The invention herein described and claimed relates to improved means for varying automatically the inductance of a circuit in a desired manner.

The means provided by the present invention may be used to important advantage in the sweep circuits of a cathode-ray tube, particularly where rapid deflection is required, to linearize substantially the sweep deflection.

Consider a television receiver having a horizontal, and/or vertical, deflection system which includes a deflection-current oscillator which is intended to supply a sawtooth current of linear waveform to the magnetic deflection coil or yoke. In practice, the sawtooth current supplied to the deflecting coil by the deflection-current oscillator tends to be exponential rather than linear, the slope of the sweep portion of the sawtooth waveform being steeper at the start than during the remaining portion thereof. Stated another way, in the absence of compensating means, the rate of change of current supplied to the deflecting coil is faster at the start than during the later portion of the sweep. This is due, at least in part, to the internal resistance of the oscillator tube, to the resistance of the oscillator transformer and to the resistance of the deflection yoke. Hence, unless compensating means are employed, the cathode-ray beam is deflected at a faster rate at the start of the sweep than during the remaining portion of the horizontal sweep, may be to stretch the left-hand portion of the reproduced picture to a noticeable and objectionable extent.

In accordance with the present invention, a sufficient amount of inductance is added to the plate circuit of the deflection-current oscillator, at the start of the conduction period (which corresponds to the sweep period of the cathode-ray beam), to retard the rate of increase of the oscillator plate current. However, during the first portion of the conduction period, the added inductance is decreased automatically at a substantially linear rate, so that during the later portion of the conduction period, the added inductance reaches a negligible value. Consequently, the maximum oscillator plate current normally flowing at the end of the conduction period is not diminished to an appreciable extent.

The prior art has employed a single-winding saturable inductor in series with the oscillator plate coil in an attempt to accomplish results similar to those described immediately above. The results attained by the prior art devices are, however, considerably inferior to those attained by the present invention. This will become clear from the description which follows.

It is a broad object of this invention to provide means for varying automatically, in a desired manner, the inductance of an electric circuit.

It is another specific object of this invention to provide improved compensating means for linearizing the beam deflection in a cathode-ray-tube system employing magnetic deflection.

These and other objects, advantages and features of the present invention, and the manner in which the objects are attained, will become clear from a consideration of the following detailed description and of the accompanying drawings, wherein:

Figure 1 is a schematic representation of the magnetic deflection system of a cathode-ray tube into which a preferred embodiment of the present invention has been incorporated; and

Figures 2, 3 and 4 are graphical illustrations which will be helpful in describing and understanding the present invention.

The magnetic deflection system shown schematically in Figure 1 includes a deflection-current oscillator 9 which, except for the means added by the present invention, is entirely conventional. Deflection-current oscillator 9 includes a pentode 10 whose first three electrodes, 11, 12 and 13, comprise the oscillator section of the tube. In addition, pentode 10 includes an input control grid 14 and a plate 15. The input control grid 14 may be coupled, by way of an interstage transformer 21, to a source 22 of synchronizing pulses. Plate 15 of tube 10 may be connected, by way of a load resistance 23, to a source of suitable positive potential, B+.

Grid-electrode 13, which functions as the anode of the oscillator section of tube 10, is connected to a source of positive potential, B+, by way of plate coil 17 of the iron-core transformer 19. Winding 28 is part of a two-winding saturable inductor 20 which is added by the present invention and whose function will be described later. The said oscillator anode 13 is coupled inductively to the oscillator control grid 12 by means of plate coil 17 and grid coil 18 of transformer 19. The low potential end of grid coil 18 is returned to the cathode 11 by way of an RC network, comprising capacitor 16 and resistors 20, 21, across which a suitable negative bias may be developed.
The operation of the conventional deflection-current oscillator thus far described is well known and need be briefly considered. The inductance of plate coil 11 is high and the impedance of the oscillator plate circuit is predominantly reactive. Consequently, the current flow through plate coil 11 builds up gradually. During the building up of the oscillator plate current, a positive potential is induced at the grid end of coil 18 and the grid circuit draws current. During the early stages of the conduction period, the magnitude of the grid current is considerably larger than that of the oscillator plate current. As the oscillator plate current rises, the oscillator plate potential drops and eventually the potential of plate 13 approaches that of grid 12. When this occurs, a sudden diversion of space current takes place from the plate 13 to the grid 12. The positive potential therebefore induced at the grid end of coil 18 by the increasing flow of plate current in coil 11 is reduced very rapidly and grid 12 swings highly negative in a very short period of time, thus blocking the flow of current through the tube. As soon as plate current ceases to flow, the negative charge on grid 12 rapidly leaks off, the grid swings in the positive direction, and current again starts to flow through the tube. The cycle just described repeats, and a current of sawtooth waveform consequently flows through primary coil 11.

In Figure 1, transformer 19 is shown to include a third winding 24 which is serially connected to the cathode-ray-tube deflecting coils 25a, 25b. The deflecting coils are, of course, so positioned, with respect to the cathode-ray tube 28, that deflection of the cathode-ray beam 27 is effected by the magnetic field established by the sawtooth current supplied to the deflecting coils from transformer 19. If desired, in lieu of the separate winding 24, a tapped connection to primary winding 11 may be used to supply a portion of the sawtooth plate current to the deflecting coils.

In the absence of compensating means, the conventional deflection-current oscillator, thus far described, supplies to the deflecting coils a sawtooth current whose rising or sweep slope is exponential rather than linear. As previously indicated, this is due principally to the internal resistance of tube 10. In the resistance of transformer 19, and to the resistance of deflecting coils 25a, 25b. It is apparent, if the inductance of the oscillator plate circuit could be made larger at the start of the conduction period, the plate current would build up more slowly, and, if the inductance of the plate circuit could then be reduced gradually at a proper rate, the plate current could be caused to build up substantially linearly. This situation was recognized by the present art and the use of a single-winding saturable inductor in series with the plate coil was proposed as a means of linearizing the sawtooth current supplied to the deflecting coils.

While the above-mentioned prior art proposal is not without merit, certain factors prevent it from being a completely satisfactory solution to the problem, as will be best understood by considering more fully the action of a single-winding saturable inductor connected in series with the plate coil. It would seem that for best results, the core of the single-winding saturable inductor should be composed of a readily saturable magnetic material of high permeability, such as an alloy of nickel, iron and molybdenum. The linearizing effects actually achieved by the use of such a single-winding saturable inductor are not, however, as good as may be expected from a first consideration. The reasons may be explained most readily by referring to Figure 2 which shows the upper portion of the hysteresis loop of a commercially available alloy of nickel, iron and molybdenum which is readily saturable and has high permeability. Observe that, in Figure 2, if the applied magnetizing force (in oersteds) is varied to the region between zero and a value of positive polarity, the variation in flux density (in gausses) per unit volume will be relatively small. For example, in Figure 2, if the magnetizing force be varied twenty H units, i.e. from zero H units to +20 H units, the flux density will only vary density would, i.e. from +12 H units to +20 B units, as indicated by the A-to-D portion of the hysteresis curve. The variation in the inductance of the saturable inductor will therefore be small. Consequently, the variation in the inductance of the saturable inductor will be insufficient to achieve the variation in total inductance of the oscillator plate circuit necessary to linearize the beam deflection, unless, of course, a saturable inductor having a very large core be used. The use of a large-core saturable inductor is, however, undesirable from the standpoint of cost and power consumption.

Examination of the hysteresis curve of Figure 2 suggests that a bias magnetizing force, whose polarity is opposite to that of the magnetizing force intended to be applied, may be advantageously employed to effect operation of the saturable inductor on the steep portion of the hysteresis curve. Stated another way, if the applied magnetizing force could be caused to vary from say —3 H units to +20 H units, wide variations in inductance could be accomplished, for the flux density would tend to vary approximately twenty B units, as indicated by the C-to-D portion of the hysteresis curve of Figure 2. The employment of direct current for biasing purposes is, however, undesirable. In the first place, a large-core inductor would have to be used in order to avoid having the D.C. component saturate the core of the inductor. In addition, a choke would probably have to be inserted in series with the low impedance D.C. supply in order to avoid shorting out of the alternating component. Such an arrangement would be undesirably large.

In accordance with the present invention, the required wide variations in the inductance of the saturable inductor are accomplished by employing a saturable inductor having two windings, of predetermined turns ratio, and passing a different current through each winding in such direction that the magnetizing force due to one current opposes the magnetizing force due to the other, the two currents having such waveforms that the polarity of the net magnetizing force reverses during the sweep period of the deflection system.

In the circuit of Figure 1, I employ a saturable inductor 28 having one winding, 28, in the plate circuit of the oscillator and the other winding, 29, in the oscillator grid circuit. Figure 3 graphically illustrates the manner in which the plate current through winding 28 increases during the conduction period of tube 10. Observe that the plate current builds up gradually to a maximum value and then, as the tube cuts off, falls rapidly to zero. Figure 3 shows the manner in which the grid current in winding 29 decreases, from a value which at the start of the conduction period is substantially larger than that of the plate.
current, to a value which just prior to cut-off is substantially smaller. As indicated hereinafore, the two windings, 28 and 29, by being represented as being of a polarity opposite to that of the plate current. Thus, the net magnetizing force applied to the core of inductor 20 is a function of the difference between the force exerted by the plate current and the force exerted by the grid current.

In accordance with the present invention, the turns-ratio of windings 28 and 29 are so chosen that, at the start of the conduction period, the magnetizing force of the grid current predominates, but during the latter portion of the conduction period, the magnetizing force of the plate current predominates. This is shown graphically in Figure 4 where the polarity of the magnetizing force applied to the core of the saturable inductor is shown to reverse during the conduction period. It has been pointed out, of course, that the graph shown in Figure 4 is related to that shown in Figure 5. The graph in Figure 4 reflects the fact that the applied magnetizing force is a function of the number of turns on each winding as well as of the current through each winding.

It has been stated above that, at the start of the conduction period, the magnetizing force due to the grid current is greater than that due to the plate current. Hence, the net applied magnetizing force, at the start of the conduction or sweep period, may be considered to be of negative polarity and is consistent with the description of the hysteresis curve of Figure 2 wherein the magnetizing force of the plate current was assumed to be of positive polarity. Figure 4 shows graphically that, during the conduction period of tube 18, the net magnetizing force applied to saturable inductor 20 decreases substantially linearly to zero, and then, as the magnetizing force due to the plate current becomes predominant, the net applied magnetizing force reverses polarity and increases substantially linearly in the positive direction.

Referring again to Figure 2, wherein is shown the hysteresis curve of the readily-saturable high-permeability material of which the core of inductor 20 is assumed to be made, it will be seen that a magnetizing force which reverses polarity, in the manner hereinafore described, will be effective to vary the flux density of saturable inductor 20 over a wide range, as for example, over that portion of the hysteresis curve lying between points C and D. During the early portion of the oscillator conduction period, the flux density of inductor 20 will vary from point C to point A'. This represents a wide variation, and the inductance is consequently high. During the latter portion of the conduction period, the variation in flux density will be small, as is indicated by the corresponding portion of the hysteresis curve of Figure 2. The inductance of inductor 20 during this portion of the cycle is therefore small. It will be seen then that the inductance of inductor 20 is maximum at the start of the conduction period, that thereafter the inductance decreases substantially linearly to a relatively low value in a time period which corresponds to a selected portion, say one-third, of the oscillator conduction period, and that for the remaining two-thirds of the conduction period, the inductance of saturable inductor 20 is very small.

In the circuit of Figure 1, the inductance of saturable inductor 20 adds to the inductance of transformer 19 to provide a total oscillator-plate-circuit inductance which, at the start of the conduction or sweep period, is of desired increased magnitude. The initial rate of rise of the plate current is therefore retarded. As the plate current rises at its reduced rate, the inductance of saturable inductor 20 decreases in a substantially linear manner, as is indicated by the C to A' portion of the hysteresis curve of Figure 2. The retarding force exerted by inductor 20 to the rise of plate current is gradually reduced, and at the expiration of say one-third of the conduction period, the retarding effect of inductor 20 is substantially removed.

As a result of the action above described, the excessive rate of rise ordinarily occurring at the start of the sweep portion of the deflection cycle is corrected and a substantially linear sweep is obtained.

In one of my experiments, I employed a two-winding saturable inductor having a core comprised of molybdenum permalloy tape. The tape had a cross section of 0.002 inch, and was wound toroidally, forming a ring having an inside diameter of three-quarters of an inch and an outside diameter of about one inch. The plate winding had 100 turns and the grid winding had 10 turns. I employed this two-winding saturable inductor in a circuit similar to that shown in Figure 1. Prior to the insertion of saturable inductor 20 into the circuit, the rate of rise of the deflecting current was 31 per cent faster during the early portion of the sweep than during the later portion. When the two-winding saturable inductor 20 was connected into the circuit in the manner shown in Figure 1, the rate of rise of the deflecting current was less than 2 per cent faster near the beginning of the sweep than near the end thereof. When a prior art single-winding saturable inductor was employed, in lieu of the two-winding inductor of the present invention, the rate of rise of the deflecting current was 19 per cent faster near the start than near the end of the sweep. It will be seen that the linearity in the output sweep of the two-winding saturable inductor of the present invention is substantially better than that of the prior art single-winding inductor.

An additional important advantage of the two-winding saturable inductor of the present invention is that the power consumption is very small, being less than that of any prior art linearizing device known to me.

Various modifications may, of course, be made without departing from the broad concept of my invention. For example, an oscillator circuit would be to connect winding 28 of saturable inductor 20 in series with the cathode-ray-tube deflecting coils 25a and 25b, instead of in series with the plate coil 17 as shown. The core of the saturable inductor 20 may preferably be a toroid, but this is not essential. However, if an air-gap core be employed, the air gap should be small in order to permit the use of less magnetic material and in order that the physical dimensions of the inductor may be small.

I have described my invention in the environment of a sawtooth-current generator of the type having a relatively long period of conduction and a relatively short period of non-conduction. This type of sawtooth-current generator happens to be particularly suited to my invention since the
grid and plate currents vary in the desired contrasting manner, i.e., currents are available for establishing a net magnetizing force whose polarity reverses during the sweep period. Other types of blocking tube oscillator or sawtooth generator may, however, be employed. If the deflection system employed is such that, in normal operation, only a single sawtooth current is produced, it will be necessary to derive a second current whose slope is sufficiently different from that of the first mentioned sawtooth current to produce the required reversal in the polarity of the net magnetizing force. This may be done readily by known means.

Having described my invention, I claim:

1. In a deflecting circuit for a cathode-ray tube having magnetic deflecting coils and a first source of non-linear sawtooth current for energizing said deflecting coils; a second source of current, the phase and waveform of said second current being such that said second current is decreasing in magnitude during at least a portion of the time said first current is increasing in magnitude; an inductor having a core of high-permeability material and having first and second windings of predetermined turns ratio; means for passing said first sawtooth current through said first winding; means for passing said second current through said second winding in such direction that the magnetizing force resulting from said second current opposes the magnetizing force resulting from said first current, the phase of said first and second currents and the turns ratio of said first and second windings being such that the net magnetizing force reverses polarity during the time said sawtooth current is increasing in magnitude.

2. In a deflecting circuit for a cathode-ray tube having magnetic deflecting coils and a first source of non-linear sawtooth current for energizing said deflecting coils, the improvement which constitutes the provision of linearizing means, said linearizing means comprising: a second source of current, the phase and waveform of said second current being such that said second current is decreasing in magnitude during at least a portion of the time that said first current is increasing in magnitude; an inductor having a core of readily-saturable high-permeability material whose hysteresis curve is steep in a region where the magnetizing force is of one polarity and substantially flat in an adjacent region where the magnetizing force is of opposite polarity, said inductor having first and second windings of predetermined turns ratio; means for passing said first sawtooth current through said first winding; means for passing said second current through said second winding in such direction that the magnetizing force resulting from said second current opposes the magnetizing force resulting from said first current, the phase of said first and second currents and the turns ratio of said first and second windings being such that the net magnetizing force reverses polarity during the time that said first current is increasing in magnitude; means for connecting said first winding in series with the plate circuit of said oscillator; means for connecting said second winding in series with the grid circuit of said oscillator, said first and second windings of said inductor being so connected that the magnetizing force in the core of said inductor resulting from the first winding opposes the net magnetizing force in the core of said inductor resulting from the second winding; means for generating saw-tooth current waves of great linearity, said oscillator comprising: a vacuum tube having at least two grids, a multi-vibrator circuit including a grid circuit and a plate circuit, a voltage divider circuit and an output circuit including an output tube; means for feeding said voltage divider circuit with a voltage source of high-voltage, said voltage divider circuit comprising: a first voltage divider having a high-voltage input and a low-voltage output; a second voltage divider having a high-voltage input and a low-voltage output; means for connecting said low-voltage output of said first voltage divider to said high-voltage input of said second voltage divider; means for connecting said low-voltage output of said second voltage divider to said high-voltage input of said first voltage divider; means for connecting said voltage divider circuit with said multi-vibrator circuit; means for connecting said output tube with said voltage divider circuit; means for feeding said output tube with a voltage source of high-voltage; said output tube comprising: a triode having a first grid, a second grid and an anode; means for feeding said first grid with a voltage source of low-voltage; means for feeding said second grid with a voltage source of low-voltage; means for feeding said anode with a voltage source of high-voltage; means for feeding said multi-vibrator circuit with a voltage source of low-voltage; means for feeding said output tube with a voltage source of high-voltage.
triode elements serving as cathode, grid and anode electrode respectively; a first transformer having a pair of windings for coupling the grid-cathode circuit of said vacuum tube to the anode-cathode circuit thereof; and a second transformer having its windings connected in series, respectively, with the windings of said first transformer in the said grid-cathode and anode-cathode circuits of said tube, said second transformer having a saturable ferromagnetic core, the windings of said second transformer being so connected in their respective circuits that the magnetizing force produced by the flow of plate current in one of said windings is opposed to the magnetizing force produced by the flow of grid current in the other of said windings.

6. A relaxation oscillator as claimed in claim 5, characterized in that the number of turns in the plate winding of said second transformer is several times greater than the number of turns in the grid winding thereof, whereby the magnetizing force developed per unit of plate current is substantially greater than that developed per unit of grid current.

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No references cited.