conductor has an attenuation of about 5.8 dB/mile at 2.5 MHz and a characteristic impedance of 75 ohms. A coaxial cable with dimensions of 0.047 inches and 0.174 inches has an attenuation of about 12.8 dB/mile at 2.5 MHz, and also a characteristic impedance of 75 ohms. See Figure 3 for a comparison of the attenuation versus frequency of the common types of communications coaxial cable.

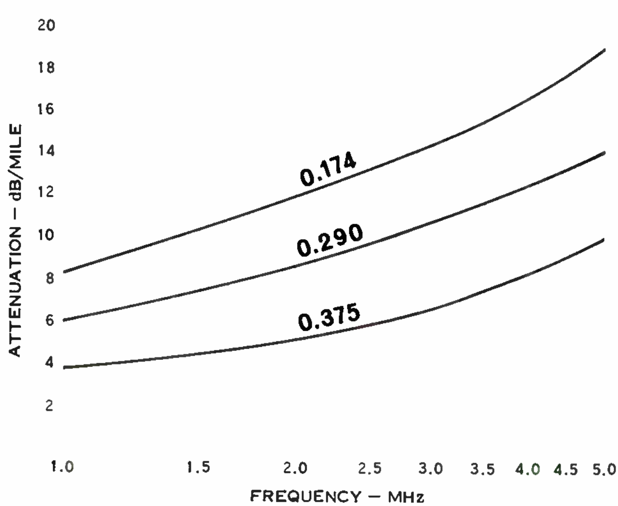

Figure 3. Response curves compare the attenuation versus frequency characteristics of the common types of communications coaxial cable.

The System

A communications coaxial cable system consists of a logical arrangement of repeater stations along the cable route. The basic requirement is that the cable network have uniform characteristic impedance, low losses and reflections, and proper protection from electric fields and disturbances such as lightning.

The original cable systems used vacuum tube repeaters. It was therefore mandatory that repeaters be spaced at wide intervals to increase reliability. With the invention of the transistor, more reliable repeaters were designed and power consumption was also substantially reduced. This made it possible to increase the number of repeaters and thereby increase the usable bandwidth of the coaxial cable.

A typical system usually contains widely spaced main repeater stations with several auxiliary stations situated between them. Customarily, the power feed for repeaters is through the center conductors of the coaxial pairs in a series loop from the main repeater stations. Hence, the maximum distance between main repeater stations is normally limited by the maximum voltage which can be efficiently applied to feed power from the main repeaters to the auxiliary repeaters. Intermediate repeater spacing depends on the loss of the cable and the problem of placing the repeater points at accessible locations.

Temperature variations are one of the most serious problems affecting the performance of a coaxial transmission system. Most of a coaxial system is buried underground, lessening the variations. Nevertheless, temperature-sensitive regulators must be employed to compensate for deviations in cable attenuation caused by temperature changes.

An example of a long-haul coaxial cable transmission system is the Bell System L4. This system employs three types of repeaters between main station repeaters: basic repeaters, regulating repeaters, and equalizing repeaters. Basic repeaters compensate for the normal loss of approximately 2 miles of cable. This repeater spacing is compared with 4 miles for the L3, and about 7.5 miles for the L1. Regulating repeaters spaced at up to 16-mile intervals provide additional compensation for changes in cable loss due to temperature variations. Equalizing repeaters at up to 54-mile intervals contain adjustable equalizers to compensate for random gain changes. These equalizers are remotely adjusted from the main station repeaters. Main station repeaters are spaced at up to 160-mile intervals. The main station repeaters contain all the functions of the other repeaters plus additional "mop-up" equalizers which compensate for un-

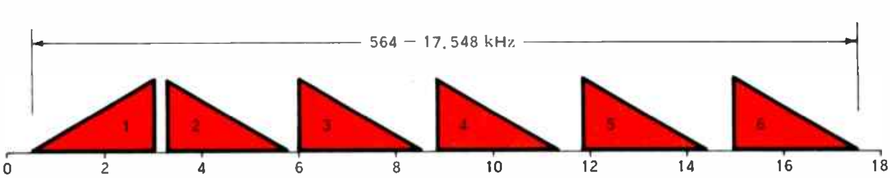

Figure 4. The modulation scheme used with the L4 combines six 600-channel mastergroups between 564 kHz and 17,548 kHz. Mastergroups 2 through 6 use the upper sideband while mastergroup 1 uses the lower sideband.

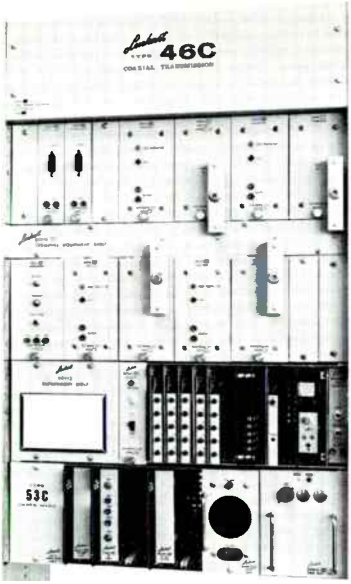

Figure 5. Up to 600 v-f channels may be processed by office arrangement of Lenkurt 46C Coaxial Transmission System shown above.

equal spacing of equalizing repeaters. These main station repeaters also supply direct current to the intermediate repeaters.

The multiplexing scheme for the L4 (Figure 4) is the combination of six 600-channel mastergroups with a frequency range of 564 kHz to 17,548 kHz. The mastergroups are separated by guard bands to permit dropping out any of the groups at a main station without demodulating the others.

Other Uses

The growth of the domestic telephone industry with each passing year decreases the number of frequency assignments available for microwave radio. For this reason increased emphasis is being given to the establishment of coaxial land lines as an alternative. Another use is in short haul cable extensions off backbone microwave radio routes. This particular application proves in some instances to be more economical than microwave.

For example, the Lenkurt 46C Coaxial Transmission System—which complements the Lenkurt 46A Radio Multiplex System — provides for as many as 600 voice channels for interconnection between microwave radio installations and coaxial cable plant. The system permits transmission on 0.174, 0.290, and 0.375 inch cables. Repeaters along the buried cable are in watertight cabinets installed in manholes.

While the system capability is 600 channels, it can be proved-in for lower capacity systems by spacing repeaters at greater distances. For example, a typical system with an initial need of 60 channels on 0.174 inch cable would require repeaters at about 10-mile intervals. Expansion to 300 channels can be achieved by inserting intermediate repeaters at 5-mile intervals. Repeater spacing for 600 channels is 2½ miles. Selected repeater sites may be equipped for dropping and adding channels according to local needs.

The future holds growing applications for coaxial cable. For example, a pulse code modulation (PCM) system now under development at Bell Laboratories will carry 3600 to 4000 channels over coaxial cable. The digital transmission system, designated T4, will operate at 281 megabits per second and will be employed on long-haul toll circuits. Its commercial use is expected by the early 1970's.

Lenkurt Electric Co., Inc.
San Carlos, California

New Delay Equalizer

Lenkurt's 971A Adjustable Equalizer corrects both attenuation and delay distortion on voice-frequency circuits used for data transmission. Because the 971A is fully adjustable, it can correct any type of circuit and provide more precise equalization than fixed type equalizers. For information, write Lenkurt, Dept. B720.

LENKURT ELECTRIC San Carlos, California, U.S.A.

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THE LENKURT DEMODULATOR is a monthly periodical circulated to technicians, engineers, and managers employed by companies or government agencies who *use and operate* communications systems, and to educational institutions. Job title, company affiliation, and nature of business must be indicated on subscription requests. Each issue features an instructive article on a subject dealing with the science of telecommunications. Permission to reprint articles may be obtained by writing THE EDITOR.

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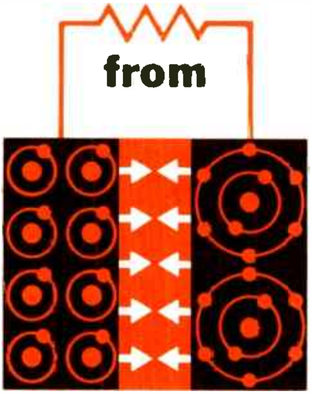
The Lenkurt DEMODULATOR

Remote Power

from



FUEL CELLS

Exotic power sources are one of the promising spin-offs from space age technology becoming available for commercial use. The fuel cell—popularized in the Gemini space flights—may become an economical source of power for remote communications sites.

Classically, a fuel is considered the storehouse of the sun's energy. In the "fossil fuels"—coal, petroleum, natural gas — this energy is usually liberated through burning. But conversions involving any intermediate process with high temperatures is not efficient. For example, the conversion of fuel to electricity in a steam turbine involves a number of steps. Fuel is first burned to produce heat. Pressurized steam then does work by turning large turbines. The turbines power an electrical generator. At each step of the conversion, energy is sacrificed.

Electrical energy is the most convenient form of energy to handle, and can be easily converted to mechanical power or heat. For this reason, investigators have been intensely interested in finding ways to produce electricity directly and with high efficiency. The fuel cell, which uses direct conversions for high efficiency, is one answer. In all direct conversion schemes, energy is extracted or transformed from one state to another without mechanical motion. With each step eliminated, greater efficiencies are gained.

The communicator is obviously interested in efficient and practical power sources to run remote relay stations and repeaters. These new devices are also being considered for large scale generation of electric power; to provide motive force for cars, trucks, boats, and even submarines; for use on space ships and satellites; for military communications systems; and almost anyplace where reliable, efficient, and quiet power generation is an advantage.

Energy Sources

Electrical power may be derived by direct conversion from a number of energy sources: thermal, nuclear, radiative, and chemical. Thermal, or heat energy was first used to produce electricity directly in a device discovered in the early 1800's. Known as a thermocouple, the thermoelectric generator consists of two dissimilar metals, such as copper and iron, joined together. When one end of the junction is heated and the other kept cool, a current is caused to flow through the thermocouple. If a number of thermocouples are stacked together forming what is called a thermopile, a usable amount of electricity can be obtained. Remotely located electronic equipment has been powered by such devices.

The heat source of the thermoelectric generator is commonly a gas flame. But a form of nuclear energy can also be tapped. Heat in this case is produced by the decay of radioactive isotopes. Workable units have been produced, but the initial cost is high. The advantage of isotopic power is reliability

Figure 1. Fuel cells for the Apollo spacecraft receive final tests at Pratt & Whitney plant. Each Apollo will use three of these units, producing up to 2 kW each from pure hydrogen and oxygen.

and long life, even though economics makes the method prohibitive except in the most demanding cases.

Another thermal conversion device is the thermionic generator. Much like the vacuum tube, heat is used to "boil off" electrons from a cathode. Collected on an anode (plate), the electron flow becomes a usable force. Different from the electron tube, the generator derives its energy from a direct heat source — even the concentrated energy of the sun has been used.

Man's use of the radiant energy of the sun as a power source is probably better known through the space age use of the solar cell. Used almost exclusively as the power source for unmanned satellites and deep-space probes, the solar cell has proved to be a reliable power generator.

Not clearly associated with direct conversion devices, but worthy of mention as an exotic power source, is the magnetohydrodynamic (MHD) generator. Not unlike the conventional electromechanical generator, the MHD generator relies on the motion of a conductor through a magnetic field to produce electricity. In this case, however, the conductor is a plasma or highly ionized gas. The MHD generator is receiving considerable attention in the field of large scale power generation.

Chemical energy represents that energy stored in a substance and released in the form of heat, light, mechanical energy, or electrical energy during a chemical change. It is with electrical energy that we are at the moment concerned; this is the basis of the fuel cell.

Efficiencies

Most of the power used in the world comes from breaking the chemical bonds in the fossil fuels — coal, petroleum, and natural gas. But conversion efficiencies place definite limitations on the use of the resulting energy.

The internal combustion engine can approach 25 to 30 percent efficiency. However, when the mechanical linkage necessary to power an automobile is added, efficiency falls to about 15 percent for the total system. Steam generation of electricity can approach efficiencies of 25 to 30 percent, and high temperature gas turbines are rated as high as 40 percent. But whenever heat is a part of the energy conversion cycle, there is a definite limit to the efficiencies that may be obtained. And friction in any machine takes its toll.

In the fuel cell there are no moving parts, and the small amount of heat produced is not part of the conversion cycle. Theoretical efficiencies in the fuel cell approach 100 percent. In a practical device, 75 percent is more realistic, although laboratory models have exceeded this in special instances.

The economic desirability of such an efficient system is obvious. But it must be remembered that, as with any new technique, developmental costs are still high and initial investment in the machine still overshadows the advantages of laboratory-gained efficiencies.

Just the same, for applications where other more conventional forms of power are not readily available — in space, under water, and in remote land areas — efficiency may outweigh higher costs.

The Gemini 7 spacecraft, for example, carried a fuel cell system weighing about 575 pounds. To provide the same electrical capability (about 2 kW) for the two-week flight, it would have been necessary to burden the vehicle with 2000 pounds of conventional batteries.

Apollo will carry a fuel cell system rated at 6 kW which, including fuel and auxiliary equipment, weighs 1200 pounds — a tenth the weight of batteries with an equivalent output. In such applications cost is no limitation.

The communicator on earth is likewise interested in power efficiencies. At the installation of a remote microwave site, conventional power sources may represent as much as 30 percent of the total cost. The fuel cell (or other direct conversion device) may in the future reduce this cost and at the same time add convenience.

Fuel Cell Theory

The operation of the fuel cell is actually the reverse of the chemical process called electrolysis, known since the beginning of the 19th century. Electrolysis produces chemical change by passing current through an electrolyte, a solution capable of acting as a conductor. For example, if electrodes are suspended in water (H_2O) and a current passed between them, hydrogen gas (H_2) will form at the cathode (negative terminal) and oxygen gas (O_2) will appear at the anode (positive terminal).

While experimenting with electrolysis in 1839, Sir William Grove discovered that the reverse was also true: he brought hydrogen and oxygen together under controlled conditions and produced water and electric current. While Grove is credited with the discovery of the fuel cell, it was not until after World War II that any concentrated developmental effort was made. And even then it remained for NASA's space need to create the final incentive to develop a usable unit.

The first fuel cells used hydrogen and oxygen. Many other chemical reactions which produce electricity are the subject of much current research. But for a basic understanding of the fuel cell, it is simplest to examine the hydrogen-oxygen unit.

Chemical Reactions

The cell contains two electrodes separated by an electrolyte (Fig. 2). Hydrogen (the fuel) is available at the anode and oxygen (the oxidizer in the chemical reaction) is at the cathode. As the two gases are applied to the electrodes, separate reactions take place. When hydrogen is passed over the anode, electrons are generated and can be made to do electrical work through an external circuit. At the cathode the electrons join with the oxygen to produce what is called an hydroxl ion, with the chemical symbol OH . The ions travel through the electrolyte to complete the electrical circuit.

A closer look at the chemical reactions in the fuel cell will further explain the process. At the anode, hydrogen gas (H_2) is absorbed in the form of hydrogen atoms (H). In the electrolyte are hydroxl ions (OH^-) produced at the cathode. An ion is an atom or group of atoms that has either gained or lost an electron. In this case an extra electron is available and the OH grouping takes on a negative charge. The hydrogen atom and the hydroxl ion join to produce water (H_2O) and at the same time free the extra electron. This electron is now available to flow through the external circuit.

At the cathode, oxygen gas (O_2) is similarly absorbed through the electrode. Here the oxygen atom (O) reacts with both the water (H_2O) in the electrolyte and the incoming electron to form hydroxl ions.

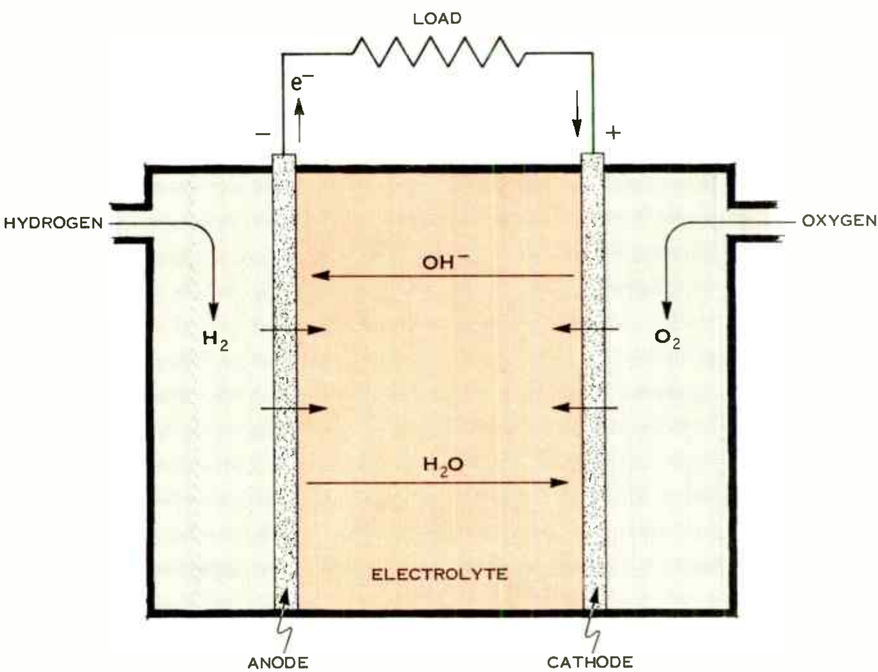


Figure 2. At the anode of the hydrogen-oxygen fuel cell. hydrogen joins with hydroxl ions to produce water, freeing electrons to do work. At the cathode, oxygen reacts with water in the electrolyte and electrons from the external circuit to form hydroxl ions.

These reactions may be summarized using chemical notation. At the cathode

$$1/2\ O_2 + H_2O + 2e^- \longrightarrow 2\ OH^-$$

That is, oxygen plus water plus electrons produce hydroxl ions.

At the anode:

$$H_2 + 2\ OH^- \longrightarrow 2\ H_2O + 2e^-$$

Hydrogen plus hydroxl ions produce water and electrons.

In summary, hydrogen and oxygen can be continually combined in such a way that water and electrical energy result.

The output of a fuel cell is low voltage, high current dc. Individual cells can be stacked in both series and parallel arrangements the same as conventional batteries to increase voltage or current.

Figure 3. Small natural gas fuel cell produces 500 watts of electricity. Smaller units can use gasoline.

Batteries vs. Fuel Cells

Conventional batteries, it should be noted, are closely related to the fuel cell. However, the battery is self contained and must either be discarded or recharged when its stored energy has been used up. The fuel cell will continue to produce electrical energy as long as fuel is supplied.

The storage battery has advantages where high power is needed over a short period of time. The fuel cell is more applicable for needs of moderate power over longer times. A combination of the two, with the fuel cell charging the storage battery between uses, could capitalize on the strong points of both. It is also characteristic of the fuel cell that when no current is being drawn, it does not expend fuel.

The hydrogen-oxygen fuel cell was the first to be produced and received most of the early research effort. In its basic form as described, it is not too difficult to follow the progress of chemical events. However, even the first successful cells were more sophisticated than our example.

For instance, the gases hydrogen and oxygen do not readily interact at room temperatures. Some cells operate at much higher temperatures (250°F to 500°F) and use chemical catalysts in the electrodes to help the reactions along.

Hydrocarbon Fuels

There are many practical reasons for development to shift now to systems that operate on fuels other than hydrogen. The hydrocarbon fuels seem ideal because of their availability. A cell using fuel oil or natural gas, for example, could be operated almost anyplace in the world without serious problems of transporting of fuel. Methane, gasoline, kerosene and alcohol are among the hydrocarbons being investigated, along with the noncarbons ammonia and hydrazine.

The engineering problems associated with fuels other than hydrogen have placed many barriers in the way of a practical system. The direct conversion of hydrocarbons is particularly difficult. But a compromise is being used — a system now under field test with the Army breaks down hydrocarbon molecules and extracts hydrogen, which can be accepted by the fuel cell. However, the indirect process is not as efficient as direct conversions.

While the complication of manufacture and transportation of pure hydrogen makes other fuels desirable, the availability of pure oxygen also presents problems. Although a ready source of oxygen, air contains some undesirable elements. Current models of hydrocarbon-air fuel cells must process the air before it is used, removing carbon dioxide and stabilizing temperature and humidity.

Hydrocarbon-air systems now being tested include a package of two 35-pound man-carried units producing 500 watts at 32 volts. Another unit with an output of 3 kW can be carried by jeep or small truck.

Applications

The possible applications of the fuel cell are about as varied as the uses of electricity — but can be extended beyond that. The use of a practical and efficient direct energy conversion device as a substitute for heat engines in the generation of electrical power immediately leads to the application of power for electronic equipment. Large scale power generators are also considered. But it is not out of the question to consider this new technique as a substitute for other motive forces. Allis-Chalmers has put fuel cells to work powering a farm tractor, and the Army is now testing a ¾-ton truck powered by a fuel cell package developed by Monsanto Research Corporation. Boats, submarines and many other vehicles will also be the subject of increased research.

Generation of electrical power at home is also being looked at. The development of a power plant operating on natural gas has been launched, with Pratt & Whitney Aircraft carrying out the program. The company also developed the fuel cells to be used on the Apollo spacecraft.

The only moving parts in the fuel cell are found in the gas flow mechanism. As a result, the fuel cell is a very quiet machine — both mechanically and electrically — an ideal advantage to the military. They are capable of resisting a good deal of shock and acceleration, and are affected very little by radiation, all points in favor of space applications. And the water byproduct is actually a plus in manned space travel where astronauts must take with them all food and supplies.

The telecommunications industry is primarily interested in fuel cells to provide power to remote locations. Brown, Boveri and Company, of Switzerland, has been operating a television relay station on fuel cell power for nearly two years.

Operators in this country have yet to put a commercial device to work in such application, but interest in the fuel cell and other direct conversion devices is high. As repeater equipment uses more solid state circuitry, thereby reducing power requirements, this type of power will become more realistic. In the meantime, engineering progress will account for increases in efficiency, reduction in size and weight, and the practicality of using common fuels.

Lenkurt Electric Co., Inc.
San Carlos, California

Lenkurt Hosts International Conference

Representatives of 25 countries participated in the plenary session of the International Telecommunications Union's (ITU) Groupe Autonome Speciale-3 (GAS-3), hosted by Lenkurt in San Francisco. Opening the session, from left, are Jean Rouviere, ITU director, from Geneva; Ben Abdellah, GAS-3 chairman, from Morocco; Gerd Wallenstein, Lenkurt vice president of planning, chairman of GAS-3 economics sub-group, and session coordinator; Charlton W. Hunter, Lenkurt president; and R. Parker Sullivan, president of General Telephone Company of California.

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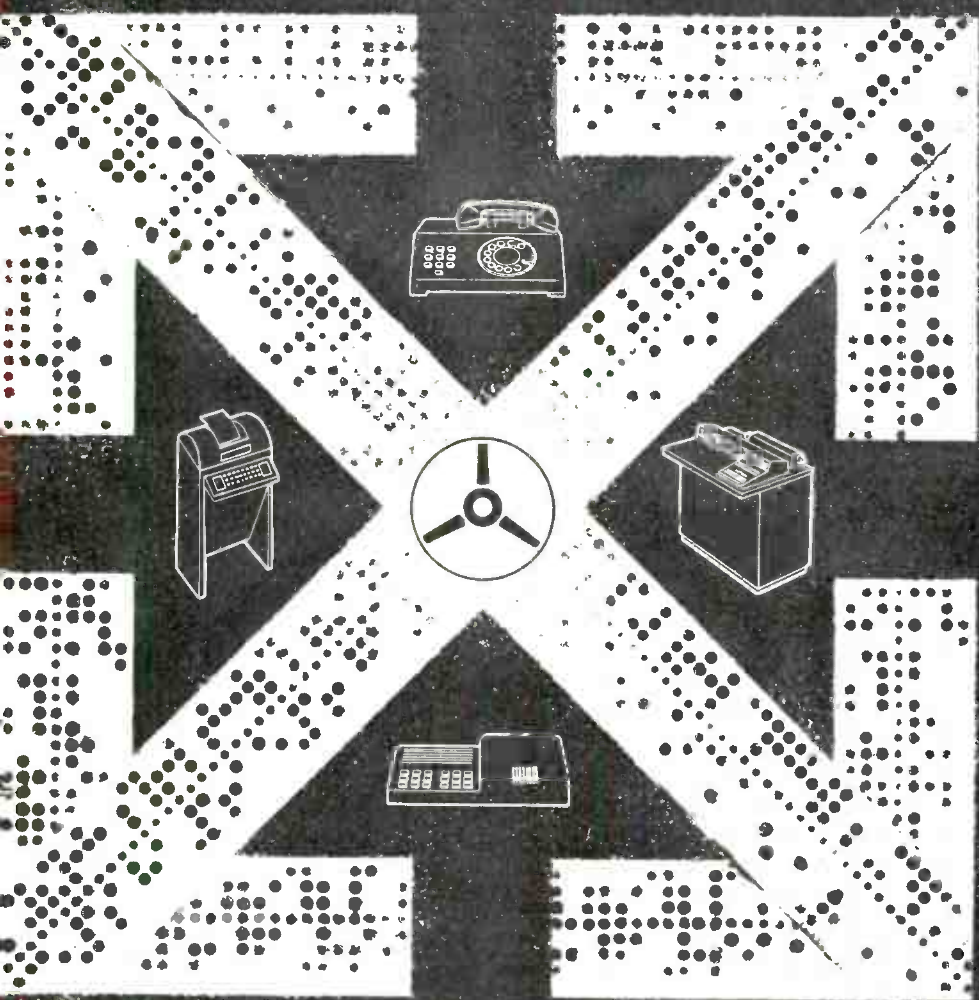
The Lenkurt DEMODULATOR

USES OF LOW SPEED DATA



With the growth of knowledge and the expansion of both business and government has come a need to provide timely and effective communications to widely separated but integrated organizations. The most obvious way to meet this need has been to increase communications speeds and expand the capacities of existing communications systems.

In this article, the Demodulator *explores some of the ways that low speed data transmission is expanding communications capacity.*

Explosions occupy an increasing amount of space in today's literature. Populations are exploding and information, aided and abetted by stories about itself, continues to explode.

At present rates, the volume of information is doubling every five years. A few years ago this took ten years and a century ago the body of knowledge available doubled at the leisurely pace of once every 50 years. Needless to say, the effective dissemination and use of all the facts and fancies coming into circulation today poses a staggering problem.

Perhaps the most promising solution to this problem is data communications—the use of machines and machine languages to transfer information from place to place by electrical means. Although the present tendency is to define telegraph and data communications separately, the two have similar transmission requirements and for the purposes of this discussion will be included under the general heading of data communications.

A typical data communications system consists of an input, modulator, transmission link, demodulator, and data sink. The input can be anything from a highly sophisticated computer to a simple business machine. The data sink might be nothing more than an output device. More often, the data sink is a depository, such as the memory bank of a computer, for the data being communicated.

The modulator and demodulator, often referred to as data sets, interface the input or output equipment with the transmission link. It is the function of the modulator to make input signals suitable for transmission. The demodulator converts the transmitted signals to their original form before sending them to an output device.

Two Categories

By using different combinations of input devices and data sinks, a remarkably comprehensive data communications system can be evolved. In general most systems fall into one of two cate-

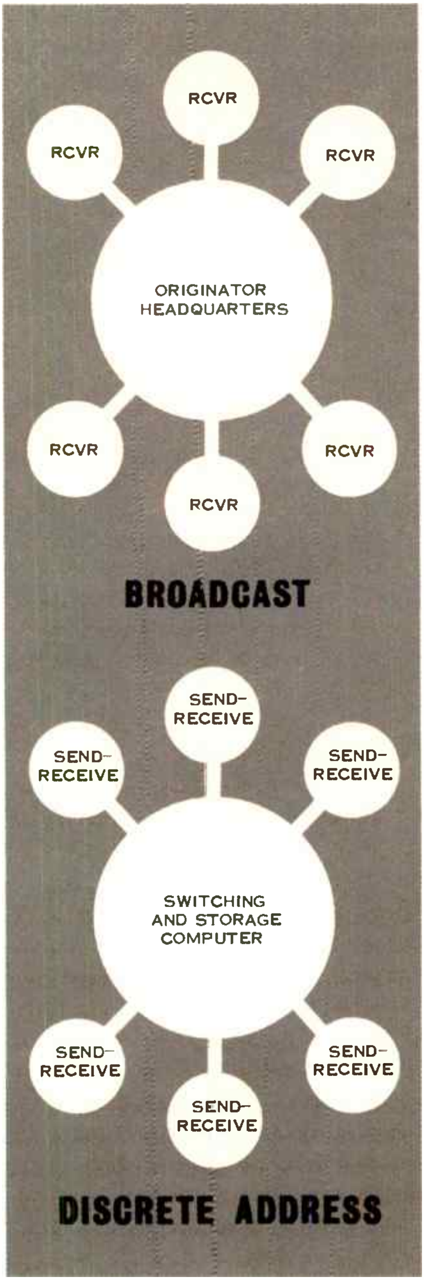


Figure 1. Data communications systems fall into one of two general categories. One is essentially a receive-only system while the other has stations with a send and receive capability.

gories. The simplest employs a number of receive-only terminals connected to a single data source. It is often compared to a radio broadcast. This procedure serves mainly to distribute information which is perishable—information intended to be used only once and then immediately.

Another procedure uses discrete addresses. The majority of the stations in this system have a send as well as a receive capability, although there are monitoring systems with send-only remote terminals which update computer information. Each remote terminal can be called by the use of addresses and any remote terminal can address other terminals in the system. More often than not this configuration uses a data sink to store information for future use.

As might be expected, data communications systems can be flexible enough to integrate both methods in a single system. For example, the broadcast method can be designed so that more than one station on the network can originate traffic to all or some of the subscribers. On the other hand the discrete address method can, by using preassigned address calls, broadcast information to several subscribers simultaneously.

New Economies

Recent changes in communications regulations have made low speed data communications more economical. Many systems use leased line circuits for transmission. These lines have been leased for specific purposes and, in the past, have had to terminate in telephone company interface equipment. Now a new tariff filed with the Federal Communications Commission makes it possible for a customer to install his own data set to interface on certain leased lines.

This change has given users the option of choosing interface equipment

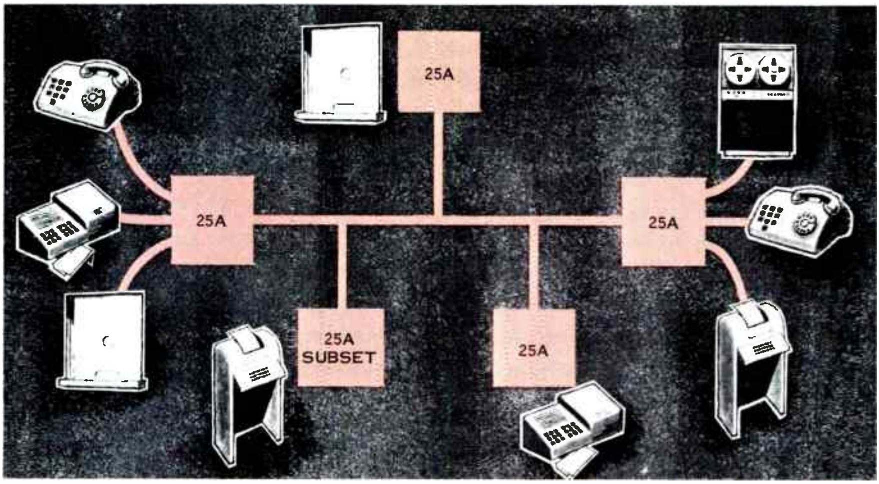


Figure 2. The Lenkurt 25A data transmission system makes it possible to use one voice circuit for a number of data channels. The 25A operates between 75 b/s and 200 b/s with a maximum of 25 channels per voice circuit.

which makes the most efficient use of a leased line. Individual users can now employ equipment which derives a number of channels from a single, leased voice-frequency circuit. From a user standpoint this enables him to satisfy several requirements—depending on the characteristics of his system—with only one voice circuit.

Speed of transmission is one system characteristic which influences the number of channels which can be derived from a single circuit. Direct computer-to-computer operations, for instance, run at extremely high speeds. Computers talking to each other under the most ideal circumstances can exchange bulk information in nanoseconds (a nanosecond is one billionth of a second). But high speed exchange requires wide-band transmission paths which minimize impulse noise and delay distortion. Such considerations raise the cost of leased services.

Lower transmission speeds can use narrower bandwidths and less ideal circuit conditions. Data at rates up to 9600 bits per second has been carried on an equalized voice circuit. With even lower speed input equipment, sharp filtering can split a voice-frequency circuit into a number of separate channels. With the remote ends of each channel serving a different terminal, the over-all traffic volume can be increased without increasing circuit costs.

Increasing Efficiency

Making the most efficient use of data communications is not merely a matter of getting the maximum number of channels on a voice circuit. The computer must be protected against having to wait for all data from one channel before calling for inputs from another channel. With data coming at 200 bits per second or less, for instance, a computer capable of receiving information at 1.5+ million bits per second would be wasting time. On the other hand, allowing only one terminal at a time to have access to a computer would in effect turn a multi-channel voice circuit into a single channel circuit. To avoid such inefficiency each communications channel feeding a computer normally terminates in a buffer unit which uses store and forward techniques to accumulate data from many sources and send it to the computer at higher and more suitable speeds. The buffer acts as an intermediate storage device which compensates for the difference in the rate of flow between input and computer.

The buffer is not an essential component of a data transmission system. With it, however, a large number of remote terminals can communicate with a single computer. The buffer collects incoming data at relatively low bit rates and literally spits groups of bits into the computer in hunks called "bytes".

Accuracy

Of course, moving data at high speeds is of no avail if the material is not received accurately. This is especially critical in a system which passes large amounts of numerical or encoded data. With numbers and random letters an end user has a much more difficult task interpreting garbles than he would if plain language were being received. Obviously, data which goes directly into a computer or other business machine must be essentially error free.

Some sources of error, such as those introduced by malfunctioning equipment or operating personnel, are easily identified and can be corrected—at least temporarily. Others, which also affect the accuracy of a transmission, are not so easily dealt with. These depend on a number of variables including speed of transmission, noise and propagation characteristics.

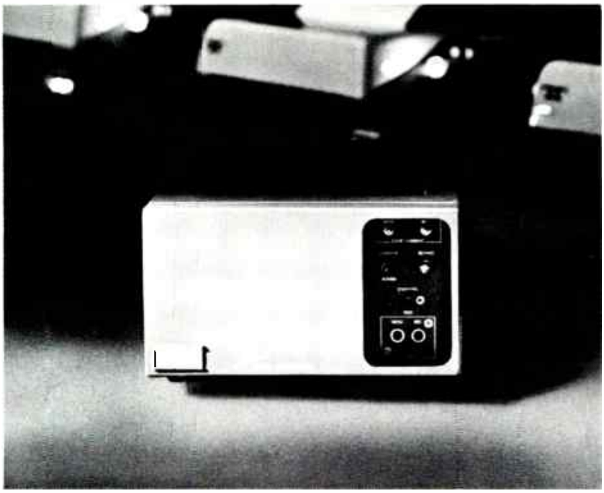
Low speed data transmissions tend to minimize these sources of error because the signals exist longer and can more readily withstand disrupting influences. Although any given system will exhibit its own peculiarities regarding error rates, one test over leased lines found an error rate of from one to eight characters per 100,000 transmitted. At this rate an error occurred as often as every half hour and as infrequently as once every four hours. In terms of a 100 word per minute system, 144,000 characters could be sent between errors.

Nationwide

Both the Associated Press and United Press International are installing Lenkurt 25A data transmission systems to take advantage of the vast voice-frequency network already available in the United States. The 25A can derive as many as 25 channels from one voice circuit. This gives each wire service its own private broadcast network. To provide, say, 20 different news services a wire service only needs one voice circuit. Two channels might carry hard news, another feature stories, a fourth general sports news, and a fifth horse racing news. Other channels might have financial news, state news or special services such as news edited and processed prior to transmission so that a tape received along with the teletypewriter copy can be used to set type. Finally, other channels might be reserved for communications between bureau offices and wire service headquarters.

The ordinary news service subscriber, either with a data subset at his terminal or via local service from a data interface point at the wire service bureau office, receives only the channels contracted for. On the other hand the bureau office, in addition to terminating the desired news channels, can originate news traffic on certain channels. With a channel of its own, a bureau can provide the wire service with fast coverage of local events. For example, a flood story in the Midwest can be sent by the nearest bureau office to the news service head-

Figure 3. Lenkurt 25A data transmission subsets are being used by news service subscribers. Each subset is tuned and set to the channel contracted for by the subscriber.



quarters and to all subscribers on that channel.

Certain designated offices can block local delivery of channels on the backbone trunk. By blocking local delivery a bureau gains a free channel for broadcasting local news to regional subscribers. A bureau in the Southwest, then, can originate its own broadcast of news about the Southwest for local subscribers.

Wall St.

The nationwide brokerage firm of Paine, Webber, Jackson & Curtis is using Lenkurt 25A equipment to connect its 51 offices with a computer in New York City. The resulting data communications system represents a non-broadcast or discrete address network. As with the wire services, voice-frequency circuits serve as the backbone for a system which makes it possible for branch offices to feed data directly to a computer which acts as a message switching system.

Since installing its data communications system, Paine, Webber has more than doubled its communications capacity and has reduced the handling time of an execution order by as much as 20 or 25 minutes. With the new system an order for the New York or American stock exchange travels over one of the 22 two-way teletypewriter channels to the company's computer where it is directed to the correct booth on the exchange floor. The data communications system gives branch offices access to the firm's over-the-counter trading, institutional, bond, research, and underwriting departments. Copies of an order and its execution are also printed in the firm's bookkeeping office to speed billing and crediting customers' accounts. The entire transaction is also recorded on magnetic tape for record-keeping purposes.

Although the system is oriented toward handling orders, conceivably it could be put to such other uses as price quotations, reporting customer accounts or handling other information which is needed on a real time basis. Essentially it is an on-line, real time system. Each remote user is on-line with the computer continuously, guaranteeing an immediate or real time response from the computer. Where data must be processed outside the system, as would be the case on the stock exchange floor, response time will depend on the quickness of floor traders in handling an order.

Near and Far

Banks are making use of low speed, on-line data communications systems to link their branch offices to a central computer containing balance information on all customers' accounts. If a customer wishes to cash a check at the bank, a teller can query the computer on a push button intercom and receive a verbal response from the computer in about 20 seconds. By using a computer the bank has a single information retrieval system for all its branch offices.

A national radio-television network is using an information retrieval system to determine instantly the status of the air time it has for sale. By querying a computer any salesman can find out what air time is available. In addition, the network management has on call an up-to-the-minute report on all time sales. Of course, data communications also provides a means of keeping the computer updated on the status of sales.

Data communications is also helping create firms which offer computer services to a number of subscribers. This timesharing concept gives various unrelated organizations, many of which would not lease their own, a computer 24 hours a day. Each user has his own code, can store information, and can run his own programs. Several colleges offer timeshare services to other colleges and business firms as well as to their own students and faculty. Some companies and computer manufacturers are also sharing computer time with outside users.

Tymshare, Incorporated in California sells time on its computer to users as close as a local phone call and as far away as Colorado and New Mexico. At present all customers—remote and local—have access to the computer through data sets transmitting directly to the computer over ordinary dialed telephone circuits. In the future, however, remote users will be able to communicate with the computer by dialing a local number which interfaces with a leased line. The leased line, terminating in Lenkurt 25A equipment, will serve

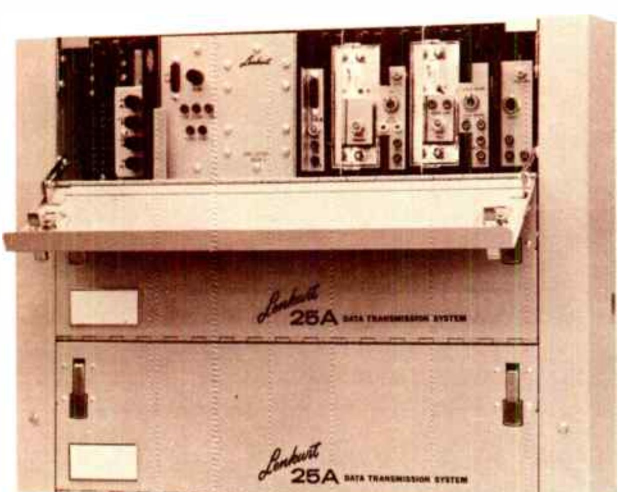


Figure 4. The Lenkurt 25A is an economical, highly reliable data transmission system which uses sharp filtering to transmit up to 50% more information than conventional systems.

as a trunk, able to handle several calls at once. This timesharing application allows users to run engineering and scientific computations or develop programs on a real time, on-line computer. It provides customers with simultaneous access to a computer with a maximum response delay of three seconds.

The Railroads

Railroads, many of which own their own communications networks, are one of the oldest users of data communications. By installing data transmission systems railroads have been able to increase their communications capacity at minimal cost. The increased capacity has in turn made it possible for the railroads to account for every car and train in their system on a real time basis.

Each car is represented by a data card and each train is represented by a stack of these cards—one for each car plus cards for the locomotive and caboose. As a car moves from yard to yard, its card, along with the other cards for cars in the train, is transmitted over data circuits to the next yard. This gives personnel at the next yard timely information for handling the incoming train.

At the same time this information is relayed to a computer to update its record of each shipment in progress. The computer, accessible from many sources by data communications, allows the railroad to make immediate replies to inquiries about a shipment.

Freight offices which book shipments are linked by teletypewriter to the communications system so that a shipping order can be processed immediately. A single message from the freight office provides the accounting department with billing information, the freight department with car requirements and the computer memory with a record of the transaction. From that point on the progress of the shipping order and the subsequent shipment can be recorded by relatively short inputs direct to the computer.

Railroads also use data for administrative traffic and train safety. One line has centralized its payroll accounting by sending timecard information over its communications system directly to a central office. At present the checks are drawn up and mailed back to the station submitting the timecards, although the processed information could be returned on a data circuit and printed directly onto check blanks.

For train safety, railroads are using a specially developed Lenkurt 960A journal data transmission system. This unit converts analog sensor signals received from heat detectors to tones which can be transmitted over standard communications facilities. Overheated journals have been cited as contributing to railroad accidents costing millions of dollars annually. The 960A, linked to a transmission system, is helping to reduce the number of these accidents.

Immediate Response

Airlines use on-line, low speed data communications to handle their passenger reservations, freight operations and aircraft maintenance schedules. During non-peak hours the airlines use the same communications to handle bulk jobs such as payroll and inventory. Pipeline and utility companies have joined their far flung operations with data communications also. The pipeline companies monitor such operational details as flow rate, pump pressure, suction, and fluid viscosity. Utility companies exercise load control by using data communications to connect substations and switching points. In both cases distant operations can be adjusted in response to variations as they occur.

Large business concerns which would not be immediately associated with a need for real time communications are using data communications to enhance

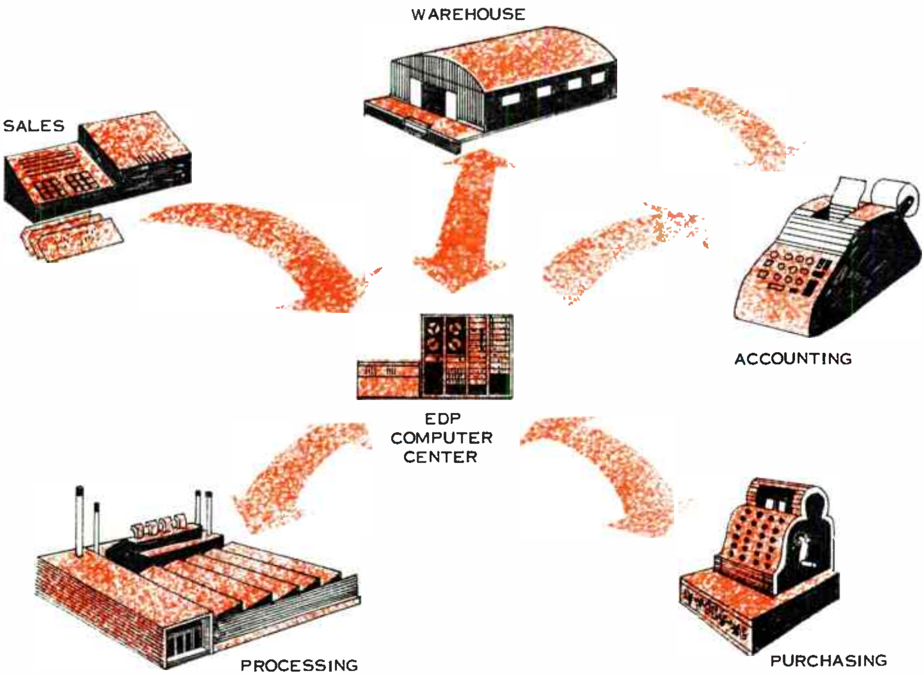


Figure 5. Management information systems can use data communications for their sales offices, manufacturing plants, and planning and support departments.

management information systems. Leased voice-frequency circuits connect central computers with warehouses, sales offices, processing plants, and accounting and purchasing departments.

With such an installation, a salesman booking an order at one of the sales offices sends that order via a data channel to the firm's computer. The computer determines which warehouse is best situated to fill the order and routes it there. At the same time the computer informs accounting that the customer's account should be billed for the item. If necessary and if programmed to do so, the computer will also inform production and purchasing of the order so that these departments can take action. If necessary, the warehouse can update the computer's inventory record.

Orders by data communications gain time—they can be filled within a few hours. Users claim that the time between writing and delivering an order can be less than twenty-four hours.

Supermarket chains with their own warehouses have used this method for restocking and inventory control. A large company which supplies consumer items to gas stations claims that orders placed by mid-afternoon can usually be on their way to the customer the next morning. Even at the slowest transmission rates information gets from place to place much faster than by conventional means. One company found that using data communications to process its daily sales spread the work load evenly over the week. Before switching to a data system, over 40% of its orders arrived on Monday and all orders spent at least two days in the mail.

Data communications can bring widely separated parts of an organization into closer coordination. Within seconds an order can be available at any number of user stations. If a computer is part of the system and is used for record keeping, the order is on file instantaneously. At the same time the computer can perform whatever accounting computations it is programmed to do.

Operating data from outlying points can be made available daily. Management then has timely and accurate information on which to base production schedules and sales promotion plans. Management also has for its immediate use information that can influence the purchase of basic commodities, the location of plants, and the regulation of cash flow.

Such interwoven systems reduce errors and paper work. A shipping invoice on a customer's order need be written only once. After that, all copies are either transmitted directly to users or are on call from a computer memory. In addition, records stored in the computer are updated automatically by direct inputs—no formal reports to be hand delivered by messenger.

More to Come

These examples only touch the more prosaic possibilities of data communications. What lies ahead depends more on man's imagination than on his technology. There has been speculation that houses might have a home learning center connected to a teacher-computer by data links.

A few public utility companies are testing data systems which, by sending information directly to the billing office, could replace meter reading. At the same time these real time readouts could warn a control center of potential system overloads.

A data input device interconnecting retail stores with banks could eliminate money. On payday an employee's bank account would be credited by a deposit from his employer. The employee could draw on that deposit by inserting his personal money-card into a remote data terminal. The remote terminal would transmit information from the money-card, along with the amount required for the transaction, to the bank. The bank in turn would compare that amount with the balance of the account in question and, if there were sufficient funds, okay the transaction and debit the account.

Coming even sooner than the money card scheme is a data communications system to give customers immediate access to hundreds of theater and sporting event tickets. By using a special terminal device in supermarkets and banks a customer can select tickets to a ballet in London, a football game in New York, and a play in Los Angeles within a few seconds. The customer's order is transmitted from the supermarket to a computer which searches for the tickets to the event and in the price range and area desired. When the seats are found, the computer causes the remote terminal to print the tickets for the customer who pays for them at the supermarket .

Data communications is bringing widely spread operations into more immediate contact and in so doing increasing the coordination between separate parts of large organizations. It is also keeping the right people informed in spite of ever increasing amounts of information. Hopefully, it will prove to be an effective solution to the problem of handling the exploding amounts of information becoming available.

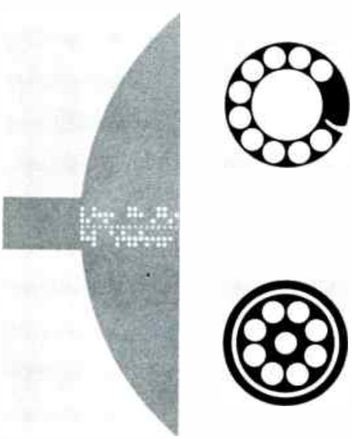
An Invitation . . .

During the year Lenkurt exhibits its diverse product line at over 25 conventions. By participating in these shows Lenkurt has an opportunity to exchange ideas with communicators in many, varied industrial and governmental fields. This fall and through the final quarter of 1967, Lenkurt will have booths at several conventions. You are cordially invited to drop in on us.

Data Systems Division Association of American Railroads	**Houston**	**Sept. 11-13**
Rocky Mountain Independent Telephone Association	**Albuquerque**	**Sept. 11-13**
New England Independent Telephone Association	**Dixville Notch**	**Sept. 10-13**
North Carolina Independent Telephone Association	**Pinehurst**	**Oct. 2-3**
Communications & Signaling Division Association of American Railroads	**Chicago**	**Oct. 8-13**
United States Independent Telephone Association	**Las Vegas**	**Oct. 9-12**
Virginia Independent Telephone Association	**Hot Springs**	**Nov. 12-15**
Fall Joint Computer Conference	**Anaheim**	**Nov. 14-16**
Florida Independent Telephone Association	**Jacksonville**	**Dec. 7-9**

Lenkurt Electric Co., Inc.
San Carlos, California

A WORD ABOUT THE LENKURT DATA FAMILY



Look to the growing Lenkurt Data Family for your data needs. Lenkurt specializes in highly stable, easily maintained and flexible data transmission systems. They are accurate and uncomplicated—and can increase the capacity of almost any communications system. For data on voice circuits, the 25A covers the range up to 200 b/s. Above that range is the 26C, a Duobinary-Datatel™ system capable of 2400 b/s. The 970A handles data on wideband or multiplex systems. Lenkurt's Data Family also includes such specialty items as the 960A journal transmission system for railroad "hot box" detection and a speech plus data panel for speech and data transmission over a single voice circuit. For more information on any or all of these systems write Lenkurt, Dept. B720.

LENKURT ELECTRIC San Carlos, California, U.S.A.
Subsidiary of
GENERAL TELEPHONE & ELECTRONICS

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THE LENKURT DEMODULATOR is a monthly periodical circulated to technicians, engineers, and managers employed by companies or government agencies who *use and operate* communications systems, and to educational institutions. Job title, company affiliation, and nature of business must be indicated on subscription requests. Each issue features an instructive article on a subject dealing with the science of telecommunications. Permission to reprint articles may be obtained by writing THE EDITOR.

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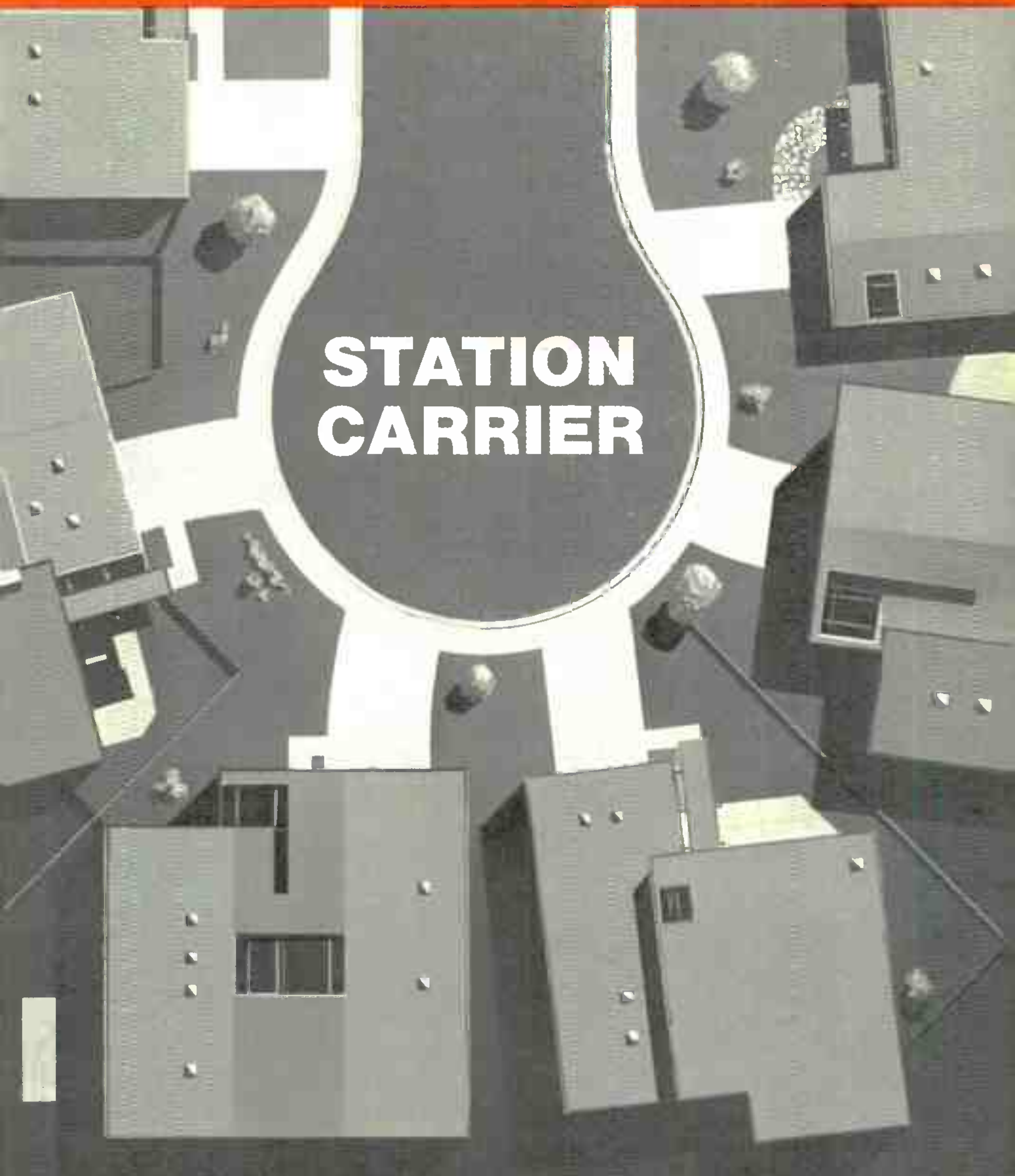
The Lenkurt DEMODULATOR



LENKURT ELECTRIC . . . specialists in VOICE, VIDEO & DATA transmission

The use of carrier equipment has been valuable in medium and long circuits for many years. Now advances in manufacturing make carrier feasible for subscriber loops.

Multiplex technology, which allows transmission of two or more speech signals over the same telephone circuit simultaneously, has been a valuable part of the telephone industry since the early 1900's. The first uses of multiplexing or carrier technique were made in long and medium haul toll circuits where the expense of electronics equipment could be justified.

As electronics manufacturing methods improved—along with advances in circuit design—it became economical to use multiplexing on shorter circuits. Not only did the circuit capacity increase, but circuit quality was also improved. Open wire facilities, previously limited to one conversation, could now carry up to 16 channels; multipair cable was expanded to 24 channels. (For a more detailed review of multiplexing theory and history, see the *Demodulator*, December 1965.)

Gradually multiplexing found its way to the shorter exchange circuits and eventually to subscriber loops. This trend was accentuated with the availability of semiconductor devices—equipment could be made smaller, required less power, and cost less. Today there are basically three types of subscriber carrier systems, each designed to satisfy certain requirements, each offering individual economic advantages.

One class of subscriber or station carrier is generally used for long distances and may carry 20 channels or more. A second type, limited to six channels, serves to expand cable facilities closer to the central office. The third is a single channel system specifically designed to add one additional subscriber to a cable pair easily and cheaply.

Suitable Upgrade

Station carrier first proved suitable for expanding cable and wire routes to rural or sparsely-populated areas. Customers in these locals were accustomed to multiparty service and shared a circuit with perhaps eight neighbors. But in recent years ambitious upgrading programs have begun. Industry-wide objectives are to establish one-party service for all customers within the next decade. However, upgrading service by adding new physical lines to remote areas is not always profitable.

With the introduction of carrier systems such as the Lenkurt XU, it became possible to carry up to 20 voice channels over two cable pairs (one for each direction of transmission). The carrier derived circuits can be used to establish any class of new service or upgrade present customers. Each of the 20 channels can provide 8-party service if necessary.

The XU subscriber carrier system effectively extends the reach of the central office to outlying areas. The subscriber terminal can be placed up to 30 miles from the central office. From this point, subscriber loops with a 1000-ohm loop resistance capability distribute service to a group of customers.

A distinct advantage of the XU type equipment occurs when the area grows to the point of rating its own exchange office. At that time the subscriber carrier system can easily be converted to exchange carrier to provide trunk service between offices.

Carrier equipment of the XU type has been typically used in areas 12 to 14 miles or more from the central office. While prove-in distances can be much less in specific cases, the usual installation serves to extend a number of channels over medium distances.

Recently two new types of carrier systems have been developed for use specifically on exchange loop cable plant. These systems—a multichannel and a single channel version—add versatility and convenience to the station carrier field. Both allow station terminals to be placed anywhere along the cable by regular telephone installers. No adjustments are necessary in the field, and maintenance is limited to the replacement of defective units. The systems are economical for new service or for upgrading programs—and both accept Schedule 4 data.

Economics

Several factors have changed the attitude of exchange plant engineers toward laying out new systems and planning the company's approach to growth areas.

As the economy of the established rural population has changed, demands for service equal to that of urban areas have increased. The migration of urban workers—long accustomed to single or two party service—to rural areas has added pressure for better telephone service. Other factors, such as the need for automatic toll ticketing and the increased cost of copper and labor also

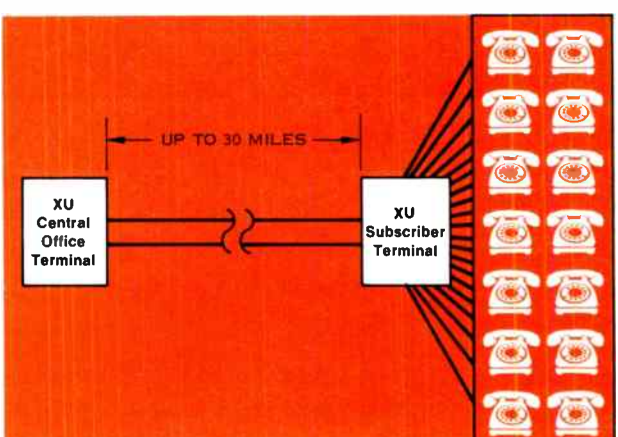
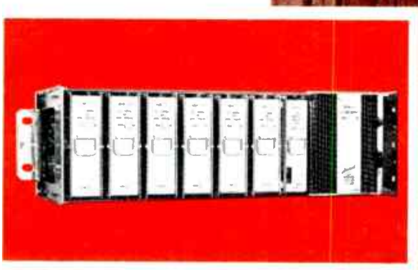


Figure 1. The Lenkurt XU subscriber carrier system expands telephone capability into outlying areas. Subscriber terminal may be up to 30 miles from the central office.



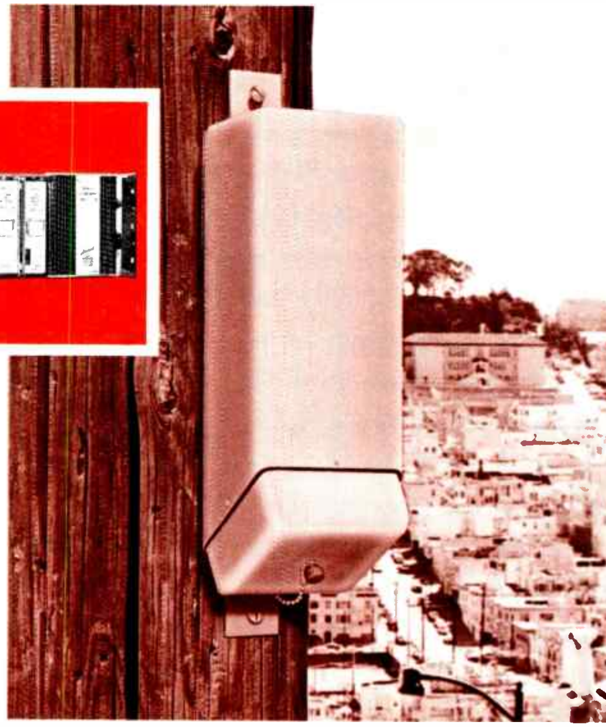


Figure 2. The station terminal in the 82A system, shown here pole mounted, may be placed randomly along the cable. Central office shelf holds six channel units and power supply in standard rack.

influence the decisions of exchange plant engineers.

The general need to upgrade service, obtain cable relief and provide growth margins in new developments has enhanced the advantage of integrating carrier equipment into the exchange loop plant. Station carrier is an obvious answer for upgrading service and providing new service in areas where spare cable pairs do not exist. Additional benefits are realized in the planning of new cable plant.

In a typical exercise to determine cable size for new exchange loop plant, an operating company will first review the expected five year circuit requirements for the area to be served. This figure may be revised to reflect personal experience of local engineers. Based on the results, a cable size is selected. But, since cable is supplied in standard numbers of pairs, it is the usual practice to choose the next larger size cable to ensure adequate facilities. This method usually results in the installation of a cable that is oversized by as much as 50 percent.

If, for example, the cable is actually oversized by 25 percent, it must be accepted that the cost per mile will also be increased by 25 percent. This condition becomes especially critical at longer distances from the central office.

By using a station carrier system, the plant engineer can realistically size his new cable to the nearest *smaller* cable instead of the next larger size. Extra circuits can be added with carrier equipment as actually required—a reduction in both initial cost and annual cost.

Transmission Advantages

Advantages of carrier derived circuits include signal consistency and stability. Long physical circuits generally contribute to increased noise, delay distortion, and degraded frequency response. These are major considerations especially when data is to be transmitted. And each of these parameters varies continuously along the length of the cable.

With a properly engineered carrier system, the quality of the signal should be almost identical at any length. In addition, net loss can be carefully controlled, and environmental conditions will have little effect on the stability of the circuits.

Multichannel station carrier, such as the Lenkurt 82A, provides an economical method of extending the capability of subscriber cable. Operating on a single cable pair, the 82A has six channels, each of which can be utilized for up to 4-party service—a maximum of 24 subscribers on each pair.

Use of multichannel station carrier becomes competitive with wire at about 3 or 4 miles from the central office—up to that point it would usually be less expensive to install new physical plant.

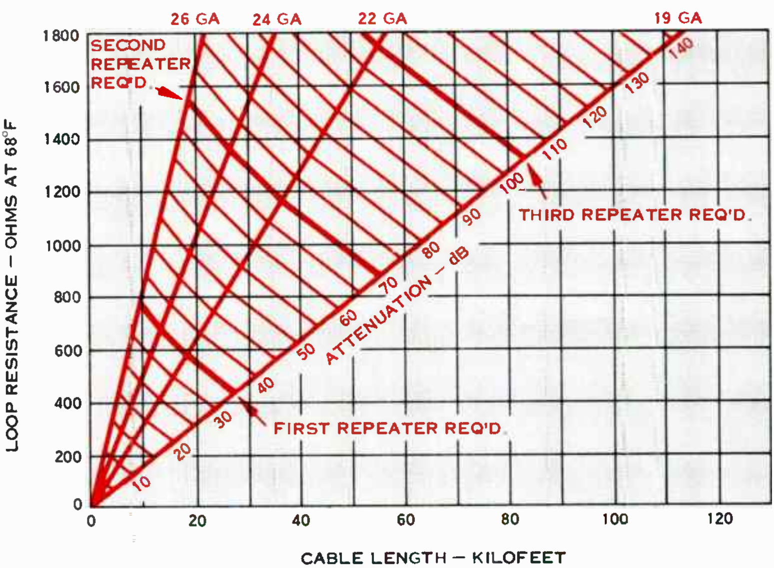
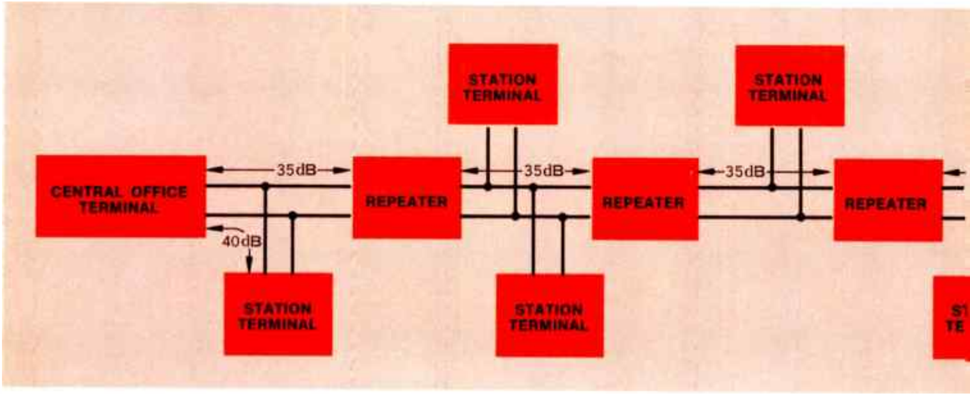


Figure 3. Cable design chart for 82A station carrier indicates repeater spacing requirements for various cable sizes. Also, loop resistance limitation of 1600 ohms sets maximum system length with 260 Vdc repeater power.

Maximum system lengths with all 19 gauge cable is 20 miles, but most applications will be from 3 to 12 miles.

The equipment will operate with any combination of 19, 22, 24, or 26 gauge cable. Without repeaters, the maximum system length is 40 dB, measured at 112 kHz. Up to three repeaters may be added at approximately the 20 to 40 dB loss points along the cable. Repeaters extend the maximum length out to 140 dB.

age the system works satisfactorily with loop resistances up to 1600 ohms. The equipment may also be strapped for 340 Vdc for longer loops, if necessary. For safety reasons, this power is fed to the cable on a balanced arrangement between the tip and ring conductors.



Loop Resistance

The length of subscriber loops on physical circuits is limited by loop resistance, usually set at a maximum of 1200 ohms dc resistance. Beyond this point the signaling on the loop begins to suffer serious degradation.

In the 82A carrier system, repeaters can extend the signal loss limitation, but dc loop resistance remains a factor—all power is fed to the repeaters and subscriber terminals over the cable. Shelf equipment common to the channel units converts the standard —48 Vdc office supply power to 260 Vdc. At this voltage the system works satisfactorily with loop resistances up to 1600 ohms.

Once preliminary engineering is completed and a cable has been designated for carrier use, installation by plant personnel is routine. Subscriber equipment will be installed at the same time as the house instrument, and can be placed at any point along the cable. No adjustments need be made in the field—automatic level controls in the station terminal will compensate for cable loss. A unit that is malfunctioning will simply be replaced by the installer.

Automatic regulation of levels at the station terminal greatly simplifies installation. At the same time this regulation reduces far-end crosstalk between systems by maintaining similar levels for all systems, regardless of channel terminal location. Crosstalk coupling is increased between channels of unequal level.

In operation, all signals leaving the central office are fixed at essentially the same level. When they reach the station terminal, the received level is detected. The signal from the station terminal back to the central office is then automatically preadjusted to compensate for

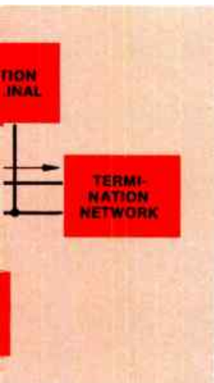


Figure 4. Typical 82A system illustrates maximum attenuation for first terminal and approximate repeater spacing. Automatic level control allows terminal placement anywhere on cable, even immediately next to repeater.

the cable loss. In this way the central office will see the incoming signal from a station unit at the same level, regardless of its distance from the central office. This unique method of regulation would allow the cable to be sampled at any length, revealing the levels at a given carrier frequency on any of the carrier pairs to be the same.

The station terminals and repeaters — identical in appearance — can be mounted on pole (Fig. 2), crossarm, strand or pedestal. They are hermetically sealed at the factory to keep out moisture.

Because repeater and station unit powering is supplied over the cable, voice frequency transmission is no longer possible. It is necessary to remove from the cable all load coils and build-out capacitors, and all bridged taps should be either terminated or removed. In addition, the cable should be properly terminated at the distant end to eliminate reflections.

Transmission from the central office to subscriber is in the frequency range of 72 to 140 kHz. The subscriber to central office transmission is spaced in the 8 to 56 kHz range. Compandors are used in both directions to reduce noise.

Add One

A third type of station carrier system adds one new channel to a cable pair, leaving the existing physical circuit in operation. This system, known as the Lenkurt 83A, is designed primarily for shorter cable lengths than the multichannel system. With prove-in at a little over a mile the 83A is an ideal unit for providing a second private line where service is already established, or for initiating new service near an existing installation.

Simplicity of use and installation, along with an economic advantage over new physical cable, mark the 83A for many applications. It might be used for upgrading from multi-party service, to add new business lines, for PABX extensions, and temporary phone installations.

The 83A also operates on most standard cables provided they are not loaded. The single station terminal may be added at any point on the cable out to the 37 dB loss point measured at 64 kHz. This corresponds to a maximum system length of about 42,000 feet on 19 gauge cable. Cable loss can be calculated from the curves in Fig. 5.

Installation

When calculating the maximum length of a system, certain considerations must be given to losses attributed to bridged taps and drop wires. Bridged

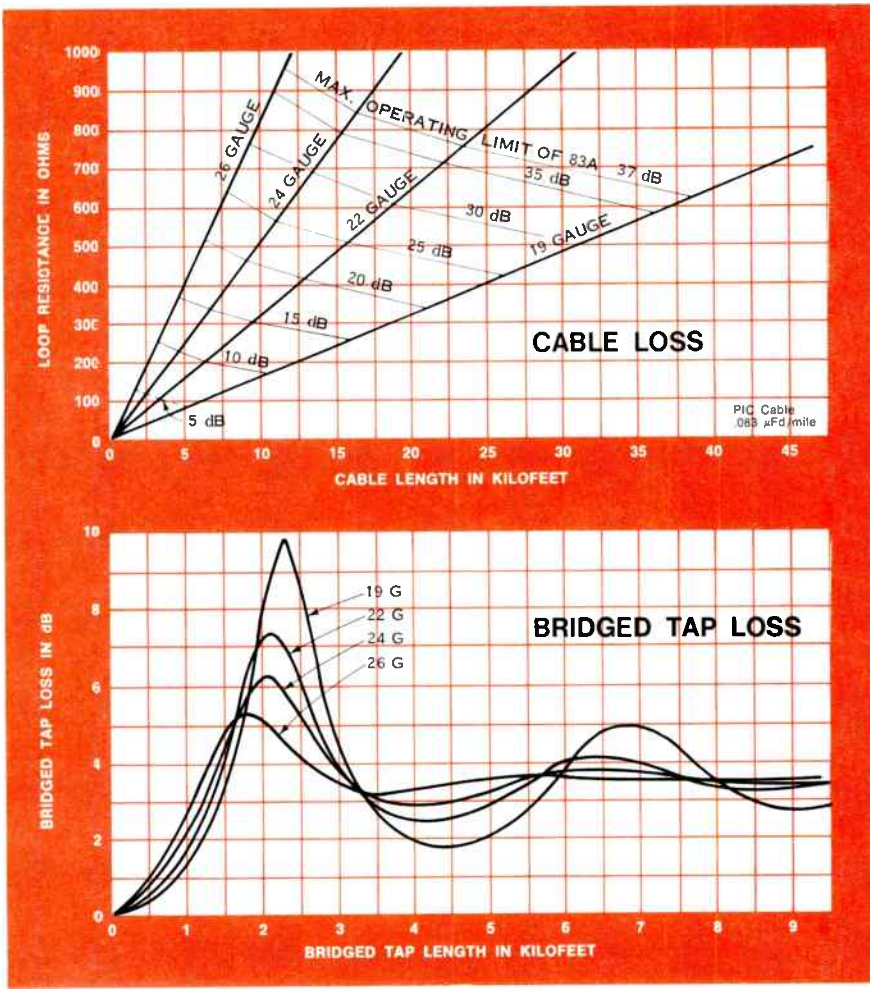


Figure 5. Cable and bridged tap losses must be calculated for 83A station carrier. Drop wire loss, if over 250 feet, must be added to total attenuation.

taps do not have to be terminated. However, they do cause attenuation at carrier frequencies, and must be considered in the maximum loss calculations. Bridged tap losses can be roughly calculated from the curves in Fig. 5. Note that this type of loss is particularly critical if the bridged tap is about 2,000 feet long. In some cases, nearly 10 dB loss is added to the carrier circuit.

Another loss must be calculated if more than 250 feet of drop wire is used. A convenient figure for drop wire loss is 0.3 dB per one hundred feet *in excess* of 250 feet. Drop wire loss in excess of 250 feet and bridged tap loss

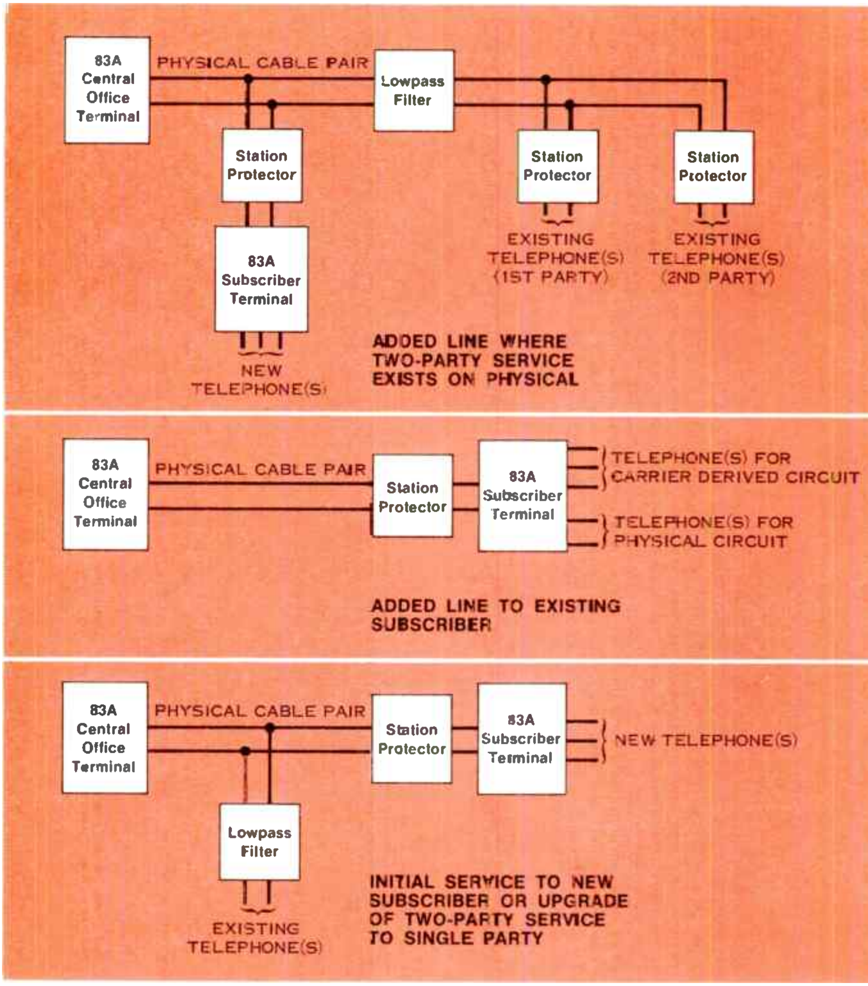
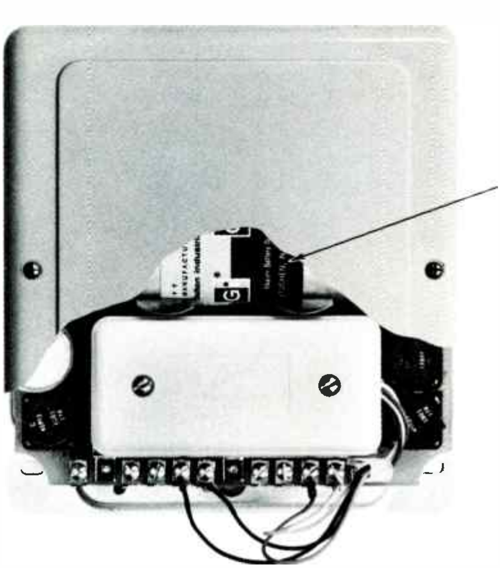


Figure 6. Typical applications of 83A station carrier equipment show the many ways additional service can be added to existing physical circuits.

must be added to cable attenuation loss to calculate the total attenuation of the cable.

Once plant records have been reviewed and cables assigned for carrier use, assignment of 83A to particular cables becomes routine. The engineering department can set an average maximum loop length for each cable, determined from the average pair makeup in the same manner used for "zoning" telephone instruments. Assignment personnel then can easily allocate the 83A terminal anywhere within the area in the same way that regular telephone installations are assigned.



Subscriber Terminal

Power Transformer

Figure 7. Attractive 83A subscriber terminal mounts inside customer's premises. Power transformer attaches to wall outlet.

Power

Station unit installation is relatively simple and straightforward. The station channel unit is mounted inside the customer's premises, probably in an out-of-the-way location such as the garage. Power for the unit comes from a nearby ac wall outlet. A small transformer reduces the voltage to 19 Vac at the plug, and standard inside wire is used to connect to the channel unit.

In the 83A, an optional nickel-cadmium battery is available for protection from commercial power failure and will keep the phone in operation up to 12 hours. Battery protection is particularly advisable if there is no other telephone on the premises. The battery is automatically trickle charged during normal operation.

It would be possible to power the station unit from the central office, but a number of tradeoffs in performance must be accepted.

In such a system, a battery is still necessary at the station unit. When the physical circuit is in use, there simply would not be enough power available on the cable to power the carrier equipment also.

The battery would obviously have to be charged from power taken off the cable—and then only when the physical circuit was not in use. These restrictions dictate that the battery charge rate would have to be set at several times normal, providing a source of maintenance trouble.

Even at this accelerated charge rate, the battery would have about a 1 to 10 work cycle: ten hours of continuous charge would provide stored power for about one hour of conversation.

Ringing would be powered by the battery also, and could become unpredictable at low voltage levels. And ringing itself draws heavily on the battery storage.

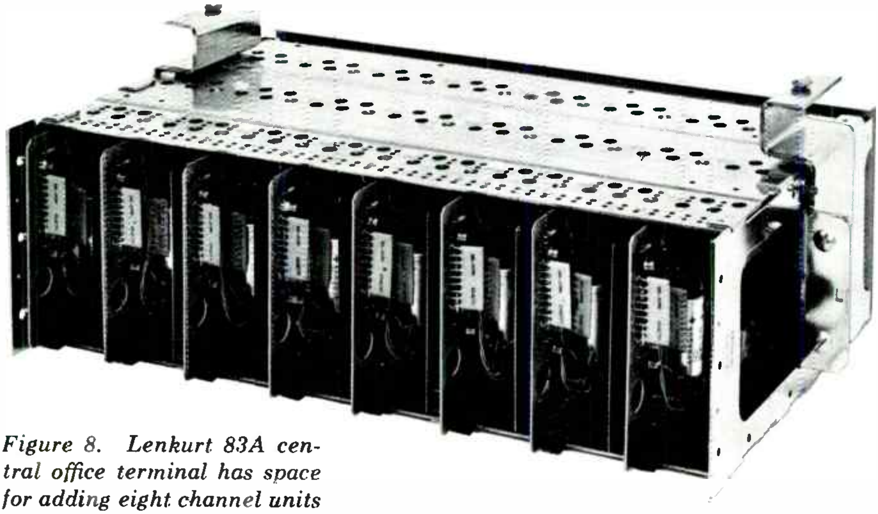


Figure 8. Lenkurt 83A central office terminal has space for adding eight channel units as needed. No common equipment is used.

Maybe a Filter

The only additional equipment to be installed in the field is an external filter, if needed. The filter is normally housed in the same wall box with the channel unit, but some systems necessitate installation on the pole or wall outside the physical drop. The filter's function is to separate the carrier signal from the telephone instrument on the physical pair.

Like the multichannel station carrier, the 83A has automatic level control at the station terminal and requires no adjustment.

The subscriber may have up to three ringing telephone subsets (extensions) operating from the carrier derived circuit. And normal dial or tone signaling will operate with the 83A without modification.

Since the physical circuit is not affected by the addition of carrier equipment, previous party lines or other service continues uninterrupted.

Carrier equipment in the exchange loop plant has added to the alternatives available in solving immediate cable shortages, and ensures more economical planning for future plant expansion. The use of carrier on these relatively short distances has only recently become feasible with advances in solid state electronics and improved manufacturing techniques. Now for the first time, carrier is competing with copper wire down to 1½ miles from the central office. This is a new concept for most plant engineers, and many in the field are not accustomed to some of the unique features of this equipment. But as open wire has given way to cable, it is felt that station carrier will begin to take its place as a standard in exchange loop plant.

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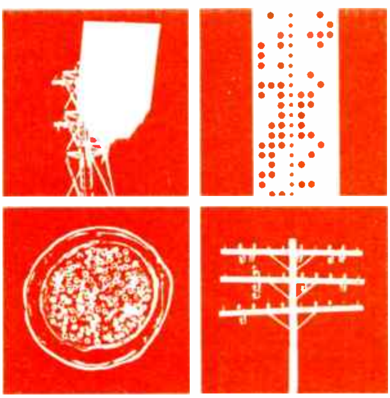

For information and descriptive literature on Lenkurt station carrier equipment or any of our complete line of voice, video or data transmission systems, contact the district sales office near you — or write Lenkurt, Dept. B720.

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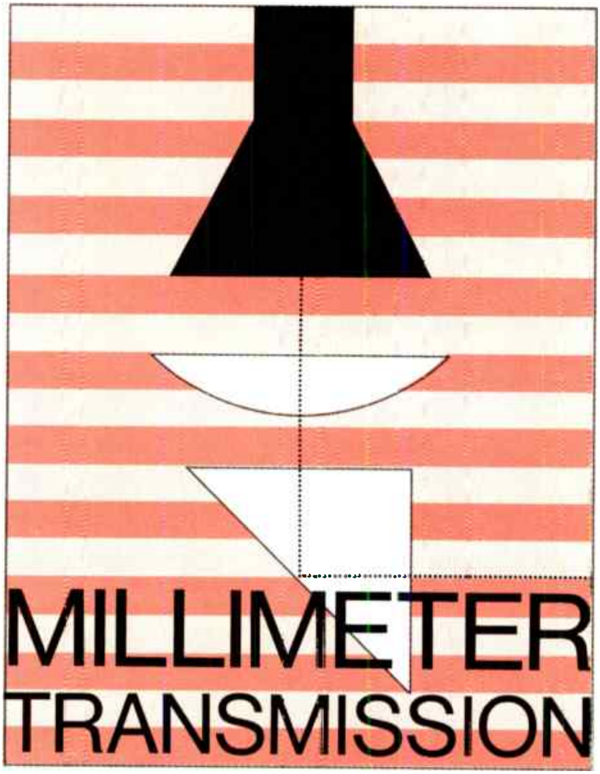

more room for communicators in the frequency spectrum

LENKURT ELECTRIC... specialists in VOICE, VIDEO & DATA transmission

The millimeter band in the electromagnetic spectrum lies in a gap between classical electric waves and optics. Traditionally this band, between the top microwave frequencies at 30 GHz and the bottom infrared at 300 GHz, has belonged to no one.

The physical properties of millimeter waves are such that until recently neither microwave nor optical techniques had been able to use them effectively. In theory the waves can serve several purposes. Their shorter wavelengths are well suited to radiometry, spectrometry, radar, and navigation.

To communicators the millimeter band is more than another source of transmission frequencies. By conventional standards it has about nine times the capacity of all the lower radio frequencies combined.

Broad bandwidth, highly directional antenna beam radiation, and small components are all available in millimeter communications systems. As might be expected these apparent advantages have some inherent difficulties. Physical size and atmospheric attenuation, aside from being valuable in certain applications, are two basic snags in the development of an operational system. Narrow beamwidth which requires precise pointing and, for a mobile system, accurate tracking are also drawbacks.

So far none of these problems has been insurmountable. Millimeter systems have been built and tested satisfactorily. All that remains is that the need for a millimeter system be great enough to support its cost.

From Optics

Because millimeter waves fall in the no man's land between electronics and optics, attempts to develop a satisfactory communications system have drawn on both fields. To date optical techniques have met with the least success.

Most optical approaches use atomic excitation, usually in a gas, to generate high frequencies. Known as the multiple quantum effect, this phenomenon is used to produce the maser or microwave version of the laser.

The phenomenon takes place in a resonant cavity where an external power source "pumps" atoms up to an excited state. When the atoms relax, they emit electromagnetic waves. In one experiment hydrogen cyanide produced a frequency of 105 GHz.

Unfortunately, the high frequency waves emitted have extremely low energy. The result is that effective generation by direct quantum mechanisms is not promising for communications applications.

Other efforts at generation include mixing coherent signals from two powerful lasers. Two lasers mixed in an element such as quartz or a potassium dihydrogen phosphate (KDP) crystal could theoretically produce millimeter waves.

Electronics

In spite of the ingenious approaches taken so far, adequate energy has yet to be developed using optical techniques. Electronic devices, in spite of obstacles, have brought more success.

Size is the major obstacle to electronic generation of millimeter waves. The usual method for generating power at radio wavelengths has been with tube type, free electron devices. But the free electron principle is directly linked to wavelength.

As the wavelength of a signal becomes smaller, a phenomenon known as the *transit time effect* seriously hampers the performance of a free electron tube. (Transit time refers to the time it takes an electron to travel from the tube's cathode to its plate.)

At short wavelengths the ac component of the voltage applied to the control grid reverses before an electron can transit the gap between plates. As a result, electrons cannot follow signal variations precisely. This causes losses in the oscillator which become excessive as the frequency increases and the wavelength shortens.

Fortunately the klystron tube was developed which overcame transit time limitations at microwave frequencies. The klystron produced continuous wave (cw) oscillations, but required small, resonant cavities at dimensions near the wavelength.

In the even smaller cavities required to produce millimeter waves a large amount of input power is lost as heat rather than converted to wave energy. This inefficiency could be accepted if the input power and the resulting output power were increased. But the small cavity does not dissipate heat fast enough to accommodate a larger input.

The klystron tubes which do operate in the low millimeter range are expensive. They have lifetimes limited to a few thousand hours and require high voltages.

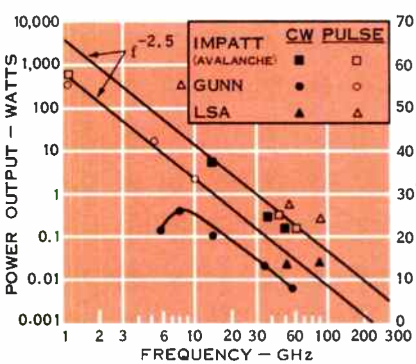

Figure 1. Maximum power produced by three solid-state devices. Note that the maximum pulsed power of the IMPATT avalanche type diode and Gunn diode decreases as frequency increases in the proportion $f^{-2.5}$.

Some electronic devices such as periodic beam devices have been able to produce relatively high outputs in the millimeter range. One such device has delivered 1 mW at 300 GHz. Similar devices have had outputs of one watt at frequencies ranging from 80 to 140 GHz but at efficiencies of 2 per cent.

Another Way

As an alternative, semiconductor devices have also been tried. They have the advantage of requiring less input power. But they still do not produce sufficient output power at high frequencies.

The frequency of most solid-state devices depends on the time it takes a space-charge (an electrical charge in space between the electrodes of a transistor or the plates of a tube) to travel through the device—the transit time. The smaller the transit time, the higher the frequency.

At General Telephone and Electronics Laboratories tests have been run using the thermoelectric effect of heated carriers in bulk semiconductors. Using this method General Telephone and Electronics Laboratories has been able to produce a pulsed output of 5 mW at 210 GHz. Generation took place in a frequency tripler. As might be expected the efficiency was quite low and, of course, the pulsed power output was not suitable to communications.

Until recently the two most promising solid-state devices were the avalanche-transit time diode and the Gunn effect diode. Both diodes have produced relatively high power and frequency outputs.

The avalanche diode uses an inductive cavity tuned to the diode capacity to build up oscillations. In the Gunn effect diode an electric field is applied across a crystal of gallium arsenide. The period of oscillation in the Gunn diode is roughly equal to the time it takes an electron to travel from one end of the crystal to the other at the voltages applied. Both diodes are transit time devices.

To attain higher frequencies in solid-state devices, therefore, it was necessary to shorten the transit time between electrodes. This meant shrinking the so called active region. The smaller active region, unfortunately, made transistors inefficient thereby limiting the output power.

The LSA

A new mode of oscillation, the "limited space-charge accumulation" (LSA), has been discovered which does not depend on transit times. The new mode makes possible high frequency, solid-state oscillators with useful power outputs. It is not susceptible to decreased powers at millimeter wave frequencies—the problem that had dogged every other attempt at generating short wavelengths.

LSA diodes, developed at the Bell Telephone Laboratories, have attained a continuous wave power output of 20 milliwatts at 88 GHz. This is reported to be the highest frequency recorded for a continuous wave, solid-state oscillator. LSA diodes operating at lower frequencies have produced correspondingly higher outputs.

In the LSA diode oscillator no space-charge is allowed to accumulate. As a result transit time does not play an important part in the oscillator's functioning, and physical size is not as critical as it is in other devices. The LSA diode, therefore, can be made thick enough to withstand relatively high applied voltages.

For LSA oscillation the diode functions as part of a resonant circuit which is tuned to the desired operating frequency. Both the diode and the resonant circuit must be properly designed and matched. Since the frequency is determined primarily by this circuit, the power is for all practical purposes independent of frequency.

LSA diodes have operated continuously for over four months in the solid-state repeater of an experimental millimeter communications system. The diodes are being tested as replacements for klystron tube oscillators which require high voltages from large regulated power supplies.

The operating life of LSA diodes is expected to be comparable to that of transistors and much greater than that of tubes which operate in the same frequency range.

Limited Successes

Most earlier millimeter transmission systems did not generate their waves directly. An experiment at TRW Systems used a 70 GHz klystron source and har-

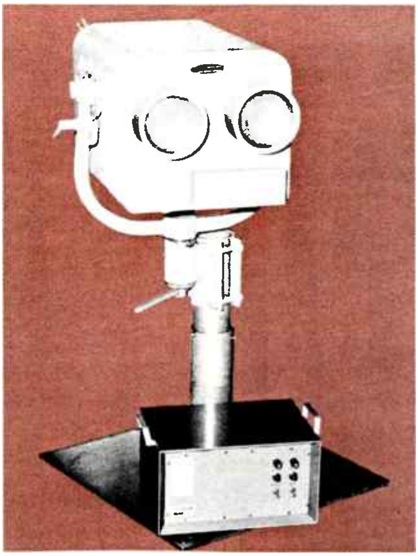

Figure 2. Sylvania Electronics System's solid-state millimeter transceiver mounts on pedestal or tripod. At the bottom of the pedestal is the power supply.

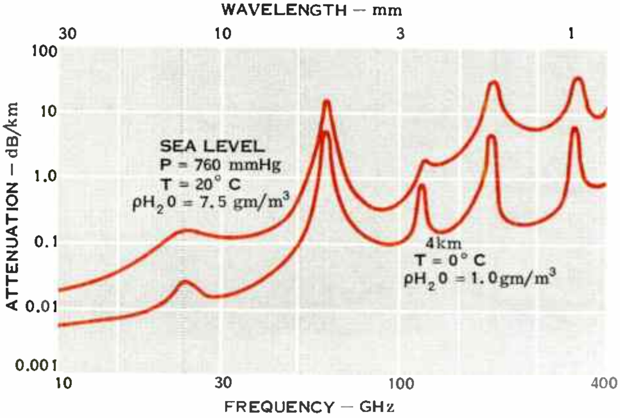

Figure 3. Attenuation of high frequencies at different altitudes is affected by oxygen and water vapor. P indicates barometric pressure, T atmospheric temperature and ρH_2O is water vapor density.

monic generation to reach 140 GHz. Another experiment at General Telephone and Electronics Laboratories operated a 90 GHz system across a distance of 1.2 miles with a high degree of reliability.

Sylvania Electronics Systems has developed a solid-state millimeter system which uses harmonic generation to reach 36-38 GHz. The transmitter uses a semiconductor amplifier and multiplier circuits to increase a low-frequency, crystal generated signal to a high frequency output. It is a frequency modulation system capable of 100 milliwatt output power.

The transmitter and superheterodyne receiver employ an identical horn and lens combination antenna. The surprising feature of the system is that it has a communications range of several miles through the atmosphere. Prior to the development of the Sylvania system, atmospheric propagation under anything less than ideal conditions was considered extremely tenuous.

In the Air

Changes in atmospheric temperature and pressure can have a critical effect on propagation. These two meteorological properties along with the oxygen and water vapor content of the atmosphere determine its dielectric constant and therefore its radio refractive index.

The refractive index indicates the speed at which a radio wave travels through a medium. In the atmosphere a change in the index of refraction can cause significant fluctuations in the angle of arrival of a signal at the receiver. In fact, a variation across the signal path can bend a signal enough to cause it to miss the receiver antenna. A change can also partially destroy a signal's coherence, making it unusable at the receiver. For a millimeter wave with its narrow beamwidth a variation in the index of refraction can be especially critical.

In general, atmospheric attenuation due to the molecular absorption of oxygen and water vapor easily disrupts millimeter waves. Fortunately, atmospheric attenuation is not constant for all wavelengths.

"Windows", as they are called, are spread across the millimeter band between oxygen and water vapor absorption lines. These windows are actually areas in the frequency spectrum which have relatively low attenuation. Fig. 3 shows where they occur in the millimeter band.

To complicate matters further the effects of scattering from water droplets are superimposed on atmospheric absorption. Here the ratio of particle size to wavelength is critical in determining the amount of energy scattered. If the scattering particles approach the size of the wavelength, near total extinction can result. Thus, it is important to consider the size of atmospheric particles in relation to the size of a wavelength.

Judged by typical particle sizes microwaves are relatively immune to rain, millimeter waves to fog, and infrared waves to haze. Obviously, atmospheric propagation in the millimeter band will be best in a hot, dry climate. Poor propagation would seem certain in wet weather, although Sylvania found that a moderate rainfall (2.5 mm/hr) had little effect on its millimeter system.

At rainfalls of 5 mm/hr and 12.5 mm/hr the range of the system did drop as low as 8.9 and 4.7 nautical miles respectively. Of course, dust and dirt could have the same effect as rain particles on these delicate waves.

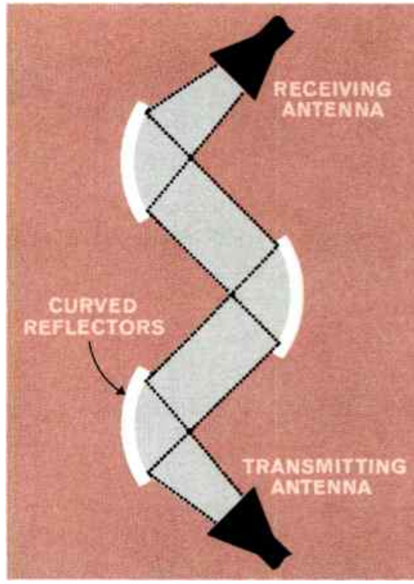

Figure 4. Reflecting beam waveguides use optical techniques to reflect millimeter wave energy along a path. Reflectors are usually curved to focus energy and reduce spreading losses.

Protection

Waveguides, on the other hand, are immune to the buffeting of the open atmosphere. They can provide a closed, controlled system which is well suited to millimeter transmission.

Waveguides do have drawbacks. They become less efficient as they are made smaller—a problem not unlike that encountered in generation.

Transmission losses increase at smaller wavelengths because currents crowd toward the surface of the guide. This phenomenon, known as the skin effect, increases resistance as the frequency becomes higher. The skin effect can be reduced by using circular waveguides with low transmission losses. Theoretically circular waveguides have an energy propagation mode with an electric field of zero along the inner wall of the waveguide. This zero electric field means low wall currents and low losses.

The circular waveguide transmits ever-increasing frequencies in the circular electric mode with ever-decreasing attenuation. Unfortunately, an extensive waveguide system is expensive. Its eventual use depends on the demand for broader communications channels.

More Optics

Other forms of guided transmission use such optical techniques as lenses, mirrors, and beam splitters. Curved mirrors form a reflective beam waveguide. In it a beam of millimeter wave energy travels from one mirror to another along a zig-zag path.

The mirrors are curved in order to focus the energy of the beam or otherwise collimate it to reduce spreading losses. Mirror size and materials must be carefully chosen to keep diffraction and surface losses low.

Beam waveguides using glass lenses to keep the beam tightly collimated suffer from losses on the order of 1-3 dB per lens. Gas lenses have much lower losses. They depend on a temperature gradient through the gas caused by heating the waveguide pipe.

The temperature difference across the gas causes a variation in the index of refraction. The gas, because of its index of refraction, forces the millimeter beam to remain in the tube's center (or just below the center where the coolest area of the gas settles because of convection). It actually focuses the beam.

Using heated gas in a long waveguide is unwieldy. In order to maintain the desired index of refraction, it is necessary to maintain the same temperature and pressure along the entire waveguide. This is not easily done over a long distance.

Detection

Detection does not run into as many problems as do transmission and propagation. Superheterodyne detection will work. The superheterodyne method mixes the incoming signal with one generated by a local oscillator to produce a usable signal. This new signal, the difference between the original two, is low enough in frequency to be applied and detected by available devices.

Any method of detection must take into consideration the angular tolerances of the narrow, millimeter wave beams. These tolerances are extremely small, imposing strict demands on the angle of arrival of a signal.

If a millimeter system is used on a moving vehicle such as a satellite or aircraft, precise position information is required. For heterodyne detection the vehicle's velocity must be known in order to compensate for Doppler frequency shifts. Moving vehicles must be tracked in angle and velocity—a function not normally associated with communications.

Useful

The broad bandwidth found in the millimeter region could accommodate high data rates easily. It appears to be ideally suited for machine-to-machine communications, especially for high speed computers. Photo transmission from space probes could be increased considerably if millimeter wave transmission were available.

In terms of equipment the millimeter band affords new possibilities for compactness. Because the size of component parts normally varies inversely with frequency, those in a millimeter system should be smaller and lighter than those used in a lower frequency system.

The beam emitted is highly directional. This, plus a high attenuation rate in the atmosphere, gives millimeter waves built-in security—of particular value to the military. On the other hand the negligible amount of attenuation in space and the expected size of equipment makes millimeter waves promising in this area.

Commercially millimeter transmission systems will help keep pace with the expanding need for wideband communications.

At present the millimeter band is waiting to be used. Technology exists which can put at least part of the band to work. But economic considerations measured against need are the most influential factors slowing its extensive use. No doubt as demands on the frequency spectrum become greater, the millimeter band will come into its own.

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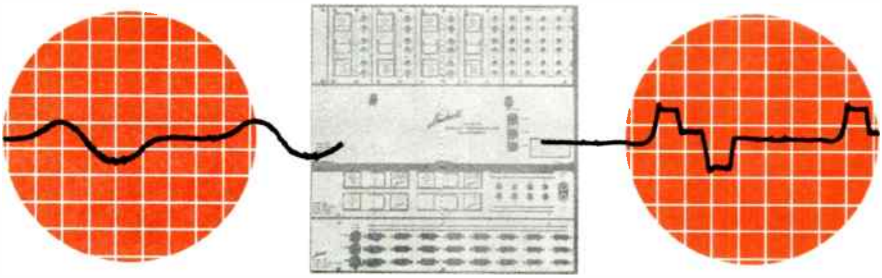

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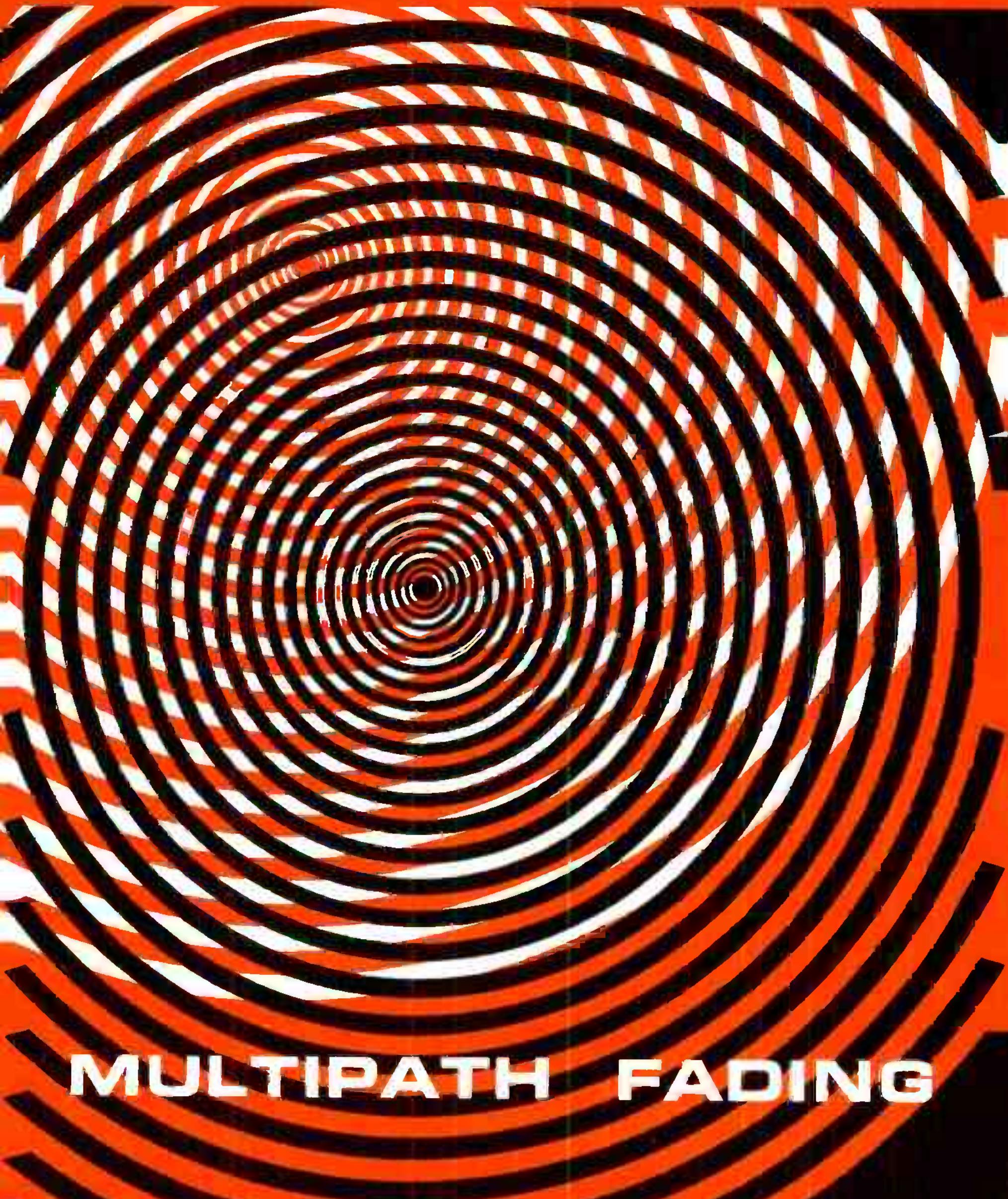


MULTIPATH FADING

. . . . wave interference caused by atmospheric discontinuities means trouble for space waves.

Electromagnetic wave propagation depends on a number of varying factors. Each of these factors can cause radical changes in the reception of a radio signal.

The sun, the earth's terrain, the weather all work their peculiar influences. The sun, for instance, has a direct effect on the ion concentration of the ionosphere. The ionosphere in turn refracts radio waves.

How a particular signal is affected by sun, terrain or weather depends on its path through the atmosphere. Three such paths have been identified and designated as sky, ground and space waves.

Ground waves, as the name implies, hug the ground. Sky waves travel to the upper atmosphere where the ionosphere refracts them back to earth. Space waves propagate through the atmosphere just above the ground. They usually travel in straight lines.

At any given frequency only one or at most two of these waves are useful. The others are either attenuated or lost when they are not bent back to earth.

Point-to-point microwave systems rely on space wave propagation. As space waves they are supposed to follow straight lines. Occasionally, however, they do not because as electromagnetic waves they are susceptible to atmospheric bending from diffraction, reflection and refraction.

The Bends

A diffracted wave bends around corners because the edges of the wave tend to fill the areas masked by obstacles. A reflected wave bends because it encounters a reflecting medium. A refracted wave bends because its speed changes. Of the three, reflection and refraction pose the biggest problems in microwave transmission.

Radio waves can be reflected from a smooth surface just as light can. The amount of reflection depends on the angle of incidence or the approach angle and the reflective quality of the material doing the reflecting. At low angle reflection the wave undergoes a 180° phase shift.

Figure 1 shows an electromagnetic wave at the point of reflection. If there had not been an obstruction, the wave front would have continued to a'b. The reflecting surface caused a change of direction which resulted in the wave front acb. As the wave front continues

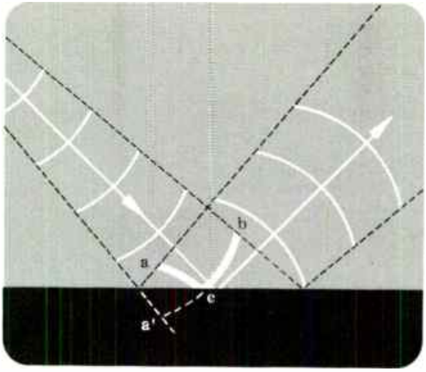


Figure 1. An electromagnetic wave undergoes a change of direction and usually a change of phase at reflection.

to arrive at the reflecting surface, it is redirected and its phase shifted 180°.

The third type of wave bending, refraction, is the least predictable. It is directly related to the condition of the atmosphere and as such also has some influence on the reflection of a radio wave.

Density changes which affect the speed of an electromagnetic wave cause refraction. To describe this effect an index of refraction—the ratio of the speed of light in a vacuum to the speed of light in another medium—was conceived.

The index was originally developed to analyze light rays, but because both light and radio waves are electromagnetic, the principle applies to radio waves as well. The speed of light, or for the purposes of this discussion the speed of a radio wave, decreases as the density of the medium of propagation increases. This relationship of density and speed is an important one.

As a radio wave moves obliquely between two differing densities (Figure 2), its change in speed alters its direction. If the wave enters a more dense area, the forward part of the wavefront slows, causing it to lag behind its upper portion. This uneven increase in speed across the wavefront forces the wave to pivot around its slower end just as a marching line of soldiers does when turning.

Atmospheric Alterations

If there were no atmosphere—therefore no density changes—a radiated signal would proceed in a straight line.

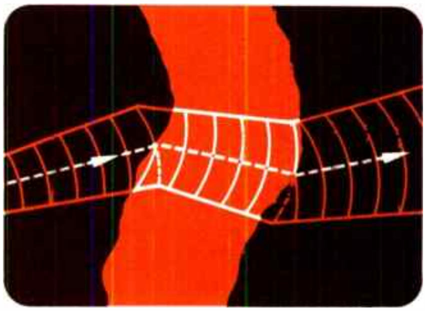


Figure 2. An electromagnetic wave is refracted when it encounters a medium of different density. The resulting speed change usually causes a change in direction.

But there is an atmosphere which can refract waves and therefore alter their relationship with the earth.

A single microwave beam, for instance, might follow a number of available paths. One might bring it down to the earth, another bend it away, or still another might lead it in a curve roughly equivalent to the curvature of the earth.

In a standard atmosphere where density decreases with height, the prevailing tendency of a space wave is to curve but at a slightly slower rate than the curvature of the earth. Unfortunately, the atmosphere does not always conform to a standard density pattern.

Figure 3 illustrates various atmospheric profiles each of which will change the propagation path of a space wave. The graphs use a modified refractive index, M, defined in units which relate the curvature of a microwave beam to the curvature of the earth. The value of M at a given altitude depends not only on the index of refraction at that altitude but also on the ratio of that altitude to the radius of the earth.

Figure 3A shows a slope which is standard for most of the earth. When the slope of the M curve is greater than normal but not negative, the tropospheric condition is known as superstandard (earth flattening), hence the radio horizon distance is increased. When the slope of the M curve is less than normal, the tropospheric condition is known as substandard (earth bulging).

Figures 3B and 3C show two profiles which indicate an atmospheric inversion. In both cases a space wave signal will be trapped at the elbow of the curve. This produces a condition known as ducting which can confine a signal to one height. When this happens, a signal caught in an unfavorably located duct can be at least partially blocked. An unfavorably located duct is one not at the same height as the receiving antenna.

K and the Earth

The need to correlate the conditions of the atmosphere and the curvature of a radio signal has led to the definition of an equivalent earth radius factor K. This factor compensates for apparent variations in the curvature of the earth caused when an electromagnetic wave bends. In effect the earth is flattened, bulged or depressed by the condition of the earth's atmosphere.

In a standard atmosphere K equals 4/3 of the curvature of the earth. With a standard atmosphere the earth does not fall away from a microwave beam in as short a distance as would be expected. The beam has a curvature less than that of the earth.

The earth appears to become increasingly flat as the value of K increases. When K equals infinity the earth ap-

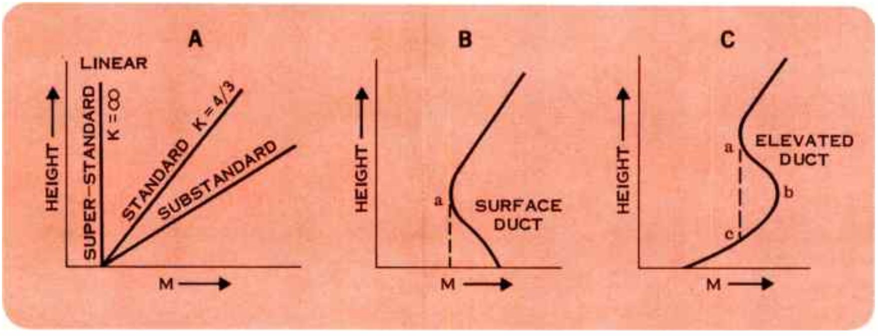


Figure 3. Typical M profiles showing atmospheric conditions. Profiles B and C indicate an inversion which can cause ducting. Each profile has associated with it different propagation characteristics.

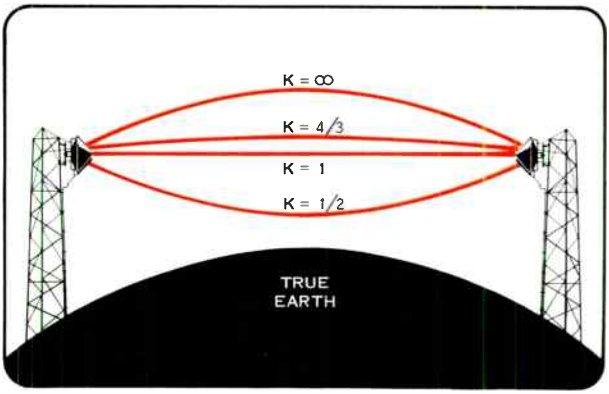


Figure 4. The equivalent earth radius factor K shows the path of a microwave beam relative to the surface of the earth. (For the purpose of illustrating this, the earth's curvature is exaggerated.)

pears to a microwave beam to be perfectly flat. In effect, when K is at infinity, the microwave beam curves at exactly the same rate as the earth.

If the value of K becomes less than one, the curvature of the beam becomes negative. The beam itself curves in a direction opposite to that of the earth. To the beam the earth appears to bulge. The effect of bulging is to put obstacles in the way of the transmission path.

The earth's actual surface also has an influence on the atmosphere. Over certain kinds of terrain the influence is negligible but over others it is especially significant.

The atmosphere over flat lands or water, for instance, is subject to temperature inversions which can cause ducting. Atmospheric turbulence in mountainous areas causes mixing which aids space wave transmission.

The earth's terrain also affects the propagation of microwaves by causing or preventing reflections. Reflections from a rough surface are usually no problem because the incident and reflective angles are quite random. A relatively smooth surface, however, can reflect signals toward the receiving antenna.

Transmission Paths

Both reflection and refraction occasionally complicate transmission paths. In itself this is not a problem. The problem arises because a radio signal is not the neat little beam depicted in most diagrams. In reality radio signals spread as they advance, becoming not just one beam but, theoretically, an infinite number of them (Figure 5).

Each component of the wave, traveling its own unique path, is subject to different reflections and refractions. Some components do not reach the receiving antenna at all. Of those that do, there can be both principal and secondary wave components.

One convenient definition of these components hinges on the paths they follow. The principal component is the direct or unobstructed component and any reflected component of the wave. Secondary components are those which travel multiple paths through the atmosphere.

At any instant the signal strength at the receiving antenna is the vector sum of its components. Combinations of the principal and secondary components produce phase interference—one cause of multipath fading.

Two components of a wave can cause a 6 dB increase in signal strength or a complete null. The degree and character of interference depends on the amplitude and phase difference of the two components.

The exact nature of a cancellation or reinforcement varies with the circumstances. Components 180° out of phase experience a degree of cancellation directly related to amplitude. On the other hand components of the same amplitude experience a degree of interference dependent on phase differences.

There are examples of multipath fading which appear to be the result of more than two interfering waves. Investigations have led to the assumption that very deep multipath fading often results from the coincident arrival of a signal weakened by its reflected component and a secondary wave.

Solutions

Although multipath fading is quite random, there are ways to compensate for it. The least subtle and most obvious solution is to provide extra signal strength—increased by an amount known as the fade margin. This has the effect of increasing the amount of fading a signal can withstand before it becomes unusable.

A fade margin figure for a typical 6-GHz path is 30-40 dB. When the signal path is over a good reflecting surface such as water, additional fade margin must normally be provided.

Fade margin can be obtained in four ways. The first is to increase antenna gain by making the antenna larger. The second is to reduce the distance between antennas. The third and fourth are either to increase the transmitter power output or decrease the receiver noise figure. The effects of these adjustments vary widely and are often limited by expense or location.

Another solution to multipath fading is the use of diversity systems. Three methods have been tested and two are known to have been put into practical operation on microwave systems. Both frequency diversity and space diversity can reduce the amount of outage time due to deep multipath fading on most microwave systems.

The third method is polarization diversity. It requires two synchronized radios transmitting the same information on the same frequency but at different polarizations. The method has been useful in lower frequency radio systems using sky waves, but with space waves both polarizations have been found to fade simultaneously.

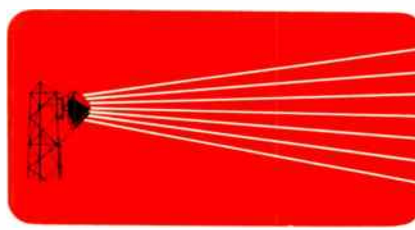


Figure 5. Radio signals spread as they travel through the atmosphere. In effect the signal becomes many beams each subject to the atmosphere's influence.

Frequency Diversity

Frequency diversity systems require at least two separate transmitters and two receivers operating on different frequencies. Normally it is not necessary to have a separate antenna for each transmitter and receiver. The receivers are connected to a diversity combiner which adds the two received signals to form a usable, combined output.

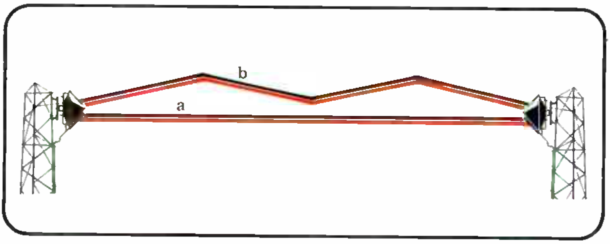


Figure 6. With frequency diversity two wavelengths travel the same refracted path (b) but will not have the same interfering effect on the direct wave (a).

Most frequency diversity systems have frequency separations of 2-5 percent of the lower frequency. This separation keeps the frequencies within the same band. Some systems use frequencies from two microwave bands, for example 6 and 12 GHz, thereby obtaining much greater separation. This latter method is called crossband diversity.

The effectiveness of frequency diversity depends on the wavelength differences of the frequencies in use. Fading occurs when the components of a signal interfere in such a way as to cause cancellation. Interference depends on the relationship of direct, reflected and secondary waves. With signals having different wavelengths but following the same paths, it is unlikely that they will cause simultaneous deep fades.

When considering any given path over which both frequencies must travel, it is easy to see why interference will not occur simultaneously on both frequencies. For each frequency there may be a number of different paths, but neither frequency can follow one path to the exclusion of the other frequency. When the wavelength of one frequency travels a distance which causes interference with the direct component of that frequency, the wavelength of the other frequency—traveling the same distance—will not have been delayed enough in its travels to interfere to the same extent with the direct component of its frequency.

As a solution to multipath fading, frequency diversity is simple and useful. The redundant arrangement of transmitters and receivers gives the system two complete electrical paths. This is a good hedge against equipment failures and an advantage when performing checks where service cannot be interrupted.

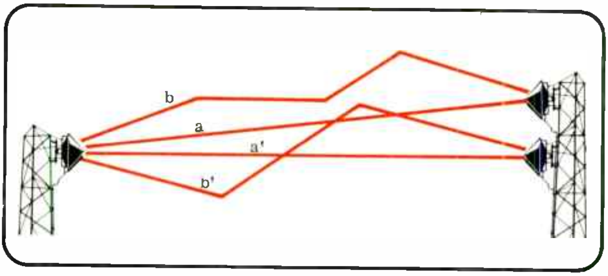


Figure 7. With space diversity the same wavelengths travel different refracted paths (b and b') but will not have the same interfering effect on the direct waves (a and a').

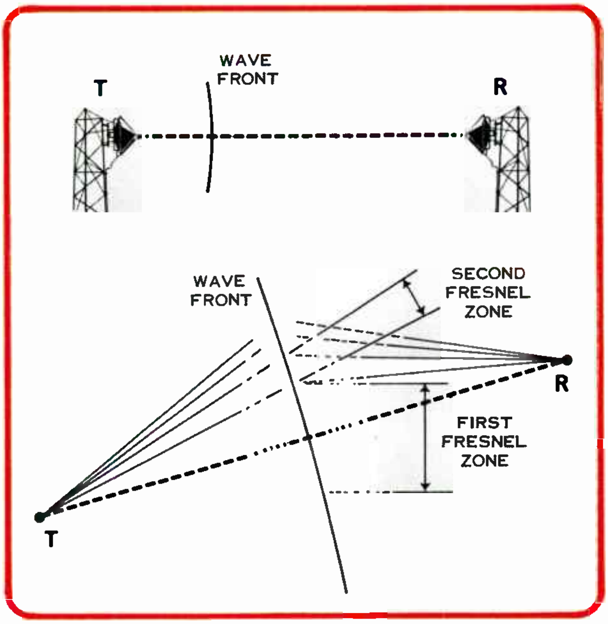


Figure 8. An unlimited number of Fresnel zones surround the direct beam. Here zones 1 through 4 are shown.

Space Diversity

In a typical space diversity system one signal is transmitted to two vertically spaced receiving antennas. At the receiving station the two signals are combined.

A space diversity system requires only one transmitter and two receivers, although most systems have a second transmitter in hot standby. In addition, a system must have at least two receiving antennas in order to provide the required vertical spacing. Each antenna must have its own waveguide.

Normally the additional antenna means a stronger if not separate antenna tower. In all probability the tower will also have to be taller in order to insure adequate vertical separation.

Unlike frequency diversity, which relies on wavelength differences, space diversity relies on path length differences. The working concept behind a space diversity system is that components of the same signal traveling different paths will not have the same interference points. The same wavelength is interfered with differently at two vertically separated points because it travels different length paths to the antenna.

Space diversity is the best protection against multipath fading if microwave frequencies are scarce. Although it does not have the advantage of two complete electrical paths, it avoids the problem of obtaining two frequencies for the same transmission path.

Interestingly, there is a growing controversy as to how the spacing between antennas should be determined. There are two schools of thought on the subject and, appropriately, they are diverse.

One approach is based on the assumption that multipath fading involves a complex interaction from more than one source of interference. This makes it difficult to calculate optimum antenna spacings on anything other than a statistical basis. As a result spacings are usually selected which are as wide as possible (based on the empirical conclusion that improvement would probably increase with separation) considering tower heights and other mechanical factors.

The other approach uses discrete, calculated spacings to combat simple two path, reflected component interference. It relies on a known vertical pattern of signal strength consisting of alternating nulls and maxima.

Fresnel Zones

Analysis of this pattern has shown that interference depends on the vertical distance between the direct component and a reflecting surface. The relationship is conveniently defined by Fresnel zones.

These zones form a series of concentric circles around the direct or shortest path between transmitter and receiver. The positions of the zones are wavelength dependent. Each zone contains wave components traveling paths no more than half a wavelength different in length. Two paths passing through corresponding points in adjacent zones will differ in length by half a wavelength.

Fresnel zones, of which there are an unlimited number surrounding a path, are numbered from the center out. Paths through the first Fresnel zone vary in length from the direct path by as much as half a wavelength. Paths through the second zone vary between half and one wavelength, those through the third by one to one and a half and so on. Each zone number represents an increase of half a wavelength in path length.

Figure 8 illustrates how the Fresnel zones surround the direct path. Each successive zone passes wave components which travel half wavelength differences. These zones can be used to determine where out-of-phase paths occur. Transmission engineers normally refer to paths passing through even zones as having components which cancel and those passing through odd zones as having components which reinforce the direct wave.

A knowledge of Fresnel zones is useful when planning a transmission path over reflecting surfaces. Because even Fresnel zones contain wave components which cancel the direct component, surfaces which reflect even zone components should be avoided. Logically the vertical distance between a direct component and a reflecting surface should

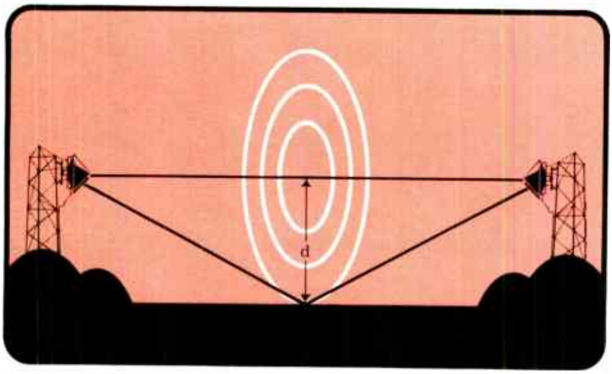
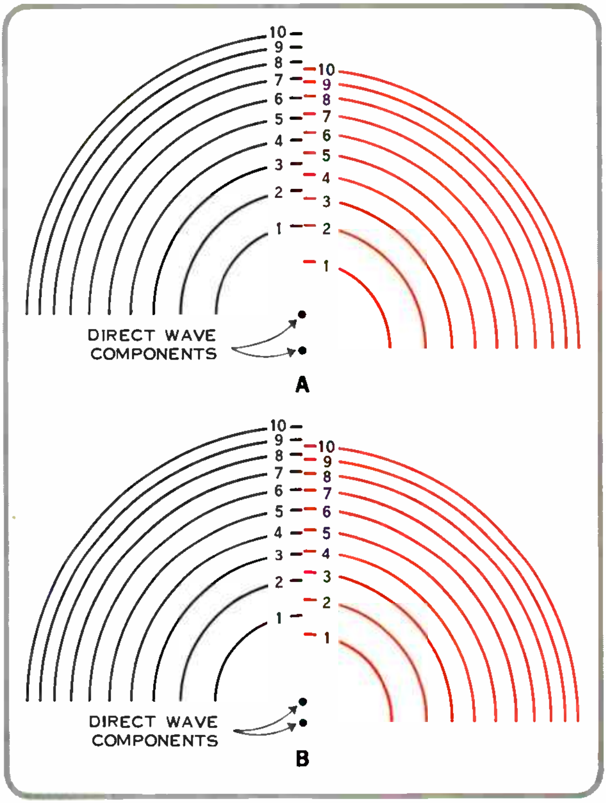


Figure 9. Reflected waves can interfere with direct waves. A distance, d, between reflecting point and direct wave equal to an odd Fresnel zone radius can cause reinforcement. If d equals an even zone radius, the two waves can cancel.

Figure 10. Fresnel zones around two direct waves can coincide. A reflection at zones 6 and 8 in A would cause cancellation. To overcome this other direct waves must be chosen to obtain the pattern in B. This is done by changing the position of at least one of the antennas.



be less than the radius of an even Fresnel zone.

Figure 9 shows the direct and reflected components of a wave. If the reflecting point is so located that components in an even zone are reflected, there will be a cancellation of the direct wave. It is for this reason that transmission paths are engineered to avoid reflections at even Fresnel zones.

On a transmission path receiving antennas are spaced to intercept two direct components. By calculating the reflecting points based on an expected value of K, it is possible to determine which direct components and which antenna heights are best suited to take advantage of the Fresnel zones.

Using the Zones

A rudimentary approach to calculated antenna spacings is to locate one antenna to receive waves reflected at an odd Fresnel zone for standard atmospheric conditions. The other antenna is then placed to receive those reflected at an adjacent even zone.

If the equivalent earth radius factor changes, the height of the direct wave changes. The positions of the Fresnel zones relative to the earth also change.

Unless there is a radical change in K, the antennas will continue to intercept reflections from adjacent Fresnel zones. As K increases, however, it is possible that reflection will occur at adjacent even or odd Fresnel zones.

This can happen because higher numbered Fresnel zones are closer together. This means that the Fresnel zones around two direct components creep up on each other (Figure 10). Eventually an even zone associated with one component can coincide with an even zone of another component. For instance, zone 8 might coincide with zone 6 on another direct component. When this happens at a reflecting point, there will be simultaneous nulls or maxima on both antennas.

To avoid this, antenna positions are sometimes fixed by determining or assuming the maximum possible value of K for the transmission path. With this method the distance between direct paths is chosen so that coincidence between even Fresnel zones will not occur at any reflecting points. There is some inefficiency in this system when K is at its normal value but this does not reduce the diversity effect.

The theory underlying the calculated approach is that reflections from locatable sources are the major contributers to multipath fading. On overland paths this is not always true. It is quite possible to have no reflections or to have two or more of them.

Studies of deep fading microwave signals have been made using paths with low coefficients of reflection. In spite of the low reflectivity, two, three, and sometimes more signal components were found. This discovery led to the belief that ground based reflection is not the only cause of multipath fading.

In Sum

Several years ago Lenkurt engineers, as well as other engineers, determined that diversity improvement would probably increase as vertical antenna separation increased. They concluded that in the 6-GHz band a spacing on the order of 30 to 40 feet offered a reasonable trade off between diversity improvement and tower height. Field experience with many systems has shown that space diversity engineered in this fashion provides extremely good protection against fading of the multipath type, whatever its source.

Based on these results space diversity appears to be an effective protection against multipath fading. It takes into account the disruptive influences of atmospheric reflection and refraction. In fact at times it capitalizes on these phenomena to obtain stronger signals than would be expected.

Whether the biggest fading damage is done by a reflecting surface or a refracting atmosphere depends on the specific path. It seems that over most microwave paths there is more multipath fading from atmospheric refraction than from reflection.

In either case space diversity or frequency diversity can protect against fading. Frequency diversity uses two frequencies and hence two wavelengths traveling over the same path. Space diversity uses two path lengths to send the same wavelength to the receiver. In both cases the different lengths prevent identical interference.

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DECEMBER, 1967
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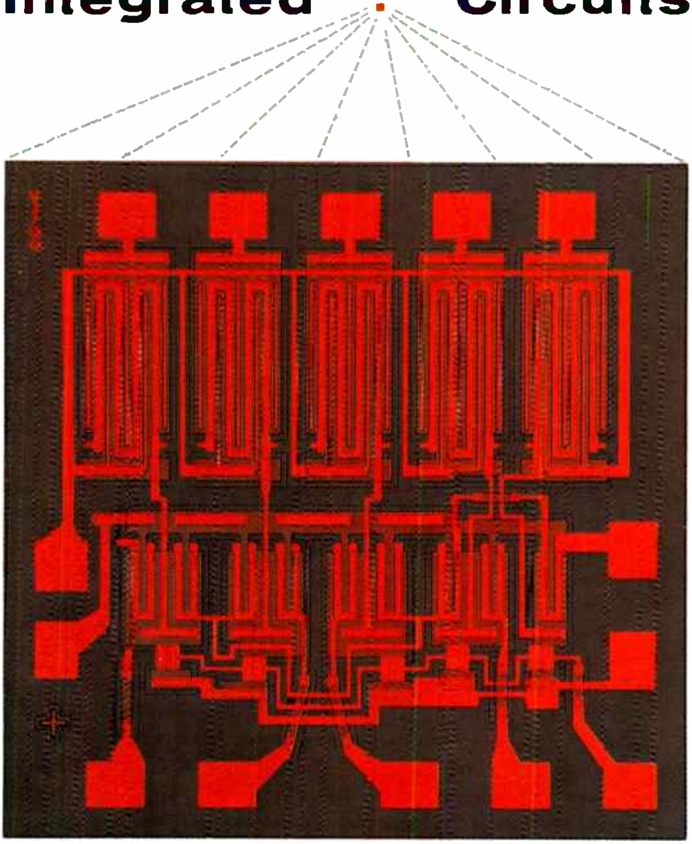
The Lenkurt DEMODULATOR

Integrated Circuits



Integrated circuits promise increased reliability and lower cost in addition to minute size.

Microelectronics, until very recently, was mainly concerned with packaging discrete components in as small a space as possible. First electron tubes and then transistors were packed tightly with diodes, resistors, coils, and capacitors to make miniaturized circuits. With vacuum tube technology, engineers were proud to get something like 6000 components into a cubic foot of space. Transistors replaced tubes, and upped the packing density to about 100,000 parts per cubic foot. And now, while it may seem like a lot of room, 10-million components might fit into that same cubic foot through the use of integrated circuits.

While all of this space saving is impressive, it is not size alone that makes integrated circuits attractive—in fact imperative—to the future of electronics design. The real savings come in manufacturing cost and reliability.

Reliability vs. Interconnection

In all microelectronics the basic motivation is to control complexity. More sophisticated needs bring more complex devices and gigantic growth in the number of parts. So great is this increase in individual items in the machines of todays electronics world that design engineers are faced with what they term the "tyranny of numbers".

The problem is one of reducing the number of components that must be individually manufactured, tested, interconnected, packaged and finally retested. Circuit reliability is inversely related to the number of individual devices and the necessary interconnection.

Early electron tube and transistor attempts at microelectronics solved many of the space problems, but did not substantially improve reliability. The number of interconnections remained the same. Integrated circuits, by their very nature, go to the root of the interconnection/reliability relationship.

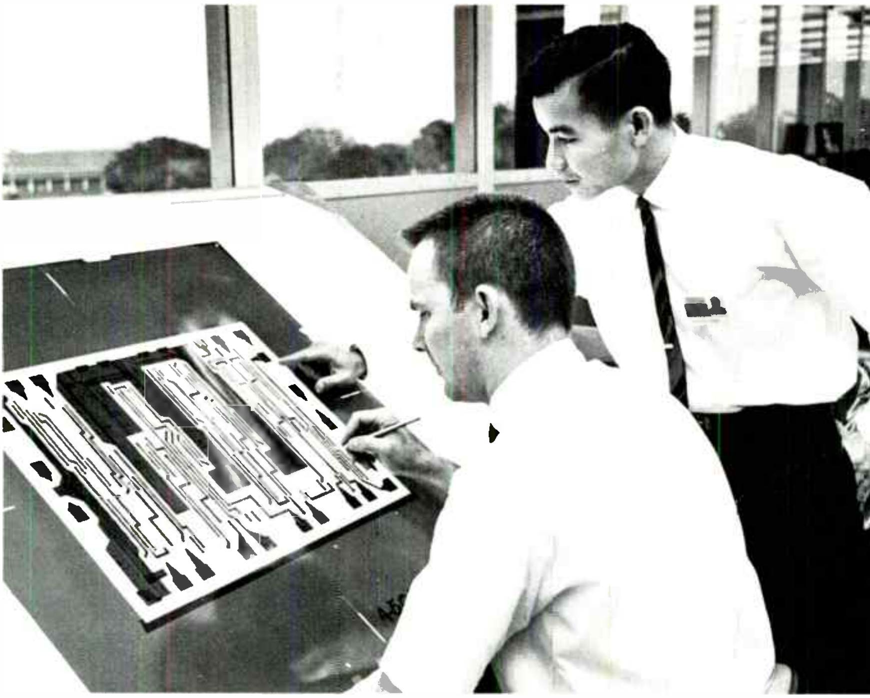
An integrated circuit contains a number of inseparably associated active and passive devices. In a monolithic integrated circuit, all of the circuit parts are fabricated within a single block of material; hybrid circuits include some discrete active devices attached to the integrated circuit components such as resistors and capacitors.

A Circuit on a Chip

Whatever the type of IC, connections, as such, are not used but are "built in" to the device itself. Instead of making a number of separate components and then joining them together to form functioning circuits, the monolithic IC approach is to construct all components at the same time on one "chip".

No new physical principles are involved in integrated circuits, but rather the innovation of mass fabrication techniques. Silicon integrated circuits are really just an extension of transistor technology. But with IC's, hundreds or thousands of circuits, each involving many transistors and other components, are produced at one time.

The creation of a monolithic integrated circuit begins with the basic circuit design. A breadboard model may even be constructed with discrete components to test circuit operation. Then



Courtesy Fairchild Semiconductor

Figure 1. Original art work for an integrated circuit must be prepared in exacting detail. Reduced, it will control fabricating process.

the IC equivalent is drawn representing all of the components and necessary interconnections in the circuit (Figure 1). A separate piece of art work, usually about 30 by 30 inches, is made to represent each of the many steps in the manufacturing process.

The circuit is reduced photographically about 500 times, and then is stepped and exposed repeatedly across a small glass plate. The image on the plate or mask can later be transferred to the surface of a silicon wafer for the fabrication of integrated circuits. In this way as many as 1500 identical circuits may be placed on one wafer—all produced at the same time, all with the same characteristics (Figure 2).

From the finished wafer each circuit or chip is separated, connecting wires are attached, and the IC is packaged in a convenient form.

Manufacturing Process

The raw material from which IC's are fabricated begins as a large ingot of carefully grown silicon. It is between 1 and 2 inches in diameter and about a foot long. The silicon is "doped" with very small but accurately controlled quantities of impurities which change the electrical properties of the material (the basis of all semiconductors).

Glass-like and very brittle, the ingot is cut with a diamond carborundum saw into wafers 12 mils (0.012 in.) thick. After additional processing and polishing, the finished wafer is no thicker than 6 mils.

This wafer will serve as a mechanical

base or substrate for future operations. Onto this substrate another layer of silicon is added by a process called epitaxial growth. The epitaxial layer, about 2 mils thick, has the same crystal structure as the substrate, but is different electrically because of different doping.

Now a series of steps is taken to carefully change the properties of the epitaxial layer in selectively masked areas (Figure 3). In this way the circuit, first drawn in an area almost a yard square in order to obtain good dimensional accuracy and now only slightly larger than a period, can be transferred to the wafer.

The wafer is first exposed to oxygen at high temperature, resulting in a layer of silicon dioxide, called the passivating layer. This layer is coated with a photosensitive resin and with the first mask in place is exposed to light. The exposed areas become hardened, but those under the mask can be rinsed clean of resin. Next the wafer is subjected to an acid which etches away the silicon

Courtesy Sylvania Electric Products

Figure 2. Integrated circuit wafer is compared to half dollar. Each square is an entire circuit.

dioxide layer not protected by the hardened resin.

Diffusion of Impurities

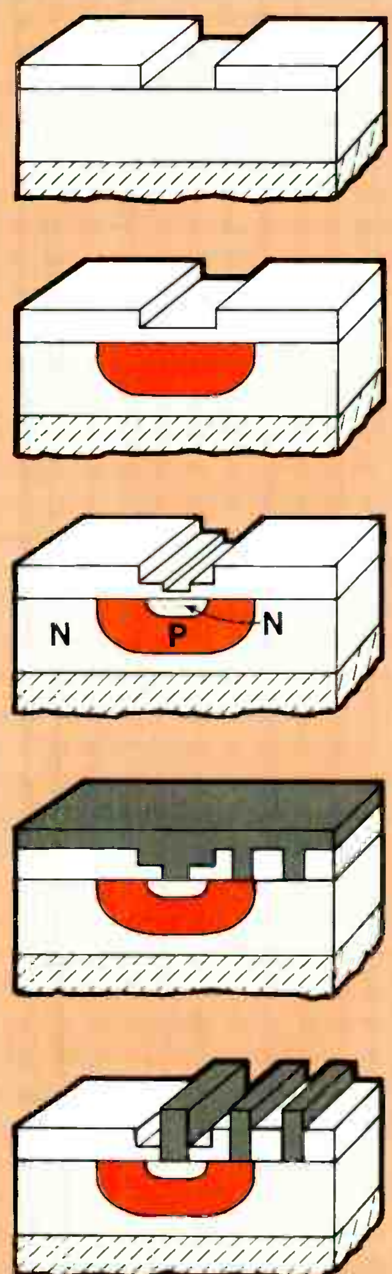
The result of the photo etching is a window through which selective parts of the chip may be exposed to a diffusion process. Diffusion is accomplished by "soaking" the wafer in a furnace with an impurity-rich atmosphere. These impurities will diffuse into the silicon only in the areas not protected by the silicon dioxide layer.

The routine is repeated over and over—photo resistive coating, masking, exposure, rinsing, etching and diffusion. With each step another function is added—a transistor emitter or collector, a resistor or capacitor.

The type of semiconductor produced is determined by controlling the types and amounts of impurities introduced to the silicon. One form of impurity will result in an excess of conduction electrons. This is called N-type silicon. Another impurity will leave a deficiency of conduction electrons, resulting in P-type silicon.

To create a diode, a junction is formed between P-type and N-type material—a PN junction. A transistor requires two junctions, and may be PNP or NPN.

While some values of resistance and capacitance can be diffused into the epitaxial layer, in many cases it is more practical and exacting to add these functions *on top* of the finished active devices. This may be done by a thin or thick film process. Minute quantities of metal are laid down through sputtering or evaporation for thin films or by a silk screen process for thick films. A very thin and narrow piece of metal makes an accurate resistor and can even be trimmed later to touch up the value for more critical tolerances. Capacitors likewise can be made with thin film. It is possible to use the silicon substrate



Window etched through silicon dioxide to expose epitaxial layer to diffusion.

Impurity is diffused into silicon. In the process, new oxide layer forms over entire surface.

Repeated etching and diffusion create other parts of device. NPN areas now form a transistor.

New windows are cut for placement of leads. Surface is covered with metal, typically aluminum.

Metal is etched away leaving leads to each part of device.

Figure 3. Simplified illustration of integrated circuit manufacture shows steps of etching, diffusion and metalization.

as one plate, and the thin-film layer as the other.

Economy of Duplication

All of these processes take place at the same time on *all* circuits on the wafer. It is here that the reduced cost of manufacturing is realized. What can be done to one circuit can be done to hundreds at the same time.

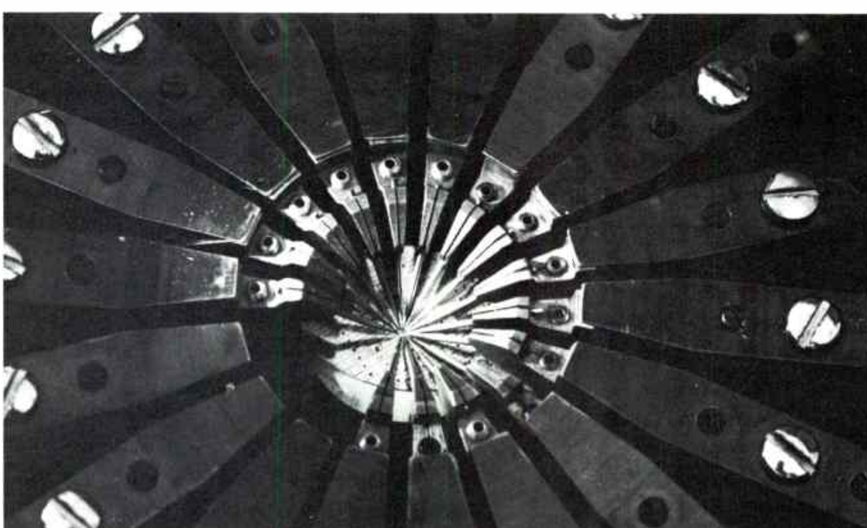
But not every circuit or chip on a wafer is going to be perfect. Seemingly minor defects caused by dust particles and other imperfections can be fatal to such small units. Manufacturing techniques are constantly being improved, but still the yield from a wafer is not 100 percent. And the percentage goes down with more complex circuits.

After all diffusion processes have been completed, but while the wafer is still intact, each circuit is automatically tested. The wafer is stepped through a computer-controlled device where probes determine whether each circuit is acceptable or not (Figure 4). If the circuit does not come up to specification, it is marked, fished out later and destroyed.

The chips, measuring about 0.04 inches on a side, are then separated using a diamond scribing point. They are now ready for packaging—one of the most expensive steps on the assembly line. Until now all manufacturing processes were carried out at the same time for all circuits on a wafer. In fact, many wafers are treated together as a group. At the packaging stage circuits must receive individual manual attention for the first time.

Packaging Methods

Before the chip can be sealed in one of the more than 250 types of packages, a means of connecting it to other component parts must be accomplished. One technique uses the bonding of tiny gold wires to the connection "pads" on the chip (Figure 5). These wires are



Courtesy Fairchild Semiconductor

Figure 4. Computer-controlled probes reach down to test individual circuits while still on the wafer. Imperfections in crystal structure, dust, and failure to meet mechanical and electrical tests all affect the yield from a wafer.

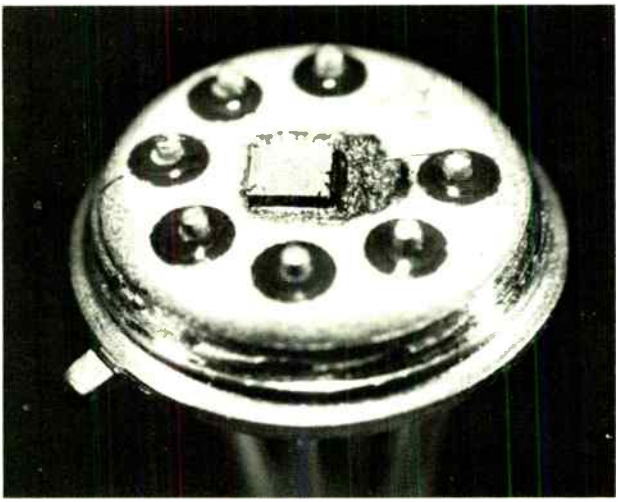


Figure 5. Small gold wires connect IC to terminals of standard TO-5 package.

Courtesy Fairchild Semiconductor

then attached to larger terminals for easy access.

Another scheme — generally called the "flip-chip" method — involves the building of small humps of metal on the pads. The chip can then be turned face down on a larger substrate or frame and bonded by soldering, thermo-compression or ultrasonics (Figure 6). This process lends itself to automation and physical durability.

A method of building up heavier metal leads coming directly from the circuit is also being developed. These "beam leads" make external contact easier and also add structural strength to the entire device.

Once the IC has been packaged it must again be tested. Special tests are made for frequency response in linear devices and switching speeds for digital circuits. They are also subjected to a variety of mechanical tests, shock, vibration, acceleration and temperature changes to ensure dependability.

Operating Speed

When fast switching times are required—always a consideration in digital equipment—an interesting dependency on size makes integrated circuits valuable.

The ultimate factor limiting the operating speed of any electronic device is the velocity of electromagnetic propagation (the speed of light). In space this rate is approximately 186,000 miles per second, or about one foot in 10^{-9} seconds (one nanosecond). Electric current flowing through a conductor will have a speed somewhat slower than this, depending on the characteristics of the conductor.

If a switching circuit is to operate in the nanosecond range, the distance between circuit components must be measured in fractions of an inch. Integrated circuits make this possible.

Typical applications of the digital integrated circuit include many associated with computers: flip-flops, adders, gates, buffers, and memory cells.

The linear integrated circuit, as the name implies, is applicable to most amplifying chores and may be the building block for anything from a simple audio amplifier to a complex communications network. Linear IC's are found in analog computers, communications equipment and even hi-fi systems.

Again, it is not so much the major breakthrough in technology that is seen in the final equipment, as it is the ingenuity of the designer effectively using available tools. For example, Lenkurt engineers are currently investigating ways of using digital integrated circuits to perform analog functions—especially desirable for economic reasons as well as reliability.

A typical monolithic integrated circuit contains a number of transistors and associated passive components interconnected to provide a functional circuit. After packaging, the integrated circuit becomes a unit of some larger design—interconnected to perform the functions of an entire system or piece of equipment. And so numbers of integrated circuits are stacked in smaller and smaller spaces just as tube and transistor circuits were before them.

(IC's)^2

The next logical jump in technology is to combine a number of circuits onto a single chip, with the same advantage of reduced interconnections and manufacturing ease. Several such devices, using a technique known as medium or large scale integration (LSI), are now on the market (Figure 7).

Large scale integration is particularly applicable to computer and other digital technology, where the same type logic circuit may be used hundreds or thousands of times. LSI is capable of offering 100 logic gates on a single chip. This tends to reduce manufacturing and packaging costs. However, increasing the number of components on a chip results in decreasing cost only to a point. Beyond a certain level, circuit complexity tends to reduce the yield of usable chips on a wafer—a chip is only as good as any of its parts—and cost per component begins to rise.

LSI is having a definite effect on the circuit designer who has always had

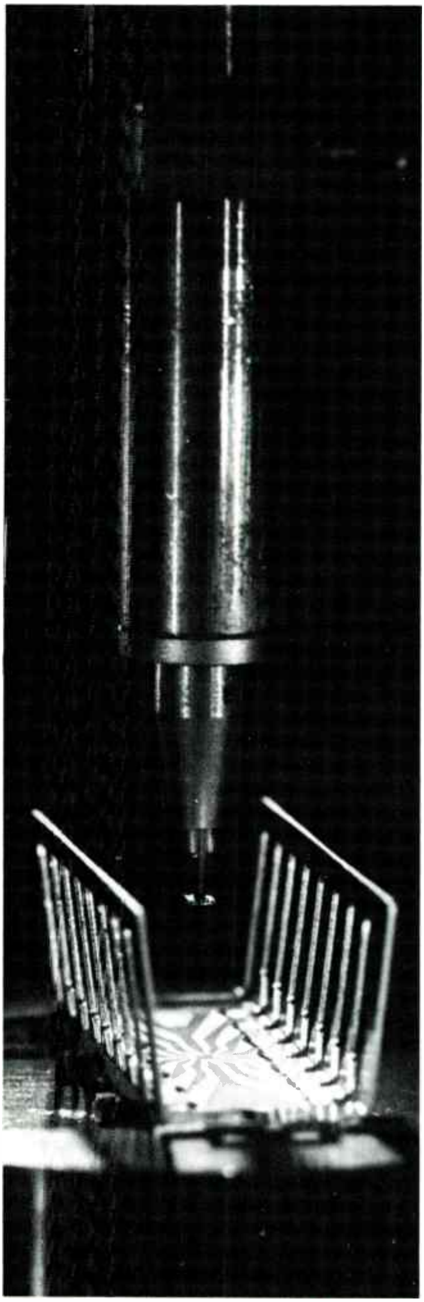


Figure 6. Recently developed technique shows Fairchild integrated circuit about to be mounted face down on frame. All contacts are made at one time.

freedom to choose components according to his own specifications. As entire circuits, and beyond that entire functions, become standardized in manufacture, the design engineer's ingenuity may have to be applied to the use of standard circuits instead of to the design of original units.

At least three types of LSI packages will probably be offered:

1. Stock items ready for use (mainly logic and memory units).

2. Basic units, such as gate circuits, which require final metalization. Interconnection will be provided according to the buyers specifications.

3. Custom units, where specifications demand original design.

LSI circuits at present are more appropriate for digital than linear systems because of the repetitive nature of the elements used. And because components on an LSI chip are closer together than discrete IC's, operating speeds of digital systems are further increased.

IC's and Communications

Miniaturization of electronic systems has been an obvious product of integrated circuits, even though it must be remembered that the more basic value of IC's is in cost and reliability. Com-

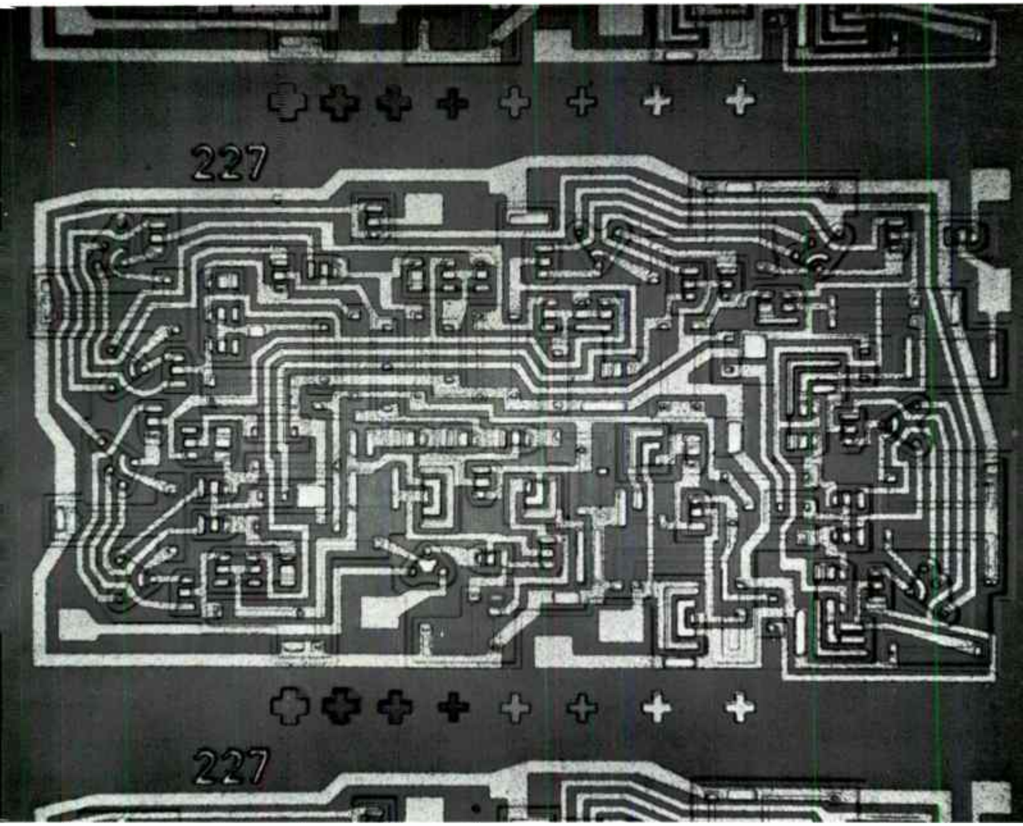
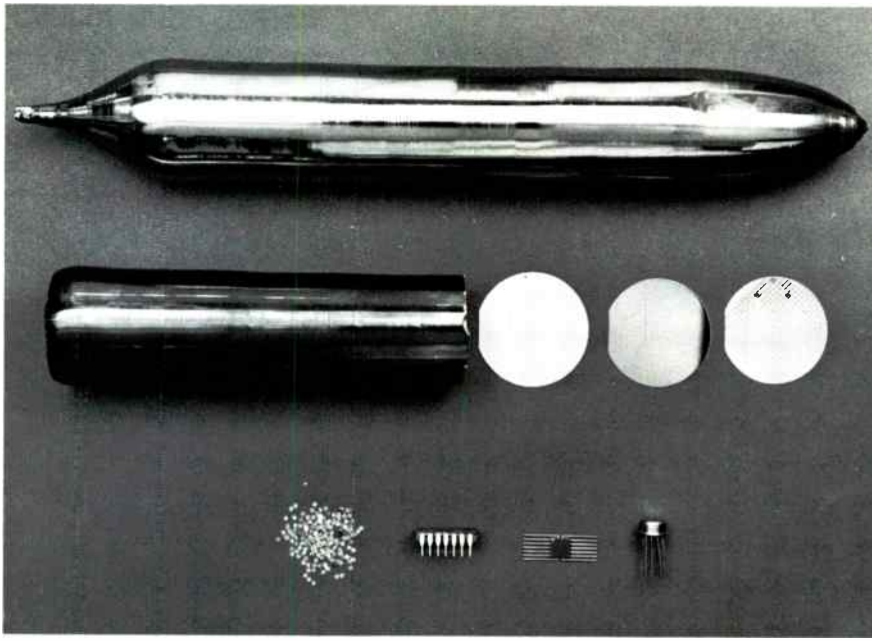


Figure 7. Sylvania IC contains 116 transistors, resistors and diodes to produce 40 gate circuits on each chip. Used in computers or digital communications equipment.



Courtesy Fairchild Semiconductor

Figure 8. Silicon ingot (top) is sliced, and then polished before integrated circuits are fabricated. From the finished wafer (middle, right) come hundreds of chips (bottom, left) ready for packaging. Shown are Fairchild's Dual In-Line, a flatpack, and a TO-5 can.

puters that would have filled rooms by previous technology now stand in the corner or even on a desk top. And the size advantage is now being applied effectively to the designs of new communications systems, especially as linear devices become more practical.

IC's, including transistors, diodes, resistors and capacitors, are so small that the manufacturer's assembly line is now characterized by rows of microscopes. But filter circuits—so important to the telecommunications industry—have remained a problem. These filters require very high quality inductors, large coils of wire that are heavy, bulky and relatively expensive.

A solution in constructing inductorless filters using integrated circuit technology has been proposed by Lenkurt engineers. While still in the experimental stage, the technique exhibits a great deal of promise for the future in keeping communications systems economical, reliable and small.

Simply stated, the method replaces each inductor in a complex filter network with a circuit that behaves electrically like an inductor. This circuit consists of one capacitor and a circuit called a gyrator. Low-sensitivity, high-Q circuits have been produced in a package roughly a quarter of an inch square. This compares in size to a coil of about 1.5 inches in diameter and 1 inch thick.

Data and PCM

The first area of telecommunications to be significantly affected by integrated circuits will be where digital techniques are used. Here, the extensive developmental effort placed in digital IC's for computers can be easily transferred to data transmission and its cousin pulse code modulation (PCM).

For data and for PCM, circuits are needed to deal strictly with digital pulses—signals that are either *on* or *off*. In PCM transmission, for example, binary digits are used to represent discrete values of a voice signal. In the first generation PCM system, bit rates of 1.5 Mb/s are used, requiring very fast sampling and switching. Digital integrated circuits are almost a must. And in future systems, with rates approaching 300 Mb/s, the need is even more pronounced.

Integrated circuits also provide a means of manufacturing extremely stable resistors as part of the miniature circuit. Because all resistors are made at the same time, and with their close proximity will be subjected to identical changes in environment, they are excellent components in critical communications applications.

Hybrids Sometimes Appropriate

Much of this discussion has centered around monolithic integrated circuits. Hundreds of circuits, including all active and passive components, are processed as a unit on one wafer. And the wafer is repeated hundreds and thousands of times. Obviously this is advantageous whenever great quantities of the same circuit are needed.

Many telecommunications equipment designs will use "off the shelf" IC's both of digital and analog variety. But some specific applications will not require the large quantities needed to justify monolithic integration.

In these cases hybrid IC's may be more appropriate. The equipment manufacturer could produce much of the circuit using in-plant thin or thick film capability. Other components—including active devices—would be added as separate units. Single transistors, or standard integrated circuits could be bonded to a unique circuit of the manufacturer's design. Bell Laboratories, for example, has used this approach for a tone-generating circuit in some Touch-Tone telephones.

Integrated circuits may also affect the design of future microwave radio equipment. With their fixed component relationships and close spacing, IC's may solve the problem of manufacturing circuits with uniform performance to operate at microwave frequencies.

The IC Promise

The entire electronics industry is facing a change of great magnitude—a physicist might call it a technological quantum jump. Integrated circuits as they stand promise price savings and reliability. Large scale integration will open roads to miniaturization still hard to visualize accurately. A hundred transistors on a chip, or a hundred-thousand on a wafer are foreseeable in the next five years.

Whether it's a shoe-box size computer, a carrier system inside a telephone handset, or even wrist watch television—the integrated circuit is the gadget dreams are made of.

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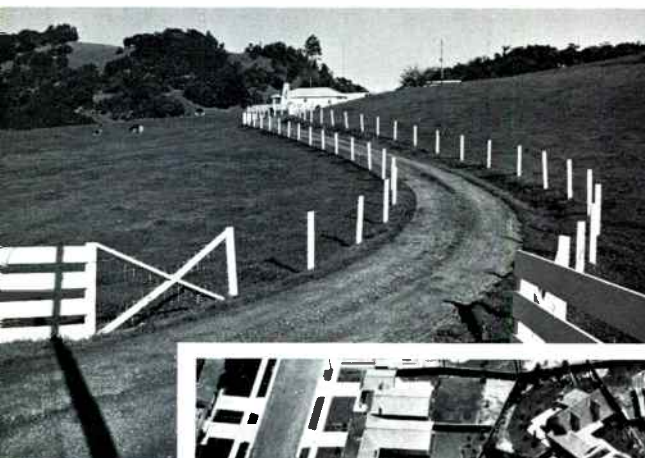

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