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E. L. NORTON

2,324,797

DIFFERENTIATING AMPLIFIER

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FIG. 1

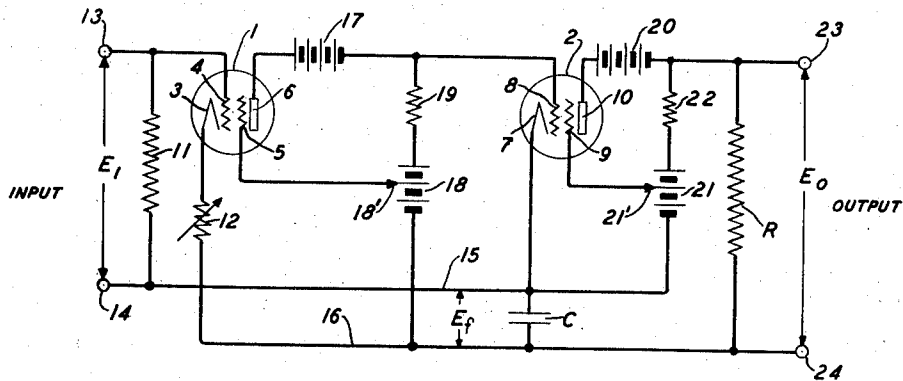


FIG. 2

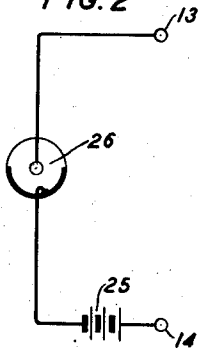


FIG. 3

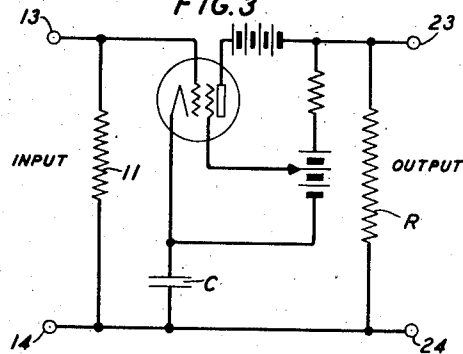
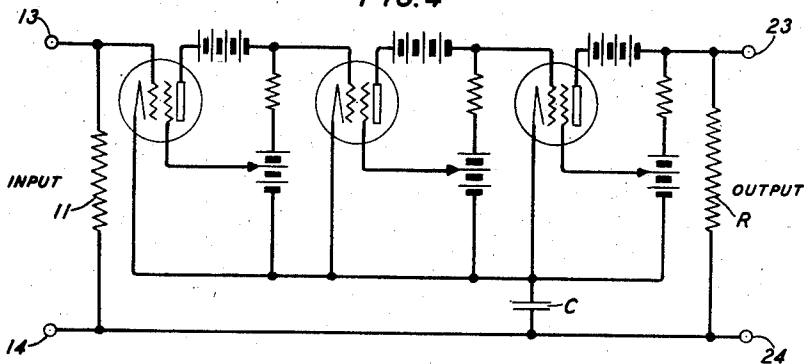


FIG. 4



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DIFFERENTIATING AMPLIFIER

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11 Claims. (Cl. 250—27)

This invention relates to feedback amplifiers and more particularly to feedback amplifiers adapted to deliver an output voltage or current which varies in magnitude substantially linearly with the time derivative of the input voltage.

Amplifiers capable of differentiating a voltage are useful for a number of specialized applications, among which are measuring the frequency of the input voltage or measuring the velocity of some moving object capable of varying the amplifier input voltage linearly with respect to its displacement. For most purposes and in particular for measuring purposes, it is very desirable that the amplifier be capable of operating over a rather wide range of frequencies down to and including direct current variations. It will be at once appreciated that the requirements for such an amplifier are quite exacting particularly where linearity is to be maintained for variations in direct current voltages as well as for a wide range of alternating current voltages.

It is the object of this invention to provide a differentiating amplifier capable of producing an output voltage which is substantially linearly proportional to the time derivative of its applied input voltage and which is operative over a wide frequency range down to and including very slow direct current variations.

The foregoing object is obtained by this invention by providing an amplifier comprising at least one stage and a feedback path therefor including a capacitor for providing a feedback voltage in substantial quadrature to the output voltage.

The invention may be better understood by referring to the drawing wherein

Fig. 1 discloses the invention applied to a two-stage amplifier;

Fig. 2 shows one means of applying an input voltage to the amplifier; and

Figs. 3 and 4 disclose the invention applied to a one-stage and to a three-stage amplifier, respectively.

Referring now to Fig. 1 wherein is disclosed a two-stage amplifier, employing vacuum tubes 1 and 2. While these tubes are shown as tetrodes for illustrative purposes, applicant is fully aware that tubes with a different number of electrodes such as triodes and pentodes may also be used. Tube 1 is shown as having a cathode 3, control grid 4, screen grid 5 and anode or plate 6. Plate and screen grid supply voltages are furnished by batteries 17 and 18 serially connected through coupling resistor 19. A self-bias rheostat 12 is connected in the cathode circuit to provide adjustment to normal bias when different average

input voltages are impressed on control grid resistor 11. Normal plate current through tube 1 will cause a voltage drop in resistor 19 approximately equal to the voltage of battery 18. The screen grid voltage is adjustable by means of a slider 18' associated with battery 18.

The input circuit of tube 2 is coupled to the output circuit of tube 1 through coupling resistor 19. Tube 2 is also shown as a tetrode with cathode 7, control grid 8, screen grid 9 and anode or plate 10. This tube is supplied with plate and screen grid voltages by batteries 20 and 21 serially connected through resistor 22. Normal bias for the control grid is equal to the difference between the sum of the voltages of batteries 18 and 21 and the sum of the drops across resistors 19 and 22, the bias path being from cathode 7 through battery 21, resistor 22, resistor R, battery 18, resistor 19 to control grid 8. The screen grid voltage is adjustable by means of a slider 21'.

A feedback condenser C is connected so that all of the current flowing through the output resistance R must flow through condenser C. The control grid of tube 1 is connected to the input terminals 13, 14 in series with the condenser C in such a polarity that a voltage applied to the input will result in a charge on the condenser of such a sign that the net voltage on the grid of tube 1 is reduced. The voltage on the control grid of tube 1 will therefore be equal to the difference between the applied voltage and that due to the charge on C. With a high gain amplifier the required grid voltage is extremely small, so that the charge on the condenser is substantially proportional to the input voltage.

The output voltage, however, is proportional to the current through R, which is the same as the current through C. Since current is the differential of the charge the output voltage will be proportional to the differential of the input voltage.

With the capacity feedback connections as above described, it has been found that the output voltage E_o developed across resistor R can be mathematically expressed as

$$E_o = RC \frac{dE_i}{dt} \quad (1)$$

where:

E_o , R, C and E_i are as previously defined and the expression

$$\frac{dE_i}{dt}$$

is the time derivative of the input voltage E_i .

that is, the rate at which the input voltage changes.

The operation of this circuit can be understood by first considering voltage E_i a direct current voltage of unvarying magnitude. It is clear that the output voltage E_o will be zero since there will be no alternating current component of output current from tube 2, or stated otherwise, the time derivative of the input voltage is zero as shown in Equation 1. Now assume the direct current input voltage E_i to be slowly changed. This will at once cause a change in the output current of tube 2 and a corresponding change in potential across resistor 22, which change will cause a current to flow through resistor R and capacitance C , the magnitude whereof will be proportional to the rate at which the input voltage is varied. The feedback action of capacitor C causes the output current through resistor R , and hence the output voltage E_o , to vary substantially linearly with the rate at which the input voltage E_i is varied. If the input voltage is changed at a constant rate, its time derivative is constant and the output voltage is, therefore, constant. If the input voltage be a sinusoidal alternating current voltage, the same considerations apply and the output voltage E_o will be substantially proportional to the frequency of the input voltage and may be expressed mathematically as

$$E_o = Kf \quad (2)$$

where:

f = frequency of input voltage E_i

K = a constant depending upon R , C and the maximum value of the input voltage, $E_{i(max)}$.

It has been found that by properly selecting the magnitudes of capacitor C and resistor R and by using tubes and associated circuits capable of high gain, the linearity expressed by Equations 1 and 2 can be retained over a wide range of frequencies down to and including direct current voltage variations. In general the possible voltage gain of the amplifier should be large compared with $2\pi FRC$, where F is the highest frequency to be transmitted. To extend the operating range to the higher frequencies, the capacitance of capacitor C may be lowered and for this purpose capacitor C is preferably made adjustable in convenient steps under control of any suitable selector switch, not shown. With the smaller condenser the output voltage in accordance with Equation 1 will be lower.

The output voltage E_o may be observed directly by high impedance voltage indicator or it may be fed into any direct current power amplifier, not shown, capable of amplifying both direct and alternating current, the output whereof may be connected to any suitable indicator or recorder, also not shown.

Fig. 2 shows one means which may be employed for producing a varying input voltage for the amplifier shown in Fig. 1 as well as for the amplifier shown in Figs. 3 and 4 hereinafter described. A photocell 26 serially connected with a battery 25 is connected to terminals 13 and 14 which terminals correspond with similarly numbered terminals in the other figures. A variation in the illuminating intensity falling on cell 26 will cause the current through resistor 11 and hence the voltage thereacross to vary accordingly. Therefore the rate at which the illumination is changed or the frequency thereof

will produce a proportional output voltage E_o across output terminals 23, 24 of the differentiating amplifier. These variations in the illuminating intensity may be produced by a moving opaque object, the velocity or frequency of oscillations of which is to be observed. It will be understood, of course, that the opaque object is so arranged as to partially intercept the light falling on photocell 26 so that movements thereof will vary the illuminating intensity received by photocell 26. Many other similar uses of this invention will readily suggest themselves to those skilled in the art.

Fig. 3 shows the invention applied to a single stage amplifier. The feedback voltage across capacitor C , which is substantially equal to the input voltage across terminals 13, 14, is in substantial quadrature with the output voltage at terminals 23 and 24 for the same reasons given for Fig. 1 and the operation of the circuit is essentially like that already described for Fig. 1. Of course, due to the inherently lower over-all gain of this single stage amplifier, its range is limited to a considerably lower frequency than for the two-stage amplifier described in connection with Fig. 1.

Fig. 4 shows the invention applied to a three-stage amplifier with inherently more over-all gain than available for the amplifiers shown in Figs. 1 and 3. In this figure, the feedback voltage is fed back to the control grid of the first stage. The operation of the circuit is obvious from the description already given for Fig. 1.

While specific amplifiers have been shown for illustrative purposes, it is obvious to those skilled in the art that most any direct current amplifier may be arranged to operate with the capacity feedback of this invention.

What is claimed is:

1. A differentiating amplifier adapted for delivering an output voltage substantially linearly proportional to the time derivative of the input voltage comprising at least one amplifier stage, an input circuit and an output circuit for the amplifier, a feedback path from the output circuit to the input circuit, and a capacitor in the feedback path to provide a feedback voltage to the input circuit which is in substantial quadrature to the output circuit voltage.
2. A differentiating amplifier adapted for delivering an output voltage substantially linearly proportional to the time derivative of the input voltage comprising at least one amplifier stage, an input circuit and an output circuit for the amplifier, a feedback path from the output circuit to the input circuit, and a resistor and a capacitor serially connected in the output circuit, the capacitor also forming a part of the feedback path to the input circuit to provide a feedback voltage to the input circuit which is in substantial quadrature to the output circuit voltage.
3. A differentiating amplifier adapted for delivering an output voltage substantially linearly proportional to the time derivative of the input voltage comprising at least one amplifier stage, an input circuit and an output circuit for the amplifier, a feedback path from the output circuit to the input circuit, and a resistor and a capacitor serially connected in the output circuit, the capacitor also being serially connected in the feedback path to the input circuit to provide a feedback voltage to the input circuit which is in substantial quadrature to the output circuit voltage.

4. A differentiating amplifier adapted for delivering an output voltage substantially linearly proportional to the time derivative of the input voltage comprising at least one amplifier stage, an input circuit and an output circuit for the amplifier, a feedback path from the output circuit to the input circuit, and a resistance means and a capacitance means serially connected in the output circuit, the capacitance means also forming a part of the feedback path to the input circuit to provide a feedback voltage to the input circuit which is in substantial quadrature to the output circuit voltage.

5. A differentiating amplifier adapted for delivering an output voltage substantially linearly proportional to the time derivative of the input voltage comprising a single stage vacuum tube amplifier having input and output circuits, a feedback path from the output circuit to the input circuit, and a resistance means and a capacitance means serially connected in the output circuit, the capacitance means also forming a part of the feedback path to provide a feedback voltage in substantial quadrature to the output circuit voltage.

6. A differentiating amplifier adapted for delivering an output voltage substantially linearly proportional to the time derivative of the input voltage comprising a single stage vacuum tube amplifier having input and output circuits, a feedback path from the output circuit to the input circuit and a resistor and a capacitor serially connected in the output circuit, the capacitor also forming a part of the feedback path to provide a feedback voltage in substantial quadrature to the output circuit voltage.

7. A differentiating amplifier adapted for delivering an output voltage substantially linearly proportional to the time derivative of the input voltage comprising a single-stage vacuum tube amplifier having input and output circuits, a feedback path from the output circuit to the input circuit, and a resistor and a capacitor serially connected in the output circuit, the capacitor also being serially connected in the feedback path to the input circuit to provide a feedback voltage in substantial quadrature to the output circuit voltage.

8. A differentiating amplifier adapted for delivering an output voltage substantially linearly proportional to the time derivative of its input voltage comprising a two-stage vacuum tube amplifier, input and output circuits for each stage, the output circuit of the first stage being con-

nected to the input circuit of the second stage, a feedback path from the output circuit of the second stage to the input circuit of at least one of the two stages, a resistor and a capacitor serially connected in the output circuit of the second stage, the capacitor also being connected in the feedback path to provide a feedback voltage in substantial quadrature to the output circuit voltage of the amplifier.

9. A differentiating amplifier adapted for delivering an output voltage substantially linearly proportional to the time derivative of its input voltage comprising a two-stage vacuum tube amplifier, input and output circuits for each stage, the output circuit of the first stage being connected to the input circuit of the second stage, a feedback path from the output circuit of the second stage to the input circuit of both stages, a resistor and a capacitor serially connected in the output circuit of the second stage, the capacitor also being serially connected in the feedback path to provide a feedback voltage in substantial quadrature to the output circuit voltage.

10. A differentiating amplifier adapted for delivering an output voltage substantially linearly proportional to the time derivative of its input voltage comprising a plurality of successively connected vacuum tube stages including a first stage and a last stage, a feedback path from the output circuit of the last stage to the input circuit of the first stage, a resistor and a capacitor serially connected in the output circuit of the last stage, said capacitor also being serially connected in the feedback path to provide a feedback voltage in substantial quadrature to the output circuit voltage.

11. A differentiating amplifier adapted for delivering an output voltage substantially linearly proportional to the time derivative of its input voltage comprising at least one amplifier stage capable of transmitting a wide frequency range down to and including direct current variations, an input circuit and an output circuit therefor, a feedback path from the output circuit to the input circuit, means including a resistive element and a capacitive reactive element connected in the output circuit, said reactive element also being connected in the feedback path to provide a feedback voltage in substantial quadrature to the output circuit voltage whereby the resistive element will have developed thereacross a voltage responsive only to the rate at which the input voltage changes with respect to time.

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