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FREQUENCY SENSITIVE CIRCUIT

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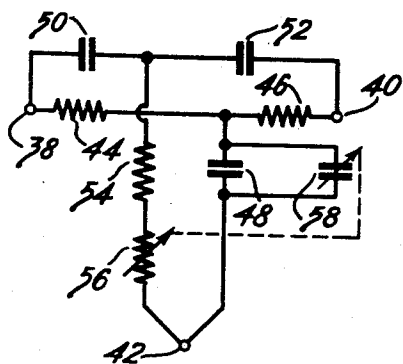
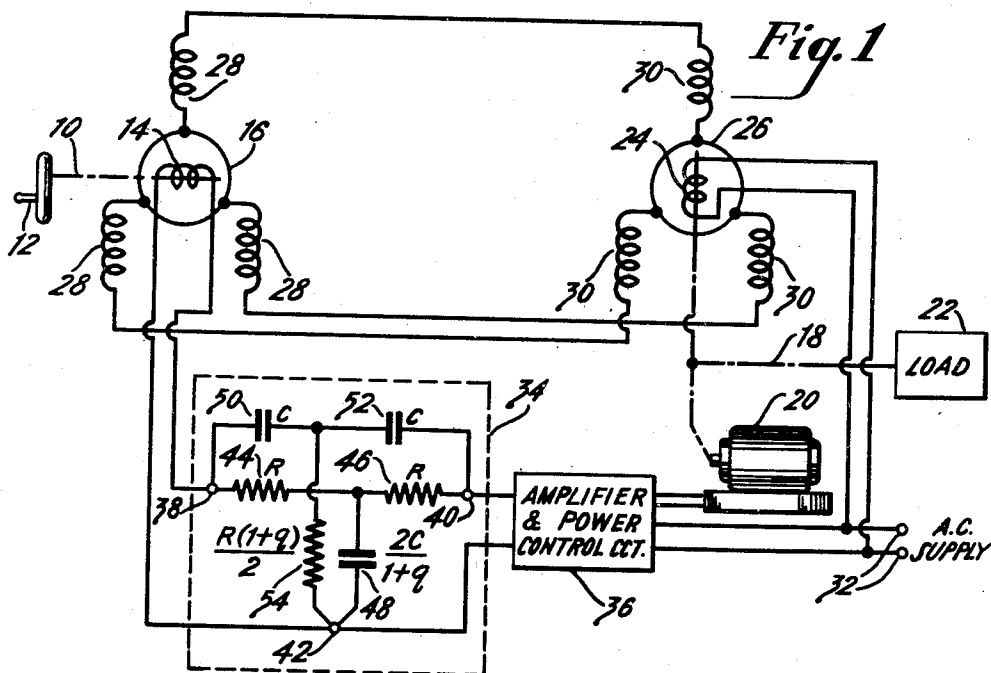


Fig. 2

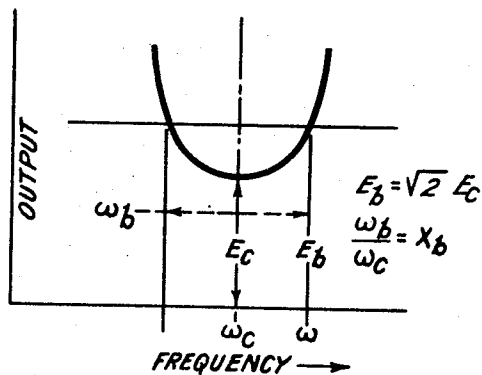


Fig. 3

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FREQUENCY SENSITIVE CIRCUIT

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This invention relates to frequency sensitive circuits, and its prime object is to provide a simple, compact and inexpensive circuit for adding to an amplitude modulated signal a component representative of the rate of change of the modulation of the signal.

It is sometimes undesirable to introduce inductive elements into frequency responsive circuits, particularly when signals of low frequency are concerned, because inductors are bulky and expensive by comparison with other reactors and because magnetic interaction may occur between the inductors and other electrical elements.

It is, therefore, an object of the invention to provide an improved frequency responsive circuit containing resistive and capacitive elements only.

A circuit of the character described may have many applications in the electrical arts. One such application is in electrical control systems of the type in which there is produced an alternating signal representative of a condition to be controlled by the system. To avoid hunting due to inertia and the like, and thus to stabilize the operation of the system, it is desirable to introduce in the control signal a component representative of the rate of change of its amplitude or, in the case of a servo or follow-up system, of the rate of change of position.

It is, therefore, an object of the invention to provide an improved method of and means for stabilizing an electrical control system.

An additional object is to provide an improved anti-hunting arrangement in a system of the character described.

A further object is to provide an improved method of and means for introducing a velocity component in the control signal of an electrical control system.

According to the invention these objects are achieved by providing two parallel paths for a signal applied thereto. One of these paths constitutes a T-network having resistive series arms and a capacitive shunt arm, while the other path constitutes another T-network having capacitive series arms and a resistive shunt arm. The values of the elements of the series arms are related to a particular frequency of the applied signal, and the shunt arms are related in value to the series arms in a manner hereinafter described.

A permissible analysis is to regard one of the two networks as advancing the phase of the applied signal while the other network retards the phase of the signal applied thereto. The impedances of the respective networks also vary the

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relative magnitude of the phase-displaced signals in each path. The combined output of the two paths comprises two components which are, respectively, in phase with the input and 90° out of phase therewith. The in-phase component remains substantially constant through a predetermined frequency range of the input, while the output component in quadrature with the input varies substantially linearly with the frequency of the applied signal through that range. The magnitude of the output varies with the magnitude of the input signal and also with the rate of change of magnitude of that signal. As will be later explained, suitable choice of the elements of the shunt arms determines the ratio in which these ingredients are present in the output.

The invention may be better understood from the following description of two embodiments thereof, when read in conjunction with the accompanying drawing in which:

Figure 1 is a diagram of an electrical control system including a circuit according to the invention,

Figure 2 is a circuit diagram of an alternative embodiment of the invention, and

Figure 3 is a graph showing the frequency response of the circuit of the invention.

Fig. 1 is a diagrammatic representation of a control system of the type known as a "follow-up" or "servo" system. The system includes an input shaft 10 rotatable, as for example, by a crank 12 or by any other appropriate means and mechanically connected to the rotor winding 14 of a synchro or "Selsyn" element 16. An output shaft 18 driven by an electric motor 20 is connected to a load 22 and also to the rotor winding 24 of another synchro element 26. The stator windings 28 and 30, respectively, of the two synchro elements are connected together as shown, and the synchro elements are connected to a source of alternating voltage indicated at 32, which may, by way of example, be the commercial supply having a frequency of 60 cycles per second.

When there is any difference between the angular positions of the input and output shafts, an alternating voltage is generated in the rotor winding of the synchro element 16. The magnitude of this voltage is proportional to the angular displacement between the two shafts and its instantaneous polarity depends upon which of the shafts leads or lags the other. Disregarding temporarily the circuit 34, the alternating control signal is applied to an amplifier 36 which may include a power control circuit. The

signal thus obtained controls the speed and direction of rotation of the armature of the motor 20. The motor drives the output shaft into positional agreement with the input shaft by which time the control signal has been reduced to zero and the motor is de-energized.

Because of the inertia of the load 22 and other rotating parts of the system, and for other reasons, the shaft 18 and the load 22 may tend to rotate in either direction about the point of agreement with the input shaft, although the motor 20 has been deenergized. This effect is known as "hunting" and reduces the stability of the system.

The basic frequency of the control signal is that of the power supply. However, as the angular disagreement between the two shafts varies, the magnitude of the control signal varies also. The control signal may be regarded as having a carrier frequency determined by the A. C. power supply and as being modulated by a signal representative of the displacement between the input and output shafts of the system. A modulated control signal of this type may be considered to be composed of a carrier and sidebands. In a common case, where the carrier frequency is 60 cycles per second, the control signal may have components in the range of, say, 55 to 65 cycles per second.

The magnitude of the control signal represents the displacement in position between the input and output of the system. The addition to the control signal of a velocity component, that is to say, of a component representative of the rate of change of that displacement, makes the combined signal anticipatory of such changes. It therefore tends to reduce hunting and to improve the stability of the system. It is, therefore, desirable, to add to the control signal a component representative of the rate of change of the position between the input and output of the servo system.

The circuit 34 is connected between the synchro element 16 and the amplifier 36, and consists of two T-networks connected in parallel with each other. The circuit has an input terminal 38, an output terminal 40, and a third terminal 42 common to input and output. One of the T-networks consists of two equal resistors 44 and 46 connected in series between the input and output terminals, and a capacitor 48 connected in shunt between the junction point of the two series resistors and the common terminal 42. The other T-network comprises two equal capacitors 50 and 52 connected in series between the input and output terminals, and a resistor connected in shunt between the junction point of the two series capacitors and the common terminal.

Each of the series resistors has a value of R ohms and each of the series capacitors of C farads. If ω_c be taken as the radian frequency of the carrier signal, that is, of the control signal when the displacement between the input and output shafts is constant, then R and C are chosen to satisfy the expression

$$\omega_c = \frac{1}{RC}$$

As before explained, one of the T-networks advances the phase of the control signal and the other retards it. If the shunt capacitor were chosen of a value of 2C farads and the shunt resistor of

$$\frac{R}{2}$$

ohms, the phase shift attributable to each network would be 90°, but in opposite directions in each case. The respective outputs of each network would then be in opposite phase, and maximum attenuation of the carrier signal would be effected. The combined output of circuit 34 would then be representative of the rate of change of the amplitude of the control signal, that is, of the rate of change of the positional difference between the shafts 10 and 18. It would contain no component representative of that difference itself.

The shunt capacitor 48, therefore, is given a value of

$$\frac{2C}{1+q}$$

farads and the resistor 54 a value of

$$\frac{R(1+q)}{2}$$

ohms, where q is equal to a positive number greater than zero. This has the effect of varying the relative magnitude and phase of the outputs of the two T-networks. Within a given range of frequencies of the input to circuit 34, the component of its output which is in phase with that input remains substantially constant, while the component which is 90° out of phase with the input varies linearly with frequency. The combined output of the circuit contains a component representative of the displacement between the two shafts 10 and 18, and another component representative of the rate of change of that displacement.

The ratio of what may be described as the "displacement" component to the "displacement rate" component depends on the value of q. For the range of frequencies met with in some practical types of servo systems, a value for q of the order of .2 has been found satisfactory.

Without entering into a detailed mathematical analysis of the operation of the circuit, the output voltage e at any radian frequency ω for unit input voltage is defined by the expression

$$e = \frac{x^2 + \frac{q(4+3q+q^2)}{1+q} + \frac{j(4+2q)x}{1+q}}{x^2 + \frac{(4+3q+q^2)^2}{1+q}} \text{ where } x = \frac{\omega}{\omega_c} - \frac{\omega_c}{\omega}$$

The approximate response of the circuit is illustrated by the curve of Fig. 3. At the carrier frequency, the output of circuit 34 is a minimum but is still a finite value. When the carrier signal is modulated and the frequency of the input varies about this point, the output increases and its phase with respect to the input varies also. When the output leads or lags the input by approximately 45°, the output is $\sqrt{2}$ times that at the minimum. The ratio x_b of the band width between these two points to the carrier frequency is a special case of x, and is then approximately equal to q.

The circuit of the invention has been found to give a linear response to signals which vary in frequency by 25 per cent from the frequency of the carrier signal.

Since the value of q determines the proportion of the displacement rate component in the signal applied by circuit 34 to amplifier 36, it may in some cases be desirable to vary the values of the shunt capacitor 48 and resistor 54. In that event, it may be desirable to employ the arrangement illustrated in Fig. 2. A variable resistor 56 is connected in series with the fixed resistor 54 and a variable capacitor 58 is connected

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in parallel with the fixed capacitor 48. The two variable elements are ganged and so arranged that by the operation of a single control the shunt resistance is increased while the shunt capacitance is decreased to a like extent.

By connecting two or more circuits of the invention in series, it is possible to introduce into the original signals components representative of the second and higher order derivatives of the frequency of the control signals.

Although the series resistors 44 and 46 and the series capacitors 50 and 52 have been described as equal to each other respectively, this limitation is inserted only because it is then easier to evaluate the response of the circuit. The characteristics of the circuit do not change materially if the resistance of the two series arms in one network, or the capacitance of the two series arms in the other network, are not equal.

There has thus been described a circuit comprising two T-networks connected in parallel, one network having series resistive branches and a shunt capacitive branch, and the other network having series capacitive branches and a shunt resistive branch. The values of the elements in the series branches are related to a given frequency of the signal to be applied to the circuit, and the values of the elements in the shunt branches are related to those in the series branches to add to the original signal a component representative of the rate of change of its amplitude. By connecting such a circuit in the control signal path of an electrical control system, hunting of the output of the system may be reduced and a substantial improvement in stability secured.

While the invention has been described with particular reference to its application to the control system illustrated in Fig. 1, it will be observed that it may be used in many other connections wherever it is desired (a) to add algebraically to a modulated alternating signal a component representative of the rate of change of its modulation, or (b) to add algebraically to a signal representing a given condition (for example, a given amount of light passing to a light-sensitive element) a component representing the rate of change of that condition, or (c) to derive from a signal, which varies in frequency through a given range, a second signal having a substantially constant component in phase with the original signal and a component 90° out of phase with the original signal, which varies linearly with the frequency of the original signal.

We claim as our invention:

1. A frequency sensitive circuit comprising a T-network having two substantially equal series-connected resistors and a shunt capacitor, and a second T-network connected in parallel with the first and having two substantially equal series connected capacitors and a shunt resistor, said shunt capacitor and resistor having respective values of

$$\frac{2C}{1+q}$$

farads and

$$\frac{R(1+q)}{2}$$

ohms, where C equals the capacitance in farads of each of the series-connected capacitors, R equals the resistance in ohms of each of the series-connected resistors, and q equals a positive number greater than zero.

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2. A circuit according to claim 1, wherein q is of the order of .2.

3. A frequency responsive network having an input terminal, an output terminal and a common input-output terminal, two substantially equal resistors connected in series between the input and output terminals, two substantially equal capacitors connected in series with each other and in parallel with said resistors between said last-mentioned terminals, a capacitor having one terminal connected to the junction point of said series-connected resistors and the other terminal connected to the common input-output terminal, and a resistor having one terminal connected to the junction point of said series-connected capacitors and the other terminal connected to said common terminal, said last-mentioned capacitor and resistor having respective values of

$$\frac{2C}{1+q}$$

farads and

$$\frac{R(1+q)}{2}$$

ohms, where C equals the capacitance in farads of each of the series-connected capacitors, R equals the resistance in ohms of each of the series-connected resistors, and q equals a positive number greater than zero.

4. A circuit for adding to a modulated carrier signal a component representative of the rate of change of modulation of said signal, said circuit comprising a T-network having two substantially equal serially-connected resistors and a shunt capacitor, a second T-network connected in parallel with the first and having two substantially equal serially-connected capacitors and a shunt resistor, the value of said serially-connected resistors and capacitors being related to the carrier frequency of said signal by the expression

$$\omega_c = \frac{1}{RC}$$

wherein ω_c equals said carrier frequency in radians per second, R equals the value of each of said resistors in ohms and C equals the value of each of said capacitors in farads, and said shunt capacitor and resistor having values of

$$\frac{2C}{1+q}$$

farads and

$$\frac{R(1+q)}{2}$$

ohms respectively, q being any positive number greater than zero.

5. A circuit for adding to a modulated carrier signal a component representative of the rate of change of modulation of said signal, said circuit comprising a T-network having two substantially equal serially-connected resistors and a shunt capacitor, a second T-network connected in parallel with the first and having two substantially equal serially-connected capacitors and a shunt resistor, the value of said serially-connected resistors and capacitors being related to the frequency of the unmodulated carrier signal by the expression

$$\omega_c = \frac{1}{RC}$$

wherein ω_c is the frequency of the unmodulated carrier signal in radians per second, R equals

the value of each of said resistors in ohms and C equals the value of each of said capacitors in farads, and said shunt capacitor and resistor having values of

$$\frac{2C}{1+q}$$

farads and

$$\frac{R(1+q)}{2}$$

ohms respectively, q being approximately the ratio of the band width of the modulated signal to the frequency of the unmodulated carrier signal.

6. In combination, a source of modulated carrier signals, a load and a circuit connected between said sources and said load, said circuit comprising a T-network having two substantially equal series-connected resistors and a shunt capacitor, and a second T-network connected in parallel with the first and having two substantially equal series connected capacitors and a shunt resistor, said shunt capacitor and resistor having respective values of

$$\frac{2C}{1+q}$$

farads and

$$\frac{R(1+q)}{2}$$

ohms, where C equals the capacitance in farads of each of the series-connected capacitors, R equals the resistance in ohms of each of the series-connected resistors, and q equals a positive number greater than zero.

7. The combination, in an electrical control system with means for producing alternating control signals representative of a condition to be controlled by said system, of a frequency sensitive circuit comprising a T-network having two substantially equal series-connected resistors and a shunt capacitor, and a second T-network connected in parallel with the first and having two substantially equal series connected capacitors and a shunt resistor, said shunt capacitor and resistor having respective values of

$$\frac{2C}{1+q}$$

farads and

$$\frac{R(1+q)}{2}$$

ohms, where C equals the capacitance in farads of each of the series-connected capacitors, R equals the resistance in ohms of each of the series-connected resistors, and q equals a positive number greater than zero.

8. The combination, in an electrical control system with means for producing alternating control signals representative of a condition to be controlled by said system, of a frequency sensitive circuit comprising a network of resistive and capacitive elements only connected in series with said control-signal-producing means, said network and the values of the elements being chosen to make said network the equivalent of two T-networks in parallel, the first having two substantially equal serially-connected resistors and a shunt capacitor, and said second T-network having two substantially equal series-connected capacitors and a shunt resistor, said shunt capacitor and resistor having respective values of

$$\frac{2C}{1+q}$$

farads and

$$\frac{R(1+q)}{2}$$

ohms, where C equals the capacitance in farads of each of the series-connected capacitors, R equals the resistance in ohms of each of the series-connected resistors, and q equals a positive number greater than zero.

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