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## CHAPTER 2

### CARRIER SYSTEMS

#### 2.1 INTRODUCTION

In the early history of the telephone system one of the major transmission problems was the struggle for distance. As telephone lines became longer and longer a serious technical limitation became more and more apparent. This was the progressive weakening of the speech currents as the distance increased. The principle of inductive loading helped extend distance but there still remained definite limits of practical telephony. These limits were overcome with the dawn of the electronic era, in which the vacuum tube made it possible to stretch the range of telephony to unlimited distances by wire and radio. The application of the vacuum tube to telephone repeaters made it possible to compensate for loss of signal strength by amplifier gain.

When vacuum tubes made amplification available for application to telephone lines, research was aimed at utilizing these lines more efficiently. The outcome of this research was a powerful new transmission method - the application of the carrier principle to wire lines. The method is to convert the audible frequencies of a communication channel to a corresponding band of frequencies centered about, or otherwise related to a particular frequency beyond the audible range, known as a carrier frequency. By suitably spacing such carrier frequencies over a comparatively wide range, several communication channels may be combined to transmit signals or voice over a single pair of wires, without interference from one channel to another.

The next two chapters will be devoted to the systems which were developed from these transmission improvements - namely the carrier system and the repeater. The discussion on repeaters will be limited to voice frequency repeaters. Carrier systems also make use of repeaters but these will be considered as an integral part of each system.

Before beginning this discussion, however, it is advisable to define several common transmission terms.

Voice Frequency Systems - Systems which transmit intelligence over lines at frequencies which fall within the useful portion of the audible spectrum; in general, the frequencies are between 200 and 4000 Hz.

Carrier Systems - Systems which employ some form of modulation at each end of the circuit, so that the signal is transmitted at frequencies above the principle audible range.

Two-Wire Operation - By its basic nature a telephone conversation requires transmissions in both directions between the customers at opposite ends of a transmission system. In the early days of telephony, most transmissions were made over paired conductors (or wires) and the transmissions in opposite directions used the same electrical path between the customers. At switching points the two transmission path terminals of one circuit were connected through cord circuits or switching mechanisms to the two transmission path terminals of a similar circuit. This method of transmission and switching was therefore designated as two-wire operation.

Thus by definition, transmission and switching operations are "two-wire" when oppositely directed portions of a single conversation occur over the same electrical transmission path or channel.

Four-Wire Operation - When carrier system operation was introduced into the open wire plant and circuits of increasingly greater length were routed in cable plant, echo and singing considerations made it necessary to separate the electrical paths used for oppositely directed transmissions between the customers involved in a single conversation. This separation is accomplished by either or both of two methods, as follows:

- a. Separate pairs in outside plant and office cabling
- b. Separate carrier frequency bands.

In the larger intertoll switching mechanisms used today such separation is also maintained through the switches.

Because two separate pairs (or 4 wires) were used for the oppositely directed transmission paths of many of the longer voice-frequency circuits in cable, circuits operated in this manner were designated as Four-Wire circuits.

Thus, by definition, transmission and switching operations are Four-Wire when the oppositely directed portions of a single conversation are routed over separate electrical transmission paths.

A distinction is sometimes made between the two methods of four-wire operation. Systems using the same frequency band in two separate paths for the two directions are said to give "real four-wire operation"; those using two frequency bands over a single path are said to provide "equivalent four-wire operation."

## 2.2 GENERAL

In the early days of telephone communication, speech was transmitted over the wirelines only at its natural voice frequencies. It was soon realized, however, that this was a very inefficient use of the costly wire plant, since the lines are capable of transmitting a much wider frequency band than the 3KHz or so required by speech. The incentive was strong for developing systems which could utilize some of the wasted frequency band above 3 KHz to provide additional telephone channels. The advent of the electron tube provided the needed tool for such a development, and the first carrier system made its appearance during World War I. This system, designated type "A", is now obsolete, and has been followed by a succession of carrier systems designated by the letters of the alphabet, which are briefly described in this chapter.

All of the carrier systems, except the type "L" which requires coaxial cables or microwave radio systems, were designed to be applicable to one or more of the already existing types of line facilities. The application of a carrier system to a line requires the addition of carrier terminals and repeaters, and frequently also, special treatment of the line itself such as the carrier transposing of open-wire lines or the balancing of cables. The cost of this equipment and line treatment therefore represents the cost of the telephone channels furnished by the carrier system.

A carrier system would not be used unless it proved in economically. For a carrier system to prove in, the cost of obtaining additional telephone channels by means of the carrier system must be less than the cost of obtaining the same number of channels on that route by other means, such as stringing new wires or cables and equipping them with voice frequency systems. An important part of the cost of carrier systems is the cost of the terminals. This is a fixed cost per system regardless of its length, for a particular type of system. When expressed in terms of cost per mile, it looms up as a much larger part of the total cost on short than on long systems. It follows that for

each type of carrier system, there is some minimum length of system below which the carrier costs per telephone channel mile are so great that the system does not prove in, and it is more economical to obtain the telephone channels by other means. The fact that carrier systems have tended to prove in more naturally and by larger margins on long than on short circuits, has had a large effect on the engineering of the telephone plant. This effect has been to drive voice-frequency systems out of the long toll circuit field and to relegate them more and more to the shorter circuits which feed the main toll routes. Today, practically all circuits over 50 miles long and many shorter ones, are carrier circuits. The trend toward the use of carrier for long circuits receives added impetus from the fact that better transmission performance can be obtained from long carrier systems than from long voice-frequency systems.

The carrier systems are classified as "long haul" and "short haul" systems. The long haul systems are designed to meet all the transmission requirements of a toll link, for the longest systems which would be encountered in the United States, 2000 to 4000 miles. The minimum length for which most of the long haul systems prove in is usually of the order of 75 to 100 miles. The short haul systems have the specific purpose of extending the carrier applications to shorter distances, some of them proving in at as short a length as 10 to 15 miles. This result is attained by reducing the cost of the terminal and line equipment, which is made possible by lightening the transmission requirements in view of the shorter distances to be spanned. Consequently, for the short-haul systems there is not only a minimum length at which the system proves in but also a maximum length beyond which the transmission requirements of toll links will not be met.

It is evident that the carrier systems increase the efficiency of use of the wire lines by the principle of superposition. That is, they add additional speech channels to the line, each utilizing an otherwise unused part of the frequency band. For example, when a type "C" carrier system is added to an open-wire pair, three additional 2-way telephone channels are superimposed above the regular voice-frequency channel, using frequencies up to about 30 KHz. To the same pair can be further added a type "J" carrier system furnishing twelve more channels in the frequencies between about 36 and 143 KHz. When both systems are used, the open-wire pair furnishes sixteen two-way

toll telephone circuits. The stacking of channels one above the other with different carrier frequencies is known as frequency division multiplex.

Following World War II, a new concept of telephone multiplex was introduced. This culminated in the development of the T1 carrier system for wire lines. In this system, the telephone signals are transmitted by means of a series of pulses of energy. The conversion of the telephone signal into energy pulses from which it can be reproduced at the receiving end is known as pulse modulation. It makes possible the transmission of a number of separate signals over a wire line or by a single radio carrier by means of time division multiplex. This is, the intervals between the successive pulses of a given signal can be employed to transmit comparable pulses of other signals.

### 2.3 FUNDAMENTALS OF CARRIER TELEPHONE SYSTEMS

In ordinary telephone transmission a pair of wires between telephone subscribers ordinarily carries one conversation and is required to transmit intelligence or voice frequency energy in both directions. In other words, we speak and hear over the same pair. This is called a two-wire system and is possible because of the circuit arrangement of the subscribers instrument, see Figure 2-1.

If we attempt to use one pair for more than one conversation at one time, we succeed only in making a four person conference out of it in which each person can hear everything everyone else says. Adding more instruments only adds more confusion, see Figure 2-2.

Changing to a four-wire system has definite advantages in carrier telephony. Since we are developing a simple carrier system, we will convert our circuit to "four-wire." This simply means that when A talks to B, one pair is used. When B talks to A, a different pair is used. Even with our simple telephone circuit the confusion has been reduced somewhat since now only two receivers can be actuated by any one transmitter, see Figure 2-3.

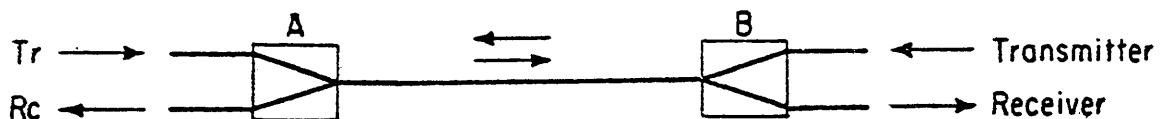


Figure 2-1 Two Wire System (One Conversation)

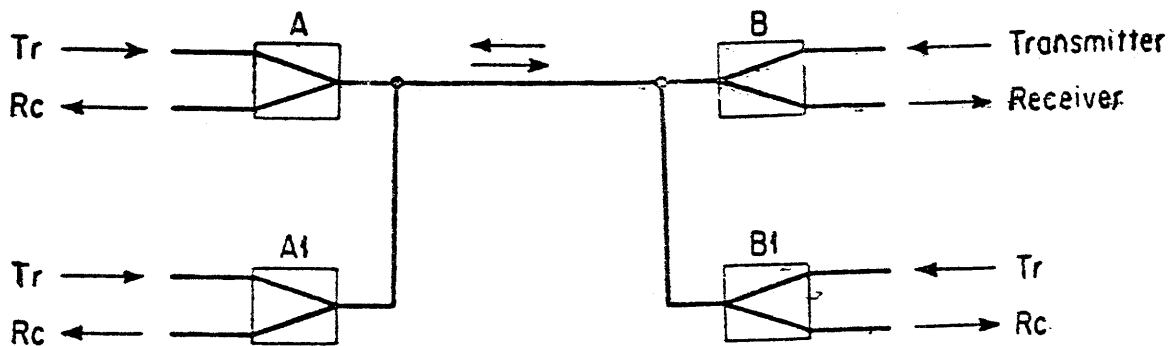


Figure 2-2 Two Wire System (Two Conversations)

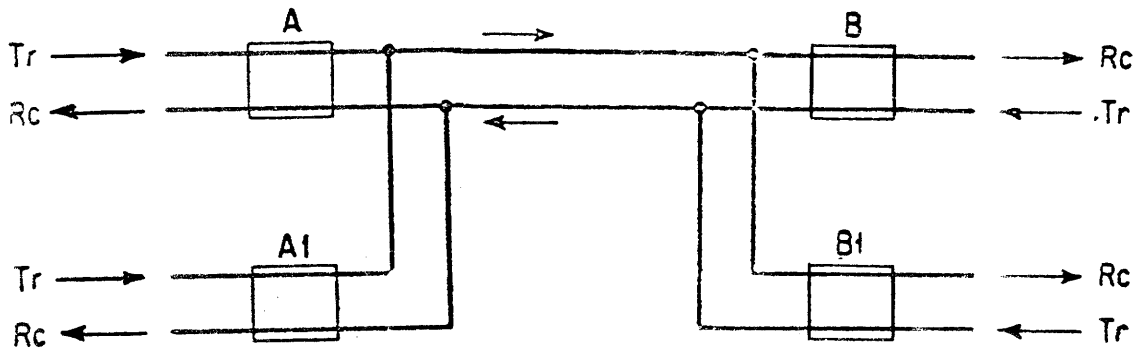


Figure 2-3 4 Wire System

Speech transmitted over telephone lines, generally speaking, is in the range of 200 to 3500 Hz. If we can change the frequency range of the speech of customers A1 and B1 from the 200 to 3500 Hz range to a range of, say 4200 to 7500 Hz and, further, arrange to separate the A-B from the A1-B1 conversations at the receiving ends of the circuit, we can use two pairs of wires for two separate conversations or even more with a saving in plant investment. This is the beginning of a carrier system, see Figure 2-4.

Carrier telephony consists of superimposing voice frequencies on a carrier frequency and then transmitting this information to a point where the reverse will occur. The full range of voice frequencies is 50 to 8000 Hz or higher. For telephone use a range of 200 to 3500 Hz is

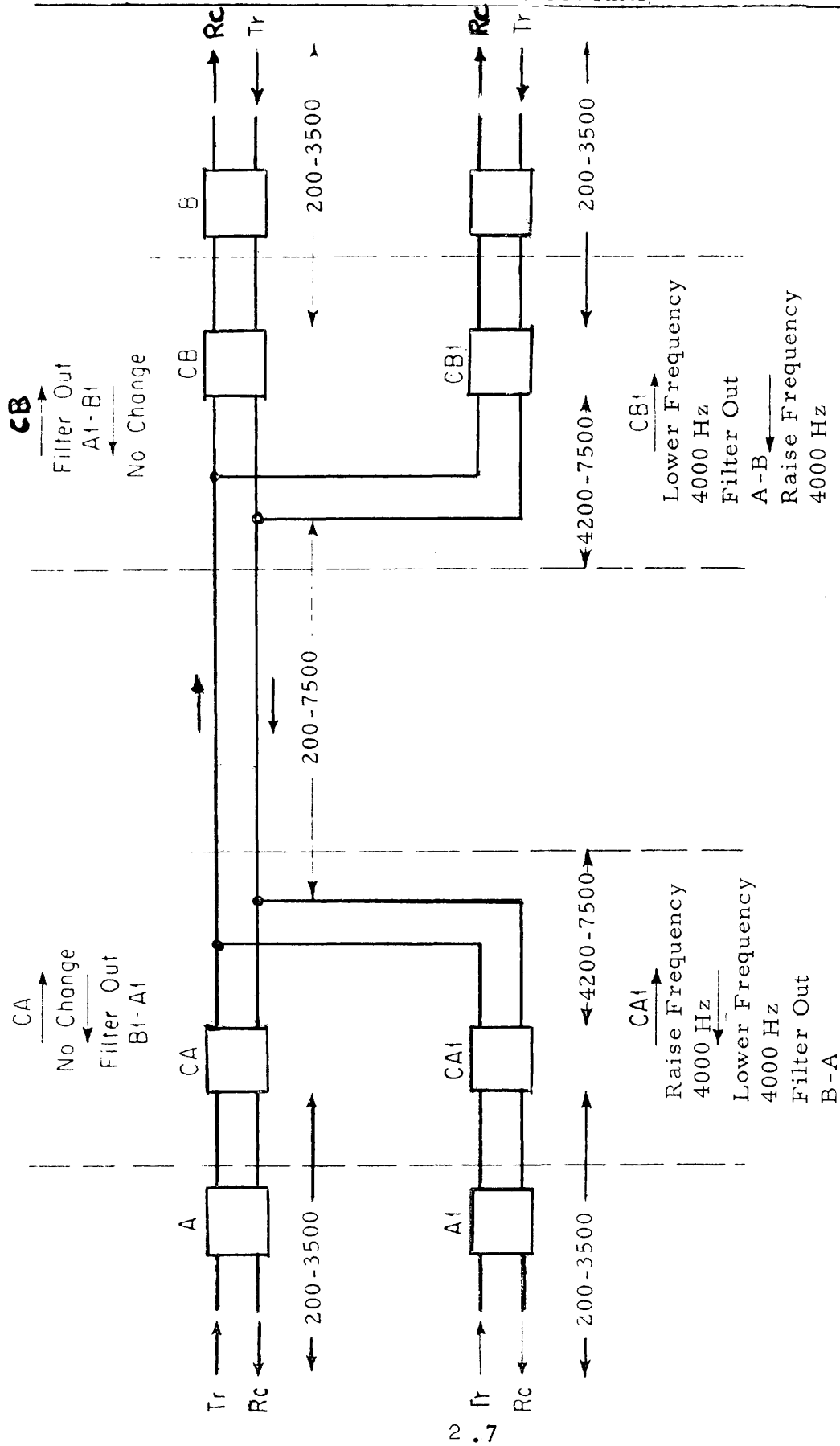


Figure 2-4 Simplified Carrier System



sufficient. This range will allow one subscriber to identify any other subscriber. The carrier frequencies are steady frequencies other than voice frequencies, usually higher than the voice range. Superimposing is accomplished by modulation.

#### 2.4 AMPLITUDE MODULATION

The type of modulation employed in the majority of the systems is that known as amplitude modulation (AM). As shown later, when the amplitude of a carrier wave is modulated by a signal, the result is a wave composed of the carrier frequency plus an upper and a lower sideband which differ from the carrier by the frequency of the signal. It is evident that the two sidebands are redundant, since they both contain all of the intelligence of the signal, and that the carrier is superfluous, carrying no intelligence at all. Therefore in most of the multichannel systems, maximum efficiency is attained by removing the carrier and one sideband by means of filters, and transmitting only the other sideband. However, in certain of the systems where economy is a main object, both of the sidebands and also the carrier are transmitted.

When single-sideband transmission is employed, it is evident that the carrier signal in a given channel has the same bandwidth as the original voice-frequency channel. The single sidebands corresponding to the different telephone channels handled by the system are usually placed in adjacent positions in the carrier frequency band, one every 4 KHz. With modern filters this permits a useful band for each channel which is somewhat wider than 3 KHz.

When the voice frequency is superimposed or impressed on the carrier frequency by amplitude modulation there is obtained, among other things, the sum and the difference of the two frequencies. For example if we let:

V = voice frequency  
C = carrier frequency

Then the results of modulation may be expressed in the basic formula:

$C \pm V = \text{frequency output.}$

Using the voice frequency band 200 to 3500 Hz and assuming a carrier frequency of 7000 Hz:

$$\begin{aligned}C + V &= 7000 + (200 \text{ to } 3500) = 7200 \text{ to } 10,500 \text{ Hz} \\C - V &= 7000 - (200 \text{ to } 3500) = 3500 \text{ to } 6,800 \text{ Hz}\end{aligned}$$

The band of  $C + V$  is called the upper sideband and the band of  $C - V$  is called the lower sideband. A reverse process is necessary to regain the original voice frequency band. This is known as demodulation.

## 2-5 FREQUENCY MODULATION

The use of frequency modulation (FM) is confined entirely to radio systems operating in the very high frequency band or above, where it has certain definite advantages over amplitude modulation in minimizing interference from "static" and extraneous signals. It depends upon varying the frequency of a carrier wave of fixed amplitude above and below a central or normal frequency in accordance with the amplitude variations of an applied signal voltage. The process is roughly illustrated by the wave diagrams of Figure 2.5. The amount of frequency change that is produced by the signal is called the frequency deviation and, ideally, this should be as high as possible in order to obtain the maximum signal to noise ratio. However, since it is obvious that the total bandwidth of the modulated wave to be transmitted will increase with increases in the maximum frequency deviations on both sides of the unmodulated carrier frequency, it is necessary as a practical matter to arbitrarily limit the maximum permissible deviations to values that will keep the total bandwidth that must be assigned in the radio spectrum to each FM channel as narrow as feasible. The maximum permissible deviation has been specified by the Federal Communications Commission at 75 KHz for FM broadcasting, and at 15 KHz for such applications as mobile radio service.

As in amplitude modulation, frequency modulation results in a modulated wave containing the carrier frequency and other frequencies above and below the carrier frequency.

In addition to the carrier frequency itself, the modulated wave includes an infinite series of side frequencies having values equal to the carrier frequency plus and minus the signal frequency and all of its integral multiples.

The following three statements can be listed as specifications of FM:

- a. The amplitude of the carrier remains constant as the carrier frequency is varied by modulation.
- b. Deviation (i.e., frequency swing) is proportional to the amplitude of the modulating signal. Maximum deviations occurs at peaks of audio signal.
- c. The rate of frequency change is proportional to the frequency of the modulating signal.

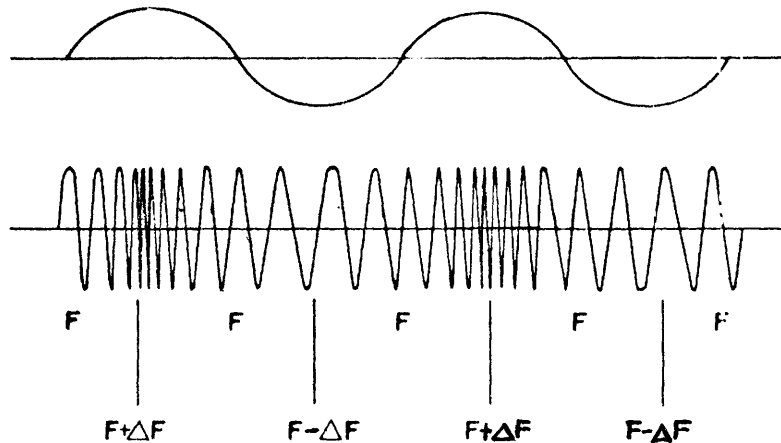


Figure 2-5 Frequency Modulation of Carrier Wave

## 2.6 PULSE CODE MODULATION

In amplitude or frequency modulation, the amplitude or frequency of a sinusoidal carrier is continuously varied in accordance with the modulating function. In contrast with this, pulse code modulation uses a series of pulses instead of a sinusoidal carrier to carry the information contained in the modulating function.

In the operation of this new type of modulation the voice signal applied to each channel is in effect, transmitted sample by sample. Instantaneous samples of the signal voltage are taken at intervals sufficiently close together to permit a receiver to produce a faithful reproduction of the original signal. Sampling takes place at a rate which is slightly higher than twice the highest frequency component of the signal.

These samples must be coded into a series of on or off pulses. The amplitude of the basic signal being sampled, however, may vary continuously over a wide range and may thus have an infinite number of values. The specific samples approximate the actual voltage of the signal. To keep the total number of codes within reasonable limits, it is necessary to divide the total amplitude range of the signal into a number of finite steps or quanta. Each sample is quantized, that is, it is assigned a specific voltage value between specific limits. The sample is in effect scaled off against some known yardstick and given a definite value. It has been found that when as many as 128 quantum steps are employed, speech signals can be reproduced with a high degree of fidelity. The amount of error between the actual amplitude of the sample and its assigned quanta level gives rise to the term quantizing noise.

These specific voltages are then coded into a binary pulse code. In a binary or off-or-on system 128 separate codes require the use of seven positions or "bits" per code.

At the receiving end each 7-element code signal is translated into the single amplitude pulse which the code represents. The successive amplitude pulses are then applied to a low pass filter (cutting off at 4000 Hz in the case of a voice wave) the output of which will be an exact copy of the original wave sent. Figure 2.6 is a simplified sketch of the pulse code modulation principle.

There is an optimum rate for the transmission of short pulses through a band-limited medium. For a low pass characteristic which transmits up to some frequency  $f_1$  Hz,  $2f_1$  pulses per second can be sent. Thus a 750 KHz channel could carry 1.5 million pulses per second. Consider the transmission of 4 KHz telephone messages by 8 digit\* binary PCM over a channel which has a bandwidth of 750 KHz.

It was previously seen that our sampling rate should be 8,000 times per second or one sample per 125 microseconds. Each sample will result in one code character consisting of eight code elements (1's or 0's). If we can send 1.5 million pulses per second, eight pulses can be sent in 5.33 microseconds. If only the information pertaining to one message is sent, the pulse pattern vs time would consist of an

\*Actually it is assumed that seven digits represents the message sample, and the eighth pulse is for supervisory and signalling purposes.

8-pulse character, taking 5.33 microseconds, then idle time for about 120 microseconds, followed by another 5.33 microseconds of use, and so on. Obviously, the channel is not used very efficiently. On the other hand, if code characters from other channels are sent during the idle time, not one, but about 24 telephone messages could be transmitted over our 750 KHz channel. Interleaving signals on a time basis in this way is called time division multiplex.

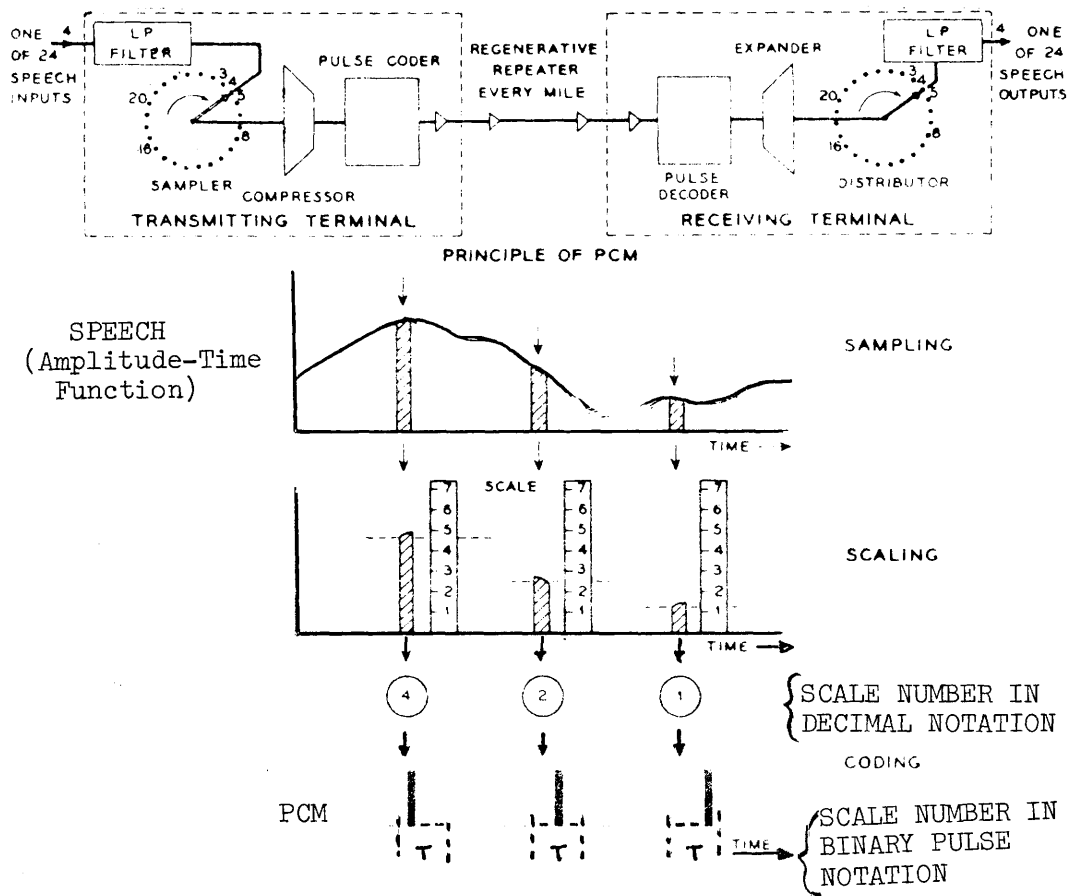


Figure 2-6 Pulse Code Modulation

## 2.7 A TYPICAL CARRIER SYSTEM TERMINAL

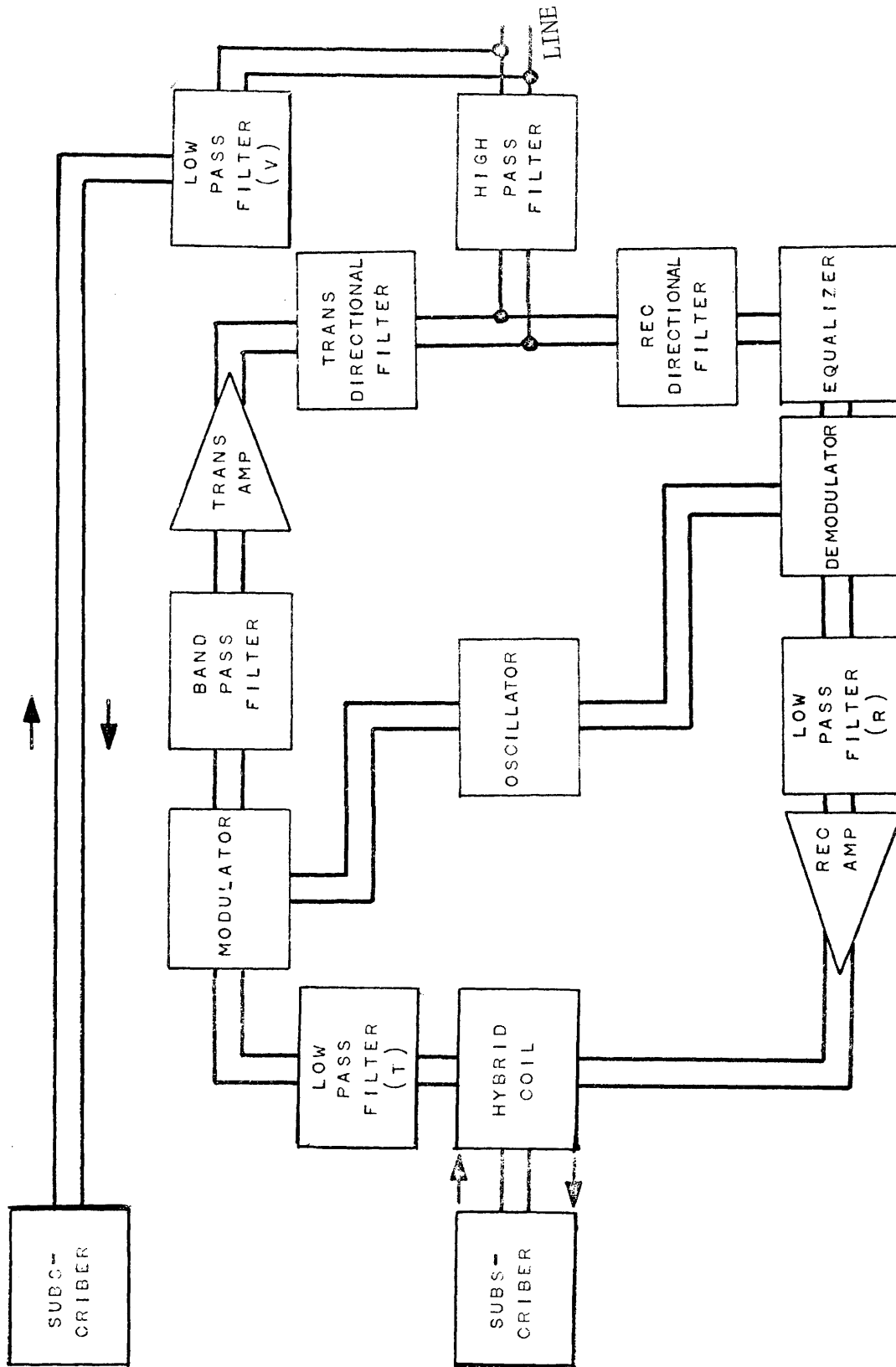
As was stated before, the majority of the Bell System carrier systems make use of amplitude modulation. In developing a typical terminal, therefore, discussion shall be limited to this type of system. In Figure 16-4 additional equipment designated C was added to devise an arrangement by which subscribers A and B may talk to each other without interfering with or being interfered with by two other subscribers A1 and B1. They are the carrier components. The blocks designated C are the filters, modulators and demodulators required in a carrier system.

A carrier terminal Figure 2-7 may be divided into three portions, the voice frequency, transmitting and receiving portion.

In the voice frequency portion the low pass filter (V) allows the voice frequency channel to pass through but blocks the carrier frequencies. The high pass filter lets carrier frequencies into carrier equipment while it blocks out the voice frequencies. This path is established for one message circuit, receiving and transmitting.

In the transmitting portion of Figure 2-7 the voice frequencies from the subscriber are directed into the transmitting portion of the carrier channel by the hybrid coil. The low pass filter (T) eliminates any undesirable frequencies outside of the voice frequency band 200 to 3500 Hz. The oscillator produces the carrier frequency. Each terminal has its own oscillator. The modulator impresses the voice frequency band on the carrier frequency and produces the upper and lower sidebands. In most carrier systems only one sideband is transmitted and this is called Single Side Band transmission. The band pass filter removes all frequencies except one of the sidebands. The transmitting amplifier steps up the sideband being transmitted to the desired power level for transmission. The function of the transmitting directional filter is to keep the frequencies being received from coming into the plate circuit of the transmitting amplifier. This establishes the transmitting circuit.

In the receiving portion of the carrier terminal, the receiving directional filter blocks out the frequencies of the sideband being transmitted but allows the sideband being received to enter the receiving circuit. As the transmitted sideband is conducted to the receiver via the transmission



TYPICAL SINGLE CHANNEL CARRIER TERMINAL

Figure 2-7

lines the higher frequencies are attenuated more than the lower frequencies. The equalizer adds loss for the lower frequencies so that all frequencies will pass into the demodulator at the same level. The demodulator combines the carrier frequency with the received sideband and one of the resultant products is the voice frequency. The low pass filter (R) removes all the products of demodulation except the voice frequency. The receiving amplifier steps up the power level of the voice frequencies to that required for transmission to the subscriber. The receiving frequencies are then directed to the subscriber through the hybrid coil, thus establishing the receiving circuit.

In the system just described we had two message paths over one pair of wires. It would be possible to add more message paths using this same pair of wires by adding more carrier terminals using different carrier frequencies.

From this typical terminal it can be seen that an important feature of every carrier system consists of the modulators and demodulators which shift the frequencies of the telephone signals. Another feature of all carrier systems is the need of filters needed to select the desired signals from the modulators for transmission to the line, and to separate the line channels from each other for application to their respective demodulators, at the receiving end of the line. Filters are also used to separate groups of channels from each other.

The signals are usually transmitted over the lines between the terminals in two groups, one consisting of the E-W (east-to-west) one-way channels of all the telephone circuits handled by the system and the other consisting of the W-E (west-to-east) one-way channels of the same telephone circuits. As noted earlier, the two groups may be transmitted over different pairs, or over the same pair in different frequency ranges. The channels constituting a group are amplified by one common carrier line amplifier (or repeater) at each repeater point.

The lines, of course, have considerably greater attenuation at the higher frequencies needed for carrier transmission than at voice frequencies. Therefore carrier line amplifiers must be spaced at much shorter intervals along the line than most voice-frequency repeaters. The length of the repeater sections on any system is a function of the line attenuation, the standards for allowable noise



at the end of the system on each telephone channel, the maximum length of system, the noise on the line sections and the amplifiers, and, in the case of multichannel systems, of the amount of modulation in the line amplifiers. Since the line attenuation is greatest for the highest frequency channel transmitted by the system, the repeater spacing is usually determined by the rules as applied to that channel.

Because the line attenuation is great at the carrier frequencies, the variation in attenuation with temperature (and with weather in the case of open-wire lines) is also large. Furthermore, both because of the large attenuation and also because of the wide frequency band required for most carrier systems, the difference in attenuation between the highest and lowest transmitted frequency is large. These considerations impose severe transmission problems on the carrier systems which are solved in different ways on the various systems.

The variations of the lines with frequency and temperature are compensated for by equipment associated with the line amplifiers. It will be noted that though the total effects to be compensated may have very great magnitudes, the distribution of the compensation among many line amplifiers reduces the problem at each amplifier to manageable proportions. The equipment which does the compensating falls into two categories, namely, basic equalizers which compensate for the attenuation-versus-frequency distortion of the lines under mean ambient conditions, and regulating networks which adjust for the variations in the attenuation and in the attenuation-versus-frequency characteristics of the line due to changes in temperature (and other causes). The regulating networks are automatically operated, usually under control of one or more pilot frequencies wedged in between the telephone channels. In some cases, the flat gain variations may be controlled by a d-c pilot channel similar to that used in the pilot-wire regulations of voice-frequency systems, or by the energy in the carrier channel themselves. The specific application of the techniques to the various carrier systems is described in later sections.

The pilot frequencies, when used, are of course supplied by the system terminals. Another feature of carrier terminals, therefore, consists of the means for generating the pilot frequencies, and also the carrier

frequencies required by the various modulators and demodulators. In most systems, these frequencies must be very exact in order that the signal and pilot frequencies will accurately match the pass bands of the filters through which they must be transmitted, and that they will fall properly into their allotted frequency positions on the lines. It may be noted that in those systems in which the carrier is not transmitted, which is the case with many of the systems, the carriers supplied to the modulators and demodulators at the two ends of the system must be generated by physically separated oscillators. Any actual difference between the carrier frequencies at the two ends, which ideally should be identical, results in a corresponding displacement of the same number of cycles in all the frequencies in the telephone signals emerging from the system. The tolerance for such frequency displacements is at most a few cycles, which in terms of per cent error in the carrier frequencies necessitates considerable accuracy.

## 2.8 SUMMARY AND DESCRIPTION OF THE CARRIER SYSTEMS

Some of the important information on Bell System carrier systems is tabulated on Table 16-1. It will be noted that for all the systems there is given the minimum length below which it is not normally economical to use the system. For the short haul systems, a maximum length is given beyond which the transmission would be likely to fail to meet standards, due to noise, crosstalk, equalization, regulation, or for other reasons.

## 2.9 HISTORY AND GENERAL DESCRIPTIONS OF THE CARRIER SYSTEMS

### Type

- A** The first carrier system introduced in 1917 was known as the "A" system and provided four 2-way channels above the voice channel on open wire pairs in the frequency range between 5 and 25 KHz. The system used single sideband transmission, and each channel used the same frequency for both directions of transmission; directional discrimination was secured by hybrid coil balance at terminals and repeater stations as with 2-wire repeaters. Later systems used separate pairs for each direction of transmission. A total of seven type "A" systems were installed in the United States, but all have long since been removed. The last one in service was between Merced and Yosemite Valley, California.

TABLE 2-1A MAJOR BELL SYSTEM CARRIER SYSTEMS

SHORT HAUL

	N1	N2	O	ON1	ON2	T1	N3
Line Facility	Cable	Cable	O.W.	Cable	Cable	Cable	Cable
Channels	12	12	16	20	24	24	24
Modulation	A.M.	A.M.	A.M.	A.M.	A.M.	P.C.M.	A.M.
Sidebands	2	2	1	1	1		1
Transmitted Carrier	Yes	Yes	Reduced	Reduced	Reduced		Yes
Method of Operation	(2)	(2)	(1)	(2)	(2)	(2)	(2)
Frequency Allocations (KHz)							
Lowest Trans. Freq.	36	36	2	40	36	(3)	36
Highest Trans. Freq.	268	268	156	264	268	(3)	268
System Length (Miles)							
Minimum	15	15	15	15	15	10	35
Maximum	200	200	150	200	200	50	200
Approx. Repeater Spacing (Miles)	5	5	50	5	5	6000 Ft.	5
Frogging	Each Rept.	Each Rept.	Each Rept.	Each Rept.	Each Rept.	No	Each Rept.
Compandors	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pilots	No	No	No	No	No	No	No

NOTES:

- (1) Equivalent Four Wire
- (2) Real Four Wire
- (3) Line Signal Consists of Bipolar Pulses at rate of 1.544 x 10<sup>6</sup> Bits/sec

TABLE 2-1B MAJOR BELL SYSTEM CARRIER SYSTEMS

LONG HAUL

	C5	J2	K2	L1	L3	L4
Line Facility	O.W.	O.W.	Cable	Coax.	Coax	Coax.
Channels	3	12	12	600(4)	1860(5)	3600
Modulation	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.
Sidebands	1	1	1	1	1	1
Transmitted Carrier	No	No	No	No	No	No
Method of Operation	(1)	(1)	(2)	(2)	(2)	(2)
Frequency Allocations (KHz)						
Lowest Trans. Freq.	6	36	12	60	308	280
Highest Trans. Freq.	30	143	60	3096	8320	20,448
System Length (Miles)						
Minimum	60	125	75	75	75	75
Maximum	1000	4000	4000	4000	4000	4000
Approx. Repeater Spacing (Miles)	150	30	17	8	4	2
Frogging	No	No	No	No	800 Mi.	800 Mi.
Compandors	No	No (3)	No	No	No	No
Pilots	Yes	Yes	Yes	Yes	Yes	Yes

NOTES:

- (1) Equivalent Four Wire
- (2) Real Four Wire
- (3) Compandors are sometimes added for Crosstalk and Noise Control, but are not part of the System Terminals
- (4) Or two one-way TV channels
- (5) Or 660 Telephone Channels and two one-way TV channels

Type

**B** The "B" system was introduced in 1920 and provided three channels above the voice channel on one open wire pair. Different frequencies were used for transmission in opposite directions, making it possible to rely upon filter selectivity instead of impedance balance to separate the directions of transmission. This system transmitted a single sideband and the carrier frequency, using the lower sidebands of carrier frequencies at 6, 9 and 12 KHz, in the East and West direction, and the upper sidebands of carrier frequencies at 15, 18 and 21 KHz in the West to East direction. A score of type "B" systems were installed. The last one in operation was between Spokane and Lewiston, Washington.

**C** The type "C" system made its appearance in the 1920's. It was the first really successful carrier system and is still a member of the family of carrier systems. The last and current standard model, the C5, is a fairly complete redesign to incorporate the advantages of the modern techniques of varistor modulators, filters with molybdenum permalloy coils, new types of vacuum tubes, and feedback amplifiers. It operates on open wire facilities and provides three telephone circuits in addition to the normal voice-frequency circuit, on a single open wire pair.

The frequency allocations used in the type "C" systems lie between 6.3 and 16 KHz for transmission from East to West and between 17.7 and 30.2 KHz for transmission from West to East. The upper and lower halves of this range are used for the opposite directions of transmission. The channels are single-sideband with suppressed carriers. To reduce crosstalk, there are several "staggered" frequency allocations, some using upper and others using lower sidebands. The C5 system is available in four allocations, the CA, CB, CS and CU. These allocations are shown in Figure 2-8.

It will be noted that the "allocations" differ from each other not only in the frequencies the channels occupy but also in whether the channels are upper or lower sidebands.

Type

- C Unlike the more complicated systems the type "C" systems translate each telephone channel to its assigned frequency position on the line in a single stage of modulation. The required carriers are not multiples of any base frequency but are generated by individual oscillators, one for each modulator and demodulator. One pilot is transmitted in each direction on all of the type "C" systems. The pilot frequency is located 50 Hz from the frequency of the suppressed carrier of the middle channel, between the carrier and the transmitted sideband. In the longer systems, the pilots are used for the automatic regulation of the systems. In the systems which are so short as to have no repeaters, the regulation may be manual.

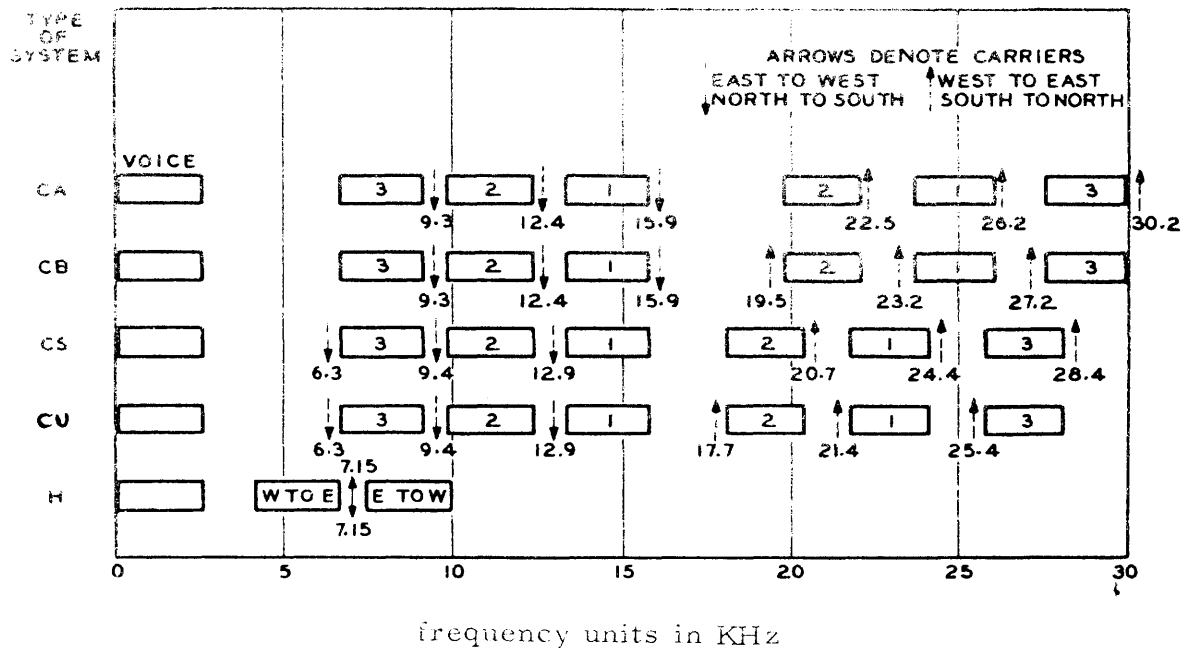


Figure 2-8 Frequency Allocations of Type C and H Carrier Systems

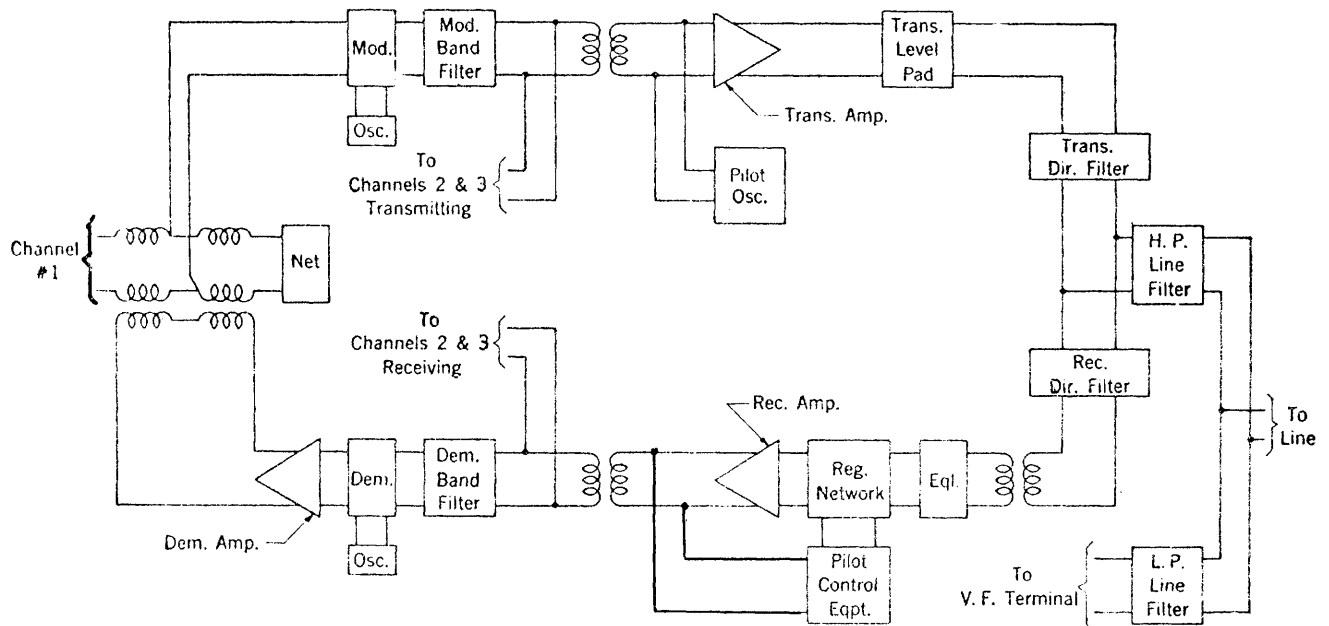


Figure 2-9 Type C Carrier Telephone Terminal

Type

- C The type "C" systems are designed so that the repeater spacings are the same as for the voice-frequency systems (about 150 miles) and therefore the repeaters are located in the same stations as the voice repeaters. Spacing will vary with cable conditions.

Figure 2-9 is a simplified schematic of one channel of a Type "C" carrier system. The basic arrangements of the components, such as modulators, bandpass filters, directional filters, line filters, etc., are typical of those used in most carrier systems. Hence, circuit schematics will not be discussed for other carrier systems to be covered hereafter.

- D The "D" system was designed for use on short circuits in areas of slow growth on open wire lines (1927). It provided one 2-way telephone circuit on a pair in addition to the voice frequency circuit. Like the "C" it employed single sideband transmission with the carrier suppressed, and used different frequencies

Type

- D for opposite directions employing the lower sidebands at 10.3 and 6.87 KHz. The DA system employed a transmitting amplifier which extended the length of circuit to which the system could be applied to about 200 miles. About 550 type "D" systems have been installed.
- E The "E" (1926) is a single channel system for power lines. It transmits a single sideband with the carrier suppressed. With the aid of V.F. switching the same frequency band is used for both directions of transmission. The carrier band may be placed anywhere between 50 and 150 KHz. Eleven "E" terminals grouped into three systems were placed in service.
- F "F" was assigned to a single channel system using "C" equipment in 1927. **Designed for foreign use.** No U.S. installation.
- G-1 "G1" (1935) is a system designed for use on open wire lines for short distances not exceeding 30 miles and provides a single channel in addition to the voice channel. A novel feature is that the carrier is generated only at one terminal. The carrier and both sidebands are transmitted and the same frequencies are used for both directions. A frequency band between 6500 and 14,000 Hz is required on the line.
- H The "H" system (1936) employs the same frequency allocation as the "D" system but the same frequency of 7.5 KHz is used for both directions of transmission. The carrier is suppressed and the lower sideband is used in the West of East direction and the upper in E to W. May be operated on either AC or DC. Panel mounted for relay rack or cabinet. Has a repeater as well as terminals and may be used for long circuits where only a single channel is required.
- J This system provides twelve 2-way long-haul telephone channels on one open-wire pair, and has frequency allocations such that a type "C" carrier system and a voice-frequency system can also be operated on the same pair. Thus, with the advent of the type "J" system, one open-wire pair became capable of furnishing a total of sixteen 2-way telephone channels.

Type

- J The development of the type "J" system began at about the same time as that of the type "K" and type "L" systems, and reached the stage of a field trial on a 250-mile line between Wichita, Kansas and Lamar, Colorado in 1937 and 1938.

In the type "J" systems, the west-to-east channels are transmitted in the lower part of the frequency range between about 36 and 84 KHz, and the east-to-west channels are transmitted in the upper part of the frequency range between about 92 and 143 KHz. The two oppositely directed groups of channels are sent on the same pair and are separated from each other by directional filters at each repeater point.

In order to reduce crosstalk between systems operating on the same pole line, the type "J" systems have been provided with four slightly different frequency allocations in the above general ranges. These are designated the JNA, JSA, JNB, and JSB systems, as shown in Figure 2-10. The frequency allocations for the west-to-east direction are the same for all four type "J" systems except that in two of them the channels are inverted. In the east-to-west direction the allocations are staggered in increments of one KHz, two of them being also inverted.

In the terminals of a type "J" system, the twelve telephone channels handled by the system are modulated and combined to form a basic group of channels lying between 60 and 108 KHz, by the channel bank which is also used in the type "K" and type "L" systems. It will be noted that 12 voice-frequency channels are individually modulated by carriers spaced at 4 KHz intervals from 64 KHz to 108 KHz inclusive. The lower side bands are selected for each channel by filters with the result that the 12 channels occupy the frequency range from 60 to 108 KHz. This is the band occupied after the first step of modulation for transmission in each direction and is likewise the band occupied before the last step of demodulation for transmission in each direction. The basic group is translated to the desired frequency allocation



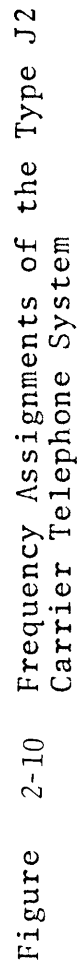


Figure 2-10 Frequency Assignments of the Type J2 Carrier Telephone System

Type

J on the line by group modulators, requiring two stages of modulation in the sending end and two stages of demodulation in the receiving end of the system.

The terminal equipment also supplies the line pilots. The frequencies of the pilots on the lines are the same for all four of the type "J" allocations, and are 40 and 80 KHz in the west-to-east direction, and 92 and 143 KHz in the east-to-west direction. The 80- and 92-KHz pilots are used for flatgain regulation, while the 40- and 143-KHz pilots are used for slope regulation. The pilots are actually injected at the input to the first group modulator at such frequencies as to reach the line at the above frequencies after passing through the two group modulators.

K This system was the first of the all cable carrier systems developed for use in this country. Most of the installations were made just prior to and during the World War II period.

The type "K" system provides twelve 2-way telephone channels on two 19-gauge nonloaded pairs in aerial or underground toll cables. These pairs cannot at the same time be used for voice-frequency systems. The type "K" system operates on a 4-wire basis using one pair for each direction of transmission. The two pairs are ordinarily in different cables, although in special cases a single cable may be used which has a shield between layers to separate the pairs into two groups. Because of the higher attenuation of the 19-gauge pairs at the carrier frequencies, the line amplifiers must be spaced at about one-third the interval required for voice-frequency systems, or about every 17 miles. On a route which also has voice-frequency systems, therefore, the carrier system requires two "auxiliary" repeaters between each pair of main stations where the voice-frequency repeaters are located. On new routes not already equipped with voice-frequency systems, the main, attended stations may be as far apart as 100 to 200 miles. The auxiliary stations are arranged to be unattended, with suitable alarm indications of troubles, to the nearest main station.

Type

- K The twelve telephone channels are transmitted on the cable pairs as the upper sidebands of carriers located every 4 KHz from 12 to 56 KHz, inclusive. The total frequency band transmitted on the line therefore extends approximately from 12 to 60 KHz. The original voice-frequency telephone bands are translated to the line frequencies, and vice versa, by a double modulation process. The first step takes place in the channel modulators forming part of a "12-channel bank" which translate the twelve voice bands to a group of lower sidebands, lying between 60 and 108 KHz. This is done in order to realize the performance obtainable with quartz filters, which type of filter would not be suitable at the lower frequencies that would be involved in a single modulation process translating the voice bands directly to the 12- to 60-KHz range. The second stage of modulation in the type "K" system takes place in a group modulator which translates the 60- to 108-KHz band as a whole, to the line frequencies between 12 and 60 KHz. The frequency allocations for the two stages of modulation are shown in Figure 2-11.

All carriers used in the modulation processes are suppressed, but pilot frequencies of 12, 28, 56 and 60 KHz are transmitted from the K2 terminals along with the carrier speech bands. These serve automatically to regulate the gain and the frequency characteristics of the system, the 60-KHz pilot acting to regulate the flat gain of all of the line amplifiers, and the other three pilots serving to control the gain and the frequency characteristic of "twist" amplifiers placed in the line at occasional intervals. The 60 KHz pilot, not used in the earlier K-1 system, provides a novel method of regulation. By keeping the sum of the transmitted pilot and all other frequencies at a constant power level, variations at the input of the line amplifiers is due only to the line and can be corrected by negative feedback.

Crosstalk is controlled for type "K" carrier operation by three measures, two of which are evident by inspection of Figure 2-12. This figure shows the manner in which the carrier system is applied to the cables. The first crosstalk reducing measure is the use of pairs in two different cables for the two opposite directions of transmission. This effectively eliminates all near-end crosstalk between different type "K" systems using the same cables. The second crosstalk reducing measure is the frogging of the oppositely directed one-way carrier channels between the two cables at each carrier repeater point. As shown in Figure 2-12 the two directions of transmission are alternated between the two cables in successive

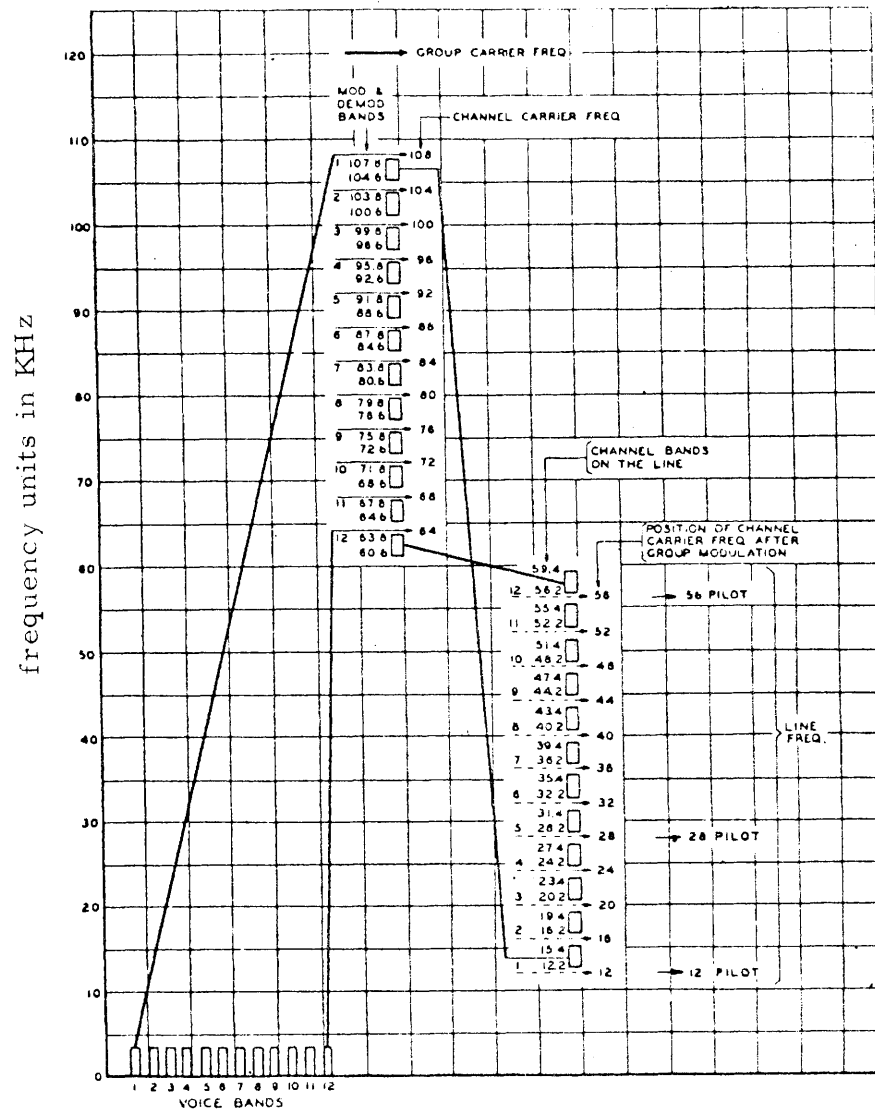


Figure 2-11 Frequency Allocations, Type K Carrier System

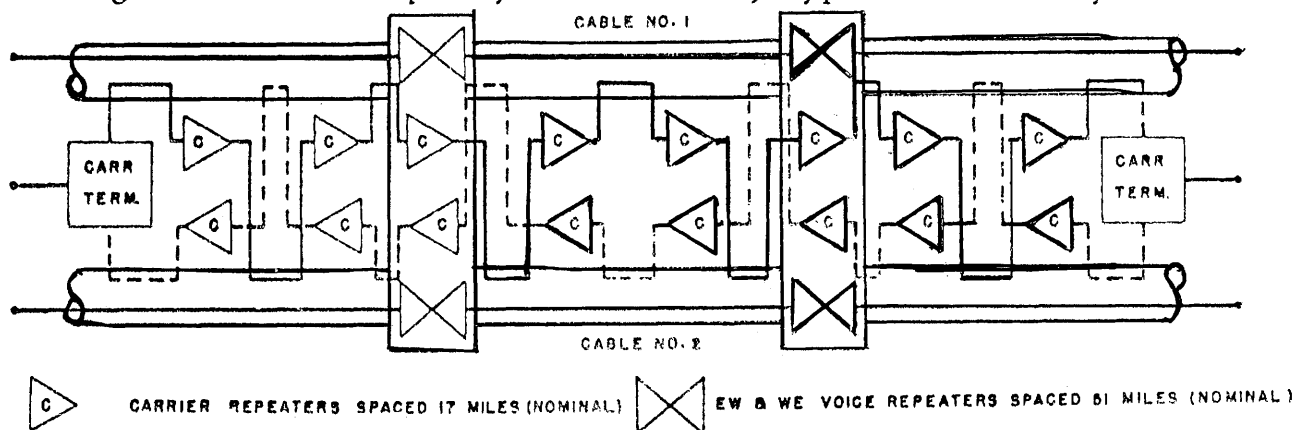


Figure 2-12 Block Schematic, Type K Carrier System

Type

K repeater sections. If the carrier circuits were not frogged, the high level signals at the output of a carrier repeater on one system could crosstalk into the paralleling voice-frequency pairs in the cable and could then be propagated back a short distance on the voice-frequency pairs to a point ahead of the carrier repeaters, where they could again crosstalk into another carrier system at the low level input to its carrier repeater. When the systems are frogged as shown, the second crosstalk coupling in the interaction crosstalk path just described terminates in the disturbed carrier system at a high level point at the output of a repeater, and therefore is less serious by the gain of a carrier repeater.

Crosstalk between systems transmitting in the same direction is reduced by the use of special balancing coils interconnecting the various "K" system cable pairs at certain repeater stations.

**L** The Type L-1 Carrier System was developed just prior to World War II but most of the installations were made after the war ended. The "L-3" Carrier System was introduced about 1953. Type "L" carrier telephone systems are designed for application to coaxial conductors. The telephone terminal equipment may also be used on microwave radio systems or other mediums capable of handling an extremely wide range of frequencies. The coaxial cable structure is inherently self-shielding against crosstalk from paralleling tubes.

Separate coaxial tubes are used for opposite directions of transmission, using the same frequency spectrum for both directions. It is, therefore, a true four-wire system. One coaxial tube transmits in one direction, and another tube transmits in the opposite direction.

The type "L-1" Carrier System has a capacity of handling either 600 telephone message channels or two one-way 2.7 KHz black and white television channels on one pair of coaxial tubes. Special terminals permit transmission of color television with slight picture degradation.

Type

- L The type "L-3" Carrier System is capable of handling 1,860 telephone message channels or 660 message channels and one 4 MHz television channel simultaneously on one coaxial tube. Therefore, each pair of tubes will transmit 1,860 telephone conversations or 600 conversations together with 2 oppositely directed black and white or color television programs.

In the "L-1" system the first modulation step places 12 voice channels in the 60 to 108 KHz range to form a channel bank identical with the channel banks used in the "J" and "K" systems, as previously discussed. In a second step of modulation, five channel banks are translated to the frequency band between 312 and 552 KHz. This constitutes a basic supergroup of 60 voice channels. The final modulation step translates the supergroups to appropriate line frequency positions as shown in Figure 2-13, which also indicates the carrier frequencies used in the group and supergroup modulators.

The "L-3" Carrier System was designed to operate over a broader frequency band than the "L-1" system. This design provides for a maximum of as many as 1860 two-way telephone channels in the frequency range between 312 and 8284 KHz. As shown in Figure 16-14, ten 60 channel supergroups are modulated with appropriate carriers to form a master group of 600 voice channels in the frequency range between 564 and 3084 KHz. The first master group is transmitted on the line at these frequencies, while further modulation steps are used to place the second between 3164 and 5684 KHz, and the third between 5764 and 8284 KHz. In addition, a single supergroup may be transmitted below master group No. 1 in the basic supergroup range of 312 to 552 KHz.

Through the use of submaster and master group equipment in a manner similar to the "L-3" master group 1 arrangement, 720 channels can be realized on existing "L-1" lines.

In both systems sixty-Hz A.C. power for the operation of repeaters is fed from terminal and main repeater points over a series loop made up of the two center conductors of the pair of coaxials used

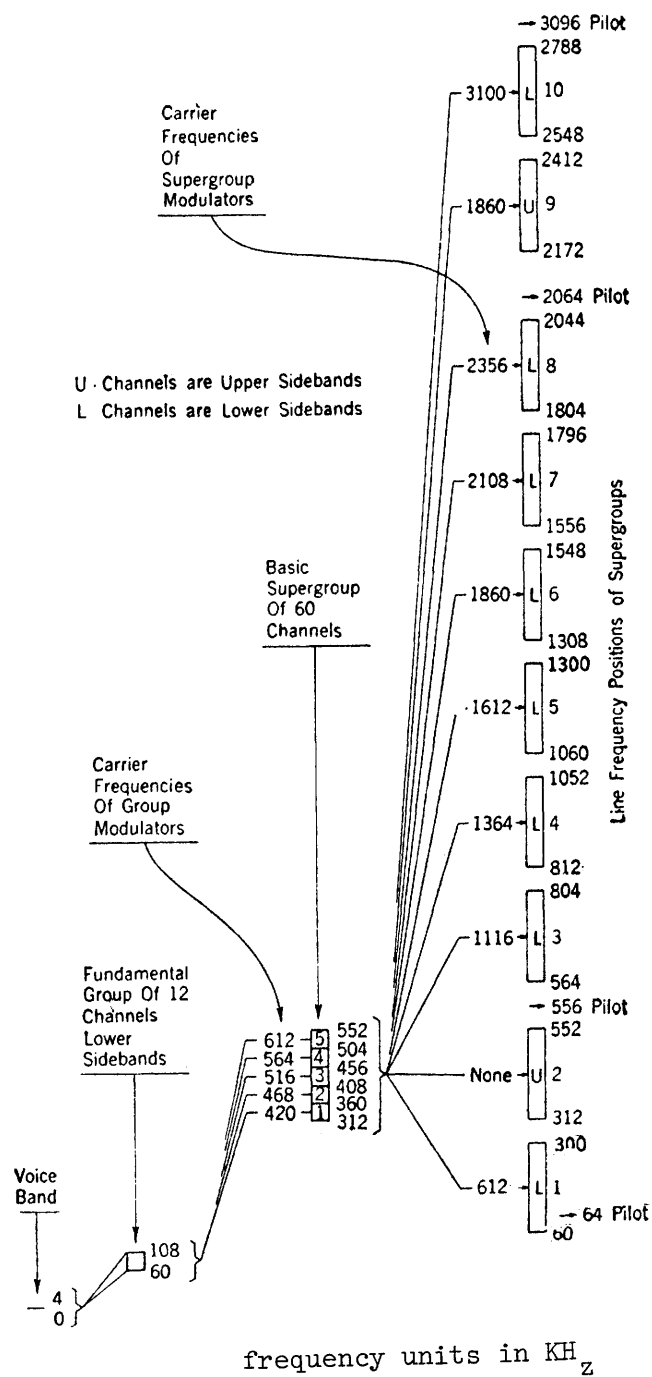


Figure 2-13 L1 Coaxial System Frequency Allocations

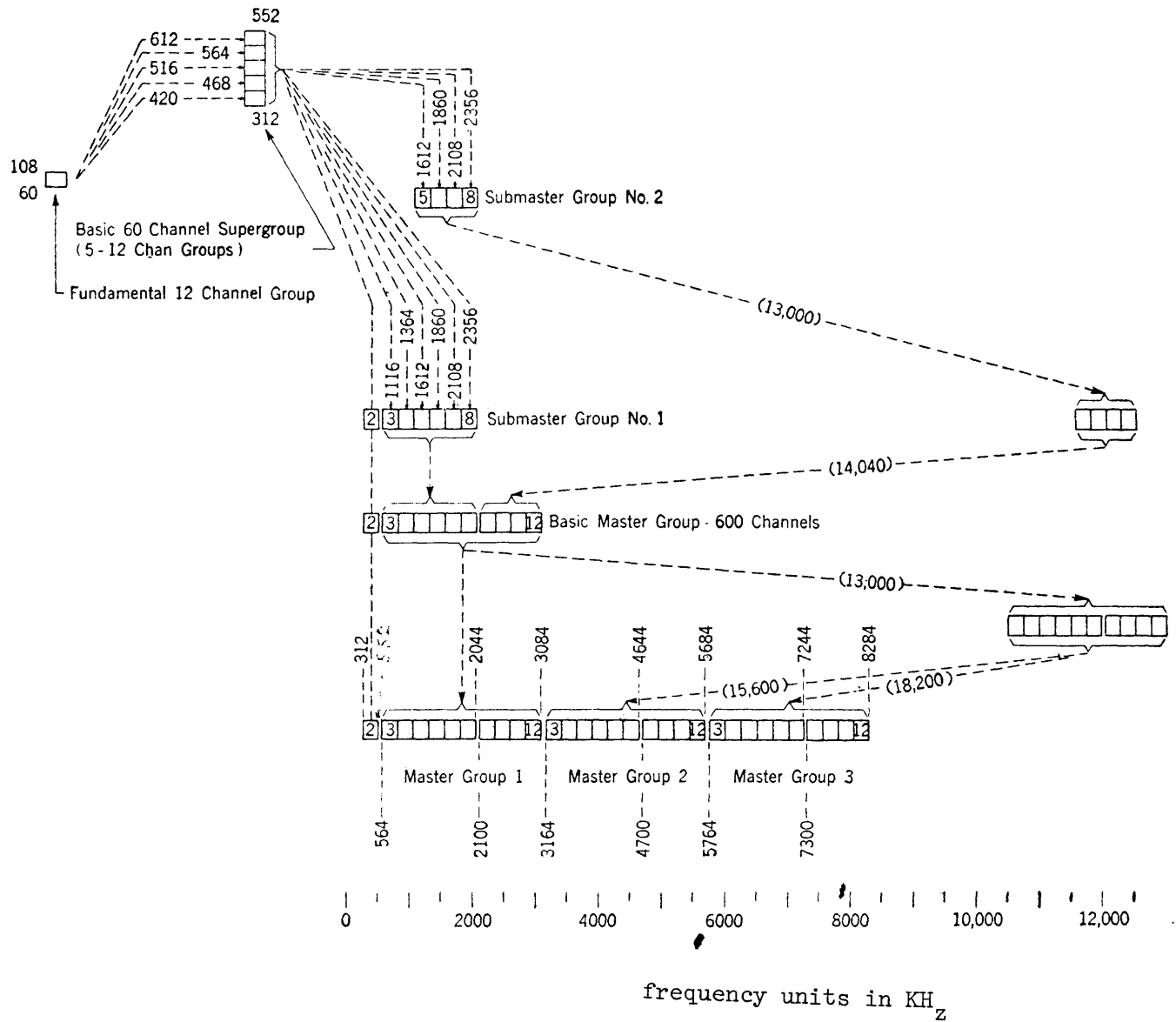


Figure 2-14 Frequency Translations of L3 System



Type

- L for the two directions of transmission. The 60-Hz currents are separated from the high frequency transmission currents by means of power separation filters.

Regulation in the "L-1" system is accomplished with the use of four pilot frequencies of 64,556, 2064 and 3096 KHz. The 2064 KHz pilot is used to vary gains of amplifiers to compensate for line attenuation caused by temperature variations. The other three pilots control adjustable equalizers.

Regulation in "L-3" systems employs six pilot frequencies at 308, 566, 2064, 3096, 7266 and 8320 KHz. The 7266 KHz pilot controls amplifier gains compensating for line attenuation changes due to temperature variations. The other five pilots control adjustable equalizers.

The L-1860 multiplex plan differs from the earlier L-3 plan shown in Fig. 2-15 by eliminating the sub-master group stages of modulation. Additional carrier frequencies are used instead to modulate the super-groups directly to their basic master group allocation. The final frequency spectrum remains the same.

The L-4 system is the latest in the family of heavy duty coaxial cable transmission systems. It is capable of handling 3600 two-way message circuits (conversations) one each pair of coaxials. Although the nominal repeater spacing is reduced to 2 miles, the relative cost per channel mile is much lower than the L-3 system.

There are a five types of repeaters used in the L-4 system: basic, regulating and equalizing line repeaters, transmitting and receiving main station repeaters.

The basic repeater has a fixed gain that is about equal to the loss of 2 miles of 3/8 inch coaxial cable. At intervals of no more than five basic repeaters, regulating repeaters are used. These repeaters have a variable gain to compensate for changes in cable loss due to temperature. The equalizing repeater has all of the functions of the regulating repeater plus the circuitry for effecting remote control of six variable

Type

- L equalizers under command from a main station control center. The main station repeaters are capable of all of the functions of an equalizing line repeater as well as providing 10 additional adjustable equalizer networks. The receiving main station repeater also provides post-regulation of the lower edge of the transmission band.

Just as in the L-3 system, a final multiplexing step is required to stack the 600 channel message blocks into one broadband array for L-4. The MMX-2 has been developed to translate six basic 600 channel message groups, LMX-2, into a 0.564 to 17.548 MHz broadband signal. The L-3 carrier terminal has been redesignated as MMX-1.

Automatic protection of transmission equipment is provided on a one spare for three regular basis, with individual mastergroups being transferred rather than a complete bank of six. Each MMX-2 bay accommodates three transmit and three receive L4 coaxial tubes with a maximum capacity of 10,800 voice channels. Although the MMX-2 terminal handles a frequency band twice as wide as MMX-1, the new system occupies less space, is easier to install, is less expensive, and produces a cleaner signal.

Development of a new L-carrier with even more capacity has begun. The L5 coaxial system is planned to use a pair of 0.375 inch coaxial tubes for 9,000 circuits consisting of 15 master groups in a bandwidth of 48 MHz. Route capacity is anticipated at 90,000 circuits at an even lower cost per channel mile than L4. Service is aimed at the early 1970's.

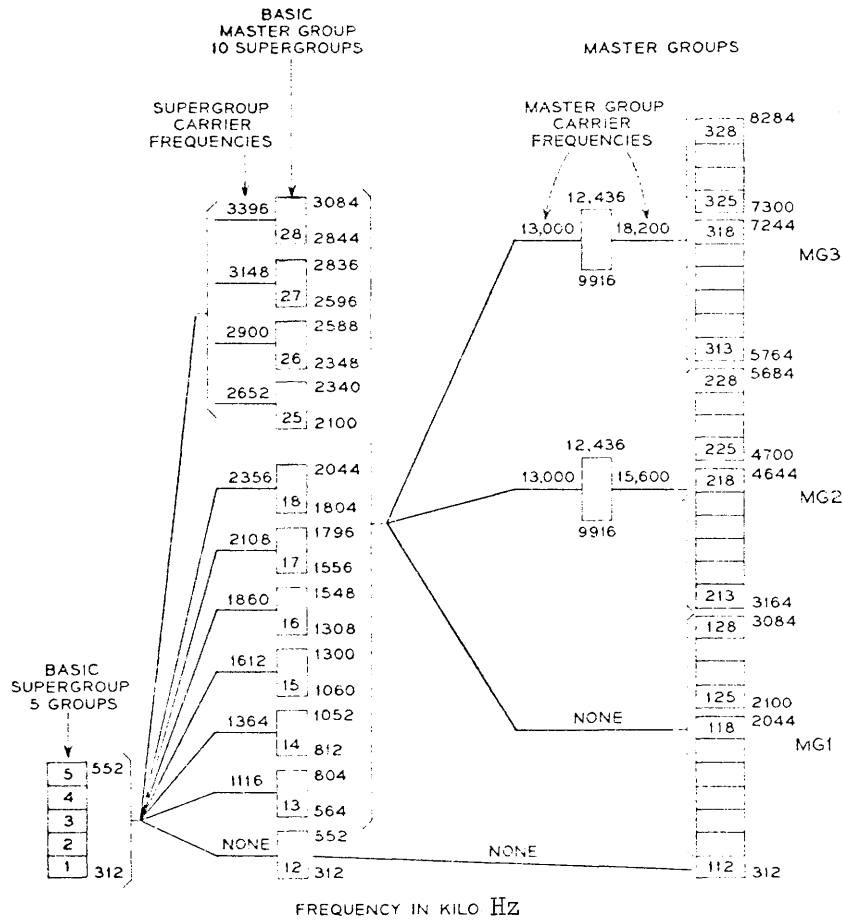


Fig. 2-15 - Frequency allocation - L1860 multiplex.

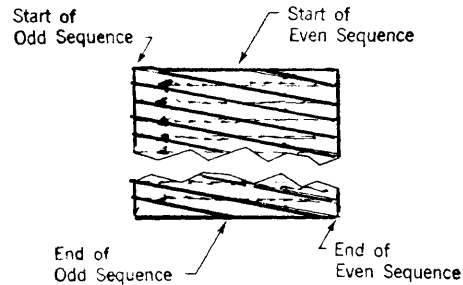


Figure 2 -16 TV Scanning Sequence

Type "L" carrier system facilities are used for the transmission of television signals as well as for multiple channel voice transmission. Transmission of a television signal necessarily requires the employment of a very wide band of frequencies. This results from the fact that, television depends upon the repetitive detail scanning of a scene at extremely rapid intervals. Standard practice in the United States for black and white television calls for 525 horizontal lines for each complete scanning of the scene and for 30 complete scans per second, with the reproduced image having a width to height ratio of 4 to 3. In practice, a single complete scan or "frame" is accomplished in two steps. In the first step, the scene is scanned over the odd-numbered 262-1/2 lines to form one "field"; and the second step, it is again scanned over the even 262-1/2 lines. This procedure, known as interlaced scanning, affects the eye of the viewer of the image as if the total scene were being reproduced 60 times per second instead of 30, and thus minimizes "flicker."

The scanning sequence is shown in Figure 2-16. For each line, the electron beam in the television camera and in the cathode-ray receiving tube moves horizontally across the image. At the same time it moves vertically downward a distance corresponding

Type

- L to two lines, under the control of the sweep circuit voltages applied to the deflecting plates or coils of the tubes. The scanning beam is blanked out at the completion of each horizontal line and returned quickly to the starting point of the next line, as indicated by the dotted lines in the figure. The process is repeated until the bottom of the image is reached. The beam is then blanked out for a longer interval while it is returned to the top of the image for the start of the next scanning sequence. The duration of each scanning line is 54 microseconds and 9.5 microseconds are allowed for the horizontal retrace of the beam. The image is scanned at the rate of 15,750 lines per second.

To maintain the exact synchronization between the camera and the receiver that is obviously necessary, synchronizing pulses generated at the image pickup point are applied to the camera tube and transmitted to the receiver along with the image signals. The synchronizing pulses are superimposed on the signal blanking pulses in such a way that they can be "clipped" from the image signal and applied to the saw-tooth generators which control the deflections of the scanning beam. As previously noted, the horizontal synchronizing pulses must recur at the rate of 15,750 per second and the vertical pulses, which return the beam from the bottom to the top of the image, must recur at the rate of 60 times per second.

Figure 2-17 (A) indicates graphically the form of the TV signal at the receiver for two scanning lines covering a total time of 127.0 microseconds. The image signal, which is applied to the control electrode (grid) of the picture tube, may vary between zero amplitude for "white" and an amplitude which effectively blocks the electron beam to produce "black" in the image. The synchronizing signals, it may be noted, rise above the black level to a region sometimes called "blacker than black." Figure 2-17 (B) illustrates the form of the longer vertical synchronizing pulse, which extends over a period of 190.5 microseconds. Vertical and horizontal synchronizing pulses are separated for application to their proper respective deflecting coils by means of a simple RC timing circuit which recognizes the

Type

- L large difference in their time duration. The vertical pulse is "serrated" as shown so that the horizontal pulses will continue during the vertical deflection period to avoid the possibility of their falling out of step. A series of "equalizing" pulses is included before and after the vertical synchronizing pulse to take care of the time factors introduced by the fact that the first scanning field is completed in the middle of a line, and the second at the end of a line.

Considering the transmission of the total television signal, it is evident that the indispensable synchronizing pulses alone make the signal rather complex. The part of the signal carrying the image must be much more complex if satisfactory image detail (resolution) is to be obtained. Thus if a scene is to be analyzed as the horizontal beam crosses it in the same detail as is provided by the 525 line dissection of the image vertically, the signal might take  $4/3 \times 525$  or 700 different values for each horizontal trace. This would correspond to a variation at the rate of 350 Hz per line which would mean  $350 \times 525 \times 30$  or approximately 5-1/2 MHz. Furthermore, if the scene being televised was one in which there were many transitions between black and white, such as a black and white checkerboard pattern, the image signal would tend to take the form of a square wave. Accurate transmission in such a case would theoretically involve frequencies extending toward infinity. Actually, practical experience indicates that entirely satisfactory resolution for black and white images is obtained from a video signal including frequencies up to a maximum of about 3 million cycles, although the standard broadcast TV signal is normally considered as 4.2 million cycles in width. In any event, it is to be noted that the lower frequencies are indispensable. Included here are the vital synchronizing pulses as well as the major values in the image structure. The higher frequencies become increasingly less important as they approach values which tend to enhance the detailed accuracy of the picture beyond the practical limit of perception of the normal eye. As might be expected also, the major energy content of the signal tends to be concentrated in the lower frequencies.

Type

- L For transmission over the Type "L-1" carrier system, the frequency range on the line between about 200 and 3100 KHz is employed. The lower frequency is limited by equalization difficulties and the upper by the characteristics of the line repeaters. Since the standard video signal begins at about 30 Hz and may be considered as extending upward, in this case, to about 2800 KHz, it is necessary to translate it by modulation procedures to place it in the proper position for transmission over the line. This is accomplished by two stages of modulation, as indicated in Figure 2-18. The carrier frequency of the first modulation stage is 7944.72 KHz. A bandpass filter permits the passage of the lower sideband, extending from about 5100 KHz up to the carrier frequency plus a small part of the upper sideband, extending from the carrier frequency up to about 8100 KHz. This latter is known as a "vestigial sideband" and is included in the passed band to insure first that there is no clipping of the lower sideband and second to reinforce the lower frequencies of the signal which are of vital importance. The second modulation stage employs a carrier of 8256 KHz to translate the foregoing main and vestigial sidebands to the range between about 200 and 3100 KHz, with the carrier frequency now appearing at 311.27 KHz.

The color television currently standard in the United States employs a video signal extending from a few cycles to about 4.2 MHz. This is necessary because the color or chrominance information of the signal is modulated on a subcarrier whose frequency is 3.579545 MHz.

Such a frequency band is too broad for transmission over ordinary "L-1" facilities. Color transmission in this case requires the use of an additional modulation step which effectively shifts the color subcarrier down to a value of 2.612 MHz. This results in some degradation of the "luminance" or black-and-white part of the signal which, however, has little visible effect in a color picture. When a purely black-and-white signal is sent over the same line, an automatic switch changes the filters so as to permit the signal to occupy the full frequency band.

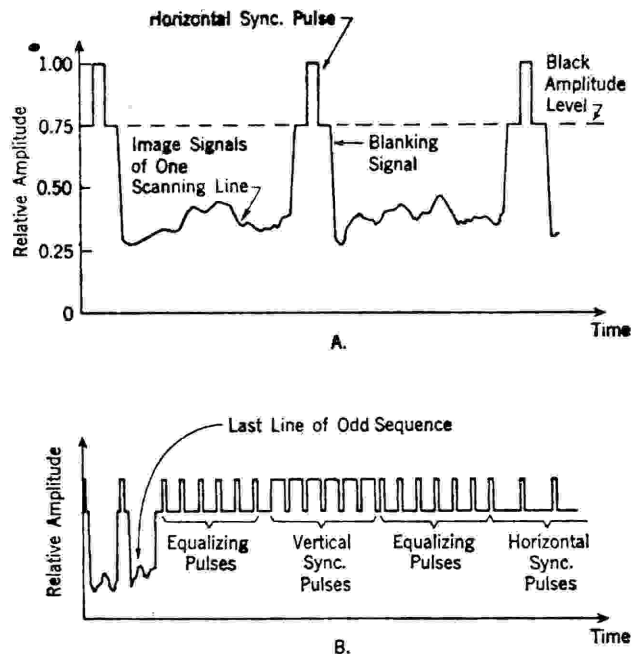


Figure 2-17 TV Signal Form

Type

- L Transmission of an unmodified color signal is well within the capacity of "L-3" systems. Here, the 0-4.2 MHz color signal is modulated with a 4139 KHz carrier so that it appears on the "L-3" line as an upper sideband extending between the carrier frequency and about 8340 KHz. A vestigial lower sideband extending downward to approximately 3640 KHz is also transmitted. This still leaves room for 660 telephone circuits in the 512 KHz to 3084 KHz band. At the receiving end the video signal is restored to its original 0-4200 KHz band by modulation with the same carrier frequency of 4139 KHz. The demodulating carrier is generated locally but is controlled by synchronizing pulses transmitted along with the video signal.



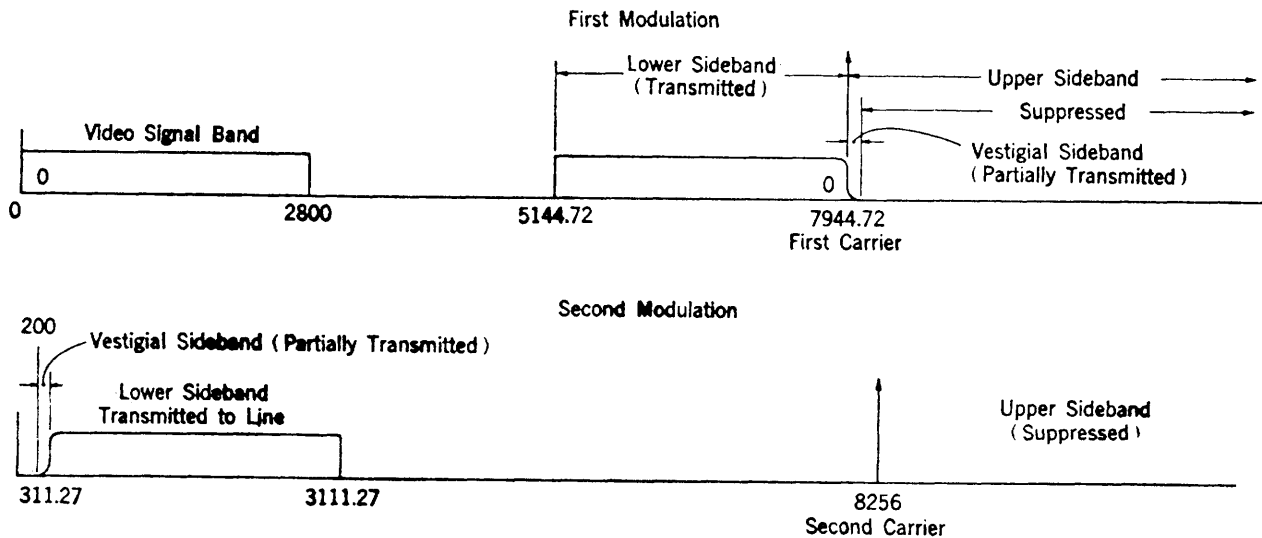


Figure 2-18 Video Signal Frequency Translations

Type**M**

The "M1" carrier system was developed primarily to provide rural telephone service by means of carrier transmission over power distribution lines, open wire telephone lines, or a combination of the two. Unlike other systems, carrier equipment is installed on the subscribers premises. The "M1" system uses amplitude modulation with double sideband and carrier transmitted. A maximum of five frequency divided channels are provided. Transmission from the common (central office) terminal is within a frequency band of approximately 152 KHz to 233 KHz. From the subscribers' terminals the transmitted frequencies are in a band from approximately 287 KHz to 413 KHz; on a reverting call connection the carrier frequency of the calling subscribers transmitter is automatically raised by 10 KHz.

Ringling, dial and switch-hook signals are accomplished by the interruption of the carrier; a 30 Hz rate is used for ringling. Power is derived from the 60 Hz power line.

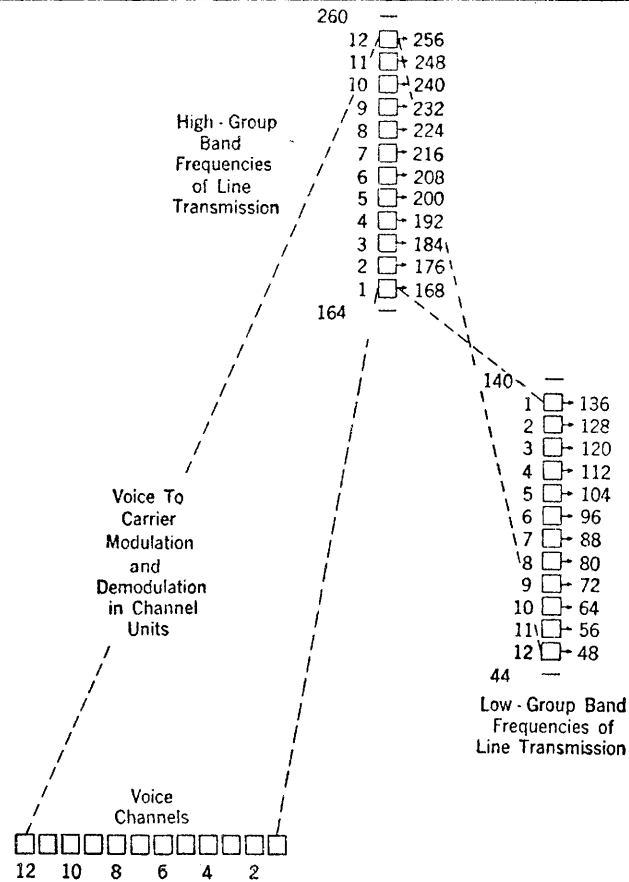
Type

M The length of lines is limited to about 15 to 20 miles for power lines or to about 40 miles for open wire telephone lines.

N The "N1" carrier system was designed specifically for short haul circuits up to 200 miles in cable. The system provides 12 two-way telephone circuits on two nonloaded pairs or a quad in a single cable. The system is designed to operate on a "4-wire" basis using separate pairs and different frequency bands for each direction of transmission. Double sideband modulation with transmitted carriers spaced 8 KHz apart is utilized, considerably simplifying carrier supply arrangements compared to single sideband carrier systems.

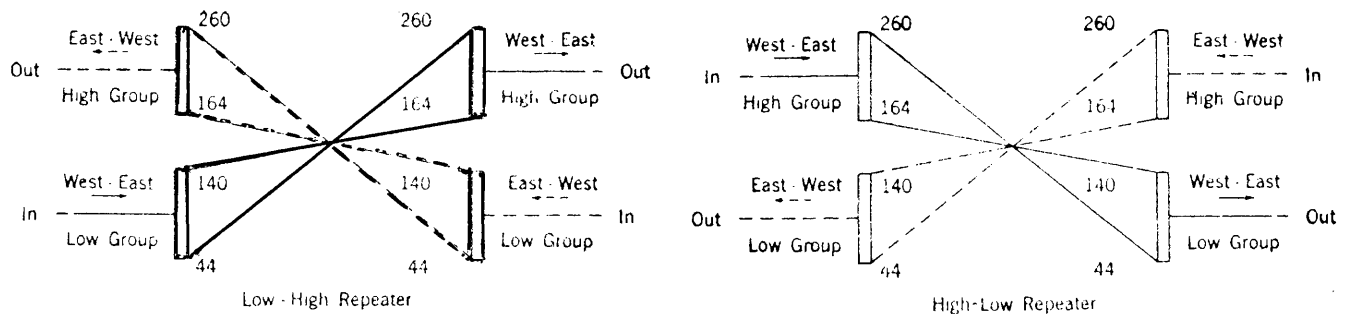
The frequency allocation of the Type "N" system is given in Figure 2-19 and 2-20. The frequencies on the line are nominally 164 to 260 KHz in one direction of transmission with channel 1 carrier at 168 KHz and channel 12 carrier at 256 kc. In the other direction the frequency band nominally is 44 to 140 KHz with channel 1 carrier at 136 KHz channel 12 carrier at 48 KHz. Group modulation from one frequency band to the other is accomplished by modulating the group with the 304 KHz group carrier and selecting the lower sideband. An additional channel numbered 13 and occupying the frequencies 40 and 264 KHz is available to replace channel 1 in case signaling difficulties are encountered in long systems, or to replace any other channel which may be inoperative due to interference from extraneous sources. The frequency space below 36 KHz is unused except for the transmission of d-c power over the simplex to repeaters. Operation on a channel 2-13 basis is now preferred over channels 1-12 due to superior frequency response and noise performance.

Devices known as "compandors" are used to compress the range of speech volume as transmitted to the line and to expand it to its original range at the receiving end of the line. This process improves the signal to noise and crosstalk ratio for the system and eliminates the need for special crosstalk balancing and noise treatment for the cable pairs.



frequency units in KHz

Figure 2-19 Type N Carrier Frequency Translations  
Channels 1-12



frequency units in MHz

Channels 1-12

Figure 2-20 Type N Carrier Repeater Frequency Translations

Type

- N      Frequency frogging is used at each repeater whereby the frequency groups are interchanged for each direction of transmission, and the frequency sequence of the individual channels is inverted. This is done by modulating both groups with a single 304 KHz carrier. The frequency frogging minimizes the possibility of interaction crosstalk around the repeaters through paralling V.F. cable pairs. It also permits the same repeater spacing to be used for both directions of transmission.

Regulation of line transmission is accomplished in each repeater and in the receiving group unit in each terminal by thermistors in the feedback circuits of the respective amplifiers using the energy of the transmitted frequencies (primarily the channel carriers) as pilots.

Another feature of the Type "N1" carrier systems, not provided on previous types, is a built-in signalling system using a single frequency above the voice range (3700 Hz) in each direction of transmission. These signaling systems are suitable for intertoll dialing and supervision.

The "N2" carrier terminal is a transistorized version of this system designed to meet the transmission performance requirements of intertoll trunks handling direct distance dialing and message channel traffic.

The transmission plan is the same as for the earlier "N1" terminals. Since carrier line frequencies, levels, type of modulation, and the use of compandors is the same, the "N2" terminals may connect to the same cables and the same repeated line circuits that are suitable for "N1" use.

Type

N The "N2" terminals are designed to work with separate, type E, single-frequency signaling equipment or multi-frequency key pulsing. No provision will be made for the 3700 Hz out-of-band signaling provided optionally for "N1" terminals.

"N3" carrier is a 24 channel, completely transistorized four-wire short haul cable system. "N3" operates on the same frequencies as "N1" and "N2" over "N" repeated lines.

"N3" carrier uses the building block of a twelve channel group. The voice signals are compressed, modulated, filtered and combined in the transmitting channel equipment. The reverse process takes place in the receiving channel equipment. The channels are filtered, demodulated and expanded in order to retrieve the voice frequency. Transmitted carriers are used to demodulate the even numbered channels. Nontransmitted carriers are obtained from a common supply to demodulate the odd numbered channels. Two twelve channel groups are combined into a broadband 24 channel signal.

"N3" carrier group equipment is similar to that used in "N2". High-group and low-group transmit and receive units are available for application to any established N carrier line frequency plan.

The "N3" carrier system uses a common carrier supply rather than a locally generated one. The supply is derived from an 8 KHz oscillator operating into a binary divider for stability. A 4 KHz tap of a "J", "K" or "L" primary supply can be used when available.

0 The Type "O" carrier system is designed to provide relatively short-haul carrier channels over open wire conductors on an economic basis. It makes use of miniaturized equipment and many of the other features of the Type-N system including compandors, frequency-frogging and built-in 3700 Hz signaling.

Type

- 0 The "O" carrier system operates on a two wire basis over an open wire pair suitably transposed for such carrier transmission.

"O" carrier provides a maximum of 16 voice channels "stacked" from 4 subsystems designated OA, OB, OC and OD. Each subsystem provides 4 channels in frequency ranges as follows:

	Low Groups		High Groups
OA System	2 to 18 KHz	and	20 to 36 KHz
OB System	40 to 56 KHz	and	60 to 76 KHz
OC System	80 to 96 KHz	and	100 to 116 KHz
OD System	120 to 136 KHz	and	140 to 156 KHz

If all 4 channels of the OA system are used, the V.F. channel on the pair must be discontinued, but some carrier telegraph channels may be added in the spectrum space below 2 KHz. If the OA system is operated as a 3 channel system, it may be used as a supplement to a V.F. circuit on the same pair in exactly the same manner as a Type C system. The OB, OC, and OD systems use frequency frogging at the repeaters in the same manner as the Type "N" cable systems. OB, OC, and OD systems may be used on the same pair as Type "C" or Type OA systems (but not both) to obtain 12 additional carrier channels. Two types of repeaters are provided for the "O" carrier systems. One type is for the Type OA system which does not provide frequency frogging. The other is for the OB, OC, and OD systems which do provide such frogging.

Unlike the N2 system, twin sideband transmission is used, with the upper and lower sidebands of a single carrier providing two channels transmitting in the same direction. Thus only two carriers, spaced 8 KHz apart, are required to obtain the 4 voice channels. Figure 2.21 indicates the frequency translations employed in the O system. The two carriers are transmitted over the line, and their combined power is used for regulation of the amplifiers at repeater and group receiving terminals to correct for line attenuation variations.

Type**ON**

The Type "ON1" cable carrier system is a composite system using Type "O" carrier terminal equipment and Type "N1" repeater equipment. Since the Type "O" terminal equipment provides for single sideband channel operation, it is possible to obtain 5 basic 4 channel groups (20 channels total) within a line frequency group band width equivalent to that used for the 12 double sideband channels of the Type "N1" system. Figure 2-22 indicates the modulation and demodulation steps of the Type "ON1" system and the frequency spectrums used. Note that the basic 4 channel group frequency band is the same as for the "O" system and the high and low group line frequency spectrums are approximately the same as for the Type "N1" system.

(Low group 4KC lower at both ends and)  
(High group 4KC higher at both ends)

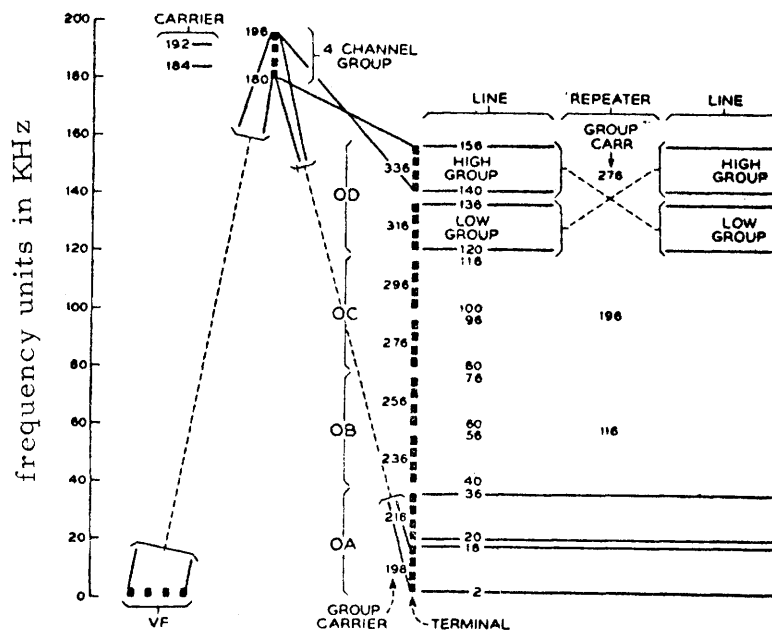


Figure 2-21 Type O Modulation Plan

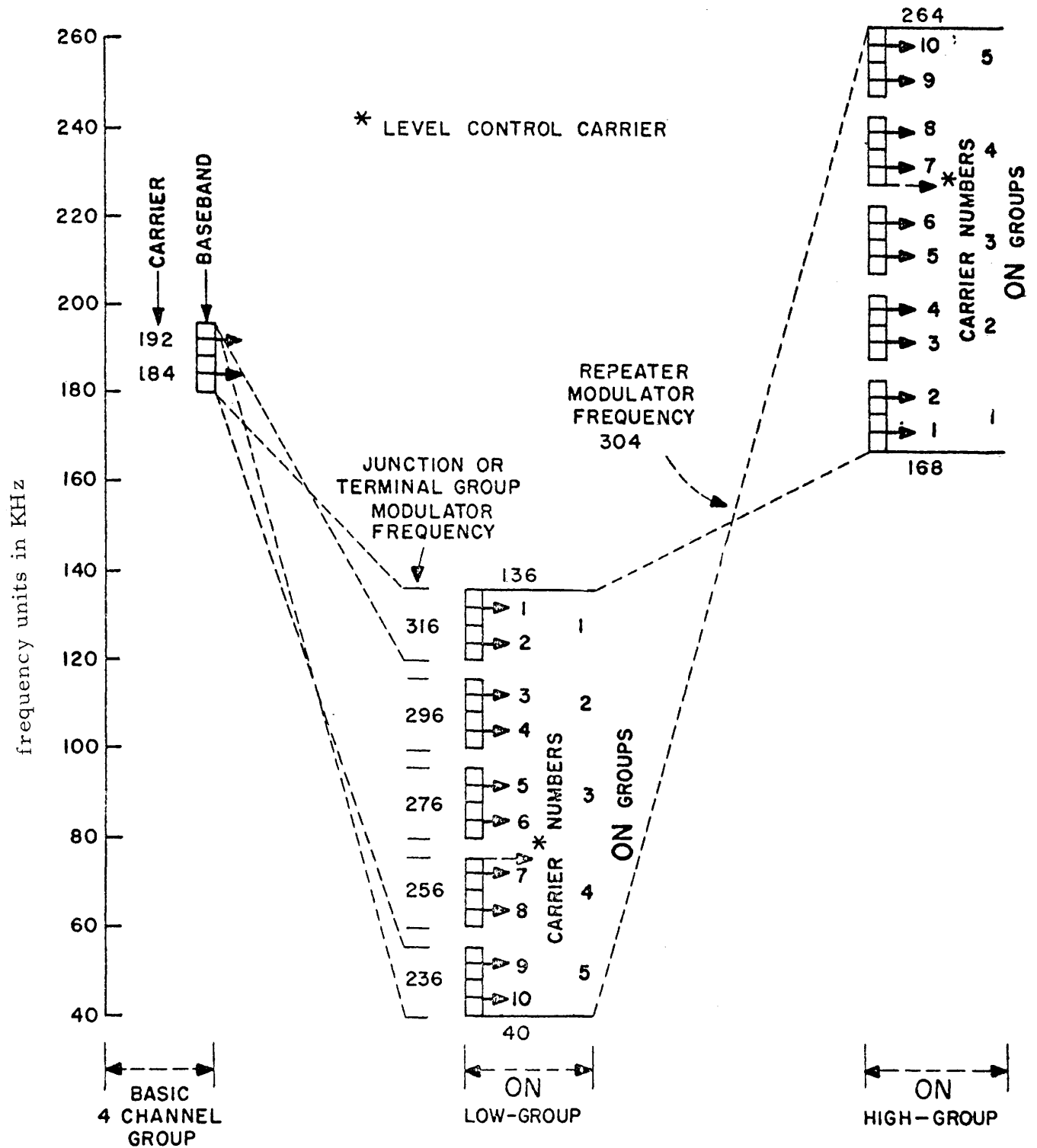


Figure 2-22 ON1 Carrier System Modulation Plan



Type

ON Because of the ease of transition between cable and open wire, and because this transition can be made at any point, the "ON1" system is adapted to open-wire, cable and radio-link combinations. For example:

- (1) Any number of type "O" channels up to 20 can be installed at one end of the cable, transmitted over two pairs in the cable to a junction with one or more open-wire lines, and then distributed to the open-wire facilities in any way desired. The 20 channels might be divided among five OB systems on five separate open-wire pairs or connected to a family of OA, OB, OC and OD Systems on one pair, and a fifth system of any type on a second pair.
- (2) The cable can be located between two open-wire lines. It is not necessary that the cable terminate at a central office at either end. Alternately, open-wire can occur between two cables.
- (3) The "ON1" arrangement can be applied readily to radio systems either directly or through intervening cable or open wire.
- (4) Type "ON1" channel terminals can be installed at each end of the cable to obtain a maximum of 20 all-cable circuits per quad in "N" cables.

A terminal is made up of standard "O1" channel units and group-transmitting units, and slightly modified "O1" group-receiving, twin-channel, and group-oscillator units.

The "ON1" repeaters located between the junction or the terminal and the type "N" carrier line are similar to "N1" repeaters.

In order to more fully utilize the frequency carrying capabilities of the "N" type high frequency line and of some microwave radio systems the "ON2" carrier system was developed. The "ON2" system provides 24 voice-frequency channels as compared to the 20 obtainable with "ON1". The "ON2" carrier can be used for systems to be operated over all cable, all radio, and cable-radio combinations.

Type

ON Standard arrangements are available for stacking four of these systems so that up to 96 voice frequency channels can be multiplexed on a single radio path.

The 24 channels of the "ON2" system are arranged at the terminal in the frequency band from 36 to 132 KHz (see Figure 2-23). For transmission on the line 36 to 132 KHz is used as the low band and is modulated with a 304 KHz oscillator to produce 172 to 268 KHz which is the high band. The resultant carriers are the same as those of channels 2 to 13 of the "N1" carrier system.

Like the "ON1", the "ON2" is basically an arrangement of stacked "O" carrier terminals which are combined for transmission over an "N1" carrier line. The "ON2" uses a stack of 6 of these 4 channel terminals in order to obtain a total of 24 channels. As indicated in Figure 2-23 the only differences in the 4 channel terminals used for "ON2" as compared to "ON1" are in the group oscillator and the group receiver.

**P** Unlike other types of carrier systems, the "P" was designed to operate between a telephone office and small groups of rural customers instead of between two telephone offices. This system provides up to four two-way channels for simultaneous operation on a single pair of wires above a voice-frequency circuit. Each channel uses a transmitted carrier and double-sideband transmission for each direction. The carriers are spaced at 12-KHz intervals and are arranged in the frequency band between 12 and 96 KHz.

Each channel, capable of serving eight telephones on a party line, requires one terminal at the central office and another mounted on a pole near the customers' premises. To make this system economically feasible, it was necessary to reduce the cost of terminal equipment to a minimum. This was accomplished by using the latest devices and techniques, including transistors, silicon aluminum varistors, ferrite inductors, printed wiring, etc.

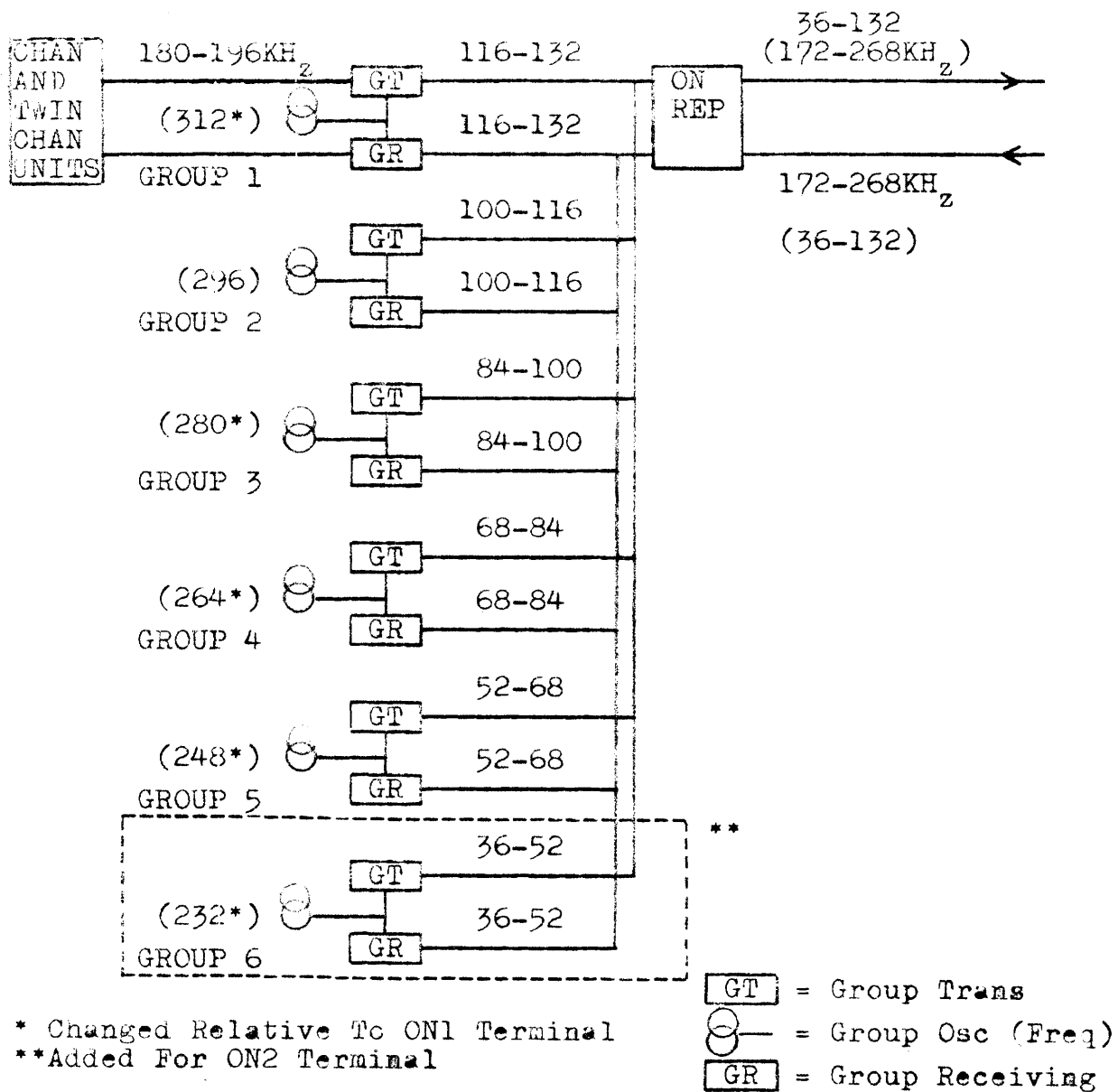


Figure 2-23 Block Diagram of 24 Channel ON2 Terminal

Type

**T** The "T1" Carrier System, a completely transistorized 24-channel PCM system, is designed to provide an economical facility for short haul trunks primarily in the large metropolitan areas.

In the type "T1" Carrier System, 24 voice channels are combined into a single pulse amplitude modulated (PAM) wave by time division multiplexing. The sampling rate for each channel is 8000 samples per second. The PAM signal is compressed and encoded into a pulse code modulation (PCM) signal for transmission over the line. A 7-digit code is used to represent each PAM sample. At the distant terminal, the received pulse train is decoded, expanded, amplified, and distributed to 24 low-pass filters. The low-pass filters extract the envelope of the received PAM pulses, which is a very close approximation to the original signal.

An additional digit is added to the 7-digit code representing the PAM sample to carry the signaling information. This increases the number of digits per channel to eight and provides a 2-state signaling channel which is adequate for dial pulse and E & M lead signaling. For revertive pulse signaling a 3-state signaling channel is required. The additional state is obtained by using the least significant digit (seventh digit in the code representing the PAM sample) for signaling information while pulsing is in progress.

In a time division system, synchronization of the terminals at the two ends is essential. Synchronization includes both timing and framing. Timing is marking the individual pulse positions or times when a decision must be made as to whether or not a pulse is present. Framing is the process of uniquely marking a particular pulse position so that the individual channel pulse positions are identifiable. The transmitting section of the terminal obtains its timing information from a 1.544-MHz crystal oscillator. The repeaters and the receiving section of the terminal derive their timing from the incoming pulse train.

Type

T Framing is accomplished by inserting a framing pulse position after each group of 24 coded samples. A pulse is inserted in the framing pulse position on every other frame; on the alternate frames the pulse position is left blank. This gives the framing pulse a unique pattern that is seldom duplicated by any other pulse position for more than a few frame intervals at a time.

The signal to be transmitted over the repeatered line consists of a train of pulses. The pulse position repetition rate is  $1.544 \times 10^6$  positions per second. This is made up of 24 eight-digit codes in each frame (7 for the PAM sample and 1 for signalling for each of the 24 channels) plus 1 framing digit or 193 pulse positions per frame. Since the sampling rate is 8000 times a second, there are 8000 frames transmitted each second. The information in the signal is contained in whether or not a pulse is present in a particular pulse position.

Figure 2-24 is a simplified "T1" system. A system terminal consists of 24 channel units and 29 common equipment units. The channel units contain the signaling converters and connect to two-wire or four-wire trunk circuits. The four-wire type units also contain individual channel amplifiers.

The common equipment includes the compressor, encoder, decoder, expander, common amplifier, and the digital control circuits. The sampling and demultiplex gates with their associated filters are also considered part of the common equipment, because it is desirable to concentrate these circuits into a few packages located physically close to the remainder of the common equipment in order to reduce lead length. Therefore, the common equipment alone provides 24 complete 4-wire voice channels. The channel units serve only as the matching units between these channels and the external trunk circuitry.

The "T1" carrier system is designed to work on existing types of 19- and 22-gauge paper - or pulp-insulated staggered twist, paired exchange cables. Short sections of 24- and 26-gauge cables may be used if the

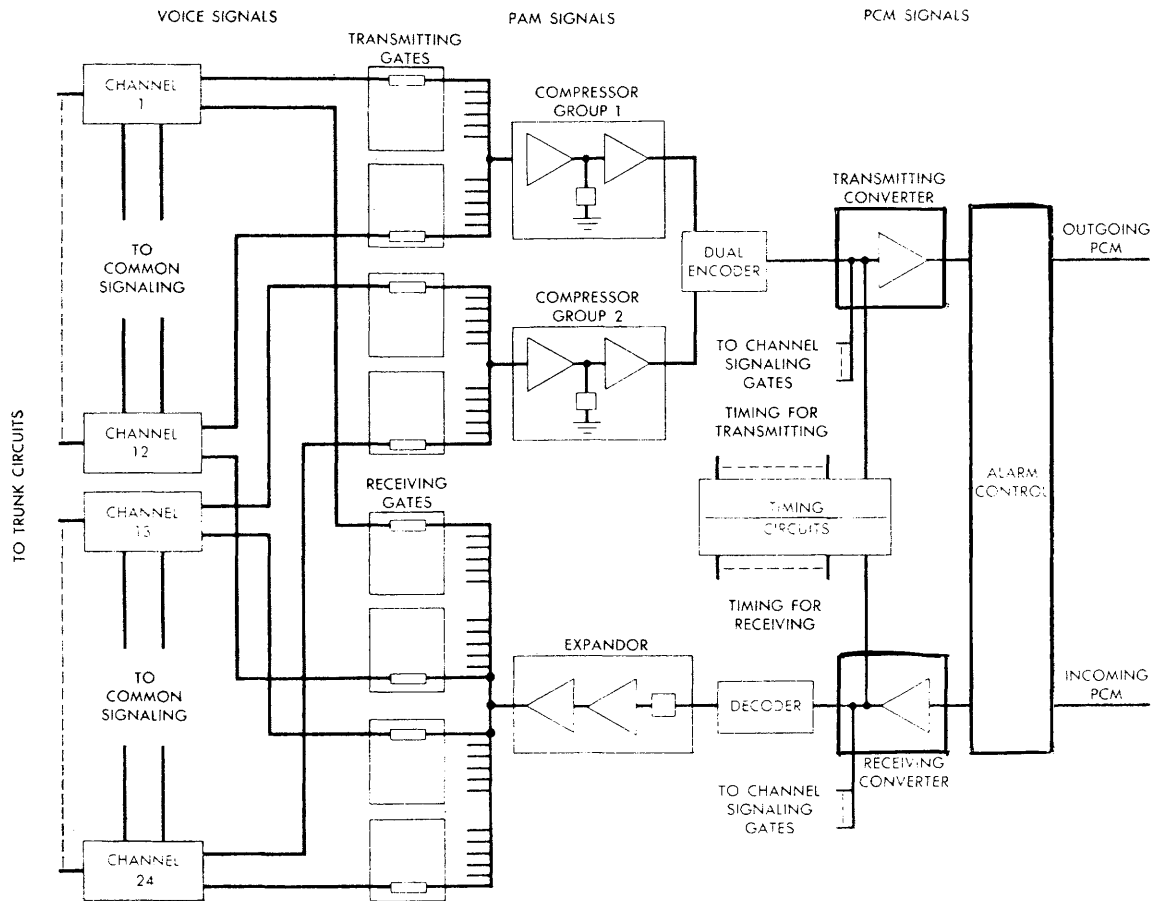


Figure 2-24 T1 Carrier Terminal

Type

T repeater spacing is reduced appropriately. The system will operate over these types of facilities for distances up to at least 50 miles. Two cable pairs are required, one for each direction of transmission.

To reduce the effect of intersystem crosstalk, the particular pulse train selected for the "T1" system uses bipolar pulses. The signal to be transmitted over the repeated line consists of a train of pulses. The information in the signal is contained in whether or not a pulse is present in a particular

Type

T pulse position. Successive pulses, regardless of the number of intervening spaces, are made to be of opposite polarity. However, the significance of a pulse in any particular pulse position is independent of its polarity. Therefore, it is possible to convert from a unipolar pulse train (all pulses of the same polarity) to a bipolar pulse train (successive pulses of opposite polarity) by inverting every other pulse and to return to a unipolar pulse train by full wave rectification.

Attenuation and distortion of the pulse train results from transmission over cables. Since the information is contained in the presence or absence of a pulse in a particular pulse position, the signal is capable of regeneration. Regeneration consists of deciding whether or not a pulse is being received in a particular pulse position and, if one is, of sending out a completely new pulse. Deciding whether or not a pulse is being received entails two things: knowing when to make the decision, i.e., timing, and determining whether or not the received voltage exceeds a predetermined threshold. All of the repeaters in the "T1" system are of the regenerative type.

Timing is accomplished by rectifying the incoming bipolar pulse train to obtain a unipolar pulse train with  $1.544 \times 10^6$  pulse positions per second. This unipolar pulse train has a strong single-frequency component at 1.544 MHz, which is at exactly the same frequency as the crystal oscillator in the transmitting terminal. This sine wave is used to mark the individual pulse positions.

The pulses are regenerated by blocking oscillators (separate blocking oscillators for the positive and negative pulses of the bipolar pulse train). A threshold bias circuit sets the decision level to regenerate a particular pulse. Both a received pulse above the threshold and a timing pulse from the timing circuit are required to trigger the blocking oscillator.

Type

**U** The U1 Carrier System, is a new carrier telephone service for customer loops. Using frequency modulation techniques, the system provides an additional two-way, single-party telephone circuit over an existing customer's loop.

A single system for one customer loop consists of only two relatively small transmitter/receiver units. One unit is located in the central office and transmits at 30 KHz; the other unit, called the "subscriber set," transmits at 18 KHz and is located on the customer's premises. A conventional telephone is connected to the subscriber set.

The system has a transmission range of 15,000 feet over nonloaded, 26-gauge, copper conductor pairs (or greater length on coarser gauges equivalent to 40 db loss at 30 KHz), and can transmit either dial pulse or Multifrequency signals and the necessary supervisory signals. A system can provide "second line" service to a single customer, or it can be used to provide the only service to another customer located near an existing customer loop.

The carrier system (added channel) is connected to the existing loop (original channel) through high-pass filters. The original channel remains undisturbed except for the insertion of two low-pass filters. One low-pass filter is included in the subscriber set of the carrier system; the other filter is installed in the central office. When the carrier system serves a separate customer over a working loop (not as second line service to the same customer), an option is available which assures privacy for each customer. When the system is used in this manner, the low-pass filter and two capacitors in the subscriber set are not used, and identical elements are installed outside the customer's premises (on a pole for example). Thus, signals from the original channel are not within reach of the added channel customer. The option protects both customers equally.



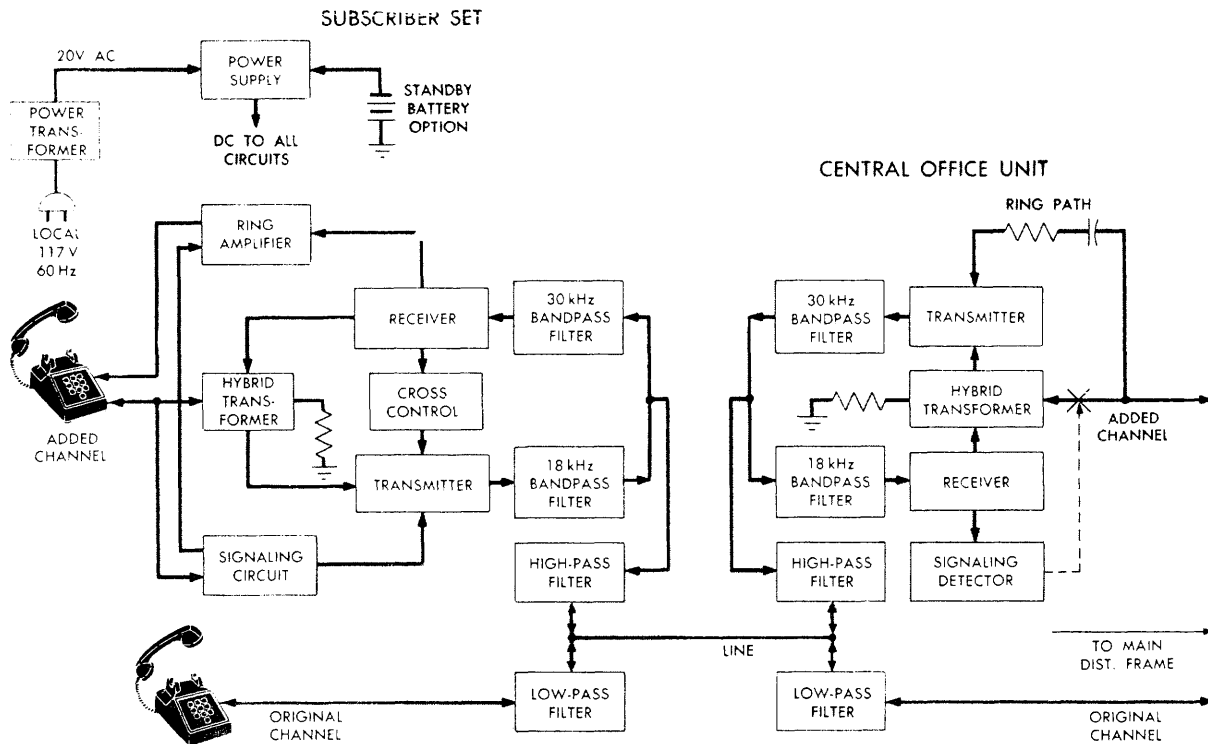


Figure 2-25 U1 Carrier System

Type

- U In each unit of the carrier system (see Figure 2-25), the transmitter and receiver are coupled by a hybrid transformer at voice frequencies and by parallel band-pass filters at carrier frequencies. The units are basically similar except for special circuits required for ringing and supervision. The subscriber set also contains a power supply circuit, which obtains its power from the commercial source in the customer's home.

The transmitter in the central office unit consists of a buffer input stage, a 30 KHz carrier oscillator, and a buffer output amplifier. The carrier oscillator

Type

U is modulated by voice frequencies through a bias voltage supplied by the buffer input stage. The dc bias voltage is adjustable so that the carrier frequency can be set to 30 KHz when the unit is manufactured. The buffer amplifier following the carrier oscillator derives the modulated carrier signal through the 30 KHz bandpass filter to the customer loop.

The central office receiver consists of a two-stage preamplifier, an 18 KHz demodulator, a low-pass filter, and an audio output amplifier. When the voice frequency signal is recovered by the demodulator, the low-pass filter passes the signal to the two-stage output amplifier and rejects carrier frequencies.

Dial pulses (transmitted from the subscriber set by interruptions of the 18 KHz carrier at the dial-pulse rate) are recovered by the signaling detector circuit, which responds to the presence or absence of the dc voltage at the output of the low-pass filter. This signal determines the state of a carrier detector transistor, which in turn drives a relay. Contacts of this relay are in the two-wire voice frequency line from the central office. Switching equipment in the central office responds to these relay contacts as the customer goes off-hook or when he dials on the telephone set.

Supervision in the opposite direction is accomplished by modulating the 30 KHz carrier with a portion of the ringing signal. When the telephone set is on-hook, however, the relay contacts in the voice frequency line are open, and there is no continuity from the central office switching equipment to the input of the hybrid transformer. Therefore, to sound the bell of the customer's telephone, a separate, high-loss path is provided from the two-wire line directly to the central-office transmitter. An 85-volt ring signal causes the 30 KHz carrier oscillator to deviate almost 2 KHz.

The subscriber set for the carrier system consists of a transmitter and receiver, similar to those of the central office unit, a cross control circuit, a ring amplifier, a signaling circuit, and a power supply.

Type

- U    The transmitter has an adjustable dc bias circuit, specifically designed to minimize drifting of the carrier frequency during dial pulsing. The receiver does not require a carrier detector circuit since the carrier signal from the central office is continuously transmitted.

The automatic cross control circuit reduces the probability of "far end" crosstalk between systems when several systems are superimposed on pairs in the same cable and the systems are located at various distances from the central office. The automatic cross control is a clamping circuit between the carrier oscillator and the output buffer stage which adjusts the level of the transmitted signal depending on the level of the received signal. The circuit can reduce the transmitter output to a level 15 db below maximum when the cable loss is zero.

The ring amplifier circuit in the subscriber set is driven from the audio output stage of the receiver. When the telephone set is off-hook, the ring amplifier circuit is disabled. The amplifier in one subscriber set can supply power to sound the bell in as many as three telephones.

A two-transistor network in the subscriber signaling circuit is energized when the telephone set goes off-hook. The circuit supplies power to the transmitter and disables the ring amplifier.

## 2.10 MICROWAVE RADIO SYSTEMS

The essential elements of any radio system are (1) a transmitter for modulating a high-frequency carrier wave with the signal, (2) a transmitting antenna that will radiate the energy of the modulated carrier wave, (3) a receiving antenna that will intercept the radiated energy after its transmission through space, and (4) a receiver to select the carrier wave and detect or separate the signal from the carrier. Although the basic principles are the same in all cases, there are many different designs of radio systems. These differences depend upon the types of signal to be transmitted, the distances involved, and various other factors, including particularly the part of the frequency spectrum in which transmission is to be effected.