Jan. 30, 1968 V. M. CHAPTAL DE CHANTELOUP 3,366,939

DEVICE HAVING CHANGEABLE RESISTANCE AND INTERNAL INDUCTANCE

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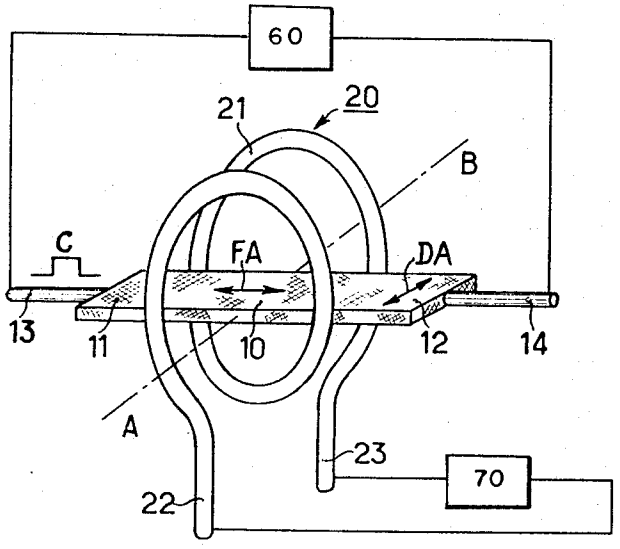


FIG.1

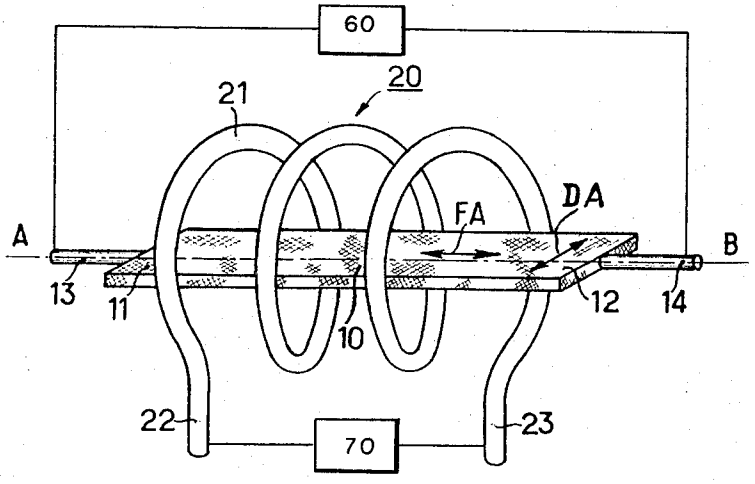


FIG.2

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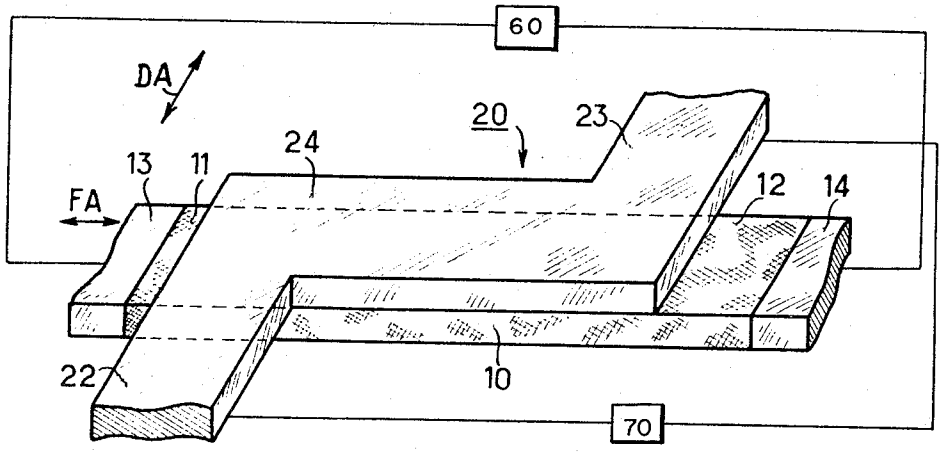


FIG.3

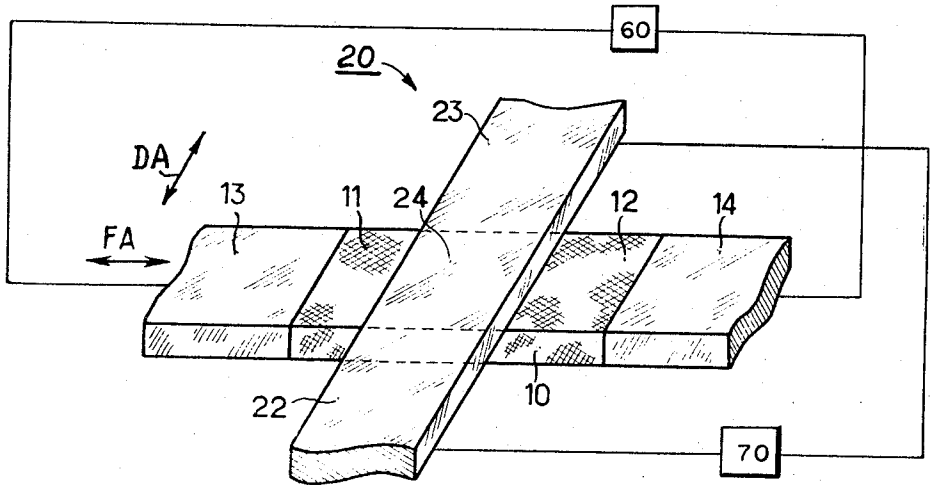


FIG.4

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DEVICE HAVING CHANGEABLE RESISTANCE AND INTERNAL INDUCTANCE
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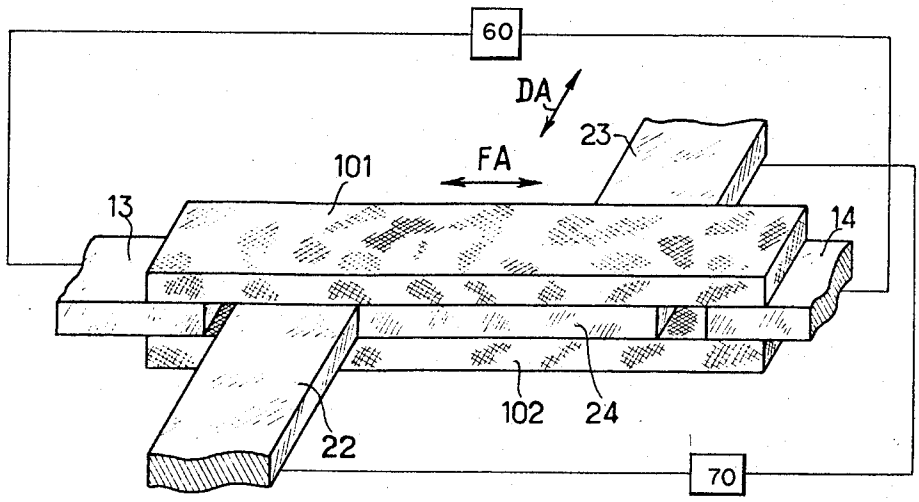


FIG.5

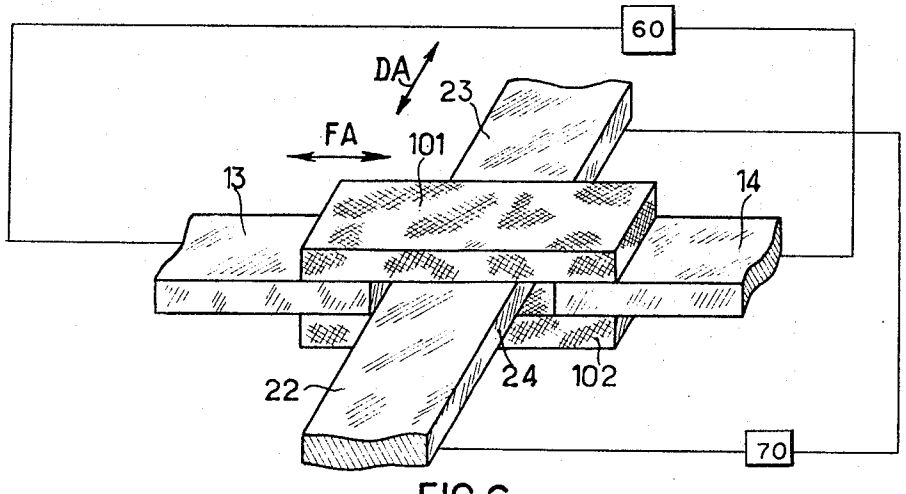


FIG.6

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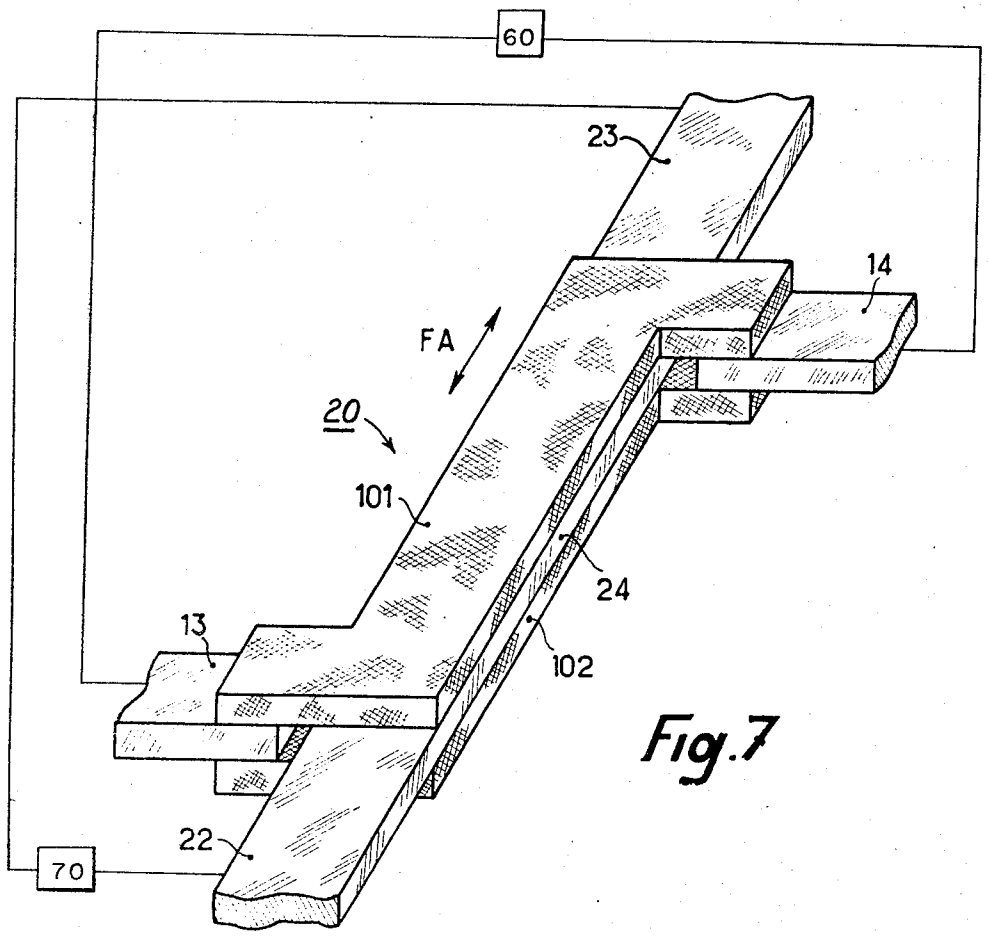


Fig.7

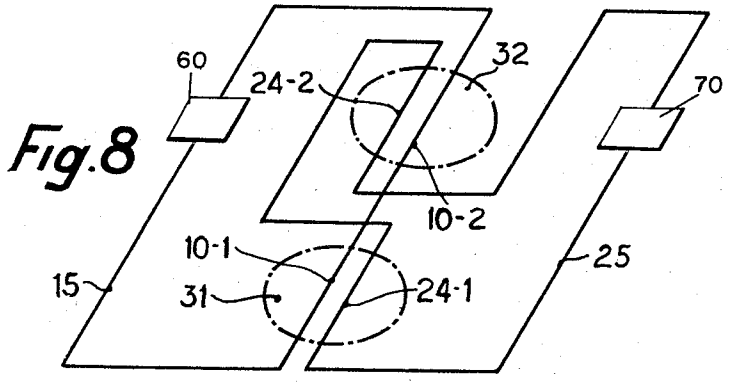


Fig.8

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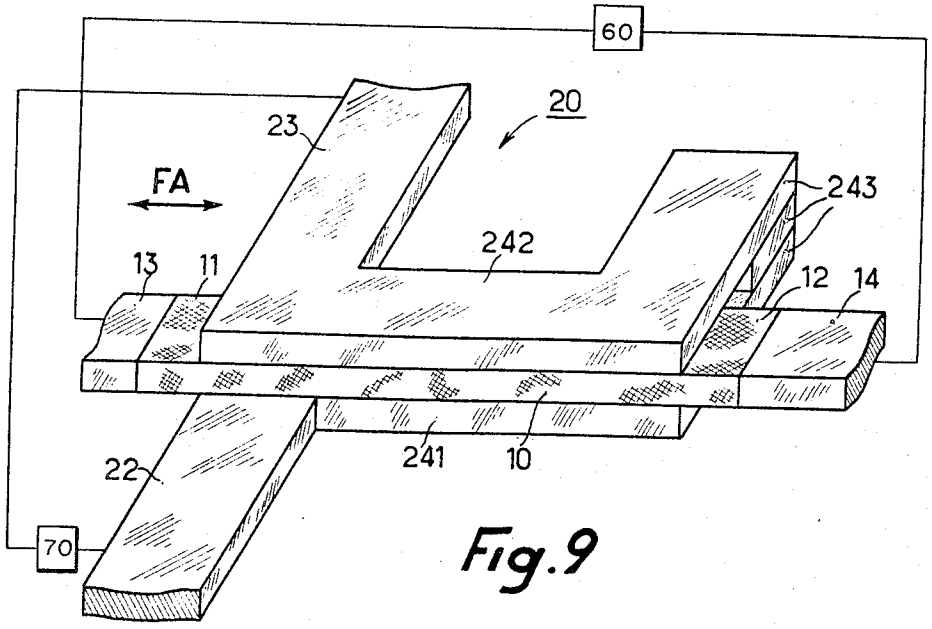


Fig. 9

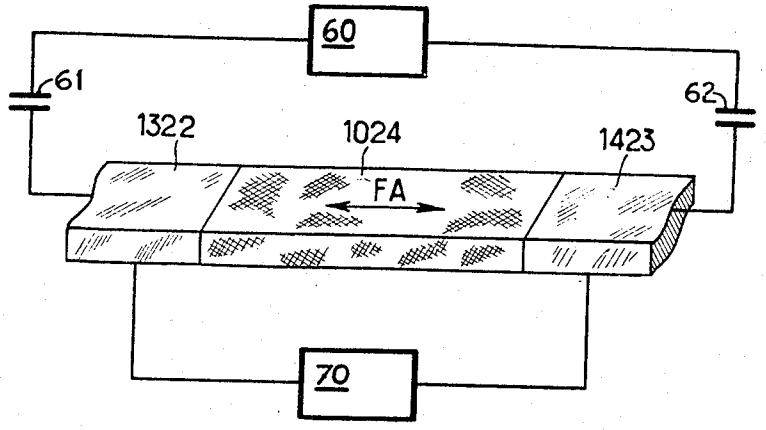


Fig. 13

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DEVICE HAVING CHANGEABLE RESISTANCE AND INTERNAL INDUCTANCE

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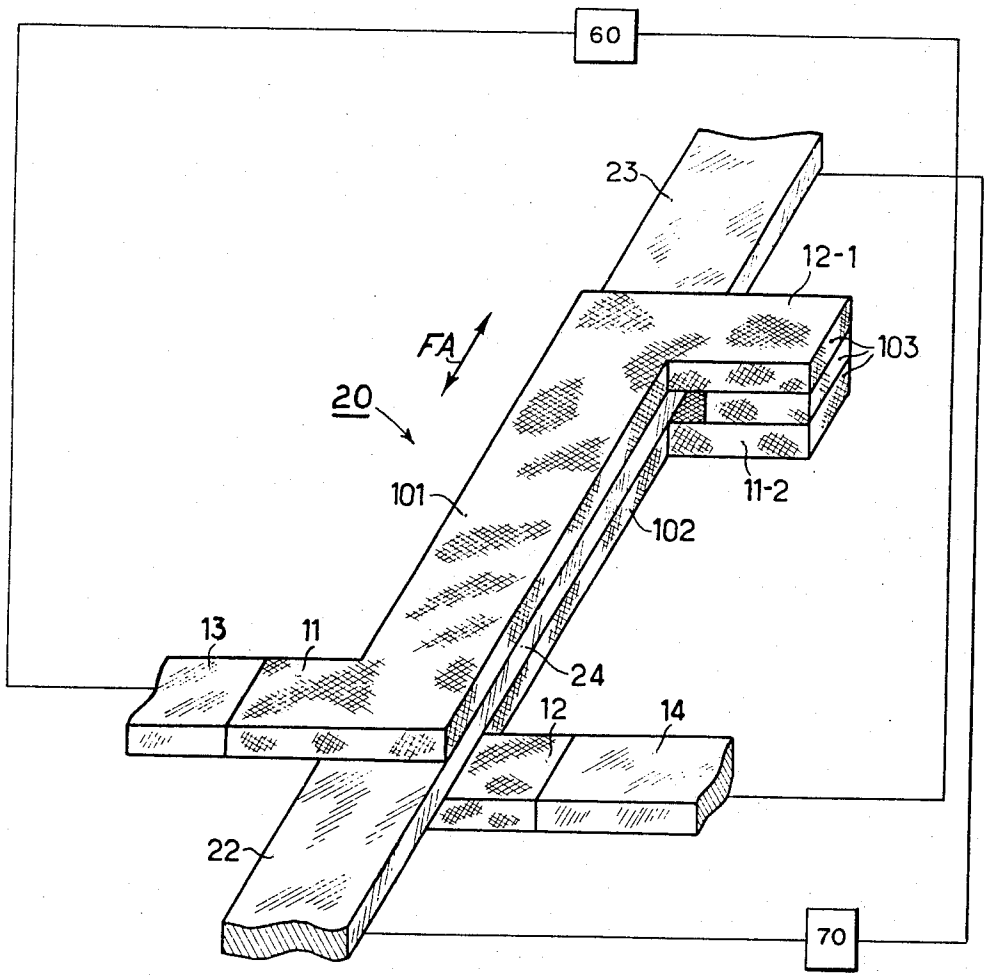


FIG.10

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FIG.11

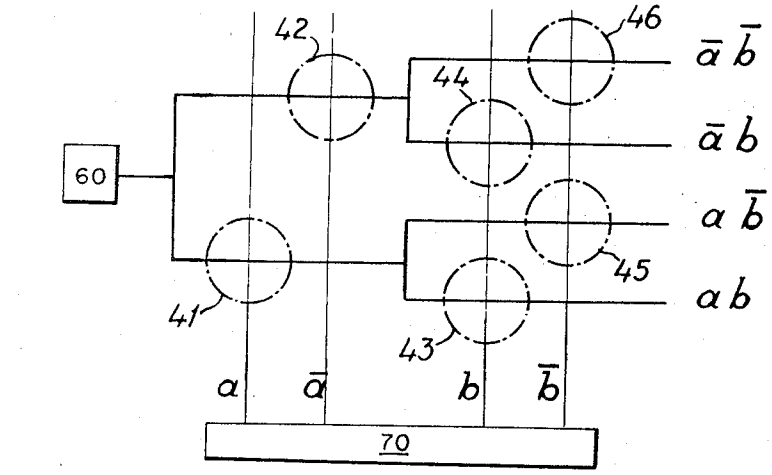


FIG.12

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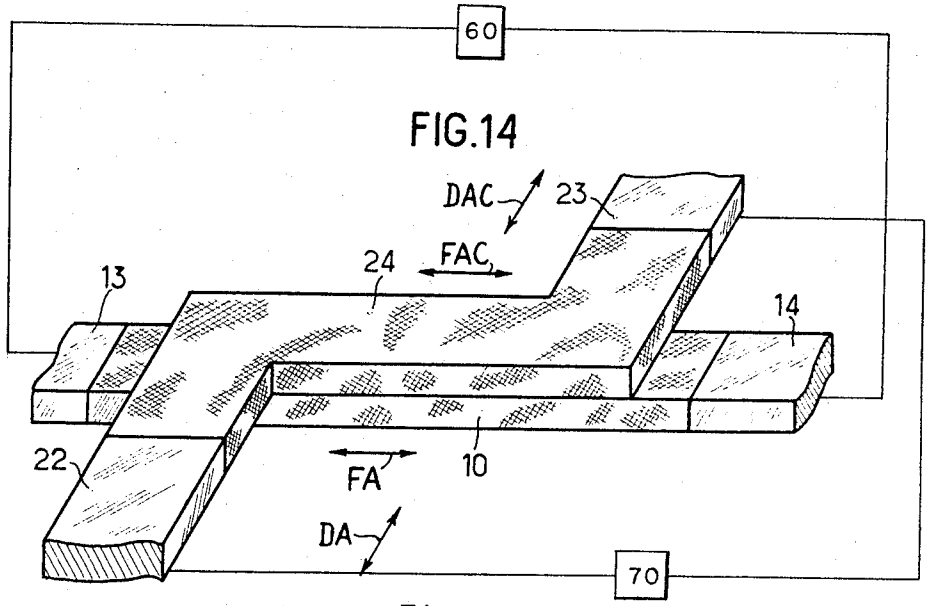


FIG.14

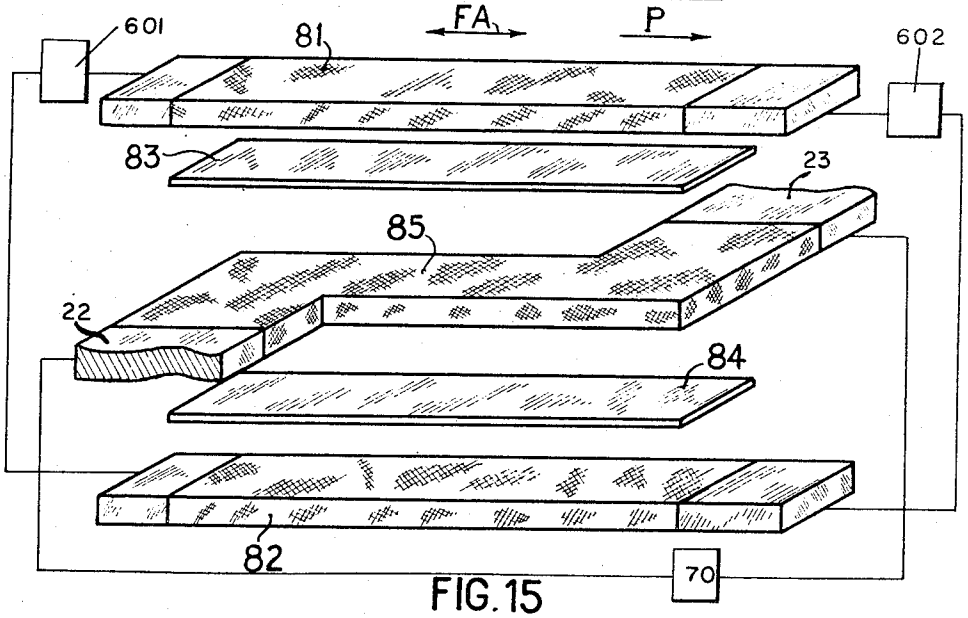


FIG.15

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DEVICE HAVING CHANGEABLE RESISTANCE AND INTERNAL INDUCTANCE

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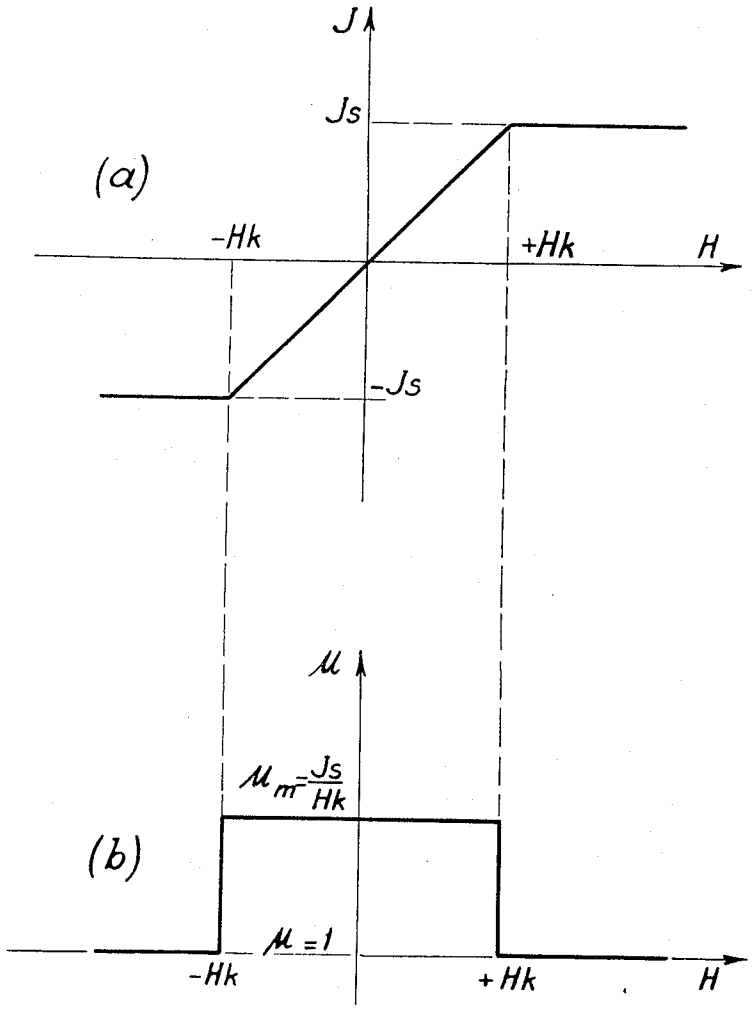


Fig.16

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United States Patent Office

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3,366,939

DEVICE HAVING CHANGEABLE RESISTANCE AND INTERNAL INDUCTANCE

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Filed Feb. 1, 1965, Ser. No. 429,485
Claims priority, application France, Feb. 7, 1964, 962,975
7 Claims. (Cl. 340—174)

ABSTRACT OF THE DISCLOSURE

The invention provides devices, such as gates, making use of a particular property exhibited by a magnetic thin film element possessing uniaxial anisotropy and conducting electricity when it is subjected to a magnetic field and when a variable current is flowing through it in the direction of easy magnetization. According to this particular property, the element exhibits a resistance and an internal inductance of a first or a second value according as said magnetic field exceeds or not a given value.

The present invention relates to variable-impedance devices utilising certain properties of thin films of electrically conductive ferromagnetic material, which properties have been referred to in the copending application of the applicant, Ser. No. 426,092, filed Jan. 18, 1965.

These properties of thin films may be employed in accordance with the present invention to utilise advantageously certain electromagnetic induction phenomena which accompany the passage of a variable electric current through a conductor and the effect of which is to bring about a non-uniform distribution of the current in the said conductor.

It is known that, by reason of this effect, which is called the film effect, the resistance and internal inductance exhibited by a conductor through which an alternating current is passed depend both upon the frequency of this current and upon the apparent magnetic permeability of the conductor in a direction perpendicular to the direction of the said alternating current.

When a current pulse passes through a conductor, the resistance and the internal inductance of this conductor therefore depend, for a component of given frequency of the pulse, upon the magnetic permeability exhibited by this conductor in a direction perpendicular to the direction of this component, and if this permeability varies the resistance and the internal inductance under consideration vary in the same direction.

In accordance with the invention, the aforesaid phenomena may advantageously be utilised to provide a device having variable resistance and internal inductance.

Such a device is provided by associating with a thin film of electrically conductive ferromagnetic material having an axis of easy magnetization situated in the plane of the film, control means for creating in the plane of this film a magnetic control field whose intensity may vary sufficiently to vary the apparent magnetic permeability of the thin film along the axis of difficult magnetization, or in other words the transverse magnetic permeability of the latter, and thus to modify the resistance and the internal inductance possessed by this thin film when a variable current travels through it along the axis of easy magnetization.

The magnetic control field may be produced by an electric control current flowing through a control conductor appropriately disposed in the neighbourhood of the thin film. It may also be produced by an electric control current flowing through the thin film itself.

If the magnetic control field is produced by an electric current flowing through a control conductor disposed in the neighbourhood of the thin film, and if this control conductor is itself formed of a thin film of electrically conductive magnetic material having an appropriately directed axis of easy magnetization, the transverse magnetic permeability of the first thin film and that of the second thin film may be separately or simultaneously varied by passing a current of appropriate strength through the control conductor, whereby the resistance and the internal inductance of the first thin film and the self-inductance of a circuit connected to this first thin film may be separately or simultaneously varied.

The invention therefore concerns a device having variable resistance and internal inductance, which comprises an electric conductor made of an electrically conductive ferromagnetic material disposed in the form of a thin film and having an axis of easy magnetization in the plane of the film, connecting members being provided to pass a variable electric current through the said conductor in the direction of the axis of easy magnetization, and control means for creating in the conductor a magnetic control field whose lines of force are parallel to the plane of the film and whose intensity may vary sufficiently to vary the apparent magnetic permeability of the material forming the said conductor along the axis of difficult magnetization in order thus to vary the resistance and the internal inductance possessed by this conductor with respect to a variable current flowing through it along the axis of easy magnetization.

In accordance with one feature of the invention, the said control means comprise an electric circuit such that lines of force of a magnetic field due to a current passing through the said electric circuit extend through this conductor in the plane of the film, and these control means comprise control members for passing through the said electric conductor a control current capable of creating in the conductor a magnetic field whose intensity may vary sufficiently to vary the transverse magnetic permeability of the magnetic material forming the said conductor, and thus to vary the resistance and the internal inductance of the said conductor.

In accordance with another feature of the invention, the said electric circuit comprises the said conductor made of a thin film of ferromagnetic material, and the said control members are designed to pass through the said conductor a control current capable of creating in the said conductor a magnetic field whose intensity may vary sufficiently to vary the transverse magnetic permeability of the material forming the said conductor and thus to vary the resistance and the internal inductance of the said conductor.

The invention also concerns combined devices having both the characteristics of the above-defined devices and the characteristics of some of them which have been described in the hereinbefore mentioned copending application.

The various objects, features and advantages of the present invention will become apparent from the following description and from the accompanying drawings, in which:

FIGURE 1 illustrates a first device having variable resistance and internal inductance according to the invention;

FIGURE 2 illustrates a second device having variable resistance and internal inductance according to the invention;

FIGURES 3, 5 and 7 illustrates respectively a second, a third and a fourth constructional form of the device illustrated in FIGURE 1;

FIGURES 4 and 6 illustrate respectively a second and a third constructional form of the device illustrated in FIGURE 2;

FIGURE 8 illustrates a particular circuit arrangement of two devices identical to any one of those illustrated in FIGURES 1, 3, 5 and 7;

FIGURES 9 and 10 illustrate respectively a fifth and a sixth constructional form of the device illustrated in FIGURE 1;

FIGURE 11 illustrates a pre-selection shaft utilising devices according to the invention;

FIGURE 12 illustrates a shift register comprising magnetic cores utilising devices according to the invention;

FIGURE 13 illustrates a third device having variable resistance and internal inductance according to the invention;

FIGURE 14 illustrates a device having variable resistance and inductance which is obtained in accordance with the invention by a modification of the device illustrated in FIGURE 3;

FIGURE 15 illustrates a device having variable resistance, inductance and delay according to the invention, and

FIGURE 16 shows curves representing certain characteristic properties of a ferromagnetic material which may be employed in the devices according to the invention.

The device illustrated in FIGURE 1 comprises a signal-transferring electric conductor **10** formed of a thin film of electrically conductive ferromagnetic material, and a control member **20** consisting of a solenoid **21** connected by conductors **22** and **23** to an electric control circuit **70**.

The electric conductor **10** has in its plane an axis of easy magnetization indicated in FIGURE 1 by the double-pointed arrow FA, and an axis of difficult magnetization perpendicular to the axis of easy magnetization indicated in FIGURE 1 by the two-pointed arrow DA.

The axis AB of the solenoid **21** is directed along this axis of difficult magnetization DA.

The curves *a* and *b* of FIGURE 16 indicate respectively the values of the magnetization J and of the magnetic permeability μ of the material forming the conductor **10**, as a function of the value of the intensity H of a magnetic field whose lines of force are directed along the axis of difficult magnetization DA.

Some alloys, such as "Permalloy," have, when disposed under certain conditions in the form of a thin film, the characteristics which must be possessed by the material forming the conductor **10** of the device illustrated in FIGURE 1.

The transfer conductor **10** is connected by conductors or electrodes **13** and **14** to an electric signal-processing circuit **60**. These conductors **13** and **14** lead to ends **11** and **12** of the transfer conductor **10** whose positions are deduced from one another by translation direction along the axis of easy magnetization FA, so that the current passing through the transfer conductor **10**, when a pulse C passing through the signal-processing circuit is applied by the conductors **13** and **14** to the said conductor **10**, is directed along this axis.

The lines of force of the magnetic field induced by this current extend in planes perpendicular to the direction of the current, i.e. in planes perpendicular to the axis of easy magnetization, so that the reactions which the material forming the conductor must set up to the passage of the current depend solely upon the magnetic permeability of this material calculated in these planes and mainly upon the magnetic permeability μ calculated along the axis of difficult magnetization DA. This permeability will be termed the transverse magnetic permeability.

If, for the sake of simplicity, certain secondary phenomena such as those due to the existence of demagnetizing fields are disregarded, the operation of the devices according to the invention may be explained as indicated in the following paragraphs.

In the absence of an external magnetic field, if the intensity of the magnetic field induced by the current pulse does not exceed the field of anisotropy H_K (FIGURE 16) of the magnetic material, that is to say, if the strength of the current is below a certain critical value, the transverse permeability has the value:

$$\mu_m = \frac{J_S}{H_K}$$

J_S (FIGURE 16 (*a*)) being the value of the magnetization at saturation.

It is possible by passing a control current of appropriate value through the solenoid **21** to create in the transfer conductor **10** a magnetic field whose lines of force are directed along the axis of difficult magnetization DA, and whose intensity H_B exceeds the field of anisotropy H_K, so that the transverse permeability takes the value $\mu_s=1$ (FIGURE 16 (*b*)), corresponding to a state of magnetic saturation of this material.

The ratio $\mu_m:\mu_s$ is consequently equal to the ratio $J_S:H_K$ whose value may exceed 10,000.

Therefore, the transverse permeability of the transfer conductor **10**, and consequently the resistance and the internal inductance of this conductor, may be considerably varied by passing a control current of appropriate value through the solenoid **12**.

The device illustrated in FIGURE 2 comprises the same elements as the device illustrated in FIGURE 1, but the axis AB of the solenoid **20** is parallel to the axis of easy magnetization FA of the transfer conductor **10**.

In the absence of an external magnetic field, the transverse permeability of the transfer conductor **10** has, as before, the value

$$\mu_m = \frac{J_S}{H_K}$$

By passing a control current of appropriate value through the solenoid **21** it is possible to create in the conductor **10** a magnetic field whose lines of force are parallel to the axis of easy magnetization FA and whose intensity H_B exceeds the field of anisotropy H_K of the ferromagnetic material. It can be shown that if H_B is very much greater than H_K the apparent transverse permeability then takes the value

$$\mu'_s = \frac{J_S}{H_B}$$

Under these conditions, the ratio $\mu_m:\mu'_s$ is equal to the ratio $H_B:H_K$, which remains below the value previously obtained and is limited in practice to the value 100.

With the arrangement illustrated in FIGURE 2, the variations of resistance and internal inductance of the transfer conductor are therefore smaller than those obtained with the arrangement illustrated in FIGURE 1 when the control current varies in a given ratio.

FIGURES 3 to 10 illustrate various structures according to the invention which may be obtained by application of the printed circuit technique.

The structures illustrated in FIGURES 3 and 4 correspond to the devices illustrated in FIGURES 1 and 2 respectively. They comprise, like the latter, an electric signal-transferring conductor **10** having the same magnetic characteristics as the conductor **10** of the devices illustrated in FIGURES 1 and 2, and a control device **20**, but the latter consists simply of a rectilinear control conductor **24** superimposed upon the transfer conductor **10**. The conductor **24** is parallel to the conductor **10** in the structure illustrated in FIGURE 3. It is perpendicular to the conductor **10** in that illustrated in FIGURE 4. The transfer conductor and the control conductor are suitably insulated from one another, but for the sake of simplicity this has not been shown in the figures.

The passage of a control current through the control conductor **24** produces in the transfer conductor **10** a magnetic field whose lines of force are parallel to the

axis DA (FIGURE 3), or parallel to the axis FA (FIGURE 4).

The operation of the devices illustrated in FIGURES 3 and 4 is the same as that of the devices illustrated in FIGURES 1 and 2 respectively.

The structures illustrated in FIGURES 5 and 6 differ from those which are illustrated in FIGURES 3 and 4 by the fact that each transfer conductor **10** is replaced by two transfer conductors **101** and **102**, having the same magnetic characteristics as the conductor **10**, which are disposed in parallel on either side of the control conductor **24**. By virtue of this arrangement, the lines of force of the magnetic control field due to a control current passing through the conductor **24** are contained over almost all their length in the magnetic material of the conductors **101** and **102**, so that the electromagnetic coupling between the control conductor **24** and the magnetic material of the transfer conductors **101** and **102** is considerable, and, for a given value of the control current, the intensity of the magnetic control field in this material is as high as possible.

FIGURE 7 illustrates a variant of FIGURE 5 in which the transfer conductors **101** and **102** have a form such that they may be connected at a right angle to the portions of the conductors **13** and **14**, while the control conductor **24** is rectilinear and aligned with the conductor portions **22** and **23** which connect it to the control circuit.

The arrangements illustrated in FIGURES 3, 5 and 7 have the disadvantage that there is a strong coupling due to electromagnetic induction between the circuits to which the transfer conductors (**10**, FIGURE 3; **101**, **102**, FIGURES 5 and 7) on the one hand and the control conductor **24** on the other hand are respectively connected.

This disadvantage may be obviated by employing, for example, as illustrated in FIGURE 8, two devices identical to that of FIGURE 3, i.e., the devices diagrammatically represented in FIGURE 8 by the dash-dotted circles **31** and **32**, and connecting the transfer conductors **10–1** and **10–2** on the one hand and the control conductors **24–1** and **24–2** on the other hand, so as to cancel out the mutual inductance of the circuits comprising these conductors.

This disadvantage may also be obviated by employing either one of the devices according to the invention as illustrated in FIGURES 9 and 10.

The device illustrated in FIGURE 9 comprises a transfer conductor **10** identical to that of the device illustrated in FIGURE 3. The device comprises in addition a control member **20** comprising two control conductors **241** and **242** superimposed on either side of the transfer conductor **10** and parallel to this conductor. These control conductors **241** and **242** are connected in series to the control circuit. They are connected together at **243** at one of their ends and are connected at their other end, through conductor portions **22** and **23** respectively, to the said control circuit.

The device illustrated in FIGURE 10 comprises, like the device illustrated in FIGURE 7, a control conductor **24** aligned with the conductor portions **22** and **23** by which this control conductor is connected to the control circuit. This device comprises in addition transfer conductors **101** and **102** which are connected together at **103** at one of their ends **12–1**, **11–2** and are connected at their other end **11**, **12** by the conductors **13** and **14** respectively to the external signal-processing circuit.

The devices illustrated in FIGURES 1 to 10 may be employed as switches or pulse attenuators. Thus, they may be employed in the manner indicated in FIGURE 11 to provide a pre-selection shaft in particular for a thin-film storage device. These variable-resistance devices are diagrammatically represented in this figure by dash-dotted circles **41**, **42** . . . **46**.

These devices may also be employed in a shift register comprising magnetic cores, in the manner indicated in

FIGURE 12, in place of diodes in the transmission circuits between successive magnetic cores **51**, **52**. These variable-resistance devices are diagrammatically represented in FIGURE 12 by the dash-dotted circles **55** and **56**. They are controlled by current pulses C1 and C2 controlling the alternate transfers through the successive transmission circuits.

In the devices previously described, the magnetic control fields created in the transfer conductors for the purpose of varying the transverse magnetic permeability of these conductors are generated by currents passing through these electric control circuits insulated from the said transfer conductors.

In accordance with a feature of the invention, these magnetic control fields may be generated by currents passing through the transfer conductors themselves.

FIGURE 13 illustrates a device according to the invention which has this feature. This device comprises a transfer conductor **1024** having the magnetic characteristics of the previously described transfer conductors, an electric signal-processing circuit **60** connected to the transfer conductor **1024**, and an electric control circuit **70** also connected to the said transfer conductor. As is indicated in FIGURE 13, capacitors **61** and **62** may be employed to connect the signal-processing circuit **60** to the transfer conductor **1024** in order to isolate this signal-processing circuit from the control circuit **70** in respect of direct current. The control circuit is arranged to pass through the transfer conductor a control current capable of creating in this conductor a magnetic field which is capable of varying the transverse magnetic permeability of the latter and consequently the resistance and the internal inductance of the said conductor.

The variations of magnetic permeability of the transfer conductor **1024** may be obtained by appropriate variations of the strength of the current fed into this transfer conductor by the signal-processing circuit itself, which circuit constitutes at the same time, under these conditions, the control circuit of the device. This arrangement may advantageously be utilised in the magetic core shift register illustrated in FIGURE 12 if the level of the currents generated by the change-over of the magnetic cores during the transmission of an item of information from one magnetic core to the next is utilised to control the variation of the magnetic permeability of variable-impedance devices **55** and **56** constructed in the manner indicated in FIGURE 13. The devices **55** and **56** thus constructed are not then connected to the circuits which supply the transfer control current pulses at C1 and at C2.

The invention also concerns combined devices comprising both the features of some of the devices previously described and the features of some of those which are described in the hereinbefore mentioned copending application.

One of these combined devices is illustrated by way of example in FIGURE 14. This device having variable resistance and inductance results from a modification of the device illustrated in FIGURE 3 of the drawings accompanying the present specification, which modification resides in that the control conductor **24** is of the same form as the transfer conductor **10**, i.e., it consists of a magnetic material arranged in the form of a thin film and having the same magnetic properties as the material forming the said transfer conductor **10**.

The axis of easy magnetization of this control conductor is directed as indicated by the double-pointed arrow FAC, perpendicularly to the lines of force of the magnetic field generated by the passage of signals through the transfer conductor **10**, that is to say, in practice, parallel to the axis of easy magnetization FA of the said transfer conductor. The axis of difficult magnetization of this control conductor, in the plane of the latter, is indicated in FIGURE 14 by the arrow DAC.

By passing through the control conductor **24** an electric

control current of appropriate strength it is possible to vary not only the transverse magnetic permeability of the control conductor **24**, but also the transverse magnetic permeability of the transfer conductor **10**. This makes it possible to obtain, separately or simultaneously, variations of the resistance and the internal inductance of the transfer conductor **10** and of the self-inductance of the signal processing circuit to which the said transfer conductor **10** is connected.

The same effect may be obtained by means of the other devices previously described in the same modification is applied thereto as has just been described.

FIGURE 15 illustrates a delay line having variable resistance, inductance and delay which comprises two external line conductors **81** and **82** connecting input means **601** to output means **602**, two dielectric films **83** and **84**, a thin magnetic film **85** disposed between the two dielectric films and having an axis of easy magnetization FA parallel to the direction P of propagation of the signals along the line, and conductors **22** and **23** for connecting the magnetic film **85** to the control circuit **70**. At least one of the external conductors **81** and **82** of the delay line consists of a magnetic substance arranged in the form of a thin film having an axis of easy magnetization FA parallel to the direction P of propagation of the signals along the line.

Each of the external conductors thus constructed forms with the thin magnetic film **85** disposed in the dielectric **83**, **84** of the delay line a device having variable resistance and inductance which is similar to that illustrated in FIGURE 14 of the present description, so that the whole device illustrated in FIGURE 15 constitutes a combination of the variable delay line disclosed in the hereinbefore mentioned copending application, and of the device having variable resistance and inductance which is illustrated in FIGURE 14 of the present description. By passing a control current of appropriate value through the thin magnetic film **85** disposed in the dielectric of the delay line, it is possible to vary not only the transverse magnetic permeability of this thin film, but also that of the external conductors **81** and **82** of the delay line. This makes it possible to vary separately or simultaneously, on the one hand the transmission delay of the delay line and on the other hand the internal resistance and inductance of the external conductors of this delay line, and consequently to vary separately or simultaneously the position in time and the amplitude and shape of the signals transmitted.

The use of devices having variable resistance, inductance and delay in a pre-selection shaft makes it possible to introduce time coincidences for effecting selections, and thereby to eliminate the effects of insufficiently attenuated and damped pulses which may be transmitted by the devices under consideration. This makes it possible to widen the tolerance margins of these devices.

What is claimed is:

1. In an electric circuit comprising a source of variable current, an electric device of which the value of the resistance and the value of the internal inductance each may take either one or the other of two predetermined values in accordance with a control action, which device comprises a thin magnetic film element formed of a material possessing uniaxial magnetic anisotropy and conducting electricity, means for connecting said magnetic element to said source to establish a current flow through said magnetic element in the direction of easy magnetization, and control means for providing said control action by producing in the magnetic element a control magnetic field of sufficient magnitude to drive said material to the state of saturation, whereby the permeability of said material with respect to the direction at right-angles to that of easy magnetization, and thereby the resistance and the internal inductance of said magnetic element with respect to a variable current flowing through said magnetic element may take either one or the other of two predetermined values according as said control means is operating or not to produce said control magnetic field.

2. In an electric circuit including a source of variable current, an electric device according to claim **1**, wherein said control means includes a control electric circuit element magnetically coupled to said magnetic element and means for establishing through said control element a control current flow inducing in the magnetic element a control magnetic field of sufficient magnitude to drive said material to the state of saturation, whereby the permeability of said material with respect to the direction a right-angles to that of easy magnetization, and thereby the resistance and the internal inductance of said magnetic element with respect to a variable current established through said magnetic element by said connecting means may take either one or the other of two predetermined values according as said control current establishing means is operating or not.

3. In an electric circuit including a source of variable current, a device according to claim **2**, comprising a second thin magnetic film element identical to said first-mentioned magnetic element of the device, said two magnetic elements lying in superposed positions with a common direction of easy magnetization, said connecting means also connecting said second magnetic element to said source to establish a current flow through said second magnetic element in the direction of easy magnetization, said control element being formed of a planar strip conductor located in a position intermediate between these magnetic elements in a plane parallel to the planes of these magnetic elements and said control means being adapted, when operated, to establish through said conductor a control current flow inducing in the magnetic elements a control magnetic field of sufficient magnitude to drive the material forming said magnetic elements to the state of saturation.

4. In an electric circuit including a source of variable current, a device according to claim **2**, wherein said control element is formed of said magnetic element, whereby the resistance and the internal inductance of said magnetic element with respect to a variable current flowing through said magnetic element, and the self-inductance of any circuit connected to said magnetic element may take either one or the other of two predetermined values according as said control means is operated or not to establish said control current flow.

5. In an electric circuit including a source of variable current, a device according to claim **2**, wherein said control element is formed of a second thin magnetic film element possessing uniaxial magnetic anisotropy and conducting electricity, said two magnetic elements lying in superposed positions with a common direction of easy magnetization, said control current establishing means being adapted to establish through said second magnetic element, a control current flow which induces in the magnetic elements a control magnetic field of either a first or a second magnitude to drive either one of said magnetic elements or both of them to the state of saturation, whereby the resistance and the internal inductance of said first-mentioned magnetic element of the device and the self-inductance of any circuit connected to said first-mentioned magnetic element may be caused selectively to take either one of two predetermined values according to the operation of said control current establishing means.

6. In an electric circuit including input means and output means for transferring data representing current signals, a device according to claim **5**, comprising a third thin magnetic film element conducting electricity and possessing uniaxial magnetic anisotropy, said third magnetic element lying in a plane parallel to that of said other mentioned magnetic elements with the same direction of easy magnetization along the face of said second magnetic element opposite the face along which said first-mentioned magnetic element is located, connecting

means defining a path of current flow through each of said first-mentioned and third magnetic elements essentially in the direction of easy magnetization and connecting an end of each defined path to said input means and the other end to said output means so as to form an electromagnetic transmission line between said input means and said output means, and control means adapted, when operated, to establish through said second magnetic element a control current flow which induces in the magnetic elements a control magnetic field of either a first or a second magnitude to drive either said second magnetic element only or the three magnetic elements together to the state of saturation.

7. In an electric circuit including a source of data representing current pulses and a circuit for the transmission of said pulses, a device according to claim 1 wherein said connecting means includes said transmission circuit whereby said device is used as a gate for controlling the transfer of said pulses through said transmission circuit.

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