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The New L Multiplex — System Description and Design Objectives

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This paper discusses in broad terms the design of a radically new family of multiplex terminals, designated the L multiplex, designed to work with any of several broadband transmission facilities. The relevant historical background of multiplex terminals is covered and design objectives for the new equipment are outlined.

The new multiplex takes advantage of advances in the state of the art to reduce the size of equipment and increase reliability, while it retains the proven advantages of older equipment. Other advantages of the new multiplex include in-service maintenance, decentralized carrier supplies, and increased flexibility. The latter permits its use with as few as 60 or as many as 1860 voice channels and also adapts it for use with wideband data service. Compatibility with older multiplex equipment was maintained where possible, but in order to meet future demands for broadband service, it was decided to modify older equipment rather than compromise the design of the new to maintain compatibility.

I. INTRODUCTION

The coaxial cable and radio relay facilities of the Bell System employ the same form of frequency division multiplex. This paper describes the terminal multiplex arrangements in broad terms and discusses the design objectives for a radically new family of multiplex terminals having message channel capacities ranging from 60 to 1860. Dependent upon the A-type channel bank[1] for the first step of modulation from voice frequencies to group carrier spectrum and the reverse function of demodulation, the new multiplex accepts such groups and assembles them into a single broadband signal for transmission via the various high-frequency media. It is an order of magnitude smaller than its predecessor and offers operating advantages not formerly available. The first commercial installations were placed in service in mid-1962. Circuit and equipment design features of the new multiplex are covered in detail in companion papers.[2,3,4]

II. HISTORICAL BACKGROUND

2.1 *General*

Realization of the potential of a wire or radio system to transmit many messages simultaneously requires multiplexing equipment at the terminals of the transmission medium. Multiplexing techniques may be divided into two categories, frequency-division and time-division. Broadband facilities capable of handling hundreds of channels have used the former exclusively, and this paper is concerned with modern versions of such arrangements.

Essentially the transmitting circuits of a multiplex convert signals from a number of independent voice-frequency channels into a single broadband signal suitable for transmission over a high-frequency medium. The receiving circuits reverse this action by resolving the single broadband signal into individual VF channels. The circuit and equipment concepts for the earliest carrier systems were quite simple. With available lines severely limited in bandwidth, three or four channels were the maximum attainable. These were formed by a single modulation step using carriers which were provided by simple, individual oscillators.

As the art advanced, much broader bands of frequencies could be transmitted and the economics of system planning indicated that a basic new approach was needed. One outcome was the development of the A-type channel bank.

2.2 *A-Type Channel Bank*

In the early 1930's two carrier systems were under active development; one for 19-gauge toll cable pairs (Type K), one for open-wire pairs (Type J). Crosstalk coupling and line attenuation limited the frequency band so that only twelve channels could be transmitted. However, looming in the not too distant future was a system based on the new concept of a coaxial cable capable of transmitting a much wider band with channel potentialities 40 to 50 times greater.

To provide a common denominator for all of these systems, the A-type channel bank was developed. It became the first step of modulation and yielded twelve single-sideband voice channels with suppressed carriers spaced at uniform 4-kc intervals in a standard group frequency band from 60 to 108 kc. This channel format is standard in the Bell System and has been adopted internationally. The historical background for this choice of channel format and the continuing development of channel banks from the A1 design to the new A5 transistor version are discussed in detail in a recent paper.[1]

Next in multiplex progress was the development of equipment required to operate with channel banks to provide the hundreds of channels which coaxial and, later, radio systems could handle.

2.3 *Multiplex for Coaxial Systems*

In the Type K cable and Type J open-wire systems for which the channel bank was first utilized, the translation to line frequencies was a simple matter because the system capacity was limited to a single group. For the much higher capacity L1 coaxial system[5,6] both single-step and two-step modulation were considered.

A two-step plan was adopted for the following reasons:

1. Selectivity requirements on the band filters were eased.
2. Fewer types of band filters were required.
3. Fewer carrier frequencies had to be produced.
4. As in the case of the standard group output of the channel bank, a large group of channels could be provided in a second common standard frequency range. These two provisions insured that flexibility was built into the multiplex to facilitate interconnection of systems without requiring reduction to voice frequency for all channels.

Study of traffic conditions and the economics of various arrangements led to the conclusion that in the second modulation step the output of five channel banks should be combined into a basic supergroup of 60 channels. This basic supergroup from 312 to 552 kc also became standard both in the Bell System and internationally. In the original L1 multiplex eight supergroups were combined for line allocations from 68 to 2044 kc. Later two supergroups were added at higher frequencies, which were intended only for shorter haul traffic due to transmission limitations of the line.

The multiplexing arrangements which are represented by this array of groups and supergroups and the necessary carrier supplies encompass the equipment involved in the new L multiplex as shown in Fig. 1.

About a decade after the L1 coaxial cable system became a reality, a

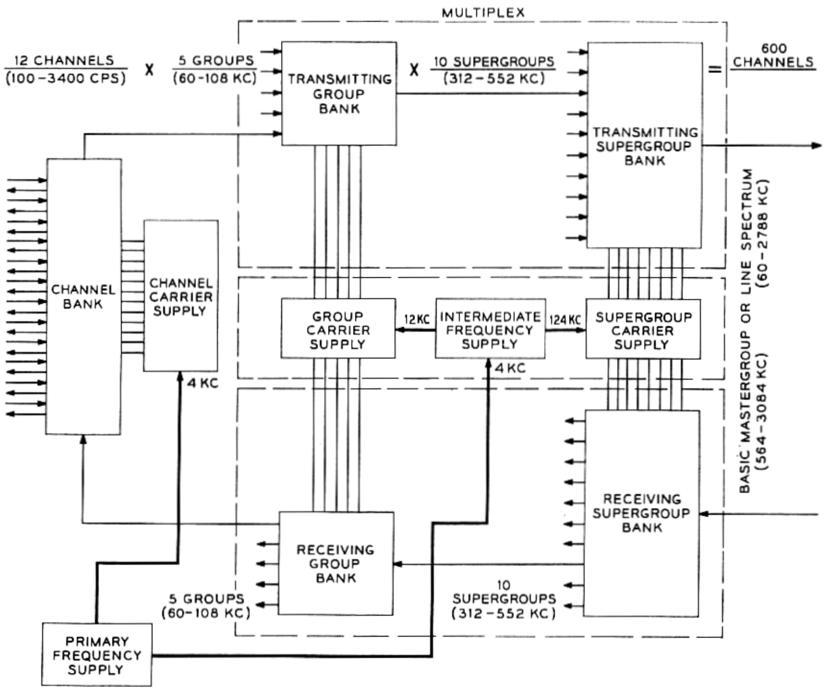

Fig. 1. — Broadband mastergroup; L multiplex equipment enclosed in dashed lines.

more complex multiplex was developed. This was required for the new L3 coaxial system[7] which employed highly refined amplifiers and pilot regulators along with extremely accurate fixed and variable equalizers. With 4-mile repeater spacing instead of the eight miles of L1, the useful transmission band was extended to about 8 megacycles. A corresponding channel capacity of over 1800 channels was achieved. To attain this larger capacity a new concept of combining three mastergroups of 600 channels was introduced. The equipment developed for this final step of modulation has not yet been redesigned. However, the new L Multiplex does provide the necessary supergroups to form a basic mastergroup for the L3 terminals.

2.4 *Multiplex for Microwave Radio*

The development of multiplex for wire systems antedated microwave radio systems by many years. However, with the design of the first commercial long-haul microwave radio system, TD-2,[8,9] it was soon evident that the earlier multiplex developed for wire systems would be satisfactory for radio terminals. The 600 single-sideband, suppressed carrier channels of the L1 multiplex matched the load capacity of a TD-2 broadband channel for many applications. The use of the same multiplex for radio and wire systems offered significant benefits in standardization. For example, it permitted efficient and flexible interchange of traffic at offices using both types of facilities.

As microwave developments progressed, the standard terminal pattern was followed. The latest long-haul radio system, TH,[10] employs the L3 mastergroup multiplex (1860 channels) on each broadband radio channel. The new short-haul lighter route radio systems, TJ[11] and TL, use partial L1 multiplex arrangements up to their maximum load handling capabilities.

2.5 *Carrier Supply*

The decision to adopt uniformly spaced channels based on harmonics of 4 kc[1] set the pattern for a common carrier supply. The earlier small-capacity systems for use on paired cables and open-wire lines used a primary generator based on a tuning fork to supply the 4 kc. Harmonics of 4 kc were formed by driving a saturable reactor as a pulse generator. The needed carriers and pilots were selected by filters. When the L1 multiplex was developed, many additional carriers and pilots were needed. Although the same general method was followed, certain alterations were made in the plan.

To obtain the higher absolute accuracy needed, the 4-kc base frequency was derived as a subharmonic from a high-stability crystal oscillator operating at the favorable crystal frequency of 128 kc. As before, the channel and group carriers were obtained from a 4-kc harmonic generator. For the supergroup carriers, however, a new 124-kc harmonic generator was added with this drive frequency derived from the 4 kc base. Frequency differences among terminals working together to provide certain special services such as VF telegraph and program were maintained to less than about one part in 10^7. Frequency precision of this order limits the shift in all channels to less than 2 cps. This was accomplished by a system of master and slave 128-kc oscillators controlled by a standard reference frequency originating at New York.

III. STANDARD ARRANGEMENTS — NEW L MULTIPLEX

3.1 *Nomenclature*

A large-capacity multiplex is assembled from many repetitive units which may be considered building blocks. Each complete multiplex is an assemblage of such blocks uniquely suitable to terminate a particular broadband facility. With the introduction of a new multiplex family, it is desirable to use a readily understood descriptive designation for each complete multiplex. The new multiplex design is radically different, but the basic system plan has been retained and the multiplex applications are identical to those of the older equipment. In view of these latter factors and the field familiarity in referring to this equipment as the "L" carrier terminal, it was decided to retain "L" as part of the various general designations. In this usage the letter L implies single-sideband channels spaced at 4-kc intervals and assembled in the standard group, supergroup, and mastergroup format.

3.2 *Standard L Multiplex Combinations*

In the older L carrier terminal, designations such as "group bank," "supergroup bank," and "carrier supply" were used. These were functionally descriptive and were logical separations since assemblages of these functional units occupied many bays of equipment. With the very great size reduction achieved in the new multiplex, these lines of separation become blurred. For example, only one transmit and one receive bay are needed to provide the group, supergroup, and carrier supply equipment for a complete 600-channel terminal. These considerations led to the descriptive coding that has been applied to the standard L multiplex family. (J coding is applied as usual for the various sub-units for manufacturing and ordering purposes.)

The various codes are:

L600A — This is the multiplex to convert as many as 50 standard groups to line frequency allocations for L1 coaxial and TD-2, TJ, and TL radio. A maximum of 600 channels is available, but smaller numbers can be provided.

L1860A — This is the multiplex to convert as many as 155 standard groups into the basic mastergroups of the L3 coaxial and TH radio systems. A total of 1860 channels (3 mastergroups + 1 supergroup) are available but fewer supergroups can be furnished. These bays do not include the final step of modulation for translation from basic mastergroup to line frequency allocations.

L60A and L120A — These differ in principle from the equipments listed above in that they are complete packages providing channel banks and voice patching units as well as the group, supergroup, and carrier supply. A total of 60 or 120 channels is available but smaller numbers can be provided. These small packages are intended to provide economical terminals for light route TJ or TL radio systems or in other special instances where ultimate traffic needs are not expected to approach the capacity of an L600A.

IV. PERFORMANCE OBJECTIVES

4.1 *General*

The ultimate objective for performance is that the new multiplex be suitable for the service demands of today and for those of the foreseeable future. One of today's more stringent demands has been brought about by customer Direct Distance Dialing. In manual operation, the end product of transmission service offered to the telephone subscriber had been inspected by the operator. In other words, a long distance telephone connection was offered to the subscriber only after the operators had conducted a satisfactory conversation over it. In Direct Distance Dialing, the subscriber himself is the first person who attempts conversation over the particular connection set up for his use by machine operation. The lack of inspection of the end product then requires much stricter maintenance of the individual facilities for adequate assurance that they will provide satisfactory service each time they are assembled in tandem to complete particular telephone connections. The number of subunits likely to be connected in tandem is increased by the complex plant layouts which make efficient use of the broadband facilities. A further increase occurs from automatic alternate routing during heavy traffic periods.

Transmission performance of the original multiplex has been generally satisfactory, and the broad objective for a new design is that its comparable performance be at least equally good. In view of the increasing emphasis on multilink operation, however, improvement in certain critical characteristics such as terminal noise and deviations from uniform frequency response across groups and supergroups would be desirable to the extent that it is economically feasible.

4.2 *Maintenance*

One important result of maintenance studies conducted over the past several years has been to demonstrate that the basic design of multiplex equipment of the same type now in the telephone plant is sound. The equipment is inherently stable in most respects, but the actual control of the net loss of telephone channels is dependent on skilled personnel to carry out a coordinated program of elaborate test and adjustment procedures. Adjustment of the flat transmission of units handling only a narrow band of frequencies is provided to compensate for departures from ideal flat transmission through units in which several of the narrow bands are handled as a single broadband of frequencies. For example, individual supergroups are adjusted to be equal at only one frequency to compensate for the frequency characteristic of the high-frequency line or radio baseband transmission. Similarly, individual groups are adjusted to be equal at only one frequency to compensate for the frequency characteristic across the supergroup. Finally, individual channels are adjusted to be equal at only one frequency to compensate for the frequency characteristic across the group band. In this way, frequency characteristics of the broader bands are equalized segment by segment. A particular set of adjustments, however, is appropriate only for the assemblage of equipment in operation at the time the final adjustments were made. Patching service to an alternate facility or substitution of spare equipment units will disturb the equalization. In fact, such mobility in the plant was found to be a principal cause of net loss deviations of individual message channels.

It also became apparent that with the increasing complexity of the telephone plant, manual maintenance methods were becoming inadequate. Accurate control of terminal transmission was dependent on the fine-grain adjustment of gains and losses of many subunits connected in tandem, where the adjustment of any one interacts with the adjustments of the others. A major difficulty was found to be coordination of the test and adjustment activities of maintenance people who may be in different offices separated by hundreds of miles. These problems point up the need for equipment design for which maintenance is less dependent on the skill of the craftsman and less demanding of his time.

Studies and feasibility trials in which new features were actually appended to the original multiplex had also demonstrated that the maintainability of a multiplex system would be enhanced by the use of terminal regulation to automate routine measurement and adjustment, and by simplifying those tests which must continue on a manual basis. By making adjustments the instant they are needed, automatic regulation minimizes the need for coordination of other adjustments. A man making a manual adjustment can feel confident that a preceding level is always being held at proper value. In other words, the usefulness of the adjustment he has just made is not apt to be destroyed by the delayed reaction of a craftsman elsewhere in the system. Regulation also provides the obvious advantage of freeing skilled manpower for maintenance tasks more demanding and less predictable than routine measurement and adjustment of pilot levels.

4.3 *Service Requirements*

Requirements for telephone service are growing more severe in at least two different ways. First, because telephone circuits are automatically made up by switches from a random assemblage of many units, individual units must be held to very close tolerances to insure a well controlled over-all net loss. Thus, requirements for precision of measurement and adjustment have become more severe than had been acceptable in the past. To meet these requirements, specific purpose test equipment is needed as an integral part of the multiplex to facilitate routine measurements of pilots in which simple and fixed selectivity, in-service test access through interlocked switching and readout on expanded scale meters are desirable design objectives. It is important also to provide convenient in-service adjustments located so that the meter can be read while making the adjustment. Meter readings should be in terms of departure from nominal to obviate the need for remembering many unique combinations of frequencies and test levels. Finally, the use of terminal regulation requires warning alarms when the necessary terminal adjustment becomes excessive. This warning will generally call for action at a location other than the receiving terminal because indications are that the levels arriving there are so far from nominal that further terminal correction will probably result in impaired performance. A pilot failure alarm is also a necessary feature to call prompt attention to a group or supergroup whose transmission has been disrupted. This feature can be had by moderate addition to the basic circuitry necessary for continuous regulation that is responsive to change in pilot output power.

A second service requirement that is growing more severe is the need for continuity of service, which will be intensified by new service offerings that encourage the use of the telephone plant outside of regular business hours to transmit data. Thus, modern equipment should not require disturbance of service merely to measure transmission accurately and to make any necessary adjustment. Therefore, a new multiplex should provide access for in-service measurement and adjustment. Hybrid-derived dual outputs have been provided in receiving units of the original multiplex to facilitate routine, in-service measurement of pilots to guide terminal adjustments. The independent hybrid output is essential to accurate power measurement to avoid the risk of serious error when power is deduced from bridging voltage measurements across impedances that are not accurately known. Similar test access is also necessary in transmitting units to facilitate maintenance of like units when it is necessary to substitute a spare for a regular unit with minimum disturbance of service.

4.4 *New Services*

In addition to providing for message service and the many forms of high-speed data services that can be handled by message channels, there is a growing need for facilities to handle even higher speed data requiring bandwidths much wider than a single message channel. Thus, a new multiplex must include terminal connectors to accommodate services which demand the wider bands available at the standard group and supergroup access to the multiplex. Group data services will displace 12 message channels; supergroup data service will displace 60 message channels.

V. PHILOSOPHY OF DESIGN

5.1 *General*

The original multiplex design dates back more than twenty years, and it was quite obvious that substantial benefit could be realized from nothing more than redesign of equipment to exploit modern components and design techniques. That simple approach, however, would neglect the importance of maintenance and fail to recognize new requirements. The actual philosophy of design has been much broader with the main purpose of producing a family of multiplex arrangements to efficiently meet the needs of today and those of the foreseeable future. The following points have been emphasized:

1. Exploit advances in the art.
2. Retain features of proven integrity in the design now in use.
3. Correct known deficiencies of the design now in use.
4. Where design differences would threaten compatibility of new equipment with old, reasonable modification of equipment in plant should be undertaken in preference to accepting compromise in the new design.

An outstanding example of advance in the art is the use of new ferrite materials in components to effect dramatic reduction in the size of filters. This is especially significant since filters represent an important part of the total bulk and cost of a frequency-division multiplex.

Design features whose operational value has been proven by years of experience include the use of single-sideband channels with suppressed carrier, standard frequency allocations for basic groups and supergroups, and the use of pilots to monitor group and supergroup transmission. All of these worthwhile features should be retained in a new design.

The multiplex equipment now in use is known to be deficient in ease of maintenance to meet the strict demands of service today. As previously discussed, the new multiplex should include terminal regulation and in-service maintenance access to minimize this deficiency. Another fault is that the older equipment was designed for heavy cross-section use and has not been economical where comparatively few channels are needed. A new multiplex design should include decentralized carrier supply, as discussed in the next section, to overcome this restriction in application.

5.2 *Carrier Supply*

In the original multiplex design, carrier power to drive the numerous modulators used in frequency translation was derived from a centralized block of interrelated equipments. Such a centralized carrier supply is economical when fully loaded because its cost is shared by a large number of telephone channels. However, this high cost of common equipment is a serious deterrent at small terminal applications. In a new design, it is practical to consider generating carrier power in small equipment units to be mounted close to the point of use. Such a decentralized carrier supply minimizes the cost of getting started and enables the addition of carrier supply capacity in smaller increments as needed. A supplementary benefit of decentralization is to minimize the bulk of interbay cabling. This is possible because it is sufficient to distribute a single base frequency in place of the several individual harmonic frequencies needed for carriers in modulation. The objective is to decentralize carrier supply to the extent that small cross-section terminals become more economical, without significant cost penalty at the heavy cross-section terminals.

5.3 *Compatibility*

It is essential that multiplex equipment of new design be compatible with that of older design because, in the normal process of plant extension, it will sometimes be necessary for a new terminal to work with one of older design at the opposite end of the high-frequency transmission medium. Even when new and old designs of terminal are used in juxtaposition in the same office, they must be operationally alike to facilitate maintenance and enable service restoration in emergencies. At the expected high rates of future production, however, the penalty of compromise in the new design to retain compatibility would apply to an indefinitely large number of units, whereas reasonable modification of older equipment to resolve incompatibility will apply to a definite number of units already in plant.

The rapid rate of growth of multiplex equipment in the Bell System plant is illustrated in Fig. 2. The curves show the number of broadband terminals shipped for L multiplex use over the past years. Broadband terminal is the unit used in programming factory production and includes proportionate shares of the multiplex equipments needed for one terminal having a message-circuit capacity of 12 channels. The lower plot shows shipments each year, and these fluctuate with business conditions. The upper curve is a plot of the cumulative total shipments, which shows a definite exponential trend in rate of growth that has persisted over the past ten years. The straight-line approximation corresponds to an annual rate of increase of about 20 per cent per year which implies that the total quantity in plant will double in about four years. It is this high rate of growth that has encouraged consideration of accepting the cost of modernizing the older equipment by modification to retain compatibility, rather than accept a compromise in the new design.

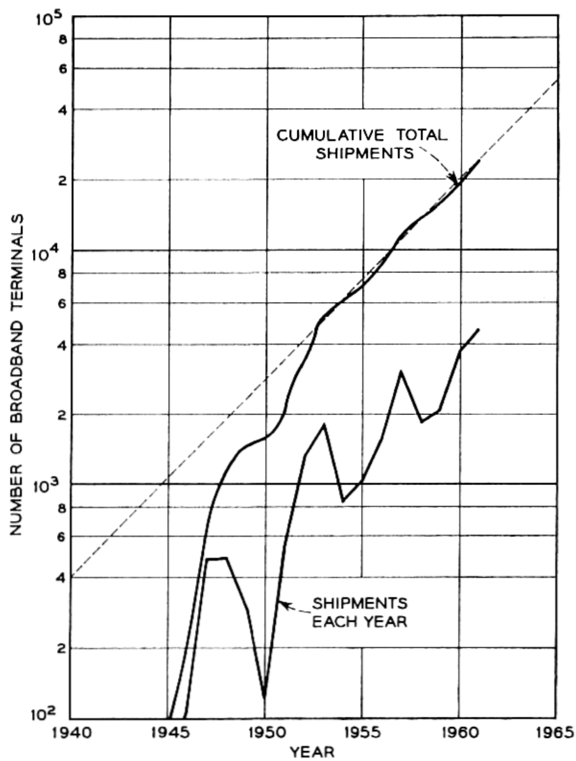

Fig. 2 — Broadband terminals shipped by Western Electric Co., 1945-1961.

An example of deliberate acceptance of incompatibility to be resolved by modification of the older plant is the new frequency allocation for Supergroup No. 1. The Bell System standard frequency allocation for Supergroup No. 1 has been the band from 68 to 308 kilocycles, and it is being changed to a new standard allocation from 60 to 300 kilocycles. This will result in additional guard space between the upper edge of Supergroup No. 1 and the lower edge of the basic supergroup, which eases substantially the design requirements on band filters for Supergroup No. 1. It is estimated that the long-term savings in filter cost for new terminals due to the change in frequency allocation will be greater than the total cost of modification of plant in service in a reasonably short time, and that substantial savings will accrue beyond that time. In addition to economy, there should also be an intangible advantage in minimizing conflict between frequency allocations standard in the Bell System and those recommended internationally.

A second example of incompatibility accepted for resolution by modification of plant in service is the use of a single transmitting cable from channel bank to group equipment. Hybrid-derived dual outputs have been provided at the transmitting carrier frequency side of A-type channel banks for test access and to facilitate in-service patching of group equipment. The hybrid coil has been an integral part of the channel bank with both outputs cabled from there to the high frequency patch bay. A single cable will be used by locating a miniature hybrid coil in the high frequency patch bays of existing installations and in the new transmitting multiplex bays. The use of a single transmitting carrier cable will result in significant reduction in cost of installation for each new channel bank, and these savings are expected to more than counteract the expense of modification where older type channel banks are to be used with the new multiplex. In addition to long-term economy, there will be considerable relief from office cable congestion, a matter of increasing concern and expense to the operating companies. The use of single cable also enables the design of a compact group distributing frame, a new equipment item that is needed urgently to reduce the time and expense of necessary plant rearrangement to accommodate growth and changing pattern of traffic.

5.4 *Continuing Development*

The companion papers previously cited describe the multiplex development completed to date. Studies are continuing to formulate design objectives for the development of other new equipment used in close conjunction with the multiplex. A matter of increasing concern is the need to insure continuity of service under emergency conditions. Emphasis is being placed on new equipments for the following purposes:

1. To enable centralized control and maintenance of the carrier facilities.
2. To prevent the propagation of trouble into otherwise unimpaired facilities.
3. To accelerate prompt restoration of service.

Another important area of study is concerned with the operational integration of standard wideband data service with basic telephone message service. Study to date of the latter area has already led to the decision to change the standard frequency allocations of the terminal pilots of the L-type multiplex. At present, a 92-kc pilot is used to monitor the transmission of each group, and the Group 3 pilot translated to 424 kc is used to monitor each supergroup. These choices are satisfactory for message service in that pilots are located near the center of the band they monitor and correspond to zero frequency or 4000 cycles per second in adjacent message channels. Since message service does not require the transmission of frequencies close to either of these extremes, the pilots do not interfere with message service and allow in-service measurement and adjustment of group and supergroup with minimum reaction on service. When the wider bands are offered for data service, however, the presence of a pilot near the center of the band is a serious restriction. This presents a basic conflict of interest in that a pilot is considered essential to good maintenance and yet its presence near the center of the band is a deterrent in standard wideband data service. The conflict has been resolved by agreement to move the pilots close to the edges of the wider bands, using 104.08 kc for group pilot and the Group 1 pilot translated to 315.92 kc to monitor supergroup transmission. These choices appear to sacrifice 4 kc of available bandwidth but the actual waste is much less because delay distortion impairs the band edges so that they would not be of much value in data transmission. The offset of 80 cps from an exact multiple of 4 kc is planned to obviate the need for an expensive crystal filter to guard against interference from channel carrier leak. It is recognized that changing the entire Bell System plant to new standard-frequency allocations for terminal pilots will incur substantial expense to convert existing equipment. Nevertheless, integration of wideband and message service is considered essential to future efficient use of the plant, and present indications are that a major part of the cost of conversion will be recovered in filter savings resulting from the use of an offset frequency.

VI. CONCLUSION

The new family of L-type multiplexes will enable the operating telephone companies to meet efficiently the need for modern communications over the coaxial cable and radio plant of the Bell System. Significant reductions in space and power requirements along with regulation and other operational advantages are made available for slightly lower first cost of installed equipment. Long-term economy should result from improved service due to more effective maintenance with less expenditure of effort.

REFERENCES

1. Blecher, F. H., and Hallenbeck, F. J., B.S.T.J., **41,** Jan., 1962, p. 321.
2. Graham, R. S., Adams, W. E., Powers, R. E., and Bies, F. R., B.S.T.J., this issue, p. 223.
3. Albert, W. G., Evans, J. B., Jr., Ginty, J. J., and Harley, J. B., B.S.T.J., this issue, p. 279.
4. Clark, O. P., Drazy, E. J., and Weller, D. C., B.S.T.J., this issue, p. 319.
5. Abraham, L. G., Trans. A.I.E.E. **67,** 1948, p. 1520.
6. Crane, R. E., Dixon, J. T., and Huber, G. H., Trans. A.I.E.E. **66,** 1947, p. 1451.
7. Elmendorf, C. H., Ehrbar, R. D., Klie, R. H., and Grossman, A. J., B.S.T.J., **32,** July, 1953, p. 781.
8. Grieser, T. J., and Peterson, A. C., Elect. Engg., **70,** Sept., 1951, p. 810.
9. Roetken, A. A., Smith, K. D., and Friis, R. W., B.S.T.J., **30,** Oct., 1951, p. 1041.
10. McDavitt, M. B., Trans. A.I.E.E., **76,** Part 1, Jan., 1958, p. 715.
11. Gammie, J., and Hathaway, S. D., B.S.T.J., **39,** July, 1960, p. 821.