The Lenkurt Demodulator

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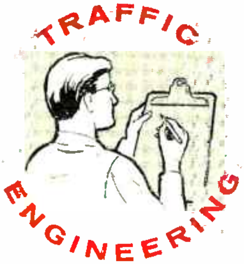
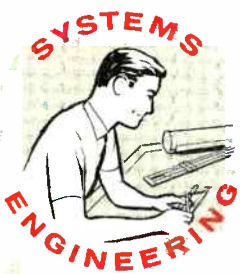
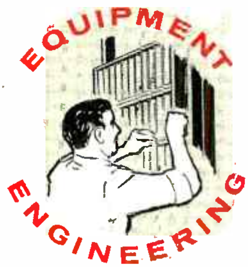
TRANSMISSION SYSTEM PLANNING

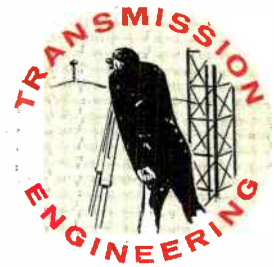
Modern communications networks are becoming more and more efficient and reliable, despite the fact that they are continually becoming more complex. These improvements undoubtedly are a result, not only of advanced engineering techniques, but more importantly, of effective planning. *However, many people in the communications industry seldom become directly involved in the intricate planning that goes into developing an efficient and reliable system.*

This article discusses some of the many considerations involved in the planning of multichannel transmission systems for a communications network.









The coordinated efforts of a number of specialized engineering functions are needed to plan and build a communications system. The size and number of such functions depend, of course, on the type of system proposed and its complexity. Certain of these functions, however, usually play an integral part in the development of all types of systems. Most significant among these is *systems engineering* — that function which has the overall responsibility for directing and coordinating the efforts of the others. These other functions include such activities as *traffic engineering, plant engineering, transmission engineering,* and *equipment engineering*. All of these functions are usually active during various stages of planning, engineering, and installation of a multichannel transmission system.

The term *communications system* is very broad. It may mean anything from a huge global complex, with thousands of miles of transmission facilities and many subscribers, down to a walkie-talkie carried by a soldier. A typical telephone communications system consists of user or *subscriber* equipment such as telephones, teletypewriters, and business or data processing machines which are connected by wire lines to a switching center. The switching center permits each subscriber line to connect with other lines of the same network. To communicate outside of the local network, however, common-use or trunk circuits must be established from the switching center to other switching centers. Such common-use circuits are typically multichannel *transmission systems* consisting of voice multiplex equipment and open-wire, cable, or broadband radio facilities with intermediate repeaters, as required.

Technical Requirements

When the need for a communications transmission system is firmly established, the technical and operational requirements that will satisfy the need must then be planned in detail. There is usually a choice of different operating arrangements and types of equipment, any of which might provide good service. The principal objectives are that the system be simple and reliable, and be practical and economical to operate. It should also be suitable for future expansion—which is almost always necessary. Accurately defining the system requirements early in the planning stage will certainly result in better overall economy and greater satisfaction in the communications services provided.

The amount of terminal equipment and the number of trunk circuits or channels required for the transmission system are determined by the intended number of users; the possible number, kind, and duration of messages sent by each of these users; and by the desired quality of service. The first task in planning the system, therefore, is to determine the volume and types of traffic that it will be expected to handle. This is usually done by a traffic engineer, whose traffic study provides the basis for estimating immediate requirements and also the nature and extent of future needs. The traffic study is essentially an analysis of the amount and type of use the proposed system will receive—in other words, the characteristic behavior of the users.

A typical transmission system must be able to handle various types of traffic, such as speech with signaling, telegraph, high-speed data, and graphics. Because each type of signal imposes a different load on the system equipment, it is also necessary to determine the distribution of each possible type of traffic.

If the proposed system is simply an expansion or an improvement of an already existing communications network, a traffic study of the intended users can be made directly. However, in planning new systems there is, of course, no way to examine the behavior of the intended users. In this case, it is necessary to extrapolate information from existing systems where the requirements very nearly match those of the proposed system. Such an indirect study can be made from the substantial amount of existing traffic data, collected by various agencies, that is applicable to the design of most communications systems.

A

B

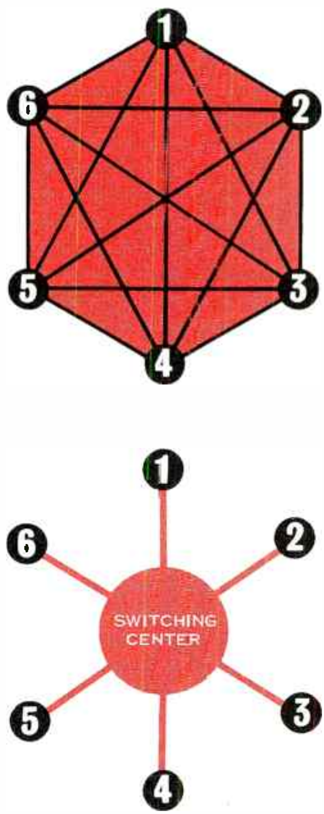


Figure 1. Example of two types of routing used in communications transmission systems. Diagram A shows six stations interconnected by direct and alternate routes. Diagram B shows the same six stations interconnected through a central switching center.

After establishing the types and distribution of traffic and the number of channels required for the new system, the technical quality and the desired operating characteristics of the circuits must be determined. The facilities that may be used to furnish transmission circuits differ greatly in such things as net loss, bandwidth, distortion, noise and load-handling capacity. To meet the specific transmission requirements, facilities must be selected that are suitable for each type of service, particularly in cases where special or unusual capabilities are needed.

When a message first enters a transmission system, it is converted into a signal whose electrical characteristics vary depending upon the particular treatment and processing it receives in the system. As the message travels through the system, its electrical characteristics are changing continuously. All along the circuit, it is being attenuated, amplified and re-amplified, shifted in frequency and phase, and even distorted, before reaching the output of the receiving terminal. So long as the signal is confined to one system its characteristics are limited to the requirements of that system.

However, before a signal can be transferred from one system to another, its characteristics must be suitable to the technical requirements of the next system. It is desirable, of course, to be able to transfer the signal to the next system in an economical and efficient manner—that is, without the need for complicated interface equipment. This is especially true in public or common-carrier systems where long-distance direct-dialing telephone communications depend upon the cooperation and coordination of hundreds of different systems. In the United States alone, there are more than 2500 independent telephone systems, in addition to the Bell System, that must interconnect to provide complete nation-wide communications.

Standards and Practices

Inherent in the development of most transmission systems is the need to recognize and accept existing operating practices and performance standards to promote a uniform system of communications networks. This need has fostered the development of numerous written standards and practices covering almost every significant aspect of electrical communications. These standards provide the basis for establishing the performance criteria of transmission systems. The use of these standards, of course, is not obligatory, but because of the benefits to be derived, they are often accepted by general or implied consent.

The standard practices for interconnecting transmission systems in North America have been developed largely by the Bell System and generally accepted by the rest of the telephone industry. To help establish international communications, many countries, especially in Europe, use the recommendations of the CCITT (International Telegraph and Telephone Consultative Committee) and the CCIR (International Radio Consultative Committee). These two committees, which are agencies of the United Nations International Telecommunications Union, have been effective in assuring that the communications practices and performance standards of various nations are compatible.

In establishing the performance requirements of many types of special purpose communications systems, it is not always practical to use the universal standards developed for common-carrier networks. This is especially true in certain private or industrial systems and in various military systems which are not necessarily expected to interface with common-carrier networks. Often, these systems must be specially designed to meet unusual or higher-than-normal performance requirements. In these cases, relying upon universal standards and practices to establish system performance criteria may not provide adequate operational capabilities. In fact, the use of such broad standards might impose objectionable restraints on the capabilities of these systems, resulting in poor or inadequate performance.

The need for unusual performance capabilities is especially evident in many military communications systems. In common-carrier communications systems, new services requiring unusual performance capabilities can be added in a deliberate, carefully-planned manner. However, military needs are apt

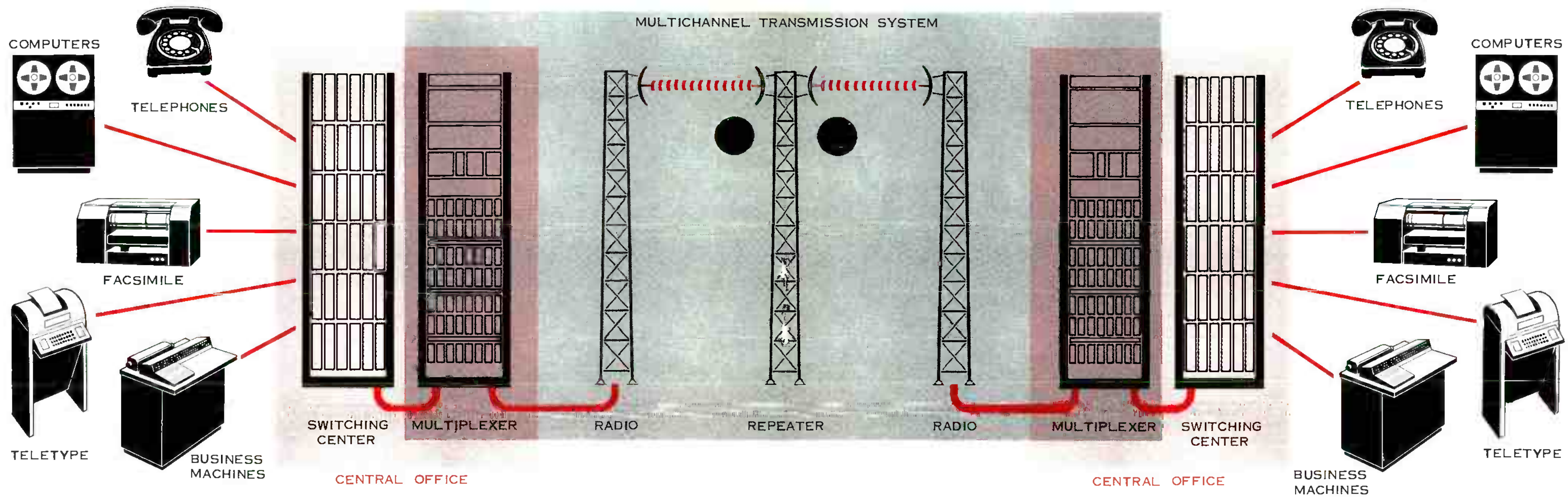


Figure 3. Typical communications network with a multichannel transmission system containing multiplex equipment, microwave radio terminals, and intermediate repeater station.

fense Communications Agency (DCA) which issues *DCS Engineering-Installations Standards* to establish uniform performance criteria for each component of the system.

After selecting the performance criteria, the next step in planning a transmission system is to prepare the specifications that will guide its engineering and development. These specifications are more effective when manufacturers are able to bid the particular features of their equipment which will best satisfy the technical and operational requirements of the proposed system. For instance, the operating company might prescribe in its specifications that the transmission system connect several points by direct and alternate routes, as shown in Figure 1A. However, a manufacturer, bidding on the job, might determine that central switching (shown in Figure 1B), rather than direct or alternate routing, provides the most economy and the best service for his particular equipment. In other words, the system planners should take advantage of the manufacturers' knowledge of the use of their products and of their experiences in systems engineering.

Planning Ahead

The system planners must also remember that one of the criteria by which the proposed system will be judged will be the specific plans for expansion to meet future growth needs. Nearly any system can be expanded—with enough money and effort. The competent engineer, however, plans for orderly and economical growth and de-

tails in his plans how it will be done and estimates how much it should cost.

When accepting bids from a communications equipment manufacturer, it is important to consider not only the initial cost, but the possible long-term costs. Under the usual pressures of doing business, it may be tempting to accept the lowest bid, while overlooking the potential limitations and costs to operate the transmission system for a long period of time. Although the initial cost of a more reliable, efficient, and capable system may seem high, it usually proves to be a real bargain when compared to the excessive costs and work required to repair and maintain an inferior system. It may also be costly later to improve the performance capabilities of a low-cost system to make it suitable for the expected increase in newer types of traffic, such as data and graphics.

The load-handling capabilities and noise performance of most of today's transmission systems are based primarily on voice traffic with allowance for the usual pilots, signaling tones, carrier leak, and a small amount of telegraph traffic. So long as these systems handle mostly voice traffic, they should certainly perform their job satisfactorily.

However, will such systems be able to handle the large amount of data traffic that is predicted for the future? This is a very important question that must be carefully considered when developing a system that is expected to operate economically and efficiently throughout its lifetime.

Data signals are presently transmitted over voice channels at a level somewhere between -5dbm0 and -15dbm0. It is desirable, of course, to transmit data signals at the highest possible level to prevent impulse noise from causing too many errors. Dial-operated data service, provided by the telephone industry, as well as other similar data services, presently operates at a level of -8dbm0. The signals from data equipment impose a much greater load on multichannel transmission systems than do ordinary voice signals. Because of this heavier loading, data service cannot be simply *added later* without first considering its effect on the load handling capacity and noise performance of the transmission system (see *The Lenkurt Demodulator,* March 1965).

For example, consider a typical 600-channel transmission system designed to perform in accordance with today's CCITT voice loading recommendations. If data service at -8dbm0 is later assigned to 120 of the 600 voice channels, then the remaining 480 channels must be removed from service to accommodate the data load. Even if only 60 of the 600 channels are used for

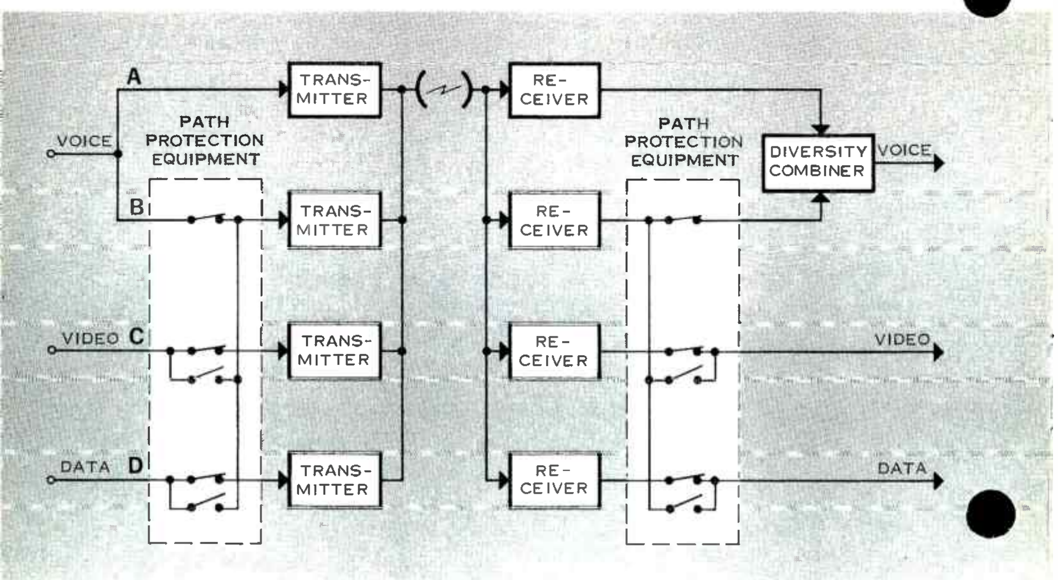


Figure 4. Functional diagram of typical one-for-three broadband radio path protection system.

to change radically and quickly, and often under the worst possible circumstances.

Because the circumstances under which a military system may be used are often unpredictable, it must be assumed that the traffic load will be severe. Military systems can expect to handle proportionately more facsimile, digital data, and other non-voice traffic than commercial systems. Digital transmission provides the speed required by modern military operations and, consequently, its use has become increasingly important in the central control of complex tactical, strategic, and air defense weapon systems, and in transmitting detailed intelligence reports, weather reports, and world-wide logistics information.

Such digital traffic imposes a much heavier load on a transmission system than ordinary voice traffic. For this reason, military systems must be capable of handling much greater average input signal powers than required for comparable commercial systems. In addition, tactical military communications equipment must be ruggedly built to withstand severe mechanical shock and vibration encountered in typical military exercises. Also, the equipment must be extremely reliable and easy to maintain, since well-trained personnel may not always be available to keep the system operating properly during emergency conditions.

Today's military communications systems range from small portable or mobile systems used in combat areas to support tactical operations, to the immense, highly complex Defense Communications Systems (DCS) which interconnects U.S. military and government installations located all over the world. The DCS is directed by the De-

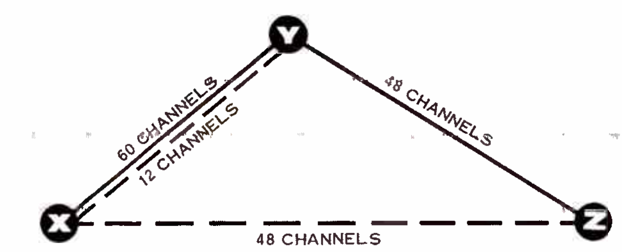


Figure 2. Possible routing for 12 channels between stations X and Y and 48 channels between stations X and Z.

data, 300 of the remaining 540 channels must be removed, leaving only 140 channels available for voice traffic.

It may be possible to lower the level of the data signals to keep more channels active, but this will drastically raise the data transmission error rate. Theoretically, the error rate in a typical binary system may increase by a *factor of 10* for every db that the signal level is decreased—due to the resulting lower signal-to-noise ratio. This means that if the level of the data signals were lowered from, say -8dbm0 to -13dbm0, the error rate may increase *one hundred thousand times.*

But what about the idle channels? Since they can no longer be used, but were part of the original system cost, they represent wasted investment and, even worse, are no longer able to produce revenue. Adding data service later to a transmission system designed primarily for voice traffic, therefore, may seriously decrease the efficiency of the system. To prevent such waste or to avoid having the system become quickly outmoded, particular attention must be paid to the traffic growth and to the load-handling requirements of the proposed system. In this regard, future traffic requirements must be carefully considered, especially for data where such things as signal levels, frequency stability, impulse noise, delay distortion, and intermodulation distortion are much more critical than for ordinary voice traffic.

Satisfying the Requirements

After specifying the technical requirements of the system it is then necessary to determine what type of equipment will be necessary to meet the initial requirements while providing for economical expansion to meet future growth. Of course, if the project is an addition to an existing system, or if it must tie into another system, the new equipment must be compatible with that already installed.

Before selecting the equipment, a number of specific technical questions must be considered. For example, should points A and B be connected by microwave or by cable? What is the distance involved, and what terrain problems are likely to be encountered? Would it be better to route the communications between X and Z via point Y? What about the accessibility of repeater sites, and which route will provide the necessary path reliability at the lowest cost?

For example, suppose two outlying points, Y and Z are to be connected to a central point X, as shown in Figure 2. Twelve voice channels are required between X and Y, while 48 channels must be provided between X and Z. No direct communication is necessary between Y and Z. After careful analysis it may be decided to run 60 channels on microwave radio from X to Y, drop 12 of them there, and run the remaining 48 channels to Z, since it is a simple matter to bridge off a 12-channel group without demodulating the entire 60 channels. Although the total length of the system connecting X and Z is somewhat greater this way, less equipment is required.

If a microwave system is considered to be the best way to satisfy the requirements, then a radio path survey must be accomplished. Profile maps, available for most areas, are helpful in performing such surveys. In many cases, however, a transmission engineer must go out and make a direct path survey of all the proposed routes. He may also have to consult meteorological records to determine what effect the climate of the area will have on path reliability.

On the basis of the path surveys, it might be decided to use frequency-diversity operation to achieve the desired path reliability. If a fading problem exists, but dual-frequency operation cannot be authorized for this particular type of service, space-diversity operation (which provides two paths using the same frequency but with different fading characteristics) may be the answer.

Antenna sizes and heights must also be established as well as a system frequency plan which will make efficient use of the spectrum available while minimizing interference with other systems or other *hops* of the same system.

Suppose the system planners are faced with the problem of providing a microwave system for a route with growing requirements for traffic capacity. Initially, one broadband microwave channel is enough, but the need for a second is foreseen—and eventually even a third channel may be required. Furthermore, the necessary system reliability demands that each channel be protected with an alternate path.

For the initial installation, two channels operating in a frequency diversity arrangement will satisfy the traffic-handling requirements and provide the necessary reliability. But what of the future? One possible solution might be a one-for-three protection system, as illustrated in Figure 4. Such a system permits a single channel (channel B) to provide *back-up* protection for three working channels. Under normal conditions, however, this protection channel does not stand idle. Instead, it operates in a frequency-diversity arrangement with one of the working channels (channel A), as shown, to make the most effective use of the frequency spectrum when carrying message traffic.

It is not necessary initially to install all four channels. A common procedure is to install first only channels A and B. Later, as more channels are needed, channels C and D can be added (one

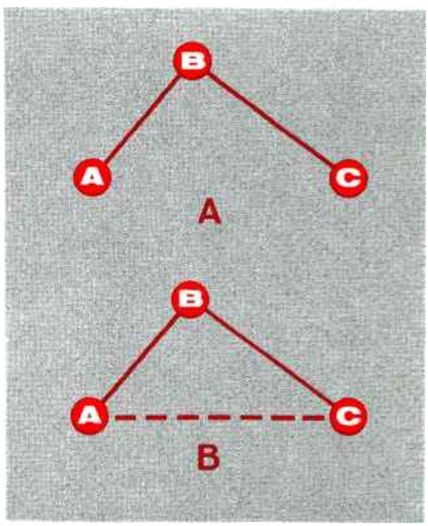


Figure 5. Diagram A shows trunk facilities interconnecting three stations without alternate routing. Diagram B shows trunk facilities interconnecting the same three terminals, but with a direct channel established between stations A and C. The additional channel between stations A and C provides an alternate route between each station in the system.

at a time or together). When this is done, channel B continues to operate in frequency diversity with channel A. However, if either channel C or channel D fails (because of either propagation or equipment problems), the baseband switching equipment disconnects channel B from the frequency- diversity arrangement and connects the traffic on the failed channel to channel B. Thus, a little foresight has provided a system with built-in expansion capability.

Another important consideration is the routing of traffic between the various terminal sites of the proposed system. For instance, consider a proposal for a communications system that interconnects three stations, A, B, and C, as shown in Figure 5A. In this system, traffic between stations A and C is routed through station B. If an outage occurs between B and C, there can be no communications to C from either A or B. The same problem arises if an outage occurs between A and B. However, if a direct link is installed between sites A and C, as shown in Figure 5B, an alternate route for traffic is immediately established between all stations. The effective use of alternate routing in a system containing more than two terminal sites, therefore, can result in a more reliable system, in addition to providing better service.

Planning a complex multichannel transmission system involves examining various equipment arrangements in order to achieve the best results. The system planners put together various combinations of "building blocks" and then analyze the results to see if they meet the specifications. They do this because their job is not merely to develop an adequate system, but to conceive the best possible system *at the lowest cost.*

Thus, practical economics play a large part in systems planning—where there is no substitute for experience. There is certainly no "guidebook" which details all shortcuts which can save money without degrading performance.

Conclusion

Developing a multichannel transmission system for a communications network is not a simple and easy task. There are many things to consider and many decisions to make before such a system can even begin to take form.

Today's transmission system must be capable of handling many types of message signals, each having a different effect upon the performance criteria of the system. Early systems handled only telephone and telegraph signals, while most modern systems must handle not only these, but possibly low-speed data, high-speed data, telephoto, and television signals as well.

The ever-increasing demand for these new communications services has brought about the development of new engineering techniques and equipment with extraordinary capabilities. However, new equipment and techniques alone do not make a reliable and efficient communications transmission system. Effective planning and a good experienced engineering team are surely just as important.

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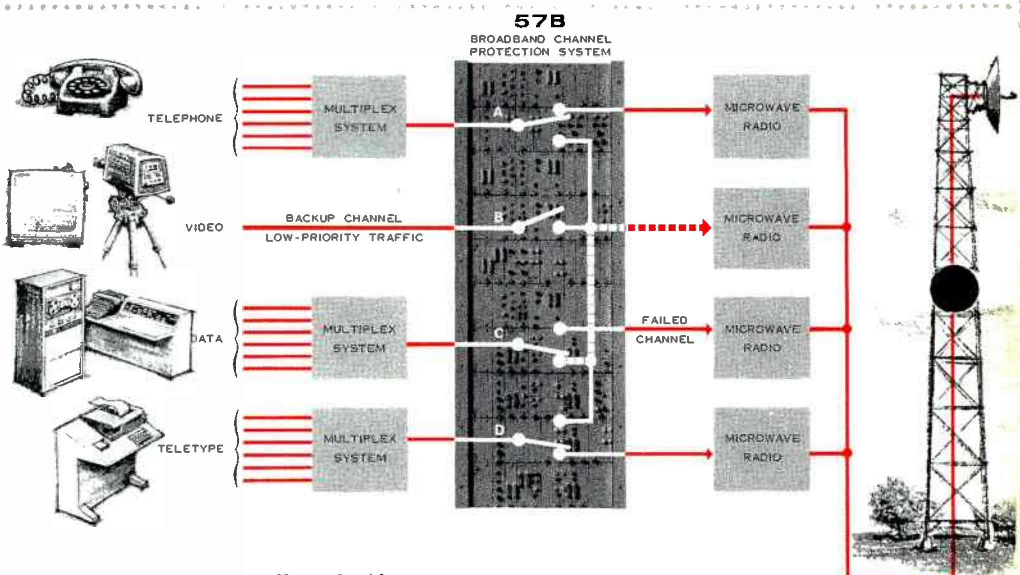

Lenkurt's 57B Broadband Channel Protection System is an economical and efficient method of improving the path reliability of microwave radio links. One radio channel can be used to provide stand-by protection for up to three other broadband radio channels, carrying higher priority traffic. More information about this economical system is contained in Form 57B-P4, available on request from the Sales Promotion Manager.

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