

Feb. 3, 1942.

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2,272,070

ELECTRIC SIGNALING SYSTEM

Filed Nov. 22, 1939

3 Sheets-Sheet 1

Fig. 1.



Fig. 2.

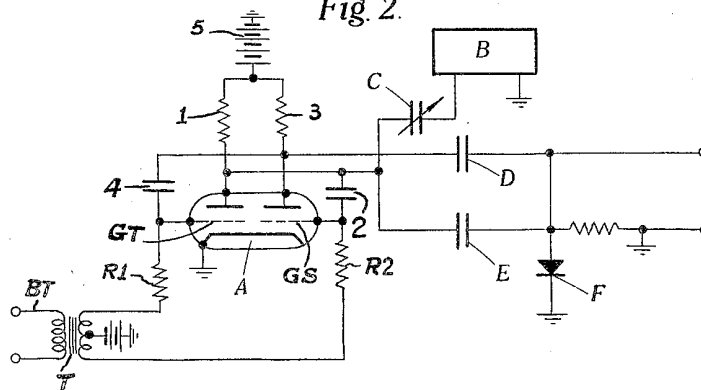
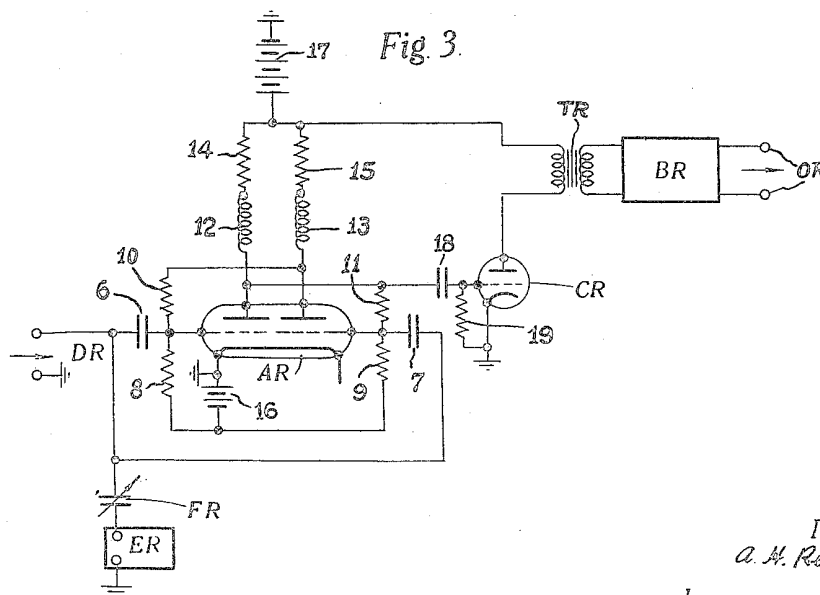


Fig. 3.



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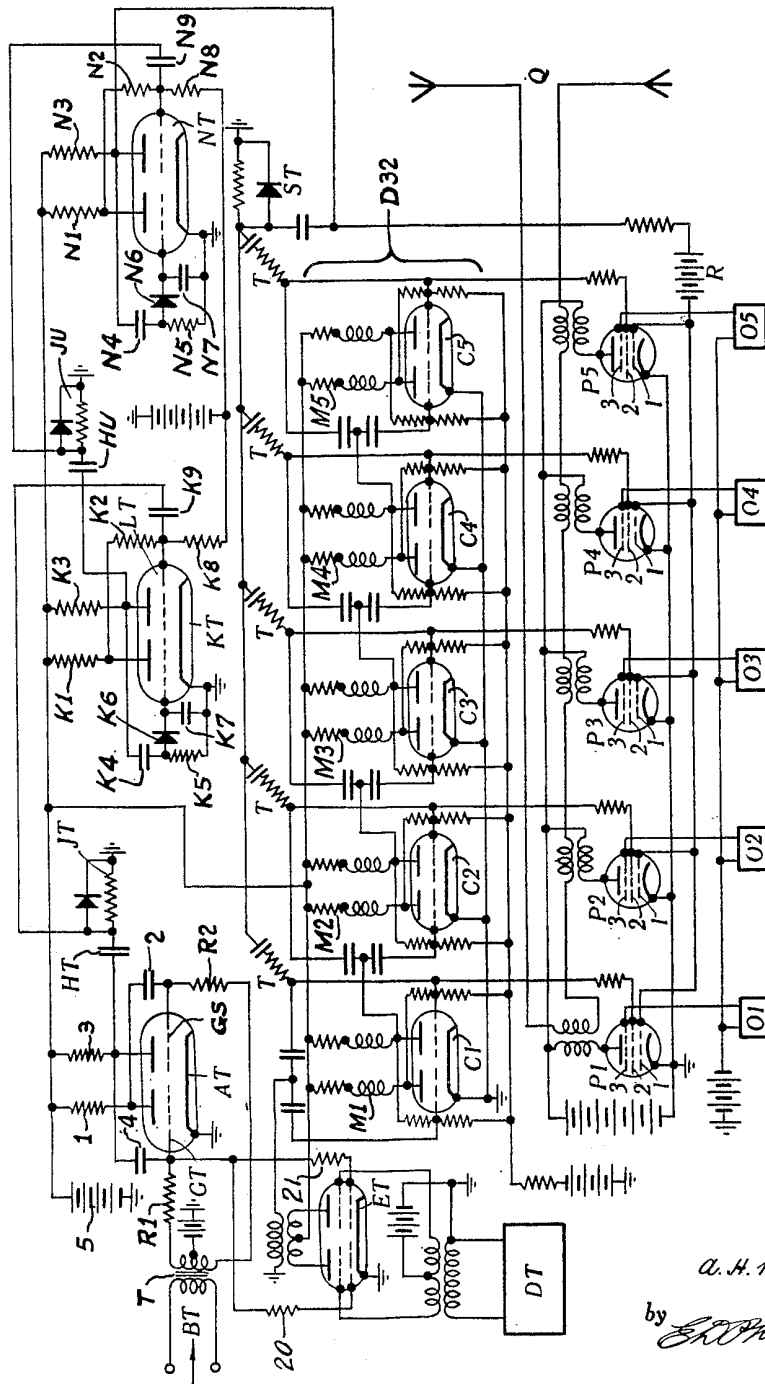
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3 Sheets-Sheet 2

Fig. 4.



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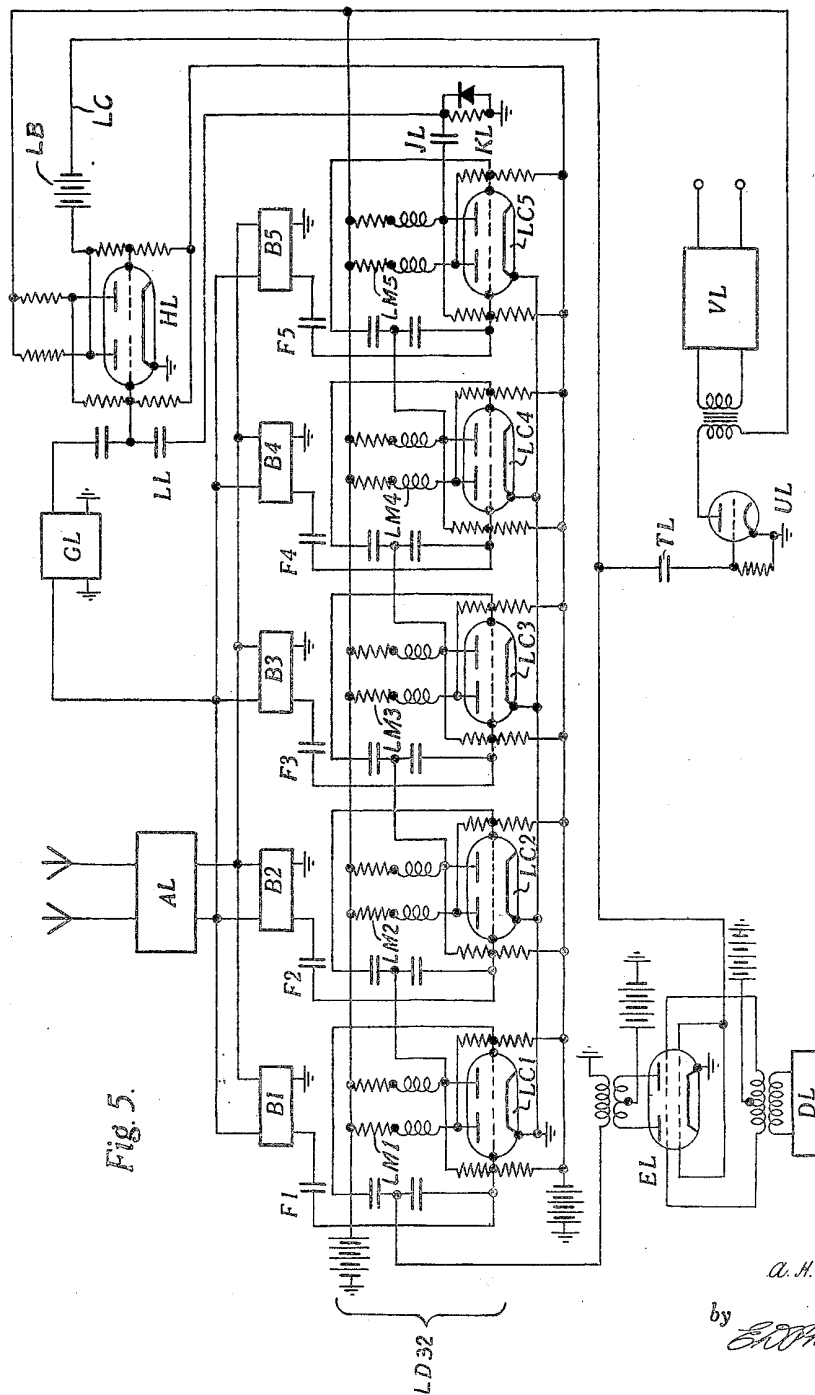


Fig. 5.

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UNITED STATES PATENT OFFICE

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ELECTRIC SIGNALING SYSTEM

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23 Claims. (Cl. 178—44)

The present invention relates to electrical signaling systems, and more particularly to systems adapted to transmit complex wave forms, for example, speech, which are practically free from any background noise.

The main object of the invention is to provide electrical signaling systems which practically have no background noise, even under conditions in which the signal-to-noise ratio would normally be about 20 decibels, or less.

The systems for the transmission of intelligence at present in use may be grouped into two large classes: (a) systems giving at the receiver indications of the occurrence or non-occurrence of actions taking place at the transmitter, for example, of the presence or absence at any given moment of particular pulses forming a part of the signals transmitted by a teleprinter transmitter, and (b) systems giving the receiver a quantitative information with regard to the amplitude at the moment in question of a variable peculiar to the transmitter, for example, ordinary telephone systems.

The information required must normally be transmitted in systems where interference noises of an amplitude dependent upon the particular problem involved, are inevitable. In systems of the type (a) means are already known for ensuring that this noise should always remain below a certain predetermined maximum value, and have practically no effect on the results received. The solution generally adopted consists in the use of a relay, or other device with trigger operation, adjusted in such a way that although actuated by the desired signal the noise, always of less amplitude than the signal, can never cause operation of said relay, or prevent its operation under the effect of the desired signals.

In the case of systems of type (b), however, the methods employed to overcome the noise effects are only palliatives for reducing the noise, but do not eliminate the noise entirely.

It is, consequently, the main object of the invention to provide means to eliminate the background noise of a signal transmission substantially completely in systems of the second of the two above-mentioned classes, and to provide arrangements for this purpose which have the desired commercial characteristics. The arrangements proposed necessitate a slight increase of the width of the transmission frequency band.

This necessary increase of the band width is in proportion on the one hand to the signal-noise ratio before the elimination of the noise, and on the other hand to the precision necessary for the

reproduction at the receiver of the signal wave form at the transmitter.

According to the present invention, a signaling system for transmitting complex wave forms, for example speech, wherein the wave form is scanned at the transmitter at predetermined instants, and at these instants signal elements are transmitted to the receiver is characterised in this, that the amplitude range of the wave form to be transmitted is divided into a finite number of predetermined amplitude values according to the degree of fidelity required. The instantaneous amplitude value of the wave form to be transmitted at each predetermined instant being transmitted in a signal code representing the nearest predetermined amplitude value above or below said instantaneous amplitude value.

The number of elements in the code may equal the number of predetermined values of the amplitude range of the complex wave, or may be equal to a number such that the total possible number of combinations of the code elements is greater than the minimum required for reproducing the complex wave form within the desired limits of accuracy.

In accordance with another feature of the invention, the amplitude of the complex wave form is transmitted at a given moment by a predetermined combination of m separate signaling channels, each having n different signal elements, the resultant possible total number of signal combinations, that is to say n^m being greater than the minimum number required for the transmission of the information within the desired limits of precision.

In accordance with another feature of the invention, the combinations of signals are automatically transformed at the receiver into a correct reproduction of the instantaneous amplitude at the moment in question of the wave form to be communicated.

In accordance with another feature of the invention, the number of possible signal elements transmitted in each channel is reduced to a value at which the undesired circuit noise in each of these channels, namely, a peak value not exceeding a predetermined limit, is incapable of affecting the occurrence or non-occurrence in the receiver of correct and definite series of operations associated with the particular combination of signals transmitted at that moment.

In accordance with another feature of the invention, the m separate signaling channels are obtained by employing m channels each utilising a different carrier frequency.

In accordance with another feature of the invention the m signaling channels are obtained by employing a carrier frequency common to all the channels, and utilizing a distributor system for the channels in known manner.

In accordance with another feature of the invention, the n different signal elements on each channel are obtained by the transmission of the carrier frequency of each channel at n different predetermined amplitudes.

In accordance with another feature of the invention, the n types of signals are obtained by the transmission on each channel of n pulses of different duration or n pairs of pulses having n predetermined different intervals of time between the pairs.

In accordance with still another feature of the invention, the n types of signals are obtained on each channel by the transmission of the carrier wave of each channel at n possible different phases.

In accordance with still another feature of the invention, the n different types of signals are obtained by the use on each channel of n different predetermined frequencies.

In one practical embodiment of carrying out the invention, in the case in which the number of channels m is equal to 1, a multi-vibrator synchronised with an oscillation generator and associated with a frequency separator are employed at the receiver for producing the signal elements.

In a practical embodiment of the invention in the case in which n is equal to 2, a frequency separator circuit associated with suitable triggering devices is used at the transmitter and at the receiver for producing at the transmitter codes representing amplitudes of the waves and for re-converting the codes into amplitudes at the receiver.

These, and still other features will be explained in detail in the following description based on the attached drawings in which:

Fig. 1 shows an example of the complex wave form of a signal to be transmitted;

Fig. 2 shows an example of a transmitting circuit incorporating features of the invention;

Fig. 3 represents an example of a receiving circuit embodying certain features of the invention;

Figs. 4 and 5 are circuit diagrams of other examples of transmitting and receiving circuits respectively incorporating features of the invention.

In a telephone transmission system, a wave form such as that of Fig. 1 can, as is well known (for example, as in transmission by means of individual pulses), be transmitted or received with negligible distortion by the successive transmission and reception of a number of separate pulses, each corresponding in amplitude (or in any other desired variable factor) to the original instantaneous amplitude of the speech, as indicated by the small circles on the curve of Fig. 1, the spacing between the pulses being considerably less than that corresponding to a period of the highest frequency contained in the speech to be transmitted. The letter D may be used to designate the ratio of the pulse frequency to the highest speed frequency.

In each possible case arising in practice, however, each of these amplitudes has to be transmitted, not with an infinite degree of precision, but with a particular finite degree of precision dependent upon the problem involved. For example, in considering ordinary speech signals at

a mean constant level, a precision of the order of $\pm 1.5\%$ should, in the ordinary way, be amply sufficient in practice, while a precision of $\pm 0.05\%$ would certainly be sufficient for a high quality of radio broadcast of music. Consequently, taking the case of 1.5% in which the percentage is relative to the maximum amplitude it is clear that in this case it is unnecessary to transmit an infinite possible number of amplitudes, but only a series of approximately 33 different values.

Embodiment I (1 channel, 33 amplitudes)

Making use of the above principle an ordinary transmission system having a transmitter and a receiver may be modified by adding 33 marginal relays to the transmitter, one for each of the 33 possible different amplitudes mentioned above. Each of these relays should be such that only the amplitudes of signals falling in the range of $\pm 1.5\%$ of its allotted value cause it to operate, and the transmitter should be arranged so that if a particular relay is operated a definite amplitude will be transmitted. Thus only 33 finite different amplitudes will be transmitted. Then if 33 similar relays are provided at the receiver each which will only respond to a single pulse of the transmitting relay, the original wave form will be received with the desired precision.

The effect of background noise in the above outline "Embodiment I" will now be considered. Assume that the band-width of the audio frequency is 3000 periods per second, and that the "normal" signal-to-noise ratio is a , where this "normal" ratio is defined as the ratio which would be observed between the maximum pulse potential of the signal and the root mean square potential of the noise if the special receiver of the present invention were replaced by an ideal linear receiver adjusted for reception with a minimum band width. Assume also that the value of the "normal" signal-to-noise ratio is independent of the frequency of the modulating wave. Now in the above outlined Embodiment I the minimum band required to transmit the resulting amplitudes at the series of instants will be $D \times 3000$. If $D=2$ this gives $2 \times 3000 = 6000$ cycles. The signal-to-noise ratio for the amplitudes received will, consequently, be $a/\sqrt{2}$.

In order completely to eliminate the noise in the receiver output, the noise peaks must always be lower than the value necessary to change the amplitude of the received pulse from its actual value to a value of a higher or lower degree in the series; that is to say, the noise peaks must be less than 1.5% of the maximum pulse amplitude, i. e. must be at least 37 decibels below the pulse potential. The effective level (root-mean-square) of the noise corresponding to this peak value of course depends upon the wave form of the noise; if, however, this noise is mostly of the nature of a steady hiss caused by thermic agitation, a peak factor of $\sqrt{2} = 3$ decibels may be assumed. For practically complete noise suppression, consequently, the loudest r. m. s. or effective value of the noise need only be 40 decibels below the maximum pulse potential. In other words $a/\sqrt{2}$ need only equal 40 db.; or a need only be 43 db.

Assuming a safety factor of three additional decibels it is found that it is unnecessary for a , the original "normal" signal-to-noise ratio on an ideal linear receiver, to exceed 46 decibels. If, however, this condition is fulfilled the output of the receiver will give a signal-to-noise ratio of

60 decibels or more, the limit only being determined by the noise generated by the receiver marginal devices themselves. This improvement has been made by doubling the band-width.

Embodiment II (5 channels, 2 pulse amplitudes)

Another case can now be considered in which it is assumed to be permissible to increase the band-width very greatly so as to obtain the best possible signal-to-noise ratio from the minimum possible incident field strength. Such a case is frequent in communication by ultra-short waves. It will be assumed that 32 amplitude values are necessary, i. e. approximately about as many as above. It is possible to obtain the necessary permutations of code elements in order to represent 32 different amplitudes by suitable combinations of five separate pulses used as the code elements, each having only two possible values—either “on” or “off”—and the circuit being designed in such a way that the correct combination of pulses is automatically transmitted, received and automatically re-translated at the receiver into the 32 original amplitudes, as will be explained hereinafter. Each pulse requires a separate transmission path. This can be carried out in a large number of different ways by employing frequencies individual to each channel, by employing the principle of distribution in time etc. The five corresponding trigger devices of the receiver now consist of simple relay devices each having an “on” and an “off” position; and the noise of the receiver can prevent perfect operation only if the noise peaks exceed half the amplitude of the pulses, i. e. are less than 6 db. down. Thus assuming a form factor of 3 db. for the noise waves and a factor of safety of 3 decibels, a substantially perfect reception will be obtained on each of the pulse channels if the actual signal-to-noise ratio, expressed as the ratio of peak signal volts to r. m. s. noise volts, is equal to, or greater than, 12 decibels for each channel.

The energy of the transmitter is divided between five channels; thus if the total transmitter power is to be the same as in a normal single-channel system the signal power per channel must be $\frac{1}{5}$ that of a normal system. The signal volts per channel will then be only $1/\sqrt{5}$ times the normal level. At the same time, in consequence of the pulse system employed, each channel requires D times the band-width necessary for speech alone thus increasing the noise volts to $\sqrt{D}$ times normal. These two factors together make the signal-to-noise ratio of each channel of the five channel system worse than the signal-to-noise ratio of a normal system by $\sqrt{5} \times \sqrt{D}$. If D is 2, this amounts to $\sqrt{10}$ which equals 10 db. Therefore, in order to give 12 decibels on each of the five pulse channels it is necessary to have an original “normal” signal-to-noise ratio a of $12 + 10 = 22$ decibels. As the output of the receiver, however, may now have a signal-to-noise ratio of 60 decibels or more an improvement of at least 38 decibels has been obtained—at the expense of an increase in the band-width by a factor of 10 only.

Embodiment IIA (same as Embodiment II with pulse modulation added)

Another improvement can be obtained by utilising either of the known pulse modulation systems, either single pulse modulation or double pulse modulation systems.

In the so-called single pulse modulation system the signals are transmitted as pulses of constant

amplitude, the duration of a pulse being proportional to the instantaneous amplitude of the signal wave form represented by the pulses. In a modification known as the double pulse modulation system an extremely short pulse is transmitted to mark the beginning and end of each of the pulses of variable duration. When the beginnings of the variable duration pulses take place at equal intervals of time, or when the end of the variable duration pulse takes place at equal intervals of time, the double pulse modulation may be further modified by suppressing the transmission of either the marking pulse, that is the pulse of short duration marking the beginning of a variable duration pulse, or the trailing pulse, that is the pulse of short duration marking the end of a variable duration pulse, whichever is equally spaced in time.

Whatever the pulse modulation system employed, if the band-width used for each pulse channel can be increased in a ratio equal to n , it is possible to employ a pulse wave-form giving to the useful portion of the pulse a duration which is only $1/n$ of the total time allocated to its transmission. Although the peak energy of the pulse is then the same as before, its mean energy is only $1/n$ of its original value. Therefore, if a type of valve is employed in which the limit is the mean heat dissipated rather than the peak power, then it is possible to increase the peak power by multiplying it by the factor n without overloading the valve involved.

In a practical case if $n=5$, for example, by this method, a quantity equal to the original total peak energy will be available for each of the five channels. The band-width required for each channel is increased in the ratio 5, thus increasing the total noise energy in the receiver also in this ratio. During $\frac{1}{5}$ of each period available for the pulses, however, the receiver is entirely inoperative and the noise has no effect. Consequently, the total noise energy which tends to disturb the action of the circuit of the trigger devices of the receiver will not be affected by the increase of the band width, giving a signal-to-noise ratio equal to that which would be obtained if the energy were concentrated on one channel only. Thus, a normal signal-to-noise ratio is required, measured under normal conditions with an ideal receiver, of 15 decibels instead of 22 decibels as before, the subsequent improvement being obtained by an additional increase of the band-width in a ratio of 5, a condition of ultra-short wave operation which can frequently be obtained in practice without inconvenience.

Other embodiments II

Neglecting now the improvement above due to the use of valves in which the output is dependent upon the mean heat dissipated rather than the peak energy, consideration may be given to other variations which may be made in Embodiment II to adapt it to the requirements of certain different cases.

Embodiment IIB (10 channels, 2 pulse amplitudes)

Assume first a case where it is necessary to increase the number of amplitude gradations but where it is still undesirable to raise, any more than absolutely unavoidable, the requirements as to the “normal” signal-to-noise ratio requisite for successful noise suppression. In other words, assume that the system of Embodi-

ment II must be modified to reproduce more than 32 amplitudes, but that it is still desired that the system should tolerate so low a signal-to-noise ratio as possible.

In such a case the number of pulse channels must be increased to a number m , in which 2^m is equal to the number of combinations required, i. e. one combination of pulses for each amplitude position required (m being taken equal to the nearest integer above the exact value given by the formula). For example, for 1,000 positions, m will be equal to 10, which gives $2^m=1,024$. This requires a factor of increase of band-width of 20 instead of 10, thus requiring a normal signal-to-noise ratio of 25 decibels instead of 22.

Embodiment IIC (3 channels, 4 pulse amplitudes)

Another case may be assumed wherein 32 gradations of amplitude are sufficient but wherein a "normal" signal-to-noise ratio of 30 decibels is available instead of 22 decibels. In this case it is clearly inefficient to employ the 5 pulse channels mentioned above. This case would be a compromise between the example with five channels given above under "Embodiment II" and the first case dealt with under "Embodiment I."

Since the 30 db. signal-to-noise ratio which is assumed to be available in the present case represents 8 db. more than were calculated to be needed in Embodiment II, it would be possible in the present case to employ in each pulse channel a device responsive to four values of amplitude instead of two. This requires about 9 db. more signal-to-noise ratio; thus there remains two decibels of the original 3 db. factor of safety, even on the assumption that five channels will still be used. Now m should be chosen so that $4^m=32$. The nearest integer above the exact value is $m=3$ and $4^m=64$. Consequently, three channels must be used, each transmitting pulses of four amplitudes values, and thus give a further safety factor of $\sqrt{5/3}$ due to the reduced number of channels (compared to Embodiment II) and the consequent increase of signal power per channel.

Certain details of the preferred circuits employed for utilising the invention will now be described.

Embodiment III

First of all, the arrangements according to the invention intended to eliminate noise in a circuit having signal-to-noise ratio α of 48 decibels, and in which 32 amplitude positions are sufficient, will be described.

The most efficient solution in this case is to employ a single pulse modulation system having 32 different code elements for the same number of amplitude positions, which when compared with Embodiment I will give an additional signal-to-noise margin of 2 decibels.

A suitable form of transmitter circuit for this case is shown in Fig. 2. In this circuit the potential of the speech input line BT is applied as shown in push-pull relation over input transformer T and input resistors R1 and R2 to the two grids GT and GS of a double triode A which is adapted to oscillate as a multivibrator to yield rectangular plate current impulses at a frequency outside the speech frequency range employed (for example, at 6000 cycles) by means of a conventional circuit 1, 2, 3, 4, 5. The effect of speech is to modulate in duration almost linearly, the resultant rectangular plate current pulses, that is, the ratio of the portion "on" to the por-

tion "off" in each period of plate current is proportional to the potential of speech at the moment concerned, while the amplitude of these rectangular pulses remains constant.

The oscillator B is loosely coupled by the variable condenser C to one of the plates of the double triode, and the frequency of this oscillator B is adjusted so as to be approximately 100 times that of A. As is well known, the oscillator A can be caused in this manner to lock itself in operation at $1/100$ exactly of the frequency of B provided that the wave form of A is sufficiently steep, which condition usually arises without the provision of special arrangements.

As the frequency ratio is 100/1 there will be more than 100 different stable phase relations between the two oscillators.

The coupling of B to A is arranged to be such that each signal of the multivibrator A can only begin at the moment of reception of a peak from B.

While the input current at speech frequency over input line BT causes the moment of inception of these multivibrator pulses to vary, there will now only be a definite number of possible inception times corresponding to the variable phase relations between the multivibrator and the oscillator B; and if the maximum of time modulation by speech is 64% there will be 32 possible values of percentage of modulation in time, as the value of the percentage varies from the maximum to zero. For any level of the incoming signals at speech frequency other than the exact level normally giving one of the 32 stable time modulation values, there will result a time modulation which is the next lower stable value nearest the exact value corresponding to the momentary speech amplitude. By combining the present invention with the system of pulse modulation, the modulation in definite steps desired has been obtained.

The output from the two plates of the multivibrator is then applied through the two small coupling condensers D and E and shunted to earth through the metal rectifier F; in this way, for each period of the multivibrator a pair of pulses is produced, which are spaced so that the time interval between these pulses only has 32 possible values, and is proportional to the speech amplitude at the moment concerned.

The output from the multivibrator is then applied to a high frequency modulator (not shown) in known manner and at the same time a small fraction of the potential at 600 kc. (or a sub-harmonic) for synchronising purposes at the receiver is transmitted as a pilot frequency by any well known means (not shown).

Fig. 3 shows an embodiment of a receiver adapted to operate in conjunction with the transmitter illustrated in Fig. 2. An ordinary "linear" receiver (not shown) is arranged to receive the modulated high frequency waves from the transmitter, and to deliver to pulse input channel DR the pulses derived from such waves. Thence the pulses are coupled over two condensers 6, 7, to two grids of a twin triode AR. This triode is incorporated in a "double stability" multivibrator circuit 8, 9 . . . 17, AR; and this circuit together with the input condensers 6, 7, constitutes a well known "frequency divider" circuit. The output from the left hand plate of AR is coupled over a condenser 18 to valve CR which is grid-leak biased by leak 19. The output of CR is then applied over transformer TR and low-pass filter BR to the output terminals OR. The effect of the

frequency divider circuit and valve CR and filter BR is to produce a normal speech-wave form from the pulses arriving at DR after amplification from the "linear" portion of the receiver.

The oscillator ER is synchronised with the oscillator B of the transmitter (Fig. 2) by employing the said pilot frequency sent from the transmitter and which is selected and amplified at the receiver. If a sub-harmonic of the 600 kc. pilot frequency from the transmitter be employed instead of the frequency of the latter itself, synchronisation is accomplished by using a suitable harmonic generator apparatus in the synchronising circuit of the receiver, or rather if desired, the oscillator ER may be eliminated, the pilot frequency being amplified and selected, or one of its harmonics, and directly employed.

The oscillator ER, or its equivalent is loosely coupled to the input circuit DR of the frequency divider as shown, by the condenser FR, the degree of coupling and the other constants involved being chosen in such a way that although neither the received pulses, nor the oscillator ER can separately actuate the divider, the triggering of the latter from one state of stability to the other is accomplished when these two potentials act in agreement.

The two 600 kc. oscillators have such a fixed phase relation that a pulse transmitted at the moment of a peak of the multivibrator oscillation of the transmitter arrives at the receiver at a peak of the multivibrator oscillation of the receiver. As the circuit of the transmitter is established so that the output pulses are always produced at such moments, these pulses will always consequently be received exactly at the moments of sensitivity of the receiver. It is a general characteristic of systems of pulse modulation such as are employed in the present invention, that the noise may slightly affect the receiver by slightly modifying the building-up time of the received pulses, unless the pulses have infinitely steep wave forms. To avoid this the receiver of the present invention is arranged so that the exact moment of the triggering operation, is determined solely by the moment of arrival of the local pulses from the receiver oscillator ER oscillating at 600 kc. To this end these local pulses may be given as steep a wave-front as desired without further increasing the bandwidth employed in the transmission. The effect of the speech modulation is merely to determine which of the several possible triggering moments will be effective to actuate the receiver multivibrator from one of its definite positions to the other, and this action is quite independent of the residual circuit noise which, consequently is eliminated.

Embodiment IV

Arrangements for eliminating noise in a circuit having an initial signal-to-noise ratio a of 22 db. and in which 32 amplitude positions are sufficient will now be examined;

As stated hereinabove, the correct solution in this case is to employ five pulse channels, each channel simply having an "on" and "off" position, the resultant factor of increase of bandwidth being 10.

Fig. 4 shows a form of transmitter particularly provided for this purpose. The valve AT is a double triode associated with a multivibrator circuit 1, 2, 3, 4, 5, AT, giving a pulse modulated output corresponding to the audio input of the speech line BT, as in Fig. 2, but without the 600 kilocycle oscillator. C1, C2, C3, C4

and C5 are five valves incorporated in five "double stability" multivibrator circuits M1, M2 . . .

M5 which are cascaded to form a frequency divider having five stages and generally designated as D32. The output of an oscillator DT operating at 600 kilocycles, for example, is supplied through push-pull coupling valve ET to the input of the first stage M1 of the frequency divider D32. A pair of grids of ET, connected over resistors 20, 21 to grid GT of the multivibrator AT as shown, are biased to such potential that ET is only active during the positive periods of the grid GT of the multivibrator AT. The conditions are adjusted so that during the positive period of GT in a cycle having the longest possible "on" interval (such as results from a maximum positive potential of the speech), 32 complete periods of DT will take place. If the modulation in time of the multivibrator AT is 100%, any number of periods of ET between 0 and 32 can be produced according to the speech potential at a specified moment. If the modulation in time is not 100% it is arranged that the difference between the numbers of periods of ET corresponding to maximum and minimum modulations respectively is 32, but the first and simplest case of 100% modulation will now be described in order to facilitate the explanation of the action of the device.

Just before the beginning of a positive half cycle of GT it is arranged that all five multivibrators M1, M2 . . . M5 are in position No. 1 of equilibrium, that is to say, that the plate current passes in all the left-hand plate output circuits of the pulse dividing valves C1—C5, but that there is no current in the right-hand plate output circuits. At the beginning of the positive half-cycle of GT and until its end, the coupling valve ET will function, which will during this half cycle cause the cycles from oscillator DT to be "counted" by successive halving in frequency divider fashion in the stages M1, M2 . . . M5.

As already known, the resultant combination of positions of equilibrium of the multivibrator stages M1, M2 . . . M5 at the end of the positive half-cycle of GT, will indicate the number of periods of DT which have been transmitted to D32. The exact relationship is $N=2^{2^p-1}$; where N is the number of cycles transmitted to D32, and p represents the order in the M1 . . . M5 succession of any pulse dividing stage which is in position of equilibrium No. 2. This No. 2 position of equilibrium is taken to represent the condition of plate current in the right-hand plate circuit, but not in the left-hand plate circuit.

For example, if the stages 2, 3 and 5 are in position No. 2, with the stages 1 and 4 in position No. 1, the number of cycles transmitted is then:

$$2^{2-1} + 2^{3-1} + 2^{5-1} = 22$$

There is thus, obviously, a particular combination of positions of final equilibrium corresponding to any number of cycles transmitted between zero and 32, that is to say, to all possible numbers in the case in question.

A small condenser HT, connected to a resistance-rectifier combination JT, is arranged to give a sharp negative pulse with a condenser K9 to the right-hand grid LT of a double triode KT at the moment of the end of the positive half period of GT. KT is incorporated in a multivibrator circuit KT, K1,

K2 . . . K7, K8, which is triggered into the "on" condition by negative pulses on the right-hand grid LT of KT but is self-restoring to the "off" condition. This circuit KT, K1 . . . K8, has a short time of operation compared with a half-period of the oscillations produced in DT, and a time of restoration equal to slightly less than half the time elapsing between the successive positive half-cycles of AT when the latter have their maximum duration. This time of restoration is determined by the constants of the resistance-rectifier-condenser circuit K5, K6, K7.

As shown in the diagram, the pulse produced by the restoration of KT is applied over a condenser N9 to a similar trigger circuit NT, N2 . . . N8. This latter circuit has a restoration time of the same order as that of KT so that NT is always re-established before the next positive half-period on the grid of GT.

The five carrier frequencies for automatically transmitting in code to the antenna Q, the instantaneous speech amplitude at input, originate in the five master oscillators O1, O2, O3, O4, and O5, and are applied to the number 3 grids of five amplifiers P1, P2, P3, P4 and P5 respectively. After amplification in this amplifier the five carrier frequencies are passed to the antenna Q. These amplifiers are so biased as only to operate when their two inner grids 1 and 2 are simultaneously made less negative. One grid 2 of each amplifier is connected in parallel with the right-hand grid of the corresponding frequency divider valve C1, C2, C3, C4, or C5; the grids 1 of the amplifiers are all connected in parallel through a compensation battery R to the right-hand plate of the valve NT of the trigger circuit.

Consequently, each amplifier can operate only when the corresponding stage of divider D32 is in position No. 2 at the same time as the valve NT is in "on" position. The particular combination of pulses transmitted on the five adjacent carriers during this latter condition will, consequently, indicate the combination of equilibrium of the frequency divider stages at the end of the action of frequency division, and, consequently, will indicate in accordance with the formula $N = \Sigma 2^{p-1}$, the number of periods of DT which have been transmitted via ET to D32 during the positive half-period of GT. This number in turn depends directly upon the momentary amplitude of the speech at the moment in question.

In order to prepare the next positive half-cycle of GT the resistance-capacity-rectifier network ST is provided, which, at the moment of restoring of NT, applies a sharp negative pulse through the de-coupling circuits T, to all the right-hand grids of the valves of the separator. The effect of this negative pulse is to restore all five multi-vibrator stages M1, M2 . . . M5 of frequency divider D32 to position No. 1, so that each valve C1, C2, C3, C4, or C5 has current in the left-hand plate circuit, but not in the right-hand plate circuit. The whole circuit is now in the same condition as at the start and consequently is ready to receive the second positive half-cycle of GT.

In summary, the complete operation is as follows:

(a) The incoming speech modulates the duration of the rectangular current pulses in the multivibrator AT, in such a manner that it gives a substantially linear relation between this du-

ration and the instantaneous amplitude of speech.

(b) The beginning of each positive half-cycle on the grid GT actuates the coupling tube E which, in turn, permits oscillator DT to actuate the five-stage frequency separator C1, C2, etc. This separating action continues through the positive half-cycle of GT, then stops, the final combination of equilibrium of the five separator stages representing the instantaneous speech amplitude at the moment in question.

(c) As soon as the positive half-cycle ceases on GT the trigger circuit KT, K1, K2 . . . K8 is triggered into the "on" condition and remains "on" for a fixed short interval before resuming its normal condition. During this interval any transient fluctuations in the multivibrator M1 . . . M5 have time to disappear and the combination of stable equilibrium is taken up.

(d) Upon the self-restoration of KT, K1 . . . K8, a pulse therefrom actuates the similar circuit NT, N1 . . . N8 into the "on" position and this circuit in turn re-establishes itself in the original position just before the next positive half-cycle of GT. While NT is in the "on" position those particular ones of the amplifier tubes P1, P2, etc., which are connected to multivibrators M1 . . . M5 that are in position of equilibrium No. 2, allow the master oscillators O1, O2, etc., to transmit the required combination of code pulses through the antenna Q on their respective carrier frequencies. The other pulse channels remain unchanged.

(e) The pulse due to the restoration of NT triggers all the dividing stages back to their position No. 1, thus preparing them for the second positive half-cycle of GT, the cycle of operations described above being repeated indefinitely.

Fig. 5 shows a form of receiver circuit adapted to operate in conjunction with the transmitter of Fig. 4. AL represents the first portion of a receiver of usual and known type connected to an antenna; the output contains a suitably amplified reproduction of the five pulse channels from the transmitter. The channel 1 is then selected by the filter B1, the channel 2 by B2, etc., each being selected by its respective filter. As in Fig. 2, an oscillator DL of approximately the same frequency as that of the transmitter, is connected through the coupling valve EL to the input of a five-stage frequency divider LD32. This frequency divider includes five double stability multivibrator circuits LM1, LM2 . . . LM5, each comprising twin triodes LC1, LC2, etc.

At the beginning of the sequence of operations all these multivibrator stages are in the position of equilibrium No. 1, that is to say, with currents passing in all the left-hand plate circuits, and no current in the right-hand plate circuits; also the coupling valve EL is blocked. As soon as the combination of pulses arrives from the transmitter, those carrier frequencies which are present in the received combination are each applied to the corresponding separator stages through the appropriate filter B1—B5. Each of these filters also contains a rectifier circuit; consequently, when the receiver is in operation, the outputs from the filters produce single pulses through the respective condensers F1—F5, on the left-hand grids of the respective separator valves LC1—LC5. The pulses are arranged to be of negative sign, and the result is that all the separator stages thus affected will be triggered from position No. 1 to position No. 2, and will remain in position No. 2.

Upon the arrival of any pulse combination the trigger circuit GL, of similar design to that of KT and NT in Fig. 4, is actuated, and in turn a pulse is generated on its restoration to position No. 1 (after a short predetermined interval of time). Such pulse operates trigger circuit HL to the "on" position. This latter is of different design from that of GL as shown. It consists of a double stability device, having a time-constant in both directions which is short in proportion to a half cycle of DL. In the "off" position HL only has current in its left-hand plate circuit and in the "on" position it only has current in its right-hand plate circuit. The operative pulse from GL to HL should therefore be of negative sign, if the connections are as shown. When HL is "off" the inner grids of EL are sufficiently negative to prevent the coupling valve EL from operating. When HL is "on," however, the increased positive potential on the left-hand plate of HL passes through compensating battery LB and wire LC to these inner grids of EL, thus causing EL to give the correct amplification.

Upon the arrival of a pulse combination, after the interval of time predetermined by the duration "hang over" of GL, HL is triggered to the "on" position. EL thus begins to transmit oscillations from DL to LD32; and the stages LM1 . . . LM5 commence to "count" the cycles of DL in much the same way that the stages M1 . . . M5 of Fig. 4 "counted" the cycles of DT. In the present case, however, the "counting" will not start from zero or normal condition but will proceed onward from the condition to which M1 . . . M5 have been set by the received combination of carrier frequencies. Thus, if the preceding carrier combination represented a count of 22, only 10 more cycles of DL will be required to bring LD32 to the "full" condition representing a count of 32, i. e. to bring all five stages to position No. 2.

Thus after an appropriate number of cycles of DL, all the multivibrator states LM1, LM2 . . . LM5 will be in position No. 2; and the following input cycle of DL will actuate all the stages back to position No. 1, which was the original position in the sequence of operations.

While the fifth stage LM5 is brought from position No. 2 to position No. 1, a positive pulse is generated by the right-hand plate of triode LC5 in this fifth stage. This latter positive pulse is applied, as shown, through the small condensers JL and LL to the left-hand grid of HL. The rectifier-resistance network KL is added to shunt to the earth the undesirable negative pulse produced when the fifth stage is changed over from position No. 1 to position No. 2. The result is that the positive pulse due to the change-over of this fifth stage from position No. 2 to position No. 1, restores HL to its "off" position which, in turn, immediately blocks EL to isolate the oscillator DL from the input of the frequency divider LD32. The "counting" action of frequency divider LD32 then ceases and the original conditions are restored throughout the circuit; these conditions remain until the arrival of the next combination of pulses from the transmitter, at which moment a similar cycle of operations is repeated.

The time during which the counting action of the frequency divider LD32 continues depends upon the particular combination of pulses received and, on account of the automatic law at the transmitter and receiver which has deter-

mined the coding and the de-coding of this combination, it is clear that this duration is in linear proportion to the instantaneous amplitude of the speech at the moment in question. In the receiver circuit the duration of the counting action is given by the time during which the trigger circuit HL remains in the "on" position during each cycle of operations. By means of the coupling condenser TL this duration is transferred to that of the plate current of the valve UL. The mean current in this latter valve, obtained by eliminating the pulse frequencies by the low-pass filter VL, will, consequently, give an exact reproduction of the original speech at the transmitter, which speech will thus have a background noise of 70 db. or less since it is due to the noise in one stage only, the remaining valves acting as simple relays, wholly unaffected by the circuit noise.

The invention has been described in the case of particular embodiments, but it is clear that it is in no way limited thereto, but on the contrary is capable of numerous adaptations and modifications without departing from the scope thereof.

What is claimed is:

1. Signal equipment for transmitting electric signals representative of a given complex wave; comprising means for transmitting any one of a finite series of finitely different signals, said signals being arbitrarily considered as respectively representing a finite series of elementary amplitude ranges which lie adjacent one another and together cover the total amplitude range of said complex wave; control means responsive to the momentary amplitude of said complex wave for controlling said first means to cause the transmission of that one of said series of signals which represents the particular one of said elementary amplitude ranges containing said momentary amplitude; and means for rendering at least one of said previously mentioned means intermittently effective to cause intermittent transmission of signals representative of the approximate amplitudes of said complex wave at successive moments.

2. Signal equipment according to claim 1, wherein said means for transmitting any one of a finite series of finitely different signals comprises means for transmitting signal pulses of finitely different durations.

3. Signal equipment according to claim 1, wherein said means for transmitting any one of a finite series of finitely different signals comprises means for transmitting signals of finitely different amplitude.

4. Signal equipment according to claim 1, wherein said means for transmitting any one of a finite series of finitely different signals comprises means for providing m separate signal channels, and means for transmitting on each of said channels any one of n finitely different signal conditions, where n^m is at least equal to the total number of said elementary amplitude ranges.

5. Signal equipment according to claim 1, wherein said means for transmitting any one of a finite series of finitely different signals comprises means for providing m separate carrier channels of different carrier frequencies, and means for transmitting on each of said channels any one of n finitely different signal conditions where n^m is at least equal to the total number of said elementary amplitude ranges.

6. Signal equipment according to claim 1, wherein said means for transmitting any one of a

finite series of finitely different signals comprises means for providing m separate carrier channels of different carrier frequencies, and means for transmitting on each of said channels any one of n finitely different signal amplitudes, where n^m is at least equal to the total number of said elementary amplitude ranges.

7. Signal equipment for transmitting electric signals representative of a given complex wave, comprising means for providing m signal channels, means for transmitting on each of said channels any one of n finitely different signal conditions so as to yield any one of N finitely different signals, where n^m is at least equal to N , said N signals being arbitrarily considered as respectively representing N elementary amplitude ranges which lie adjacent one another and together cover the total amplitude range of said complex wave, control means responsive to the momentary amplitude of said complex wave for controlling said transmitting means to cause the transmission of that one of said series of N signals which represents the particular one of said N amplitude ranges containing said momentary amplitude, and means for rendering at least one of said previously mentioned means intermittently effective to cause intermittent transmission of signals representative of the approximate amplitudes of said complex wave at successive moments.

8. Signal equipment for transmitting electric signals representative of a given complex wave, comprising means for providing m signal channels, means for transmitting on each of said channels signal variations defining any one of n finitely different durations of time so as to yield any one of N finitely different signals where n^m is at least equal to N , said N signals being arbitrarily considered as respectively representing N elementary amplitude ranges which lie adjacent one another and together cover the total amplitude range of said complex wave, control means responsive to the momentary amplitude of said complex wave for controlling said transmitting means to cause the transmission of that one of said series of N signals which represents the particular one of said N amplitude ranges containing said momentary amplitude, and means for rendering said control means intermittently effective to cause intermittent transmission of signals representative of the approximate amplitudes of said complex wave at successive moments.

9. Signal equipment for transmitting electric signals representative of a given complex wave, comprising means for providing m signal channels, means for transmitting on each of said channels any one of n finitely different signal amplitudes so as to yield any one of N finitely different signals where 2^m is at least equal to N , said N signals being arbitrarily considered as respectively representing N elementary amplitude ranges which lie adjacent one another and together cover the total amplitude range of said complex wave, control means responsive to the momentary amplitude of said complex wave for controlling said transmitting means to cause the transmission of that one of said series of N signals which represents the particular one of said N amplitude ranges containing said momentary amplitude, and means for rendering said control means intermittently effective to cause intermittent transmission of signals representative of the approximate amplitudes of said complex wave at successive moments.

10. Signal equipment according to claim 7, wherein m is 1 and n is equal to N .

11. Signal equipment according to claim 8, wherein m is 1 and n and N are each equal to 33, and wherein said means for transmitting signal variations defining any one of n durations of time comprises means for transmitting a single sharply starting and sharply ending pulse having any one of n durations.

12. Signal equipment according to claim 7, wherein n is 2 and m is an integer at least equal to $\log N$.

13. Signal equipment according to claim 9, wherein n is 2, m is 5, and N is 32, and wherein said means for providing n signal channels comprises means for generating n carriers of different carrier frequencies.

14. Signal equipment according to claim 9, wherein n is so chosen with respect to the signal-to-noise ratio at a point of intended reception that the amplitude difference between any two of said n finitely different signal amplitudes at said reception point exceeds the amplitude of substantially all noise peaks thereat.

15. Signal equipment for transmitting electric signals representative of a given complex wave, comprising multivibrator means controlled by the momentary amplitude of said wave for marking the beginning and end of a variable interval whose duration varies according to the value of said momentary amplitude, means for inhibiting the marking of the end of such variable interval except at certain instants of time whereby only an interval of one of N finitely different durations can be marked, means under control of the interval marked for transmitting a corresponding one of a finite series of N finitely different signals, and means for rendering at least one of said previously mentioned means intermittently effective, whereby said second mentioned means intermittently transmits signals representative of the approximate amplitude of said complex wave at successive moments.

16. Signal equipment for transmitting electric signals representative of a given complex wave, comprising means controlled by the momentary amplitude of said wave for establishing one of a finite number of electric conditions in dependence upon which range, of a corresponding finite number of arbitrary amplitude ranges, said amplitude occupies, means under control of the electric condition established by said first means for transmitting a corresponding one of a finite number of finitely different electrical signals, and means for rendering at least one of said previously mentioned means intermittently effective, whereby said second mentioned means intermittently transmits signals representative of the approximate amplitudes of said complex wave at successive moments.

17. A signaling system for reproducing at a reception station a wave approximately corresponding to a given complex wave delivered at a transmission station, comprising means for transmitting to said reception station any one of a finite series of finitely different signals, said signals being arbitrarily considered as respectively representing a finite series of elementary amplitude ranges which lie adjacent one another and together cover the total amplitude range of said complex wave, control means at said transmission station responsive to the momentary amplitude of said complex wave for controlling said first means to cause the transmission of that one of said series of signals which repre-

sents the particular one of said elementary amplitude ranges containing said momentary amplitude, means for rendering at least one of said previously mentioned means intermittently effective to cause intermittent transmission to said reception station of signals representative of the approximate amplitudes of said complex wave at successive moments, means at said reception station for receiving said intermittently transmitted signals, and means for producing from said received signals a wave approximately corresponding to said given wave.

18. A system according to claim 17 wherein said means for producing a wave from said received signals comprises means invariably responsive to each of said signals independent of variations of less than a predetermined amount in such signal.

19. A system according to claim 17 wherein said means for producing a wave from said received signals comprises means invariably responsive to each of said signals independent of variations of less than a predetermined amount in the duration of such signal.

20. A system according to claim 17 wherein said means for producing a wave from said received signals comprises means invariably responsive to each of said signals independent of variations of less than a predetermined amount in the amplitude of such signal.

21. A system according to claim 17 wherein said means for producing a wave from said re-

ceived signals comprises means invariably responsive to each of said signals independent of variations of less than a predetermined amount in the time of receipt of such signal.

22. A method of producing signals approximately representative of a given complex wave, which comprises analyzing the total amplitude range to be transmitted into a finite number of elementary amplitude ranges, intermittently scanning the amplitude of the given complex wave, and transmitting in response to each scanned momentary amplitude a signal representing the elementary range containing such momentary amplitude.

23. A method of reproducing at a remote point a wave approximately corresponding to a given complex wave, which comprises analyzing the total amplitude range to be transmitted into a finite number of elementary amplitude ranges, intermittently scanning the amplitude of the given complex wave, transmitting to said remote point in response to each scanned momentary amplitude a signal representing the elementary range containing such momentary amplitude receiving such signals at such remote point, purifying each of such received signals by eliminating therefrom any variations of less than a predetermined amount, and producing from such purified signals a wave approximately corresponding to said given wave.

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