July 6, 1948. D. D. GRIEG 2,444,437

MODULATING SYSTEM

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Fig. 1.

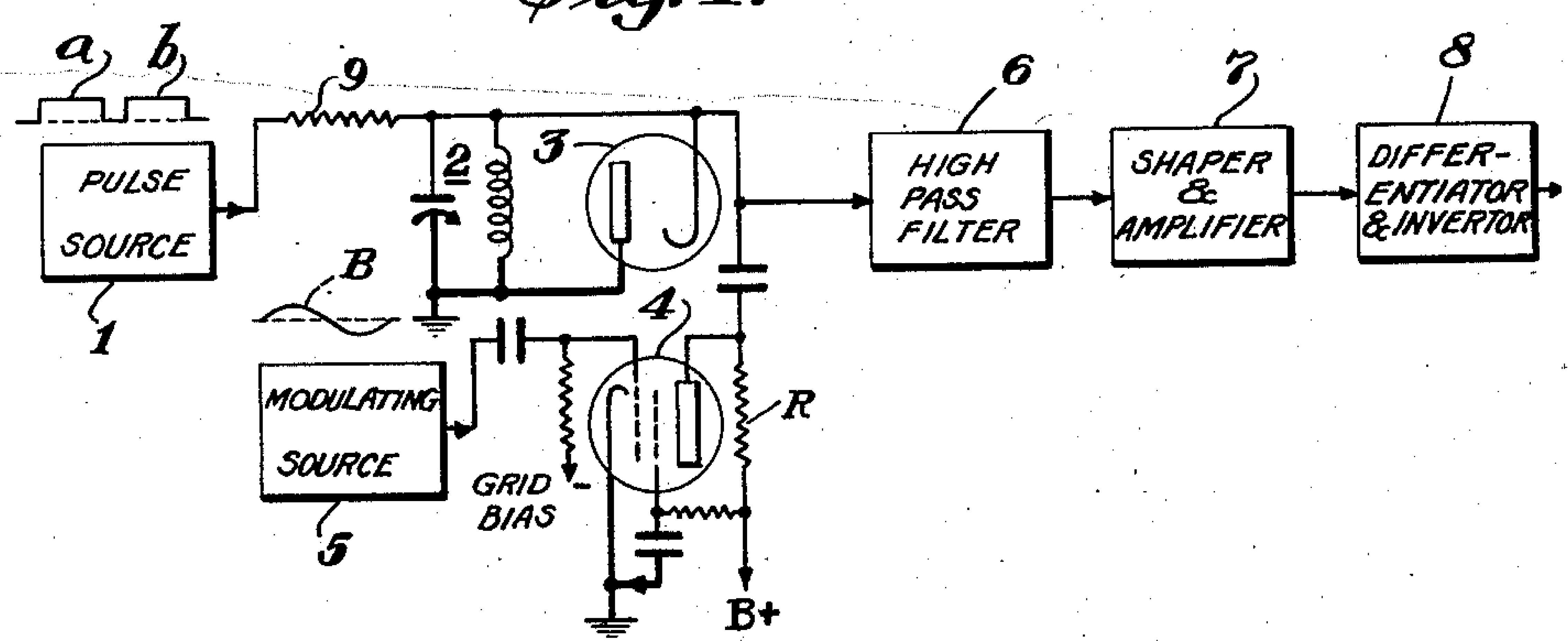

Fig. 2.

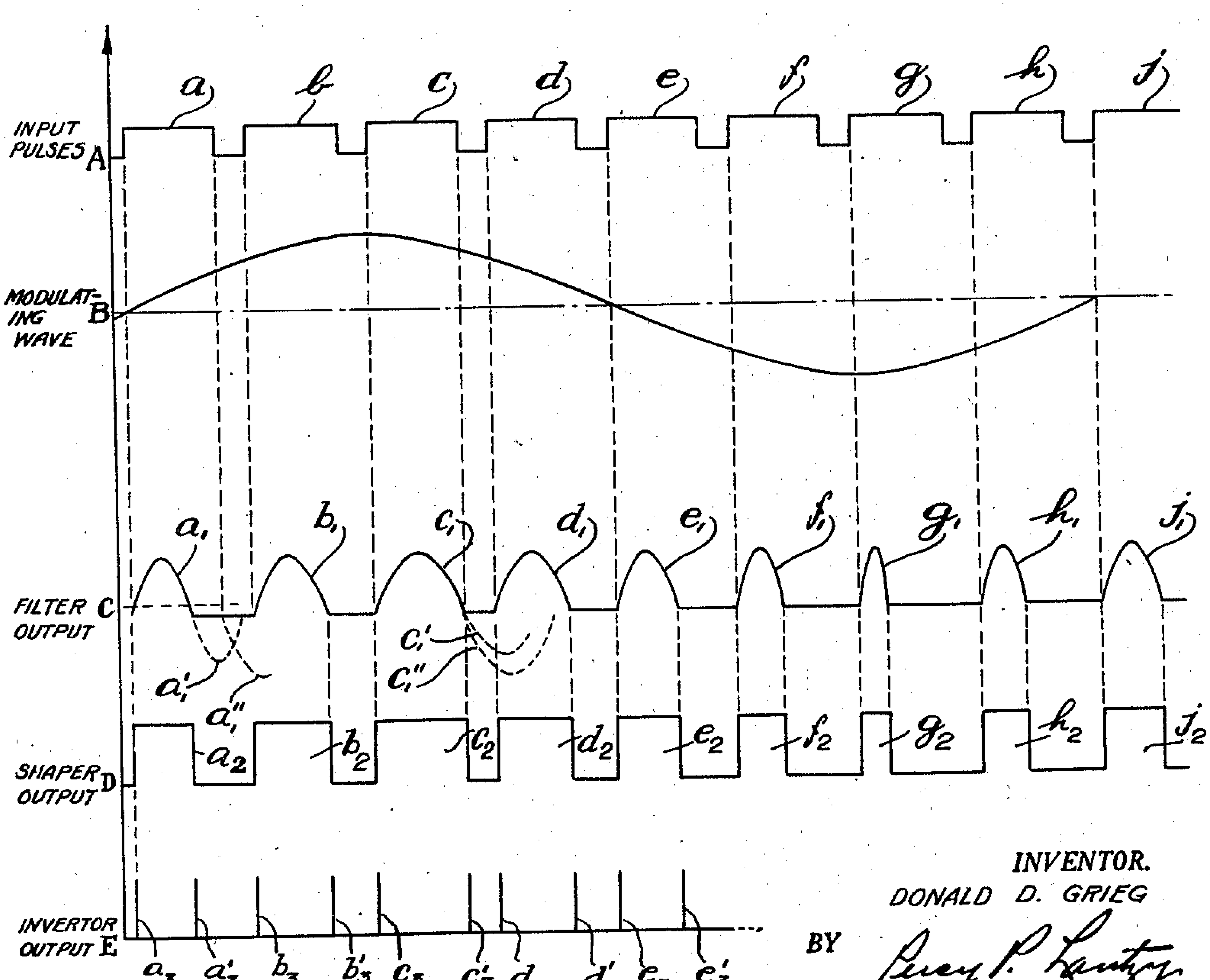

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Fig. 3.

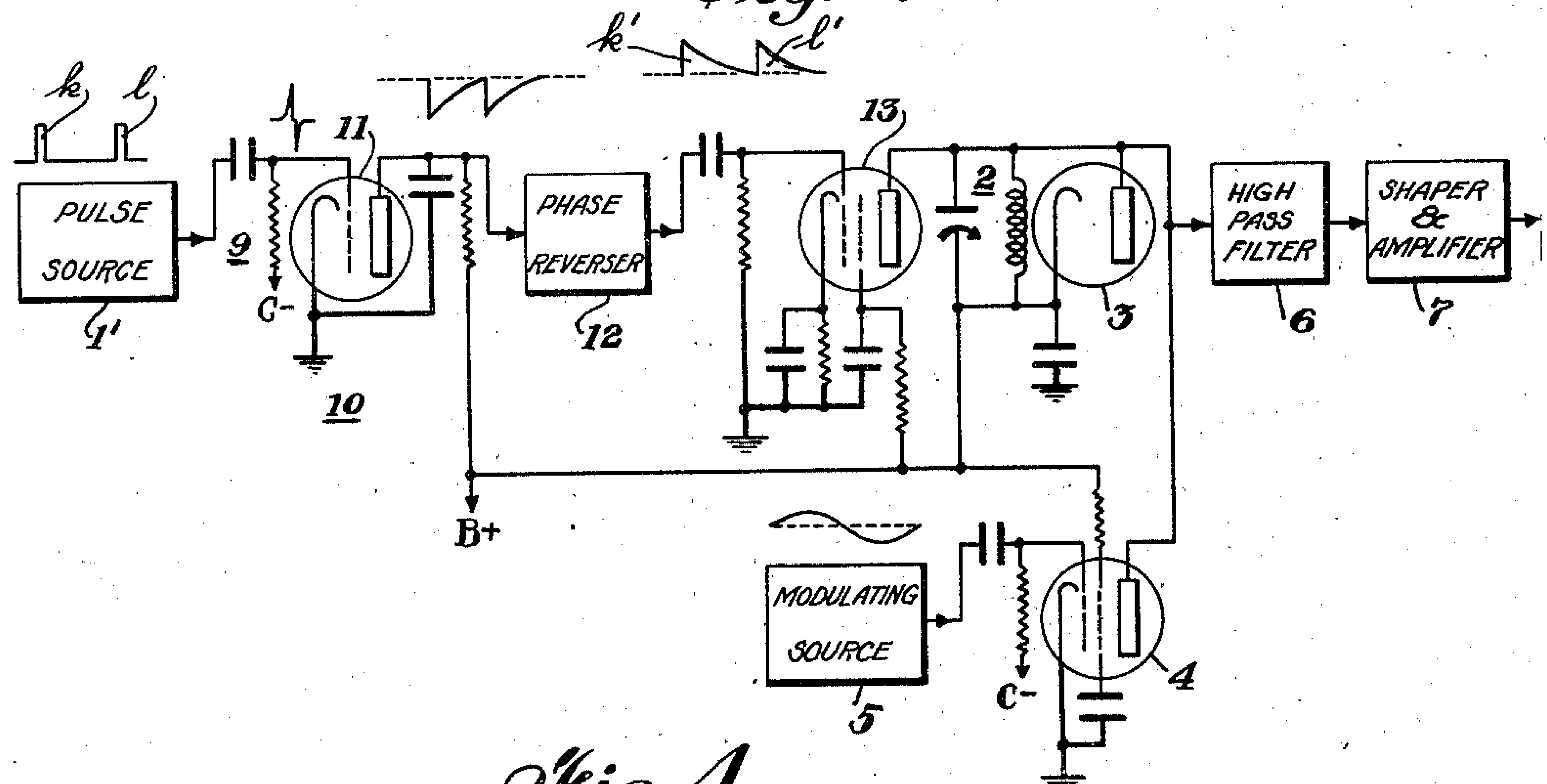
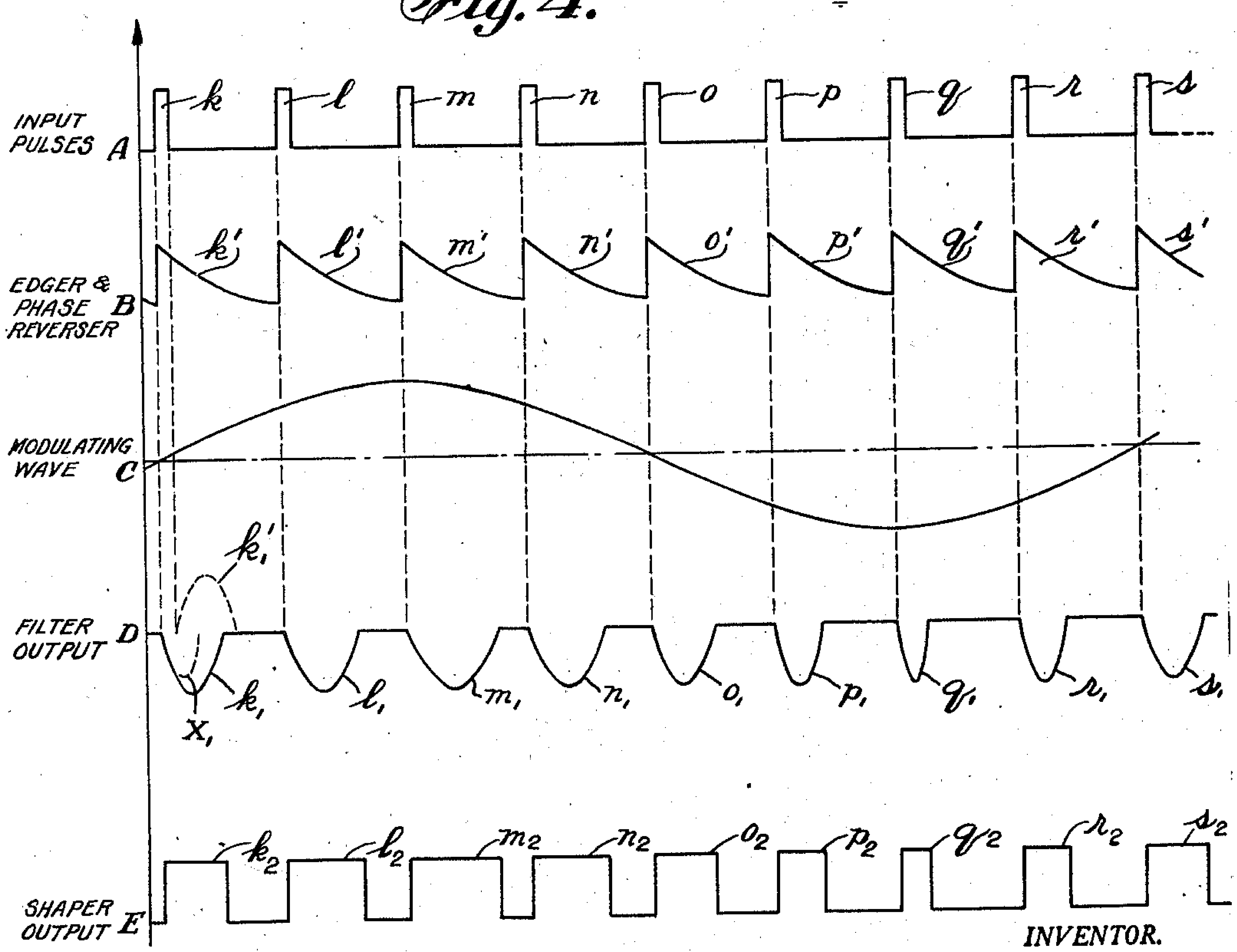


Fig. 4.



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MODULATING SYSTEM

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20 Claims. (Cl. 179—171.5)

This invention relates to improvements in modulating systems, and more particularly to novel methods and means for width-modulating pulses in accordance with intelligence-signifying signals, and is a continuation-in-part of my co-pending application Serial No. 511,406, filed November 23, 1943.

An object of the present invention is to provide a novel method and means for width modulating a series of normally equal-width pulses for transmitting intelligence.

Another object of this invention is to provide a pulse-width modulating system of improved dynamic range and minimum variation in average power.

Another object of this invention is to derive from a pulse shock-excited circuit, a series of variable width pulses modulated in accordance with predetermined intelligence to be transmitted.

These and other objects, capabilities and advantages of the invention will appear from the subjoined detail description of one embodiment and a modification thereof, illustrated in the accompanying drawings, in which:

Fig. 1 is a circuit diagram, partially in block form, of a preferred form of pulse-width modulating system in accordance with the present invention;

Fig. 2 is a diagram illustrating by way of example the time relation between a series of unmodulated pulses, a modulating wave and the resultant width-modulated pulses according to the system illustrated in Fig. 1;

Fig. 3 is a circuit diagram, partially in block form of a modified form of pulse-width modulating circuit;

Fig. 4 is a diagram similar to Fig. 2, illustrating the mode of operation of the system shown in Fig. 3.

The form of my invention shown in Fig. 1 includes a voltage source 1 of any known type which has a relatively abrupt potential change characteristic. A suitable form illustrated is one which produces substantially rectangular pulses such as a, b. This series of pulses is applied to a resonant circuit 2 across which is connected a rectifier 3 whose purpose is to limit the undulations resulting from shock excitation of the circuit 2 to the first, primary undulation of one polarity. Also in effective shunt with the resonant circuit 2 is connected a reactance circuit including tube 4 whose control grid, in turn, is energized by a modulating voltage source 5. As is well known in the art, the tube 4 presents an

additional impedance across the tuned circuit 2 whose value, if varied, will change the tuning of the circuit 2 within certain predetermined limits. In this embodiment, the tube 4 provides a resistance varying in step with the modulating signal across the tuned circuit which serves to vary the resonant frequency thereof by well known laws. Since the tube 4 is parallel to the resistor R with respect to the tuned circuit 2, there will exist a modulation component across resistor R. The resistance R is selected high relative to the resistance of the tube 4. By passing the output from the tuned circuit 2 through a high-pass filter 6, the low modulating frequency components produced across resistor R are removed. The output of filter 6 is passed through a suitable shaper and amplifier 7 for the purpose of re-shaping the pulses into the rectangular pulses, which, if desired, may be further shaped by differentiation and inversion at 8 into narrow pulses corresponding in time to the leading and trailing edges thereof.

In Fig. 2, curve A represents a series of equally spaced, equal-width rectangular pulses a to j inclusive, produced by the pulse source 1 and applied to the resonant circuit 2. The pulses of source 1 however, may be of various shapes so long as they present one edge, either leading or trailing, that follows a given timing as will be further explained hereinafter. This circuit 2 will have a normal resonance frequency which will be varied by the operation of the tube 4 in accordance with some modulating source indicated by way of example by the voltage wave B. If it is assumed that the normal resonance frequency of the tuned circuit 2 occurs at maximum negative modulating voltage, the resonant frequency will then vary between limits as determined by the maximum positive and negative points on the modulating voltage curve.

The series of waves indicated at C, Fig. 2, illustrates the first undulations which appear from the output of the resonant circuit 2 upon shock excitation of the latter from the series of applied pulses a to j. It will be noted, for example, that the resulting pulses a_1, e_1, and j_1 will all be of equal width since these pulses represent the first undulations of the shock-excited circuit which take place when the modulating voltage controlling the tube 4 is at zero value. As the modulating voltage increases, however, the tuning of the shock-excited circuit 2 varies so that the first undulations produced will be of slightly greater width, for example, pulse b_1 is wider than a_1, while c_1 occurring at the peak positive value of the modulating voltage wave is the widest modulation produced. Conversely, as the modulating voltage decreases, the pulses decrease in width, for example, d_1 will be of the same width as b_1, and as the modulating voltage curve changes to an increasing negative value the pulses become increasingly narrower so that f_1 is narrower than e_1, and g_1 at the maximum negative value is the narrowest pulse of all. As the modulating voltage curve rises, the pulses again increase in width as indicated by undulations h_1 and j_1. The undulations a_1 to j_1, after passing through the shaper and amplifier 7, may be reshaped, if desired, into rectangular pulses a_2 to j_2 inclusive, of the same spacing as the original pulses a to j respectively, but of varying width depending upon the modulating voltage applied from the source 5 upon the reactance tube 4. These final modulating rectangular pulses may, if desired, and as previously explained, be differentiated into narrow pulses a_3, a'_3, etc., corresponding to the respective leading and trailing edges.

It should be noted here that in order to obtain the shock voltage undulations across the tuned circuit as previously described it is necessary to insure that a pulse of current similar to waves A and B, passes through the tuned circuit. This is accomplished by means of the high series resistance 9 of Fig. 1.

The rectifier tube 3 eliminates the negative undulations corresponding to the positive undulations so that only the desired positive pulses are obtained. For example, the rectifier will eliminate undulation a'_1 following undulation a_1 and negative undulation c'_1 which would ordinarily follow undulation c_1. The rectifier 3 also eliminates the negative undulation which would be caused by the trailing edge of the original rectangular pulses, for example, the negative undulation a''_1 which would otherwise result from the trailing edge of pulse A and the negative undulation c''_1 which would otherwise result from the trailing edge of the pulse c, and which in this case would start simultaneously with the negative modulation c'_1 following the positive undulation c_1.

It will thus be seen that I have provided a simple pulse-width modulating system producing, either for direct transmission purposes or for an RF carrier modulating potential, pulses which will be of substantially equal amplitude and which are modulated in width according to intelligence or other signalling modulating source.

In the event that the original rectangular pulses are relative narrow, thereby preventing the production of pulses of greater width, I have incorporated in Fig. 3 a so-called "edger" circuit disclosed in my copending application above-referred to. For example, in Fig. 3 I have disclosed a pulse source 1' which may produce relatively narrow pulses k, l, etc. These pulses are first differentiated by the condenser resistor differentiating circuit 9 and applied to the "edger" circuit 10 which includes the triode 11. Produced in the output of the circuit 10 in the negative sense, are pulses having a relatively straight leading edge and an asymptotic trailing edge. For the circuit shown these resulting negative pulses are preferably passed through a phase reverser 12 producing positive "edger" pulses indicated, for example, at k', l', etc. These "edger" pulses are then applied to a high plate impedance tube 13, the output of which is connected to the resonant circuit 2. A rectifier 3 is connected, as in Fig. 1 (except for the reversal of the plate and cathode connections), in shunt with the resonant circuit 2 and the tube 4 is controlled from the modulating voltage source 5. The pulses derived from the shock-excited resonant circuit 2 are passed through the filter 6 and may be re-shaped in the shaper and amplifier 7. It will be noted, however, that the tube 4 is connected, in effect, directly to the resonant circuit 2, thus substantially eliminating the component modulation present across resistor R of Fig. 2. The low impedance of the resonant circuit 2 however, still presents modulation components which are filtered out at 6. Where the circuit 2 has a high "Q" the filter 6 may be omitted since in that case the modulation components will be negligible.

In Fig. 4, I have roughly indicated by a series of diagrams the action which takes place in the modulating circuit illustrated in Fig. 3. It will be seen that a series of narrow rectangular pulses, such as indicated at k to s inclusive are transformed by the edger and phase reverser circuits into wider "edger" pulses k' to s' inclusive, whose leading edges will shock excite the resonant circuit 12 to produce, corresponding to the instantaneous value of the modulating wave, initial undulations k_1 to s_1, respectively. The rectifier tube 3 prevents positive undulations following the desired negative undulations but the problem of negative undulations resulting from the sharp trailing edges of rectangular pulses k to s is avoided by the transformation of the rectangular pulses into "edger" pulses having an exponential trailing edge. Since it may be desirable, or even necessary, to have the resulting undulations produced by shock excitation of the resonant circuit of a width greater than the width of the original pulses, it will be clear that such result is made possible by the "edger" pulse feature of my invention. It is by this "edger" pulse feature that I eliminate the production of negative undulations that would otherwise be produced by the trailing edges of the input rectangular pulses. For example, if the input pulses were of a width less than the first undulation, the negative undulation resulting from the trailing edge would cause variations in the normal shape of the positive undulations. Such adverse effect is indicated by negative undulations k_1' and the resulting positive undulation x_1, curve D, Fig. 4, where pulse K is used as the shock exciting pulse. Thus, even with a pulse source of relatively narrow pulses my invention produces width-modulated pulses of a given shape characteristic.

From the foregoing description, it will be readily apparent that the resonant circuit 2 may be shock-excited by various pulse shapes other than rectangular and "edger" pulses so long as the pulse shapes present shock-exciting edges of a given polarity and of sufficiently abrupt potential change, timed according to a pattern in agreement with the tuning limits of the circuit. The timing of the shocks need not be regular but may be at uneven intervals so long as they are sufficiently frequent to provide a sufficient number of output pulses to adequately define the modulating intelligence.

It will also be apparent to those skilled in the art that the undulation pulses of curve C, Fig. 2, and curve D, Fig. 4, may be used directly to modulate a carrier for transmission purposes. In fact, these undulation pulses require a much narrower frequency band than the rectangular pulses of curve D, Fig. 2, and curve E, Fig. 4, the band being determined largely by the steepness of the leading and trailing edges. The signal-to-noise ratio of the undulation pulses, however, will be lower than for the rectangular pulses. The narrow pulses of curve E, Fig. 2, produced by differentiating the rectangular pulses will serve as modulation pulses for purpose of transmission better than the rectangular pulses without increasing the band width required and with reduced transmitter power requirements.

While I have described above the principles of my invention in certain specific examples, it is to be clearly understood that this description is made only by way of example and not as a limitation on the scope thereof as set forth in the objects and in the accompanying claims.

I claim:

1. Pulse-width modulating system comprising, in combination, means producing a series of voltage pulses, each pulse having at least one abrupt potential change, a tuned circuit having a predetermined resonant frequency, means shock-exciting said tuned circuit by the abrupt potential change of each pulse, dampening means connected to said tuned circuit for eliminating all undulations thereof except the first one caused by said abrupt potential change, and means varying the width of said first undulations, comprising a source of modulating voltage, and variable means controlling the tuning of said circuit to alter its resonant frequency in response to the instantaneous value of said modulating voltage.

2. The combination according to claim 1, in combination with means connected to said tuned circuit for producing a pulse from each first undulation having a width corresponding to the width at a given level on said first undulations.

3. The system according to claim 1, in which said pulse producing means includes means for producing pulses having two abrupt potential changes spaced apart with a width equal to the width of the widest undulations of the tuned circuit, and means shock-exciting said tuned circuit by one of said abrupt potential changes.

4. The system according to claim 1, in which said pulse producing means includes means for producing pulses having two abrupt potential changes spaced apart with a width less than the width of the narrowest undulations of the tuned circuit, means shock-exciting said tuned circuit by one of said abrupt potential changes, and means correcting the other abrupt potential change to a gradual potential change.

5. In a system of the type in which a tuned circuit is shock excited by a series of pulses, the steps of varying the tuning of this circuit corresponding to intelligence to be transmitted, producing a series of pulses from the oscillations produced in said shock excited circuit, and varying the width of said produced pulses in accordance with the tuning of said circuit.

6. A pulse-width modulating system comprising in combination, a source of recurring pulses of substantially constant width, a source of modulating voltage, a tuned circuit having a predetermined resonant frequency, means shock-exciting said tuned circuit in response to said recurring pulses, dampening means connected to said tuned circuit for eliminating substantially all but the first undulation thereof after each excitation, variable means controlling the tuning of said circuit to alter its resonant frequency in accordance with the instantaneous value of said modulating voltage, and means transforming the undulations from said shock-excited tuned circuit to substantially rectangular pulses whose width corresponds to the width of the respective undulation.

7. The combination according to claim 6, in which said last means comprises an output circuit including a low-pass filter and a shaper circuit connected to said tuned circuit.

8. The combination according to claim 6, in which said variable tuning means comprises an electronic tube in shunt with the said tuned circuit, and means controlling said tube from said source of modulating voltage.

9. Pulse-width modulating system comprising, in combination, a source of recurring substantially rectangular pulses of substantially constant width, a tuned circuit having a predetermined resonant frequency, means shock-exciting said tuned circuit by said recurring pulses to produce undulations whose width is dependent upon the resonant frequency of the circuit, dampening means connected to said tuned circuit for eliminating substantially all but the first undulation thereof after each excitation, means re-shaping each first undulation into a substantially rectangular pulse of a width corresponding to the width of the undulation, and controllable means varying the resonant frequency of said tuned circuit to vary the width of the undulations and the pulses derived therefrom.

10. The method of pulse-width modulation, which comprises the steps of producing oscillatory energy in response to a plurality of recurring pulses of at least a given width, eliminating all undulations of the oscillatory energy except the first, producing a series of substantially rectangular pulses having a width corresponding to the width of the respective first undulations, and varying the frequency of said oscillatory energy to correspondingly vary the width of said first undulations.

11. Pulse-width modulating system comprising, in combination, a source of recurring substantially rectangular pulses of substantially constant width, means transforming said rectangular pulses into pulses having one substantially vertical leading edge and a gradually downwardly curving trailing edge, a tunable circuit having a predetermined resonant frequency, means shock-exciting said circuit by said transformed pulses, dampening means connected to said circuit for eliminating substantially all but the first undulation thereof after each excitation, a source of modulating voltage, means varying the tuning of said circuit in accordance with said modulating voltage to produce undulations of varying width, and means transforming the undulations from said shock-excited circuit into substantially rectangular pulses of a width determined by the width of the successive undulations.

12. The combination according to claim 11, in which said last means comprises an output circuit including a low-pass filter and a shaper circuit connected to said turnable circuit.

13. The combination according to claim 11, in which said variable tuning means comprises an electronic tube in shunt with the said tunable circuit, and means controlling said tube from said source of modulating voltage.

14. Pulse-width modulating system comprising, in combination, a source of recurring substantially rectangular pulses of substantially constant width, means transforming said rectangular pulses into pulses having one substantially vertical leading edge and a gradually downwardly curving trailing edge, a tuned circuit having a predetermined resonant frequency, means shock-

exciting said tuned circuit from said transformed recurring pulses to produce undulations whose width is dependent upon the resonant frequency of the circuit, dampening means connected to said tuned circuit for eliminating substantially all but the first undulation thereof after each excitation, means re-shaping each first undulation into a substantially rectangular pulse of a width corresponding to the width of the undulation, and controllable means varying the resonant frequency of said tuned circuit to vary the width of the first undulations and the pulses derived therefrom.

15. Pulse-width modulating system comprising, in combination, a source of recurring, relatively narrow, substantially rectangular pulses of substantially constant width, means transforming said narrow rectangular pulses into wider constant-width pulses having one substantially vertical leading edge and a gradually downwardly curving trailing edge, a tuned circuit having a predetermined resonant frequency, means shock-exciting said tuned circuit by said transformed pulses, dampening means connected to said tuned circuit for eliminating substantially all but the first undulation thereof after each excitation, a source of modulating voltage, means varying the tuning of said circuit in accordance with said modulating voltage to produce undulations of varying width, and means transforming each first undulation from said shock-excited circuit into a substantially rectangular pulse of a width determined by the width of the corresponding undulation.

16. The method of pulse modulation, which includes the steps of producing a series of relatively narrow rectangular pulses of substantially constant width, producing a corresponding series of wider pulses each having a substantially vertical leading edge and an asymptotic trailing edge, translating energy of said last series of pulses into oscillatory energy, eliminating all undulations of the oscillatory energy except the first, producing a series of substantially rectangular pulses having a width corresponding to the width of said first undulations, and varying the frequency of said oscillatory energy to correspondingly vary the width of said first undulations.

17. Pulse width modulating system comprising a source of electrical pulses, means to produce oscillatory energy in response to each of said pulses, means to eliminate all undulations of the oscillatory energy except the first undulations, and means to vary the frequency of said oscillatory energy producing means to effect a corresponding variation in the base width of said first undulations.

18. The modulating system according to claim 17, further including a signal source and means to apply signals from said source to control the means for varying the frequency of said oscillatory energy.

19. The modulating system according to claim 17, further including means for shaping said first undulations to produce pulses of a predetermined form modulated in width according to variations in the base width of said undulations.

20. The modulating system according to claim 17, wherein said means to produce oscillatory energy includes a resonant circuit and said means to vary the frequency of said oscillatory energy includes means for controlling the resistance in said tuned circuit.

DONALD D. GRIEG.

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