April 29, 1947. P. K. CHATTERJEA ET AL 2,419,535

TIMEMODULATED PULSE COMMUNICATION SYSTEM

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FIG. 1.

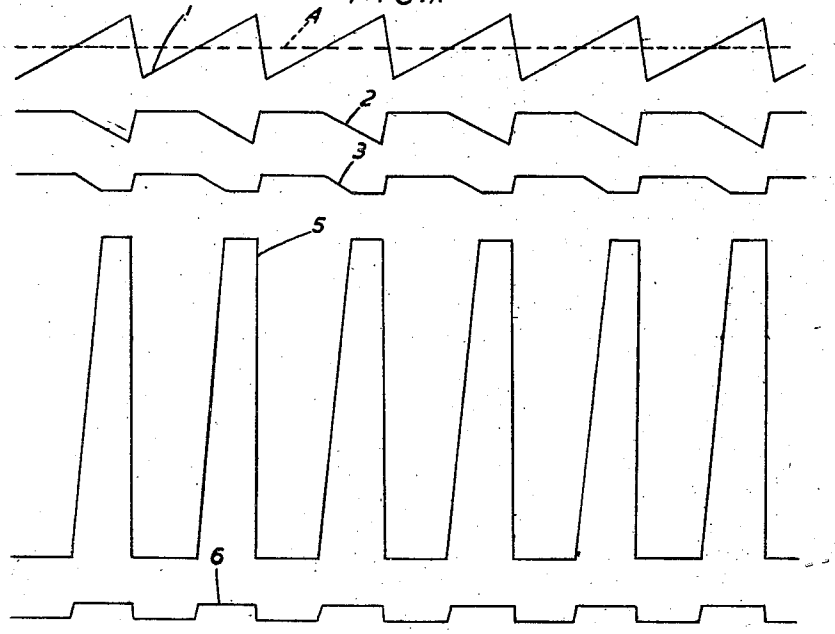
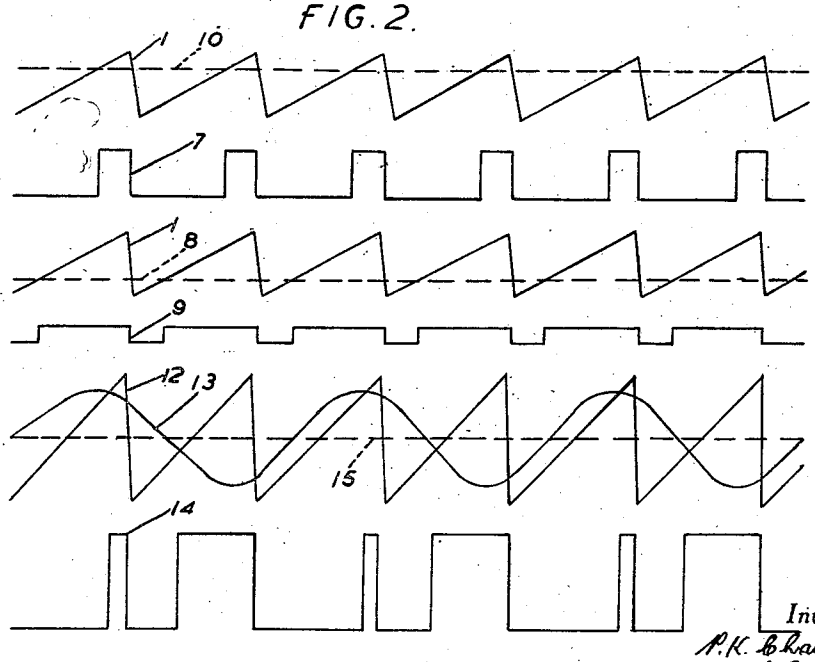


FIG. 2.



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FIG. 3.

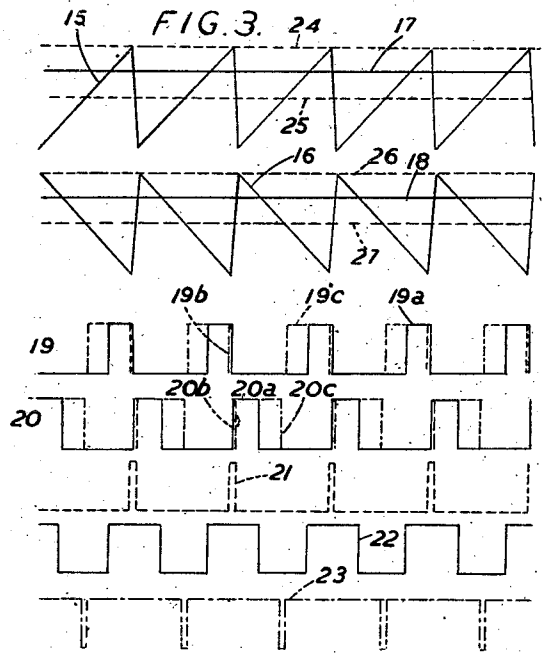
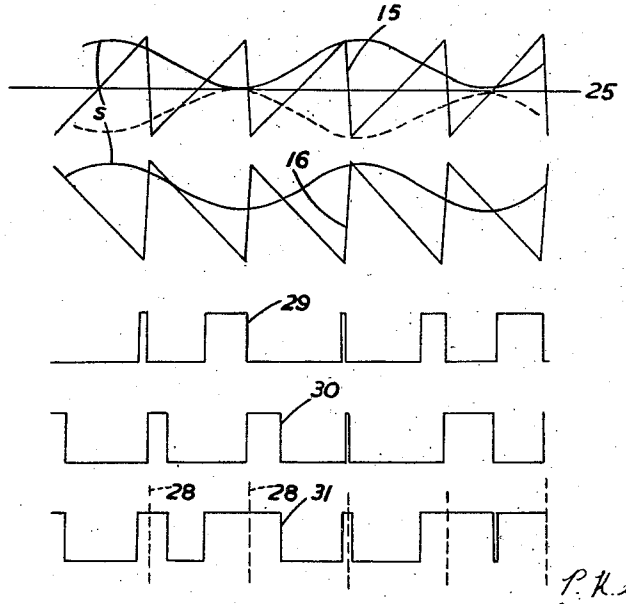


FIG. 4.



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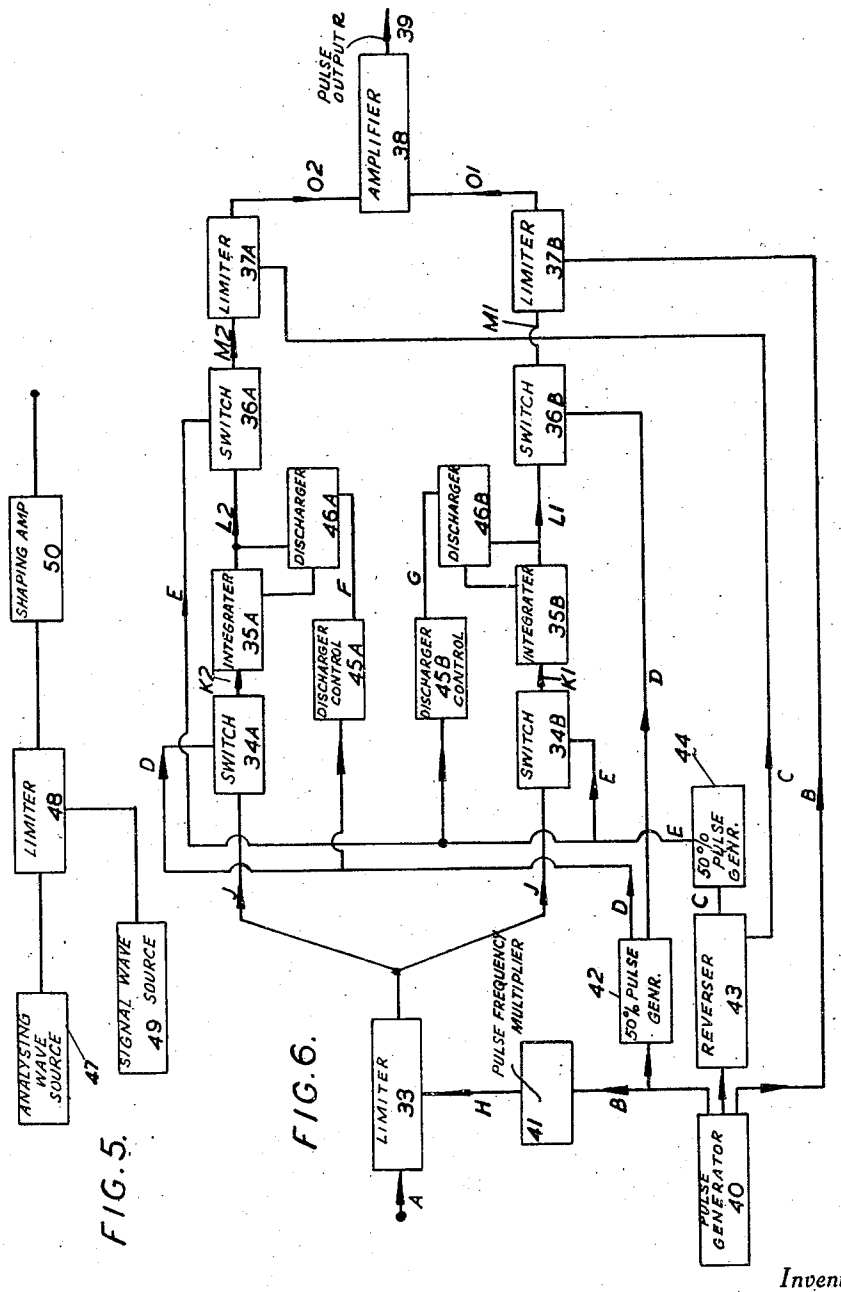


FIG. 5.

FIG. 6.

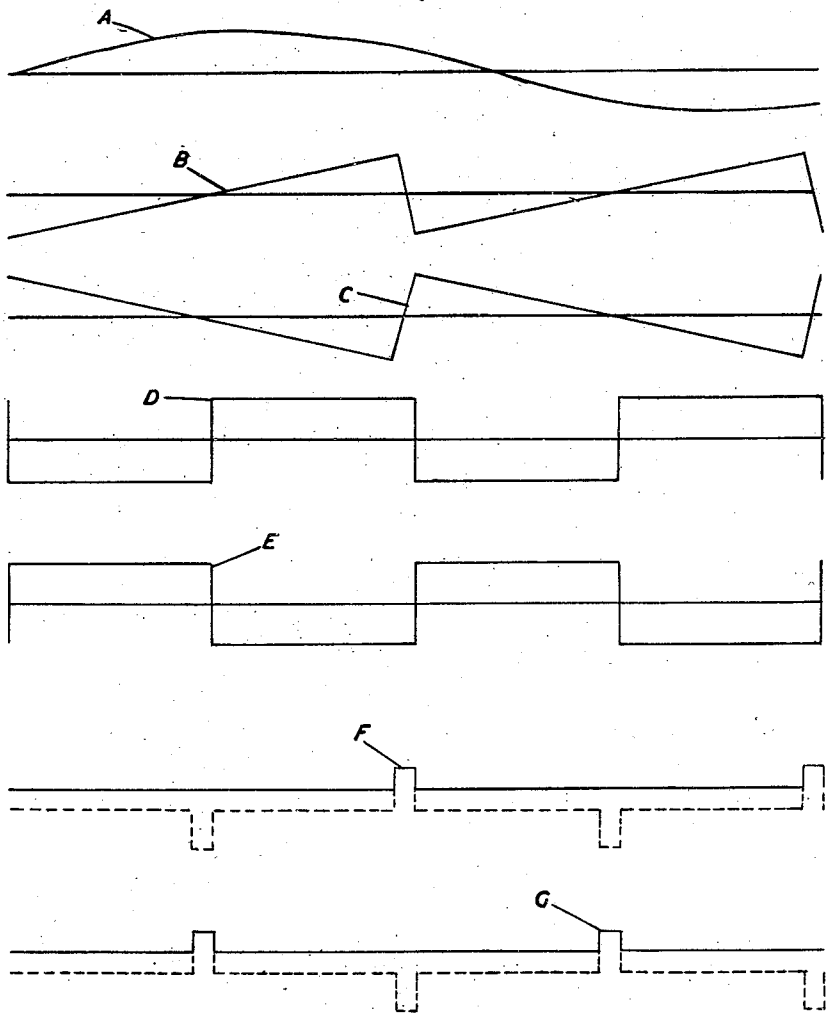
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TIMEMODULATED PULSE COMMUNICATION SYSTEM

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FIG. 7.



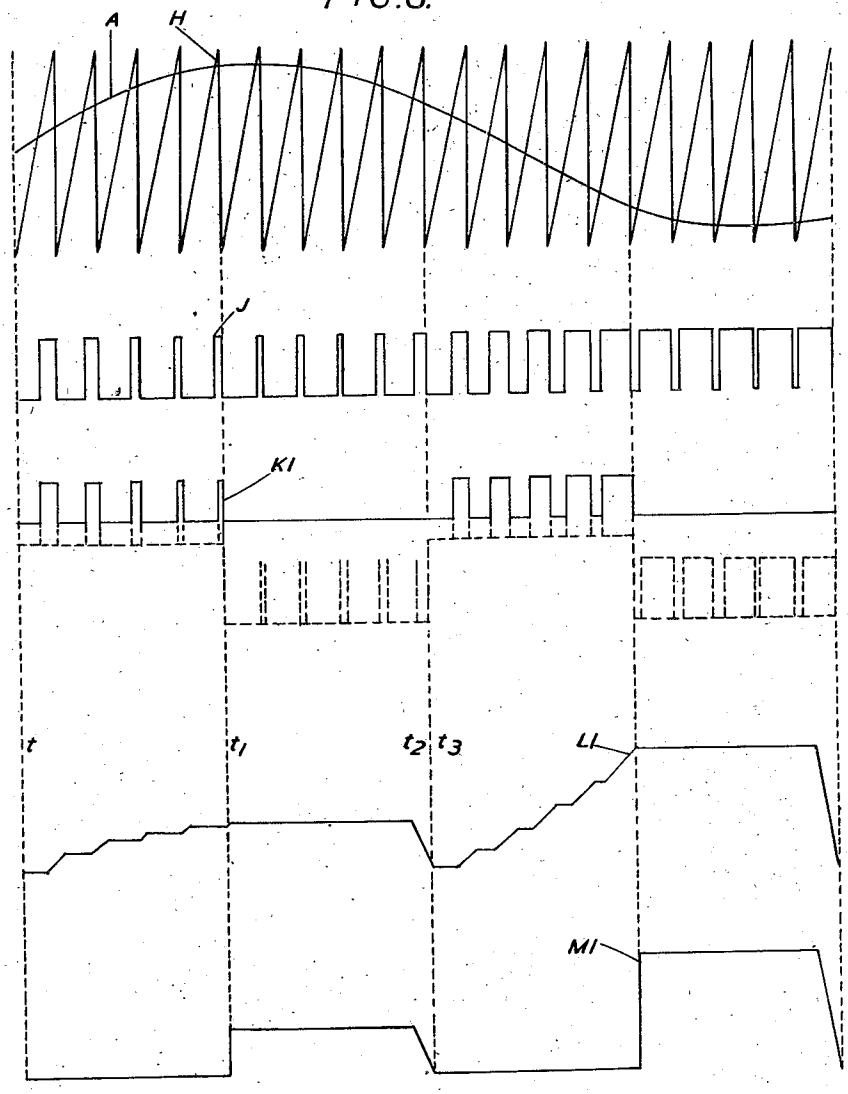
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FIG.8.



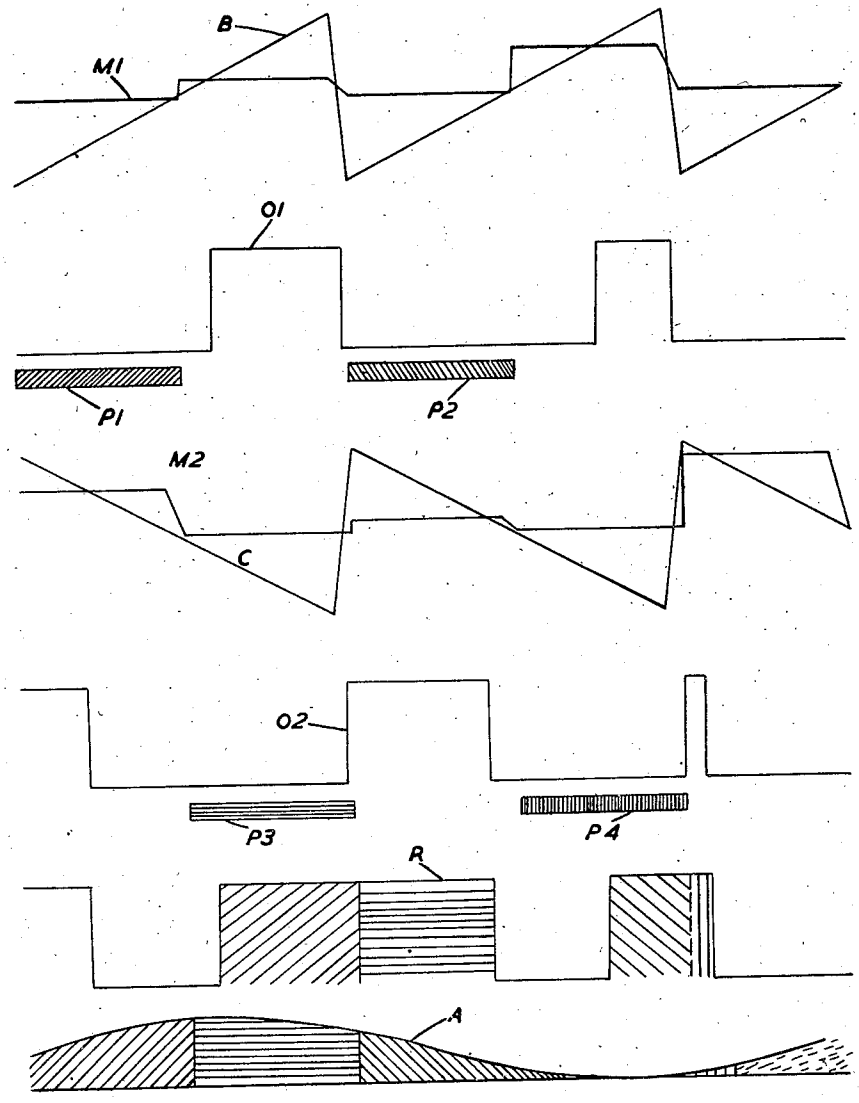
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FIG.9.



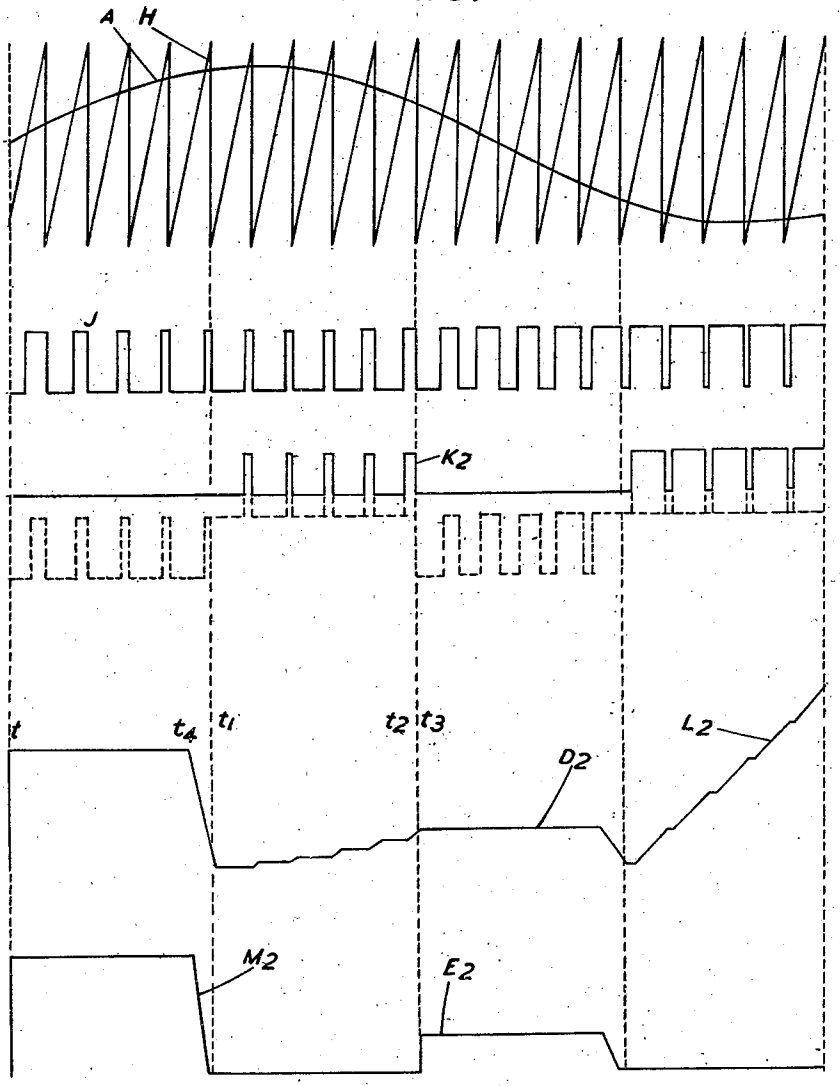
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FIG. 10.



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UNITED STATES PATENT OFFICE

2,419,535

TIME-MODULATED PULSE COMMUNICATION SYSTEM

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Application November 23, 1942, Serial No. 466,652
In Great Britain November 24, 1941

6 Claims. (Cl. 250—17)

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The present invention relates to duration-modulated pulse communication systems.

In some systems pulses of very short constant duration (marking pulses) are transmitted to mark the beginning and end of a duration modulated pulse, or if one edge of the duration modulated pulse occurs at constant time intervals, usually termed the fixed edge, then only the marking pulses marking the variable edges of the duration modulated pulses need be transmitted and the marking pulses marking the fixed edges can be inserted at the receiver at which the solid or duration modulated pulses are reconstructed from the pairs of marking pulses. The marking pulses may conveniently be said to be time modulated, that is they occur at varying intervals of time in contradistinction to the solid or duration modulated pulses. In this specification and claims the terms "duration modulation" or "duration modulated pulses" are intended to include "time modulation" and "time modulated pulses" respectively where applicable.

In previously proposed arrangements for deriving a duration modulated pulse train from a signal wave the instantaneous amplitude of the signal wave at arbitrary predetermined instants has been transmitted as a time interval, namely the duration of a pulse. It was found that for any wave form a minimum of three such instants at arbitrary sufficiently small time intervals between them are necessary to define that portion of the signal wave form occurring during the time covering the three instants. The greater the number of such instants over a given period the more accurate will be the wave form received at the receiver and the higher the component frequencies transmitted.

The present invention has for its object to increase the number of such instants or points of analysis for a given pulse repetition frequency so enabling a higher signal frequency to be transmitted, thereby overcoming one of the fundamental limitations of existing systems as well as increasing the possibility of truer representation of the signal wave.

According to one aspect of the invention, a duration modulated pulse communication system is characterised in this that two trains of pulses of equal pulse repetition frequency are used and displaced in time one with respect to the other so that the trailing edges of the pulses of one train coincide with the leading edges of the pulses of the other train and the occurrences of the leading edges of said one train and the trailing edges

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of said other train are modulated in accordance with the amplitude of the signal wave at respectively different instants of time.

According to another aspect of the invention, a duration modulated pulse communication system is characterized in this that the leading and trailing edges of the pulses of a train of pulses are modulated respectively in accordance with the amplitude of the signal wave at alternate instants of time.

According to another aspect of the invention, a duration modulated pulse communication system is characterised in that a signal wave is analysed by an analysing waveform and by said analysing wave reversed in sign. Alternatively the signal wave and the signal wave reversed may be analysed by the analysing wave at alternate instants.

From another aspect, a duration modulated pulse communication system is characterised in that the signal wave is applied to two analysing paths in which the analysing waveform or the signal waveform is reversed in one with respect to the other.

According to another aspect of the invention, a duration modulated pulse communication system is characterised in this that the signal wave is analysed by an analysing wave which has a growth of amplitude to a maximum at the end of the half period and a decay to a minimum at the end of the full period. Such a wave may be triangular for example, or any wave which has a symmetrical growth and decay of amplitude with respect to the amplitude at the end of a half period.

The invention also comprises a method of and arrangements for averaging a variable for example an amplitude of a signal wave.

The invention will be better understood from the following description taken in conjunction with the accompanying drawings in which

Figure 1 shows wave forms used in the explanation of the production of pulses of rectangular waveform;

Figure 2 shows curves used in explaining how the durations of the pulses is modulated by a signal wave;

Figures 3 and 4 show curves used in explaining the invention;

Figure 5 shows a block schematic of transmitting arrangements for carrying out the invention utilising an analysing wave of symmetrical waveform;

Figure 6 shows in block schematic an arrange-

ment for carrying out the invention utilising an analysing wave of sawtooth waveform;

Figures 7–10 show curves used in the explanation of the operation of the arrangement shown in Figure 6.

Practical work has demonstrated that the "chopped wave" method of deriving a duration modulated pulse train representative of a signal wave is preferable to other known methods such as deflection tube methods for instance utilising a cathode ray tube. The chopped wave method is described here for clarity and is as follows, assuming a 50–50 pulse with one edge fixed in time.

A sawtooth waveform 1, Fig. 1, of the accompanying drawings is established by any known means and fed in a positive sense (as shown in the diagram) across the grid and cathode of an amplifying valve. The grid on this valve is so adjusted that the operating point in the quiescent state is lower than that necessary to extinguish the anode current for any one setting of the other operating voltages. This valve can thus be made operative only after the sawtooth wave has reached half its final amplitude. These latter operating conditions of this valve which is working as a limiter, will then be represented by points on the curve which lie above the dotted line 4 in Fig. 1. This line is referred to hereafter as the "chop" or "cut" line.

2, Fig. 1, shows the resulting waveform to be obtained at the output of such a valve and due to the well-known phase relation between the grid-cathode and anode-cathode circuits of a valve, the output will also be in a sense directly opposite to the sense of the input signal. It is important to note that here the valve output current has not reached a saturation value prior to the arrival of the final amplitude of the sawtooth voltage.

If on the other hand conditions are such that saturation or other form of limiter action is present, some such waveform as 3, Fig. 1, will result across the anode-cathode output terminals. This resulting waveform 3, Fig. 1, is then amplified further, curve 5, Fig. 1, showing the result due to an amplification of 20 times, in the case of this example. Further if this amplifier valve is biassed beyond anode current cut-off very little of the troughs (positive or negative depending on the phase of this input to the initial sawtooth input) of 3, Fig. 1, will operate this amplifier valve, resulting in this case in a waveform 6, Fig. 1, which is of substantially rectangular waveform.

It will be observed that the greater is this amplification the more do the sides of the rectangle approach the perpendicular.

Now if the cut line 4, Fig. 1, were moved to a new position 10, Fig. 2 of the drawings, that is, if the cut line is moved in a positive direction relatively to its initial position (4, Fig. 1), the resulting rectangular wave will be of the form 7, Fig. 2, i. e. pulses are narrower than in 6, Fig. 1, although the same sawtooth 1, Fig. 1, has been used for 1, Fig. 2.

On the other hand a shift of the cut line (4, Fig. 1), in the negative direction to a position as shown in 8, Fig. 2, results in wider pulses, as at 9, Fig. 2, compared to 6, Fig. 1.

The point of interest to note here is that the edges of the pulses occur at points of intersection between the cut line (4, Fig. 1; 8, Fig. 2; or 10, Fig. 2) and the analysis waveform (the sawtooth in this example), and also that if the pulse has sloping sides these points of intersection are the points from which the pulse starts to rise or at which it is extinguished.

Thus it will be seen that if the cut line on the analysis wave is moved under the influence of a signal the points of intersection will follow according to the amplitude characteristics of the signal, from the mean or quiescent position (4, Fig. 1).

The case of a signal in the form of a sinusoidal wave is shown at 13, Fig. 2, superimposed on the analysis wave based on the mean position of the cut line (indicated by the dotted line 15, Fig. 2). This signal can then be regarded as the cut line itself.

Thus 12, Fig. 2, is the analysis waveform, 13, Fig. 2, the signal waveform resulting in a time modulated pulse train of the waveform 14, Fig. 2. In order to give the minimum of substantially three pulses per half period of the signal wave, the frequency of the analysis wave should be approximately six times the frequency of the signal wave, but is shown in Fig. 2 as of twice the signal wave frequency for ease of explanation.

In all existing systems of duration modulated pulses, a fundamental problem exists in the limit of working ratio between the maximum signal frequency to the pulse repetition frequency.

An object of this invention is to improve the "maximum signal frequency to pulse repetition frequency" ratio: and this object is attained by using two analyses of the signal wave and having the same pulse frequency so as to obtain two different pulse trains having corresponding pulses adjacent as regards time and each being characteristic of the same signal wave, the adjacent pulses of the different trains being transmitted as one pulse.

The invention will be further described with reference to Figures 3 and 4 of the accompanying drawings.

Referring now to Fig. 3 of the accompanying drawings, a sawtooth wave train 15 is established and is fed via a paraphase amplifier or a transformer or by any other means to obtain the second or reverse wave 16. Each of these waves is fed to respective amplitude limiter devices preferably of the grid cut-off type and being substantially identical in response. The points at which these two limiters come into operation are shown by the solid lines 17 and 18. These lines can be moved over only half of the analysis sawtooth wave; thus the cut line 17 can be moved between the limits of the broken line 24 and the broken line 25. The position of this cut line 17 which is halfway between 24 and 25 is the quiescent position. Similarly the cut line 18 can be moved between the broken line 27 and broken line 26, the line 18 being the mean position.

The pulse trains 19 (marked by the solid, broken and chain-dotted outlines) are derived from the operation of the cut line 17 (provided by the control of a limiter) and the analysis wave 15 in a manner as described hereinbefore. The solid line pulses 19*a* are obtained when the limiter action is such that the cut line is at the position given by the solid line 17. The broken line pulses 19*b* (the right-hand edge coinciding with the right-hand edge of the solid line pulses) represent position of cut line when at 24, whilst the chain-dotted pulses (the right-hand coinciding with the right-hand edge of the solid line pulse) are when 17 is coincident with 25.

Similarly pulse trains are obtained by the cut line 18, full line pulses 20*a* representing the pulses

produced with the cut line at 18, the broken lines 20b represent pulses obtained with the cut line at 26 and the chain-dotted lines 20c represent pulses with the cut line at 27.

These two sets of pulse trains 19 and 20 are added together and the waveforms 21, 22 and 23, Fig. 3, are obtained. When both limiters are operating on their respective waveforms 15 and 16 at position 24 and 26, waveform 21 results, whilst when they function at 17 and 18, waveform 22 is the result, and waveform 23 is derived when both limiters are functioning at 25, 27.

Fig. 4 of the accompanying drawings shows the same two analysis waves 15 and 16, Fig. 3, but in Fig. 4 the limiter action is controlled by a signal of waveform S.

The signal frequency is shown to be ⅖ or 0.4 pulse repetition frequency and the signal of sufficient amplitude to cause sensibly 100% modulation. 29 and 30 show the pulses obtained as the result of the two limiting actions and 31 shows the combined pulse as the result of combining the wave trains 29 and 30.

The pulses of this train 31 have two variable edges the position of each variable edge varying independently of the instant which marks or would mark the halfway point of the mean pulse shown at 22 Fig. 3. This halfway point is indicated at 28, Fig. 4.

The durations of the pulses before and after the halfway instant of the mean pulse i. e. before or after the instant 28, Fig. 4, thus define independently the characteristics of the same signal.

This, it will be observed, will result in a series of pulses which are marked by being asymmetric about the central instants of the mean unmodulated pulses at high signal frequencies and deep modulation and the resulting pulse train is therefore no longer the simple cycle operation as in the known systems hereinbefore referred to.

Whilst the foregoing description relates to the case in which the analysing wave and the analysing wave reversed have been employed, it is also possible to attain the same results by utilising the signal wave and the signal wave reversed whilst employing the same analysing wave. In this case one of the limiters used would work above the limit represented by 25 in Figure 3, as explained hereinbefore, and the limiter in the case of the signal reversed would work below this limit represented by 25 Fig. 3. The limiters would thus operate in opposite directions, so to speak, one in a positive and the other in a negative direction and would become effective respectively during alternate half cycles of the analysing waveform. This can be seen clearly from Figure 4 in which the reversed signal wave is shown in broken line. Then the pulses 29 are produced by the analysing wave and signal wave during the periods when the analysing wave is above the datum line 25 and the pulses 30 are produced when the analysing wave is below the datum line 25 and with the reversed signal wave.

The extra benefit at receiving the type of modulated pulse according to this invention is that these pulse trains can be more accurately retranslated back to the signal by any integrating circuit.

The net effect of limiting the two waveforms is to chop or cut a wave having an isosceles triangular waveform. One limiter functioning with one wave of this form can give the same double analysis result, and a limiter action on any symmetrical wave will also give the double analysis.

The law connecting instantaneous signal amplitude and time modulation however will not necessarily be linear in the latter case.

Arrangements for utilising a symmetrical waveform are shown in block schematic form in Fig. 5.

In Fig. 5, the reference 47 represents the source of the analysing waveform and is of symmetrical shape, for example, triangular shape but any wave shape which is symmetrical about its peak and with no sharp changes or discontinuity in slope may be used. 48 is an amplitude limiter of any known type, and 49 is the signal wave source or a signal wave amplifier. 50 represents a shaping amplifier operating for example as described in connection with curves 5 and 6 of Fig. 1. The limiter 48 is a circuit element having a non-linear response to voltages impressed on it and may be for example a thermionic valve. To this element is fed the signal from source 49, suitably amplified if necessary and the output of the analysis wave from generator 47, the inputs are so connected that their voltages are effectively in series. In the particular case of a valve the voltages would be in series, although they may not be applied to the same grid in a multigrid valve.

The amplitude of the source 47 must be such that its effect at the output terminal of 48 is never less than 70% of the effect due to the signal; in a normal case it will always be greater than the signal effect by approximately 15%.

The output of the limiter, the anode in the case of a valve is then a double analysis duration modulated pulse; this is fed to a transmission link through the shaping amplifier 50.

It has hitherto been shown by Heising that a speech wave may be well represented by a pulse train of flat topped pulses, i. e. of flat topped wave form, of higher repetition frequency than the highest frequency components of the signal waves to be transmitted, the pulses being modulated in duration so that their energy over a cycle of a speech frequency is proportional to the energy of the signal wave. To achieve this the pulse duration modulation of the train must be proportional to the mean amplitude or to the R. M. S. (root mean square) mean amplitude of the wave over a period equal to the pulse repetition time.

This, however, involves a high pulse frequency and transmission occupying an immense bandwidth which for practical reasons must be reduced, so that by all practical circuits previously envisaged Heising's ideal pulse modulation cannot be achieved.

The arrangements about to be described and shown schematically in Figure 6 achieve a close approximation to the ideal pulse system. In these arrangements the average amplitude over a specified period, namely equal to half a pulse repetition period, is obtained and the pulse duration modulated accordingly. A double analysis according to the invention is employed.

In Figure 6 two analysing circuits are shown, one bearing numeral references with the suffix A and the others, for similar parts, the same numeral references with the suffix B. The letters accompanying the arrows on conductor lines relate to the waveforms flowing in the conductors and correspond to the waveforms of similar designation in Figs. 7–10.

In Figure 7

A represents the signal waveform which is fed to limiter 33, Fig. 6;

B represents the output waveform of generator 40, Fig. 6;

C represents the output waveform of reverser 43, Fig. 6;

D represents the output waveform of 50% pulse generator 42, Fig. 6;

E represents the output waveform of 50% pulse generator 44, Fig. 6.

Curves F and G are derived from waveforms D and E respectively by the discharge controls 45A and 45B respectively, Fig. 6. These latter consist of known means and may consist for example of an artificial line to produce a reflection of the pulse and to combine the pulse and its reflection in opposition to control the width of the resulting pulse F, G. The control is effected by varying the electrical length of the artificial line. The waveforms F and G are then fed to the respective discharge circuits 46A and 46B, which operate on reception of the short pulses of the waveform F and G. These discharge circuits may comprise thermionic valves biased below cut off and pass current during the occurrences of F and G.

The signal A is fed to the limiter 33 together with the output of the generator 41 which generates a sawtooth of 10 times pulse repetition frequency. This is shown at H, Fig. 8, and the resulting duration modulated pulse train in the output of the limiter 33 is shown at J in Fig. 8.

The pulse train J, Fig. 8, is fed to switch 34B, Fig. 6, together with output (E, Fig. 7) of 50% pulse generator 44, Fig. 6. The switch 34B comprises a limiter amplifier and the output due to the combined voltages represented by E, Fig. 7 and J, Fig. 8 is shown at K1 in Fig. 8, the solid line representing the output of switch 34B.

Integrator 35B of known type comprising a condenser, Fig. 6, sums this output, as shown at L1 in Fig. 8, the pulses being received from t to t_1, the resulting level being held from t_1 to t_2 and then cancelled under the influence of the discharge circuit 46B, Fig. 6, during the period t_2 to t_3, the occurrence of pulse G, Fig. 7; the cycle of the integrator 35B then repeats. Switch 36B, similar to 34B, Fig. 6, is operated by the output D, Fig. 7 of the 50% pulse generator 42, thus producing the wave form M1 of Fig. 8 which is added to the wave form B in the amplitude limiter 37B.

Curves M1 and B, Fig. 9, show the action of limiter 37B, Fig. 6, and curve O1, Fig. 9, shows its output. These time modulated pulses are characteristic of the average amplitude of the signal wave over the preceding pulse frequency half-period marked by the shaded bands P1, P2, Fig. 9.

A similar set of pulses O2, Fig. 9, is derived in a similar manner through the chain of apparatus marked with a suffix A in Fig. 6 and utilising the analysing waveform reversed in sign with respect to that in the B chain of apparatus, namely curve C, Fig. 7.

Curves C and M2, Fig. 9, show the action of the limiter 37A, Fig. 6, and curve O2, Fig. 9, shows its output, but the pulses in this output are displaced by half the pulse repetition period with respect to pulses O1. The function of the A branch is similar to the function of the B branch and no further specific description of the A branch is deemed necessary. The two pulses O2 shown are representative of the average amplitudes during the periods P3 and P4 respectively. The two sets of pulses O1 and O2, Fig. 9, are applied to the input of amplifier 38 and combine to give the pulse train shown at R, Fig. 9.

Curve A, Fig. 9, shows the signal wave, and areas under the portions of the signal wave are hatched similarly to the corresponding pulse in R, Fig. 9, i. e. the energy of a pulse is characteristic of the energy represented by the area under the signal wave similarly hatched.

It will be noticed that the pulses occur delayed by half the pulse repetition period and hence the wave built back from pulse train R will be so delayed.

By squaring the signal amplitude at a suitable point in the arrangements an R. M. S. (root mean square) mean amplitude could be found and the time modulation of the pulses made characteristic of this.

Whilst in the foregoing description embodiments of the invention have been described for producing solid pulses in which the two edges thereof are variable in time, it will be clear to those well versed in the art that marking pulses, marking the leading and trailing edges of the solid pulses may be obtained in known manner. Furthermore the averaging arrangements described in connection with Figures 6 and 10 may be applied to averaging the amplitude of any wave. The amplitude of a wave may be proportional to any variable. Hence by producing such a wave it is possible to utilise these arrangements to average any variable over a predetermined period of time.

What is claimed is:

1. The method of electrical signalling by duration modulated pulses which comprises generating two trains of electrical pulses of equal pulse repetition frequency, relatively displacing said pulse trains in time to such extent that the trailing edges of the pulses of one train coincide with the leading edges of the pulses of the other train, and time modulating the occurrences of the leading edges of said one train and of the trailing edges of said other train in accordance with the amplitude of a signal wave at respectively different instants of time.

2. A duration modulated pulse communication system comprising means for generating two electrical pulse trains of the same pulse repetition frequency, a source of signal waves, means for relatively displacing said pulse trains in time so that the trailing edges of the pulses of one train coincide with the leading edges of the pulses of the other train, means for time modulating the occurrences of the leading edges of said one train and of the trailing edges of said other train in accordance with the amplitude of said signal wave at different instants of time, means for combining said two trains of time modulated pulses and means for impressing said combined waves on a signal transmission medium.

3. A duration modulated pulse communication system comprising a source of signal waves, a transmitting apparatus comprising a first set of equipment including a first source of electrical pulses having a predetermined repetition frequency and means for time modulating the leading edges of said pulses in accordance with the amplitude variations of said signal wave, leaving the other edges fixed in time, a second set of equipment including a second source of electrical pulses having the same repetition frequency as said first source and means for time modulating the trailing edges of said pulses in accordance with the amplitude variations of said signal wave, leaving the other edges fixed in time,

means for combining the two sets of time modulated pulses with such relative phase that their fixed edges coincide, and means for impressing said combined waves on a signal transmission medium.

4. A duration modulated pulse communication system according to claim 3, wherein said time modulating means in each set of equipment comprises an amplitude limiter to which is applied a wave derived from said signal wave source and an analysing wave of saw-tooth form, the relative directions of the respective last-mentioned waves being reversed in the two sets of equipment.

5. A system according to claim 3, comprising means in said first set of equipment for deriving from said signal waves a first derived wave the amplitude of which varies in accordance with the mean amplitude of the signal wave over successive separated time intervals, a first source of saw-tooth waves, a first amplitude limiter, means for applying said first derived wave and said first source of saw-tooth waves to said first amplitude limiter to obtain the first train of duration modulated pulses, and comprising in the second set of equipment means for deriving from said signal waves a second derived wave the amplitude of which varies in accordance with the mean amplitude of the signal wave over alternate separated time intervals, a second source of saw-tooth waves reversed with respect to said first source, a second amplitude limiter and means for applying said second derived wave and said

second source of saw-tooth waves to said second amplitude limiter to obtain the second train of duration modulated pulses.

6. A system according to claim 3 further comprising means for producing an auxiliary pulse train having a repetition frequency which is a multiple of the said repetition frequency, means for time modulating said auxiliary pulse train in accordance with the amplitude of said signal wave, means for applying said time modulated auxiliary pulse train to said first and second sets of equipment, integrating means in each set of equipment for integrating the energy of said auxiliary pulse train over periods equal to one half the said repetition frequency, and means for rendering the integrating means of the two sets of equipment alternatively operative.

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CHARLES THOMAS SCULLY.

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