Nov. 18, 1941. E. M. DELORAINE ET AL 2,262,838

ELECTRIC SIGNALING SYSTEM

Filed Nov. 8, 1938 5 Sheets-Sheet 1

Fig. 1.

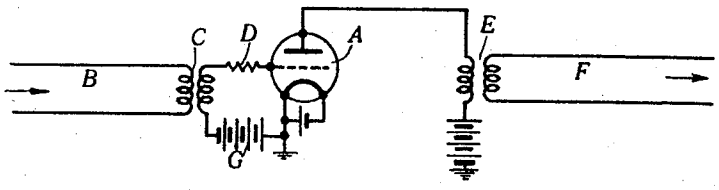


Fig. 2.

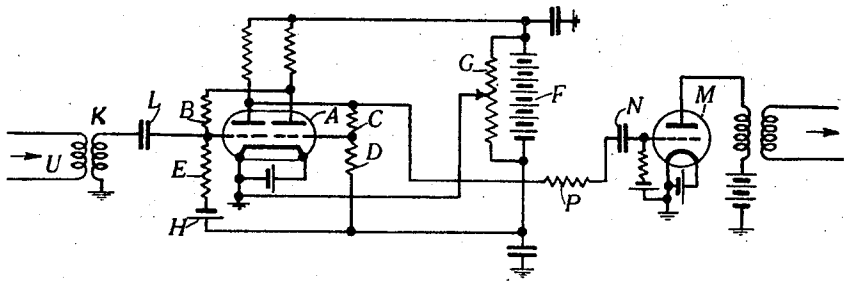
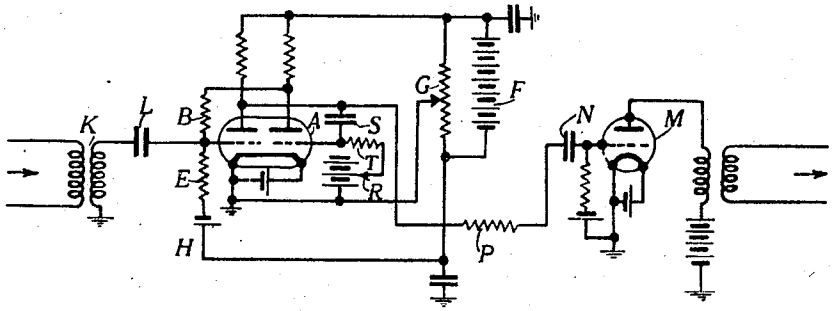


Fig. 3.



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ELECTRIC SIGNALING SYSTEM

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Fig. 3a.

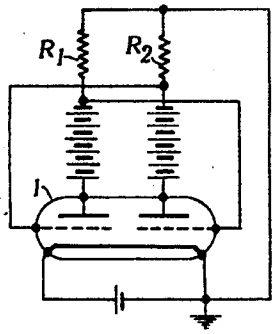


Fig. 7.

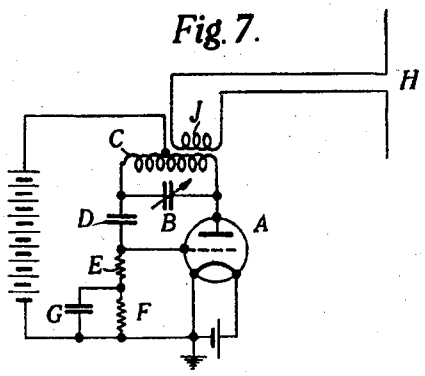


Fig. 9.

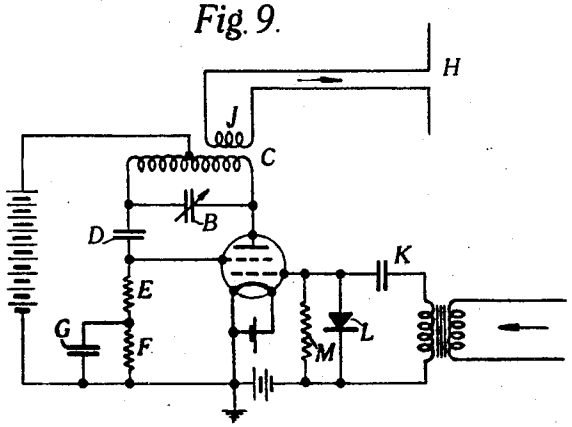
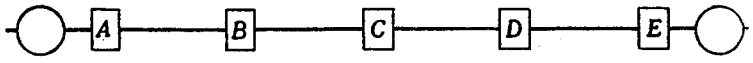


Fig. 11.



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ELECTRIC SIGNALING SYSTEM

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Fig. 4.

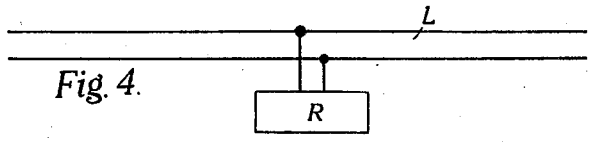


Fig. 5.

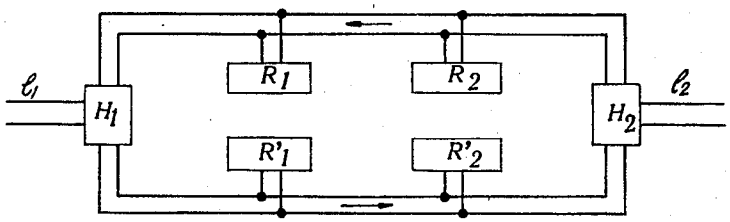


Fig. 6.

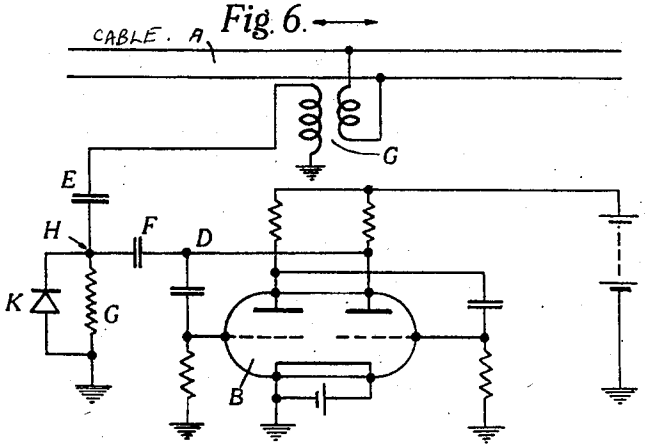
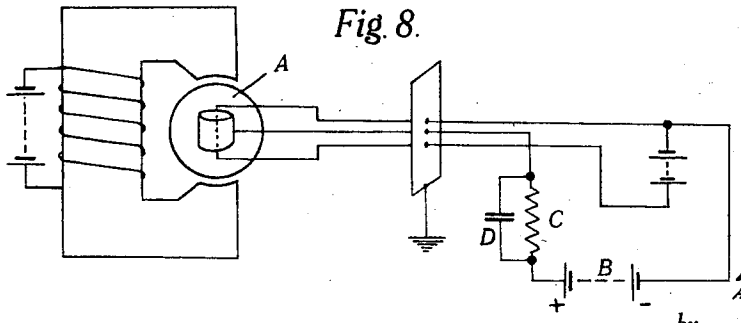


Fig. 8.



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ELECTRIC SIGNALING SYSTEM

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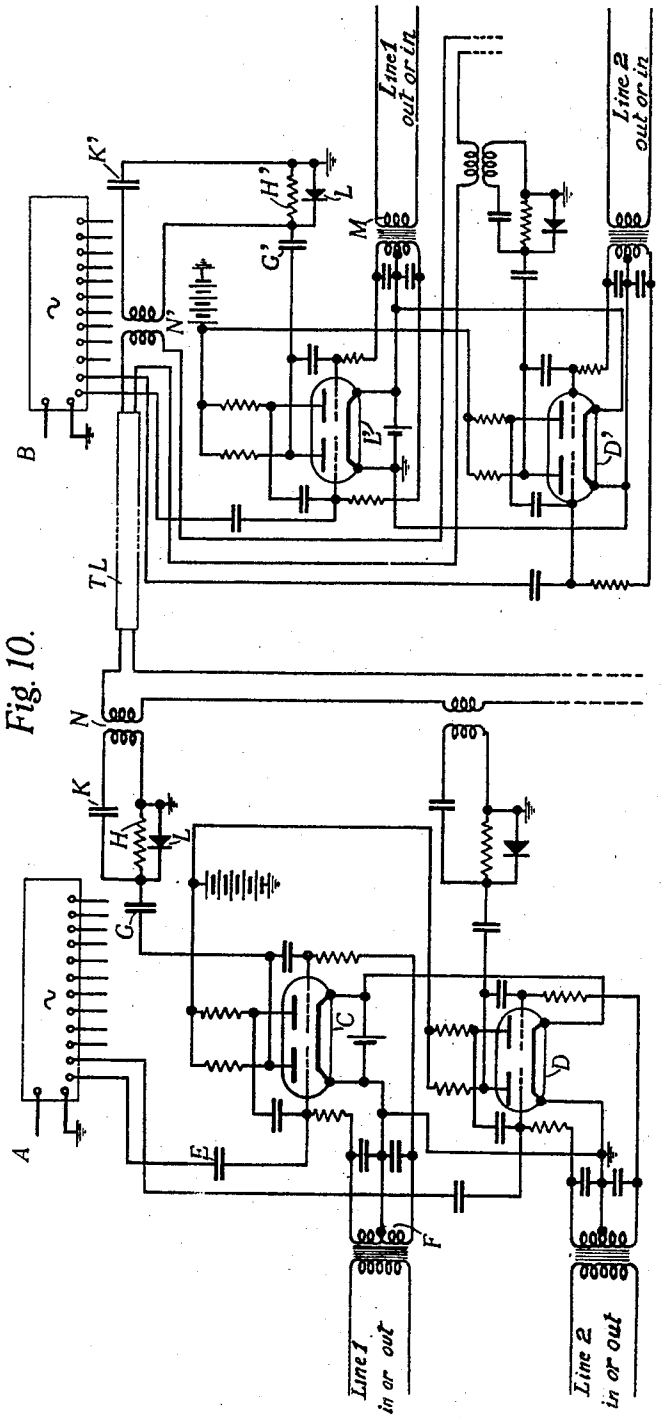


Fig. 10.

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ELECTRIC SIGNALING SYSTEM

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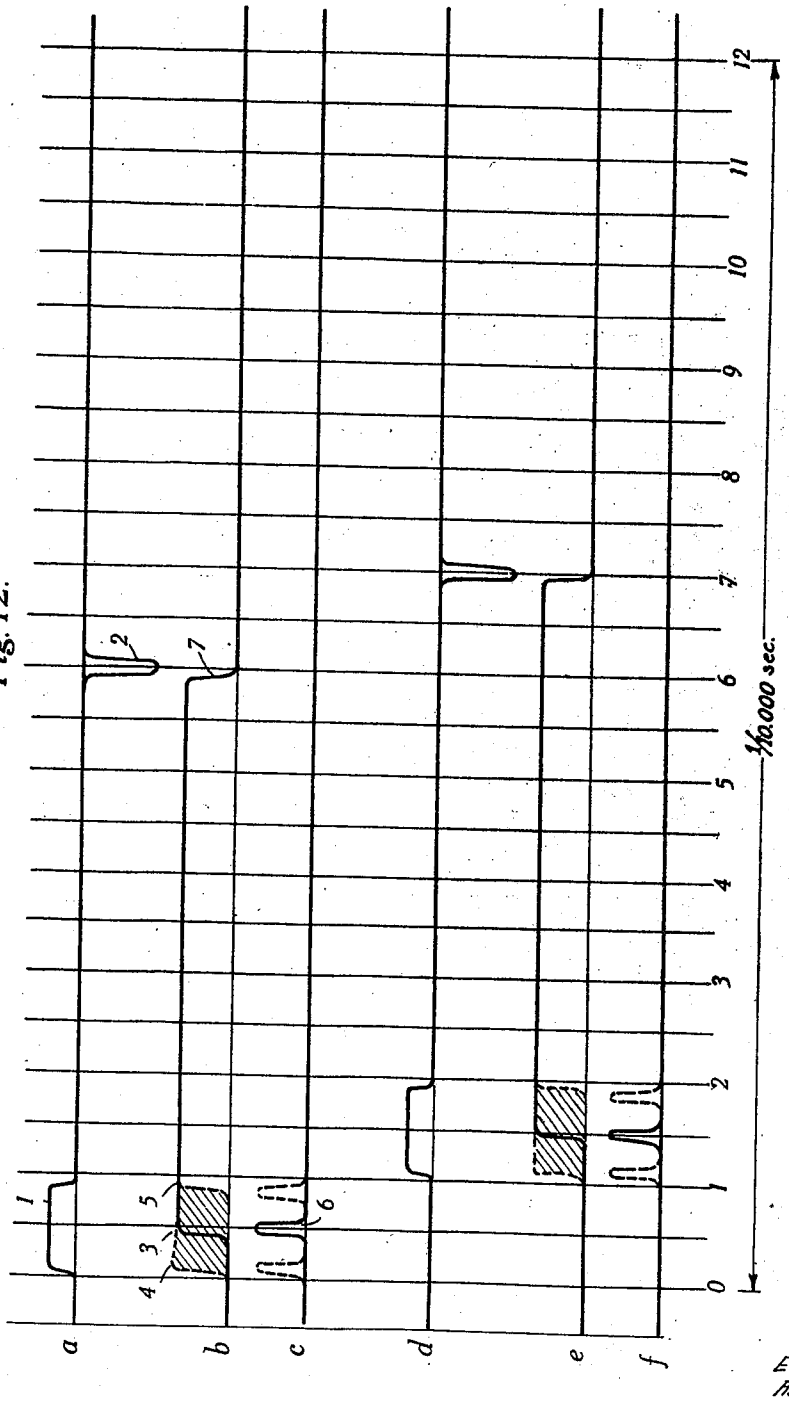


Fig. 12.

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Patented Nov. 18, 1941 2,262,838

UNITED STATES PATENT OFFICE

2,262,838

ELECTRIC SIGNALING SYSTEM

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Application November 8, 1938, Serial No. 239,454
In Great Britain November 19, 1937

8 Claims. (Cl. 178—71)

The present invention aims at providing signaling systems, particularly suitable for high and very high frequencies which will be at least as efficient as systems now in use, but which will be much cheaper to install and to maintain.

Signaling systems used heretofore, especially telephone systems had to be constructed and installed with a large degree of accuracy, thus entailing either precision in manufacture and maintenance, or the necessity of making many adjustments and measurements.

In the prior art, it was generally admitted that in order to make coaxial cable installations commercially interesting, a cable of small diameter had to be adopted. This results from the fact that the price of the cable is the most important item of the system. But such a cable has a relatively high attenuation for frequencies of 1 or several megacycles (for instance of the order of 6 db. per mile at two megacycles for a 10 mm. cable). As it does not seem advisable to use levels of more than some 50 to 60 db. below reference level, and as levels of more than a few decibels above reference level would be difficult to obtain from simple repeaters, a drop of about 60 db. per repeater section has been considered. This limits the length of such a section to some 10 miles for a maximum frequency of two megacycles and to less for the higher frequencies required in television. Long distance cables have therefore a considerable number of repeaters in tandem and the requirements as regards stability, distortion and noise are very stringent. Besides, particular attention has to be paid to arrange the installation in such a way that the breakdown of a repeater tube does not interrupt the whole service. This means: spare repeaters or even a spare cable. The repeaters have to be complicated with arrangements for keeping the levels constant notwithstanding temperature or tube variations. Even if a satisfactory service can be obtained, all this means a relatively high price for the repeaters and the accessory equipments, and an increased maintenance.

In many signaling systems now in use and projected for the future, a rather large number of repeaters are involved. As the transmission equivalent must, in general, be constant within close limits, it is therefore necessary for the gain of each repeater, or series of repeaters, to be kept within limits of variation that are very small indeed, thus involving rather expensive and complicated apparatus at these repeater stations.

Not only accidental gain changes in the repeaters, further, must be prevented, but also changes in the circuit equivalents of the cable sections themselves due to variations in temperature or other causes.

In the second place, not only variations in level must be guarded against, but also changes in the distorting properties of the cable sections; otherwise it is impossible to correct for the total distortion at the receiving station by any fixed network.

An object of the present invention is therefore to overcome the above difficulties by means considerably cheaper and more reliable than existing methods and this by converting the signals or intelligence to be transmitted into signals of special nature, thus enabling the use as repeaters of devices of simple and robust design, the details of which will be apparent from the following description:

In outline, according to the present invention, the repeaters are chosen of a type such that their peak amplitude outputs remain substantially constant in spite of variations, within prescribed limits, of the peak amplitudes at their inputs; while the speech (or other) wave-form to be transmitted is according to the invention, conveyed by a type of signal such that the non-linearity in amplification characteristics inherent in the above form of repeater produces negligible distortion in the final wave-form given out by the receiving terminal equipment.

According to one aspect of the invention, frequency or phase modulation of a carrier frequency is used, in conjunction with a repeater as described above. It is well known that considerable amplitude distortion may be applied to a carrier having either of these forms of modulation without causing appreciable distortion in the final output. This fact is used in the present instance, in a manner hitherto not known in the art, by applying one or both of these types of modulation to a carrier to be conveyed by the transmission system (e. g. of a cable) under consideration: a transmission system containing repeaters which distort in amplitude by limiting the peak outputs.

According to another, and preferred, form of the invention the wave-form to be transmitted is conveyed by a series of pulses of one or several amplitudes at the transmitter output, of constant or variable duration, and each pulse being either aperiodic in one or both current directions, or comprising a train of waves of a carrier frequency; in combination again, with repeaters for these pulses of which the peak outputs are sub-

stantially constant whatever the pulse input voltages within prearranged limits.

Another aspect of the invention lies in means for applying it to communication systems covering a wide band width, or, alternatively, to systems covering a comparatively narrow band width but in which close limits of phase variations and/or amplitude variations at different frequencies, have to be met. An example of the former is the case of the simultaneous transmission of a large number of telephone conversations, or of one or more television channels. In both these instances band widths of several megacycles have frequently to be dealt with. In the former art, to avoid serious inequalities in transmission characteristics at the extreme ends of the frequency band, it is usual to employ in addition to the speech or television itself at least two pilot channels, one at each end of the frequency range, arranged to cause automatic compensation for gain changes throughout the entire band width. As this compensating apparatus had to be applied not only at the receiving station but also at every three or four repeater stations (in general), the resulting expense and complexity is considerable; four or more repeater tubes, each with its associated apparatus, having often to be employed at these repeater points. Similar complexity of apparatus had formerly to be used in the case of a narrower band, but one requiring particularly close limits of working. According to the present invention both these cases are solved by the use of repeater apparatus that is much simpler, cheaper, and more reliable: in general only one active amplifying element is required. The preferred solution consists in the use of pulses as explained above, each pulse or group of pulses representing (according to a prearranged law) the momentary characteristic (e. g. amplitude) of the wave-form of one or of a group of communication channels. In the case of multiplex operation, the pulse or group of pulses representing each channel or channel group recurs at regular intervals, these time intervals being at least as short as one period of the highest component frequency in the channel or channel group to be transmitted. For either single or multi-channel working, the repeater outputs consist of pulses having quite definite voltages and wave-forms independent of the input (within the working limits); they are, in fact, more of the nature of the simple relays as used in telegraphy than that of the usual "quantitative" amplifier. Any wave-form distortion occurring, therefore, in the transmission medium will be corrected automatically at each repeater station—and without the use of any auxiliary apparatus.

According to a further feature of the invention, by the use of one form of device conforming to the above conditions a repeater is obtained capable of two-way operation without singing and by an additional slight modification of it an echo suppressor is obtained at each repeater station without the use of any supplementary apparatus.

Another advantage of the invention is the greatly improved facility it gives for the introduction of spare amplifier tubes, or complete spare units, at the repeater points. In the former art considerable difficulty has been experienced in solving this problem satisfactorily; a problem it is quite essential to overcome, as it is inadmissible to allow the possibility of the simultaneous failure of a complete group of circuits owing to the burning out of a tube. The simple paralleling of the amplifying element by a reserve tube gives rise to difficulties, as it is not easy to ensure having the same gain with either two tubes or a single tube in circuit. The alternative plan of switching in automatically a spare tube, or spare repeater, when failure occurs introduces an extra element of unreliability on account of the relay contacts involved. These difficulties have in the past been considered so important that in some cases it had been planned to instal a complete spare cable together with its repeaters, a very expensive solution.

The present invention entirely overcomes the above troubles inherent in the former art; the method of the simple paralleling of the amplifier tube, or the complete repeater, is now free from objections, as the change in repeater output of 3 db. or more due to the failure of one tube makes no difference at all to the output of the subsequent repeater, as long as this reduced level is still sufficient to operate the latter. At each repeater point, therefore, one or more spare repeaters or tubes may be connected in parallel, and in such a manner that all the tubes or repeater elements may be very easily removed for routine testing, and replacement. As the repeaters further are of very simple and robust construction, their cost may now be very low, thus making their duplication by reserve elements a comparatively cheap matter.

Further advantages arising from the use of the invention will be apparent from the description (below) in detail of some of the apparatus coming within its scope; and in particular, the use of the application termed the "synchronous" type of repeater for carrier frequencies of the order of 10,000 megacycles or more (in free space or on dielectric guide) frequencies for which no direct means of amplification were known in the former art.

A more detailed description will now be given of some embodiments of the present invention with reference to application to certain types of transmission problems.

Figure 1 shows one form of blocked repeater suitable when frequency or phase modulation is used. The terminal apparatus for these forms of modulation being well known in the art will therefore not be described. Such a repeater is also suitable for "single pulse" or "double pulse" modulation.

Figure 2 shows a second form of repeater—of the "trigger" type suitable for either "single pulse" or "double pulse" operation.

Figure 3 shows another "trigger" type of repeater circuit. It is suitable for "double pulse" working only; the duration as well as the amplitude, of the output pulse has a fixed value irrespective of the input within prescribed limits.

Figure 3*a* shows a diagram used in the explanation of the action of the "synchronous" type of repeater.

Figure 4 shows a repeater circuit R branched on a two-way line L.

Figure 5 shows a two-way repeater installation somewhat analogous to a 4-wire system.

Figure 6 shows an application of the arrangement of Figure 4 utilising a double triode valve.

Figure 7 shows a synchronous type of repeater suitable for operation with "double pulse" modulation with a carrier wave.

Figure 8 shows a variation of the arrangement of Figure 7 suitable for frequencies of 10,000

megacycles or even higher. The active element is a magnetron of "the transit time form."

Figure 9 shows one form of terminal equipment suitable for operation with the repeaters shown in Figures 7 and 8. It is capable of giving automatic echo suppression of the "Vodas" type at all the repeater points in the transmission system.

Figure 10 shows one form of terminal equipment for 12 channel operation on the "distributor" principle, using "double pulse" operation without carrier. (The equipment for two channels only is shown.)

Figure 11 shows a multi-repeater installation and is used to explain the 2-way action of the synchronous type of repeaters.

Figure 12 shows diagram used in explaining the action of the circuit of Figure 10.

In the simple repeater of Figure 1, phase or frequency modulated carrier waves arrive from the cable or antenna by the line B, are stepped up by transformer C to the appropriate impedance, and applied as shown to the grid of amplifier tube A. By means of transformer E the amplified output signals are applied to the output antenna circuit or cable F.

Resistance D, high compared with the grid impedance when this grid is appreciably positive, causes the positive input peaks to be cut off sharply when they exceed the value of the bias battery G.

The value of G is arranged to be such that the tube acts as a class B or class C amplifier, the gain being thus small enough, in the absence of signals, to prevent the whole system from either singing or overloading the subsequent repeaters by noise—a condition that might otherwise occur.

As the peaks are cut off, for input voltages exceeding the value of G the peak output voltage is substantially constant and independent of the input, within wide limits of the latter, limits wide enough to take into account the maximum fluctuations of the input voltage at the input of the transmission system considered.

The minimum value of this input voltage when fluctuations occur is arranged to be slightly in excess of that of the battery G; the amplifier, therefore, always operates on the flat portion of its output v. input characteristic. In cases where the input voltage in practice is less than that required to meet these conditions, one or more extra stages of amplification, using conventional amplifier circuits, are placed between the input from B and the transformer C.

A number of possible modifications of the circuit of Figure 1, giving a limiting action on the peaks at the same time as reduced gain in the absence of signals, will be immediately apparent to those skilled in the art.

The invention is not limited to frequency or phase modulation but on the contrary the invention is applicable to all processes of modulation implying the use of a carrier wave.

In the transmission of an electro-magnetic wave, four variables are involved, viz, frequency, phase, amplitude and time. Most ordinary modulation systems transmit intelligence by variation of amplitude against time, phase and frequency being kept constant. So-called frequency-modulation systems transmit intelligence by variation of frequency against time, amplitude and, perhaps, phase being kept constant. So-called phase-modulation systems transmit intelligence by variation of phase against time, amplitude and, in a certain sense, frequency, being kept constant. The "pulse-modulation" system transmits intelligence by variation of a time-interval against time, any one or more of the variables, frequency, phase and amplitude, being changed suddenly to indicate the beginning and end of the time-interval.

In other words, "pulse-modulation" consists in the transmission and reception of a number of pulses, the latter occurring at a frequency at least as high as, and normally higher than, the highest frequency component in the wave-form to be conveyed. In the simplest examples, every pulse has the same amplitude. In "single pulse" working substantially rectangular impulses are transmitted, the duration of each pulse being linearly proportional to the momentary amplitude of the wave-form to be sent. With "double pulse" operation, the duration of every pulse is constant and small compared with the time interval between adjacent pulses; the impulses occur in pairs, the time interval between the members of each pair being in this case proportional to the transmitted amplitude.

As a repeater for such a system, therefore, it is clear that the circuit of Figure 1 may be used if desired; the necessary constancy of output peak voltage, irrespective of input value within limits will be obtained by it. The circuit of Figure 1, however, has the disadvantage of giving an output pulse steepness of wave-front proportionnal to the input voltage; after a number of repeater stages therefore, under conditions when the gains of all the repeater sections are low the received pulse wave-fronts may be very considerably less steep than the original pulses from the transmitter.

In such systems, the signal-to-noise ratio for single channel working, as well as the inter-channel interference when multiplexed on the "distributor" principle, is dependent on this steepness of pulse wave-front, the steeper the wave-front the higher the signal/noise ratio, and the less the cross-talk between channels. If, therefore, at the receiver the pulse wave-front is thus made appreciably less steep than at the transmitter, the signal/noise ratio and/or the cross-talk may lie outside the required limits; to avoid this, the output pulse from each repeater should have a constant wave-front steepness (as well as constant peak amplitude), of a value at least as high as that of the original pulses from the transmitter.

To accomplish this result according to the present invention, instead of a simple amplifier as shown in Figure 1, a "trigger" device is used; the requirements for such a trigger circuit are: (*a*) an output peak amplitude constant and independent of the input voltage giving the triggering action (within limits of this input value) (*b*) to avoid singing and noise operation, the trigger must be inoperative for E. M. F. appreciably lower than that of the minimum pulse value; and (*c*) the steepness of wave-front of the output pulses both on triggering and on restoring, must be constant and independent of the input wave-form or voltage (within limits of the latter), and of a value at least as high as that of the original pulses from the transmitter.

Figure 2 shows one form of trigger circuit complying with the above conditions.

The double triode A has cross-connections from each plate to the opposite grid as shown in the diagram; the effect of these connections is to produce a circuit of the same type, in principle, as that described in elementary form in Figure 3*a*,

a circuit which possesses two positions of stable equilibrium, one with the left-hand plate current being practically at cut-off, with the right-hand plate having a current corresponding to nearly zero grid bias, and the second stable position having the above conditions reversed quite symmetrically.

The reason for the use, in practice of the circuit of Figure 2 rather than that of Figure 3*a* is that it is generally not convenient commercially, to employ two separate sources of high tension (as in Figure 3*a*) especially as the latter are floating with respect to ground, and therefore must have their capacities to ground of very low values.

In Figure 2, a source of high tension F is used having its ends grounded through condensers. A potentiometer G (of low value compared with the plate resistance of A) is connected across F with the slider (approximately at the centre point) connected to the filament and ground. In this way half the voltage value of F (a source of double the usual plate voltage required) is used as the plate supply to A, and the negative half used by means of resistances D and E to compensate on the grids of A for the high tension that would otherwise arrive at these grids.

Resistances B and C are added to allow the plates to remain positive while the grids have the correct small negative values.

For the present purpose an extra negative voltage H is added to the left-hand grid, of such a value that only equilibrium position No. 1 (with the left-hand plate current of a low value, the right-hand current being high), can be maintained, in the absence of input voltage from the line. The arriving pulses from the cable or antenna line U are stepped up in transformer K to match the grid impedance, and coupled to the left-hand grid by condenser L; a condenser of suitable value (for single pulse working) such that, in conjunction with the effective grid resistance the original rectangular wave-form of the pulses is maintained at the grid, the active grid pulses, moreover, being of positive sign.

The arrival of a positive pulse through L of sufficient amplitude reverses the equilibrium position of A; causing the circuit to trigger over to the equilibrium position No. 2, the left-hand plate now having the high current and the right-hand plate the low current value.

The steepness of wave-front of the changing-over action is substantially independent of the wave-form of the input pulse; it is proportional, on the other hand, to the resistance-capacity time-constant of the trigger circuit, taking into account the effective internal resistance of the tube plate circuit itself. As soon as the input pulse ceases, the circuit triggers back to position No. 1, the speed of this restoring process being again only dependent on the circuit and not on the wave-form of the input pulse.

Input E. M. F. of peak voltage less than a predetermined value has no effect on the trigger circuit, this marginal sensitivity being dependent chiefly on the average negative voltage on the grids of A, the higher this voltage, the less voltage required to operate the trigger, up to a point where double stability is no longer obtained. It is thus clear that the circuit of Figure 2 conforms to the three requirements as stated above: as a repeater, it is (*a*) inoperative by E. M. F. below a certain peak voltage; (*b*) it gives a peak output that is constant when operated at all; and (*c*) it gives an output pulse having a steepness of wave-front that is independent of that of the input pulses, and may be arranged to be as high as desired within reasonable limits.

The output from A is taken through the coupling tube M, by condenser N and decoupling resistance P, as shown in the diagram.

Although the circuit of Figure 2 may be used as a repeater for both single or double pulse working, there will now be described a modification of it that is rather more advantageous for the latter case.

Although, according to Figure 2 the peak voltage and steepness of wave-front in the output pulses are constant, the duration of these output pulses is not constant, but is substantially the same as that of the input wave-form. This condition is necessary for single pulse operation, but is not required, and is, in fact, a disadvantage when using the double pulse system, a system in which all the pulses should be identical in wave-form.

The circuit of Figure 3 fulfills this new condition. Resistance C of Figure 2 is replaced by the condenser S; and the right-hand grid instead of being connected to the negative end of F (Figure 2) through resistance D, is now connected direct to ground through grid leak T and the variable negative bias R. In the stationary state, therefore, the right-hand grid voltage can have only one value, that of R, which is normally small or zero. Even in the absence of the extra battery H, therefore, the circuit now can have only one position of stable equilibrium, position No. 1 in which the left-hand plate current is low, and the right hand current high. On the arrival of a positive input pulse at the left-hand grid, condenser S enables the sudden rise in current in the left-hand plate to cause a momentary reversal of the equilibrium state of the circuit, the latter triggering over as before to position No. 2, but as condenser S is unable to maintain the steady state of the circuit in this new position (it is only able to transmit surges) the circuit immediately afterwards suddenly restores itself to position No. 1, and this last action takes place after a time dependent on the circuit constants and not on the duration of the input pulse.

The circuit of Figure 3, therefore, gives the effect desired for double pulse operation; the duration of the output pulse is controlled by appropriate adjustment of condenser S together with the other circuit constants.

Another and, in general, preferred form of repeater circuit utilising a pulse generator synchronised by incoming pulses will now be described. It is very suitable for double pulse working—or for any system in which sharp pulses of constant wave-form are employed. It will be referred to here as the "synchronous" type of repeater circuit. It relies on the well known property of an oscillator e. g. of relaxation oscillator to lock itself into step with a small E. M. F. applied to its grid, when this E. M. F. has a frequency of the same order as that of the natural frequency of the relaxation oscillator.

In order to explain clearly the working of this kind of device, one may consider any type of circuit having two more or less symmetrical positions of stable equilibrium. If such a device is initially adjusted at exactly its neutral equilibrium point, midway between the two stable positions, and if it is then left entirely undisturbed by noise—it will theoretically remain at this neutral point indefinitely. In practice, of

course, the intrinsic circuit noise will give a small bias in one direction or the other, resulting, finally, in a swing to the corresponding stable position; but if at the start an impressed D. C. pulse "v" be applied in the direction of either stable position—a pulse substantially greater than the noise—then the rate of swing-over will be increased. If the circuit be quenched after time "t" and if the "swing" wave-form be truly exponential—the peak voltage reached by this swing before quenching will be: ve^{kt}, where "k" is the increment (i. e. negative decrement) of the swing-over action; an effective amplification of the pulse by the factor e^{kt} is thus obtained, a factor which, as in the normal superaction circuit may reach very high values. One simple form of symmetrical double-stability "relay" circuit suitable for the above purpose is shown in Fig. 3*a*. It comprises essentially a double triode and two resistances R_1 and R_2. If this circuit be "quenched" to its neutral equilibrium (i. e. both plate currents equal) at regular intervals, it will carry out the above function of pulse amplification. There is, however, a variation of the circuit of Fig. 3*a* which (for the purposes of "synchronous repeatering") does not require an externally applied quenching oscillator—and this is simply the conventional multi-vibrator circuit. In the multi-vibrator, (which is the circuit of Fig. 3*a*, with the direct connections between plates and opposite grids replaced by connections through condensers), the two stable equilibrium positions are changed to two quasi-stable conditions—(i. e. two positions in which the conditions are relatively stable for a limited time); and the circuit automatically "triggers" over from one of these two positions to the other, and vice versa. Just before each triggering, the circuit condition may be described as in quasi-neutral equilibrium; and the arrival of an impressed D. C. pulse during this period of the triggering cycle results in the subsequent triggering taking place earlier—or later—than would otherwise be the case (according to the sign of the pulse). If the circuit were artificially quenched at a definite time interval after the arrival of the pulse, the peak volts represented by the "swing-over" at the moment of quenching (reckoned from the voltage at the neutral equilibrium point) would be linearly proportional (within certain limits) to the peak value of the impressed pulse—and would thus represent this pulse greatly amplified, exactly as in the case of the "relay" circuit of Fig. 3*a*. In the usual multi-vibrator circuit, then, with the addition of quenching—there is an intrinsic amplifying action on the "super-reaction" principle. If, now, it is desired to use this action to give amplification of periodic signals before their application to lock into step a synchronous repeater, there should be added such a free oscillator after the multi-vibrator circuit. But in the latter there is such a free oscillator already present; and as modulation takes place not on the amplitude but on the phase of the signal pulses, there is not required any artificial quenching and there is no interest in obtaining, for the synchronising process, an amplified replica of the signal amplitudes, it is only necessary to produce an amplified pulse of constant peak voltage at a moment of time corresponding to that of the arrival of the pulses. It is thus clear that the usual multi-vibrator circuit—or, in fact, almost any form of relaxation oscillator—intrinsically permits one to combine the functions of super-reaction, pulse amplifier and synchronised oscillator in a nearly ideal manner for the property of "synchronisability" by very small impressed voltage pulses to be displayed.

Fig. 6 shows the multi-vibrator type of synchronous repeater circuit as applied to a double pulse cable system without carrier.

It has the advantages of extreme simplicity of construction, and capability of two-way operation (as is explained below); at the same time it conforms to the three requirements carried out by the trigger circuit of Fig. 3. A double triode B is associated as shown with a multi-vibrator circuit of the usual design. Double pulse signals of positive sign in the cable A, from either direction, are stepped up by transformer C to the effective grid impedance of the tube, and coupled to the multi-vibrator by condensers E and F. When the input pulses arriving at the coupling point D are of sufficient amplitude (2 volts or less), and if the multi-vibrator is adjusted so that its natural frequency is slightly lower than that of the incoming pulses, the local oscillator will lock itself into step with these pulses, in frequency and phase.

Alternatively, if that form of double pulse system is used in which one of each pair of pulses is resupplied at the receiver, the natural frequency of the multi-vibrator may be adjusted to be slightly less than half the pulse frequency as originally produced at the transmitter, the local oscillator then locking into step with the first (or second), pulse of each of the original pairs of pulses.

In either case, the adjustment is such that exact locking remains during the time modulation of the incoming pulses by the speech or other wave-form to be conveyed.

The output voltage at point D due to the multi-vibrator action has, of course, a rectangular wave-form of the same nature as that of single pulse modulation. To transform each cycle of the multi-vibrator into a sharp pulse as required for the double pulse system, the small condenser F and the resistance G is added, of such values that the wave-form of the voltage at point H is substantially the derived curve of the wave-form at D. Also to prevent the negative pulses that would otherwise occur at H due to the second half of each multi-vibrator cycle, rectifier K is bridged across resistance G in such a sense as to give a substantial short-circuit to these negative pulses. This correcting network is of the same type as that used in the double pulse transmitter described in French Patent No. 833,929 filed on June 18, 1937, and its first addition No. 49,159 filed on July 5, 1937. The multi-vibrator action causes, therefore, at point H a sharp positive peak a small fraction of a pulse cycle after each input pulse from the cable; and these local pulses, in a practical case, may have a level of 40 db. or more above that of the input pulses i. e. an effective amplification of the order of 40 db. or more is obtained. From point D the amplified, local pulse is applied back to the cable through the same transformer C as is used for the coupling of the input pulses.

The manner in which the back action of the repeater onto the preceding repeater in the chain is prevented (which otherwise would give rise to local singing conditions) is explained later in the present specification.

A simple form of synchronous repeater suitable for use on double pulse modulation (or other system comprising sharp pulses of constant

amplitude and wave-form), these pulses modulating a carrier wave of substantially higher frequency, is shown in Fig. 7.

A pulse-modulated signal consists of a number of very short high frequency wave trains. According to features of the present invention, the synchronous repeater comprises:

(*a*) An amplifier of these high frequency trains;

(*b*) A demodulator to the pulse frequency;

(*c*) A free oscillator of peaky waveform locked into step by the amplified output of (*b*); and

(*d*) A source of high frequency of the original frequency (or nearly so), modulated by the output of the locked oscillator (*c*).

The design of such a repeater will be discussed in detail below. It will be shown that a suitably adjusted super-reaction circuit, with self-quenching provides a satisfactory solution, and provides it by the use of one vacuum tube only.

A suitable 2-way repeater circuit is shown, in its simplest form, in Fig. 7. A triode A—of a design suitable for oscillation at the carrier frequency used—is connected as an oscillator by means of inductance C and condenser B. The high frequency grid connection is coupled through the blocking condenser D; and the grid leak is formed by the two resistances E and F in series.

The high frequency oscillations are made to start and stop, in trains by the action of the grid current in charging negatively the condenser G—in the well-known manner. The function of E is to prevent the high frequency from being shorted to ground by G, and may therefore be replaced if desired by a high frequency choke. If the repeater is to be used for operation in free space, the oscillating circuit is coupled, as shown, to a suitable antenna H by means of coil J; if for cable operation, J is connected to this cable—impedances being suitably matched.

As is well known, such a "squegging" oscillator will act as a self quenched super-reaction receiver; in a manner similar to that described above, the circuit will therefore greatly amplify incoming signals in the neighbourhood of its natural frequency. The circuit also acts as a demodulator to the amplified signals; if the latter arrive in pulses, therefore, a strong component at this pulse frequency will result. The requirements pointed out above under (*a*) and (*b*) are therefore fulfilled.

Respecting requirement (*c*) it will be seen that the provision of a free oscillator of peaky waveform is also already carried out in the "squeg" oscillation of the circuit; and if this latter is adjusted to be of nearly the same frequency as that of the signal pulses, the free squeg will be locked into step with the latter (within certain limits of amplitude) as is desired. The frequency of the high frequency generated by the circuit B—C has already been adjusted to be approximately that of the incoming carrier; as, therefore, at each squeg cycle a train of the local high frequency is produced, requirement (*d*) is also fulfilled.

The result, therefore, is the desired "synchronous" repeater—obtained in this case by using the normal sinusoidal type of super-reaction instead of the aperiodic described above.

At this stage, it may be of value to refer to a recent experimental result obtained on a repeater of the design of Figure 7. The carrier frequency was about 100 megacycles and the pulse frequency of the order of 10 kilocycles. With this adjustment, an effective repeater gain of between 50 and 60 db. was measured with stability.

On account of the very large band width obtainable, great interest is now centred on the possibilities of very high frequencies—of the order of 10,000 megacycles or even higher—these carrier frequencies being, in most cases, conveyed by means of some form of dielectric guide.

In the former art no practical means existed for the repeatering of such frequencies—one of the obstacles that has so far proved most serious when planning a transmission system on these lines.

The synchronous repeater, however—of the type illustrated in Figure 7—is capable of adaptation to these much higher frequencies; it is, therefore, the only practicable solution of the problem that is so far known. Figure 8 shows a simple form of such a repeater for frequencies of the order of 10,000 megacycles. "A" is a "solid anode" type of diode magnetron tube oscillating at approximately the carrier frequency of the incoming pulses (double pulse system). In series with the high tension supply B is placed a resistance C shunted by a condenser D. With suitable values of C, of D and of the tube supply voltages and constants, it has been found by the applicant that as soon as high frequency waves start being generated a change in plate current occurs which causes a building up of an additional charge on condenser D that eventually alters the plate voltage sufficiently to stop the oscillations—in fact, a series of short wave trains of carrier frequency occurs exactly as in the circuit of Figure 7. The circuit of Figure 8 may, therefore, be used as a repeater for these very high carrier frequencies, in the same manner as explained in connection with Figure 7, the waves to and from the magnetron being coupled by a single path with the waves in the dielectric guide, by any appropriate means.

A method of using any of the preceding types of synchronous repeater to give 2-way repeater action together with automatic echo suppression at all the repeater points, will now be explained.

Let us consider two "synchronous" repeaters—either of the high frequency or of the aperiodic form—separated by a distance (cable or free space) such that the time of travel of the signals over the path is slightly less than one period of the pulse frequency. As an example, let the distance be 30 km., and the pulse frequency be 8 kilocycles; then the time of travel (assuming free space) is $\frac{1}{10}$ millisecond. Let repeater B, Figure 11, initially lag being repeater A in phase by exactly $\frac{1}{10}$ millisecond: it will then receive synchronizing signals at the moments of maximum sensitivity as a super-reaction receiver, and will lock into step, being controlled by A. The pulse generated by B, however, will arrive at "A" 0.2 millisecond after the latter has generated the pulse that locked B in the first instance, and 0.25 millisecond in advance of the third pulse from A. This interval of 0.05 millisecond is great enough to prevent A, at this moment, from being sufficiently near to the point of sensitivity as a receiver to be affected appreciably by this pulse from B. The result, therefore, will be that A controls B, but that B does not control A, it is a one-way action.

If, however, the initial conditions are such that A lags $\frac{1}{10}$ millisecs. behind B in phase, the situation is exactly reversed; B will then con-

trol A, and A will have no effect on B. The circuit comprising the two repeaters and the propagation path has, in fact, two positions of stable equilibrium; in one position, the end A is the controlling factor—in the other, it is B that takes the control. If, now, there are three such repeaters separated by two equal cable sections (or paths in free space), the repeater B—now at the mid-point—is capable of (*a*) taking the control itself, or (*b*) being controlled either from A or C—according to the initial phase relations. If B lags by $\frac{1}{10}$ millisec. behind A—and C by the same amount behind B—signals will pass from A to C through the repeatering action of B; if, on the other hand, B lags by this amount behind C, and A by the same amount behind B, signals are capable of being passed in the direction C—A, through the repeater B. Each repeater is thus capable of acting in either direction, according to which of its stable equilibrium positions is in operation. But, it will control in only one direction at a time—hence there is no possibility of local echoes round the repeater sections. Further, whichever stable position it is in initially, it will remain in until artifically disturbed by some means.

Another feature of the present invention relates to means suitable for changing all the repeaters from one stable position to the other as desired. Among the possible solutions for single-channel working (e. g. for ultra short wave radio link) is the following method:

Assume (as an example of the possibilities only) that a form of "Vodas Control" is required, symmetrically from each end of the link, that gives control to that end from which speech is originated (assuming that it is from one end only at a time), and thereafter keeps the control at this end, even after cessation of the speech, until the direction of the incoming speech is reversed. For this purpose the transmitter terminal equipment at each end would comprise (essentially) simply a single tube in a circuit (see Figure 9) almost exactly similar to the repeaters (Figure 7). As a transmitter, incoming speech from the line is applied to an auxiliary grid through condenser K shunted by the metal rectifier L and resistance M, in such a manner that the average potential (positive) obtained by this auxiliary grid follows approximately the peak value of the incoming speech. The effect of this speech will thus be always to accelerate the squeg wave trains, and never to retard them in phase (i. e. the average frequency will be increased).

Let us assume that initially the link is passing signals in the direction E—D—C—B—A, Figure 11. On the cessation of speech in this direction, speech then is originated at A. The speech advances (periodically at audio frequency), the phases of the pulses from A; the result is: (*a*) an almost immediate loss of control of B onto A—and (*b*) as soon as the pulse from A arrives at B slightly in advance of that from C onto B, the control of B passes from C into the hands of A—and remains there as long as speech is arriving at A—as this speech always advances the pulses from A, and never retards them.

Immediately afterwards, as soon as the pulse from B arrives at C slightly in advance of that from D onto C, the control of C—similarly passes from D into the hands of B; and this process continues until the whole control is in the direction A—B—C—D etc., the reverse of the initial condition.

The amount of the wave-front of the speech originating at A (reckoned in "time") that is used up in this changing-over of the controls before the latter process is completed (and hence the extent of the initial syllable distortion) is a function of the ratio of the number of repeaters-sections to the number of pulses per second. For example, with 100 repeater sections a minimum of 100 pulses would be required for the control change-over to be completed; and if a pulse frequency of 100 kilocycles, is used, the initial distortion time is thus of the order of 1 millisec. (neglecting other possible sources of initial distortion due to the receiver—causes which can be largely eliminated by suitable design).

When speech in the direction A—B—C—D—E ceases, the control remains in this direction until speech is originated at the opposite end, when the control changes over once more, in a manner exactly as described.

It is thus evident that the single-tube "synchronous" repeaters described will automatically reverse their direction of operation, according to the direction of the speech.

Any of the above-mentioned types of repeater circuit (with the exception of the "synchronous" type on 2-way operation) may, of course, be used on multi-channel working—either to repeat the pulse wave-form representing the envelope of the whole group of channels combined together according to "frequency difference" methods (the methods usual in "carrier systems"), or to repeat each pulse in turn of each channel or channel-group separated in "time" by the distributor method.

To accomplish this result, no essential change in repeater design is required; it is sufficient that the pulses given out by the repeaters shall be sharp enough in wave-form to avoid appreciable cross-talk between channels.

One simple form of terminal apparatus, suitable for 12-channel operation on the distributor principle using double pulse modulation, is illustrated in Figure 10. (Only two channels are shown equipped.)

The circuits shown are particularly suitable when a number of such groups of channels are operated simultaneously, as part of the equipment—the "synchronisers" A and B—can in that case be used in common for all the groups. An advantage of the design is that the transmitting and receiving terminals are identical in all respects; and any given channel independently of all the others, may be caused to change from the transmitting to the receiving position immediately—either by means of a single switch or relay, or automatically (on the principle of the Vodas) by the first few cycles of the speech itself after the manner described in connection with Figure 9.

C and D are multi-vibrators of the usual design, oscillating at a super-signal frequency, e. g. at 10,000 cycles per second, in the case of speech transmission. By means of coupling condenser E, a 10 kilocycle E. M. F. of constant frequency and wave-form is applied to the left-hand grid of the tube C. The wave-form used is shown in curve *a* of Figure 12; the first section approximately rectangular, the whole of this portion lying just within the first twelfth of the 10,000 cycle period (see portion 1 of curve *a*). The negative half-cycle of this applied E. M. F. consists of a sharp negative pulse 2 occurring half a period after the beginning of the first portion 1.

The circuits constants of the tube C are adjusted so that the start of positive half cycle of the multi-vibrator oscillation must always synchronise with some part of the section 1. In the absence of speech from line 1—in which case the grid biases on the two grids of C are equal—the multi-vibrator natural frequency is adjusted so that stable locking takes place at such a phase that the positive half cycle commences at point (3b)—at the centre point of the portion 1. As, however, the voltage represented by 1 is practically constant throughout its duration, a slight difference in potential difference between the two grids of C suffices to cause locking to take place at a different phase, giving rise to the start of the positive half cycle at any point between 4 and 5 according to the strength and sign of this potential difference between the grids—a potential difference at audio frequency which is obtained as shown from the incoming speech from line 1, as shown, by means of the transformer F. (This part of the circuit is the same as that used in the pulse modulation transmitters described in French Patent No. 833,929 filed on June 18, 1937, and its addition French Patent No. 49,149 filed on July 5, 1937).

The start of the multi-vibrator half cycle, however, can never occur outside the limits given by points 4 and 5, on account of the strong locking action due to the E. M. F. of curve *a*.

The multi-vibrator constants are adjusted so that the end of the above positive half cycle is determined by the arrival of the negative pulse 2 from the synchroniser A. This moment is thus fixed and independent of the incoming speech.

As in the double pulse modulation transmitter already referred to, the rectangular wave-form of curve *b* is then transformed into a sharp pulse 6 (curve *c*) by means of the small condenser G in series with resistance H. The two dotted pulses each side of 6 on curve *c* show the extreme limits of variation, during speech modulation, of the sharp voltage pulse that is then present across the resistance H. Transformer N in series with blocking condenser K (large enough to prevent distortion of the pulse wave-form) is then used to step down the pulse into the impedance of the cable, as shown. As in the double pulse transmitter, the undesired negative pulse due to the end of the multi-vibrator positive half cycle at 7 is eliminated by shunting resistance H by the rectifier L in such a manner as to eliminate this unwanted pulse without affecting the desired pulse 6.

The circuit of tube D, associated with line 2, is exactly similar, except that the applied E. M. F. from the synchroniser A is now taken from another output branch of the latter in such a manner as to give the wave-form shown in curve *d* of identically the same nature as in curve *a*, but displaced in "time" by one twelfth of a period.

Curve *e*, corresponding to *b* shows the resulting wave-form from the multi-vibrator attached to line 2; and curve *f* corresponding to curve *c* shows the output pulse given by this second multi-vibrator to the cable.

The remaining gap of 10/12 of a period of the 10,000 cycle frequency is filled up by the remaining ten channels in turn—no channel over-lapping in "time" with any other, thus avoiding inter-channel interference.

As already stated, and as shown in Figure 10, the apparatus at the far end of cable—the end for the moment considered to be the receiving station—is identical in all respects to that described above. The only difference is one of adjustment. As a receiver, the natural frequency of each multi-vibrator is adjusted to a slightly lower value than when used as a transmitter; the effect of this in the absence of speech originating at the receiver or of signals from the cable, is to cause stable locking of each multi-vibrator to take place at the end of portion 1 of curve *a* rather than at its centre point (or at the end of the corresponding curve, in the case of channels other than No. 1). Point 5 of curve *b* will now represent the starting time of the multi-vibrator half cycle in the absence of signals or speech.

The synchroniser B at the receiver—of the same design and adjustment as A at the transmitter—is locked into step with A, either by conveying some of the output of A to B by a separate channel, or by other appropriate means. The exact value of the distributor frequency (referred to above as 10 kilocycles) and/or the propagation time of the cable (if necessary by adding a delay network) are modified so that this propagation time is an integral number of half periods of the distributor frequency. If a pulse from channel 1 at the transmitter synchronises at the receiver with a "channel 1" pulse at this receiver end, the same result then will also take place in the reverse direction.

Let us consider the action of the pulse 6 from transmitter channel 1 on its arrival at the receiver. Owing to the particular adjustment described above in the synchronism between B and A, pulse 6 will arrive at the centre point in "time" of an applied E. M. F. from synchroniser B—an E. M. F. of the same wave-form and phase as the portion 1 of curve *a*. The arrival of the pulse causes the multi-vibrator of receiver channel 1 to start its positive half cycle earlier than would otherwise have been the case—it is triggered by the arriving pulse to start on the arrival of the latter—at point 6 instead of point 5. As the transmitter pulse is modulated in "time" by the speech, the starting time of receiver multi-vibrator No. 1 will remain in step with it at its new values, thus following the "time" modulation at the transmitter. The result will be curve *b* exactly the same as that of the transmitter multi-vibrator at the distant end of the cable.

As the pulse frequency components are filtered from transformer M by the small by-pass condensers shown, (or by a more complicated filter if necessary), the grid winding of M will have through it a current proportional to the average area of curve *b*—i. e. proportional to the original speech wave-form at the transmitter. This speech therefore, will be given to the output line from M.

In exactly similar manner, multi-vibrator 2 of the receiver will have its starting time modulated by the pulses from channel 2 of the transmitter—and similarly for the remaining ten channels—each receiver multi-vibrator being entirely unaffected by pulses from channels other than its own, as these other pulses occur always at times of insensitivity to their locking action.

To operate any channel in the reverse direction, it suffices to raise the natural frequency of the circuit of tube L (for example) to give normal locking at point 3 instead of at 5, and to lower that of the circuit of the corresponding tube (e. g. tube C) to give normal locking at

point 5 instead of at point 3. Tube L will then control C, instead of the original reverse effect.

The design of the synchronisers A and B—common to all the groups of 12 channels—and having a twelve-phase output of the wave-form described above—may be carried out by any method already known to the art, for example, by a method similar to the "pyramid of rectangular waves" described in British Patents Nos. 344,444 and 363,403.

It will be seen the invention is not limited to the arrangements described by way of examples, but on the contrary the invention is capable of many applications without going beyond the scope of the appended claims. For instance, Fig. 5 shows a transmission system somewhat analogous to the so-called 4-wire system in which two way lines l_1 and l_2 are connected by suitable coupling network (hybrid coils H_1 and H_2) to two uni-directional lines on which are bridged repeaters R_L R_2 R'_1 R'_2 according to features of the present invention.

We claim:

1. A repeater system for repeating along a transmission path, signal modulated carrier waves wherein the signals are represented by time displaced impulses on said carrier waves, comprising a relaxation oscillator, means for biasing said oscillator normally to non-oscillatory condition in the absence of input impulses and means responsive to the received impulses for triggering said oscillator into oscillating condition, thus producing upon arrival of each impulse a corresponding single impulse of substantially constant amplitude level and having a constant wave front depending on the characteristics of the oscillator, and means for bridging said oscillator across said transmission path for repeating signals conveyed in either direction along said path.

2. A repeater system as claimed in claim 1 for pulse modulated ultra short waves further comprising means for amplifying said received pulses, means for detecting said received impulses and means responsive to said detected impulses for locking said oscillator into step with said received impulses, the output of said oscillator modulating a source of ultra high frequency.

3. A repeater system as claimed in claim 1 for aperiodic pulses further comprising a plurality of repeaters placed in succession in said transmission path, each said repeater having means for locking its oscillator in step with the received impulses, said repeaters being spaced at such distance with regard to the average pulse frequency that the successive repeaters are locked successively in phase by an incoming signal on the first repeater and follow these signals until these signals are stopped and the system is made available for a signal in the opposite direction, being therefore free from echos.

4. A repeater system according to claim 1 further comprising means responsive to signals arriving over said transmission path in one direction for conditioning said repeater for operation in the said direction.

5. A repeater system according to claim 1 wherein said oscillator is used as terminal equipment for transmission or receiving signals, further comprising means controlled by transmission and reception of signals therethrough for alternatively conditioning said oscillator for transmission or reception.

6. A repeater system according to claim 1, further comprising means responsive to operation of said oscillator for terminating said oscillations after a predetermined period.

7. A repeater system according to claim 1 wherein said oscillator comprises a dual stability system, and means responsive to received signals for synchronizing operation of said oscillator.

8. A signaling system as in claim 1, wherein a plurality of tandem connected repeaters are provided, characterised in this that each said repeater comprises a vacuum tube, and that each said vacuum tube is duplicated by another tube in parallel whereby if one tube fails the second tube alone gives sufficient gain to operate the next repeater in the series, the output of each said repeater being a simple relay device, whereby its operation is unchanged by the failure of the first tube in question.

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