April 6, 1948. E. LABIN ET AL 2,438,927

MODULATION MEANS AND METHOD

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Fig. 1.

Fig. 3.

Fig. 4.

Fig. 5.

Fig. 2.

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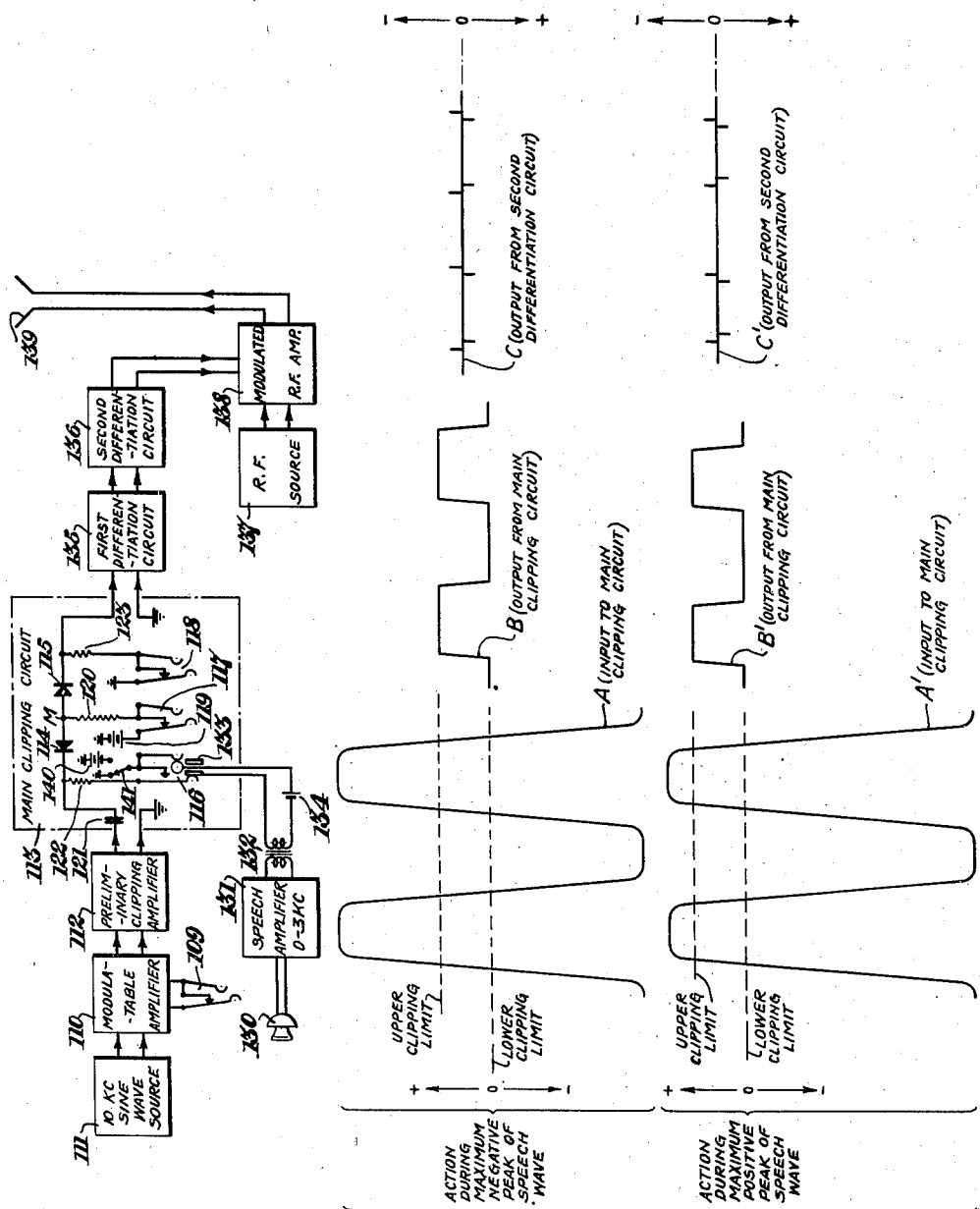


Fig. 6.

Fig. 7.

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MODULATION MEANS AND METHOD

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Fig:8.

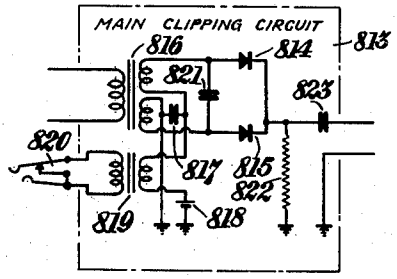


Fig:9.

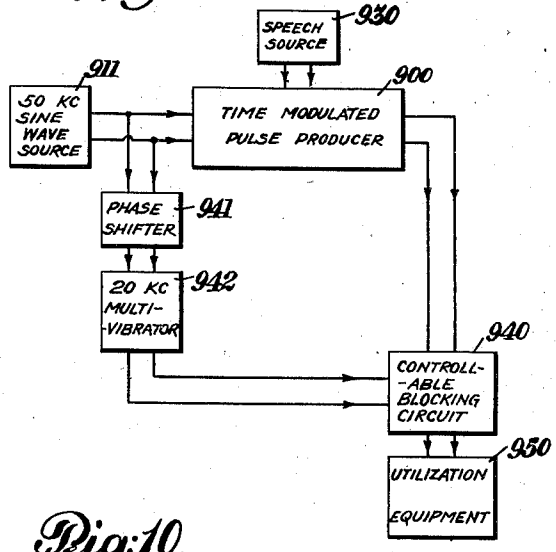
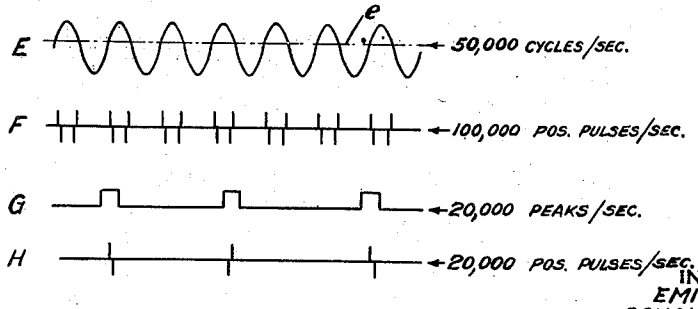


Fig:10.



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MODULATION MEANS AND METHOD

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Application August 24, 1942, Serial No. 455,899

16 Claims. (Cl. 179—171.5)

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The present invention relates to pulse generation systems and more particularly to systems for generating time modulated pulses for use in communication systems and for other uses.

Several types of systems have been proposed for effecting communication by transmitting a number of pulses of current, the exact times of transmission of such pulses being controlled in accordance with the speech or other intelligence to be transmitted. In some cases the pulses of current are themselves transmitted to a distance over wires, but in other cases they are used to modulate carriers so as to produce brief wave trains generally referred to as carrier pulses. Such systems of communication have been described in U. S. Patents 2,266,401, 2,256,336, 2,265,337, 2,262,838, and in copending U. S. applications 386,282 (now Patent No. 2,406,019, issued August 20, 1946) and 425,108, respectively filed on April 1, 1941, by E. Labin and on December 31, 1941, by E. M. Deloraine and E. Labin, as well as in a large number of other foreign patents and applications. In accordance with the systems heretofore proposed, the generation of time modulated pulses was effected either by means of special vacuum tubes having cam-like target or masking means cut to a predetermined shape, or by providing multivibrator arrangements controlled by resistance/condenser time constants and capable of being influenced by the modulating signals so as to vary the vibrator rate.

It is an object of the present invention to provide a simpler, more reliable, and more economical method of generating time modulated pulses.

More particularly, it is an object to provide a system for generating time modulated pulses by the use of ordinary types of circuit components without requiring specially designed tubes.

It is a further object to provide such a system for generating time modulated pulses which shall be capable of being stabilized by a master source of fixed waves, such as a sine wave oscillator or a stable unmodulated relaxation oscillator.

More particularly, it is an object to provide such a system wherein the time of the generated pulses is controlled by a fixed unmodulated wave.

Other objects of the invention will readily appear to those skilled in the art from the following detailed description of the invention, taken together with the annexed drawings, in which;

Fig. 1 is a schematic diagram of a time modulation transmitter embodying one form of our invention;

Figs. 2 and 3 are sets of curves used for explaining the operation of Fig. 1;

Fig. 4 is a schematic representation of an arrangement for producing triangular waves which may be substituted for a portion of the system of Fig. 1;

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Fig. 5 is a schematic representation of a clipping circuit which may be substituted for the clipping circuit shown in Fig. 1;

Fig. 6 is a schematic diagram of a time modulation transmitter embodying a modified form of our invention;

Fig. 7 is a set of curves used in explaining the operation of the system of Fig. 6;

Fig. 8 is a schematic represenation of a modified type of clipping circuit which may be substituted for the clipping shown in Fig. 1 or that of Fig. 6;

Fig. 9 is a schematic diagram of a modified form of system suitable for producing pulses with a very small degree of time modulation and particularly suitable for producing time modulated pulses to be received in accordance with the harmonic reception methods described in the abovementioned applications 386,282 and 425,108; and

Fig. 10 is a set of curves used in explaining the operation of the system of Fig. 9.

Referring more particularly to Fig. 1, 10 is a saw-tooth wave generator synchronized by a sine wave oscillator 11 and connected to deliver its saw-tooth output (preferably via a preliminary clipping amplifier 12) to the main clipping circuit 13.

As shown in Fig. 1, this main clipping circuit 13 comprises a conventional pentode 14 connected in the usual resistance-coupled fashion but preferably having a high resistance 15 in series with its control grid lead and having shorting-type jacks 16, 17 and 18 connected respectively in the control grid return lead, the suppressor return lead, and the screen grid return lead. Except for this high resistor 15 and the jack 16, the circuit connections of the pentode 14 are essentially conventional, comprising on the input side the usual input coupling condenser 19, and the usual grid bias resistor 20, the latter being connected through jack 16 to C battery 21. The output side of the circuit comprises the usual load resistor 22 connected to the usual plate supply battery 23, as well as a conventional output coupling condenser 24. The screen is biased positively by screen battery 25 in the usual manner.

In addition to the input applied from saw-tooth generator 10 via amplifier 12, an additional lower frequency modulating signal is applied to the circuit 13 through the jack 16. As illustrated in Fig. 1, the modulating input consists of speech from a telephone transmitter 30 which is applied via amplifier 31, transformer 32, and plug 33 to jack 16 of the main clipping circuit 13, being thus applied to the control grid of pentode 14 in series with battery 34.

The output from the main clipping circuit 13 is fed through a wave differentiation network 35 which may be of any known type and then through another similar differentiation network

36, which may also supply amplification if desired. The output from circuit 36 is then applied to modulate a radio frequency amplifier 38 which is excited from a suitable radio frequency source 37 so as to produce a train of carrier waves responsive to each modulating impulse received from the circuit 36. The output of amplifier 38 is then applied to antenna 39 for radiation to a distant point.

The operation can best be understood by consideration of the curves of Figs. 2 and 3 in connection with the circuit of Fig. 1. The saw-tooth generator 10 produces waves such as shown in curve U of Fig. 3. The preliminary clipping amplifier 12 then cuts off the bottom portions of these waves so as to pass only a wave such as shown in curve V of Fig. 3, commonly called a "blanked saw-tooth wave." Such wave V is then applied via coupling condenser 19 to the control grid of pentode 14, being thus superposed upon the speech voltage and the bias voltages from batteries 34 and 21.

It may be assumed, for convenience, that the voltage of battery 34 is just equal to the peak voltage of the loudest speech waves arriving over transformer 32. Thus the tip of plug 33 is positive with respect to the sleeve thereof at all times excepting on the extreme negative peaks of the speech waves. For convenience, it may be further assumed that the potential of battery 21 is polarized to bias the control grid positively instead of negatively and is sufficiently great that when this voltage is superposed upon the voltage of curve V, the most negative portion of the curve V extends only slightly below cut-off. If this be so, and if it be assumed that at the moment under consideration, the speech signal arriving from transformer 32 has its maximum negative value, then the resulting wave applied to the control grid of pentode 14 will be positioned as shown in curve W of Fig. 2 with its most negative portion only slightly below the cutoff threshold E_{co}. If the threshold of grid current E_{gc} is fairly close to the cutoff threshold E_{co}, the greater part of the voltage wave will lie above both these thresholds as shown in curve W in Fig. 2.

Considering now in greater detail the action of the pentode in response to the applied wave W shown in Fig. 2, it will be seen that when this wave starts upward from its lowest value below E_{co} there is at first no response until the wave passes above the threshold E_{co}. Then as the wave continues to rise from E_{co} toward E_{gc} an amplified voltage wave is produced in the output circuit of the pentode, the form of this voltage wave being shown in curve X of Fig. 2. (Actually this output voltage wave is of opposite sign from the input wave, but to facilitate comparison of the curves it is shown as if there were no reversal of sign.) When the input voltage wave W passes above the upper threshold of E_{gc}, the output voltage of the pentode abruptly ceases to vary, since the commencement of grid current flow imposes such a high load as to overload the driving stage and the coupling condenser 19. In addition, the flow grid current through resistance 15 gives rise to a voltage drop across this resistance which subtracts from the grid driving voltage thus further affecting the limiting action.

The output voltage wave X from the pentode 14 will therefore correspond exactly to those portions of curve W which lie between E_{co} and E_{gc} as can be plainly seen by comparing curves W and X in Fig. 2. To facilitate comparison of these and the other curves the curves X, Y, Z are all shown with polarity opposite to that of the curve W, as indicated by the designations "−0+" at the right of curve Z. Also, these three curves have their zero line offset with respect to the zero line of curve W to further facilitate comparison of curves W and X. In addition, it will be noted that the curves are drawn as if no amplification occurred in any of the stages, although it is clear that amplification will inherently occur in the clipper stage and may be included in other stages.

The output wave X is next differentiated in network 35 to yield a series of alternately positive and negative pulses as shown in curve Y of Fig. 2. The upward (i. e., negative) pulses corresponding to the inclined leading edges of the nearly square waves X, have a duration theoretically corresponding to the duration of these inclined rising edges of the wave X, while the downward pulses produced by the vertical trailing edges of the nearly square waves X have theoretically greater amplitude but zero duration.

The alternate positive and negative pulses from the first differentiation network 35 are then transmitted through the second similar network 36, a suitable amount of amplification being preferably included in one or both of these networks. The effect of the second differentiation is to produce an upward pulse of extreme narrowness for each vertical rise of current in curve Y and to produce a downward pulse of similar narrowness for each vertical falling portion of curve Y. Thus, each of the moderately narrow upward pulses of curve Y would be converted into a pair of pulses substantially offset with respect to one another, the first of these being an upward pulse, the second being a downward pulse, but each of the very narrow downward pulses of curve Y is converted into two pulses which are so nearly simultaneous that their offsetting is not readily apparent. All these pulses are clearly shown in curve Z of Fig. 2.

The output of the second differentiation network 36 is then applied to modulate the radio frequency amplifier 38, thus producing brief wave trains which are radiated from antenna 39. The modulated amplifier 38 is so arranged that normally no carrier is radiated therefrom and only positive modulation signals are effective to cause it to deliver carrier power to the antenna. Therefore, only the downward or positive pulses of curve Z are effective, the upward ones being in effect cut off by the inherent response characteristics of the amplifier 38.

It should be noted that the effective downward pulses of curve Z correspond to the downwardly concave corners *p*, *q*, *r*, etc., of curve X, while the upward pulses of curve Z correspond to the upwardly concave corners *x*, *y*, *z*, etc., of this curve. Thus, the timing of the effective or downward pulses of curve Z depends upon the time of intersection of the input wave W with the upper threshold E_{gc}. It should be understood, however, that if desired, one or the other of the differentiation networks 35 and 36 may be connected to effect a phase reversal; in which case the pulses effective in modulating the carrier would be those derived from corners *x*, *y*, *z*, of curve X and which depend for their timing upon the moments of intersection of curve W with the lower threshold E_{co}.

The above description of operation, as well as the associated curves W, X, Y, Z of Fig. 2 relate

to the operation during the intervals when the speech wave or other modulating signal has substantially its maximum negative value (so that the potential of the speech wave just offsets the potential of battery **34**, giving the tip of plug **33** a zero potential with respect to its sleeve). In contrast to the conditions occurring during such time it will be useful to consider the conditions occurring during the opposite extreme of the modulating signal (i. e., when the tip of plug **33** has its maximum positive potential with respect to the sleeve thereof). Operation during the latter condition is illustrated in curves W', X', Y', Z' in the lower part of Fig. 2, these curves being aligned with the corresponding curves W, X, Y, Z for ease in comparison.

The operation of generator **10** and preliminary clipping amplifier **12** is unchanged regardless of the potential of the modulating signal, and consequently the curves U and V apply just as before. Because of the positive potential of the plug tip with respect to its sleeve the control grid of pentode **14** is biased much less positively than before and therefore the applied blanked sawtooth waves W' are positioned lower with respect to the cutoff level E_{co}. In the case chosen for illustration it is assumed that the speech signal voltage added to the voltage of battery **34** gives a resultant negative bias large enough to overcome the positive bias of battery **21** and thus to bring the mean control grid potential below zero. Accordingly, curve W' is illustrated as lying predominantly below the threshold E_{co}. Actually, it is usually preferable to employ a smaller modulating signal so that the grid bias would become a little less positive and the curve W' would be positioned only a little lower than curve W.

The clipping action of the circuit **13** takes place essentially as before thus producing the wave X' in the same manner previously described for the wave X. Because of the different positioning of the curve W' with respect to the two thresholds E_{co} and E_{gc}, however, the generally rectangular prominences of wave X' are somewhat narrower than the corresponding ones of wave X. The differentiating network **35** produces curve Y' with alternate upward and downward impulses in the same manner as described for curve Y, but owing to the narrower prominences of curve X', the time interval between each upward impulse and the succeeding one is substantially smaller than for the curve Y. The second differentiation in network **36** converts each pulse of curve Y' into a pair of offset pulses of opposite polarity a pair of more or less perceptibly offset pulses of opposite polarity, the curve Z' being thus similar to curve Z except that two successive offset pulse pairs are spaced somewhat closer together.

The pulses from curve Z' are applied to modulate amplifier **38** and as previously described only the downward pulses are effective for this purpose. The short wave trains of carrier frequency radiating from antenna **39** therefore have their timing dependent only on the moments of intersection of curve W' of the upper theshold E_{gc}.

If it is desired to use the pulses for some other purpose than to modulate amplifier **38** (e. g., for direct transmission over the wire) a clipping or half wave rectifier circuit may be employed to select only the downward pulses of curve Z and Z' or only the upper pulses thereof as may be desired.

In the above described embodiment of the invention the pulses produced are time modulated in such fashion that each pair of useful (i. e., downward) pulses has one pulse fixed and one pulse which moves in time in accordance with the modulating signal. For many purposes it is desirable that the two pulses should both move in symmetric fashion, one being advanced by the same amount that the other is retarded. In order to achieve this result the wave form applied to the preliminary clipping amplifier **12** may be modified to some symmetric form. One suitable form for this purpose is a simple triangular zigzag which may be generated as shown in Fig. 4. Referring more particularly to the latter figure, **41** is a source of square waves. This source may be of any known type and may, for example, comprise a master sine wave oscillator, a multivibrator synchronized thereby for producing approximately square waves, and a clipping circuit for rendering the waves more perfectly square. The output of such square wave source **41** is applied to an integrating network **42** thus producing zigzag waves of symmetric triangular form. The wave generating arrangement of Fig. 4 may be substituted for elements **10** and **11** in Fig. 1, and in such case the output waves which would be obtained from the second differentiating circuit **36** would have essentially the same form as shown in curves Z and Z' except that two successive downward pulses would shift equally in opposite directions in response to variations of the modulating signal.

Instead of plugging the plug **33** into jack **16** as shown, this plug may be inserted either in the jack **17** or **18**. When inserted into either jack **17** or **18** only the cutoff threshold but not the grid current threshold will be influenced by the speech signals (assuming that the sawtooth form of Figs. 2 and 3 is employed). Therefore, the corners *x, y, z* of curve X will not vary with the speech wave and the spacing of these lower corners will be the same for X as for X'. The height of the trapezoidal waves X and X' will vary in accordance with the speech signals and the spacing between the upper corners will vary correspondingly. Thus, the corners *p, q, r* of curve X will differ from the corresponding corners of curve X' even through the lower corners of both these curves have the same spacing. Only the downward pulses of curve Z and Z' therefore will be useful in such systems for use as time modulated impulses.

Fig. 5 represents another form of clipping circuit which may be substituted for the clipping circuit **13** of Fig. 1. Instead of employing the two grid thresholds of one single tube for effecting the upper and lower clipping actions, the arrangement of Fig. 5 employs only the cut-off thresholds of two different tubes. Referring more particularly to this figure, the main clipping circuit designated generally as **13'** comprises two pentodes **14'** and **14''** connected in a conventional two-stage resistance coupled circuit, but having three jacks **16'**, **17'** and **16''** included in the control grid and suppressor grid return leads of the first pentode and in the control grid lead of the second pentode respectively. The elements **15'**, **19'**, **20'**, **21'**, **22'**, **23'**, **24'**, **25'** correspond exactly to the similarly numbered elements of previously described clipping circuit **13** while the elements **20''**, **21''**, **22''**, **23''**, **24''** and **25''** are corresponding circuit components for the second pentode **14''**. Since the grid current threshold E_{gc} is not intended to be used in connection with this type of clipping circuit the screen and plate biases

may be made of conventional value even if this makes the grid bias comparatively large. In selecting the biases, prime consideration should be given to sharpness of the cutoff.

If the input signal wave applied by condenser 19' to the input of pentode 14' is large it may happen that this input signal will sweep past not only the cutoff threshold E_{co} but also the grid current threshold E_{gc}. Such action, however, is not harmful provided that the grid current threshold is arranged at a point higher than the desired level of the upper threshold.

The operation of the clipping circuit is as follows: The input waves applied to the pentode 14' sweep from below to above the cutoff point and thus produce a response which is at first zero and then suddenly rises. Whether or not these waves later pass a comparatively remote grid current threshold is immaterial. The output waves which are, of course, of reversed polarity, are then applied to the second pentode 14' through the output coupling condenser 24' and there these waves are clipped by the cutoff threshold of the second tube 14''. Because of the inverted polarity of the waves this second clipping (although it removes the negative portions of the waves and passes only the positive portions) will have the effect of cutting off the tips, since the tips of the waves are now negative. Thus, the two successive clippings each of which cut off the negative portions of the waves, are equivalent to the double or gate clipping action previously described for circuit 13. The biases 21 and 21' can readily be adjusted to bring the effective clipping levels of the two tubes as close together as may be desired. This is one advantage of this type of circuit.

If the plug 33 is plugged to jack 16' the effect will be to displace both thresholds with respect to the input wave (or more accurately to displace the input wave with respect to both first thresholds). Such action is therefore exactly similar to the action of circuit 13 when the plug 33 is plugged into jack 16 thereof. If, however, the plug is inserted in jack 17' or jack 16'' of circuit 13' the modulating action is different. Modulation applied to jack 17' varies only the cut-off level of tube 14' while modulation applied to tube 16'' varies only the cut-off level of tube 14''. Each of these types of modulation, therefore, moves only one threshold of the double clipping circuit and care should be taken that the output pulse chosen for utilization has its time determined by the threshold which is thus moved.

Instead of employing sawtooth or triangular waves as the basis for derivation of the time modulated pulses it is possible to employ simple sine waves. The use of such sine waves results in a simple structure and tends to produce more stable time modulation. The use of such sine waves is therefore preferred in all cases where time modulation using small deviations is to be employed or, if larger deviations are employed, where the lack of absolute linearity between the modulating signal and the extent of deviation is not objectionable. A system employing sine waves as a basis for deriving time modulated pulses is illustrated in Fig. 6.

Referring more particularly to Fig. 6, 111 is a 10-kilocycle crystal controlled oscillator producing sine waves which are applied through amplifier 110 and preliminary clipping amplifier 112 to the main clipping circuit 113. This main clipping circuit may be of the type represented by 13 in Fig. 1 or of the type represented by 13' in Fig. 5. For the sake of generality, however, 113 is illustrated as being of a different type employing dry rectifiers instead of pentodes. The two dry rectifiers 114 and 115 are connected back to back and a small positive voltage is applied from battery 119 through resistor 120 to the intermediate point M between them. The resistor 120 is preferably at least several times larger than the low forward resistance of the rectifiers, although it should be low in comparison with the high "back" resistance thereof. The input wave from amplifier 112 is applied through coupling condenser 121 to resistor 122 which is preferably several times lower than resistor 120. The output of the circuit is delivered across another resistor 123 which may be of the same order of magnitude as resistor 122. It will be understood that if the following stage has a suitable value of input resistance resistor 123 may be omitted.

For modulating the clipping action, speed signals from telephone transmitter 130 are supplied over the speech amplifier 131 and transmitter 132 via the plug 133 to jack 116. The battery 134 is in series therewith and for convenience in description this battery may be assumed to have just sufficient potential so that at the maximum negative peaks of the speech wave the tip and sleeve of the plug 133 have the same potential, the tip being positive at all other times.

The output of main clipping circuit 113 is fed to the output portion of the equipment comprising elements 135, 136, 137, 138 and 139 which correspond to the similar numbered elements of Fig. 1.

The operation of the system shown in Fig. 6 can best be understood by consideration of this figure in conjunction with the curves of Fig. 7, since waves from source 111 pass through amplifier 110 and preliminary clipping amplifier 112 and are thus converted into the approximately trapezoidal form shown in curves A and A' of Fig. 7. In the curves of Fig. 7 it is assumed that the upper and lower quarter of the sine wave have been removed by the clipping amplifier 112 so that only the central half remains. Since it is not essential that the clipping action of amplifier 112 be a sharp clipping action giving perfectly square corners the curves A and A' of Fig. 7 have been shown with slightly rounded corners.

The curve A represents conditions when the speech input wave has its maximum negative value so that the total voltage produced by the speech wave and battery together is zero. At this time the main clipping circuit acts just as if the plug 133 were not plugged in. The input wave A is symmetrical with respect to the zero line as shown so that the potential at the left-hand side of the rectifier 114 varies equally above and below ground potential. Because of the rectifying action of element 114 the intermediate point M of the clipping circuit is unable to be raised above its natural or open circuit potential since it cannot receive current through rectifier 114. Thus, the potential of point M will follow the input potential only up to the point when the input potential equals the potential of battery 119. Any potential rise beyond this limit (represented in Fig. 7 by a dotted line marked "upper clipping limit") will not be transmitted to point M so that only those portions of curve A lying below such upper clipping limit will pass through to point M. In transmission from point M to the output of the main clipping circuit the rectifying action of element 115 similarly eliminates all

potential variations below ground potential, since the point M cannot draw current from the right-hand side of the circuit but can only deliver current thereto. As a result all portions of the curve below the lower clipping limit (i. e., below the zero line) will be blocked and not transmitted to resistor 123.

Therefore, the only parts of curve A which will be transmitted to resistor 123 will be those portions between the two dotted lines marked, respectively, "upper clipping limit" and "lower clipping limit" of Fig. 7. The resulting truncated trapezoidal waves are shown in curve B of Fig. 7. (Actually the corners of such waves will not be perfectly square, but since it is desirable to have the clipping as sharp as practicable the corners are shown in the ideal square form.)

As in the previously described system the clipped waves are next transmitted through the two differentiation networks 135 and 136 which produce an output proportionate to the second derivation of curve B. The output of the second derivative circuit 136 is shown in curve C.

The above description of the curves A, B and C relate to the action of the main clipping circuit 113 and the differentiation networks 135, 136 during a maximum negative speech wave peak. Corresponding operations during a maximum positive speech wave peak are illustrated in curves A', B' and C' and can readily be understood by comparison with curves A, B and C. During the positive speech wave peaks when the tip of plug 133 is positive with respect to the sleeve thereof, a negative bias is thereby applied through low resistor 122 to the leftside of rectifier 114 and thus the truncated sinusoidal input from amplifier 112 is superposed on this negative bias so as the resulting wave A' lies principally below zero potential, as shown in the lower portion of Fig. 7. Accordingly, the trapezoidal wave form B' produced by the clipping action is correspondingly narrow; and the corresponding pairs of pulses of C' are more unequally spaced.

The output from network 136, whether it has the form of curve C or curve C' or some intermediate form is then applied to amplifier 138 to modulate the latter. Only the downward pulses of curve C which represent positive polarity voltages will be effective to cause the radiation of carrier although, if desired, a phase reversal may be incorporated in one of the differentiation circuits to render only the other pulses effective.

If the plug 133 is inserted into jack 117 or jack 118, then instead of displacing both thresholds together with respect to the wave, the modulating signal applied to jack 117 will displace the upper and lower clipping limits in opposite directions while if applied to jack 118 it will displace only the lower clipping limit. Care should therefore be taken that the pulses of curves C and C' which are chosen for utilization should be dependent upon the clipping limit which is moved.

Still another form of clipping circuit is shown in Fig. 8. Referring more particularly to this figure 814 and 815 are a pair of rectifiers connected to the split secondary of transformer 816 so as to fully rectify any waves applied to this transformer. The split secondary of transformer 816 has its two halves joined by a condenser 817 whose impedance is preferably moderately low for the 10 kilocycle foundation wave while being substantial for the speech frequencies used for modulation. The lower half of this split secondary is directly grounded so as to apply a zero bias to rectifier 815 while the upper half of the split secondary of transformer 816 is positively biased by means of battery 818 connected through secondary of a speech input transformer 819. A jack 820 enables application of speech to the primary of transformer 819. Preferably, by condenser 821 connected across the secondary of transformer 816, it is more or less tuned to the 10 kilocycle frequency thus minimizing wave distortion and increasing amplitude. An output resistor 822 and an output coupling condenser 823 serve to couple the full wave output of the circuit with the succeeding stage.

The operation of this circuit is analyzed in considerable detail in our copending application, Serial No. 455,897, filed on even date herewith for "Push-pull modulation systems," now Patent No. 2,416,329, issued February 25, 1947. Briefly, the circuit serves to full wave rectify the 10 kilocycle sine applied thereto. During intervals when the speech arriving over transformer 819 just neutralizes the voltage of battery 818 the circuit acts as a perfectly paired full wave rectifier giving a series of half sine waves which meet at sharp cusps evenly spaced a half cycle apart. The opposite extreme speech voltage when the upper rectifier 814 is strictly positively biased, the rectifier is unbalanced and the full wave rectified output consists of a series of peaks of alternately large and small amplitude meeting each other in sharp cusps whose time spacing is alternately longer and shorter than half period.

It will be clear that when outputs containing such cusps are applied to the two differentiating networks 135 and 136 the output from the network 136 will have large voltage pulses corresponding to each sharp cusp and will have at all other times substantially small voltages since it is well known that the second derivative of a curve is proportional to the sharpness of the curve at any point thereof. In case triangular waves such as those of Fig. 4 are used as the input in the system of Fig. 1 while the clipping circuit of Fig. 8 is used in place of 13 thereof, it may then occur that the similarity of curvature at the peaks of these triangular waves to the cusps produced by rectification will be of the same magnitude. In spite of such similarity of magnitudes, however, the pulses corresponding to the peaks can be readily distinguished from its corresponding cusps since they will be of opposite polarity.

Although clipping circuit 113 has been shown in connection with the system in Fig. 6, it will be understood that any one of the three clipping circuits 13, 13' or 113 may be used in either the system of Fig. 6 or that of Fig. 1 (or in the system of Fig. 1 as modified by replacing 10 and 11 with the circuit of Fig. 4). It should also be understood that each of these circuits may be further replaced by its equivalents, for example, by substituting electronic diode rectifiers for the dry rectifiers 114 and 115 in circuit 113, or by substituting triodes for the pentodes in circuits 13 and 13'. In fact, the system at present believed preferable corresponds to Fig. 6 with electronic diodes substituted for the dry rectifiers illustrated.

It should also be understood that only one threshold is essential in circuits 13, 13' and 113, since the threshold which determines the timing of the unused pulses may, if desired, be omitted. Thus E_{cc} plays no essential part in circuit 13 when used in Fig. 1; and therefore the system will still operate if the biases are shifted so that

the applied wave never falls below this threshold. Similarly, rectifier 114 and battery 119 are unessential and may be omitted from circuit 113 in Fig. 6. If there is a polarity reversal in one of the differentiating circuits so that the opposite pulses are used the converse will be true, threshold E_{gc} or rectifier 115 being unessential. Similarly in circuit 13' of Fig. 5 either tube 14' or tube 14'' may be adjusted to act as a simple amplifier without clipping depending upon which set of pulses from the subsequent differentiation circuits is to be utilized. In Fig. 8, however, both rectifiers play a useful part.

Although displacement of the critical threshold (i. e., the threshold whose intersections determine the timing of the pulses ultimately to be used) with respect to the foundation waves is preferably effected by applying the modulating signal to one of the jacks 116, 117 or 118 of Fig. 6 a similar effective displacement of such critical threshold with respect to the foundation waves may be achieved by plugging into jack 109. When the modulating signal is applied to jack 109 so as to modulate the amplitude of the foundation waves the time displacement of pulses may be effected in one of two ways depending on the initial displacement of the critical thresholds with respect to the center line of the foundation wave. If, for example, the critical thresholds are placed symmetrically above and below the center line of the foundation wave, variation of the amplitude of the foundation wave will produce at the output of the clipping circuits a rectangular wave of constant width but with sides whose slopes vary with the amplitude modulation. Double differentiation of this wave will produce time modulated pulses similar to the pulses described previously.

On the other hand if the critical threshold is offset with respect to the center line, it is clear that the absolute number of volts of offsetting of the critical threshold with respect to the center line of the foundation wave will remain constant and therefore as the foundation wave doubles in amplitude the threshold which was initially offset half-way between the center line and the fixed line will only be offset one-quarter of the way from the center line to the peaks. Thus, if the position of the threshold is measured not in terms of absolute volts, but in terms of the foundation wave which it intersects it is clear that the amplitude modulation of the foundation wave will, in the presence of a substantial initial offset, produce a substantial variation in the relative position of the critical threshold with respect to the foundation wave.

Fig. 9 represents a modified time-modulation system which is arranged to generate M times as many pulses as are required and then to block off all but the desired ones thereof. The actual pulse producing element of the system of Fig. 9 may be of any desired type. For convenience it may be assumed that the circuit of Fig. 6 is used.

Referring more particularly to Fig. 9, the sine wave source 911 is of a frequency 5 times higher than the corresponding sources 11 or 111 in Figs. 1 and 6. This sine wave source delivers its 50 kc. waves to the time modulated pulse producer 900 which may, for convenience, be assumed to comprise elementary circuits 110, 112, 113, 135 and 136 from Fig. 6. The speech source 930 which supplies the modulating signals to pulse producer 900 may be assumed to include elements corresponding to 130, 131, 132, 134 and 133 of Fig. 6.

The pulses produced in the circuit arrangement 900 are then delivered to a controllable blocking circuit 940 which serves, as hereinafter explained, to block the transmission of certain ones of the pulses. For controlling this blocking action, a portion of the 50 kc. sine wave energy from source 911 is led off through phase shifter 941 to a multivibrator 942. This multivibrator may be of any suitable type capable of operating at a subharmonic of twice the frequency of a syncronizing input. The multivibrator 942 should be adjusted to operate at 20 kc., being synchronized with every fifth half cycle of the sine waves applied over phase shifter 941 (if necessary a full wave rectifier may be interposed between the source and the multivibrator to facilitate synchronization in this manner). This multivibrator should be adjusted so that the positive portions of its generally square wave output are of considerably shorter duration than the negative portions thereof, the output from such multivibrator being then generally of the form shown in curve G of Fig. 10. The output from the multivibrator 942 is applied to control the blocking of circuit 940, thus determining which of the pulses from circuit 900 will be blocked and which will be passed. The output from the circuit 940 is applied to any suitable utilization equipment 950. Preferably, this equipment 950 comprises elements corresponding to 137, 138, 139 of Fig. 6.

The operation of the system of Fig. 9 can best be understood in conjunction with the curves of Fig. 10. The 50 kc. sine waves from 911 are represented by curve E and serve to actuate the pulse producer 900 in the same way as described in connection with Fig. 6.

As was explained in connection with Fig. 6, the time position of the upper (or positive) ones of the pulses delivered (from 136) depends upon the level of the upper clipping limit with respect to the foundation wave, being thus determined by the potential of battery 119 and jack 117 (see Fig. 6), as well as by the D. C. potential superposed upon the foundation wave through switch 141 and jack 116 (see Fig. 6). The dotted line *e* extending across curve E represents schematically the relative position of the effective upper threshold with respect to the foundation wave. The upper pulses of curve F, therefore, correspond to the intersections of this line *e*, with the curve E. In order to render ineffective all but certain ones of the pulses of curve F, the output wave G from the multivibrator 942 is applied to control the blocking circuit 940. During the brief positive intervals of curve G, the circuit 940 is unblocked so that any input applied thereto can pass through to utilization equipment 950. During all the rest of the time the blocking circuit 940 is blocked so as to be incapable of transmitting any wave form applied to its input. Accordingly, of all of the pulses from curve F, only those shown in curve H are transmitted to the utilization equipment. As in the case of Fig. 6, it is assumed that the utilization equipment responds only to the upwardly directed pulses of curve H, the downwardly directed pulses thereof being effectively blocked by the inherent action of the utilization equipment. It will be understood, however, that the waves may be reversed so as to employ the other pulses if this is preferred.

As can be clearly seen from a comparison of curves F and G of Fig. 10, only every fifth one of the upper pulses of curve F is transmitted. In

view, however, of the fact that the sine wave source **911** is at 5 times the frequency shown for use in the system of Fig. 6, the total number of upward pulses according to curve H will be the same as in the output of the system of Fig. 6. The amount of deviation of any one pulse from its mean position will be less for a given modulated signal voltage, since a given displacement of threshold *e* with respect to curve E will produce only one fifth as much time displacement at the intersection points as will be produced by the same displacement of a corresponding threshold across the sine wave of one fifth the frequency.

It will be understood that the factor of multiplication may be any desired number although preferably an odd number is employed. Thus, instead of 5 one could take 3, 7, 9, 11, 13, etc., as factor. If the factor be generally designed as M, the sine wave source **911** should have a frequency

$$\frac{M}{2}$$

times as great as the frequency of recurrence of the pulses desired. In the case above described, it was assumed that a pulse recurrence frequency of 20,000 pulses per second was desirable, since this was the recurrence frequency normally produced by the arrangement of Fig. 6 which had been previously considered. In order to attain the desired 20 kc. pulse recurrence frequency, the sine wave source **911** was set to have a frequency equal to

$$\frac{5}{2}\times 20 \text{ kc.}$$

the factor M being, therefore, 5. The resultant curve F, contained 100,000 upward pulses per second and 100,000 downward pulses per second. By means of the curve G which passed every fifth one of the upward pulses (as well as every fifth one of the downward pulses), the number of upward pulses was reduced from 100,000 per second to 20,000 per second, i. e., the desired number. The downward pulses of Fig. 10 could have been suppressed before transmission through circuit **940**, but in the case chosen for illustration, it was assumed that this was unnecessary since it was assumed that the utilization equipment would respond only to the upward pulses of curve H.

Although for convenience, the system of Fig. 9 has been described upon the assumption that the equipment **900** comprised pulse producing portions from Fig. 6, it will be clear that such apparatus **900** might equally well incorporate the corresponding portions of Fig. 1. Similarly, also, the modified systems obtained by substituting in Fig. 1 or Fig. 6 any one of the clipping circuits **13**, **13'**, **113** or the circuit of Fig. 8 might be used for the pulse producer **900**.

The system of Fig. 9 is further applicable to other types of systems described in our copending application, filed by us of even date for "Modulation system." Such system is very similar to that of Fig. 1 or 6 of the present invention except that elements such as **36** or **136** of the present application are replaced by full wave rectifier and limiter equipment thus eliminating the second differentiation step described in the present application. At the same time that this is done, the upper and lower clipping limits of the clipping circuits employed are brought as close together as conveniently possible so that the interval of time required for the passage of the foundation wave from the lower to the upper limit is only a small fraction of a cycle. By such an arrangement the pulses produced by a single differentiation are rendered sufficiently narrow and are used after full wave rectification for application to the desired utilization circuit. In incorporating such a system in the system of Fig. 9, all parts of the system between the master oscillator and the utilization circuit (i. e., the narrow two-level clipping circuit followed by a single differentiation network and then by a rectifying limiting network and preceded by the required amplifiers and preferably by preliminary clipping amplifier) would be incorporated in the time modulation arrangement **900** of Fig. 9.

Another type of system described in our copending application entitled "Push-pull modulation system" (filed of even date herewith) is suitable for use in the system of Fig. 9. According to such a modulating arrangement a clipping circuit similar to that shown in Fig. 8 has its output phase inverted and applied to a detector of the grid leak type having a narrow grid base. Because of the inherent bias adjusting action of the grid leak, the applied cusped wave derived from the clipping circuit of Fig. 8 is automatically alined so that only the most positive tips of the cusps exceed the grid current threshold. Because of the narrow grid base, only the portions adjacent these tips lie above the current threshold and are transmitted. Such an arrangement which skims the cusps may be used to serve the purpose, which in the present invention is served by two differentiating circuits following the clipping circuit. In incorporating such a modified pulse producer in the system of Fig. 9, the apparatus **900** would be assumed to include any desired amount of pre-amplification, then a clipping circuit according to Fig. 8 followed by a cusp skimming arrangement, as just described.

Although certain embodiments of our invention have been shown and described for purposes of illustration, it will be clear that many modifications, additions and omissions may be made within the scope and spirit thereof, as defined in the appended claims.

What is claimed is:

1. A time modulation system comprising a source of foundation waves having a frequency

$$\frac{M}{2}$$

times the desired pulse recurrence frequency—where M is an integer greater than 2, means for producing a pulse in response to each passage of said foundation wave through a predetermined amplitude level, a blocking circuit, means for deriving from said source a control wave, means for applying said produced pulses to said blocking circuit, and means for applying said control wave to said circuit for passing only every Mth one of said produced pulses.

2. A time modulation system comprising a source of foundation waves having a frequency

$$\frac{M}{2}$$

times the desired pulse recurrence frequency—where M is an odd integer greater than 2, means for producing a pulse in response to each passage of said foundation wave through a predetermined amplitude level, a blocking circuit, means for deriving from said source a control wave, means for applying said produced pulses to said blocking circuit, and means for applying

said control wave to said circuit for passing only every Mth one of said produced pulses.

3. A time modulation system comprising transmitting means having a pair of rectifiers connected in circuit in back-to-back relation, an input connection to the first of said rectifiers, an output connection for the second of said rectifiers, means to apply a foundation wave of a given frequency to said input connection, first control means for determining the potential of said input connection relative to the axis potential of said wave, second control means for determining the potential of the circuit connection between the two rectifiers, third control means for determining the load impedance at said output connection, a source of signal energy, whereby gate limits are produced by the mutual action of said control means, and means to apply signal energy from said source to one of said control means to effect variations in the relative relation of the potential of the axis of said foundation wave and at least one of said gate limits.

4. The system defined in claim 3 wherein the means for applying signal energy to one of said control means includes means for applying the signal energy to said first control means, whereby the axis of said foundation wave is varied according to the signal energy relative to given gate limit potentials.

5. The system defined in claim 3 wherein the means for applying signal energy to one of said control means includes means for applying the signal energy to said second control means, whereby said variation of said one gate limit includes variation of the other of said gate limits in the opposite direction to the variation of said one gate limit.

6. The system defined in claim 3 wherein the means for applying signal energy to one of said control means includes means for applying the signal energy to said third control means, whereby said one gate limit is the lower gate limit.

7. A time modulation system comprising a source of foundation wave of fixed frequency having a relatively fixed reference axis of amplitude, transmitting means having a variable threshold and connected to transmit portions of said wave which lie in a given region determined by said threshold, whereby the transmitted wave has discontinuities corresponding to the instants at which said foundation wave is at the same amplitude level as said threshold, a source of signal wave, means for varying the amplitude level of said threshold under control of said signal wave, while maintaining said reference axis of said foundation wave at said fixed amplitude whereby said instants are displaced in time, and means for twice differentiating said transmitted wave to derive pulses corresponding to said instants.

8. A system according to claim 7 wherein said foundation wave is of fixed amplitude and said means for varying the amplitude level of said threshold with respect to said foundation wave comprises means for varying the absolute amplitude between said threshold and said fixed reference axis of said foundation wave.

9. A system according to claim 7 wherein said means for varying the amplitude level of said threshold with respect to said foundation wave comprises means for biasing the threshold by a fixed amount with respect to said fixed reference axis of said foundation wave and means for varying the amplitude of said foundation waves whereby said fixed bias represents a relatively variable amplitude level with respect to said fixed reference axis of said foundation wave.

10. A time modulation system comprising a source of foundation waves of fixed frequency having a relatively fixed reference axis of amplitude, transmitting means having an input connection to which a wave of said source is applied and gate limits for limiting the passage of energy dependent on relative amplitude levels of upper and lower limits of said gate to said fixed reference axis of said foundation wave, first control means for determining the amplitude of said input connection thereby controlling said reference axis of amplitude of said wave relative to given amplitude limits for said gate, second control means for determining the amplitude of the upper limit of said gate, third control means for determining the amplitude of the lower limit of said gate, a source of signal energy, means for applying said signal energy to one of said control means to effect variations in the relative amplitude between said reference axis of said foundation wave and at least one of said gate limits while maintaining said reference axis at its fixed value, whereby the output wave of said transmitting means has discontinuities corresponding to the instants at which said foundation wave is at the same amplitude level as said one gate limit, and double differentiation means for producing from said output wave pulses displaced time according to the occurrence of said instants.

11. A time modulation system comprising a source of foundation waves of fixed frequency having a relatively fixed reference axis of amplitude, transmitting means having an input connection to which a wave from said source is applied and gate limits for limiting the passage of energy dependent upon the relative amplitude levels of upper and lower limits of said gate with respect to said reference axis of said foundation wave, means for determining the amplitude of said input connection thereby controlling said reference axis of said wave relative to given amplitude limits for said gate, control means for determining the amplitude of the upper limit of said gate, control means for determining the amplitude of the lower limit of said gate, a source of signal energy, means for applying said signal energy to one of said control means to affect variations in the relative amplitude between said reference axis of said foundation wave and at least one of said gate limits while maintaining said reference axis of said foundation wave at its relatively fixed value with respect to said signal wave, whereby the output wave of said transmitting means has discontinuities corresponding to the instants at which said foundation wave is at the same amplitude as said one gate limit, and means for producing from said output wave pulses displaced in time according to the occurrence of said instants.

12. A time modulation system comprising a source of foundation waves of fixed frequency having a relatively fixed reference axis of amplitude, transmitting means having an input connection to which a wave from said source is applied and gate limits for limiting the passage of energy depending upon the relative amplitude level of upper and lower limits of said gate with respect to said reference axis of said foundation wave, means for determining the amplitude of said input connection thereby controlling the reference axis of said wave relative to given amplitude limits for said gate, control means for de-

termining the amplitude of the upper limit of said gate, control means for determining the amplitude of the lower limit of said gate, a source of signal energy, means for applying said signal energy to the first mentioned control means to effect variations in the relative amplitude between said reference axis of said foundation wave and said upper gate limit while maintaining said reference axis at its relatively fixed value with respect to said signal wave whereby the output wave of said transmitting means has discontinuities corresponding to the instants at which said foundation wave is at the same amplitude as said one gate limit, and means for producing from said output wave pulses displaced in time according to the occurrence of said instants.

13. A time moduatlon system comprising a source of foundation waves of fixed frequency having a relatively fixed reference axis of amplitude, transmitting means having an input connection to which a wave from said source is applied and gate limits for limiting the passage of energy dependent upon the relative amplitude levels of upper and lower limits of said gate with respect to said reference axis of said foundation wave, means for determining the amplitude of said input connection thereby controlling the reference axis of said wave relative to given amplitude limits for said gate, control means for determining the amplitude of the upper limit of said gate, control means for determining the amplitude of the lower limit of said gate, and a source of signal energy, means for applying said signal energy to the second mentioned control means to affect variations in the relative amplitude between said reference axis of said foundation wave and said lower gate limit while maintaining said reference axis of said foundation wave at its relatively fixed value with respect to said signal wave, whereby the output wave of said transmitting means has discontinuities corresponding to the instants at which said foundation wave is at the same amplitude as said one gate limit, and means for producing from the output waves pulses displaced in time according to the current at said instants.

14. A time modulation system comprising a source of foundation waves with fixed frequency having a relatively fixed reference axis of amplitude, transmitting means having a connection to which a wave of said source is applied and gate limits for limiting the passage of energy depending upon the relative amplitude level of upper and lower limits of said gate with respect to said reference axis of said foundation wave, means for determining said reference axis to said foundation wave, means for determining the amplitude of said input connection thereby controlling said reference axis of said wave relative to given amplitude limits for said gate, control means for determining the displacement between upper and lower limits of said gate, a source of signal energy, means for applying said signal energy to said control means to effect variations in the absolute amplitude between said gate limits while maintaining said reference axis of said foundation wave at its relatively fixed value with respect to said signal wave, whereby the output wave of said transmitting means has discontinuities corresponding to the instants at which said foundation wave is at the same amplitude as said gate limits and means for producing from said output wave pulses displaced in time according to the occurrence of said instants.

15. A time modulation system comprising a source of foundation waves having a frequency

$$\frac{M}{2}$$

times the desired pulse recurrence frequency—where M is an odd integer greater than 2, means for producing a pulse in response to each passage of said foundation wave through a predetermined amplitude level, and means for passing only every Mth one of said produced pulses, said means for producing a pulse in response to each passage of said foundation wave through a predetermined amplitude level comprising non-linear transmitting means having a discontinuity threshold and connected to transmit all portions of said waves which lie on a given side of said threshold, whereby the transmitted waves have corners corresponding to the instants of intersection of said foundation waves with said threshold, a source of signal waves, means for varying the position of said threshold with respect to said foundation waves under control of said signal waves, whereby said instants of intersection are displaced in time, and means for doubly differentiating said transmitted waves to derive pulses corresponding to said corners.

16. A method for decreasing the time displacement for a signal modulated pulse on a time modulated pulse wave comprising generating a foundation wave having a frequency greater than that of the desired pulse recurrence frequency, deriving pulses from said wave, modulating said pulses with said signal to produce time modulated pulses at said greater frequency, and eliminating sufficient of said pulses to obtain a time modulated pulse wave having said desired pulse recurrence frequency.

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