June 1, 1954 J. L. GARRISON ET AL 2,680,230

COMPENSATING NETWORK

Filed Oct. 19, 1950

FIG. 1

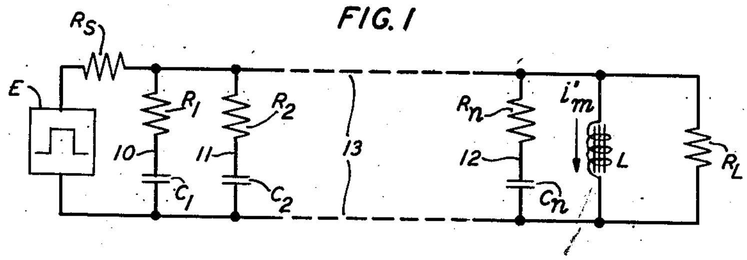


FIG. 2

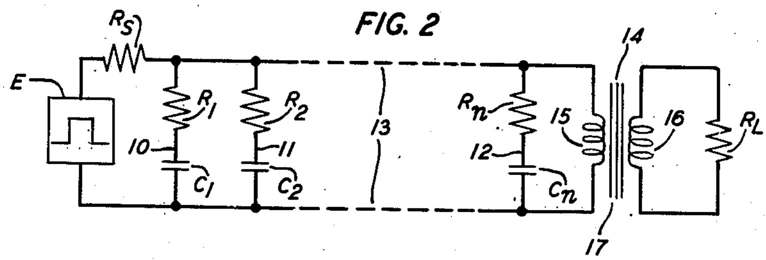


FIG. 3

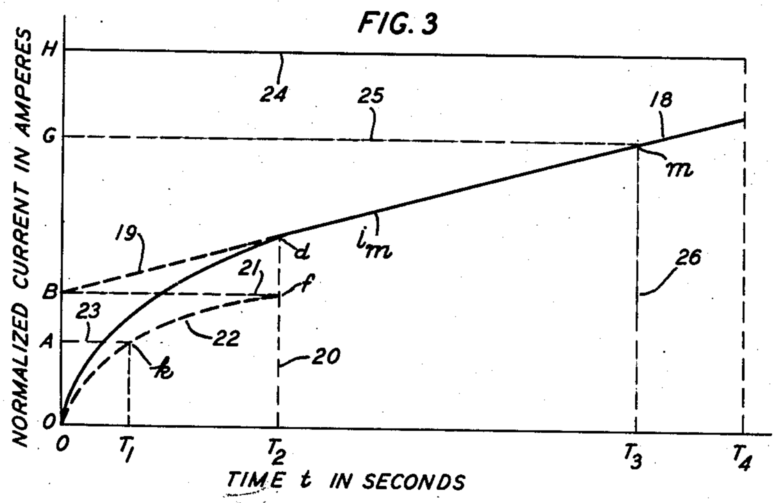
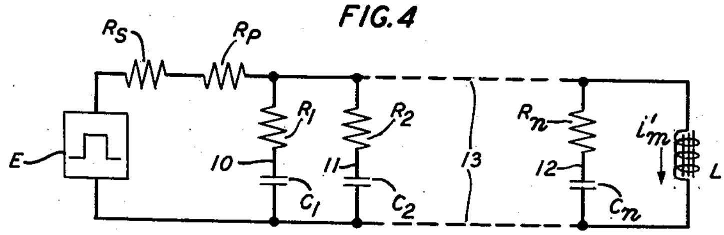


FIG. 4



INVENTORS: J. L. GARRISON
J. P. WHISTLER

BY Ralph T. Holcomb
ATTORNEY

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COMPENSATING NETWORK

Jedediah L. Garrison, Madison, N. J., and John P. Whistler, San Marino, Calif., assignors to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

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1

This invention relates to wave transmission and more particularly to a compensating network for use with a magnetic-cored inductor.

The principal object of the invention is to obtain throughout the pulse period a constant current through, and a constant voltage across, a resistive load connected to a source of unidirectional voltage pulses in a circuit which includes a magnetic-cored inductor.

A more specific object is to obtain a rectangular voltage pulse from a unidirectional voltage pulse impressed upon a magnetic-cored coil.

When a unidirectional voltage pulse is impressed upon a resistive load which has a magnetic-cored inductor connected in shunt or in series therewith, neither the voltage across the load nor the current therethrough remains constant over the period of the applied pulse. This is due to the fact that the magnetizing current taken by the inductor is not constant over this period. This current rises rapidly at first, as the eddy current flux is established throughout the core structure, and then gradually becomes substantially linear. Since the current drawn from the source varies, its terminal voltage also varies, due to the voltage drop caused by its interval impedance. Therefore, both the voltage supplied to, and the current through, the load will vary accordingly. Such a varying voltage and current are, in many cases, undesirable. For example, a rectangular voltage pulse at the load may be required, or a constant current to actuate a current-operated device.

In accordance with the present invention a compensating network is associated with the inductor to make the load current and voltage substantially constant. In the embodiments shown the network comprises a plurality of impedance branches connected effectively in parallel with the inductor. Each branch includes a resistance and a capacitance connected in series. One or more of the branches are designed to make the current drawn from the voltage source substantially linear over the period of the voltage pulse, and one or more other branches are designed to make this current substantially constant over this period. When this current is constant, the ohmic drop in the source is constant, the terminal voltage remains constant, and the load voltage and current remain constant throughout each pulse period.

The nature of the invention will be more fully understood from the following detailed description and by reference to the accompanying drawings, of which:

Fig. 1 is a schematic circuit of one embodiment

2

of a compensating network in accordance with the invention in which the inductor shunts the load;

Fig. 2 shows the compensating network of Fig. 1 applied to a transformer;

Fig. 3 shows current-time characteristics used in a graphical determination of certain factors appearing in the design formulas for the component elements of the network; and

Fig. 4 is a schematic circuit of another embodiment of the invention in which the load and the inductor are connected in series.

Taking up the figures in greater detail, Fig. 1 shows a source of unidirectional rectangular pulses of voltage E and internal impedance R_S, a resistive load of impedance R_L connected to the source, an inductor designated by its inductance L connected in shunt with the load, and a compensating network in accordance with the invention comprising three impedance branches 10, 11 and 12 all connected in shunt with the inductor L. If more precise compensation is required, the compensating network may include additional shunt branches, as indicated by the broken lines 13. Each of the branches comprises a resistance and a capacitance connected in series. In the branch 10 the resistance has a value R_1 and the capacitance a value C_1, in the branch 11 these elements are R_2 and C_2, respectively, and in the branch 12 they are R_n and C_n.

As indicated, inductor L is assumed to have a magnetic core associated therewith and may, for example, be a retardation or choke coil, the winding of a relay, or the mutual inductance between the primary and secondary windings of a transformer. The latter case is illustrated by Fig. 2, which is the same circuit as shown in Fig. 1 except that the inductor L has been replaced by a transformer 14 with a primary winding 15, a secondary winding 16, and a magnetic core 17. The branches 10, 11 and 12 may be placed on the primary side of the transformer 14, as shown, or one or more of them may be transferred to the secondary side, if the values of their component elements are changed to take account of the transformation ratio of the transformer.

In its simplest form the compensating network consists of only the two branches 10 and 11. The circuit will, therefore, be as shown in Fig. 1 if the branch 12 is open-circuited or removed. In accordance with the invention, the values of the resistance R_1 and the capacitance C_1 in the branch 10 are shown to make the current drawn from the source E substantially linear over the period T_4 of the unidirectional voltage pulse and the value of R_2 and C_2 in the branch 11 are chosen to make this current substantially constant over the period T_4. With this current constant, it follows that the voltage drop across the source impedance R_S will be constant, the terminal voltage will be constant and, therefore, the voltage across and the current through the load R_L will also be constant. As a result, a rectangular voltage pulse will be impressed upon the load R_L.

The value of R_1 depends upon the magnitudes of the source impedance R_S, the load impedance R_L, and a certain normalized current B. The value of C_1 is dependent upon these same factors and a time constant T_1. The value of R_2 depends upon R_S, R_L, B, and the normalized steady state value H of the magnetizing current, and the value of C_2 is dependent upon the same factors and a time constant T_3. The factors B, T_1 and T_3 may be determined by the characteristic of the magnetizing current i_m' drawn by the inductance L from the source E over the pulse period T_4. Explicitly, these element values are given by the following formulas:

$$R_1=\frac{1}{B}-\frac{R_SR_L}{R_S+R_L} \qquad (1)$$

$$C_1=\frac{T_1\left(R_1+\frac{R_SR_L}{R_S+R_L}\right)}{R_1^2} \qquad (2)$$

$$R_2=\frac{1}{H-B}-\frac{R_SR_L}{R_S+R_L} \qquad (3)$$

and

$$C_2=\frac{T_3\left(R_2+\frac{R_SR_L}{R_S+R_L}\right)}{R_2^2} \qquad (4)$$

A graphical method of determining the required values of the factors B, T_1 and T_3 will now be presented with the aid of Fig. 3 in which normalized current in amperes is plotted against the time t in seconds over the period T_4 of the pulse. The solid-line curve 18 gives the normalized magnetizing current i_m drawn by the inductor L. The normalized current i_m is obtained by dividing the magnetizing current i_m', indicated in Fig. 1, by the voltage E of the source. The current i_m' may be found with the aid of a cathode-ray oscilloscope or it may be computed, for example, from information presented in a paper by A. G. Ganz entitled "Applications of Thin Permalloy Tape in Wide Band Telephone and Pulse Transformers," published in the Transactions Section of Electrical Engineering, vol. 65, April, 1946, pages 177 through 183.

It will be noted that the curve 18 rises sharply at first and then more gradually until at the point d, corresponding to the time T_2, it becomes substantially linear and remains linear for the rest of the pulse period T_4. The required value of the normalized current B is obtained by extending the linear portion of the curve 18 to the left, as shown by the broken line 19, until it intersects the current axis.

Next, a perpendicular line 20 is dropped from the point d on the curve 18 to the time axis and a horizontal line 21 is drawn from the current axis at the point B to intersect the perpendicular 20 at the point f. Then the broken line curve 22 is constructed by lowering the curve 18 at each point by a distance equal to the difference between the curves 19 and 21. Thus, curve 22 starts at zero and rises smoothly to the point f. Now, to find the time constant T_1, a horizontal line is drawn from a point A on the current axis equal to 0.632 B until it intersects the curve 22 at the point k, and a perpendicular is dropped from this point to the time axis to find T_1.

If the values of B and T_1 thus found are substituted in Formulas 1 and 2, values of R_1 and C_1 will be found such that, if only the compensating branch 10 is employed, the current drawn from the source E by this branch and the inductor L will be substantially linear over the pulse period T_4, as shown by the straight line 19 and the straight portion of the curve 18. As already pointed out, however, this current should not only be linear but should also be constant. The compensating branch 11 is added for this purpose. The method employed is to build up the linear current already obtained to a constant value equal throughout the pulse period to the steady state value H shown by the horizontal line 24. The required value of the resistance R_2 is found from Equation 3. The time constant T_3 may be found graphically by drawing a horizontal line 25 from a point G on the current axis, where

$$G=0.632\ (H-B)+B \qquad (5)$$

until it intersects the curve 18 at the point m, and then dropping a perpendicular line 26 from this point to meet the time axis at T_3. The required capacitance C_2 may now be found from Equation 4.

If the compensating network employs only the two branches 10 and 11 with the element values determined as explained above, the current drawn from the source E will be substantially constant over the pulse period T_4, as shown by the curve 24, the ohmic drop in the source impedance R_S will be substantially constant, and the voltage across and current through the load R_L will be nearly enough constant for most applications. However, a further improvement in the constancy of this current and voltage may be made, if required, by adding one or more impedance branches to aid the branch 10 in making the current linear, and one or more branches to aid the branch 11 in making the current constant. Each of these additional branches preferably comprises the series combination of a resistance and a capacitance, and the branches are connected in shunt with the inductance L. The branch 12 shown in Fig. 1 is one such added branch. If additional branches are used, the required values of the elements R_1, C_1, R_2 and C_2 will, in general, differ from those obtained by the formulas presented herein. The required values of the component resistances and capacitances in the added branches may be found from additional normalized currents and time constants which may be found from the characteristic of the magnetizing current shown in Fig. 3 by a graphical method similar to the one described above.

When the compensating network is used with a transformer, as in the circuit of Fig. 2, the required values of the component elements in the branches 10 and 11 may be found in the manner already described, except that in this case the magnetizing current characteristic 18 will, of course, apply to the transformer 14 instead of the inductance L.

Another embodiment of the invention is shown in Fig. 4, which is the same circuit as that shown in Fig. 1 except that the shunt load R_L is omitted and a series load of impedance R_P is connected between the source E and the first shunt branch 10. In this case the required values of the elements in the branches 10 and 11 to make the current drawn from the source E substantially constant throughout the period T_4 of the voltage pulse are given by the following formulas:

$$R_1=\frac{1}{B}-R_S-R_P \qquad (6)$$

$$C_1=\frac{T_1(R_1+R_S+R_P)}{R_1^2} \qquad (7)$$

$$R_2=\frac{1}{H-B}-R_S-R_P \qquad (8)$$

and

$$C_2=\frac{T_3(R_2+R_S+R_P)}{R_2^2} \qquad (9)$$

in which the factors B, H, T_1 and T_3 are determined in the manner previously described.

In the circuit of Fig. 4 if only the two compensating branches 10 and 11 are used the current through and voltage across the load R_P will be substantially constant over the pulse period T_4. The constancy may be further improved, if required, by the addition of one or more branches such as 12, as explained above in connection with Fig. 1.

What is claimed is:

1. In combination, a resistive load of impedance Z adapted for connection to a source of unidirectional voltage pulses of internal impedance R_S, a magnetic-cored inductor connected in shunt with said load, and a compensating network for making the voltage across and the current through said load substantially constant over the pulse period, said network comprising a plurality of impedance branches connected effectively in shunt with said inductor, each of said branches comprising the series combination of a resistance and a capacitance, the resistance R_1 and capacitance C_1 in one of said branches having values chosen to make the current drawn from said source substantially linear over said period, and the resistance R_2 and capacitance C_2 in a second of said branches having values chosen to make said last-mentioned current substantially constant over said period, in which R_1, C_1, R_2 and C_2 have approximately the following values:

$$R_1=\frac{1}{B}-\frac{R_SZ}{R_S+Z}$$

$$C_1=\frac{T_1\left(R_1+\frac{R_SZ}{R_S+Z}\right)}{R_1^2}$$

$$R_2=\frac{1}{H-B}-\frac{R_SZ}{R_S+Z}$$

and

$$C_2=\frac{T_3\left(R_2+\frac{R_SZ}{R_S+Z}\right)}{R_2^2}$$

where H is the normalized value of the steady state magnetizing current drawn from said source by said inductor, and the factors B, T_1 and T_2 may be found graphically by plotting a first curve of the normalized magnetizing current in amperes against time over one period of said pulses, extending linearly the linear portion of the curve to the current axis to find the point of interception B, constructing a second curve by lowering the first curve at each point by a distance equal to the difference between the extended portion of the first curve and B, reading the time T_1 at which the second curve attains a value equal to 0.632 B, and reading the time T_3 at which said first curve attains a value equal to

$$0.632(H-B)+B$$

2. In combination, a resistive load of impedance Z adapted for connection to a source of unidirectional voltage pulses of internal impedance R_S, a magnetic-cored inductor connected in series with said load, and a compensating network for making the voltage across and the current through said load substantially constant over the pulse period, said network comprising a plurality of impedance branches connected effectively in shunt with said inductor, each of said branches comprising the series combination of a resistance and a capacitance, the resistance R_1 and capacitance C_1 in one of said branches having values chosen to make the current drawn from said source substantially linear over said period, and the resistance R_2 and capacitance C_2 in a second of said branches having values chosen to make said last-mentioned current substantially constant over said period, in which R_1, C_1, R_2 and C_2 have approximately the following values:

$$R_1=\frac{1}{B}-R_S-Z$$

$$C_1=\frac{T_1(R_1+R_S+Z)}{R_1^2}$$

$$R_2=\frac{1}{H-B}-R_S-Z$$

and

$$C_2=\frac{T_3(R_2+R_S+Z)}{R_2^2}$$

where H is the normalized value of the steady state magnetizing current drawn from said source by said inductor, and the factors B, T_1 and T_2 may be found graphically by plotting a first curve of the normalized magnetizing current in amperes against time over one period of said pulses, extending linearly the linear portion of the curve to the current axis to find the point of interception B, constructing a second curve by lowering the first curve at each point by a distance equal to the difference between the extended portion of the first curve and B, reading the time T_1 at which the second curve attains a value equal to 0.632 B, and reading the time T_3 at which said first curve attains a value equal to $0.632(H-B)+B$.

3. In combination, a resistive load of impedance Z adapted for connection to a source of unidirectional voltage pulses of internal impedance R_S, a magnetic-cored inductor connected in parallel with said load, the series combination of a resistance R_1 and a capacitance C_1 in a path shunting said inductor for making the current drawn from said source substantially linear over the pulse period, and the series combination of a resistance R_2 and a capacitance C_2 in a second path shunting said inductor for making said current substantially constant over said pulse period, in which R_1, C_1, R_2 and C_2 have approximately the following values:

$$R_1=\frac{1}{B}-\frac{R_SZ}{R_S+Z}$$

$$C_1=\frac{T_1\left(R_1+\frac{R_SZ}{R_S+Z}\right)}{R_1^2}$$

$$R_2=\frac{1}{H-B}-\frac{R_S Z}{R_S+Z}$$

and

$$C_2=\frac{T_3\left(R_2+\frac{R_S Z}{R_S+Z}\right)}{R_2^2}$$

where H is the normalized value of the steady state magnetizing current drawn from said source by said inductor, and the factors B, T_1 and T_2 may be found graphically by plotting a first curve of the normalized magnetizing current in amperes against time over one period of said pulses, extending linearly the linear portion of the curve to the current axis to find the point of interception B, constructing a second curve by lowering the first curve at each point by a distance equal to the difference between the extended portion of the first curve and B, reading the time T_1 at which the second curve attains a value equal to 0.632 B, and reading the time T_3 at which said first curve attains a value equal to

$$0.632(H-B)+B$$

4. The combination in accordance with claim 3 which includes an additional impedance branch shunting said inductor, said additional branch comprising the series combination of a resistance and a capacitance proportioned to make said current more nearly constant.

5. The combination in accordance with claim 3 which includes an additional impedance branch shunting said inductor, said additional branch comprising the series combination of a resistance and a capacitance proportioned to make said current more nearly linear.

6. The combination in accordance with claim 5 which includes a second additional impedance branch shunting said inductor, said second additional branch comprising the series combination of a resistance and a capacitance proportioned to make said current more nearly constant.

7. In combination, a resistive load of impedance Z adapted for connection to a source of unidirectional voltage pulses of internal impedance R_S, a magnetic-cored inductor connected in series with said load, the series combination of a resistance R_1 and a capacitance C_1 in a path shunting said inductor for making the current drawn from said source substantially linear over the pulse period, and the series combination of a resistance R_2 and a capacitance C_2 in a second path shunting said inductor for making said current substantially constant over said pulse period, in which R_1, C_1, R_2 and C_2 have approximately the following values:

$$R_1=\frac{1}{B}-R_S-Z$$

$$C_1=\frac{T_1(R_1+R_S+Z)}{R_1^2}$$

$$R_2=\frac{1}{H-B}-R_S-Z$$

and

$$C_2=\frac{T_3(R_2+R_S+Z)}{R_2^2}$$

where H is the normalized value of the steady state magnetizing current drawn from said source by said inductor, and the factors B, T_1 and T_2 may be found graphically by plotting a first curve of the normalized magnetizing current in amperes against time over one period of said pulses, extending linearly the linear portion of the curve to the current axis to find the point of interception B, constructing a second curve by lowering the first curve at each point by a distance equal to the difference between the extended portion of the first curve and B, reading the time T_1 at which the second curve attains a value equal to 0.632 B, and reading the time T_3 at which said first curve attains a value equal to

$$0.632(H-B)+B$$

8. The combination in accordance with claim 7 which includes an additional impedance branch shunting said inductor, said additional branch comprising the series combination of a resistance and a capacitance proportioned to make said current more nearly constant.

9. The combination in accordance with claim 7 which includes an additional impedance branch shunting said inductor, said additional branch comprising the series combination of a resistance and a capacitance proportioned to make said current more nearly linear.

10. The combination in accordance with claim 9 which includes a second additional impedance branch shunting said inductor, said second additional branch comprising the series combination of a resistance and a capacitance proportioned to make said current more nearly constant.

References Cited in the file of this patent

UNITED STATES PATENTS

Number	Name	Date
1,801,342	Gannett et al.	Apr. 21, 1931
2,035,457	Blumlein	Mar. 31, 1936
2,317,482	Peterson	Apr. 27, 1943
2,431,952	Maxwell	Dec. 2, 1947
2,470,825	Mathes	May 24, 1949
2,480,511	Schade	Aug. 30, 1949