



(22) Date de dépôt/Filing Date: 1994/12/07

(41) Mise à la disp. pub./Open to Public Insp.: 1995/06/11

(45) Date de délivrance/Issue Date: 2003/11/04

(30) Priorité/Priority: 1993/12/10 (93 14871) FR

(51) Cl.Int.⁵/Int.Cl.⁵ G01V 3/28

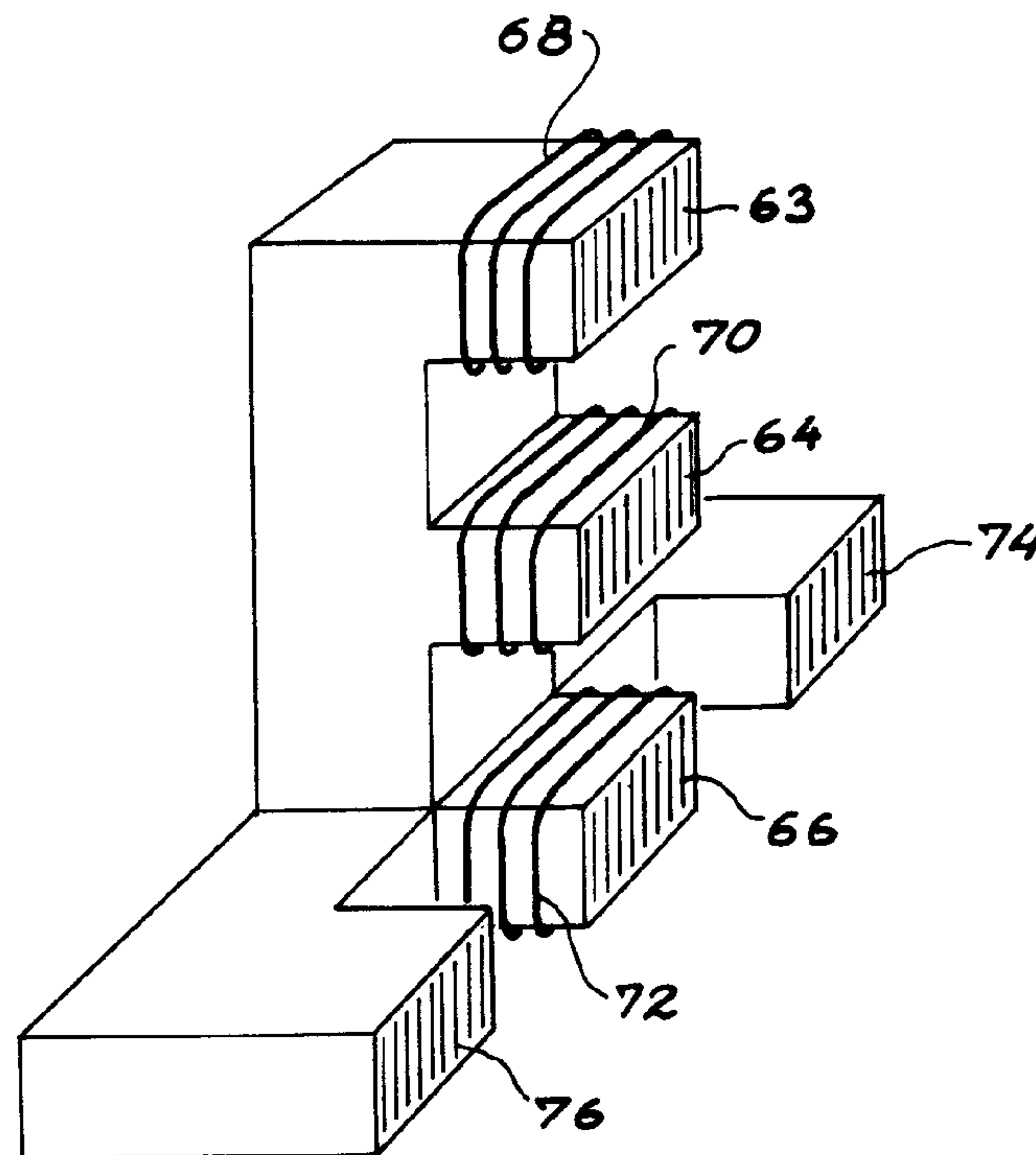
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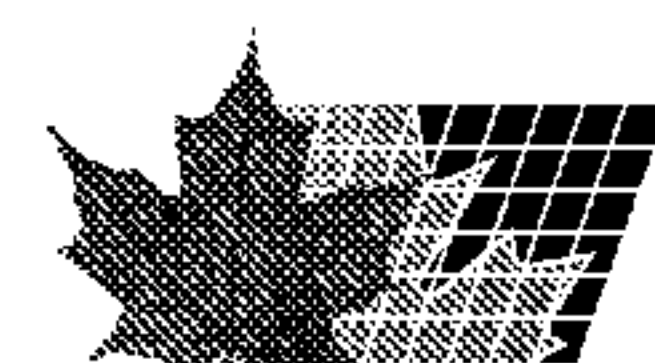
(54) Titre : MICRODISPOSITIF POUR MESURER LES CARACTERISTIQUES ELECTROMAGNETIQUES D'UN
SUPPORT ET UTILISATION DE CE DISPOSITIF

(54) Title: MICRODEVICE FOR MEASURING THE ELECTROMAGNETIC CHARACTERISTICS OF A MEDIUM AND
USE OF SAID MICRODEVICE



(57) Abrégé/Abstract:

Microdevice for measuring the electromagnetic characteristics of a medium comprising at least one emitting or transmitting coil (31), at least one receiving coil (41,51), means for generating an a.c. voltage at the terminals of the transmitting coil or coils and means for measuring a signal at the terminals of the receiving coil or coils. It also comprises an electrically insulating, soft magnetic material circuit serving as a support for each of the coils and which is open on the medium to be measured.



DESCRIPTIVE ABSTRACT

Microdevice for measuring the electromagnetic characteristics of a medium comprising at least one emitting or transmitting coil (31), at least one receiving coil (41,51), means for generating an a.c. voltage at the terminals of the transmitting coil or coils and means for measuring a signal at the terminals of the receiving coil or coils. It also comprises an electrically insulating, soft magnetic material circuit serving as a support for each of the coils and which is open on the medium to be measured.

(Fig. 2)

Microdevice for measuring the electromagnetic characteristics
of a medium and use of said microdevice.

DESCRIPTION

Technical Field

- 5 The object of the present invention is a microdevice for measuring the electromagnetic characteristics of a medium and the use of said device.

It is used in the field of measuring electromagnetic characteristics of a medium to be checked. An example of such an
10 application is the measurement of characteristics, particularly the conductivity and susceptibility, of geological deposits traversed by a borehole.

Prior Art

The term "logging" is used to define any continuous measurement of variations, as a function of the depth, of a given
15 characteristic of deposits traversed by a borehole. The first logging tools were introduced by the Schlumberger brothers in 1927. The principle of the measurement consisted of measuring by means of electrodes the electrical resistivity
20 of deposits traversed by boreholes filled with conductive muds. As a result of the evermore frequent use of non-conductive muds, for which the resistivity loggings by electrodes functioned poorly, Doll introduced in 1949 another resistivity logging principle, namely the measurement by electromagnetic
25 induction (H.G. Doll, "Introduction to induction logging and application to logging of wells drilled with oil-based mud", Petroleum Transactions, pp. 148-162, 1949). Numerous devices operating according to one or other of the two aforementioned principles were designed and manufactured, making
30 it possible to determine the resistivities of deposits with a vertical resolution from a few metres to a few dozen

centimetres (the vertical resolution of a tool being the measurement of the finest band detectable by the tool).

However, the need to characterize deposits on finer scales for determining their dip has made it necessary to design
 5 very small devices, known as microdevices, which are mounted on blocks or pads bearing against the wall of the borehole. These microdevices aim at a good vertical resolution of approximately 1 cm. In the case of electric contact resistivity microdevices, such a resolution can be obtained as a result
 10 of the very small size of the electrodes. However, with the increasing use of non-conductive drilling muds, a need has appeared for induction-based conductivity measuring microdevices. The operating principle of such a device, such as is explained in an article by Wong Cho Chew et al entitled
 15 "Theory of Microinduction Measurements", (IEEE Transactions on Geoscience and remote Sensing, vol. 26, No. 6, November 1988) is shown in fig. 1. A low frequency a.c. current $I_E = I_0 e^{i\omega t}$ flows in a so-called emitting or transmitting coil 1 producing a magnetic field of the same frequency,
 20 which in turn induces eddy currents I_F in the deposit. These eddy currents are proportional to the conductivity of the rock and are phase-shifted by 90° with respect to the emitting or transmitting current. In turn they induce in a so-called receiving coil 2 an electromotive force signal phase-shifted
 25 by 180° with respect to the transmitting current. Frequently two receiving coils connected in opposition are used so as to eliminate the direct flux ϕ_1 generated by the transmitter and so as to only be sensitive to the secondary flux (ϕ_2) from the deposit. The resultant induced voltage is then
 30 directly proportional to the conductivity of the rock.

Despite several theoretical studies, such as that of Chew et al referred to hereinbefore, few practical solutions have been found to the resolution problem defined hereinbefore.

- 3 -

With such induction devices, it is only possible to obtain a vertical resolution of a few centimetres.

5 In addition, the practical limitations to the use of such devices are numerous, because they are sensitive to the actual drilling fluid, as well as to irregularities in the borehole wall, particularly to stand—off variations (sensor—wall spacing). These two phenomena can lead to interfering signals of greater magnitude than the signal of the deposit. Other interfering signals result from the coupling with other neighbouring
10 devices when several of them are located in the same borehole, or from the coupling of the device with the central support of the tool.

Description of the invention

15 The present invention proposes a simple solution to all these problems.

The present invention therefore relates to a microdevice for logging a medium comprising a transmitting coil and two receiving coils, characterized in that it also comprises an E—shaped, electrically insulating, soft magnetic material circuit open to
20 the medium to be measured and having a median portion and three lateral branches perpendicular to said median portion and parallel to one another, the coils being wound onto said lateral branches in such a way that the receiving coils are located on adjacent lateral branches.

25 The present invention further relates to a microdevice for logging a medium comprising a transmitting coil and two receiving coils, also comprising a second transmitting coil, an electrically insulating, soft magnetic material circuit serving as a support for each of the coils and which is open on the medium to be measured and which has a median portion and four lateral, parallel branches perpendicular to the median portion.

30 According to a second embodiment of the invention, the magnetic circuit has a median portion and four parallel, lateral branches perpendicular to the median portion.

It can then have two receiving coils located on the two central, lateral branches, between
35 two external lateral branches,

each carrying a transmitting coil.

It can also have two transmitting coils located on two central, lateral branches, between two external lateral branches, each carrying a receiving coil.

- 5 The central, lateral branches can have different lengths from the external lateral branches.

According to another embodiment of the invention, the magnetic circuit comprises a median portion and five parallel, lateral branches between which are wound, in this order, a first
10 transmitting coil, a first receiving coil, a second receiving coil connected in opposition to the first receiving coil, a third receiving coil connected in opposition to the second receiving coil and a second transmitting coil.

A microdevice according to the invention, as described herein-
15 before makes it possible during the measurement of the electromagnetic characteristics of a geological deposit through a borehole, to achieve a good vertical resolution of approximately 1 cm, a limited coupling with the drilling fluid and with similar, adjacent microdevices and in general a
20 better insensitivity to borehole wall irregularities.

The invention also relates to a method for measuring the electromagnetic characteristics of a medium, using a micro-
device as defined hereinbefore. A particular case is that where the characteristics measured are the conductivity and
25 susceptibility of a geological deposit.

With such a method, it is possible to obtain measurements having a good vertical resolution (approximately 1 cm) and only slightly influenced by drilling fluids, any similar, adjacent devices and irregularities of the borehole walls

through which the geological deposit is reached.

Brief description of the drawings.

The invention is described in greater detail hereinafter relative to non-limitative embodiments and with reference
5 to the attached drawings, wherein show:

Fig. 1 the principle of measuring conductivity by induction.

Fig. 2 a microdevice according to a first embodiment of the invention in position in a borehole.

Figs. 3a and 3b the vertical and radial characteristics for
10 a microdevice according to a first embodiment of the invention.

Figs. 4a and 4b two microdevices according to a first embodiment of the invention in profile with different separating distances between the two receivers.

15 Figs. 5a and 5b the vertical and radial characteristics of microdevices according to figs. 4a and 4b.

Fig. 6 a microdevice according to the invention seen in perspective.

Fig. 7 another variant with unequal E branches.

20 Fig. 8 an electrical arrangement for measuring the signal and characteristics of the medium to be investigated, in the case of an E-shaped device.

Figs. 9a to 9c a second embodiment of the invention.

Fig. 10 a third embodiment of the invention.

25 Figs. 11 and 12 means for forming a screen between the transmitting coil and part of the environment outside the area of interest.

Detailed description of embodiments.

Fig. 2 illustrates a microdevice for measuring conductivity
30 by induction according to the invention in the measuring

position in a borehole. The borehole is in the form of a cylindrical hole T traversing a deposit (F), G representing a mud cake of limited thickness (a few millimetres), against the wall of the deposit F traversed by the borehole.

- 5 The device is in the form of an E-shaped magnetic circuit with a median portion 6 and three lateral branches 3,4,5 perpendicular to the median portion and parallel to one another.

10 In addition, in the embodiment shown in fig. 2, the lateral portions 3,4,5 are of equal lengths and the two spacings between two adjacent lateral portions 3-4 and 4-5 are different. Onto the lateral branches are wound three windings or coils, namely an emitting or transmitting coil 31 and two receiving coils 41,51, wound in opposition onto two adjacent, lateral branches. The magnetic circuit is preferably
15 constituted by an electrically insulating and magnetically soft material. This material has a relatively high magnetic permeability not varying with the temperature in the useful range (i.e. the range defined between the temperature at
20 the surface of the borehole and the temperature deep in the well and level with the geological deposits traversed, e.g. $0^{\circ}\text{C} \rightarrow 200^{\circ}\text{C}$. Alternatively and in known and forecastable manner in such a way that consideration can be given to a correction during or after logging. Thus, this covers materi-
25 als such as those of the ferrite type, divided iron, iron carbonyl or also materials based on iron in the form of laminated sheets.

The transmitting coil 31 is supplied by a low frequency alternating current $I_0 e^{i\omega t}$ (of a few dozen Hertz to a few dozen
30 kiloHertz).

The voltage induced at the terminals of each receiver 41,51 is the sum of two contributions, on the one hand the variation of the direct magnetic flux produced by the transmitter and on the other the variation of the secondary magnetic flux produced by the eddy currents induced in the deposit. So as to only be sensitive to the signal from the deposit, the receivers are wound in opposition and their respective number of turns is correctly adjusted in such a way that the contribution of the direct flux is eliminated. Another way of obtaining such a result is to adjust the cross-section on the ends of the magnetic circuit, because the voltage induced at the terminals of a coil is proportional, not only to its number of turns, but also to its cross-section.

The choice of a "balanced" arrangement has in our case the other advantage of eliminating any disturbance to the signal linked with variations in the magnetic and electrical characteristics of the magnetic circuit during logging.

The use of a soft magnetic circuit open on the side of the medium to be measured (E-shaped in fig. 2) permits the channelling of the magnetic field produced by the transmitting circuit into the deposit of the borehole. Therefore said magnetic field induces eddy currents in the deposit, mainly in an area A (cf. fig. 2) facing the magnetic circuit and only slightly beyond said area, which by itself eliminates any disturbing signal from "peripheral" areas (areas B, C and D in fig. 2).

Thus, it is possible to study in a more precise and quantitative manner the coupling of the microdevice with the deposit, e being the measured signal (voltage induced at the terminals of the receiver):

$$e = k \iiint_{\text{rock volume}} \sigma(x, y, z) S(x, y, z) dx dy dz$$

in which:

k is a constant $k = N_R \omega^2$, (N_R being the number of turns and $\omega = 2\pi f$),

5 $\sigma(x, y, z)$ is the electrical conductivity of the rock at point (x, y, z) ,

$S(x, y, z)$ is the sensitivity at the point (x, y, z) , the higher S , the greater the signal from point (x, y, z) of the deposit.

10 It is possible to use cylindrical coordinates r, θ, z , the axis z being parallel to that of the borehole and chosen in the manner indicated in fig. 1. Assuming a distribution of the rocks independent of the angle θ , the following radial characteristic is defined:

$$G_r(r) = \int_{-\infty}^{+\infty} S(r, z) dz$$

15 In this characteristic, it is possible to deduce the "investigation depth", which is the depth r_i for which the area under the curve $G_r(r)$ reaches 50% of the total value of the area (cf. fig. 3a). Thus, the vertical characteristic G_v is defined:

20 $G_v(z) = \int_0^{\infty} S(z, r) dr$

It is possible to deduce from this curve the "vertical resolution" r_v , which is the curve mid-height width (cf. fig. 3b).

Fig. 4 shows two microdevices according to the invention. The difference between them is the distance between the two parts 4, 5 of the circuit on which the receivers 41, 51 are wound. This distance is greater in the microdevice of fig. 4a than in that of fig. 4b. On the basis of the corresponding radial and vertical characteristics shown in figs. 5a and

5b, it is clear that a vertical resolution of 14 to 18 mm (fig. 5a) and an investigation depth (fig. 5b) of approximately 13 mm (13.7 mm, the same in both cases) are obtained.

However, in the best possible cases, the existing microdevices
5 have an investigation depth of 1 cm for a vertical resolution of 3 to 5 cm in insulating mud. Thus, as a result of the configuration according to the invention, there is an improvement to the vertical resolution by approximately a factor of 2, there being no deterioration to the investigation depth.

10 On the basis of figs. 5a and 5b, it can be seen that the closer the receiver 41 is to the receiver 51, the finer the vertical resolution, the investigation depth remaining virtually unchanged. It is therefore possible to "adjust" the vertical resolution by choosing a varying distance between
15 the two receivers.

Finally, the closer the receivers are to one another, the less the device is sensitive to interfering signals, which are due on the one hand to the signal from the mud cake G between the measuring device and the borehole wall (cf. fig.
20 2) and on the other hand to the variations in the sensor-wall distance. Thus, in the device of fig. 4b, the radial characteristics has a maximum at approximately $r_m = 4\text{mm}$ (cf. fig. 5b). This means that the contribution to the signal of the "near" parts (between 0 and 4 mm) of the microdevice
25 is attenuated. It is precisely from these parts that the aforementioned interfering signals come.

Another advantage of the microdevice according to the invention is the weak coupling between several microdevices when they are arranged on several pads or blocks, e.g. for a tilt-
30 metry or clinometry measurement. This avoids having to have recourse to the conventional solutions of multifrequency

excitations or switched excitations, which requires a much more complex electronics associated with each microdevice. In the same way, the coupling between the central support of the generally metallic tool is greatly reduced.

- 5 Fig. 6 shows an embodiment of the invention. Mumetal sheets (Fe-Ni-Mo) with a thickness of 53 μm are arranged so as to form an asymmetrical E-shaped magnetic circuit. In this construction, the transmitting circuit 31 is placed on a lateral branch 3 and the two receivers 41,51 are connected
10 in opposition on the two other branches 4 and 5 in such a way that in the absence of a conductive medium facing the sensor, the resulting voltage is zero. Typically such a device has a height h (cf. fig. 6) of a few dozen millimetres.

- An arrangement in which the transmitting circuit is positioned
15 on the central branch, whereas the receivers are connected in opposition on the outer lateral branches is more sensitive to wall irregularities than the arrangement in which two receiving coils are wound in opposition on two adjacent lateral branches.

- 20 Fig. 7 shows another embodiment in which the branches of the magnetic circuit have unequal lengths (e.g. $l_1 \approx l_3 \neq l_2$).

A transmitting circuit is connected on any random one of the extreme lateral branches, each of the other branches supporting a receiving circuit, both connected in opposition.

- 25 Fig. 8 illustrates an electronic connection example for a microdevice according to the invention shaped like an E. This microdevice comprises a transmitting coil 31 and two receiving coils 41,51 connecting in opposition. The arrangement incorporates means for generating an a.c. voltage at
30 the terminals of the transmitting coil and means for measuring

a signal at the terminals of the receiving coils.

In the case of application to logging by induction in a borehole, the voltage measured in the receiving coils has in fact two components, namely a component at $\pm 180^\circ$ with respect to the transmitting current and making it possible to measure the conductivity of the rock and a component at $\pm 90^\circ$ with respect to the transmitting current and from which it is possible to deduce the susceptibility. Another component at 90° of the transmitting current and corresponding to the direct flux induced by said current in the receiving coils is eliminated by the connection in opposition.

The transmitting coil 31 is supplied by a generator 18, which delivers a phase reference signal to a phase detector 20, to whose input are connected the terminals of receivers (41, 51) connected in opposition.

At the output of the phase detector, two signals, one at 180° and the other at 90° with respect to the reference signal, make it possible to calculate respectively the conductivity and susceptibility of the rock.

A second embodiment of the invention is illustrated in figs. 9a to 9c. In each of the latter an electrically insulating, soft magnetic material circuit has a median portion 28 and four parallel, lateral branches 30, 32, 34, 36 perpendicular to the median portion. Two not shown transmitting coils are connected on external branches 30, 36 and are preferably connected in series. Two not shown receiving coils are connected on internal branches 32, 34 and are preferably connected in opposition.

The measurement of the signal can take place with an electrical diagram similar to that of fig. 8. The transmitting

coils are connected to means for generating an a.c. voltage at their terminals and their receiving coils to means for measuring a signal at their terminals.

The two internal branches 32,34 are of equal length (fig. 5 9a) smaller length (fig. 9b) or greater length (fig. 9c) compared with the length of the external branches 30,36, the compensation of the flux directly induced in the receiving coils by the transmitting coils appearing easier in the first case than in the two latter cases. It is naturally 10 possible to reverse the position of the two transmitting coils with those of the two receiving coils.

A third embodiment of the invention is illustrated in fig. 10. An electrically insulating, soft magnetic material circuit comprises a median portion 38 and five parallel, lateral 15 branches 40,42,44,46,48 perpendicular to said median portion.

Two not shown transmitting coils are connected in series on the external, lateral branches 40,48 and three not shown, receiving coils are connected on the three external branches 42,44,46, the central receiving coil connected at 44 being 20 connected in series-opposition with the two other receiving coils connected at 42 and 46.

For the two latter embodiments described, it has been possible to see a very good vertical resolution (approximately 1 cm) a weak coupling with the fluid of the borehole and with other 25 sensors, if other sensors are used in the same borehole.

Other embodiments of the invention are illustrated in figs. 11 and 12.

It is a question of solving the problem of magnetic flux leaks from transmitters to areas of the environment to be

measured and which lack any interest. For this purpose,
in the direct vicinity of the branch or branches having a
transmitting coil are positioned means for forming a screen
or shield between said coil and the area which is of no inter-
5 est.

Such means can be in the form illustrated in fig. 11, which
diagrammatically shows a device according to the invention
having three branches 50,52,54 carrying a transmitting coil
56 (external branch 50) and receiving coils 58,60 (branches
10 52,54), connected and supplied in the manner described herein-
before. The device has a supplementary branch 62, e.g. made
from the same material as the remainder of the device and
on which no coil is wound. This supplementary branch, which
is parallel to the other branches and perpendicular to the
15 median portion, is in the vicinity of the branch 50 on which
is wound the transmitting coil. Thus, the flux of the latter
is not in part lost in the areas of the medium to be measured
which are of no interest, so that a better directivity is
ensured. Moreover, this embodiment makes it possible to
20 ensure a better decoupling with respect to other sensors.
It is possible to adapt a supplementary branch to a device
having four or five coils (like those of figs 9a to 10) as
soon as a transmitting coil is located on an external branch.

In all cases, it is also possible to adapt on either side
25 of a branch carrying a transmitting coil, with respect to
a plane passing through the median portion of the device
and through its lateral branches carrying coils. Thus, fig.
12 shows a device having three lateral branches 63,64,66
on which are wound receiving coils 68,70 and a transmitting
30 coil 72.

On either side of the branch 66 carrying the transmitting coil there are two branches 74,76 not carrying coils and e.g. made from the same material as the rest of the device. These supplementary branches 74,76 have also an effect of channelling the flux to the areas of interest. They also permit a better decoupling with respect to other sensors located in the borehole.

The two solutions described hereinbefore for channelling the flux of a transmitting coil can also be combined.

- 10 The invention described is applicable to conductivity and susceptibility logging in geological deposits traversed by boreholes. It can more generally apply to the measurement of the electromagnetic characteristics of electrically conductive materials, e.g. by measuring their conductivity and/or
- 15 susceptibility.

CLAIMS

1. Microdevice for logging a medium comprising a transmitting coil and two receiving coils, characterized in that it also comprises an E-shaped, electrically insulating, soft
5 magnetic material circuit open to the medium to be measured and having a median portion and three lateral branches perpendicular to said median portion and parallel to one another, the coils being wound onto said lateral branches in such a way that the receiving coils are located on adjacent lateral
10 branches.
2. Microdevice according to claim 1, the two spacings between adjacent lateral branches being equal to one another.
3. Microdevice according to claim 1, the two spacings between adjacent lateral branches being different from one another.
15 her.
4. Microdevice according to claim 1, the lateral branches being of unequal length.
5. Microdevice according to claim 1, also comprising means for forming a shield between the transmitting coil and an
20 area lacking interest of the medium to be examined.
6. Microdevice according to claim 5, comprising a supplementary branch on which no coil is wound and in direct vicinity of the branch on which is wound the transmitting coil.
7. Microdevice according to one of the claims 1, 5 or
25 6, two supplementary branches being located on either side of the branch on which is wound the transmitting coil with respect to a plane passing through the median portion and three lateral branches.

8. Microdevice for logging a medium comprising a transmitting coil and two receiving coils, also comprising a second transmitting coil, an electrically insulating, soft magnetic material circuit serving as a support for each of the coils
5 and which is open on the medium to be measured and which has a median portion and four lateral, parallel branches perpendicular to the median portion.
9. Microdevice according to claim 8, the two receiving coils being located on the two lateral, central branches,
10 the two external lateral branches in each case carrying a transmitting coil.
10. Logging device according to claim 9, comprising a fifth lateral branch parallel to the four other lateral branches, as well as a third receiving coil, the coils being connected
15 in the following order starting from one of the outermost lateral branches: a first transmitting coil, a first receiving coil, a second receiving coil connected in opposition to the first receiving coil, a third receiving coil connected in opposition to the second receiving coil and a second transmitting coil.
20
11. Microdevice according to any one of the claims 8 to 10, also comprising means for forming a shield between at least one transmitting coil and an area without interest of the medium to be examined.
- 25 12. Microdevice according to claim 11, comprising a first supplementary branch on which no coil is wound and in direct vicinity of one of the branches carrying a transmitting coil.
13. Microdevice according to claim 12, comprising a second supplementary branch on which no coil is wound and in direct
30 vicinity of the other branch carrying a transmitting coil.

14. Microdevice according to claim 11, two supplementary branches being located on either side of one of the branches carrying a transmitting coil, with respect to a plane passing through the median portion and lateral branches carrying
5 coils.
15. Microdevice according to claim 8, the two transmitting coils being located on the two central, lateral branches, the two external lateral branches in each case carrying a receiving coil.
- 10 16. Microdevice according to claim 15, also comprising means for forming a shield between at least one transmitting coil and an area without interest of the medium to be examined.
- 15 17. Microdevice according to claim 16, two supplementary branches being located on either side of at least one of the branches carrying a transmitting coil, with respect to a plane passing through the median portion and the lateral branches carrying coils.
- 20 18. Microdevice according to either of the claims 1 and 8, the soft magnetic material being chosen from among ferrite, divided iron, iron carbonyl or a material based on iron in the form of a laminated sheet.
19. Method for measuring the electromagnetic characteristics of a medium using a microdevice according to any one of the claims 1 to 18.
- 25 20. Method according to claim 19, where the measured characteristics are the conductivity and susceptibility of a geological deposit.

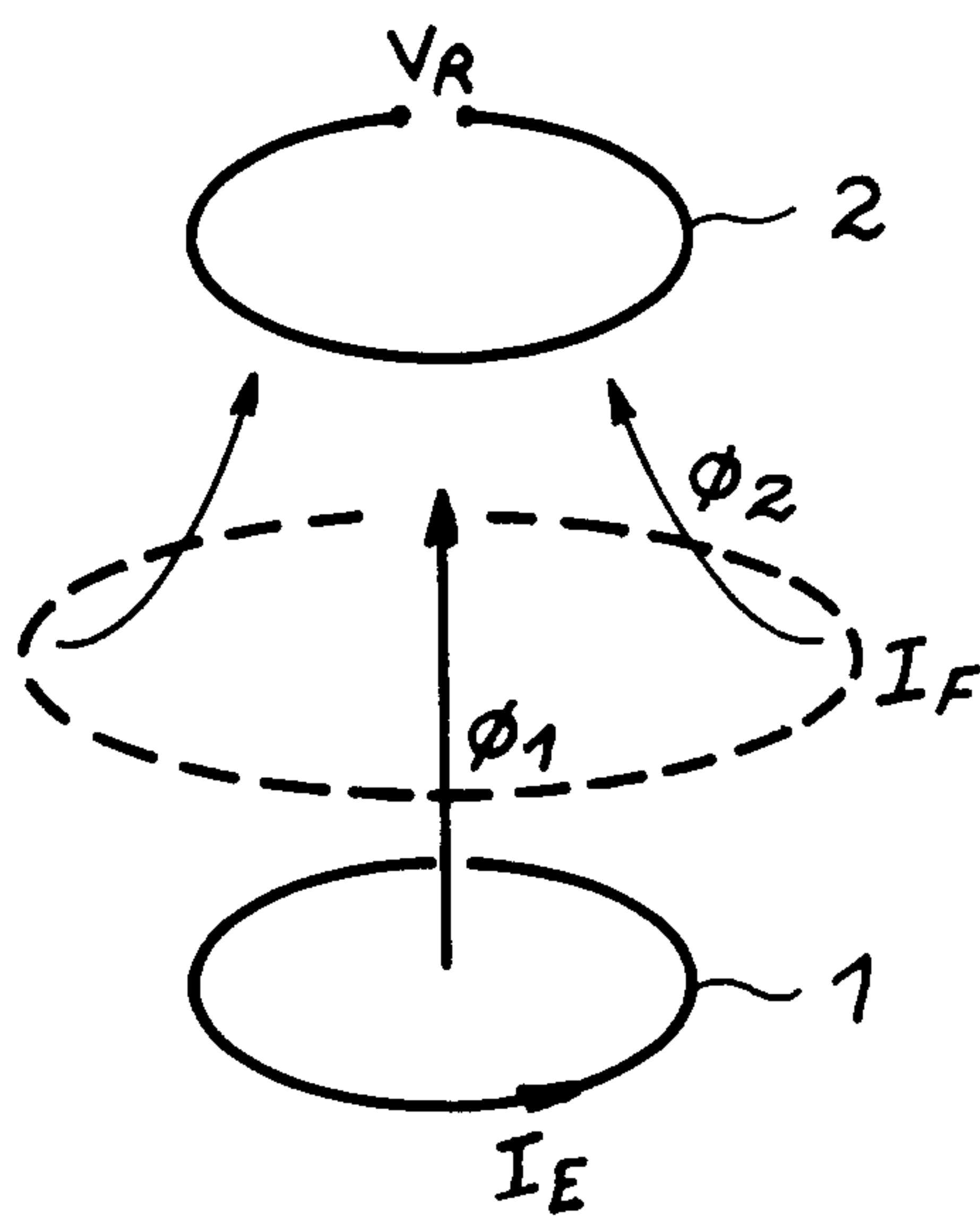


FIG. 1

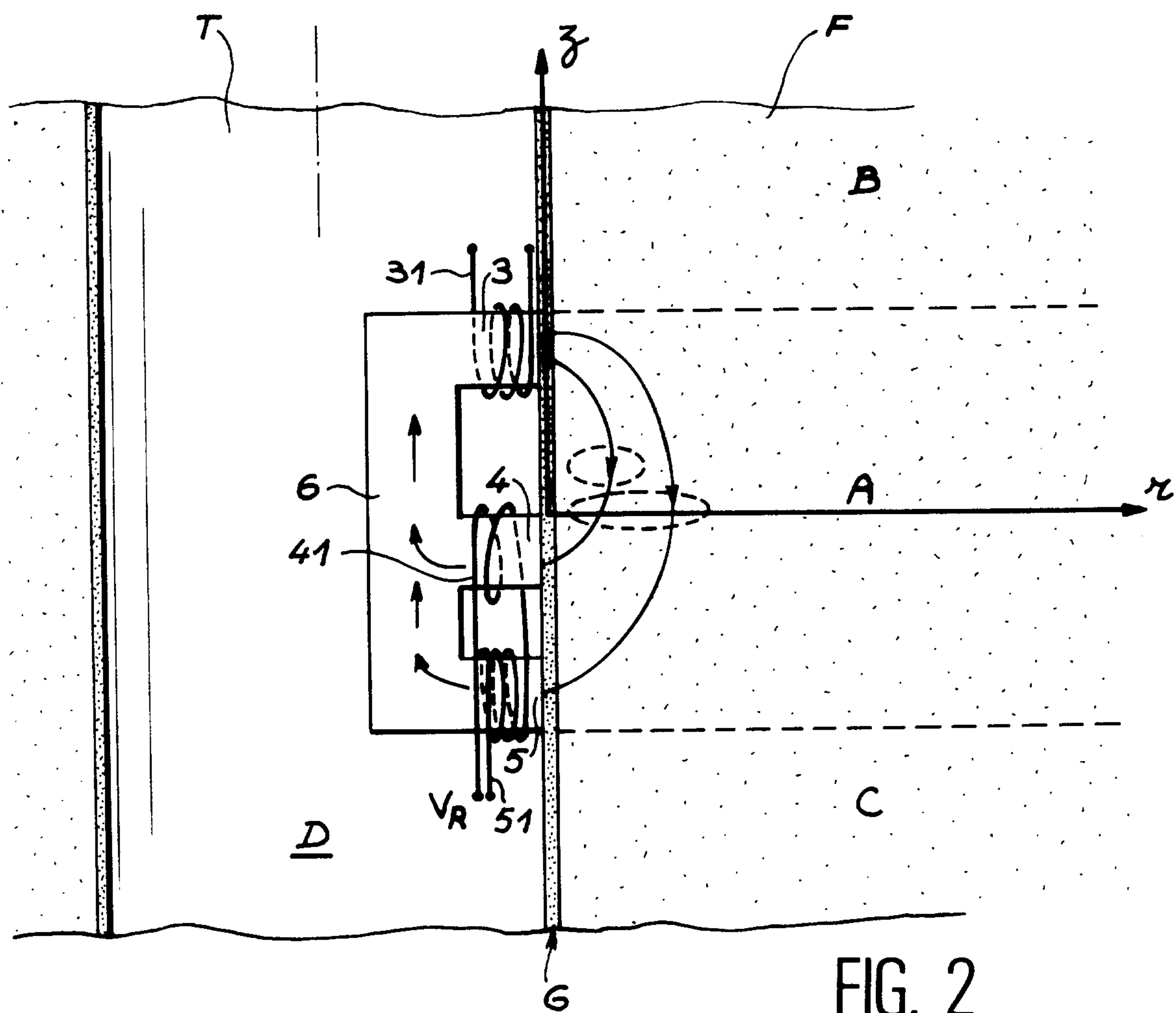


FIG. 2

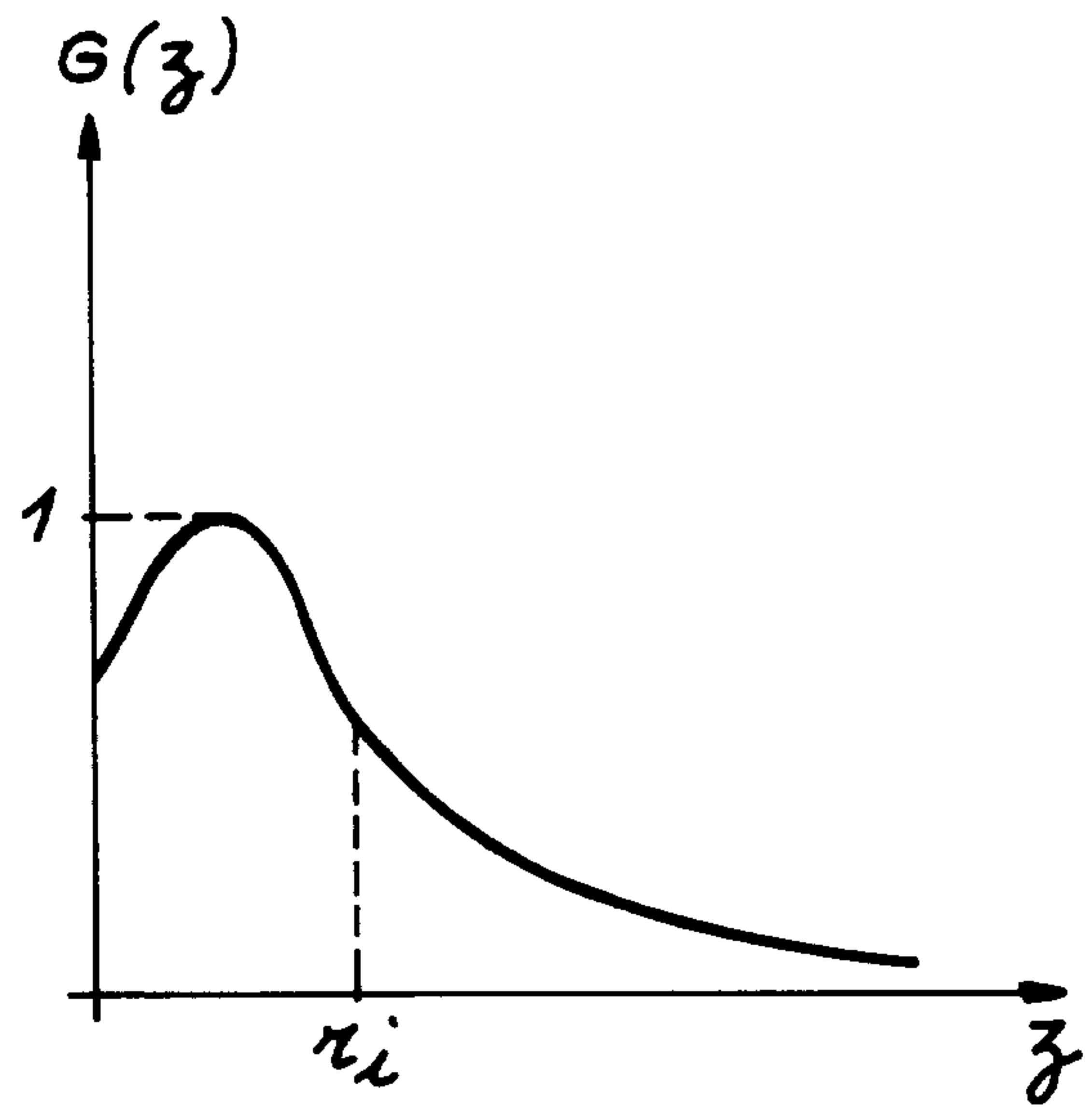


FIG. 3a

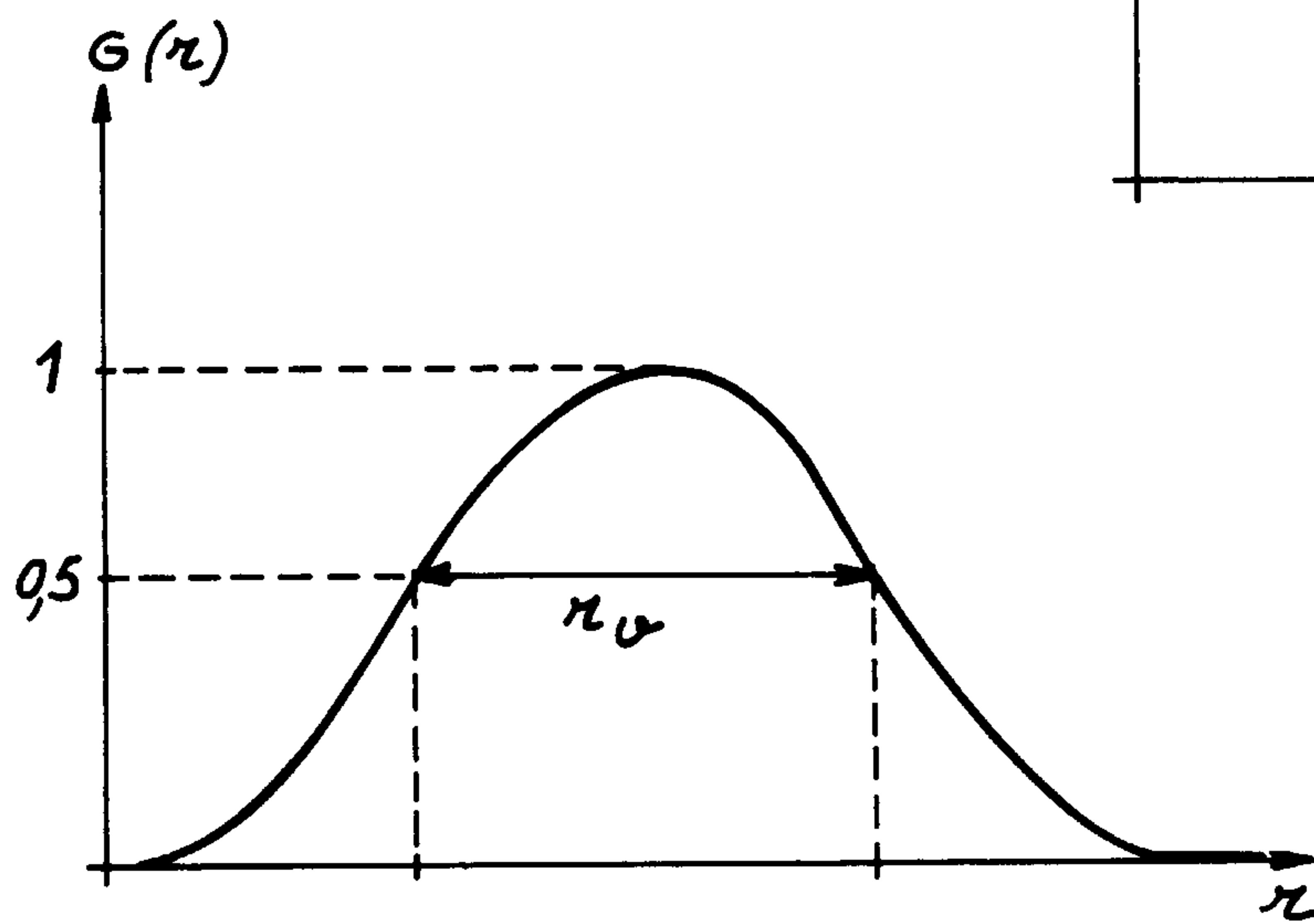


FIG. 3b

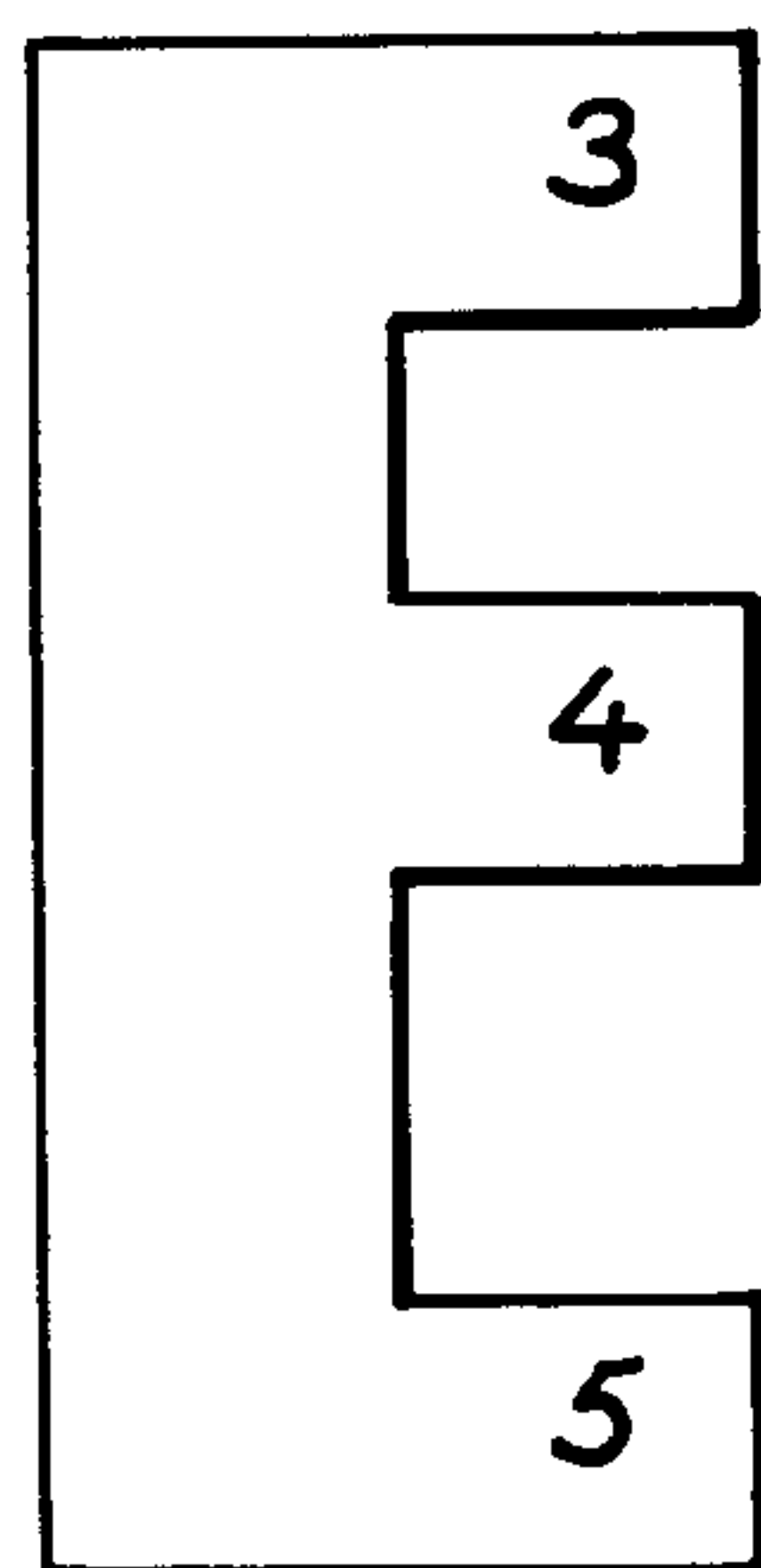


FIG. 4a

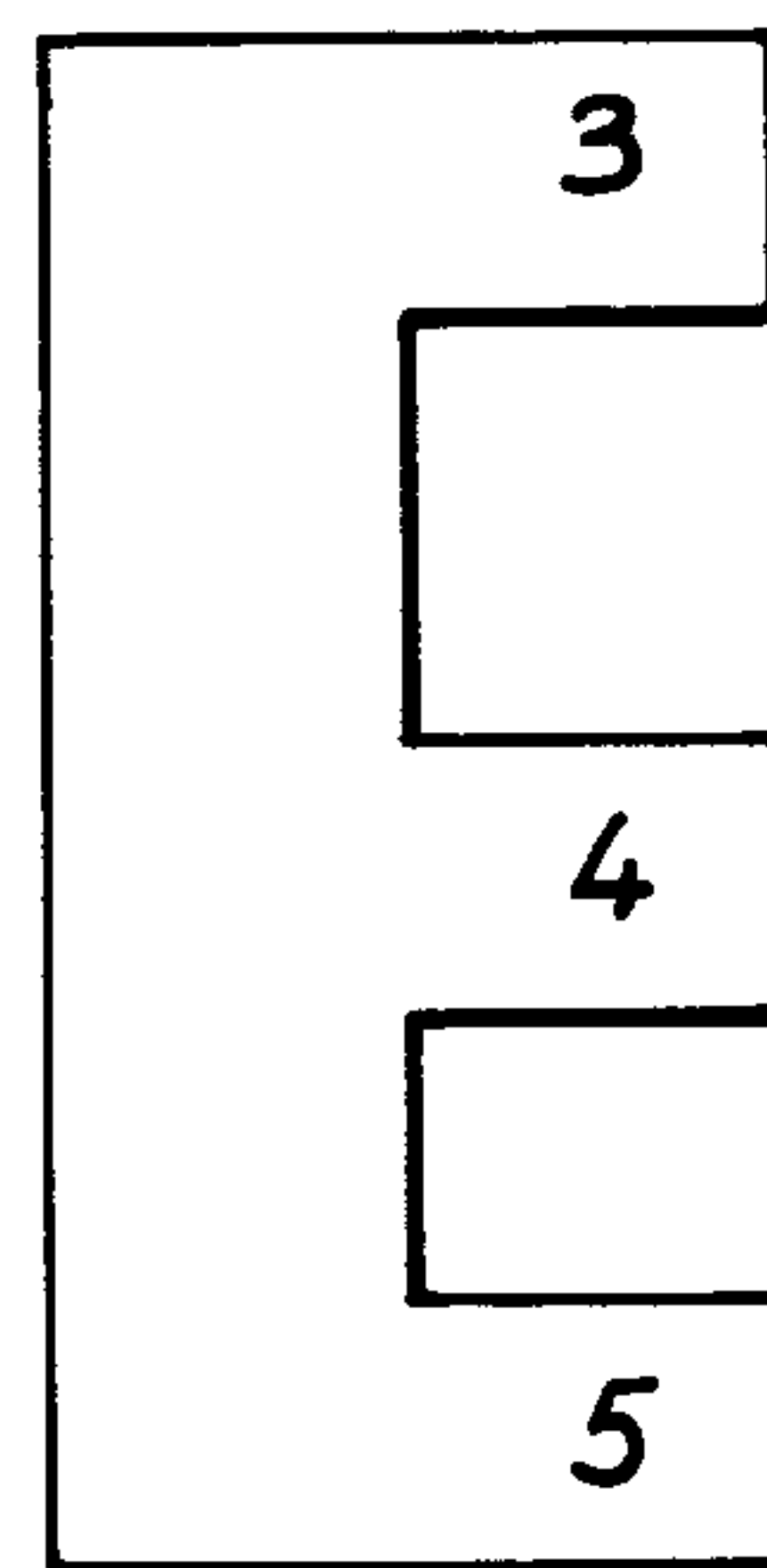


FIG. 4b

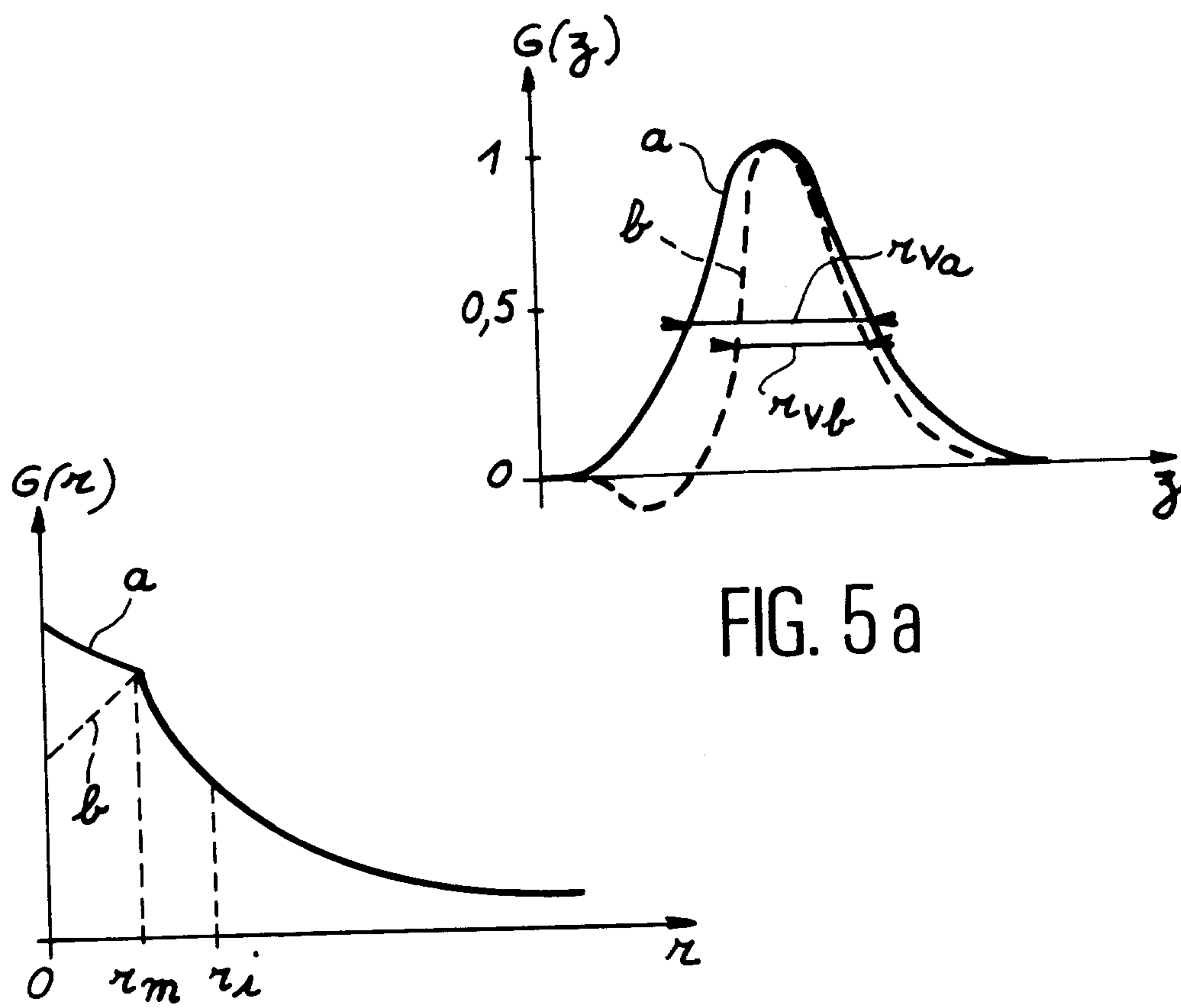


FIG. 5 a

FIG. 5 b

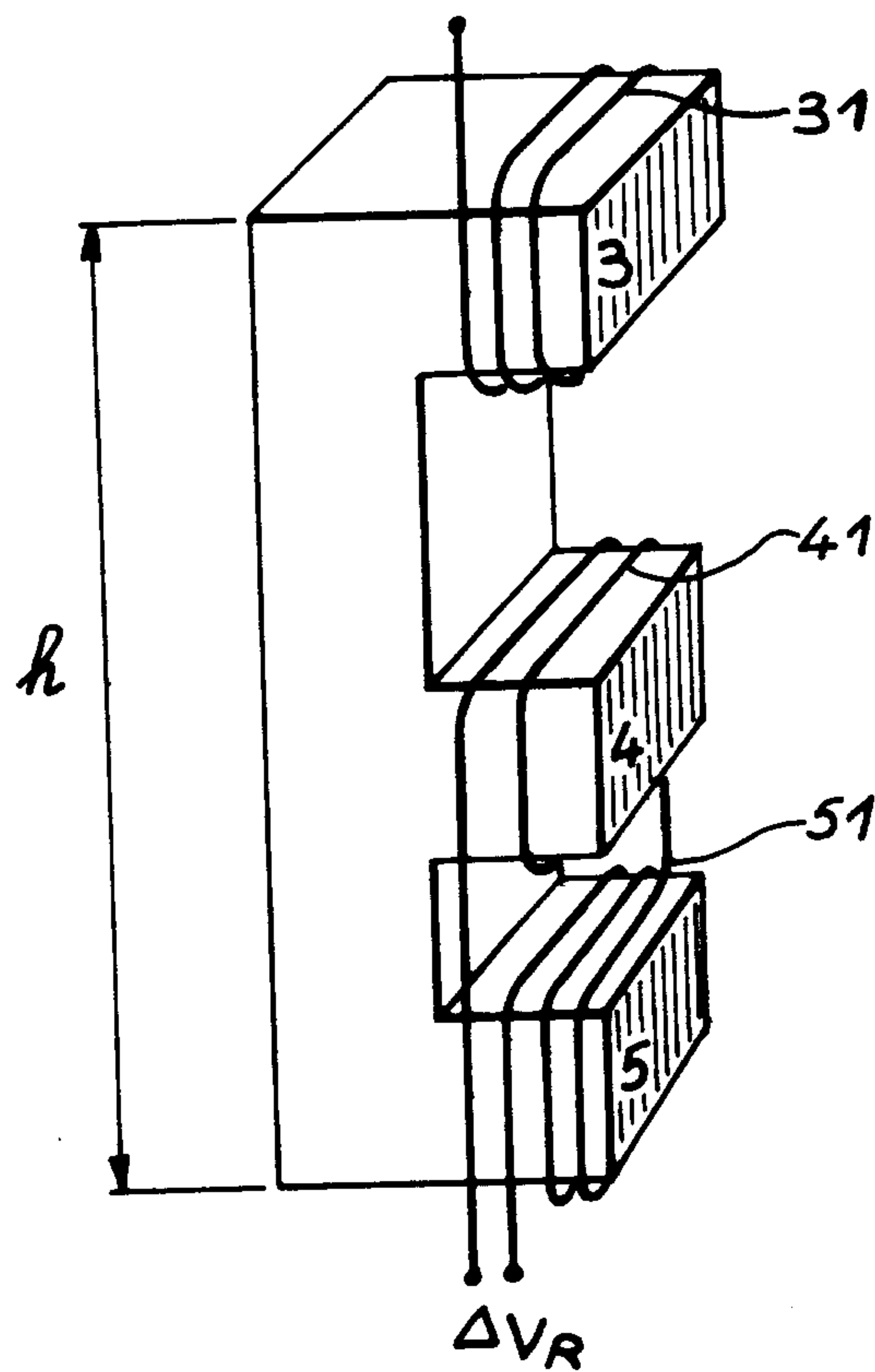


FIG. 6

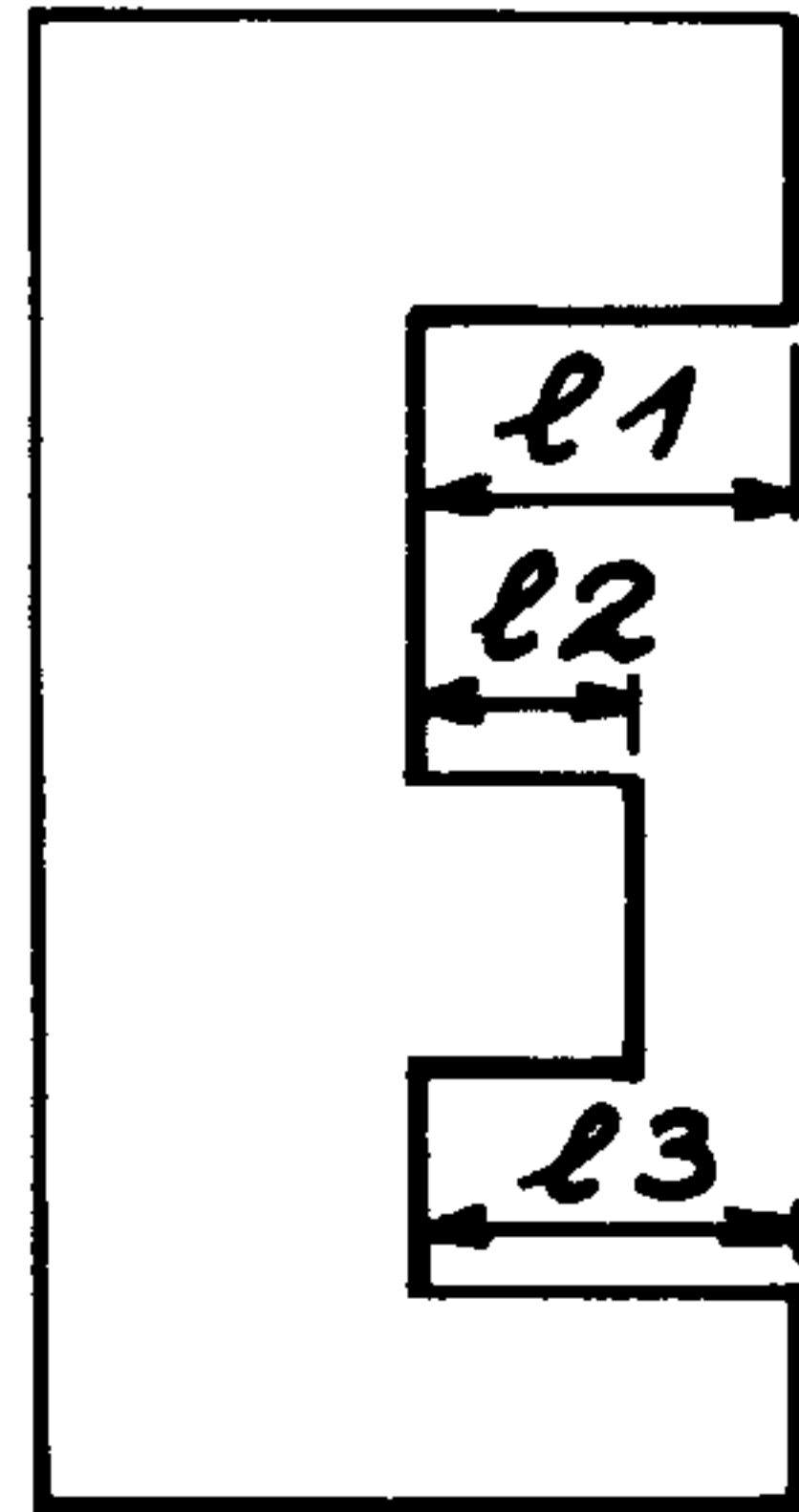


FIG. 7

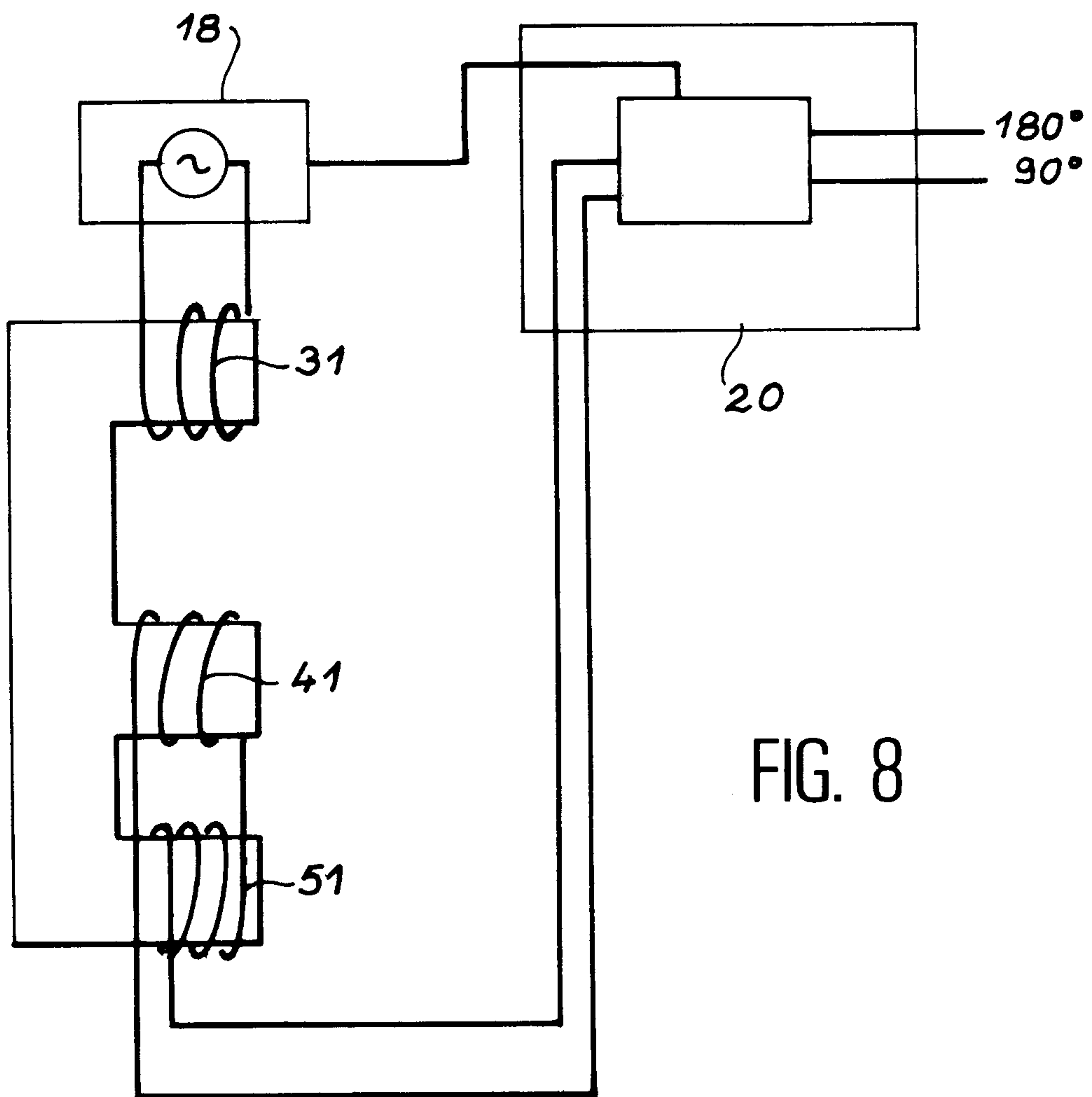


FIG. 8

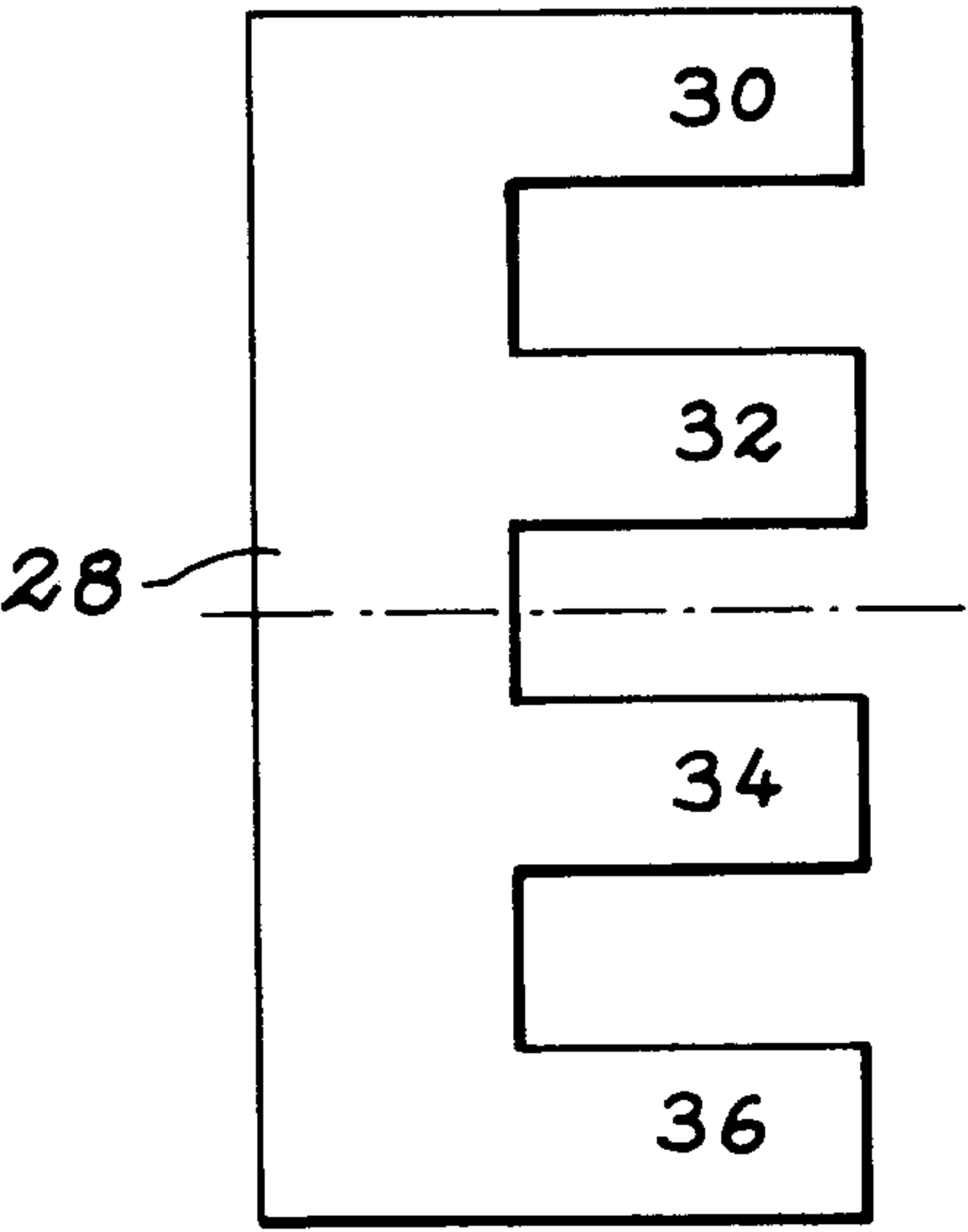


FIG. 9a

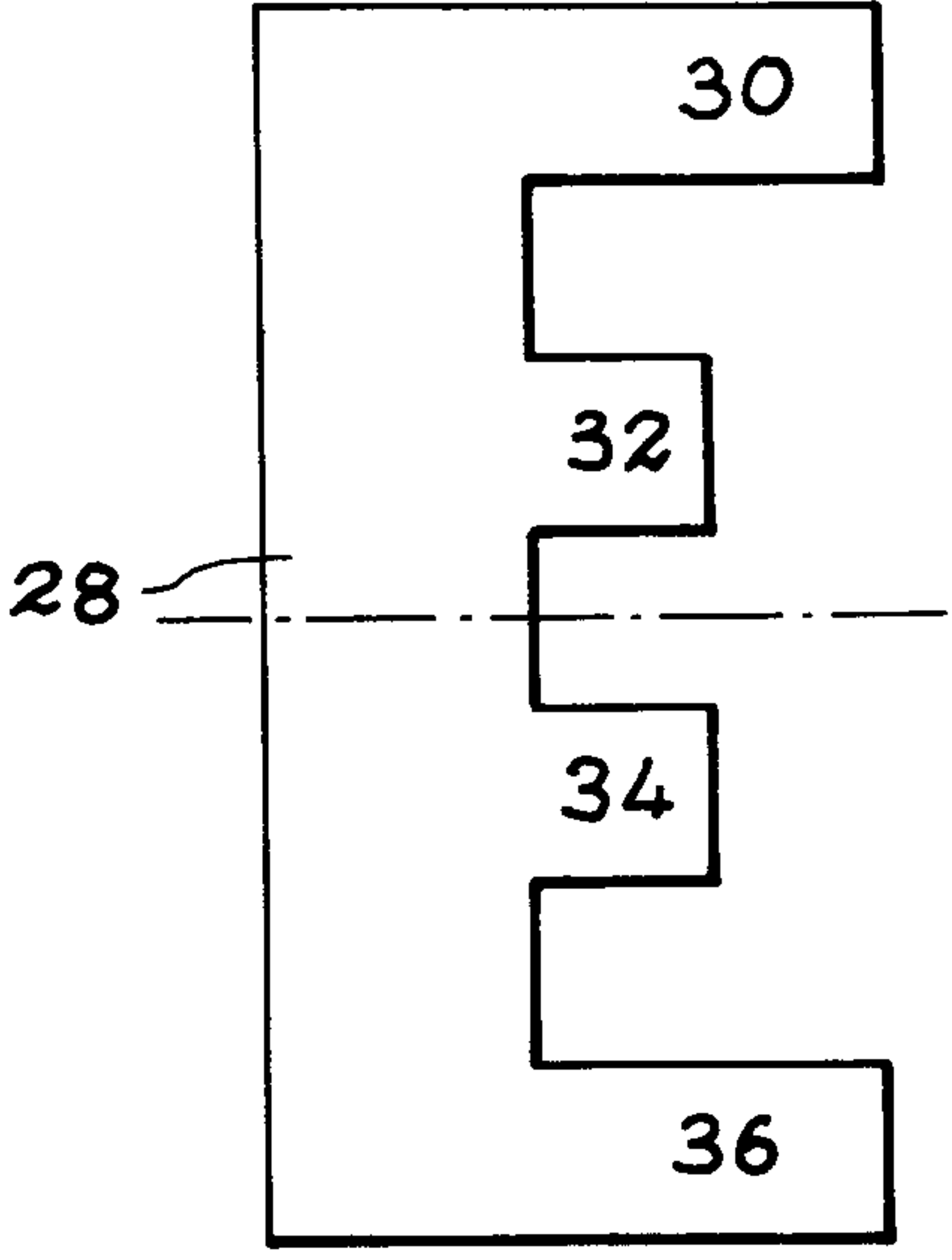


FIG. 9b

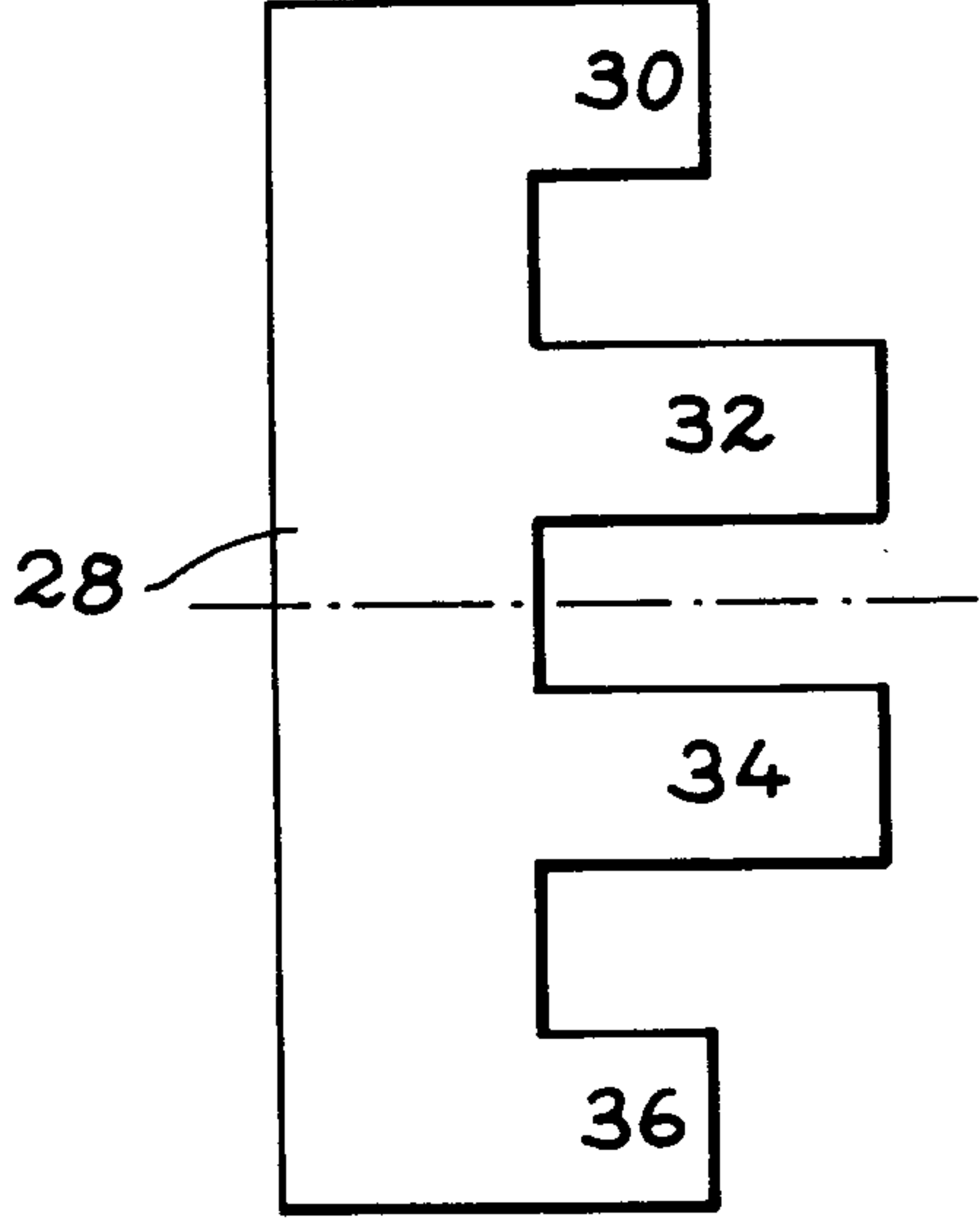


FIG. 9c

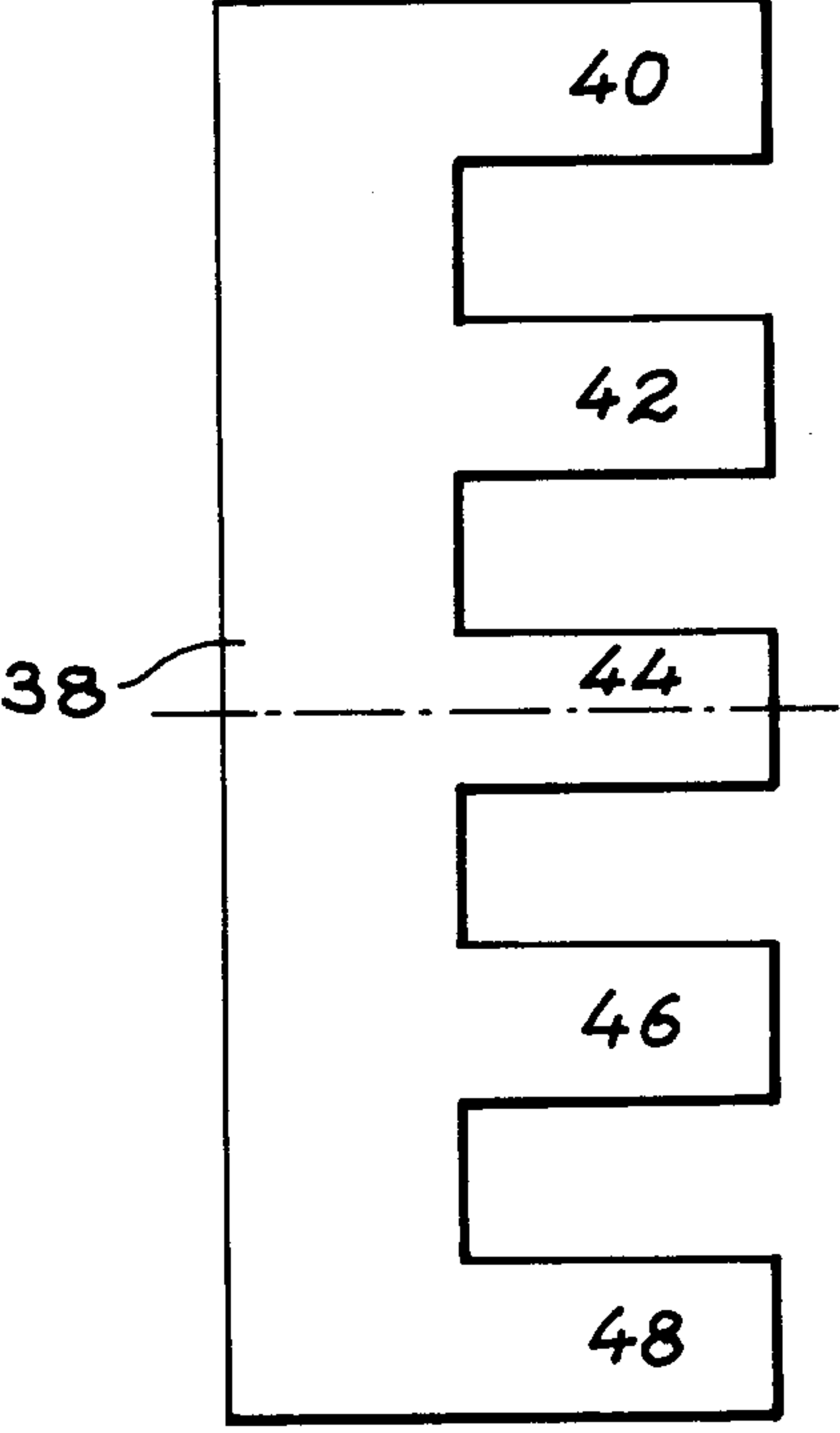


FIG. 10

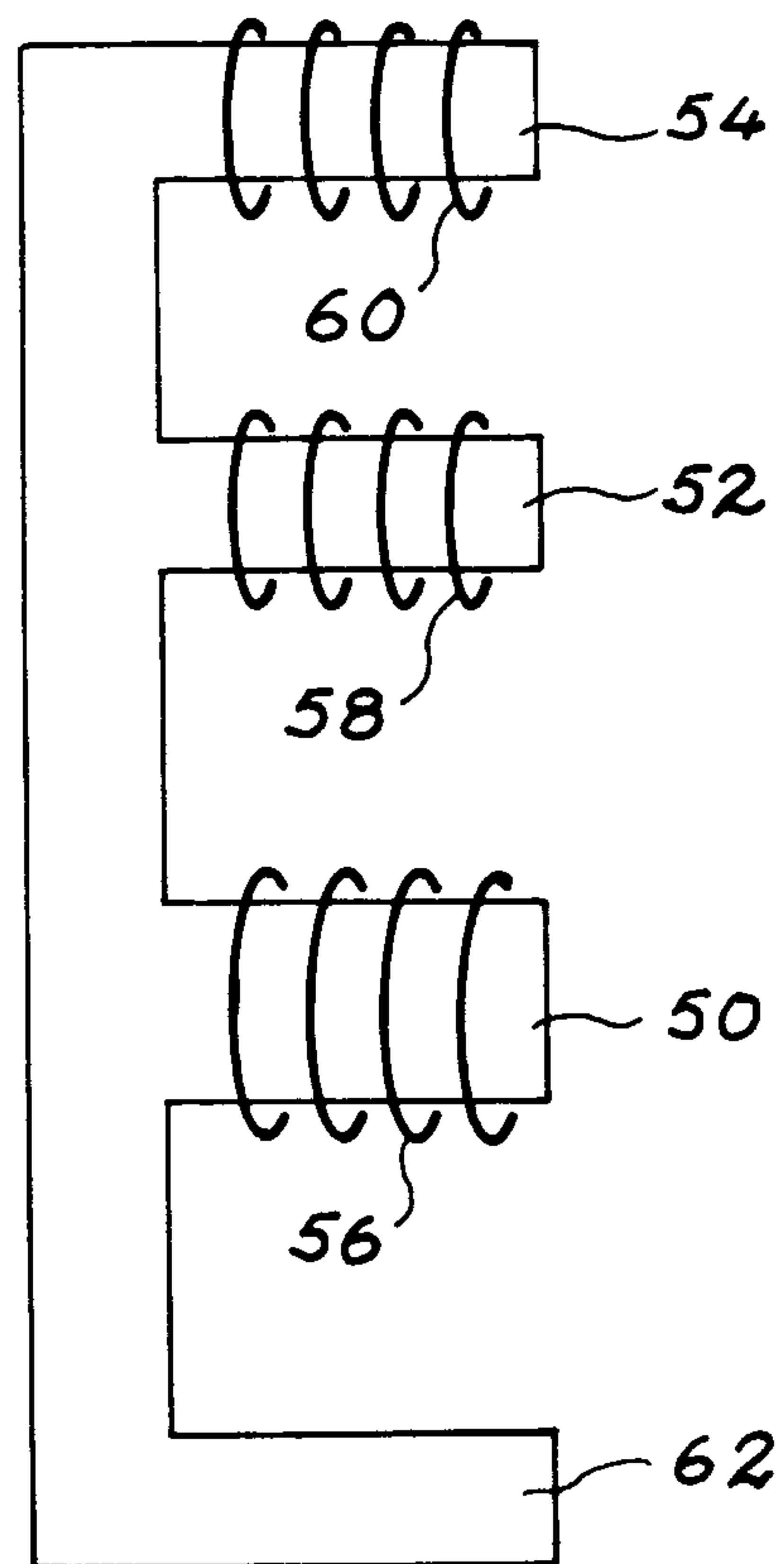


FIG. 11

FIG. 12

