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A Carrier System for 8000-Cycle Program Transmission

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With the rapid expansion of broad-band carrier telephone systems throughout the country, the use of these facilities for program transmission has become desirable. This paper describes a carrier program system capable of transmitting a band up to about 8000 cycles wide.

Introduction

FROM the beginning of radio the Bell System has supplied the broadcasting industry the needed interconnecting links between broadcasting stations, studios, and other program originating points. For many years these facilities have been provided at audio frequency over loaded cable pairs,[6] or over open-wire lines.[8] Because present growth of message facilities over main traffic routes is predominantly in broad-band carrier telephone circuits, it has become desirable to adapt these new carrier facilities for the transmission of high-quality program material.

The carrier program system to be described operates in conjunction with message circuits and can be used to provide a band width of either 5000 or 8000 cycles. It can be applied to type K multipair cable,[9] type L coaxial cable,[16] and type J open-wire carrier systems.[11] Use of the 8000-cycle band of course requires more complete equalization than the 5000-cycle band, and requires the frequency space normally occupied by three message channels. It is expected that the 5000-cycle band can be accommodated by displacing two message channels. The carrier program system was developed by 1942 but, owing to the war, its first commercial application was not made until early in 1946 on the transcontinental type K route west of Omaha. It is now in use in all sections of the country, particularly the west and south, on type L as well as type K systems and has been successfully tested on type J. In general, a band width of 5000 cycles is used in these applications.

Objectives

Existing audio-frequency program circuits may be as long as 7000 miles, may have 100 or more dropping or bridging points, any one of which may occasionally transmit to all of the others, and may be arranged for automatic reversal of the direction of transmission by means of a control signal.

In order to coordinate with these existing circuits and studio loops, a carrier program system must be capable of duplicating this flexibility while maintaining the desired standards of quality of transmission.

In setting an objective for the standards of transmission quality of this new system the trend towards wider band widths has been recognized. Most of the major networks now use a 100 to 5000-cycle band width. A large part of the present audio-frequency cable facilities, however, can be arranged to transmit a band from 50 to 8000 cycles. It was decided to match this grade of transmission in the design of the new carrier system. For the cases where still higher quality is desired, a 15-kilocycle carrier program system has been developed and is now available.

Design Features

The 12-channel bank of message circuits forms the basic building block of the broad-band carrier telephone systems. In the channel bank, each of the 12 voice-frequency channels modulates one of 12 carriers spaced 4 kilocycles apart from 64 to 108 kilocycles. The lower sideband resulting from each modulation is selected by a band filter and combined with the other 11 lower sidebands to give a channel group occupying the frequency space from 60 kilocycles to 108 kilocycles. This channel group is then further modulated as a unit to its appropriate place on a broad-band spectrum for transmission over the line.

In order to arrange a channel bank for program transmission, message channels, 6, 7, and 8 are disabled, clearing a space from 76 kilocycles to 88 kilocycles in the group-frequency spectrum. In a program terminal separate from the channel bank, an audio frequency program modulates an 88-kilocycle carrier derived from the message channel carrier supply. Its lower sideband is selected by a band filter and, combined with the lower sidebands of message channels 1 to 5 and 9 to 12, gives a group-frequency spectrum shown diagrammatically in Fig. 1. This figure also shows the same spectrum after it has been modulated with a 120-kilocycle group carrier for transmission over a type K line. Other line-frequency spectra are similarly produced in type J and type L group modulators.

The reversing and control signal in an audio-frequency program circuit is a d-c. signal superimposed on the program pair. It may be applied at the studio which originates the program, and conditions all of the amplifiers along the line to transmit away from the originating studio. As long as the signal is applied, the direction of transmission is locked so that no other control station can inadvertently break the network. When the transmission from this studio ends, the signal is removed, and the next originating point applies it. This effects such reversals as are required for transmission and again locks all amplifiers. By this means it is possible to use a single pair of wires and one set of amplifiers for transmission in either direction as required. The carrier system over which the carrier program channel is transmitted is constantly in operation in both directions simultaneously, and therefore requires no reversal. The program terminal itself, however, must be switched between transmitting and receiving lines if equipment is not to be needlessly duplicated for transmitting and receiving. In any case, a control signal must be carried through the carrier circuit and delivered to connecting audio-frequency circuits at the receiving end as a d-c. signal. This is accomplished by means of a 78-kilocycle control signal (42 kilocycles at K line frequencies) which is transmitted along

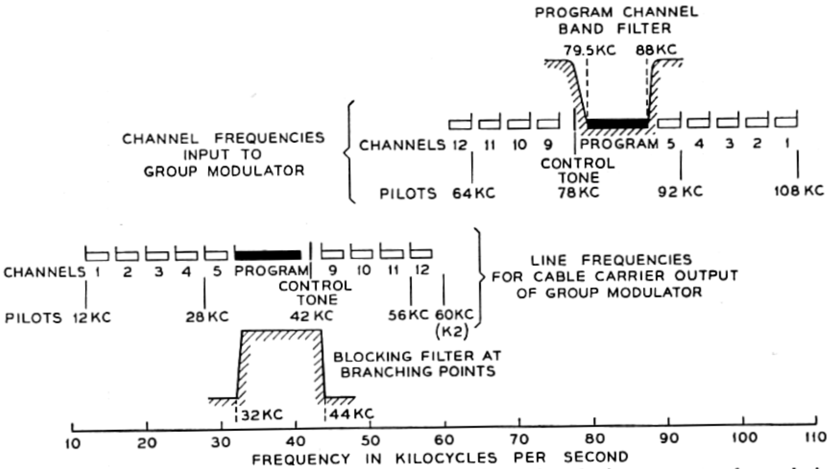


Fig. 1—Frequency allocation for one program channel and nine message channels in cable carrier systems.

with the program channel outside of its frequency band. This signal is generated in the transmitting program terminal whenever the d-c. signal is impressed from the transmitting audio-frequency circuit. At the receiving program terminal, the tone is converted into a d-c. signal which is impressed on the receiving voice-frequency facility. When there is no transmitted d-c. signal, there is no high-frequency signal and no received d-c. signal. Each program terminal, then, is ready either to receive d-c. from the voice circuit and send out 78 kilocycles to the carrier circuit or to receive 78 kilocycles from the carrier circuit and send out d-c. to the voice circuit. The program transmission path is maintained in the last established direction, regardless of the presence or absence of control, until a reversing signal is received.

The arrangement of the circuit elements in a carrier program terminal is shown in the block schematic of Fig. 2. The transmission circuit wiring is

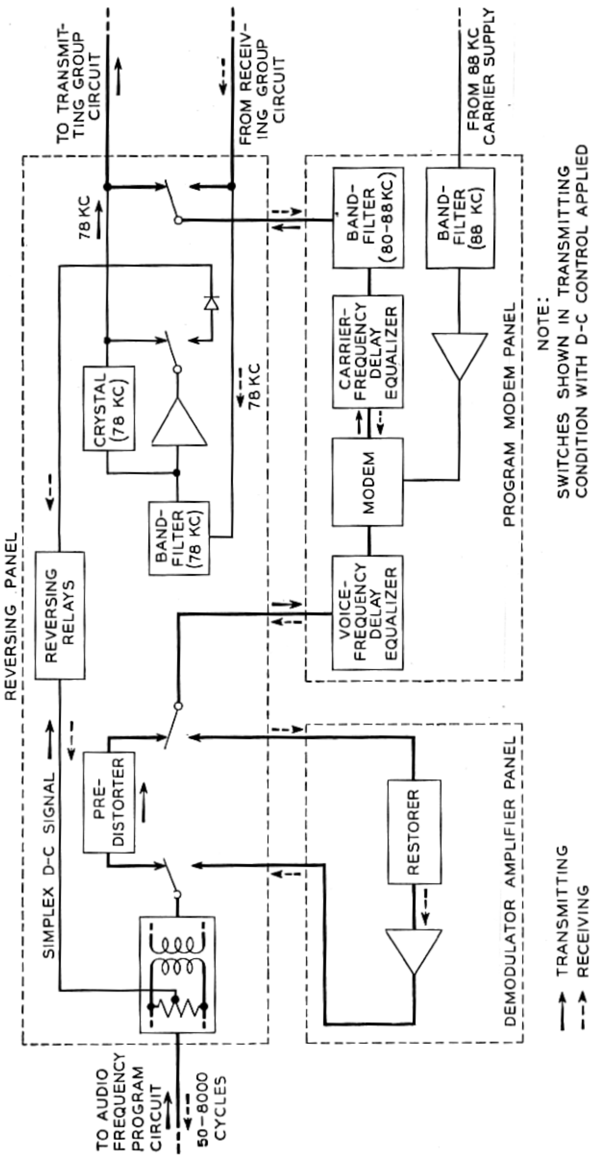


Fig. 2—Block schematic of carrier program terminal.

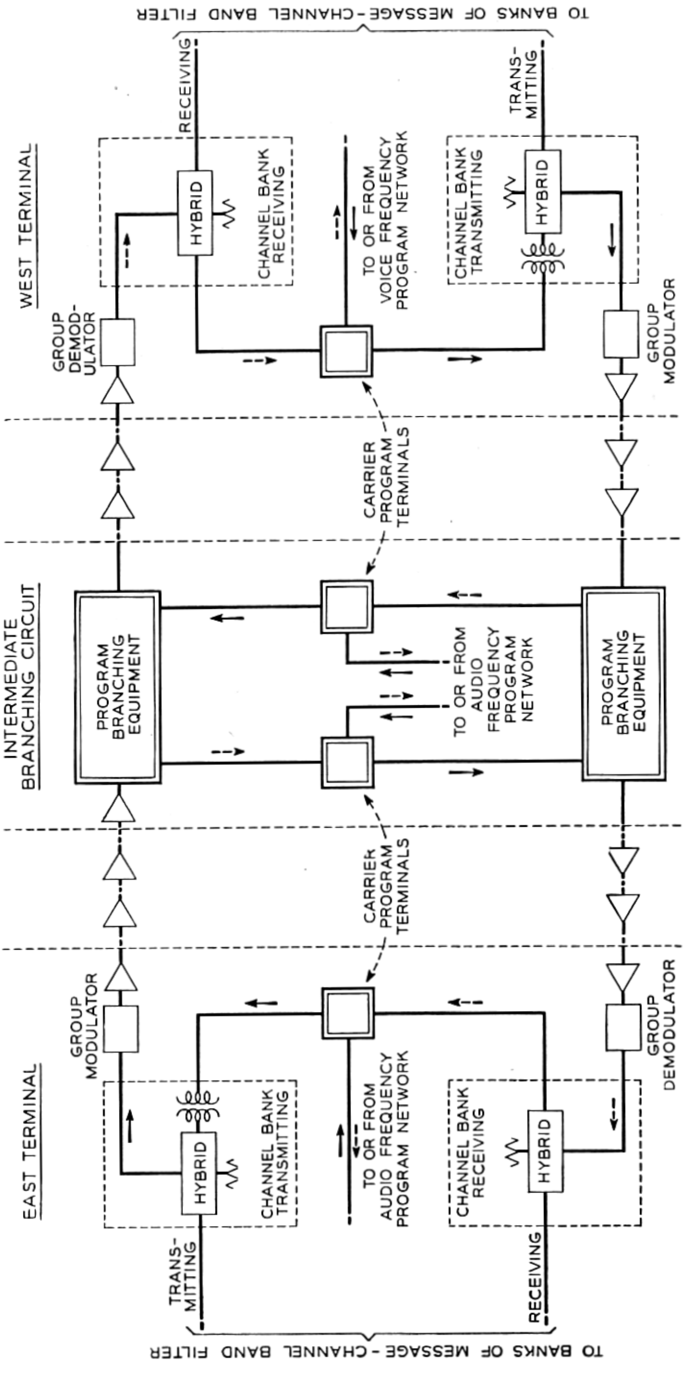


Fig. 3—Program link of cable carrier system with one intermediate branching point.

shown in heavy lines. The reversing and control circuits, indicated in light lines, are permanently connected to the external audio-frequency circuit and to the transmitting and receiving carrier line circuits regardless of the condition of the switching relays. Figure 3 shows a carrier program system including two terminals and a branching point as it is connected to a type K system. The program equipment is identified by double-line blocks. The carrier program terminals are connected into the networks in the same way as the audio-frequency facilities, through equalizers, amplifiers, bridges, and reversing circuits. Connected as one leg of a reversible bridge, a carrier program circuit may feed or be fed by any of the other legs, which may include cable, open-wire, studio loop, or other carrier circuits.

Terminal Circuit

As Fig. 2 indicates, a carrier program terminal consists of three elements: a modulator-demodulator or modem, a demodulator amplifier, and a reversing and control circuit. The heart of the terminal is the modem, which translates the program material from its original audio band to its desired position in the carrier-frequency spectrum or vice versa. It consists essentially of the non-linear varistor to which the carrier and program material are applied, and the band filter which selects the desired sideband from the modulation products. The varistor is connected in the double-balanced bridge arrangement in which the signal, carrier, and sideband circuits are each balanced against the other two. It is composed of copper-oxide elements and, in order to meet the conflicting requirements for high carrier-to-signal ratio and low transmitted carrier leak, a high degree of balance between the varistor bridge arms must be maintained. This is accomplished by building up each bridge arm of 16 copper-oxide elements connected in series-parallel. This modulator as compared to one using single-element bridge arms, has the same impedance, 12 decibels better carrier balance, 12 decibels greater carrier power capacity, and with the higher carrier power, 12 decibels lower non-linear distortion products. An amplifier provides the required power and a narrow-band filter gives additional suppression to carrier frequencies of other channels which are fed from the same carrier supply.

The band filter, which represents a major development in itself and is described in another paper,[17] introduces a considerable amount of delay distortion. This is corrected by delay equalizers incorporated in the modem circuit as shown in Fig. 2. Most of the delay correction is done in the audio-frequency branch of the circuit by a 31-section network which also includes equalization for the small residual attenuation distortion of the filter in its pass band. At the lower end of the audio-frequency band, however, attainment of the required phase characteristic with audio-frequency elements is more difficult. Consequently, the delay correction for that portion of the band below 1000 cycles is actually done at sideband frequency, using quartz crystal elements. The design of these delay equalizers is described in another paper.[18] Transmission through the resulting modem unit is essentially constant in both attenuation and delay over the usable frequency range.

The demodulator amplifier is a conventional two-stage resistance-coupled amplifier. It is stabilized by 25 decibels of feedback to a nominal gain of 38 decibels, variable over a 12-decibel range by a potentiometer in the feedback circuit. The transmission characteristic is flat within 0.3 decibel over the 35 to 15,000-cycle frequency range. The output impedance is stabilized by the use of an output bridge for obtaining the feedback voltage. This amplifier feeds a -10 vu point in the circuit and can deliver up to $+18$ decibels above one milliwatt of output. Noise is kept to a minimum by operating the input stage vacuum tube at reduced voltages, mounting it and the magnetically shielded input transformer on a vibration-reducing suspension, and providing heavy filtering for the A and B battery circuits.

The limiting source of noise in any communication system is usually the transmission medium. In the carrier program system, the transmission medium is a carrier system which introduces noise energy equally distributed over the program band. The program energy being transmitted, however, is heavily concentrated at the lower frequencies. In order to increase the signal-to-noise ratio without an increase in total transmitted power, a predistorting network is introduced ahead of the modem, which attenuates the lower frequencies relative to the higher. The total discrimination is about 18 decibels, distributed symmetrically on a logarithmic frequency scale above and below 1500 cycles. A restoring network having an inverse characteristic is inserted in the receiving program path to return the program energy distribution to normal. The noise improvement thus obtained is about 7 decibels.

The reversing circuit consists of a set of five relays and a 78-kilocycle amplifier-oscillator. Two of these relays, as shown in Fig. 4, set up the transmission circuits for transmitting or receiving. The transmitting relay connects the predistorter in the audio-frequency circuit and connects the modem output to the transmitting high-frequency line. The receiving relay connects the modem to the receiving high-frequency line and inserts the restorer and demodulator amplifier in place of the predistorter. These relays are interlocked so that only one at a time can be operated. Their operation is supervised by two other relays, one transmitting and one receiving, which respond to the transmitting and receiving control signals respectively. The supervisory relays are similarly interlocked so that the control signal from only one direction at a time can be effective. They are so connected to the transmission relays that, when no control signal is applied, both supervisory relays are released and the transmission relays maintain the circuit condition established at the last reversal.

A two-stage, tuned, feedback-stabilized amplifier is used to raise the level of the 78-kilocycle receiving control signal selected from the receiving high-frequency line by a narrow-band crystal filter. A copper-oxide rectifier converts the amplified signal to d-c. to operate a sensitive relay connected

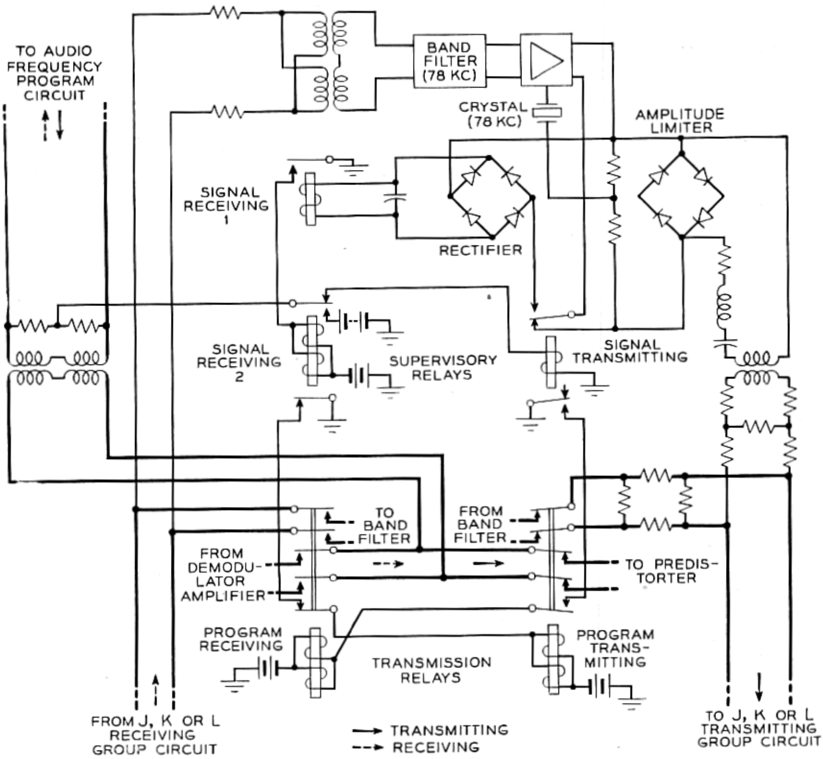


Fig. 4—Schematic of reversing and control circuit.

to the receiving supervisory relay. The supervisory relay, besides controlling the transmission circuits, also sends on a control signal as a d-c. simplex on the audio-frequency pair leaving the program terminal.

The same 78-kilocycle amplifier used for receiving the control signal is also used as an oscillator to generate the high-frequency control signal in the transmitting direction. The transmitting supervisory relay, under the control of a d-c. control signal coming in on the audio-frequency pair, disconnects the receiving control signal rectifier and connects instead a varistor limiter across the output and a 78-kilocycle crystal from the output to the input, phased for positive feedback.

Type K Branching Circuit

Because of the operating requirements of a radio broadcasting network there is need for complete switching flexibility. On a national network there may be scores of intermediate points, where the program must be tapped for local broadcasting and may originate in the case of special events. If, to obtain this flexibility, the network were made up of short carrier links, bringing the program down to audio frequencies at the end of each link, there would be in some cases, between the originating studio and the most distant broadcasting station, 50 to 100 or more links in tandem, involving double that number of band filters. Terminal phase and attenuation distortion, however, are proportional to the number of links. By means of advanced filter and equalizer designs, the present system has been made suitable for about 10 to 13 links in tandem. Additional arrangements therefore are needed at intermediate points to serve local broadcasters, without breaking in on the through program transmission. The branching circuit serves this need. End branching circuits which split off a program circuit from a carrier message route are needed for some network branches and are less elaborate than the through branching circuits which provide full switching service at intermediate points on a main trunk route.

The flexibility of the through branching circuit is illustrated in the following functions which it performs under remote control:

1. Provides a receiving leg on a reversible through program circuit.
2. Splits the network to provide independently reversible links in each direction with the same or different program material on each link.

These functions are performed with negligible reaction on the associated through-message circuits. A block schematic for one direction of transmission on a type K system is shown in Fig. 5.

For splitting the network a band elimination filter[17] blocks frequencies in the program assignment (32–44 kilocycles) while passing the remaining message frequencies. As network rearrangements are made during the program switching interval transmission may be rerouted through the phase simulating network[17] which is substituted for the BEF when the program is to go through instead of being blocked. The simulation of phase, which must be close in order to avoid disturbance of voice-frequency telegraph superimposed on any of the message channels, extends over all but the two channels adjacent to the program. The transfer from one transmission path to the other is accomplished by a chain of make-before-break relays in such a manner that transmission on the message channels is virtually unaffected.

Junctions of transmission circuits are made with resistance hybrid con-

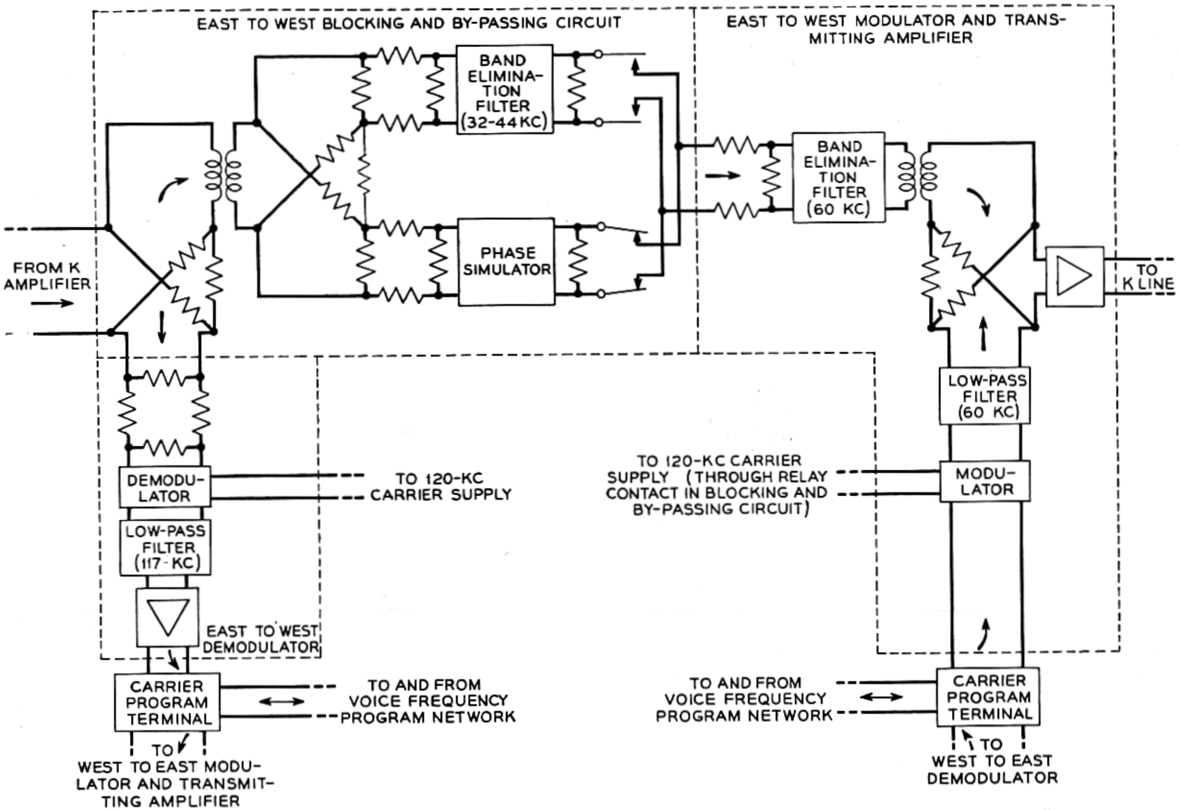


Fig. 5—Block schematic of type K branching circuit (one direction of transmission represented).

figurations to minimize transmission distortion and to give some directional discrimination.

Frequency translation from the 32–40 kilocycle range of the program on the line to the 80–88-kilocycle range of the program terminal is provided by modulating and demodulating circuits having 120-kilocycle carrier. It is of interest to note that the transmitting 120-kilocycle carrier is supplied through relay contacts which are normally open so that spurious noise and transmission will not interfere with the through program. The relay contacts are closed when the blocking filter is in circuit, thus permitting a local program origination only when the through circuit is cut off.

Relay control circuits have been arranged to coordinate with existing control practices and circuits so that reversibility may be under studio control and network splitting under local control.

Gain to offset circuit losses is supplied at the output by a transmitting amplifier so that the over-all loss of the through circuit is zero. Patching to spare circuits is thus facilitated.

In a K2 carrier system[15] the transmitting amplifier has unique properties in that it is self-oscillating at 60 kilocycles at an amplitude which complements the signal amplitude to produce a constant total output power. This feature is used as a carrier system line regulation control, and when a new program originates at the branching point it is necessary to generate another 60-kilocycle signal to complement the new total signal output, and to effectively block all 60-kilocycle received from the previous line section. A 60-kilocycle BEF is provided for that purpose.

These branching arrangements, developed for type K systems, have also been adapted for use with type L groups. Blocking and bridging functions are provided as they are for type K and in addition to the complete branching circuits, include simplified arrangements which make use of otherwise idle groups for carrier program circuits without message channels.

Branching Circuit Performance

The performance characteristics of the blocking and by-passing circuits are shown in Fig. 6, which represents transmission vs. frequency over the type K range of line frequencies. The solid line gives the normal transmission characteristic for through transmission of the program and the nine message channels. The dotted line is the program blocking characteristic indicating 80-decibel minimum suppression over most of the 32–44-kilocycle frequency range. The dashed line is the characteristic effective during the brief interval in the switching process when both branches of the circuit are connected. Its similarity to the other two characteristics is a measure of the effectiveness of the phase simulation over most of the message channel spectrum. Its departure from the other characteristics in the channel 5 and channel 9 allocations marks the end of the region in which the phase of the blocking filter can be successfully simulated. Outside of this region, in parts of channels 5 and 9, the switching operation shifts both phase and amplitude of the transmission and precludes the use of these channels for voice-frequency telegraph or telephoto services.

Equipment

As previously stated a carrier program terminal consists of a modem unit, a demodulator-amplifier panel, and a reversing panel. As shown in

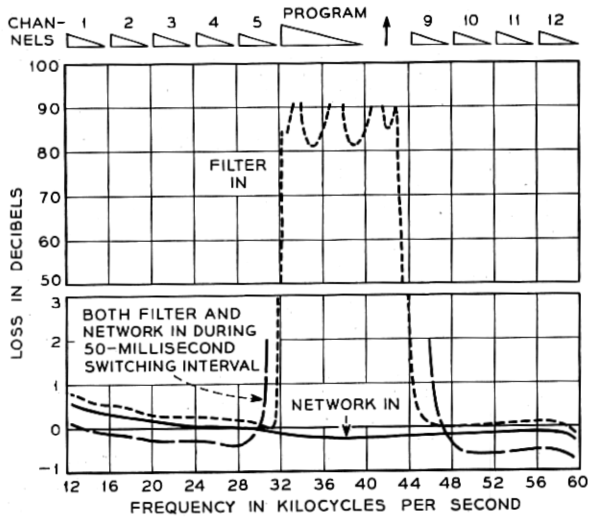
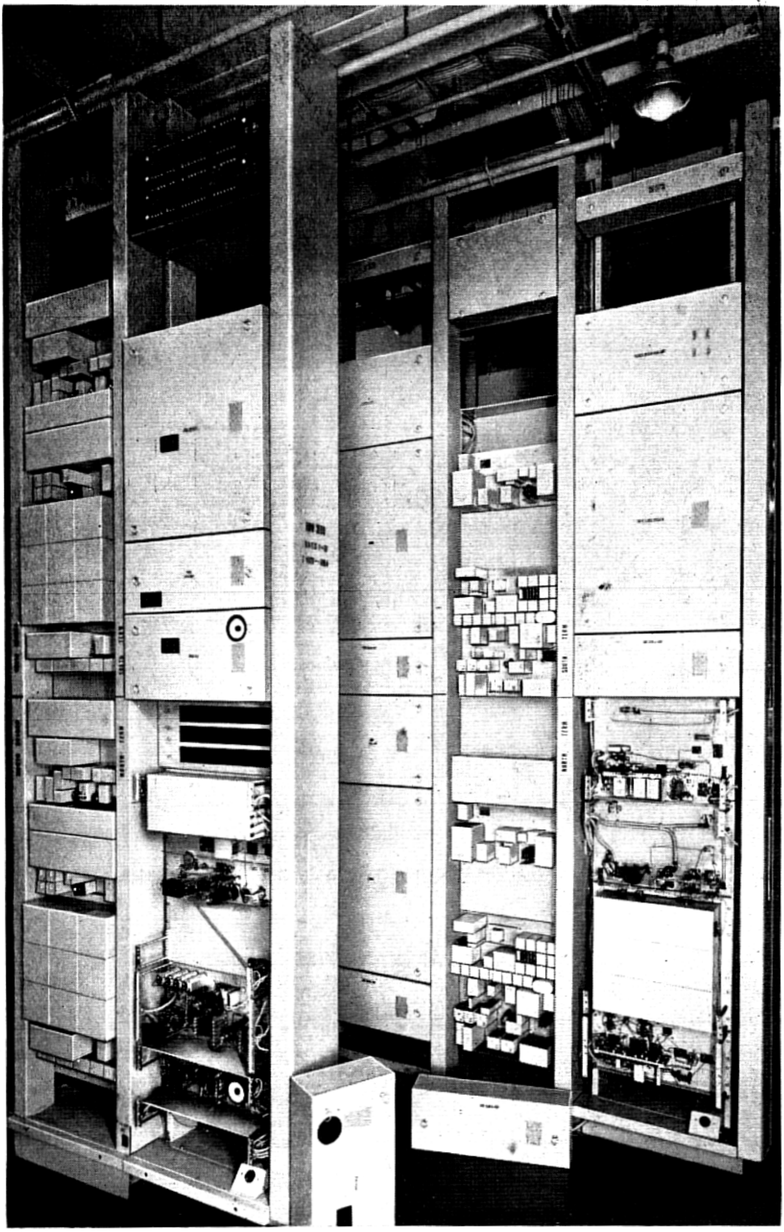


Fig. 6—Transmission characteristics of blocking and by-passing circuit under normal conditions and during switching.

Fig. 7 two such terminals, together with fuse panels for 24 and 130-volt battery supply for several bays, are mounted in one standard cable duct type bay 19″ wide and 11′6″ high. The equipment is mounted on the bay in a group, from top down, in the order mentioned. The front or wiring side of the equipment is provided with three separate covers which furnish the necessary electrical shielding as well as physical protection. Connections to carrier systems are made through carrier program high-frequency patching jacks on a 4-wire basis and to the program circuits through audio frequency testing jacks on a 2-wire basis from which point the carrier program channel is lined up for program service at the proper transmission levels for both directions of transmission.

A through branching circuit consists of two sets of line bridging equipment and two carrier program terminals mentioned above. As shown in



LINE BRANCH BAY (FRONT) TERMINAL BAY (FRONT) TERMINAL BAY (REAR) LINE BRANCH BAY (REAR)

Fig. 7—Photograph of an early installation of carrier program terminals and associated type K branching circuits.

Fig. 7 the line bridging equipment is mounted in one standard cable duct type bay 19″ wide and 11′ 6″ high. The equipment for each direction of transmission is mounted on the bay in a group consisting of a modulator and transmitting amplifier, blocking filter and by-passing network with switching relays, and demodulator and demodulator-amplifier. The rear or wiring side of this equipment is also provided with three separate covers. The apparatus or front side of two of the panels, modulator and demodulator-amplifiers, is equipped with parallel vacuum tube sockets so that the vacuum tubes can be removed from the circuit for testing purposes without

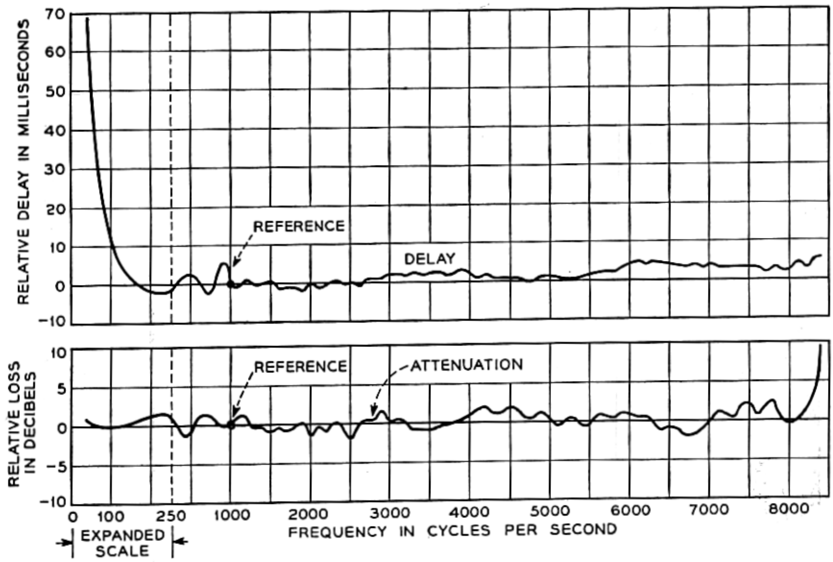


Fig. 8—Typical 10-link attenuation and delay distortion characteristics. The length of this circuit was 7300 miles.

interfering with service in the same manner as is done on K2 carrier telephone equipment.[15]

The necessary carrier supply for this equipment is obtained from regular standard carrier supply bays used for other broadband carrier equipment. The presence of undesired residual harmonics of 4-kilocycles from this carrier supply necessitates modification of the carrier circuits at several points to provide additional suppression to undesired components which would otherwise appear as 4 or 8-kilocycle tones in the program channel.

System Performance

The longest commercial network circuits now in operation are in the order of 7000 miles long, including the transcontinental backbone route and feeder circuits along the Atlantic and Pacific coasts. On the assumption that these routes may some day be largely in carrier, exhaustive tests were made in 1947 of carrier program transmission applied to type K systems between Omaha and Los Angeles, looping back and forth as required to build up long circuits. Live program material transmitted around a 7300-mile loop consisting of 10 carrier links in tandem was judged to be of excellent quality by juries composed of experienced and critical observers. Attenuation and delay characteristics of this circuit relative to the 1000-cycle point are shown in Fig. 8 and indicate that design objectives are met with enough margin to justify practical operation over about 13 links in tandem. Background noise was about 53 decibels below the peak signal. Frequency shift due to differences in carrier frequency at the 20 terminals was less than 2 cycles. The time required for a complete reversal counting from the initial control signal release was 3 seconds. Shorter lengths will, of course, have even better performance. These characteristics, while they do not represent perfection in transmission quality, strike a balance between the various engineering limitations, which makes this system compare favorably with the best facilities previously available.

Conclusion

At the end of 1948, three years after the first installation, there were approximately 75,000 miles of carrier program circuits in service, about 70 per cent of them established full time. This is a substantial proportion of the total mileage of all grades of program service, which is in the order of 175,000 miles. The portions of the main transcontinental routes formerly carried by open-wire lines are now in carrier cables.

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