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[illegible]

FIG. 2

GAIN

54

55

VOLTS

E_0 AND $E_1 \times 10^6$

50

E_1

51

52

E_0

53

SECONDS

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ELECTRONIC AMPLIFIER

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8 Claims. (Cl. 175—183)

This invention relates to electronic amplifiers and particularly to an amplifier for amplifying low frequency signals.

In many instances an amplifier is desired for amplifying weak signals so as to enable such signals to operate alarms, meters, recorders and the like. Generally an amplifier of this character is designed to provide uniform amplification of signals of varying amplitude and thus is not suited to the amplification of signals which vary over a wide range, for example, where the stronger signals are of the order of one hundred or one thousand times as large as the weaker signals. In accordance with the invention an amplifier suitable for amplifying signals of widely varying strength is provided by incorporating an exponential control of the gain of the amplifier whereby all signals are amplified to an extent varying in accordance with the strength of the signals and the amplified signals may be interpreted in terms of the known characteristics of the exponential gain control system.

In general terms, the primary object of the invention is to provide an improved amplifier having exponential output characteristics.

Another object of the invention is to provide an amplifier of the above-stated character which is particularly adapted for amplifying low frequency signals of the order of one or two cycles a second or less.

Another object of the invention is to provide means whereby minute electrical signals may be indicated or recorded accurately for purposes of comparison or measurement, particularly in cable surveying apparatus or the like where the signals vary in amplitude over a wide range. It will be apparent that if one signal is only about one percent of the amplitude of another signal, the usual indicating or recording devices do not permit of an accurate comparison of the two signals where the instrument is provided with a uniform scale, since the smaller signal could not be detected or the larger signal would be off the scale. If, however, the smaller or weaker signals are amplified to a greater extent than the larger or stronger signals according to a known exponential law, the deflections or recorded amplitudes of the signals may be accurately measured or compared. It is therefore a still further object of the invention to provide a novel amplifier of this character which may be used with standard indicating or recording meters.

Other objects and advantages of the invention will appear from the following description of the

electrical amplifying system shown in the accompanying drawing, wherein:

Fig. 1 is a diagrammatic view of a system embodying the invention; and

Fig. 2 is a graph illustrating the characteristics of the amplifier shown in Fig. 1.

The electronic amplifier shown in Fig. 1 is particularly adapted for, and has been illustrated in connection with, cable depth measuring apparatus such as that disclosed and claimed in our prior Patent No. 2,238,072, granted April 15, 1941, for "Method of and means for locating concealed bodies." In apparatus of this character the signaling impulses generated in the pick-up coils in the sled, as it is dragged over the cable, are exceedingly weak and vary over a wide range and it is necessary to measure or record such signals for comparison with extreme accuracy for proper interpretation.

In accordance with the present invention the signals from the pick-up coils mounted in the sled are amplified by a special amplifier in which the output voltage varies as some root of the input voltage, for example, the square root of the input voltage, the output signals being used to operate a recording meter whereby accurate comparison of the two impulses produced as the sled passes over the cable is facilitated. In accordance with the further feature of the invention, the amplifier characteristics may be readily varied to obtain any desired exponential characteristics. Obviously, the invention is not limited to the particular application mentioned but may be applied to the measurement or determination of minute electrical signals from various sources.

The cable depthometer sled is represented at 10 in Fig. 1 and carries a plurality of pick-up coils 11, which may be arranged in various ways as described in our prior patent referred to above. The terminals of the coils 11 are connected through a cable 12 and a chopper or interrupter 13 to the input transformer 14 of the amplifier. Since the signals generated in the coils 11 are of low frequency and in reality of the character of direct current impulses, a chopper is employed as explained in our prior application for the purpose of converting signals into alternating current or oscillations of any suitable frequency that will be efficiently amplified by the electronic amplifier. Where the signals are of a sufficient high frequency or in applications where an amplifier is available to handle the initial signal frequency, the chopper or interrupter 13 may be omitted.

The amplifier comprises two push-pull trans-

former coupled stages comprising the space-discharge devices or vacuum tubes 16 and 17 connected to the secondary winding of the transformer 14 and the space-discharge devices or vacuum tubes 18 and 19 connected to the secondary winding of the intermediate coupling transformer 20. The vacuum tubes 16, 17, 18 and 19 are preferable voltage amplifier pentode tubes of the 6K7 type providing stable high-gain amplification, but the invention is not limited to this type of tube. In general, vacuum tubes may be employed in the amplifier which are of the type of which the gain may be readily controlled, as for example any variable-mu tube which can be controlled by varying the grid bias to vary the overall gain.

In the preferred arrangement shown, the control electrodes of the tubes 16 and 17 are connected to the terminals of the secondary winding of the transformer 14 and the grid return circuit including conductor 21 connected to the midpoint of said secondary winding is connected to a source of variable potential dependent upon the amplitude of the output voltage for controlling the gain of the first stage of the amplifier. As will be explained, the application of the gain control voltage is accomplished in a particular manner, i. e., the variation of the gain of the amplifier is rapid enough to control the individual signal impulse but not so fast as to cause "motor boating" (the generation of low frequency oscillations). In general terms, this essential result is accomplished by controlling the rate of change of the gain control potential derived from the output of the amplifier and applied to one or more stages thereof. The gain of the second amplifier stage is similarly controlled by a bias potential applied through conductor 22 to control electrodes of the vacuum tubes 18 and 19.

The final stage of the amplifier may be coupled through a transformer 25 to the output circuit 26. A resistor 27, for example of 0.5 megohm, is bridged across the circuit 26 and the alternating output voltage is rectified by a rectifier 28 in case a meter such as the meter 30 of the direct current recording type is utilized to provide an indication of the magnitude of the signals.

The output circuit of the amplifier is also connected by a conductor 32 to an amplifier and rectifier 33 of conventional construction arranged to generate a direct current in the circuit thereof proportional to the amplitude of the output voltage of the amplifier. The circuit 34 is bridged by a condenser 35, for example of 1 mf. capacity, and by a potentiometer 36 having, for example, a total resistance of 50,000 ohms. The variable tap 37 of the potentiometer 36 is connected to the conductors 21 and 22 for controlling the gain in the respective stages of the amplifier through the filter circuits shown. When the variable tap of the potentiometer 36 is adjusted to the point indicated by the dotted line 38, no exponential control is exercised upon the characteristics of the amplifier, which then operates as a linear amplifier, a battery 39 furnishing normal bias for the control electrode circuits of the vacuum tubes 16, 17, 18 and 19.

In accordance with one feature of the invention, when the variable tap 37 is moved from the zero position the gain of the amplifier varies in accordance with the n th root of the input signal. Thus the tap may be moved to such a position that the gain of the amplifier is proportional to the square root of the input signal

and if the tap is moved further, the gain will be proportional to the cube root of the input signal, etc. Ordinarily, the variable tap of the potentiometer 36 is suitably adjusted to provide the desired exponential characteristic of the amplifier and then is left at such adjustment during the subsequent use of the apparatus.

The rectified current proportional to the output signal of the amplifier is translated into a bias potential by the drop across the potentiometer 36 and is thus added to the constant bias potential of the battery 39. The combined bias potential varying in accordance with the instantaneous output voltage is applied to the conductors 21 and 22 arranged to control the gain of the respective stages of the amplifier as pointed out above. The gain control circuit including conductor 21 contains a filter system including an inductance 40, for example, of 50 henries, a series resistor 41 and grounded condensers 42 and 43 connected to the terminals of said resistor. The resistor 41 may be of the order of 50,000 ohms. The capacities of the condensers 42 and 43 are critical depending upon the duration or frequency of the input signals since the exponential gain control must follow each individual signal so that the gain of the amplifier is a maximum when the input signal is small and is reduced to a minimum upon the occurrence of a larger input signal of maximum amplitude. In the case of signals picked up from a cable depthometer arrangement as described above where the signals are not less than 100 milliseconds in length, the condenser 42 is preferably of 0.5 mf. and the condenser 43 of 0.1 mf. capacity. In this case the filter will not pass an alternating current of greater frequency than ten cycles per second, the time constant of the gain control being also affected to a certain extent by the condenser 35.

A somewhat similar filter circuit is provided in series with the conductor 22 in the grid return circuit of the second stage of the amplifier, said filter circuit including an inductance 45, for example of 50 henries, a series resistor 46 of 100,000 ohms and a shunt condenser 47 of 0.1 mf. capacity. However, these constants of the elements of the second filter circuit are not critical since the gain control is primarily effected through the first stage of the amplifier.

The interconnections of the tubes 16, 17, 18 and 19 of the amplifier and the other detailed circuits of the cathode, anode and the control, screen and suppressor grids of these tubes are in accordance with general principles well known in the art except as pointed out below. When the input signal is impressed upon the control grids of the tubes 16 and 17 through the transformer 14, the signal is amplified by the tubes 16 and 17 and impressed upon tubes 18 and 19 through the interstage coupling transformer 20. In the tubes 18 and 19 the grid return circuit is connected to the upper and lower control electrodes which are the suppressor grids whereas the suppressor grids of the tubes 16 and 17 are grounded. The connection of the suppressor grids to the grid return circuit results in the exercise of a greater control upon the amplification factor of the tubes 18 and 19 by variation of the gain control potential and this connection could also be utilized in the first stage of the amplifier if desired.

Fig. 2 shows the characteristics of the amplifier for two successive input signals, one of which

is assumed to be twice as large as the other. The two input signals are represented by the curves 50 and 51 and, as shown, each signal impulse has a duration of approximately 400 milliseconds. The curves 52 and 53 represent the output signals produced by impulses 50 and 51 respectively, as recorded by the meter 30, the impulses 52 and 53 being reduced in scale with respect to the input signals. The curves 54 and 55 represent the variation in the overall gain of the amplifier when the impulses 50 and 51 are impressed upon its input circuit. It is assumed that the potentiometer 36 has been adjusted to provide a variation in the gain of the amplifier proportional to the square root of the amplitude of the input signal. Referring to Fig. 2, it will be noted that as the potential of the input signal E_i increases from zero to a maximum, the rectified portion of the signal in the output circuit alters the bias of both stages of the amplifier through the circuits including conductors 21 and 22, and the overall gain is reduced as indicated by curve 54 which has a minimum point corresponding to the maximum value of the input signal E_i . Thus it will be seen that the time constant of the gain control is such as to enable the gain of the amplifier to follow variations in the amplitude of the individual signals. It will be understood that the signals impressed upon an amplifier embodying the invention may be either direct current signals or one half of an alternating current signal or the envelope or modulation of a signal on an alternating current. If the time constant of the gain control is suitably designed in accordance with the duration of the signals for signal envelopes applied to the amplifier in accordance with the principles set forth above, it will be apparent that the amplifier may be utilized in many different applications.

It will be noted that the curves 52 and 53, representing the output potential E_o are more nearly of the same magnitude than the input signal E_i represented by the curves 50 and 51. In the curves shown by way of example, the output signals are proportional to the square root of the input signals. It will be apparent that with an amplifier embodying the invention minute input signals of widely varying amplitude may be accurately compared or measured since, after amplification, their magnitudes bear a known predetermined relation to the amplitudes of the initial signals but are not directly proportional which would be the case if a linear amplifier were employed.

The amplifier embodying the invention is widely different in arrangement and result from the ordinary type of vacuum tube amplifier provided with automatic volume control. In the ordinary amplifier the time constant of the automatic volume control is relatively long compared to the shorter signals being amplified so that the control of the gain of the amplifier depends upon the average signal strength. Furthermore, in such amplifiers the output is not proportional to the input signals or any fixed power or root thereof over the entire range of signals and therefore would be of no utility in those applications for which the present amplifier may be used, such for example as in the measurement or comparison of individual signals.

Various modifications of the system shown and described for the purpose of explaining the invention will occur to those skilled in the art and may be made without departing from the scope

of the invention as set forth in the appended claims.

We claim:

1. In combination, means for generating low frequency signals of the order of one or two cycles a second, an amplifier having its input circuit connected to said first-named means and means connected to the output circuit of said amplifier for varying the gain of the amplifier in proportion to a root of the input voltage whereby the voltage variations in the output circuit vary exponentially but to a smaller extent than the corresponding input voltages for signals of different amplitudes, said means for varying the gain of the amplifier including means whereby the output response of the amplifier to each individual signal impulse is controlled in accordance with the magnitude thereof.

2. In combination, means for generating low frequency signals of the order of one or two cycles a second, an amplifier having its input circuit connected to said first-named means and means associated with the output circuit of said amplifier for varying the gain of the amplifier in proportion to a root of the input voltage whereby the voltage variations in the output circuit vary exponentially but to a smaller extent than the corresponding input voltages for signals of different amplitudes, the timing of said means for varying the gain of the amplifier being sufficiently rapid to control the amplitude of the output signal corresponding to each individual signal impulse impressed upon the input circuit.

3. Cable surveying apparatus comprising a movable sled adapted to be dragged over the cable, a plurality of pick-up coils associated with said sled in which signals are induced in the proximity of the cable by the movement of the sled, means for chopping said signals, an amplifier for amplifying said signals, said amplifier including means for varying the overall gain of the amplifier in accordance with the square root of the amplitude of the impressed signals, and recording means connected to the amplifier for recording the amplitude of the signals after being amplified by said amplifier.

4. Cable surveying apparatus comprising movable coil pickup means in which signals are induced in the proximity of the cable and an electronic amplifier connected to said pickup means for amplifying the signals, said amplifier embodying means for varying the gain of the amplifier during the period of each signal impulse and in a manner to produce output signals proportional to a root of the amplitude of the signals picked up by said means.

5. Cable surveying apparatus comprising a plurality of spaced pickup coils movable in relation to the cable to produce successive impulses therein as the coils are moved relative to the cable, an amplifier for amplifying said signals, said amplifier including means for varying the gain thereof during the period of each signal impulse and in accordance with a root of the amplitude of the signals impressed thereon from the pickup coils, and recording means connected to the amplifier for making a record corresponding to the amplitudes of the successive signals.

6. Cable surveying apparatus comprising a plurality of spaced pickup coils movable in relation to the cable to produce successive signals as the coils are moved across the cable, means for chopping said signals, amplifying means for amplifying the chopped signals, said amplifying

means including means for varying the gain of the amplifier in proportion to a root of the input voltage at a rate sufficiently rapid to control the amplitude of the output signal corresponding to each individual signal picked up by said pickup coils, and recording means connected to said amplifier means for making a record of the amplitudes of the successive signals.

7. In a low frequency signaling system, an amplifier having an input circuit, means for generating variable amplitude low frequency signals of the order of one or two cycles a second and impressing said signals upon said input circuit and means connected to the output circuit of said amplifier for varying the gain of the amplifier in proportion to a root of the input voltage, the timing of said means for varying the gain of the

amplifier being sufficiently rapid to control the amplitude of the output signals corresponding to each of the individual signal impulses impressed upon the input circuit.

8. In a low frequency signaling system, means for generating variable amplitude low frequency signals, means for chopping said signals, a variable gain amplifier upon which said chopped signals are impressed and a gain control circuit connected to the output of said amplifier for imparting a desired exponential characteristic to the gain of the amplifier and including means whereby the gain control is varied in response to each individual low frequency signal in accordance with its amplitude.

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