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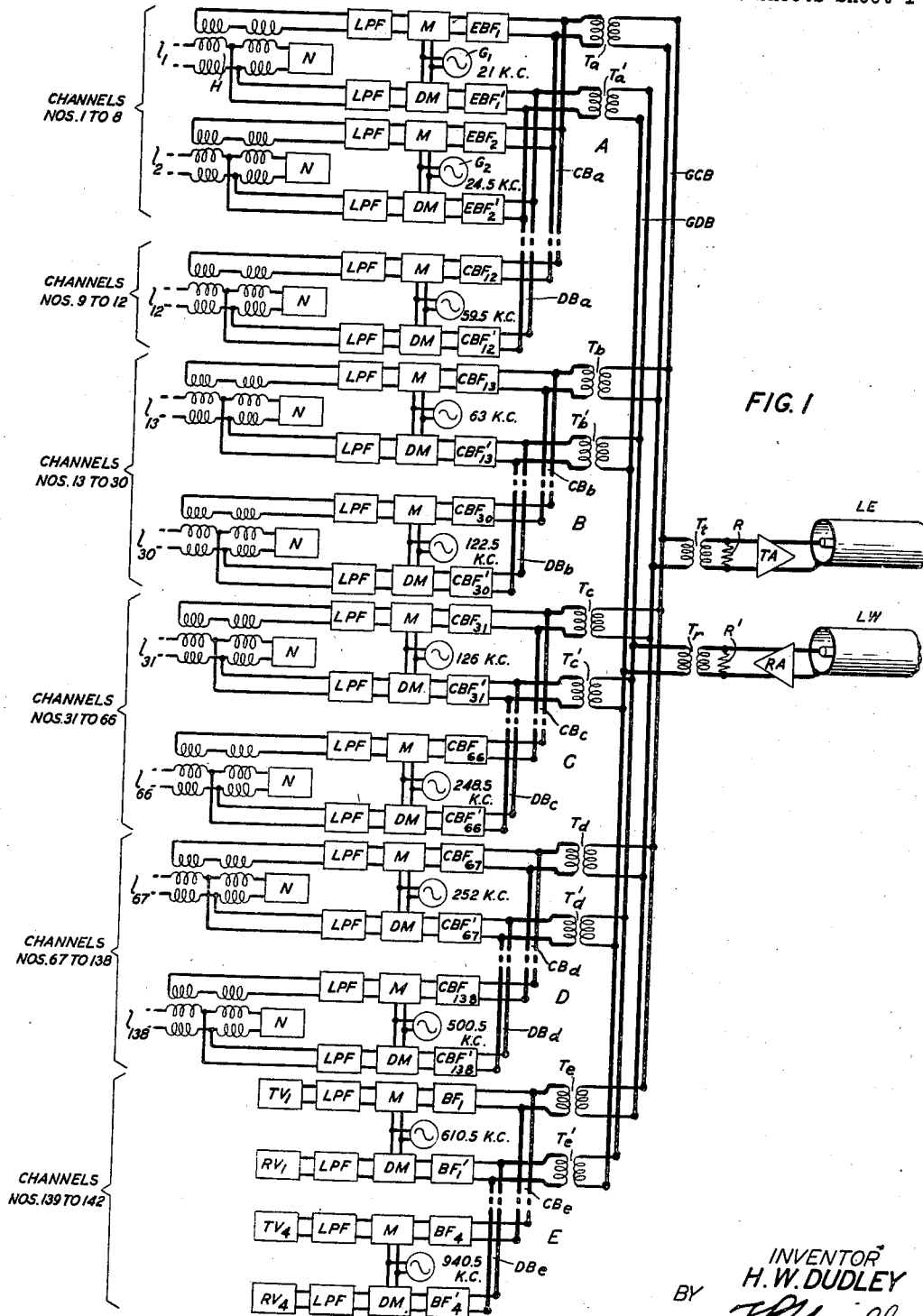
H. W. DUDLEY

2,105,910

CARRIER WAVE TRANSMISSION SYSTEM

Original Filed July 31, 1931

2 Sheets-Sheet 1



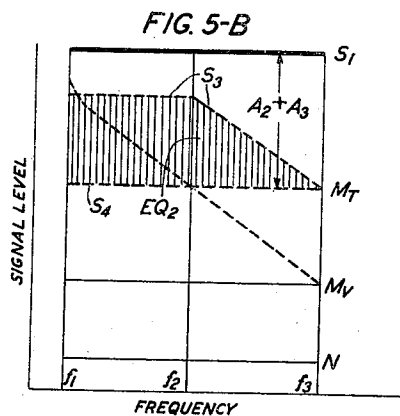
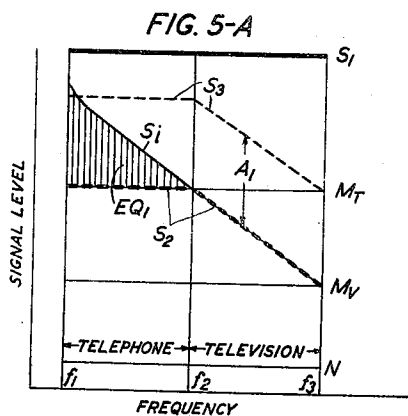
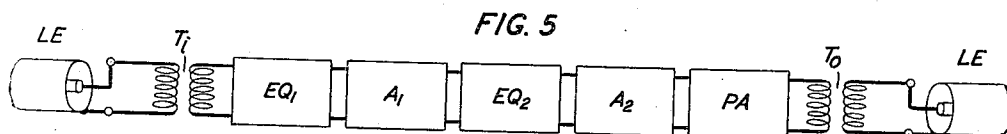
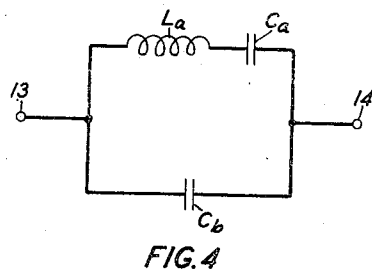
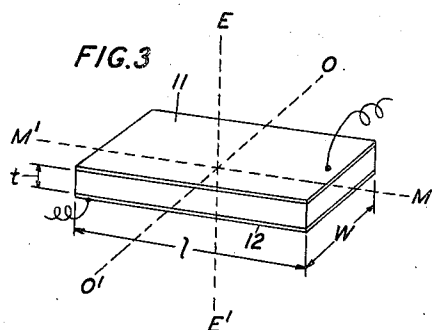
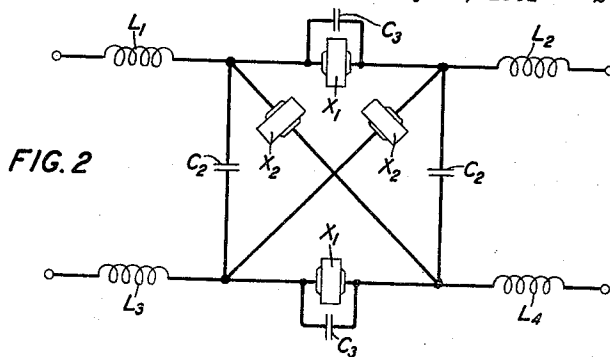
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CARRIER WAVE TRANSMISSION SYSTEM

Original Filed July 31, 1931 2 Sheets-Sheet 2



INVENTOR
H. W. DUDLEY
BY *T. P. Merville*

ATTORNEY

UNITED STATES PATENT OFFICE

2,105,910

CARRIER WAVE TRANSMISSION SYSTEM

Homer W. Dudley, Garden City, N. Y., assignor to
Bell Telephone Laboratories, Incorporated, New
York, N. Y., a corporation of New York

Original application July 31, 1931, Serial No.
554,206. Divided and this application July 25,
1935, Serial No. 32,993

19 Claims. (Cl. 178-44)

This invention relates to multiplex transmission systems and more particularly to multiplex systems employing carrier waves.

This is a division of applicant's application Serial No. 554,206, filed July 31, 1931, now Patent 2,009,438, issued July 30, 1935, relating to carrier wave transmission.

An object of the invention is to provide an improved system in which carrier currents, respectively modulated with signals representative of different types of intelligence and each including components extending over a wide frequency range, are transmitted in selected portions, respectively, of the frequency range of a communication medium.

Another object is to increase the efficiency of a communication system by transmitting carrier currents modulated with signals of one type in a portion of the frequency range of a communication medium, the upper limiting frequency of which portion is determined by an operating condition of the system, and transmitting carrier currents modulated with signals of a second type, which is less susceptible to the effect of said operating condition, in another portion of the frequency range of the communication medium.

Other objects and the various features of the invention will appear hereinafter in the description of a specific embodiment of the invention.

In a multiplex transmission system employing carrier waves, several factors unite to impose a limit on the number of carrier wave channels that can practically be superposed on a single pair of conductors. One is the increasing attenuation with rise in frequency that is met in the transmission line. With the lines commonly in use, a frequency of the order of forty to one hundred thousand cycles per second has been found the highest it is desirable to employ, the increasing difficulty in preventing cross-talk between adjacent lines militating against extension of the frequency range. By suppressing one of the two side-bands resulting from the modulation process, the width of the signal band to be transmitted has been reduced. It is also common practice to suppress the carrier wave during the modulation process and to supply it in the demodulation process from a local source. There is also to be considered the frequency spacing of the carrier waves, or more pertinently, the frequency interval between the signal bands in adjacent carrier wave channels.

In determining the spacing between bands, account must be taken of the fact that the selectivity afforded by filters for selecting a particu-

lar band of frequencies to the exclusion of others is proportional rather than absolute so that they are effectively less selective at high frequencies than at low. A dissipational filter having a given ratio of reactance to resistance, such as shown for example in G. A. Campbell Patents 1,227,113 and 1,227,114, dated May 22, 1917, which might require a spacing of 1,000 cycles per second between bands at a frequency of 30,000 cycles per second, would require a proportionately greater spacing at 60,000 cycles per second, viz. 2,000 cycles per second. If it were thus made necessary to increase the spacing between bands as the carrier frequencies became higher, it is readily seen that a condition would quickly be reached where the interval between bands would exceed the width of the band and the available frequency range would be utilized very inefficiently. It is possible and has been the practice to place a number of filter sections in tandem to improve the selectivity, but long before the selectivity becomes great enough to separate channels spaced perhaps 1,500 cycles apart at frequencies of the order of a hundred thousand cycles per second, the signal distortion caused by the filter, as a result of their discrimination against the extreme frequencies of the signaling band, becomes intolerable. In a long transmission system it may be desirable for switching purposes to reduce the signals impressed on the carrier waves to their normal frequencies at a number of points, each time reapplying the signals to carrier waves. Since any cutting of the side-band by the filter is multiplied at each successive point, a high grade system requires a very nearly flat frequency-attenuation characteristic in the pass-band of each filter. A deviation from linearity of not more than 1 decibel over a 2,500 cycle band is contemplated in applicant's system.

Heretofore, the range of frequencies actually employed in carrier telephone systems has been so restricted that the filters required but small waste space between channels. In attempting to translate a plurality of low frequency channels to closely adjacent positions at much higher points in the frequency spectrum, however, and subsequently to restore the translated channels to their original frequencies, the lack of selectivity of the filters becomes a serious limitation. It has been proposed to obviate this difficulty by employing successive processes of modulation and successive processes of demodulation. In the first stage, the low frequency channels are divided into several groups. The channels in each group are then applied to respective carrier

waves of relatively low frequency, perhaps of the order of thirty thousand cycles per second, which differ from each other by little more than the width of the signal bands to be created. At these frequencies the filters are very effective in separating the bands, so that the side-bands to be eliminated can be so effectively suppressed that they do not interfere with the transmitted side-bands of adjacent channels. In the second stage of modulation, the several groups of carrier wave channels are translated to respective positions in the wide range of frequencies to be applied to the transmission line. The groups are not as closely spaced together as are the channels, however, since at the higher frequencies the filters require a greater frequency spacing between the waves which they are to separate. The resulting band of channels, therefore, has in it many intervals that cannot be utilized for signaling purposes. The inverse process is used at the receiving terminal of the system.

While the frequency translating systems used heretofore have been incapable of utilizing completely even a restricted frequency range, their limitations become especially important when an attempt is made to take advantage of the wide range of frequencies which can be efficiently transmitted over a pair of coaxial conductors. With reasonable spacing of repeaters a useful frequency range of a million cycles or more is practicable with this type of transmission line. Even with half this frequency as an upper limit, more than a hundred carrier telephone channels are available, provided that it be feasible to space the channels uniformly close together.

In accordance with applicant's invention a carrier wave system is provided wherein, even at frequencies many times greater than now commonly employed on lines, the respective bands of signal waves may be separated at any frequency level throughout a wide frequency spectrum of transmitted waves. A feature of applicant's system resides in the use of particular selective circuits. The latter are of a band-passing type incorporating piezoelectric crystals, of quartz, for example. The selectivity of the preferred forms of these filters is such that in a system where the highest frequency is above half a megacycle per second and the width of the respective signal bands to be transmitted is 2,500 cycles per second, a spacing of 3,500 cycles per second or less can be maintained between carrier waves. The unused space between channels is 1,000 cycles, i. e., of the order of only one or two tenths of one per cent of the highest frequency transmitted. To separate a number of incoming bands into respective channels at a terminal station it is necessary only to connect these channels in parallel through a plurality of these filters. To divert any particular channel from the main transmission line for transmission over a branch line, similarly, only the selective devices are essential. This avoids the process that would be required in systems proposed heretofore of translating a group of channels to a lower frequency position, separating the desired channel from the others of its group and then restoring both, separately, to their original high frequencies.

The nature of applicant's invention will appear more fully in the following description of a system embodying it in specific form. While the signaling sources are indicated as telephone and television apparatus, it will be obvious that waves from other signaling sources can be impressed on

the carrier waves. In any event, the signal modulated carrier currents which are most affected by conditions affecting the operation of the system and which, in a specific case, may, for example, be due to the level of the noise currents, are transmitted in a portion of the frequency transmission range of the medium having an upper limiting frequency determined by the effect of the undesired conditions on the efficient transmission of this type of signals, and signal modulated carrier currents, which are affected to a lesser degree by such conditions, are transmitted in a portion of the range extending upwardly from such limiting frequency. Furthermore, the carrier wave system of applicant's invention may be incorporated in a system involving double frequency translation so that the advantages inherent in both systems may be combined to still further extend the frequency range over which the selective circuits can effectively be employed.

In the drawings,

Fig. 1 shows schematically one terminal of a combined telephone and television carrier wave transmission system in accordance with applicant's invention;

Fig. 2 shows a preferred form of the piezoelectric selective circuits;

Fig. 3 represents a piezoelectric crystal;

Fig. 4 shows the equivalent electrical circuit thereof;

Fig. 5 shows a preferred form of repeater; and Figs. 5A and 5B show graphically the successive steps of equalization and amplification occurring in said repeater.

Referring now to Fig. 1 there is shown a terminal circuit for effecting two-way frequency translation of signals between a plurality of relatively low frequency signaling circuits and a pair of transmission lines adapted to transmit carrier waves extending over a wide range of frequencies. Each of the low frequency channels, which are represented here as telephone and television signaling circuits, is associated with individual modulating and demodulating apparatus and through these, with the high frequency transmission line. A separate conductor pair is shown for each direction of transmission, although with a single pair of conductors different frequency ranges could be used for this purpose, in a manner well-known in the art. The telephone lines l_1, l_2 , etc., of which one hundred and thirty-eight are represented, and their respective associated modulating and demodulating apparatus, are divided into a plurality of groups in order to simplify the problem of efficiently connecting them to the transmission line, as will be more fully explained hereinafter. Signals transmitted between the several telephone lines and the carrier frequency line are otherwise subjected to very similar treatment.

Telephone signals from line l_1 enter hybrid coil H, pass through the output winding of the latter to a transmitting channel which includes a low-pass filter LPF. The latter, which may be of the type disclosed in the G. A. Campbell patents, supra, is designed to suppress all frequencies above the signal band it is desired to transmit. A 2,500 cycle band extending from perhaps 250 to 2,750 cycles per second is satisfactory. To modulator M, which may be of the balanced type disclosed in J. R. Carson Patent 1,343,306, issued June 15, 1920, is applied this 2,500 cycle band of speech signals together with a carrier wave sup-

plied by high frequency generator G₁, so that a speech modulated carrier wave results.

The carrier wave applied to the modulator M of the first channel has a frequency of 21 kilocycles per second. The carrier wave applied to the modulator M in the adjacent channel is 3.5 kilocycles higher. In succeeding channels similarly the carrier waves are increased in 3.5 kilocycle steps, the last channel, the 138th, having a carrier frequency of 500.5 kilocycles per second. In the process of modulation, the carrier wave is suppressed by virtue of the balanced arrangement of the modulator circuit. One side-band, preferably the upper one, also is suppressed, as by means of a succeeding band-pass filter EBF₁. At 60 kilocycles per second an electrical band filter of the type disclosed by Campbell, supra, is satisfactory, and, as indicated, such filters are used in channels 1 to 8 where the highest carrier frequency is 56 kilocycles per second. In channels 9 to 12 of the first group and in all channels of higher frequency, band passing filters CBF incorporating piezoelectric crystals as will be described hereinafter are employed. Of the two signal side-bands produced, the lower one in the first channel extends from 20.75 kilocycles per second down to 18.25 and the upper one from 21.25 kilocycles per second to 23.75. Since the side-band applied to the transmission line from the adjacent channel ranges from 24.25 kilocycles per second down to 21.75, the upper side-band of channel 1 must be well suppressed if it is not to cause interference, and so with the upper side-bands of the other channels.

The output terminals of the filters EBF and CBF in channels 1 to 12 are connected to a common collecting bus CB_a, which is preferably formed from a coaxial conductor having a characteristic impedance of about 80 ohms, and which in turn is connected to transformer T_a. The impedance ratio of transformer T_a is selected so that the mean impedance of the several filters in their pass-bands is matched with the impedance into which the secondary of transformer T_a works. In general, the impedances of the filters in their pass-bands as seen from the transformer decreases with rise in frequency. The mean impedance of the first twelve, comprising group A, may be of the order of 600 ohms. Outside the pass-bands the filter impedances rapidly become so high as to give practically no bridging effect.

The next eighteen channels, 13 to 30, comprising group B, are similarly connected to a common collecting bus CB_b. The mean output impedance of the several filters CBF in this group may be 150 ohms; the impedance matching transformer T_b is designed accordingly. An approximately geometrically increasing number of channels is included in the groups succeeding group B, there being 36 in C and 72 in D. The number of channels to be included in each group is determined by the maximum allowable percentage deviation of the impedance of any filter from the mean impedance for which the transformer is designed, and therefore, by the maximum allowable percentage deviation of the frequency of any given channel of the group from the mean frequency of the group. The higher the frequency the greater the number of channels that may be included in each group. The secondary windings of the several group transformers T_a, T_b etc. are connected to the group collecting bus GCB, which is connected through transformer T_t to the transmitting amplifier TA and to the outgoing line LE.

Amplifier TA preferably comprises a suitable number of tandem screen grid stages leading up to a final stage or stages of capacity-neutralized push-pull tubes. Across the input of this amplifier is shunted a resistance; 8000 ohms was found to be a satisfactory value in one case. Transformer T_t was so proportioned that a fixed impedance of 80 ohms was presented to the group transformers. The transmission line LE preferably comprises a central conductor and a hollow return conductor maintained in coaxial relation by means of insulating washers or beads spaced at intervals along the central conductor. A suitable conductor of this type is described in greater detail in U. S. Patent 1,781,124, issued November 11, 1930 to H. R. Nein. The high degree of freedom from cross-talk of this type of conductor permits the assemblage of a plurality of them within a common cable sheath.

The receiving circuits are arranged in a manner similar to the transmitting circuits, as shown in Fig. 1. Signals arriving over line LW pass through the receiving amplifier RA and transformer T_r to the group distributing bus GDB. The receiving channels are grouped in accordance with the frequencies of the carrier waves employed exactly in the same manner as the transmitting channels. Transformers T_{a'}, T_{b'}, etc., serve to match the mean impedance of the respective groups of filters with the impedance presented across their respective primary windings. Signals passing through these transformers are applied to the respective channel distributing buses DB_a, DB_b, etc.

From the distributing buses each of the receiving band passing filters EBF'₁, EBF'₂, CBF'₁₀, etc. selects its particular band of modulated signal waves. The bands received may be 2500 cycles wide and spaced with 1000 cycles between their adjacent edges, as are those transmitted. Each filter may be identical with the filter in the transmitting channel using the same carrier frequency; those in receiving channels 1' to 8' may therefore be of the electrical filter type and those in channels 9' to 138' of the crystal type. The succeeding demodulators DM may be of the balanced type disclosed in the Carson patent, supra. Preferably both modulator and demodulator are neutralized, as for example in the manner shown in Ballentine Patent 1,560,332, November 3, 1925. The carrier wave which must be introduced to effect demodulation may be applied from the same source that is used in conjunction with the associated local modulator. The telephone signals resulting from the demodulation pass through a low-pass filter LPF to the input terminal of hybrid coil H, whence they are applied to the telephone lines l₁, l₂, etc.

In Fig. 2 is shown schematically a preferred form of the crystal band-passing filters utilized in accordance with applicant's invention. The filter, per se, is the invention of W. P. Mason and together with the theory underlying its operation and design is fully disclosed in his Patent 2,045,981 issued June 30, 1936. In the diagram, L₁, L₂, L₃ and L₄ are inductances of equal values connected in series with the four terminal leads of the filter. The condensers C₂, C₂, connected between inductances L₁ and L₃ and between L₂ and L₄, respectively, are of equal capacity, as are the condensers C₃, C₃. The condensers C₃ are shunted around the respective identical quartz crystal elements X₁, X₁. The diagonally connected crystals X₂, X₂, are likewise identical.

The proportioning of the various elements of

this lattice type filter to obtain the desired transmission characteristics may be determined by calculation. When doing so the crystals may be considered as equivalent to the electrical circuit of Fig. 4. This circuit comprises a parallel branch network connected between terminals 13 and 14, one branch consisting of an inductance L_a in series with a capacitance C_a and the other branch comprising a simple capacitance C_b . The magnitudes of these equivalent elements are determined by the dimensions of the crystal as represented in Fig. 3. The length l of the crystal is taken parallel to the mechanical axis MM' , the width w parallel to the optical axis OO' and the thickness t parallel to the electrical axis EE' . Electrodes 11 and 12 are applied to the large faces of the crystal, that is, to the surfaces perpendicular to the electrical axis, preferably by the electrical deposition of a layer of silver or other metal to secure an intimate contact over the whole surface. For a quartz crystal

$$L_a = \frac{118lt}{w} \text{ henrys}$$

$$C_a = \frac{0.289wI \times 10^{-14}}{t} \text{ farads}$$

and

$$C_b = \frac{40.5wt \times 10^{-14}}{t} \text{ farads}$$

where the dimensions are in centimeters.

In electrical filters, the ratio Q of the reactance of the coils to the resistance thereof is a measure of the effectiveness with which the filters can transmit a selected band of waves to the exclusion of others. In filters used heretofore values of Q of the order of one hundred or two hundred were obtained, the latter figure being considered quite high. In the case of the quartz crystal filter, however, values of Q up to several thousand can be obtained. Such high Q 's are obtainable in fact as to bring in another factor, viz., delay distortion, as the limiting one in the spacing of the channels. In any filter, the attenuation at the edge of the pass-band depends on the amount of resistance therein and on the number of reflections to which signals traversing it are subjected. The higher the value of Q , the greater the number of reflections, and accordingly the greater becomes the phase difference between waves of different frequencies. Applicant has found, however, that despite the degree of selectivity required in his system and the number of filters that it may be necessary to connect in tandem in the longest circuits, the distortion caused by this phase delay is not prohibitive.

Above the frequency range required for the carrier telephone system a carrier television system may be added. Four transmitting and four receiving television channels or more may be provided, two of which are represented in Fig. 1. Each band of television signals may have a range of 100 kilocycles per second. A spacing of 110 kilocycles between carrier waves would be sufficient when band selective circuits using piezoelectric crystals are employed. With the television carrier wave of lowest frequency fixed at 610.5 kilocycles per second an interval of somewhat more than 10 kilocycles is left between the carrier television and the carrier telephone channels.

Signals from television transmitter TV_1 are passed through the low-pass filter LPF to eliminate extraneous waves that may be present above the 100 kilocycle band it is desired to transmit.

In the balanced modulator M the television signals are impressed on a carrier wave of 610.5 kilocycles. The crystal filter BF_1 suppresses the upper side-band and higher products of modulation to prevent interference with the transmitted side-band of the adjacent television channel. The modulated waves from the four channels are applied to a collector bus CB_a , as in the carrier telephone circuit, for connection with line LE through transformer T_e . The inverse process whereby carrier television signals arriving over line LW are reduced to their normal frequencies and applied to the television receivers RV_1 , RV_2 , etc., will be obvious from the description of the analogous process in the carrier telephone receiving circuit.

Television signals are much less affected than telephone signals by noise currents in the transmission system. While the level of the carrier telephone signals may have to be maintained at all times at least 65 decibels above the level of noise, the carrier television signals may be attenuated to as low as 30 decibels above the noise level. This fact is utilized in the design of the repeater circuit shown in Fig. 5. Figs. 5A and 5B will aid in an understanding of the nature and function of the several elements of the repeater that may be included in the transmission circuit. The repeater circuit is shown for one-way repetition from the left-hand section of line LE to its right-hand section. For repetition in the opposite direction the repeater would be connected in line LW , with its elements reversed. That is, with transformer T_1 connected to the right-hand section of line LW and transformer T_0 connected to the left-hand section of line LW . Similar connections may be provided at different repeating stations included in the system. These latter diagrams show the energy level of telephone and television signals at successive points in the system. As applied to the transmission line, either from a terminal station or from a repeater station, all signals are at the level S_1 . Because of the unequal attenuation to which waves of different frequencies are subjected by the transmission line, the level of the signals arriving at the input transformer T_1 of a succeeding repeater may be as represented by the solid line S_1 . The carrier telephone signals of highest frequency f_2 have been attenuated down to the minimum permissible level M_T determined by the noise level N , which is 65 decibels lower. The width of the television band is such that waves of the highest frequency f_3 are likewise attenuated to a minimum level M_V , which is only 30 decibels above the noise level N . To equalize the signals, i. e., to bring them all to the same level, each might be attenuated to the level of the lowest one, viz., to M_V . This is not desirable since the telephone signals would then be only 30 decibels from the noise level and serious interference would result. Again, all signals might be amplified 35 decibels, which would bring those of lowest amplitude, i. e., those of frequency f_3 , to the minimum permissible telephone level M_T and then each signal attenuated in an equalizer to a common level M_T . The amplification however would raise the signals of low frequency to an unnecessarily high level and thereby demand greater power carrying capacity of the equalizer.

In applicant's preferred form of repeater the telephone signals alone are first reduced to the level M_T in an equalizer EQ_1 to which the signals arriving over the transmission line are passed by the input transformer T_1 . The attenuation-frequency characteristic of the equalizer, which is

represented by the shaded area of Fig. 5A, is such that the telephone signals are reduced to the level M_T without substantially affecting the television signals. The heavy dotted line S_2 indicates the signal level at this stage. Following equalizer EQ_1 is an amplifier A_1 . The maximum level applied to the amplifier, it will be noted, is M_T , which is considerably lower than would be the case had amplification preceded equalization. In the amplifier, the energy level of all signals is raised uniformly to the level represented by the dotted line S_3 , so that the television waves of low-energy level are brought to at least the level M_T . All waves are now reduced by the succeeding equalizer EQ_2 to a level S_4 which, as shown in Fig. 5B, is at or somewhat above the minimum telephone signal level M_T . The characteristic of this second equalizer is represented by the shaded area of Fig. 5B. The succeeding voltage amplifier A_2 and power amplifier PA raise the signals uniformly to their original level S_1 for application through output transformer T_o to the line.

In a system such as the present one, wherein the channels are uniformly distributed in the frequency spectrum, it is possible to obtain such a frequency allocation that the most objectionable of the modulation products created in the amplifiers fall in the frequency interval between channels. With these products thus located, appreciably more modulation is permissible than would otherwise be the case. Frequency allocation of this sort is effective chiefly because it is a relatively narrow band of frequencies within the speech band that contributes most to inter-channel cross-talk. The distance of the center of this narrow, high energy band in a given carrier band from the lowest frequency of the carrier band transmitted may be represented by $\bar{d}$, the mean absolute frequency of this narrow band as it appears, for example, in the n th carrier frequency channel by $\bar{d}_n$, the width of the speech band by b , and the frequency interval between channels by c . The disturbing modulation products of chief concern are of the second order. Foremost among these are the summation and difference frequencies resulting from the intermodulation of the principal disturbing frequencies $\bar{d}_1, \bar{d}_k, \bar{d}_n$, etc. of the several channels j, k, n , etc. If the principal disturbing frequencies were at the center of the speech band, i. e., if $\bar{d}$ were equal to

$$\frac{b}{2}$$

the summation frequencies and the difference frequencies resulting from their intermodulation could both be made to fall exactly in the center of the interchannel "dead" space, where they would have least effect on the desired signals. It would only be required that the frequency allocation of the several channels be such that the lowest frequency of any channel be expressible as

$$(1) \quad K(b+c) + \frac{c}{2}$$

The frequency actually contributing the most to interchannel modulation is not the mid-frequency of the speech side-band but one corresponding to a speech frequency of the order of 1,000 cycles per second. The summation frequencies and the difference frequencies resulting from the modulation of this most disturbing frequency as it occurs in the several carrier bands cannot both be made to fall at the center of the frequency interval between channels. If

either these worst summation frequencies or these worst difference frequencies are made to appear at the centers of the interchannel spaces, the other will fall within the signal bands if the latter are closely spaced. A compromise can be reached, however, by making these two groups of frequencies fall equi-distantly from the center of the interchannel space, where neither will lie in the signal bands provided the dead space is at least 1,000 cycles wide. The essential feature of this allocation is that the lowest frequency of any given channel be expressible as

$$(2) \quad K(b+c) + \frac{b+c}{2} - d$$

or, in other words, that the bottom frequency a of the lowest complete channel that might be fitted into the uniform allocation system be expressible as

$$(3) \quad a = \frac{b+c}{2} - d$$

While approximately 1,000 cycles is the most important single frequency as regards modulation effects and the frequency allocation can be determined from the foregoing equations with it as a basis, greater accuracy is obtainable by considering the fact that frequencies above and below it also contribute disturbing modulation products. It is desirable that the bands of summation frequencies and the bands of difference frequencies contributed by these frequencies occupy the same frequency range between channels and not be offset one from the other. At one extreme is the case where c is equal to $2b$; the summation frequencies and difference frequencies just fill the interchannel space if the channels are allocated on the basis that the most important frequency is at the center of the signal band, i. e., that

$$d = \frac{b}{2}$$

At the other extreme is the case where c is zero and 1,000 cycles is properly considered the most important frequency for the purposes of determining the frequency allocation. For intermediate values of c a corresponding intermediate value of the most important frequency, lying between 1,000 cycles and the mid-frequency f_m of the speech band transmitted, may be assumed. Thus, in a system where a speech band of from 250 to 2,750 cycles per second is used and a particular value of c of 1000 is selected for c , then the frequency to be considered the most important one, and therefore to be used in evaluating $\bar{d}$, is determined from the general expression

$$1000 + \frac{c}{2b}(f_m - 1000)$$

Substituting, we have

$$1000 + \frac{1000}{2 \times 2500}(1500 - 1000)$$

$$= 1100 \text{ cycles per second}$$

Then, for an upper side-band system, the corrected value of $\bar{d}$ to be used in Equations (2) and (3) is $1,100 - 250 = 850$ cycles per second. For a lower side-band system $\bar{d}$ is $2,750 - 1,100 = 1,650$ cycles per second. The lower side-band system shown in Fig. 1 is based on a harmonic relation of the carrier frequencies. By reducing all carrier frequencies by 6,500 cycles (as by a heterodyning process) the requirements of Equations (2) and (3) can be met. The carrier frequen-

cies would then be 20.35 kc., 23.85 kc., 27.35 kc., etc. A corresponding upper side-band system would have carrier frequencies of 21.65 kc., 25.15 kc., 28.65 kc., etc.

5 The cross-talk between two adjacent carrier systems can be reduced by staggering the frequency bands of one with respect to those of the other. Where the lower side-band is used in one system and the upper side-band in the adjacent
10 system and the optimum frequency allocation set forth above is observed, a certain reduction in cross-talk is therefore obtained.

While applicant's invention has been described as embodied in a specific carrier wave signaling
15 system, it is apparent that it may find application in various other wave transmission systems within the scope and spirit of the appended claims.

What is claimed is:

20 1. A signal system comprising a transmission medium, means for supplying thereto signal modulated carrier current including components extending over a wide frequency band, and including means for limiting the maximum frequency
25 of said band to a value fixed by the noise level of the system, and means for also supplying to said medium carrier current modulated with other signals including components extending over a wide frequency band, the upper
30 limiting frequency of which is less susceptible to noise at the noise level of the system and occupies a different position in the frequency spectrum than the first-mentioned band.

35 2. A signal system comprising a transmission circuit means for producing carrier current modulated by a signal current including components extending over a frequency band, means for supplying said signal modulated current band to said transmission circuit said means including
40 means for limiting the maximum frequency of said band to a value determined by the noise level of the system, means for modulating a carrier current of different frequency than said first-mentioned carrier by a signal including components
45 extending over a frequency band to produce a signal modulated current which is affected to a lesser degree by noise at the noise level of the system, and means for supplying said last mentioned signal modulated current to said
50 transmission circuit.

3. A signal system comprising a transmission medium, means for applying thereto a signal modulated carrier band including means for limiting the maximum frequency of said band to
55 a value fixed by the level of noise in said system, and means for applying to said medium, above said maximum frequency, carrier current modulated by signals of a different type which are less susceptible to noise at the noise level of the system.
60

4. A signal system comprising a transmission medium, and means for applying thereto a band of carrier telephone signals including means for limiting the maximum frequency of said band to
65 a value fixed by the level of noise in said system, and means for applying to said medium, above said maximum frequency, a band of television signals.

5. A signal system comprising a transmission
70 line, means for transmitting thereover signal modulated carrier in one frequency range, means for transmitting thereover carrier current modulated with signals of a different type than said first-mentioned signal in a higher frequency
75 range, and means for limiting the lowest frequency

of said second-mentioned signal modulated carrier to a value such that at all points in said line the energy level thereof with respect to the noise level is maintained at least one-half that of the first-mentioned signal relatively
5 to said noise level.

6. A signal system comprising a transmission line, means for transmitting thereover carrier telephone signals in one frequency range and carrier television signals in a higher frequency
10 range, and means for fixing the lowest frequency of the carrier television signals supplied to said line at a value such that at all points in said line the level of said carrier television signals is at least thirty decibels above the noise
15 level.

7. A signal system comprising a transmission medium which may be used for the transmission of signals in a wide frequency range, means for supplying signals of one type in a portion of
20 said range and including means for limiting the maximum frequency of the current supplied to said portion to a value fixed by the noise level of the system, and means for supplying signals, less susceptible to noise at the noise level of the
25 system, in the remaining portion of said range.

8. A signal system comprising a transmission medium which may be used for the transmission of signals in a wide frequency range, means for supplying carrier currents of different frequencies each modulated with signals of one type in a portion of said range, and including means
30 for limiting the maximum frequency of the current supplied to said portion to a value fixed by the noise level of the system, and means for supplying signals less susceptible to noise at the noise level of the system in the remaining portion of said range.
35

9. A signal system comprising a transmission medium which may be used for the transmission of signals in a wide frequency range, means for supplying carrier currents of different frequencies each modulated with signals of one type in a portion of said range, said supply means including means for limiting the maximum frequency
40 of the current supplied to one of said portions to a value being fixed by the noise level of the system, and means for supplying carrier current modulated with signals less susceptible to noise at the noise level of the system, in the
45 remaining portion of said range.

10. A signal system comprising a medium having efficient transmission characteristics extending over a wide frequency range, means for supplying thereto signal modulated carrier currents corresponding to a plurality of spaced channels in a portion of said range, said supply means including means for limiting the maximum frequency of the current supplied to said portion to a value determined by the noise level of the system, and means for supplying to said medium a plurality of television modulated carrier currents respectively corresponding to a plurality of spaced channels in the remainder of said range.
60

11. A signal system comprising a medium having efficient transmission characteristics extending over a wide frequency range, means for supplying thereto signal modulated carrier currents corresponding to a plurality of equally spaced channels in a portion of said range, said supply means including means for limiting the maximum frequency of the current supplied to said portion to a value determined by the noise level of the system, and means for supplying to said medium a plurality of television modulated carrier
75

rier currents respectively corresponding to a plurality of equally spaced channels in the remainder of said range.

12. A signal system comprising means for
 5 producing a carrier current modulated by a signal including components extending over a frequency band and for producing a carrier current of different frequency than the first-mentioned
 10 carrier and modulated by a signal including components extending over a frequency band, a transmission circuit the transmission characteristic of which for one of said signal modulated
 15 currents is determined by the level of noise in the system, means for applying said signal modulated carrier currents to said transmission circuit, and means for compensating the attenuation of said circuit for the respective signal modulated
 20 currents by equalizing the said one signal modulated current, simultaneously amplifying the equalized and other signal modulated
 25 currents and simultaneously equalizing said amplified currents.

13. In combination with a transmission circuit, means for supplying thereto a plurality of
 25 signal currents, each including components extending over a wide frequency band and respectively occupying different portions of the frequency spectrum, one signal band having a
 30 different allowable minimum energy level than the other, and means for compensating the attenuations of said transmission circuit for the respective signal bands comprising means for
 35 equalizing said one band and amplifying said equalized band and the other band, and means for equalizing the amplified bands.

14. In a signaling system, a transmission line, means for applying thereto signal waves respectively in different frequency ranges, the minimum
 40 allowable level of waves in one of said frequency ranges being higher than that of waves in another, means to equalize waves from said line in said one frequency range, means to amplify said

equalized waves and the waves in said other frequency range, and means to equalize said amplified waves in said other frequency range.

15. In combination, a transmission line, means to apply carrier wave telephone signals thereto in
 5 one frequency range, means to apply carrier wave television signals thereto in a higher frequency range, means to equalize said telephone signals from said line, means to amplify television
 10 signals from said line and said equalized telephone signals, and means to equalize said amplified television signals.

16. In a circuit transmitting a plurality of signals having different minimal levels, means for
 15 amplifying one of said signals from below the minimal level of another of said signals to above said level, and means to equalize said amplified signals.

17. In a circuit transmitting a plurality of signals having different minimal levels, means for
 20 reducing the frequency-amplitude distortion of one of said signals, means for amplifying another of said signals from below the minimal level of said one of said signals to above that level, and
 25 means to reduce the frequency amplitude distortion of said amplified signals.

18. In a circuit transmitting signal waves respectively in different frequency ranges, said
 30 waves having different minimum allowable transmission levels, means to equalize waves in each of said frequency ranges in successive stages.

19. A circuit over which are transmitted signal waves respectively in different frequency
 35 ranges, a repeater for said waves comprising means for equalizing the level of the components of different frequencies included in one of said ranges, an amplifier supplied with the equalized
 40 components and those in the other of said ranges, and means for equalizing the amplified components included in both of said frequency ranges.

HOMER W. DUDLEY.