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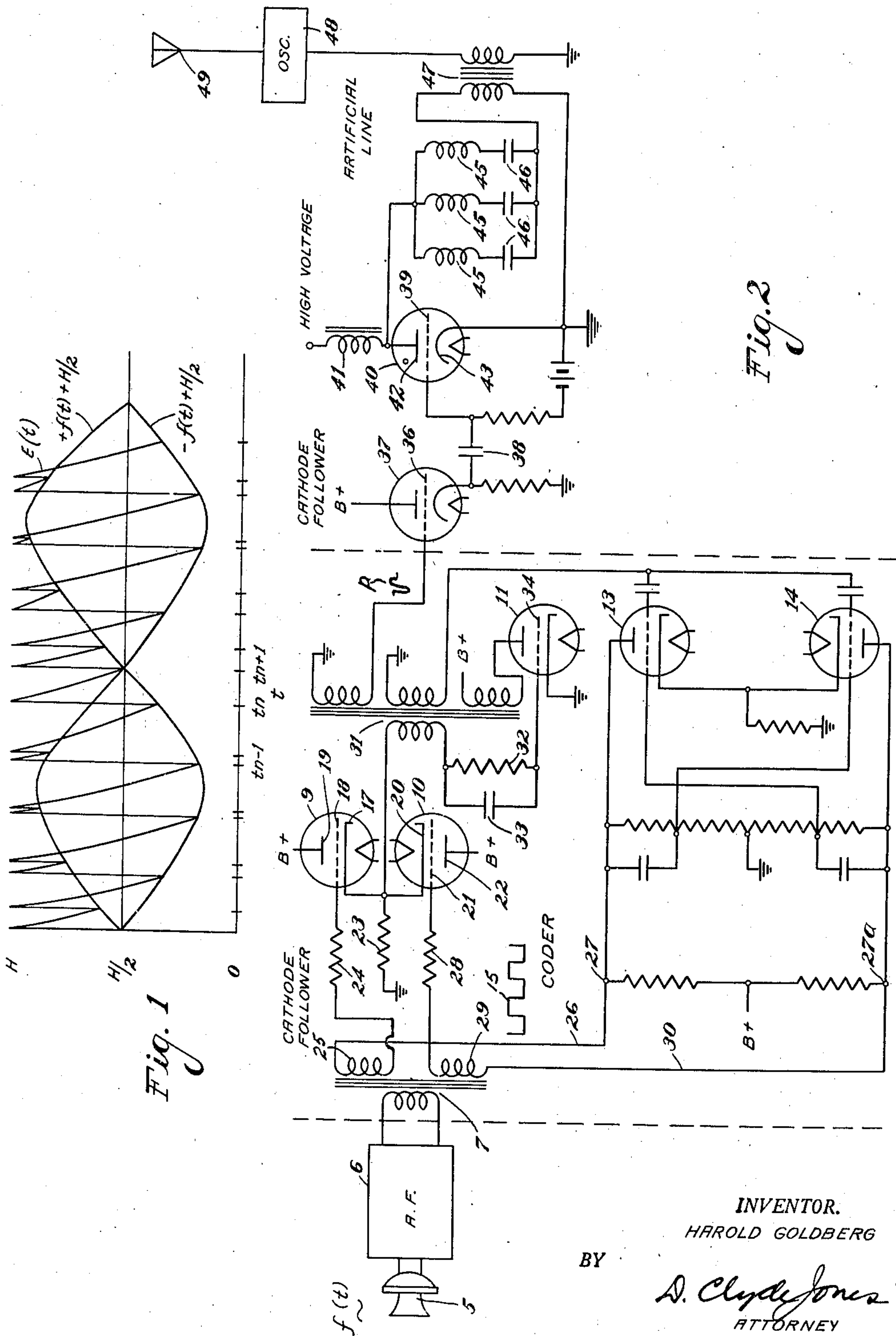
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2,466,230

PULSE TIME MODULATION SYSTEM

Filed Feb. 9, 1946

2 Sheets-Sheet 1



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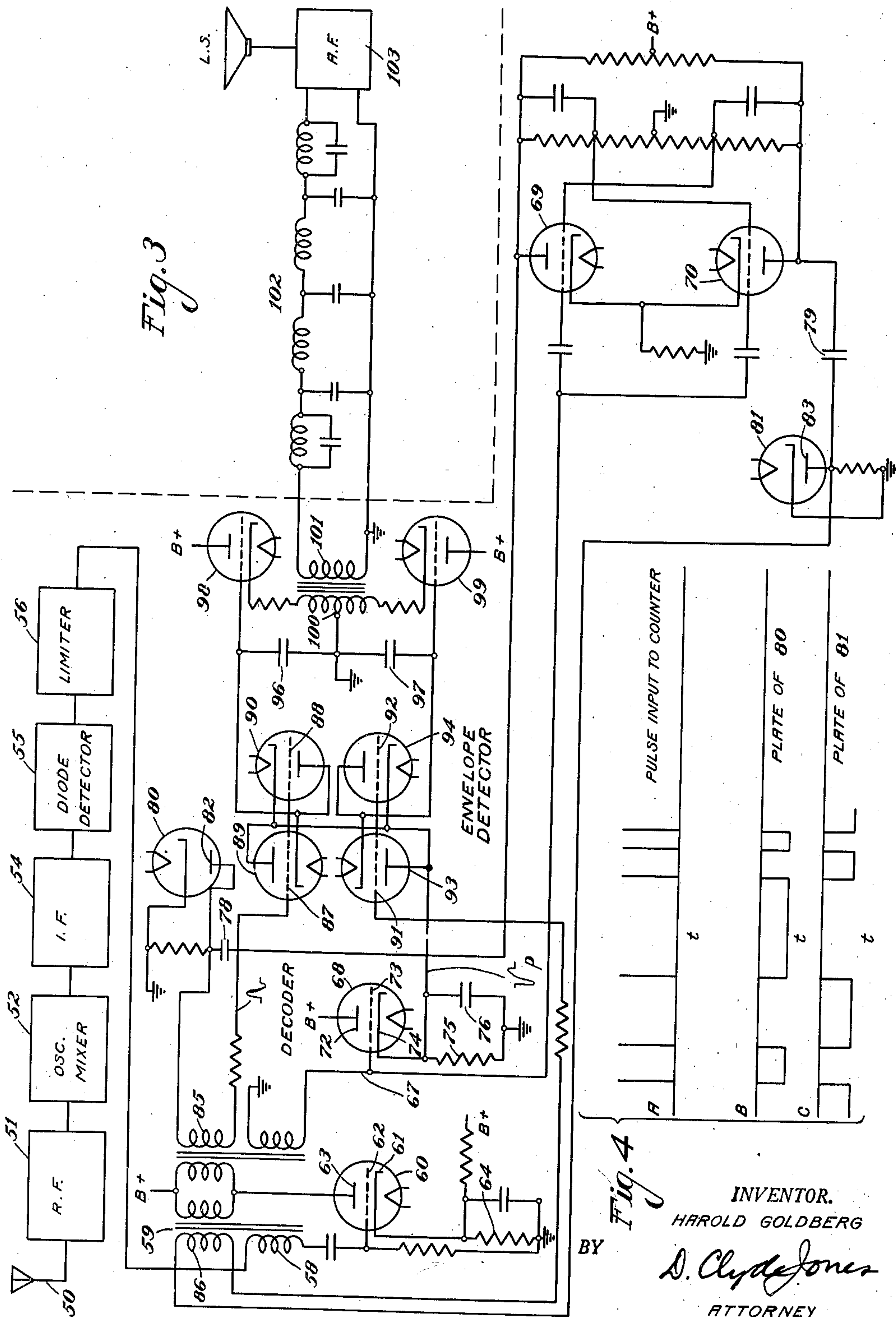


Fig. 4

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PULSE TIME MODULATION SYSTEM

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7 Claims. (Cl. 250—17)

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This invention relates to a method of and to apparatus for push-pull, pulse period transmission and reception of signals.

In prior pulse modulation systems, the average value of the generated pulses is not constant but is a function of the modulation of the signal to be transmitted. This condition does not afford the degree of secrecy sometimes required, since an ordinary receiver can detect the transmitted modulation and decipher it, although the resulting signal will be somewhat distorted.

The main feature of the invention relates to a method of and to apparatus for communication in which the signal is transmitted in the form of a train of pulses coded according to an exponential function of time as a result of sampling the modulating signal, the polarity of the modulating signal being reversed after each sampling, the instantaneous amplitudes being equal. Thus, there is provided pulse modulation in which the sum of every two pulse periods is a constant, except for second order effects, so that unauthorized deciphering of the coded message is rendered more difficult.

The invention will best be understood from the following description when taken with the drawings in which:

Fig. 1 is a chart useful in explaining the coding and decoding principle;

Fig. 2 is a diagrammatic showing of the coding and transmitting portion of the present signalling system;

Fig. 3 is similarly a diagrammatic showing of the reception and decoding portion of this system; and

Fig. 4 is a chart showing certain wave forms present in the decoding portion of the system.

The principle of the coding and decoding system of the present invention can best be understood by reference to the chart of Fig. 1, which illustrates one embodiment of my invention. In this chart curve $+f(t) + H/2$ represents the modulation voltage representing the information to be transmitted by the coder and finally reproduced by the decoder at the receiving station and the curve $-f(t) + H/2$ represents a voltage equal to $f(t) + H/2$ in amplitude at any given instant but opposite in sense. According to this invention samples only of the signal are transmitted, the sampling being effected at intervals determined by the intersection of an exponentially decaying curve $E(t)$ and the modulating signal curve $f(t) + H/2$. The sense of the modulating signal is reversed after each sampling, as hereinafter described. The effect of this reversal is

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indicated in Fig. 1 by means of curves $+kf(t) + H/2$ and $-kf(t) + H/2$, these curves representing the envelopes of the corresponding voltages. It will be understood, however, that actually pulses of alternately opposite sense will be derived from the cathode followers 9 and 10 (Fig. 2). If $+kf(t)$ is sampled at time t_n then $-kf(t)$ is sampled at time t_n+1 and $+kf(t)$ is sampled at time t_n+2 while $-kf(t)$ is sampled at time t_n+3 , etc. In this system, the sum of two adjacent periods is a constant except for second order effects, an advantage if greater secrecy is desired. It is preferred that the signal have amplitudes between the limits 0 and H in the coder to be described. For music or speech this is not objectionable since multiplying by a constant or the adding of a constant does not constitute a distortion. The curve $E(t)$ has a specific time constant which is not restricted by the coding or decoding arrangement. However, in a pulse modulation system which is based on this coding and decoding principle, the time constant must be such that, in the absence of the signal when a line of height $H/2$ is sampled, the sampling rate must be at least twice the highest frequency component in any signal which is to be sampled by the device.

The function $+f(t) + H/2$ is sampled in the following manner. The exponential $E(t)$ starting from height H decays until it intersects function $+f(t) + H/2$. Such an intersection is indicated at time t_n . At time t_n a pulse is generated and $E(t)$ is instantaneously restored to height H. $E(t)$ now decays exponentially until it intersects $-f(t) + H/2$, at t_n+1 . At this instant, another pulse is generated and $E(t)$ is again restored to the value H. This method is continued during the signalling period. The pulses generated at each intersection now represent the result of coding signal $\pm f(t) + H/2$ and may be transmitted by any means known to the art. It may be seen that the interval between any two consecutive pulses is a measure of the amplitude of $\pm f(t) + H/2$ at the end of the interval and this measure is according to the coding function $E(t)$.

Decoding is represented by the same chart. An exponential function $E(t)$ is started from a height H, and allowed to decay. It is started by a pulse, such as at time t_n , which has been transmitted and received by methods already known in the art. It is allowed to decay until the pulse at t_n+1 is received at which time it is again restored to height H, etc. The intervals between successive received pulses are the same

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as those between the transmitted pulses but the individual pulses suffer a fixed time delay in transmission. If the time constant of $E(t)$ in the decoder is the same as that in the coder, then the minima of the resulting wave produced by $E(t)$ and its restoration to height H at each pulse all lie on curves which are replica of $\pm f(t) + H/2$ except for a multiplicative or additive constant. The detection of the envelope of the output of the decoder $\pm f(t) + H/2$ may be done by means already well known in the art.

In practicing the present method, the transmitting apparatus of Fig. 2 may be employed. The transmitting portion of the system comprises a microphone 5 to pick up the signal to be transmitted. This signal is amplified in the audio amplifier 6 and is supplied through the transformer 7 to a coder unit which samples the function of time to be transmitted, in the manner described above.

Generally this coder comprises two cathode followers including the triodes 9 and 10 which function together as an electronic switch. The coder also includes a blocking oscillator which comprises triode 11 and which is controlled by the output of the cathode followers. The coder also includes a scale-of-two counter comprising the triodes 13 and 14, which counter is governed by the output of the oscillator to generate a rectangular wave 15, the polarity of which changes with each pulse generated by the blocking oscillator. This rectangular wave switches or renders inoperative the two cathode followers so that they operate alternately and therefore only one cathode follower amplifies at a given time. The two followers are fed modulating signals of opposite sign. Inasmuch as it is undesirable for the switching of the cathode followers to take place during the sampling interval, the pulse which operates the scale-of-two counter is delayed slightly in time, from the pulse which is transmitted as the output of the coder. This delay is accomplished since the output pulses of the blocking oscillator are not unidirectional but have a considerable overshoot as indicated at p . The overshoot is used to trigger the scale-of-two counter. This counter circuit, in addition to controlling the switching of the followers, also functions to supply the biasing voltage for the followers. The followers are switched due to the fact that any great inequality in the average voltage applied to the two grids will cut off one of them.

Specifically, the coder may be described as follows: the triode 9 of one of the cathode followers is provided with the cathode 17, control grid 18 and anode 19 while the triode 10 of the other cathode follower is provided with the cathode 20, control grid 21 and anode 22. The cathodes 17 and 20 are connected together and to ground through resistor 23, the purpose of which will be described. As long as the cathode follower triodes 9 and 10 are operating in their class A region, resistor 23 has no effect and does not hinder the operation of the followers to pass the signal $\pm kf(t)$. The control grid 18 is connected in series with the resistor 24, secondary winding 25 of the transformer 7, and conductor 26 to terminal 27 of the scale-of-two counter. The control grid 21 is similarly connected in series with the resistor 28, secondary winding 29 of the transformer 7, and conductor 30 to the terminal 27a of the scale-of-two counter. Winding 29 is connected in reverse phase relationship with respect to winding 25.

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The triode 11, the transformer 31, the RC combination of resistor 32 and condenser 33, the cathode followers 9 and 10 and the resistor 23 constitute a blocking oscillator circuit, which produces a recurring voltage for the initiation of pulses.

In the absence of a modulation $\pm f(t) + H/2$, the blocking oscillator operates at a constant rate determined by the characteristics of the triode 11, transformer 31, the RC constant of resistor 32 and condenser 33, and the voltage across resistor 23 as well as the biasing voltages applied to the control grids 18 and 21 of the cathode followers. The action of the blocking oscillator is such that it goes into violent oscillation if the voltage on grid 34 of triode 11 exceeds a certain value which is termed the firing voltage. When the firing voltage is exceeded, the condenser 33 receives a large negative charge. The oscillation of the blocking oscillator collapses and the negative voltage on condenser 33 prevents further oscillation of the oscillator. The negative charge on the condenser 33, however, will leak off at a rate determined by the product RC. As soon as the grid voltage of the oscillator has exceeded the firing voltage, this operation is repeated. At each oscillation, a pulse is generated. The interval between firings is a function of the output of the followers.

The pulse generated may either be radiated or transmitted over conductors in the well-known manner. However, as herein indicated, each pulse is applied to the grid 36 of a triode 37 connected as a cathode follower. The output of the cathode follower is applied through the condenser 38 to the grid 39 of a gas-filled discharge tube 40 of the thyatron type, included in a triggered power supply circuit. An inductance coil 41 is connected between the anode 42 of tube 40 and a source of high voltage. An artificial line comprising inductors 45 and condensers 46 connected in series parallel is arranged to be charged from the high-voltage source. When the tube 40 is rendered conducting by the application of a pulse to its grid 39, the artificial line discharges through the space between the anode 42 and the cathode 43 of the discharge tube, inductance coil 41 preventing the high-voltage source from being short-circuited. The output of the artificial line is delivered through a transformer 47, to a well-known oscillator transmitting unit 48 and the antenna 49.

If the signal-modulated pulses are radiated, as indicated, they are intercepted on an antenna 50, at a receiving station (Fig. 3) where they are recreated by a suitable receiver into signals corresponding to the original signal. Specifically, the receiver is herein illustrated as comprising a radio frequency stage 51 in which the received pulses are amplified and are then delivered to a local oscillator and mixer 52 to translate the signal into an intermediate frequency. These intermediate frequency signals are amplified by the intermediate frequency amplifier 54 and thereafter are detected preferably by a well known diode detector 55. The detected signals are then passed through a vacuum tube limiter or clipping stage 56 so that all signals derived from the receiver are positive pulses of constant amplitude.

These positive pulses are supplied through the winding 53 of the transformer 53 to an envelope detector which serves as a push-pull pulse period demodulator and functions to detect the envelopes of alternate minima in the output of the decoder

and to combine the resulting push-pull output. The envelope detector includes a triggered blocking oscillator comprising a triode 60 with its cathode 61, its grid 62 and anode 63, to act as a pulse amplifier, sharpener, and clipper. The network including the resistor 64 in the cathode lead provides a bias voltage for the grid 62 which normally keeps the oscillator circuit from oscillating. A positive pulse from the receiver triggers the oscillator circuit and causes it to generate a single blocking oscillator pulse. These oscillator pulses are of constant amplitude and because of their form it is possible also to obtain a delayed pulse by reversing the sense of the output pulse from the transformer. Thus, there is provided a method for obtaining a delayed pulse without the use of delay networks. The delayed pulse is applied over conductor 67 to trigger a decoder, including triode 68 as well as to control a scale-of-two counter comprising the triodes 69 and 70. The above described envelope detector is described and claimed in a co-pending application of myself and James A. Krumhansl, Serial No. 646,616, filed February 9, 1946, and assigned to the same assignee as the present invention.

The triode 68 has its anode 72 connected to a source of potential positive with respect to ground and has its grid 73 connected to the delayed pulse conductor 67. The cathode 74 of the triode has a resistor 75 shunted by a condenser 76 connected between it and ground, and these elements constitute an RC network which has a product equal to that of the resistor 32 and the condenser 33 at the transmitter. It will be understood that a positive pulse applied to the grid 73 of the decoder causes the condenser 76 to charge to a fixed value. However, the subsidence of the positive pulse results in the cut-off of triode 68 so that condenser 76 discharges exponentially through resistor 75 as indicated graphically in Fig. 1 by the curve $E(t)$.

The scale-of-two counter, comprising the triodes 69 and 70, functions after the manner of an Eccles-Jordan circuit to produce two rectangular wave outputs. These outputs are capacitively coupled, by the condensers 78 and 79, to the diodes 80 and 81 respectively.

These diodes act as direct current restorers and give rise to the wave forms B and C (Fig. 4) on the diode plates 82 and 83 respectively while the graph A illustrates the correlated pulse input to the counter. It will be seen that the voltages on the diode plates 82 and 83 alternate with each other and are never positive. To each of these voltages, there is added a normal pulse from transformer windings 85 and 86 respectively and the combined voltages are respectively applied to the grids 87 and 88 of the envelope detector 89, 90 as well as to the grids 91 and 92 of the envelope detectors 93 and 94. In this manner, the two envelope detectors are activated alternately and each by itself determines the alternate minima of the decoder. The outputs of the two detectors are therefore push-pull versions of the original modulation. The two detectors are respectively coupled by the condensers 96 and 97 to cathode followers including the triodes 98 and 99. The transformer winding 100 in the cathode circuits of the followers 98 and 99 combine the push-pull outputs, the resultant being applied through a secondary winding 101 of the transformer to a low-pass filter 102 and then amplified in the audio amplifier 103. The decoded signals, thus amplified, are reproduced by the loud speaker LS.

What I claim is:

1. In a pulse modulation system, a source of periodically recurring voltage, a source of modulation voltage, means for producing an additional voltage equal in amplitude to said modulation voltage but of opposite sense, and means for alternately causing said modulation voltage and said additional voltage to control the periodicity of said recurring voltage according jointly to an exponential function of time and to the corresponding amplitudes and sense of said modulation and additional voltages.

2. In a pulse modulation system, a source of signal voltage, means for producing an additional voltage equal in amplitude to said signal voltage but of opposite sense, means for alternately sampling said voltages at intervals varying as an exponential function of time and as a function of the respective amplitudes of said voltages, means for generating pulses at intervals corresponding to said sampling intervals, and means for transmitting said pulses as a train of pulses variably positioned as to time.

3. In a pulse modulation system, a blocking oscillator, a source of voltage corresponding to information to be transmitted, means for producing an additional voltage equal in amplitude to the first mentioned voltage but of opposite sense, means for alternately utilizing said voltages for causing operation of said blocking oscillator at variable intervals said intervals also depending on an exponential time function, and means responsive to each operation for transmitting a pulse, the resulting pulses being positioned as to time according both to said exponential time function and to the amplitudes and sense of said voltages.

4. In a pulse modulation system, a blocking oscillator, a source of voltage corresponding to information to be transmitted, means for producing an additional voltage equal in amplitude to the first mentioned voltage at any given instant but of opposite sense, a pair of electron discharge devices connected as cathode followers and each having an anode, a cathode and a control electrode, said cathodes and anodes being connected for parallel operation, means for impressing the first mentioned voltage on the control electrode of one of said devices, means for impressing the second mentioned voltage on the control electrode of the other of said devices, means for alternately rendering said devices inoperative whereby a single output of pulsating voltage is obtained, means utilizing said output in combination with an exponential time function for controlling operation of said blocking oscillator, and means responsive to each operation for generating and transmitting a pulse.

5. The method of communication which comprises originating a first voltage corresponding to a signal to be communicated, producing a second voltage at all times equal in amplitude to said first voltage but of opposite sense, alternately sampling said voltages at intervals varying as an exponential function of time and as a function of the amplitude of the voltage being sampled, generating pulses at intervals corresponding to said sampling intervals, and transmitting the generated pulses as a train of pulses variably positioned as to time.

6. In a pulse modulation system, a source of signal voltage, means for producing a second voltage which at any given instant is equal in amplitude to said signal voltage but of opposite sense, means providing a D. C. voltage, means for combining one of the aforesaid voltages and said

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D. C. voltage to obtain a first composite voltage, means for combining the other of the aforesaid voltages and said D. C. voltage to obtain a second composite voltage, means for alternately sampling said composite voltages at intervals varying as an exponential function of time and as a function of the respective amplitudes of said composite voltages, means for generating pulses at intervals corresponding to said sampling intervals, and means for transmitting said pulses as a train of pulses variably positioned as to time.

7. In a pulse modulation system, a source of signal voltage, means for producing a second voltage which at any given instant is equal in amplitude to said signal voltage but of opposite sense, means providing a D. C. voltage, means for adding one of the aforesaid voltages to said D. C. voltage to obtain a first composite voltage, means for subtracting the other of the aforesaid voltages from said D. C. voltage to obtain a second composite voltage, means for alternately sampling said composite voltages at intervals varying as an ex-

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ponential function of time and as a function of the respective amplitudes of said composite voltages, means for generating pulses at intervals corresponding to said sampling intervals, and means for transmitting said pulses as a train of pulses variably positioned as to time.

HAROLD GOLDBERG.

REFERENCES CITED

The following references are of record in the file of this patent:

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Certificate of Correction

April 5, 1949.

Patent No. 2,466,230.

HAROLD GOLDBERG

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows:

Column 2, line 28, for " $+f(t)$ " read $\pm f(t)$;
and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 2nd day of August, A. D. 1949.

[SEAL]

THOMAS F. MURPHY,
Assistant Commissioner of Patents.