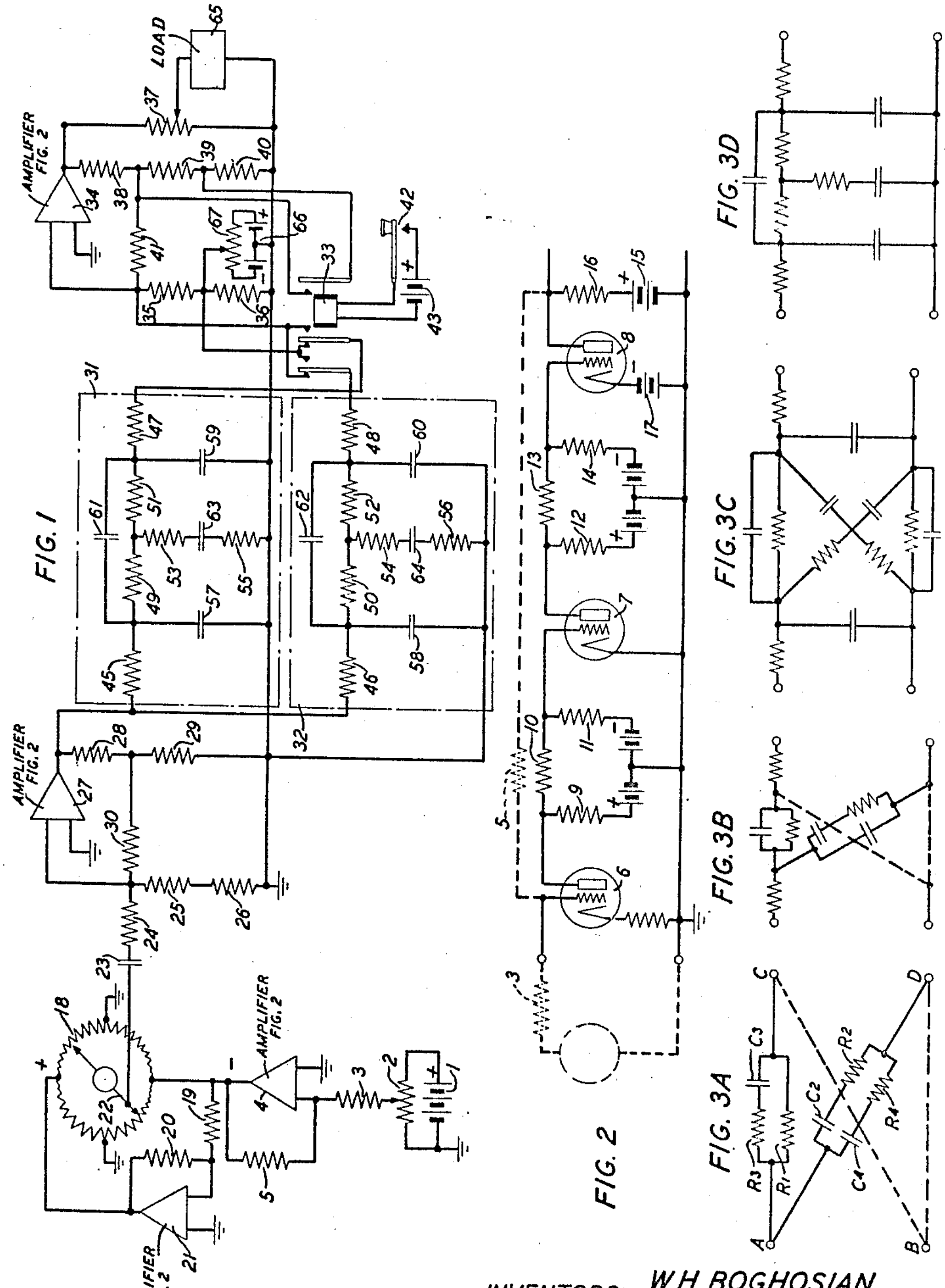
235-404 SR
XR 2,458,553
SEARCH ROOM

ELECTRONIC COMPUTING DEVICE

Filed Feb. 23, 1944



INVENTORS: W.H. BOGHOSIAN
H.G. OCH

BY W.L. Dawson

ATTORNEY

Patented Jan. 11, 1949

2,458,553

UNITED STATES PATENT OFFICE

2,458,553

ELECTRONIC COMPUTING DEVICE

William H. Boghosian, Forest Hills, and Henry G. Och, New York, N. Y., assignors to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application February 23, 1944, Serial No. 523,514

6 Claims. (Cl. 250—27)

1

This invention relates to electrical computing devices in which the data are represented by electrical quantities.

The object of the invention is to remove perturbations of the currents due to observational inaccuracies and other undesired variations.

A feature of the invention is a pair of electrical networks having different time constants both so proportioned as to cooperate with a third network.

Another feature of the invention is means for switching either of the two networks into the circuit, and for retaining the inactive network at a voltage such that, when switched into the circuit, the transient disturbance produced by the switching operation will be reduced.

A further feature of the invention is means for changing the contants of the circuit to properly cooperate with the network switched into the circuit.

In the drawings:

Fig. 1 shows a typical computing system embodying the invention;

Fig. 2 shows an amplifier used in the system of Fig. 1; and

Figs. 3-A, B, C, and D show modifications of the networks in Fig. 1.

In Fig. 1, a source of voltage 1 is connected across the winding of a potentiometer 2. The brush of potentiometer 2 is moved either manually or automatically in accordance with some observed quantity, such as the horizontal distance to an artillery target.

The voltage selected by the wiper of potentiometer 2 is applied through resistor 3 to the input circuit of an amplifier 4, which may be of the type shown in Fig. 2, having a feedback resistor 5.

The amplifier shown in Fig. 2 may conveniently be of the type disclosed in allowed United States application, Serial No. 391,331, filed May 1, 1941 by K. D. Swartzel now United States Patent 2,401,779 issued June 11, 1946, and assigned to the assignee of the present application. Vacuum tubes 6, 7, 8 are coupled by any suitable interstage networks 9, 10, 11 and 12, 13, 14 such as shown in United States Patent 1,751,527, March 25, 1930, H. Nyquist, to form a three-stage, high-gain amplifier. Though, for convenience the vacuum tubes 6, 7, 8 have been disclosed as triodes, if a larger voltage amplification is desired these triodes may be replaced with tetrodes or pentodes, with a corresponding change in the power supplies.

A source of voltage 15 supplies power through

2

resistor 16 to the anode of vacuum tube 8. Another source of voltage 17 has a negative pole connected to the cathode of vacuum tube 8. The voltages of the sources 15, 17 are so chosen that, in the absence of a signal voltage applied to the control electrode of vacuum tube 8, the sources of voltages 15, 17 with the resistances of the resistor 16 and the anode-cathode circuit of vacuum tube 8 form a balanced bridge, and no voltage is supplied to the output circuit. When a signal voltage is applied to the control electrode of vacuum tube 8, the resistance of the anode-cathode circuit is changed, the bridge is unbalanced and a voltage is supplied to the output circuit.

As the amplifier shown in Fig. 2 has an odd number of stages of amplification, the voltage supplied to the output circuit will be opposite in polarity to the signal voltage applied to the input circuit of vacuum tube 6, that is, the amplifier shown in Fig. 2 reverses the polarity of the applied voltage.

If a signal voltage be supplied to the input circuit of vacuum tube 6 through a resistor 3, and negative feedback from the anode of vacuum tube 8 be supplied through a resistor 5, the voltage amplification of the amplifier will be proportional to the ratio of the resistance in the feedback path to the resistance in the supply path. If the feedback resistor 5 is connected to a voltage divider across the output circuit of vacuum tube 6, the voltage amplification will be the quotient of the ratio of the feedback and series resistances and the fraction of the output voltage applied to the feedback resistor.

If a large amount of feedback be used, the effective impedance of the input circuit of the amplifier shown in Fig. 2 is small and may be considered as substantially zero. Similarly, the effective output impedance of vacuum tube 8 is small, and vacuum tube 8 may be considered substantially as a zero impedance voltage source.

If the voltage selected by the wiper of potentiometer 2 is proportional to +D, the distance to a target, the output voltage of amplifier 4 will be proportional to −D. The output circuit of amplifier 4 is connected to a tap of the potentiometer winding 18, and through resistor 19 to the input circuit of amplifier 21. Amplifier 21 may be of the type shown in Fig. 2, having a feedback resistor 20. The output circuit of amplifier 21 is connected to a tap of the potentiometer winding 18 diametrically opposite to the first tap. The equidistant intermediate points of the potentiometer winding 18 are grounded.

The potentiometer winding 18 may be in the form of a length of resistance wire wound evenly on a card of suitable material, shaped as indicated in the drawings so that the voltage along the winding has a sinusoidal variation. The card is formed into a circle concentric with the shaft rotating the brush 22.

The brush 22 is rotated, either manually or automatically in accordance with some observed quantity, such as the azimuth angle of the target. The voltage selected by the brush 22 will then be proportional to a rectangular coordinate of the position of the target, in the present case, say, to the x coordinate.

It will be understood that the present invention is not limited to the particular observing means shown, but may be used with any observing system which produces a voltage proportional to a linear variation in some observed quantity.

Brush 22 is connected through capacitor 23 and resistors 24, 25, 26 to ground. The voltage developed across resistors 25, 26 is applied to the input circuit of the amplifier 27, which may be of the type shown in Fig. 2. Resistors 28, 29 form a voltage divider connected across the output circuit of amplifier 27, supplying reverse feedback through resistor 30 to the input circuit of amplifier 27.

The output circuit of amplifier 27 is connected to the input circuits of the networks 31 and 32.

The network 32, or 31, with the capacitor 23 acts to produce a current proportional to the smoothed, weighted time derivative of the voltage selected by the brush 22. If the brush 22 is moved proportionally to the displacement of a body, the current from network 32 will be proportional to the speed or rate of the body.

The output circuit of network 32 is connected through the left break springs of relay 33 to the input circuit of amplifier 34 which may be of the type shown in Fig. 2. The output circuit of network 31 is connected through the center break springs of relay 33 and resistor 36 to ground.

Resistors 35, 36 are connected in serial relationship across the input circuit of amplifier 34. The output circuit of amplifier 34 is connected to the winding of a potentiometer 37. The brush of potentiometer 37 is moved, either manually or by known automatic means, proportionally to some time interval, such as the time of flight of a shell. The voltage selected by the brush of potentiometer 37 will then be proportional to the product of the smoothed and weighted rate from the network multiplied by the time interval, that is, to the linear change during the time interval. The voltage selected by the brush of potentiometer 37 is supplied to any suitable computing circuit, represented by the load 65. If the linear change during the time interval is to be measured, the load 65 may be any suitable meter or other indicating device.

Resistors 38, 39, 40 form a voltage divider across the output circuit of amplifier 34, supplying through resistor 41 reverse feedback to the input circuit of amplifier 34.

Relay 33 may be operated by any suitable means, such as the key 42 controlling the current from a source 43.

The operation of relay 33 connects the output circuit of network 31 through the center make springs of relay 33 to the input circuit of amplifier 34 and opens the connection to resistor 36. The operation of relay 33 also connects the output circuit of network 32 through the left make springs of relay 33 and resistor 36 to ground and opens the connection to amplifier 34. The operation of relay 33 also short circuits resistor 39 at the right make springs.

In order to adjust the output voltage of amplifier 34 exactly to zero for no applied signal voltage, a biasing voltage of the proper polarity from the grounded source 66 and potentiometer 67 may be applied through resistor 35 to the input circuit of amplifier 34. The output circuits of the networks 31, 32 when switched to the input circuit of the amplifier 34 should have the same potential as the input circuit so as to reduce transients due to the switching. The output circuit of the inactive network is thus connected through the springs of relay 33 to the junction of resistors 35 and 36 and is thus maintained at the same biasing potential as the input circuit of amplifier 34.

In many computing systems, such as artillery computers, the observed object or target is moving without acceleration, that is, in a straight line at constant speed. The observations are usually made in a system of polar coordinates, in which the linear and angular speeds or rates of change are continually varying. When observations are converted into rectangular coordinates, the rates of change in the coordinates should be constant. Because of the continual variation in the linear and angular rates of change, the observers will tend to overrun and underrun the target in a roughly cyclic manner, and these perturbations, together with undesired variations due to the turns of wire on the potentiometers and various spurious variations, are reproduced in the representations of the rectangular coordinates.

From the electrical quantity varying with a rectangular coordinate of the position of an observed object, the present invention derives an electrical quantity varying with the rate of change of the rectangular coordinate, smoothed and weighted to a preferred average.

If a voltage proportional to the experimentally determined values of a linearly varying quantity is applied to a network, and the output of the network is to be proportional to the smoothed values of the time rate of change of the quantity, weighted over a predetermined past time interval in accordance with the theory of least squares, it may be shown that the indicial admittance, or response with time to unit voltage impulses, should rise from zero to a maximum during the interval and decrease to zero at present time, the function having approximately a parabolic variation.

In the present network, the indicial admittance or weighting function has this form, and may be represented by the following function:

$$f(t)=.9493e^{-1.6t}-8.6763e^{-2.4t}+34.7311e^{-3.6t}-27.0041e^{-4.8t}$$

By known methods, this exponential function may be expressed, in terms of admittance on a unit time basis, as

$$Y(p)=.9493\frac{p}{p+1.6}-8.6763\frac{p}{p+2.4}+34.7311\frac{p}{p+3.6}-27.0041\frac{p}{p+4.8} \quad (1)$$

The admittance of a resistance R in series with a capacitance C is

$$Y(p)=\frac{1}{R}\cdot\frac{p}{p+\frac{1}{RC}}$$

Thus, each term of Equation 1 may be satisfied by a resistance of proper value in series with a capacitance of proper value.

Smoothing networks of this character require an appreciable time to charge the capacitors before the output of the network settles down and accurately represents the desired data. Within reasonable limits, the more the network smooths the applied quantities, the more accurately the output will represent the true value of the data, and the longer will be the settling time.

In some computers, such as anti-aircraft artillery computers, the guns should commence firing on the target as soon as possible after observations have commenced. As the first observations will not be very accurate, it is not necessary to smooth and weight these early data as completely as later data. Thus, in the present system, when the key **42** is operated at the commencement of observations, the network **31** having a settling time of 10 seconds is switched into the circuit. The observed data are smoothed by this network for say 20 to 30 seconds, then key **42** is released and network **32**, having a settling time of 20 seconds, is switched into the circuit.

The settling time is approximately the time required for the transient current due to a unit rate impulse to reach 99 per cent of its final value. For a settling time of 10 seconds, Equation 1 becomes

$$Y(p)=\frac{.09493p}{p+.16}-\frac{.86763p}{p+.24}+\frac{3.47311p}{p+.36}-\frac{2.70041p}{p+.48} \qquad (2)$$

and for a settling time of 20 seconds, Equation 1 becomes

$$Y(p)=\frac{.047465p}{p+.08}-\frac{.433815p}{p+.12}+\frac{1.736555p}{p+.18}-\frac{1.350205p}{p+.24} \qquad (3)$$

Equations 2 and 3 are of the form

$$Y(p)=\frac{Ap}{p+a}-\frac{Bp}{p+b}+\frac{Cp}{p+c}-\frac{Dp}{p+d}$$

This may be factored as follows

$$Y(p)=\frac{p}{p+b}\left(-B+(p+b)\left[\frac{A}{p+a}+\frac{C}{p+c}-\frac{D}{p+d}\right]\right)$$

$$=\frac{p}{p+b}\left(-B+A\left[\frac{\left(1-\frac{b}{a}\right)p}{p+a}+\frac{b}{a}\right]+C\left[\frac{\left(1-\frac{b}{c}\right)p}{p+c}+\frac{b}{c}\right]-D\left[\frac{\left(1-\frac{b}{d}\right)p}{p+d}+\frac{b}{d}\right]\right)$$

$$=\frac{p}{p+b}\left(\left[-B+A\left(\frac{b}{a}\right)+C\left(\frac{b}{c}\right)-D\left(\frac{b}{d}\right)\right]+\left[\frac{A\left(1-\frac{b}{a}\right)p}{p+a}+\frac{C\left(1-\frac{b}{c}\right)p}{p+c}-\frac{D\left(1-\frac{b}{d}\right)p}{p+d}\right]\right)$$

Thus, Equations 2 and 3 may respectively be factored into

$$(Yp)=\frac{p}{p+.24}\left[.239967-\frac{.047465p}{p+.16}+\frac{1.157703p}{p+.36}-\frac{1.350205p}{p+.48}\right] \qquad (4)$$

and

$$Y(p)=\frac{p}{p+.24}\left[.239967-\frac{.09493p}{p+.08}+\frac{.433815p}{p+.12}-\frac{.578852p}{p+.18}\right] \qquad (5)$$

A network may be divided into two portions in cascade, if the reaction of the latter portion of the network on the first portion is prevented by some unilaterally conductive device, such as the amplifier **27**. The common factor

$$\frac{p}{p+.24}$$

in Equations 4 and 5, which represents the serial combination of a capacitor and a resistor, thus may be divided out, and is represented by the capacitor **23** and resistor **24** connected between the brush **22** and the input circuit of the amplifier **27**.

If the voltage selected by the brush **22** be proportional by some scale factor of say volts per yard, to say the x coordinate of the position of some moving body, the voltage selected by the wiper of potentiometer **37** should be proportional, to the same scale factor, to $\dot{x}t$, the linear change in x during the time t, which is the time rate of change of x multiplied by the time interval. The potentiometer **37** fractionates or divides the output voltage of the network. If tm be the maximum value of the time interval, the voltage supplied to the winding of potentiometer **37** should be $\dot{x}tm$, which is fractionated by the potentiometer **37** in the ratio

$$\frac{t}{tm}$$

so that the voltage selected by the wiper of potentiometer **37** will be

$$(\dot{x}tm)\frac{t}{tm}$$

or $\dot{x}t$. The voltage amplification ratios of the amplifiers **27**, **34** are adjusted so that the product of the voltage amplifications of the amplifiers **27**, **34** is equal to tm.

If the voltage across resistor **29** is

$$\frac{1}{K}$$

of the output voltage of amplifier **27**, and the voltage amplification of the amplifier **27** without feedback is large, it may be shown that the output voltage e_0 of the amplifier **27** is related to the voltage e selected by the wiper **22** by the following equation

$$e_0=-\frac{1}{K}\times\frac{R30}{R24}\times\frac{p}{p+\frac{1}{R24C23}}\cdot e \qquad (6)$$

The proportionality factor

$$\frac{1}{K}\times\frac{R30}{R24}$$

is the effective voltage amplification factor of the amplifier **27** and this factor may be equal to, or a factor of, tm.

The factor

$$\frac{p}{p+\frac{1}{R24C23}}$$

of Equation 6 is the factor

$$\frac{p}{p+.24}$$

of Equations 4 and 5. Thus, if **C23** be 1 microfarad, **R24** will be 4.16 megohms.

In a lattice network having series admittances

Y_a and lattice admittances Y_b, the transfer admittance when operated from a zero impedance generator to a zero impedance load may be written as

$$Y=\frac{Y_a}{2}-\frac{Y_b}{2}$$

This leads to a direct synthesis of the admittance function as a lattice network by selecting the positive elements for the series arms and the negative elements for the lattice arms.

$$YA=2\left[.239967+\frac{1.157703p}{p+.36}\right]=\frac{1}{R1}+\frac{1}{R3}\left(\frac{p}{p+\frac{1}{R3C3}}\right)$$

$$YB=2\left[\frac{.047465p}{p+.16}+\frac{1.350205p}{p+.48}\right]=\frac{1}{R2}\left(\frac{p}{p+\frac{1}{R2C2}}\right)+\frac{1}{R4}\left(\frac{p}{p+\frac{1}{R4C4}}\right)$$

in which:

R1=2.08362
R2=10.53410
R3=.43189
R4=.37031
C2=.59331
C3=6.43168
C4=5.62585.

Equation 5 may be similarly solved.

The equivalent lattice network will then be as shown in Fig. 3A, having the series arms R1 in parallel with the series combination of R3 and C3 between terminals A—C and B—D, and the lattice arms R2 in series with C2 in parallel with the series combination of R4 and C4 between terminals A—D and B—C. As the series and lattice impedances have a common resistive term, these resistors may form series arms as shown in Fig. 3B. As the remaining series and lattice admittances have a common reactive term, these reactances may form shunt arms as shown in Fig. 3C. The remaining lattice may then be transformed into a bridged T-network, to produce the final form shown in Fig. 3D.

In a typical embodiment of the invention, the network **31** had a 10 second settling time and the network **32** had a 20 second settling time. The capacitor **23**, which should have a stable dielectric such as polystyrene, has a capacity of 1 microfarad and the resistor **24** a resistance of 4.167 megohms. Resistor **25** is 20 megohms and resistor **26** about 10,000 ohms. Resistors **28** and **29** are 15,000 and 12,000 ohms. The amplifier **27** has a voltage gain of 25.5, thus resistor **30** is 10 megohms.

In the network **31**, resistors **45** and **47** are .76 megohm; resistors **49** and **51** are 3.67 megohms; resistors **53** and **55** are 11.55 megohms; capacitors **57** and **59** are 2.8 microfarads; capacitor **61** is 0.80 microfarad and capacitor **63** is 2.45 microfarads.

In the network **32**, resistors **46** and **48** are 1.58 megohms; resistors **50** and **52** are 2.86 megohms; resistors **54** and **56** are 8.26 megohms, capacitors **58** and **60** are 3.82 microfarads; capacitor **62** is 2.17 microfarads and capacitor **64** is .64 microfarad.

Resistor **35** is 12.83 megohms and resistor **36** is 10,000 ohms. Resistors **38**, **39**, **40** are 40,000 ohms, about 10,000 ohms, and about 18,000 ohms. Resistor **41** is 5 megohms.

It will be noted that the sum of all the series resistors in the 10 second network, namely, **45**+**49**+**51**+**47**, is equal to the sum of all the series resistors in the 20 second network, namely, **46**+**50**+**52**+**48**. The amplification of amplifier **34** is therefore not changed in switching from one to the other except for commercial variations in these sums. This tendency is corrected by switching resistor **39** so as to make a corresponding change in the output voltage supplied to the feedback resistor **41**.

What is claimed is:

1. In a computer, a source of voltage, means connected to said source and adusted to draw from said source a voltage proportional to varying with a measured quantity, a first feedback amplifier having an input and an output circuit, a capacitor and a resistor connected in serial relationship from said means to the input circuit of said first amplifier, a second feedback amplifier having an input and an output circuit, and a network connected from the output circuit of said first amplifier to the input circuit of said second amplifier, said capacitor and resistor and said network being so proportioned that the indicial admittance to said voltage varies from zero through a single maximum to zero, and the output of said second amplifier is a smoothed, weighted average of the rate of change of the voltage drawn from said source.

2. In a computer, a source of a voltage, means connected to said source and adjusted to draw from said source a voltage proportional to varying with a measured quantity, a first feedback amplifier having an input and an output circuit, a capacitor connected from said means to the input of said amplifier, a second feedback amplifier having an input and an output circuit, and a network connected from the output circuit of said first amplifier to the input circuit of said second amplifier, said capacitor and said network being so proportioned that the output of said second amplifier is proportional to the time rate of change of said voltage weighted in accordance with a function varying from zero through a maximum for past times to zero at the present time.

3. In combination, a source of a voltage varying with a measured quantity, a first amplifier having an input and an output circuit, a first resistor connected from said output to said input circuit, a capacitor in serial relationship with a second resistor connected from said source to said input circuit, a second amplifier having an input and an output circuit a potential divider having an adustable tap connected across the output circuit of said second amplifier, a feedback resistor connected from said tap to the input circuit of said amplifier, a plurality of networks connected in parallel relationship to the output circuit of said first amplifier, said networks having series resistors of different resistances and switching means for at will, connecting one of said networks to the input circuit of said amplifier and adusting said tap to maintain constant the gain of said second amplifier.

4. In combination, a grounded source of voltage, a first amplifier having grounded input and output circuits, a first capacitor connected from said source to said input circuit, a first resistor connected from said input circuit to said output circuit, a second amplifier having grounded input and output circuits, a load connected to the output circuit of said second amplifier, a second resistor connected from the input circuit to the output circuit of said second amplifier, and

a network connected from the output circuit of said first amplifier to the input circuit of said second amplifier, said network including third, fourth, fifth and sixth series resistors, a second capacitor connected to ground from the junction of said third and fourth resistors, a third capacitor connected across said fourth and fifth resistors, a fourth capacitor in serial relationship with a seventh resistor connected to ground from the junction of said fourth and fifth resistors and a fifth capacitor connected to ground from the junction of said fifth and sixth resistors, said first capacitor and said network being so proportioned that the indicial admittance of the combination varies from zero through a single maximum to zero.

5. In combination, a grounded source of voltage, a first amplifier having grounded input and output circuits, a first capacitor connected from said source to said input circuit, a first resistor connected from said input to said output circuit, a second amplifier having grounded input and output circuits, a second resistor connected from the input to the output circuit of said second amplifier, a plurality of networks connected in parallel relationship to the output circuit of said first amplifier, each of said networks including a plurality of series resistors, the total resistance of the series resistors of one network being equal to the total resistance of the series resistors of the other networks, and a plurality of shunt capacitors connected to ground from the junctions of said resistors, and switching means for, at will, connecting any one of the series of resistors to the input circuit of said second amplifier, said first capacitor and each of said networks being so proportioned that said networks have different settling times but in each case the indicial admittance of the combination varies from zero, through a maximum, to zero.

6. In combination, a grounded source of voltage, a first amplifier having grounded input and output circuits, a first capacitor connected from said source to said input circuit, a first resistor connected from said output to said input circuit, a second amplifier having grounded input and output circuits, a load connected to the output circuit of said second amplifier, a second resistor connected from the output to the input circuit of said second amplifier, and a plurality of networks connected in parallel relationship to the output circuit of said second amplifier, each of said networks including third, fourth, fifth and sixth resistors, the sum of the resistances in each network being the same, a second capacitor connected to ground from the junction of said third and fourth resistors, a third capacitor in series with a seventh resistor connected to ground from the junction of said fourth and fifth resistors, a fourth capacitor connected to ground from the junction of said fifth and sixth resistors, a fifth capacitor connected in parallel with said fourth and fifth resistors and switching means for, at will, connecting any one of said networks to the input circuit of said second amplifier, said first capacitor and each of said networks being so proportioned that said networks have different settling times but, in each case, the indicial admittance of the combination varies from zero, through a maximum, to zero.

WILLIAM H. BOGHOSIAN.
HENRY G. OCH.

REFERENCES CITED

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

UNITED STATES PATENTS

Number	Name	Date
2,099,536	Scherbotskoy	Nov. 16, 1937
2,217,957	Lewis	Oct. 15, 1940
2,251,973	Beale et al.	Aug. 12, 1941
2,324,797	Norton	July 20, 1943
2,365,014	Silverman	Dec. 12, 1944