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Marshall et al. [45] **Reissued Date of Patent: Feb. 7, 1989**

[54] ACOUSTIC SURFACE WAVE DEVICES

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[73] Assignee: **The Secretary of State for Defence in Her Britannic Majesty's Government of the United Kingdom of Great Britain and Northern Ireland,** London, England

[21] Appl. No.: **4,381**

[22] Filed: **Jan. 12, 1987**

Related U.S. Patent Documents

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[64] Patent No.: **3,836,876**
Issued: **Sep. 17, 1974**
Appl. No.: **249,573**
Filed: **May 2, 1972**

[30] **Foreign Application Priority Data**

May 5, 1971 [GB] United Kingdom 13125/71

[51] **Int. Cl.**^{4} **H03H 9/145;** H03H 9/25; H03H 9/42; H03H 9/64

[52] **U.S. Cl.** .... **333/151;** 310/313 D; 333/109; 333/153; 333/194; 333/196

[58] **Field of Search** .... 333/150-155, 333/193-196, 1, 100, 109; 310/313 R, 313 A, 313 B, 313 C, 313 D

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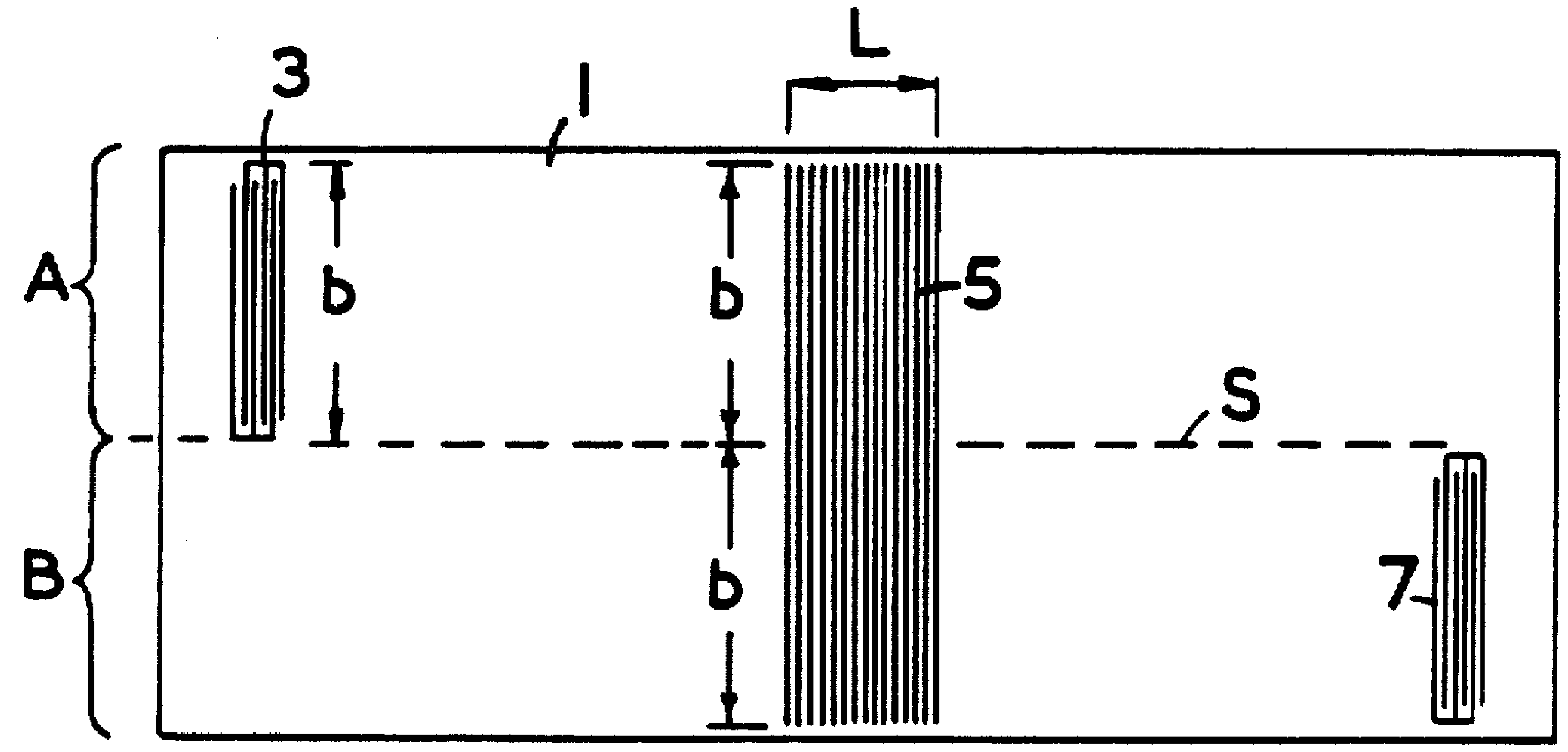
Primary Examiner—Marvin L. Nussbaum
Attorney, Agent, or Firm—Pollock, Vande Sande and Priddy

[57] **ABSTRACT**

Acoustic surface wave devices of a novel class characterized by the provision of coupling means comprising at least several spaced filamentary electrical conductors extending over a first region and a second region for causing acoustic surface waves propagated across the coupling means in the first region to interact with acoustic surface waves propagated across the coupling means in the second region, by means of alternating electric signals induced on the filamentary electric conductors. The regions to be coupled are preferably formed on piezoelectric material, but modified forms of the coupling means can be made operable with other materials and suitable biassing fields. The described devices include acoustic beam width changing, impedance matching, track changing and phase-sensitive switching devices; a hybrid junction device, resonator and recirculating filter devices, tapped acoustic delay lines, unidirectional transducers, acoustic surface wave reflectors and mode discriminators, electrically-controlled acoustic beam switches and directional couplers, acoustic beam splitters, and means for reducing unwanted reflections of acoustic surface waves.

41 Claims, 11 Drawing Sheets



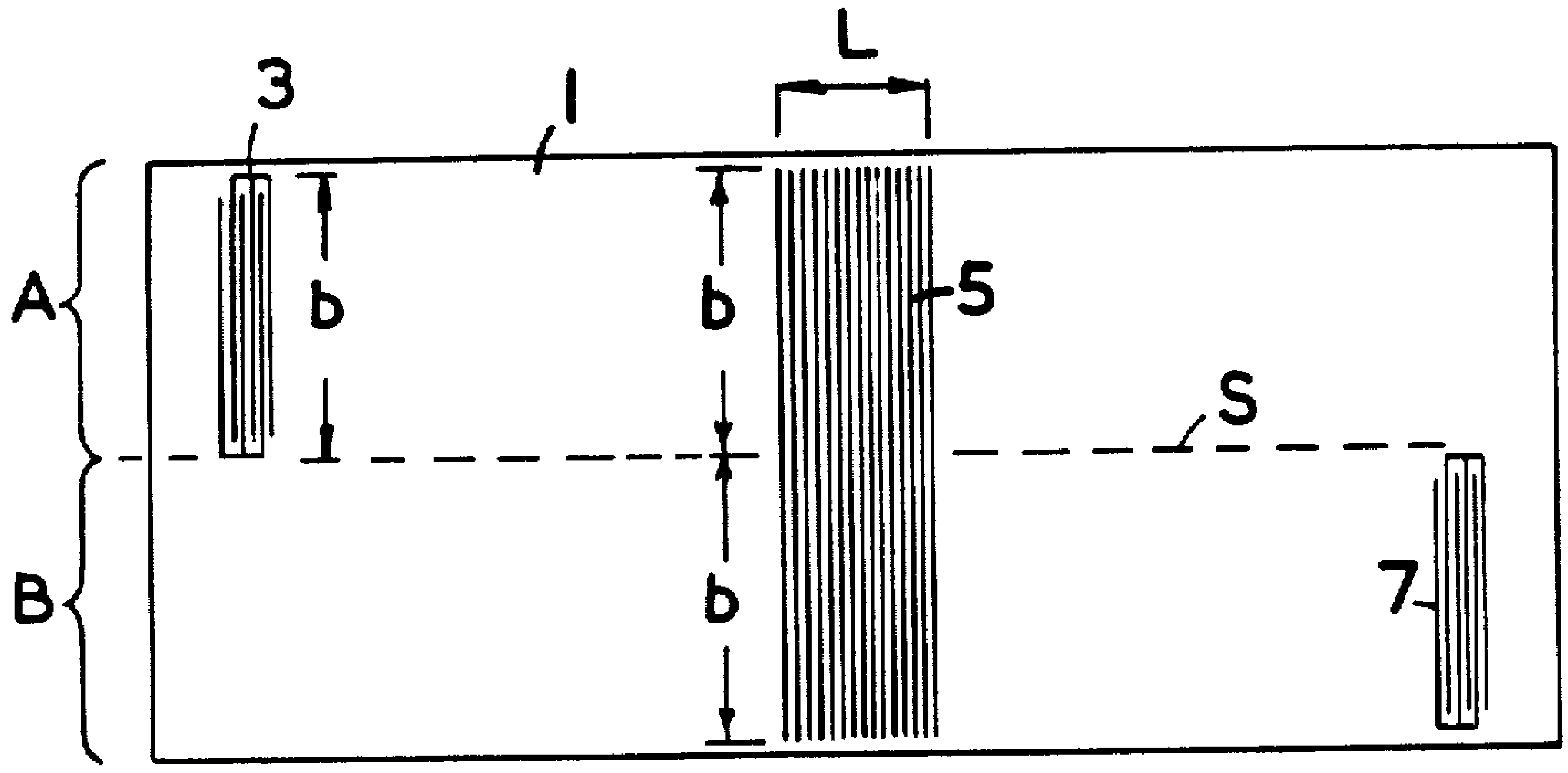


FIG. 1

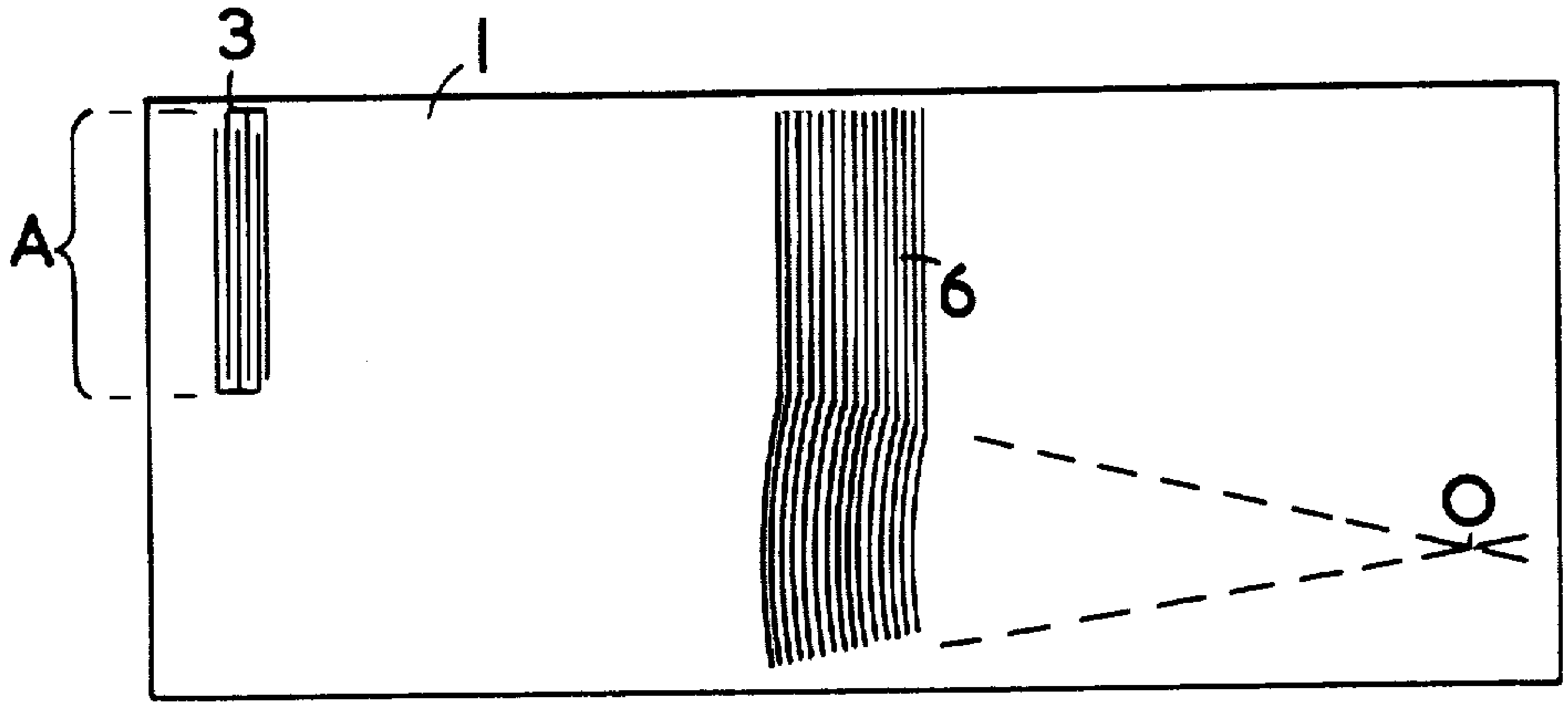


FIG. 2

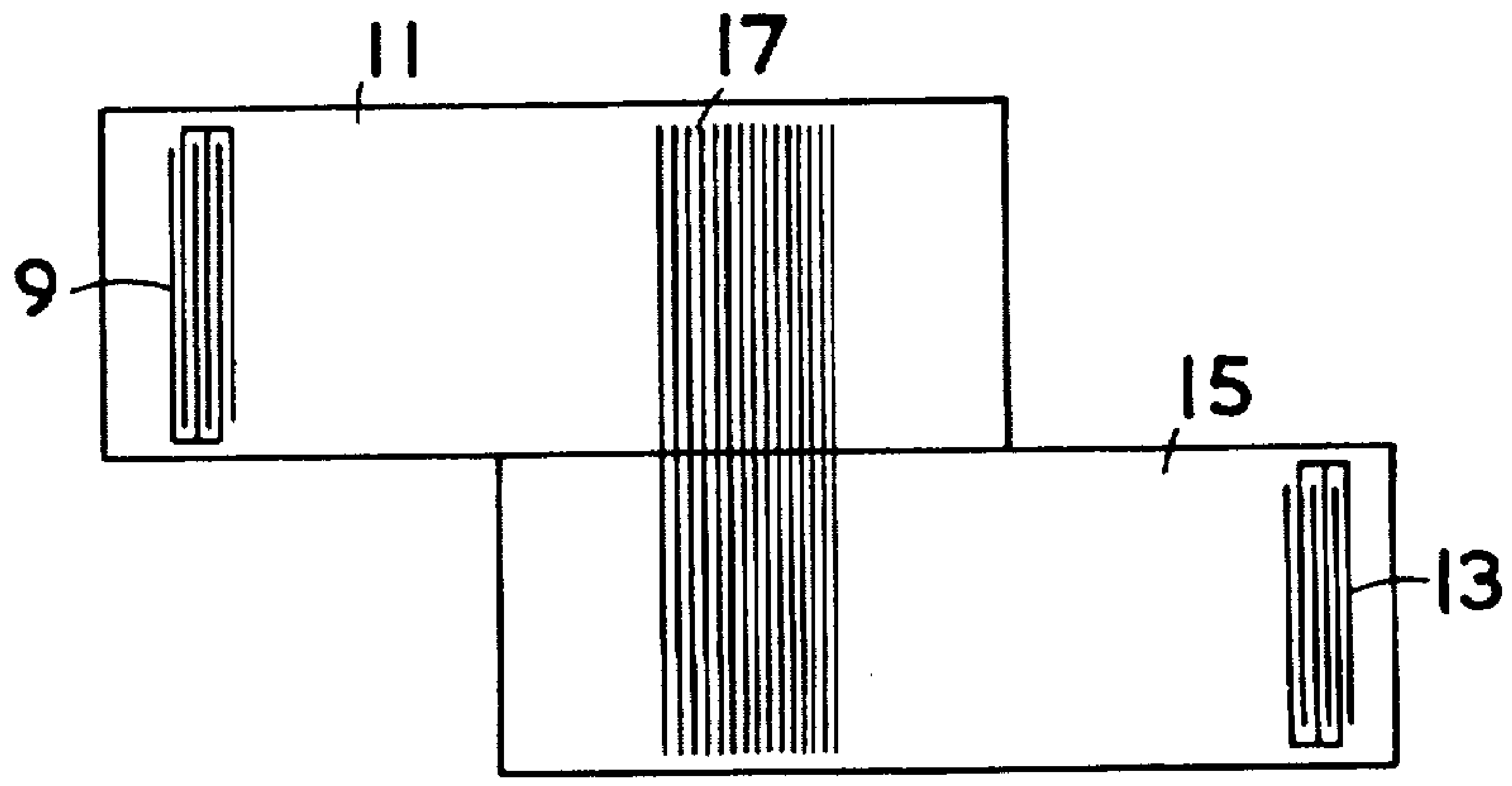


FIG. 3

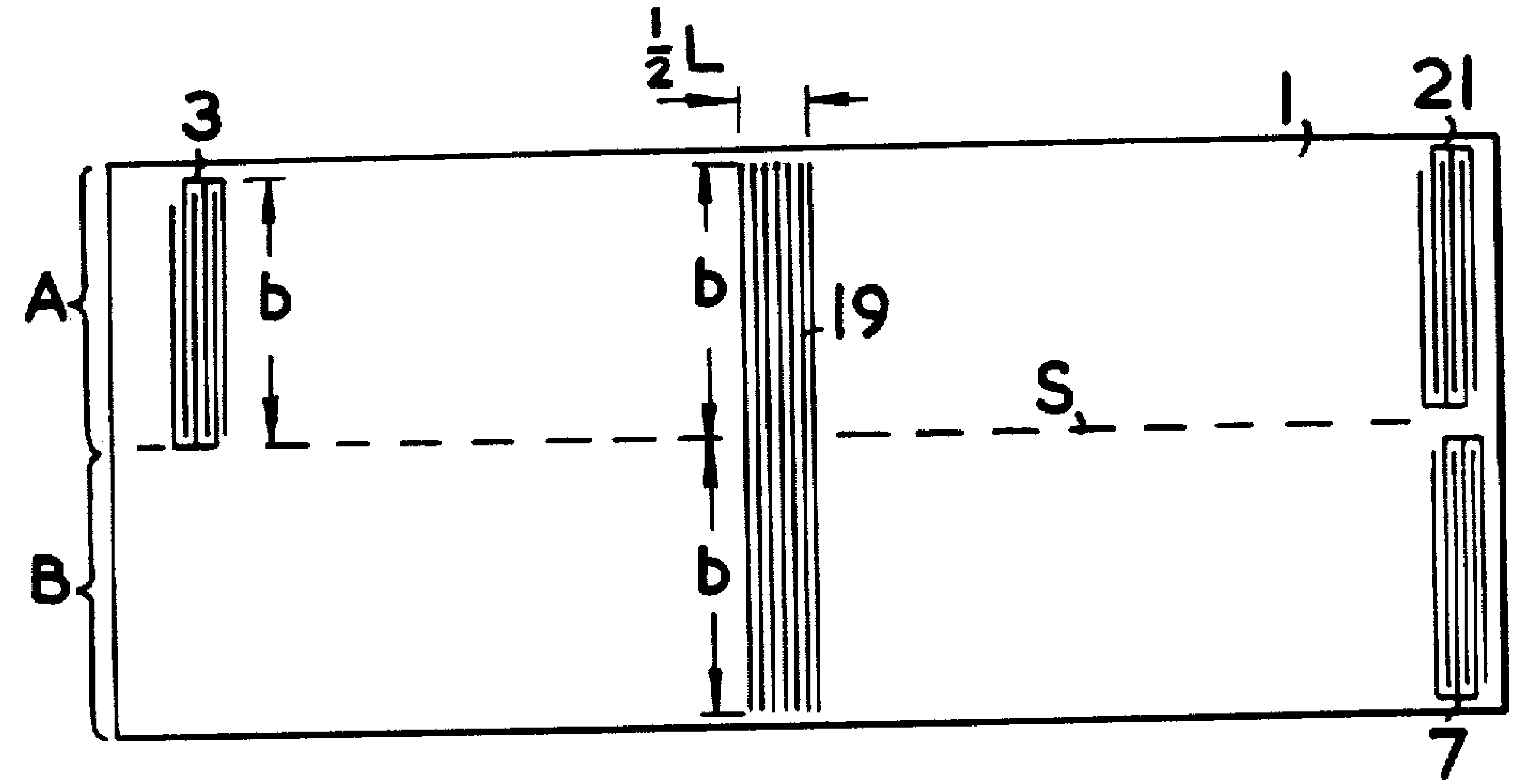
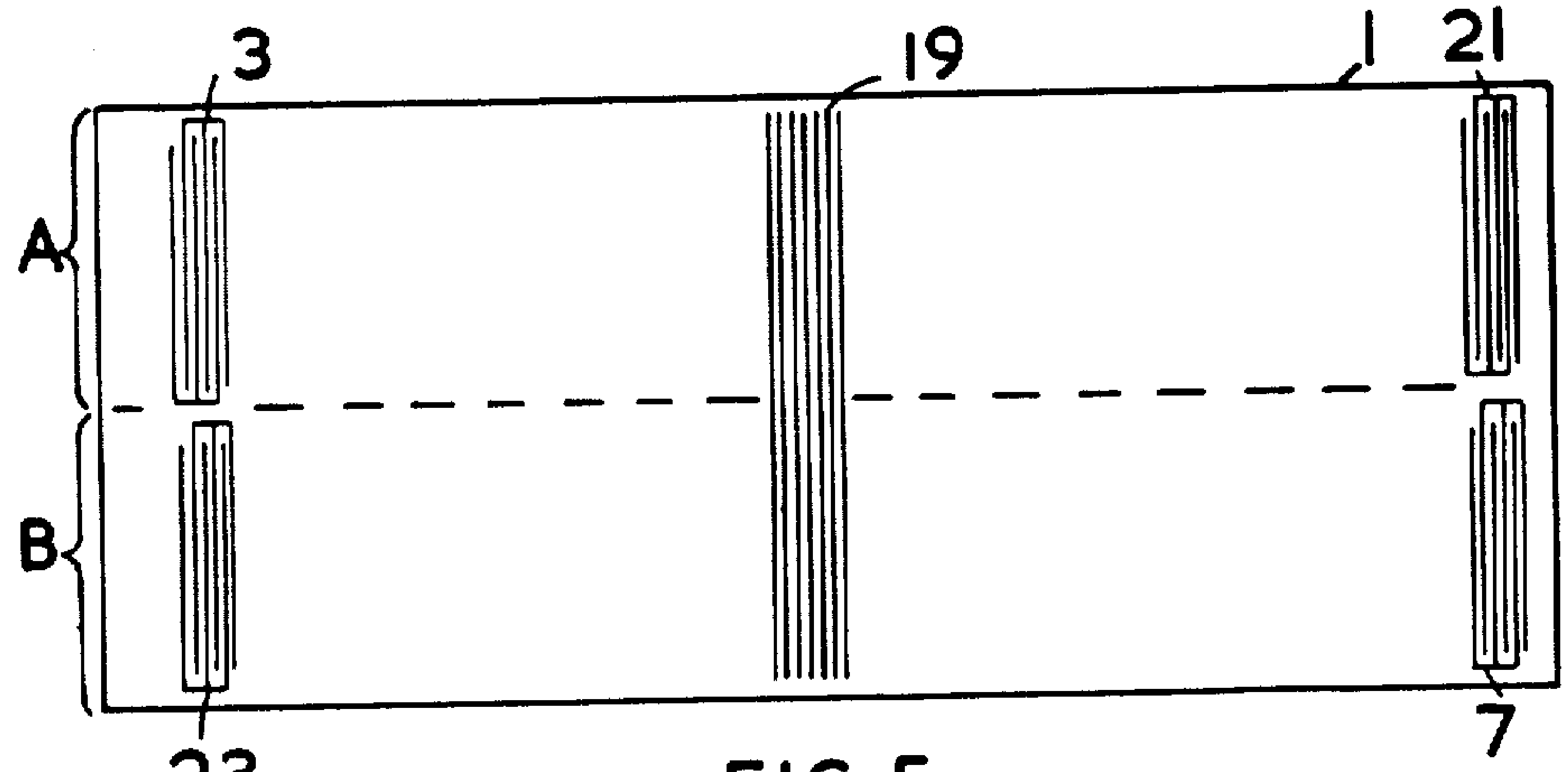


FIG. 4



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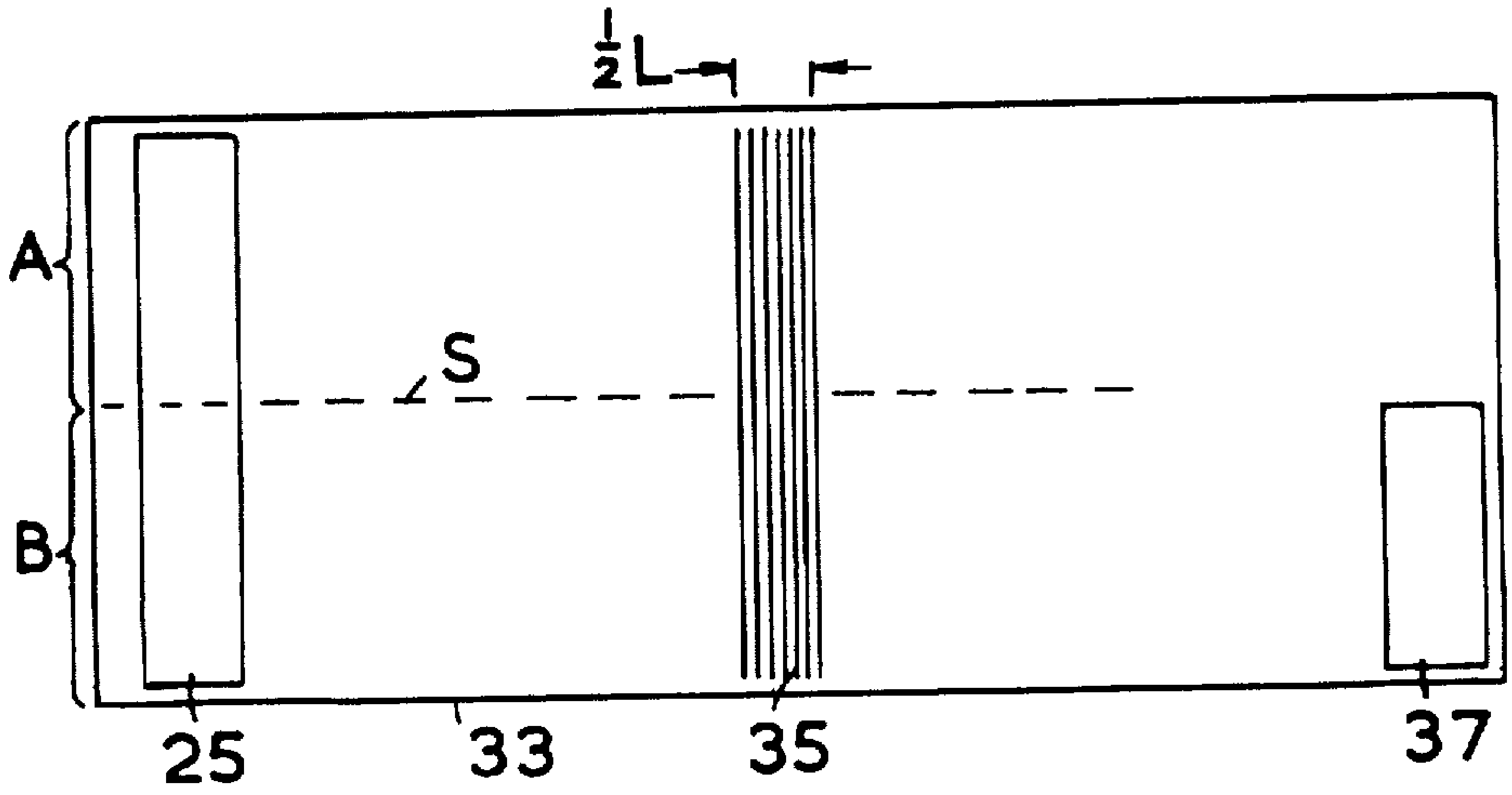

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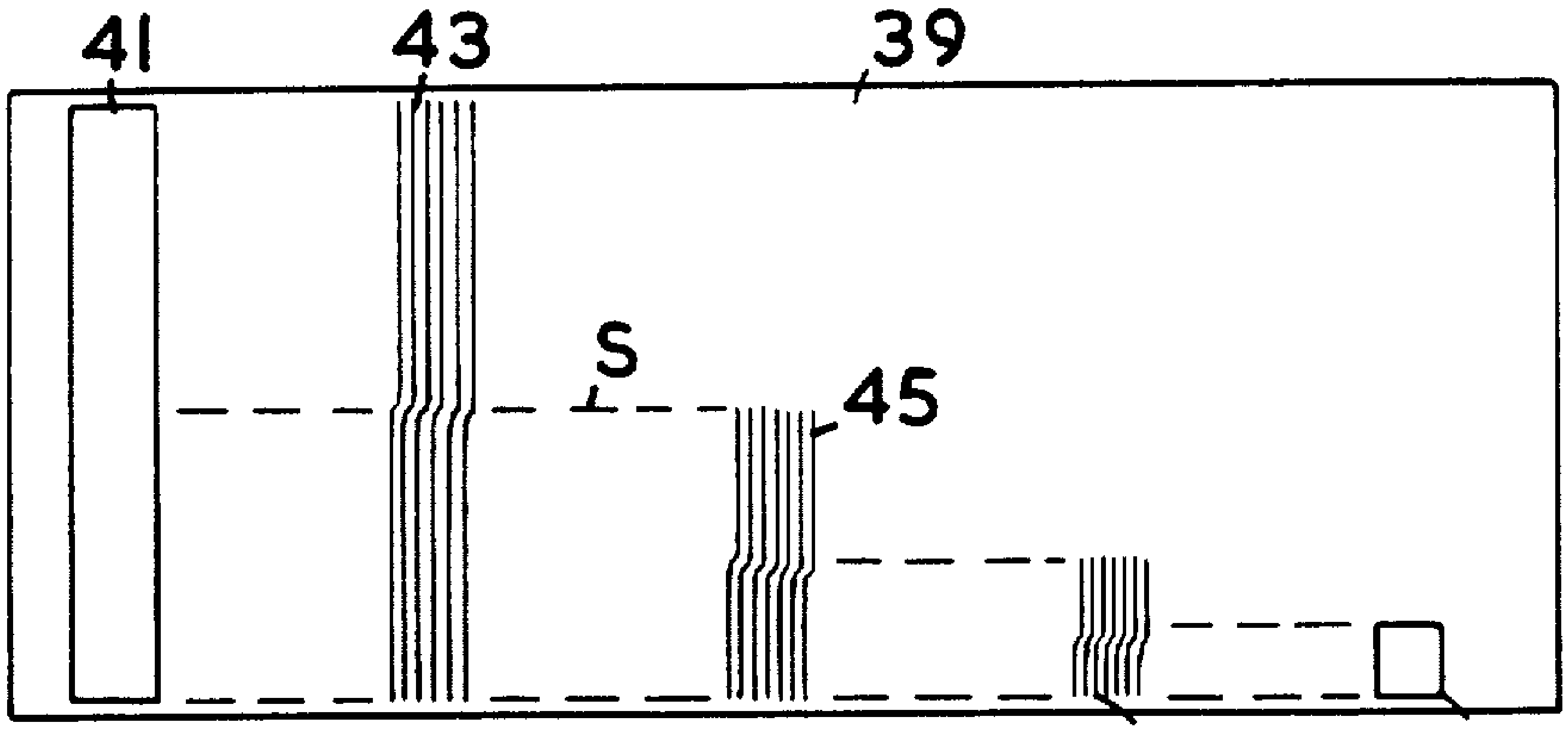

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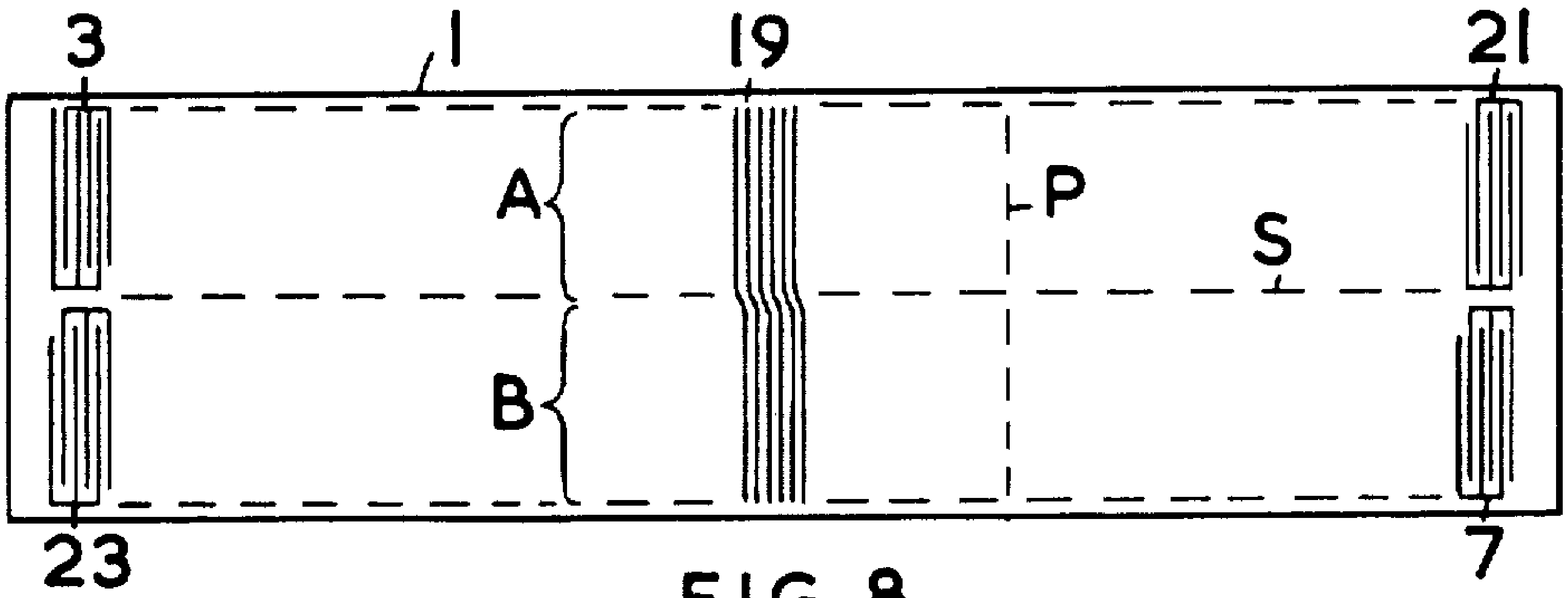

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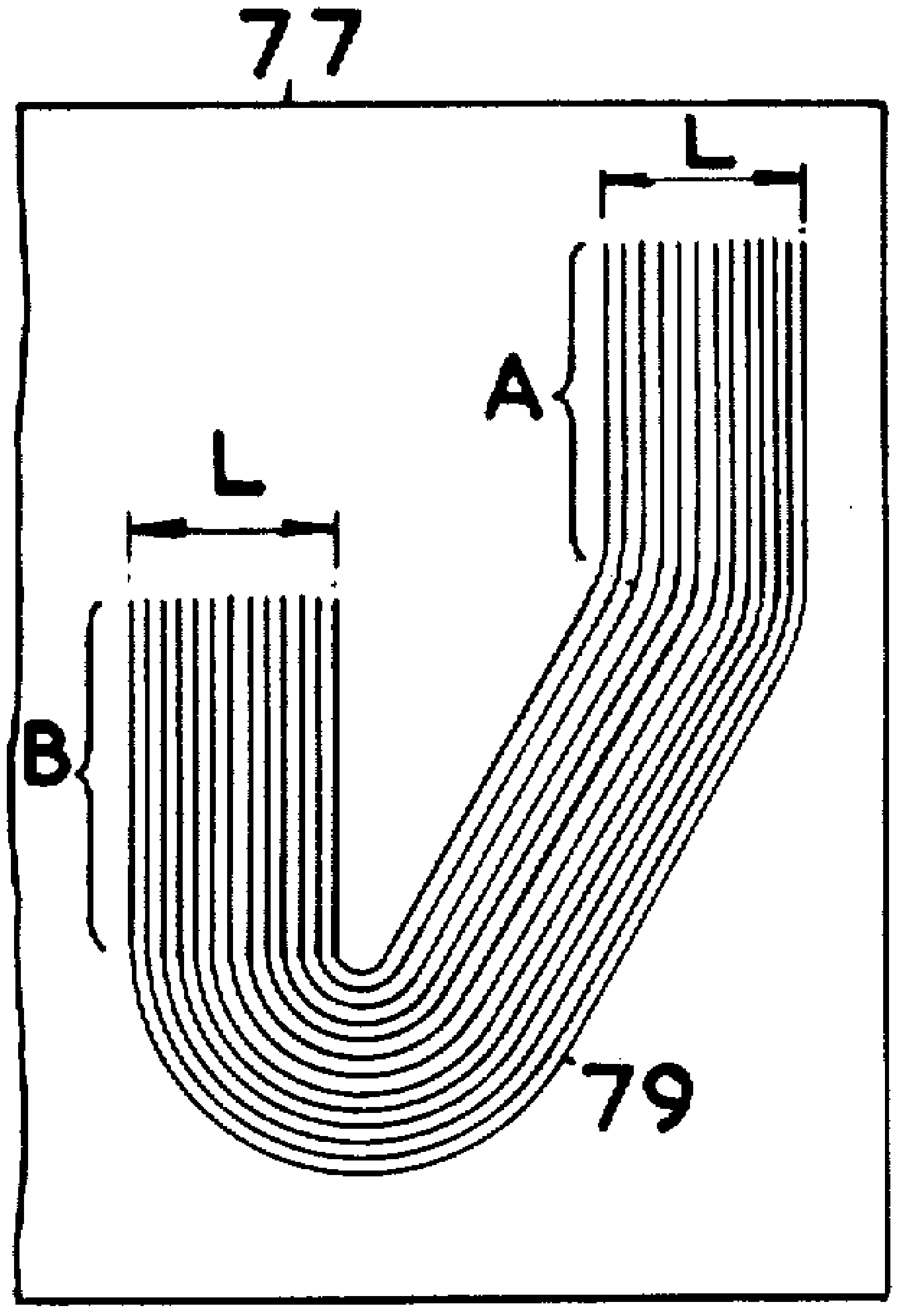
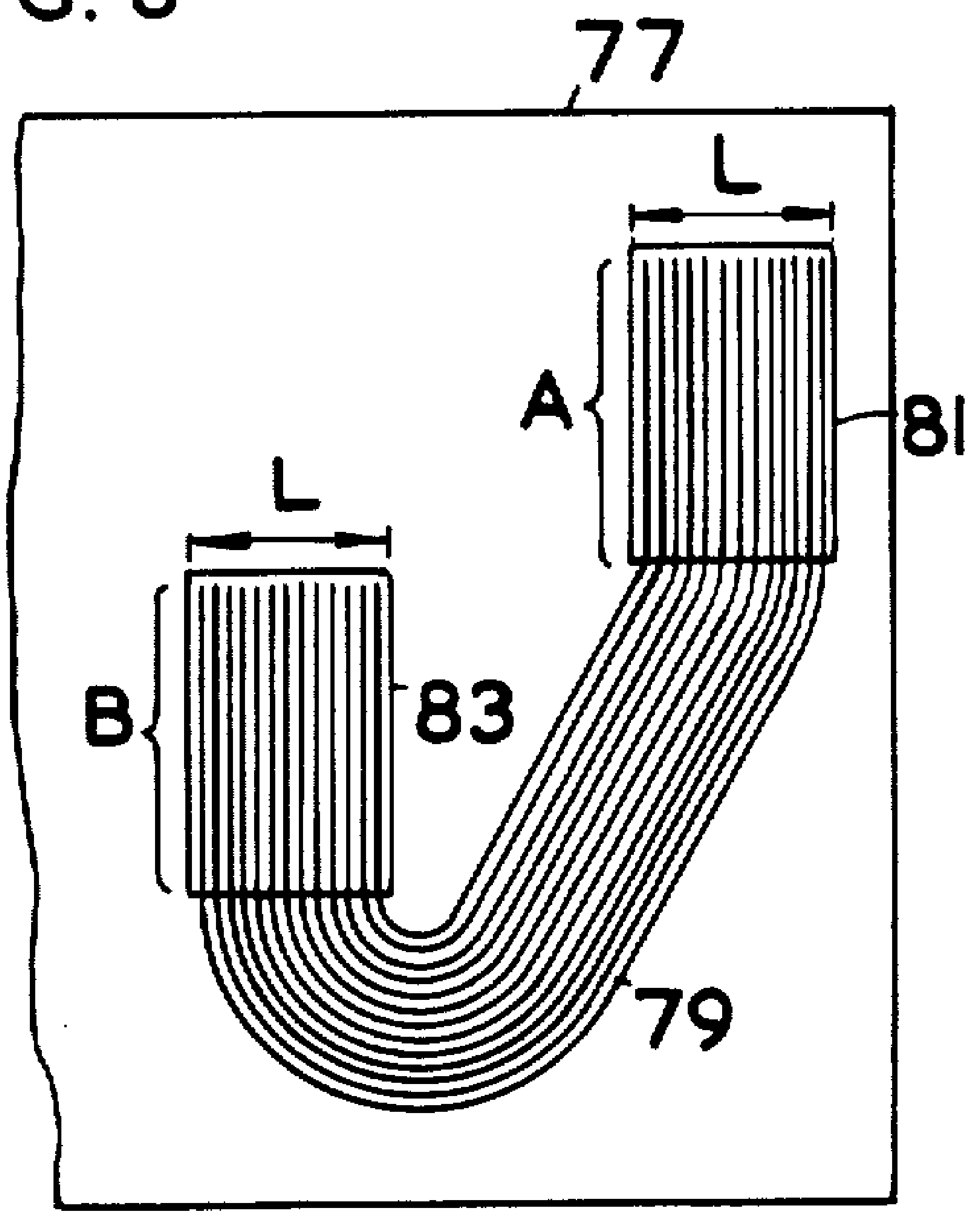


FIG. 11



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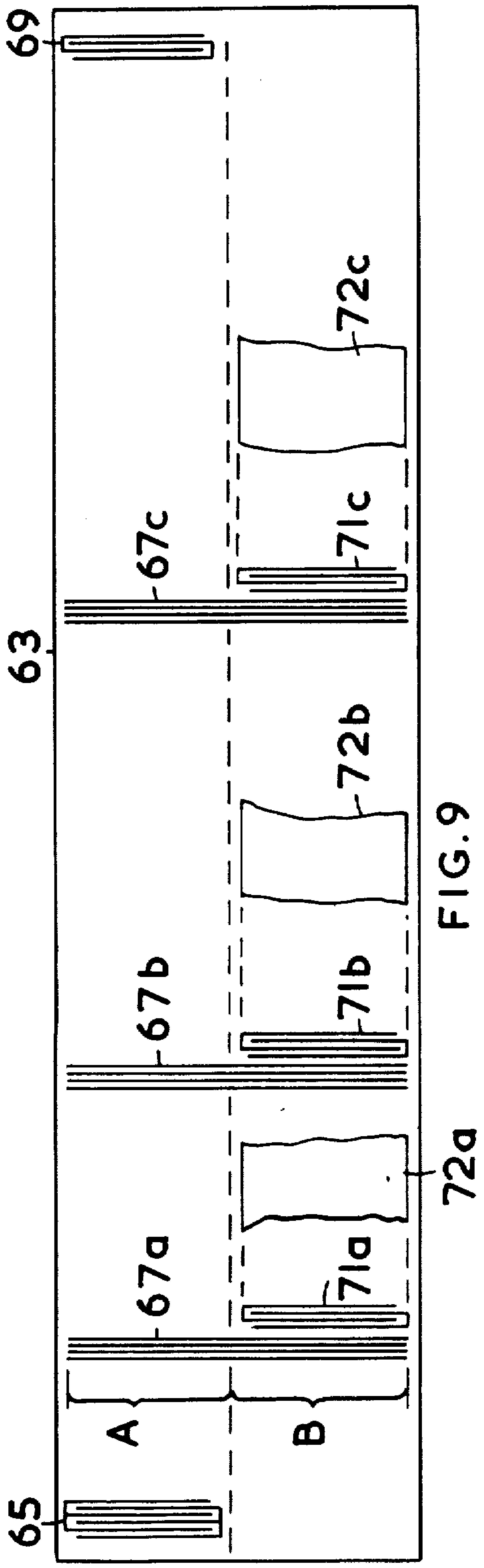
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FIG.9

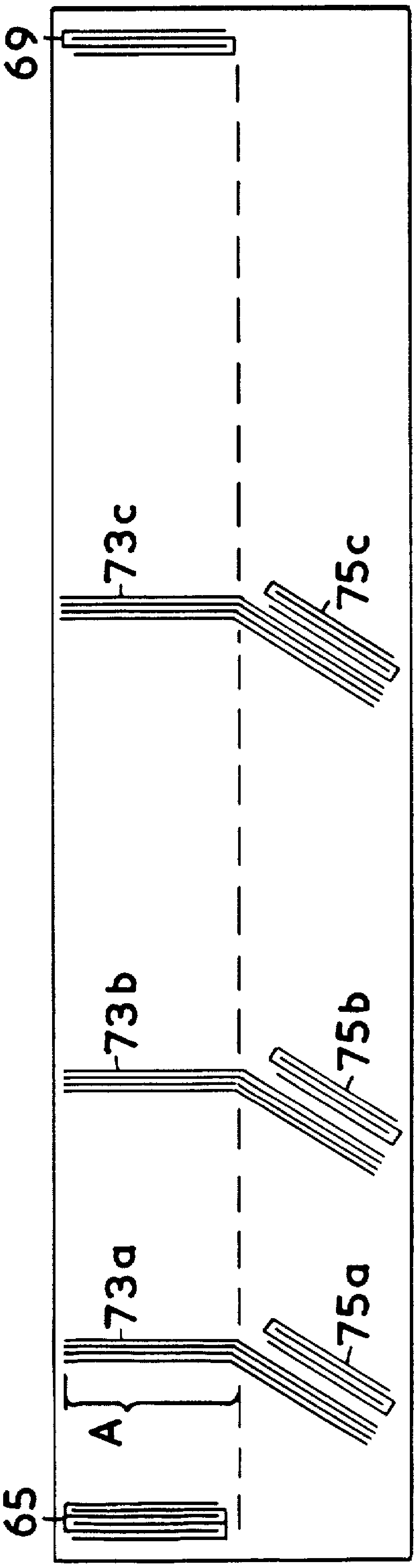
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FIG.10

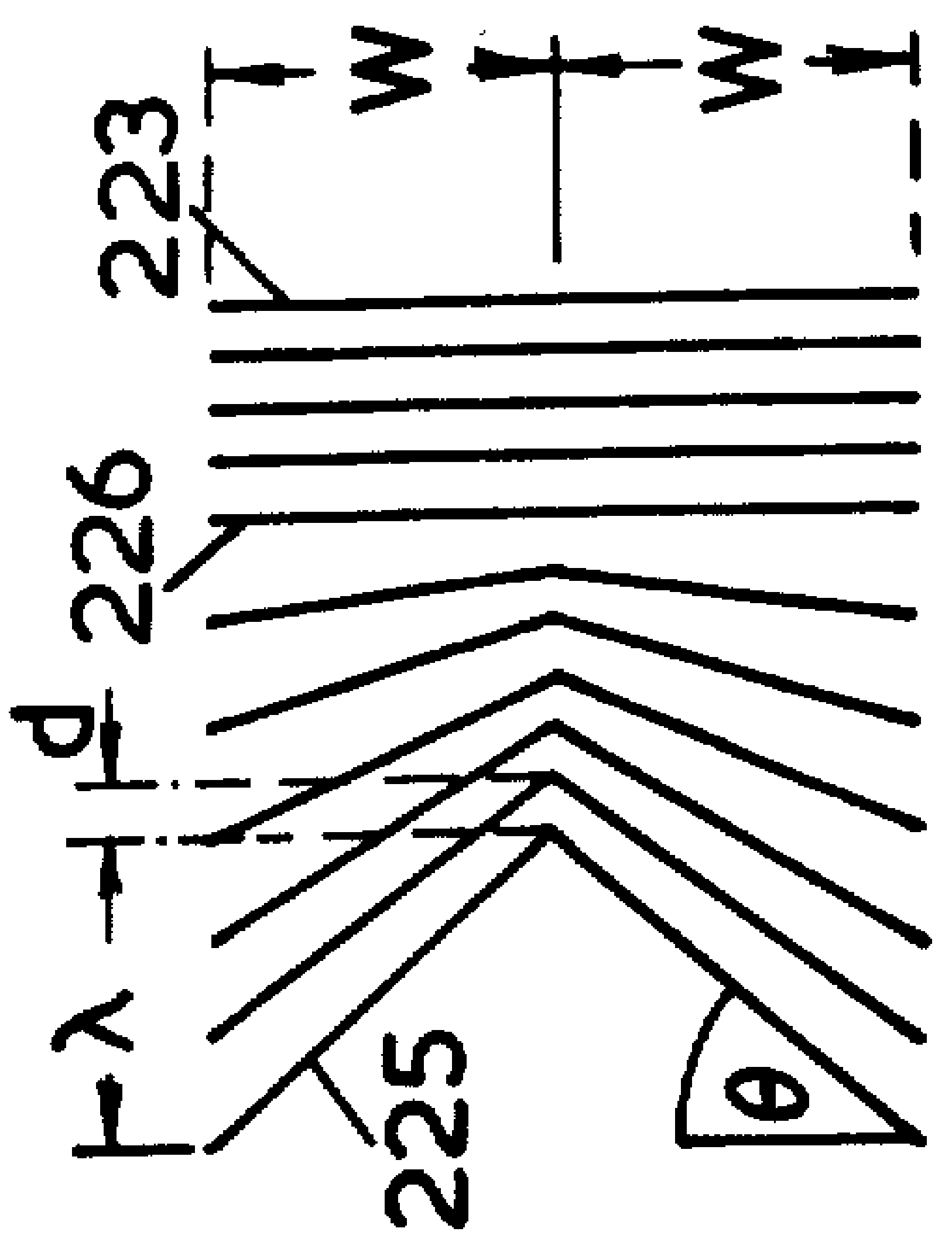
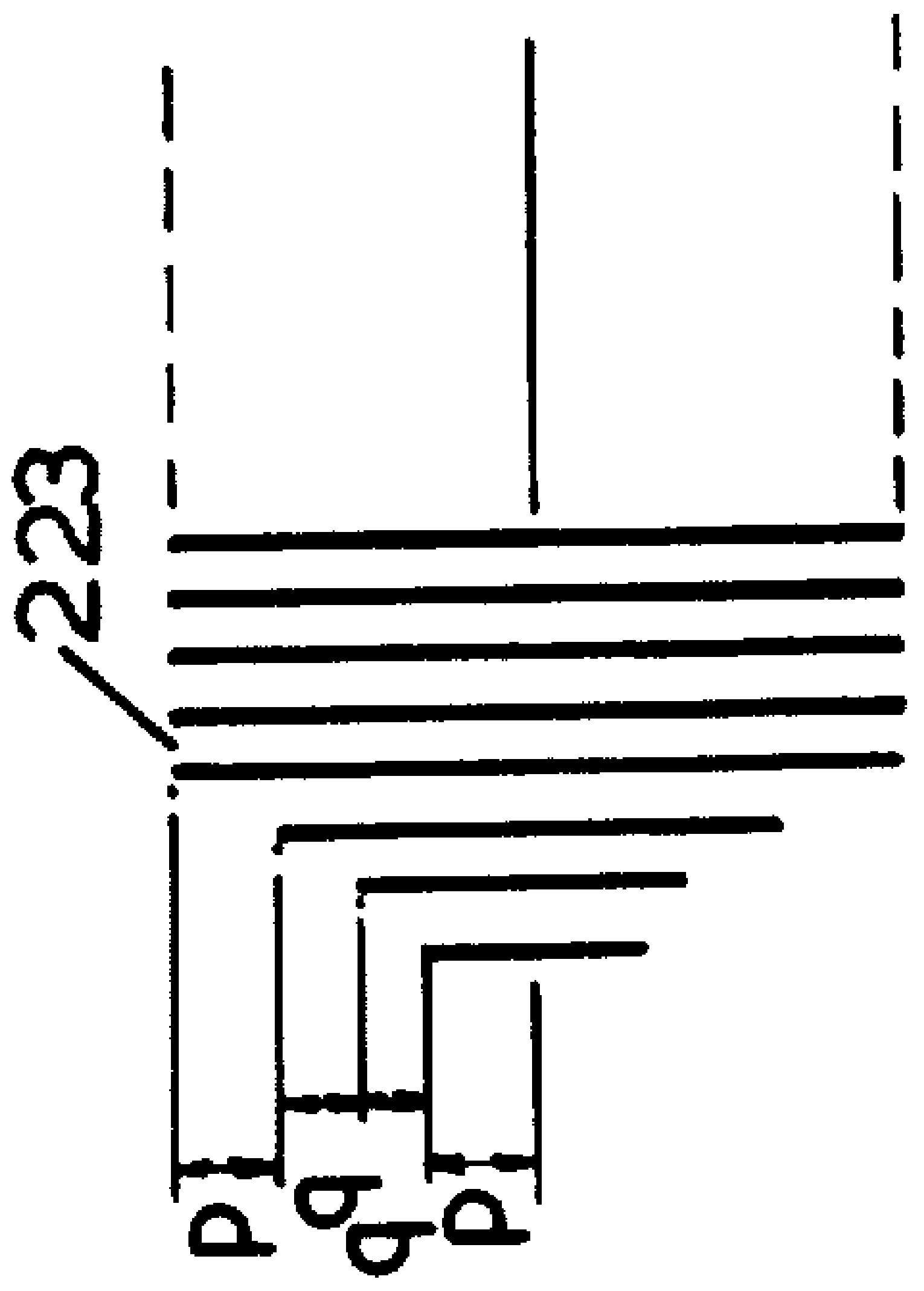


FIG. 32.



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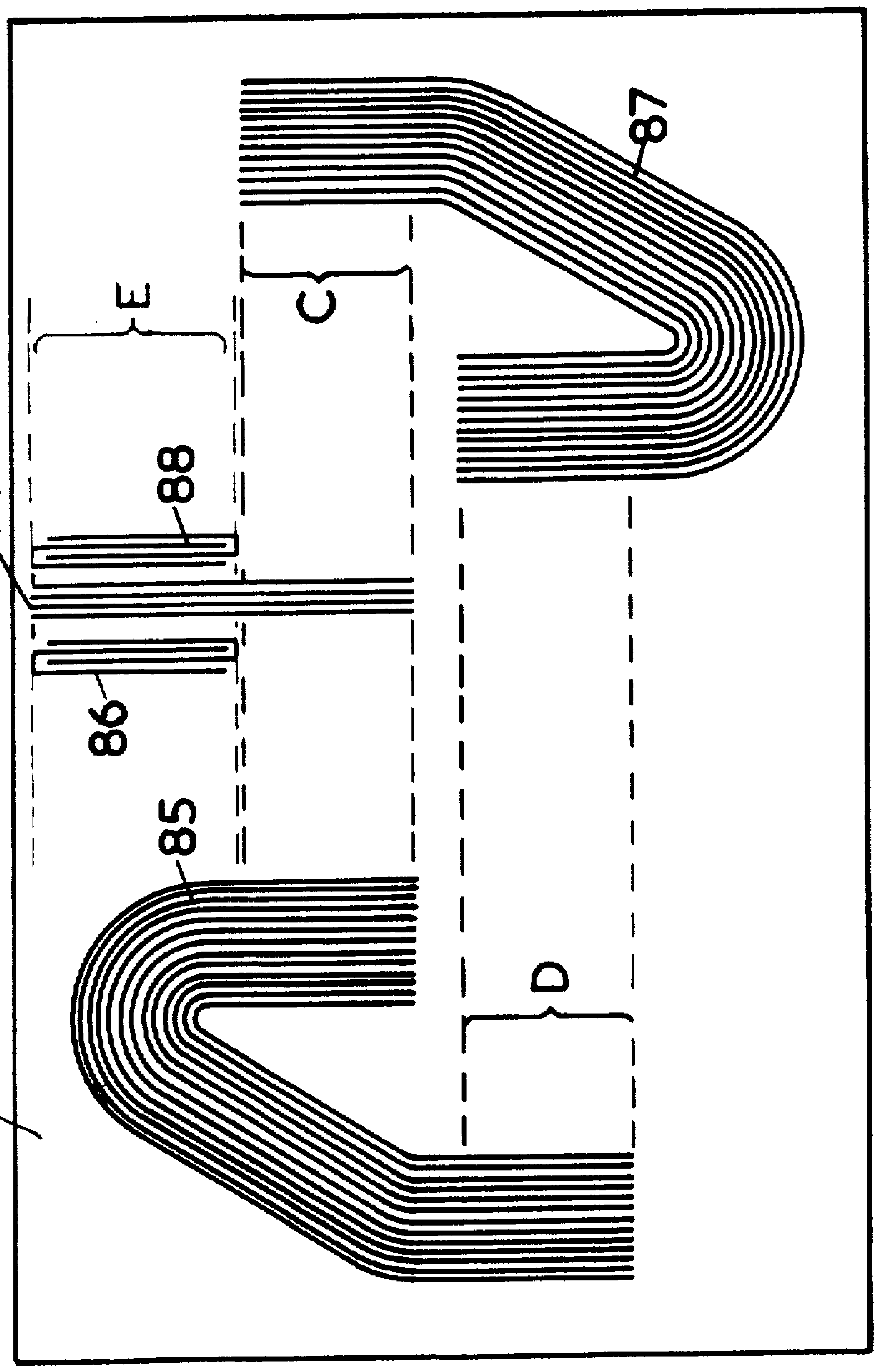

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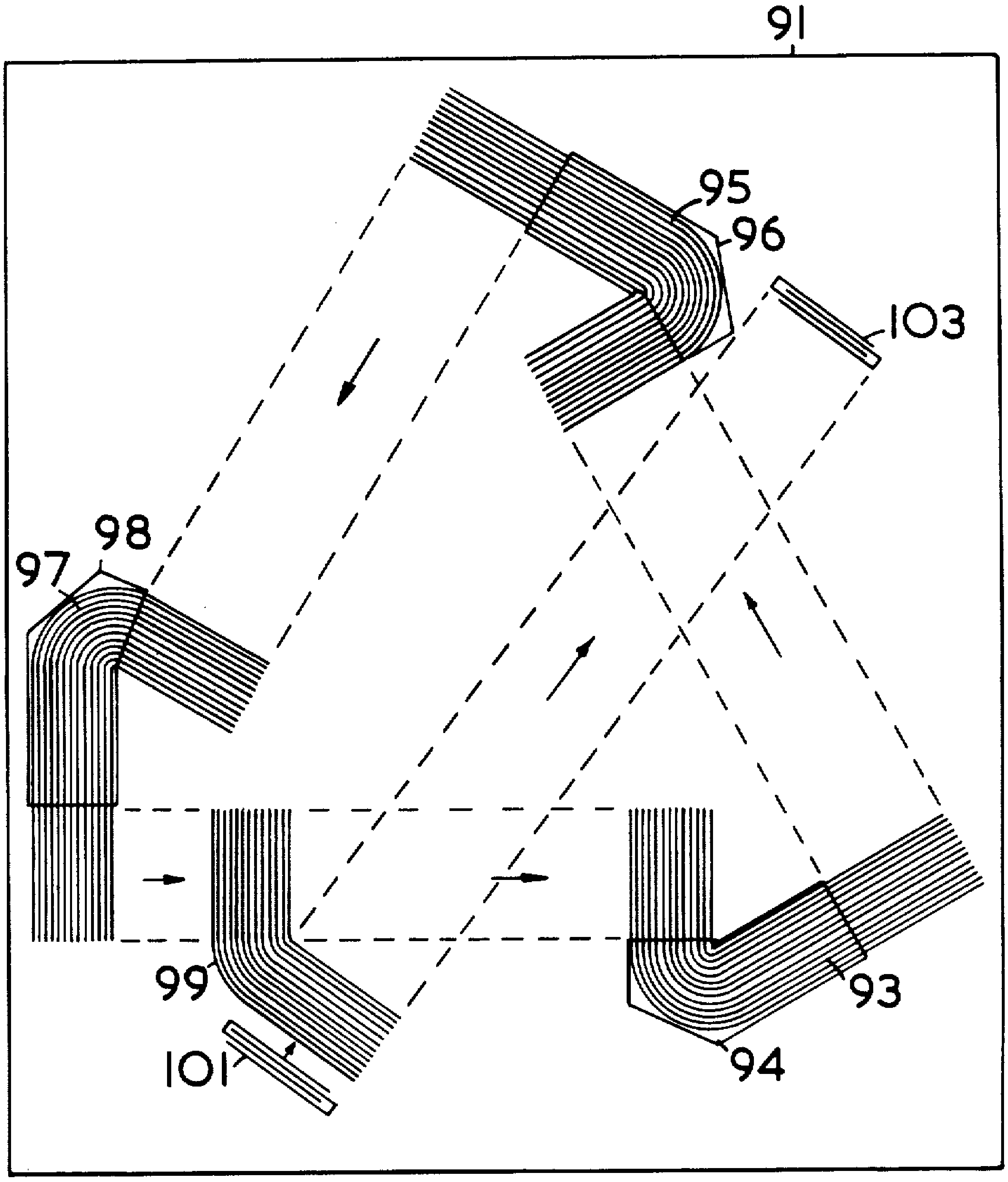

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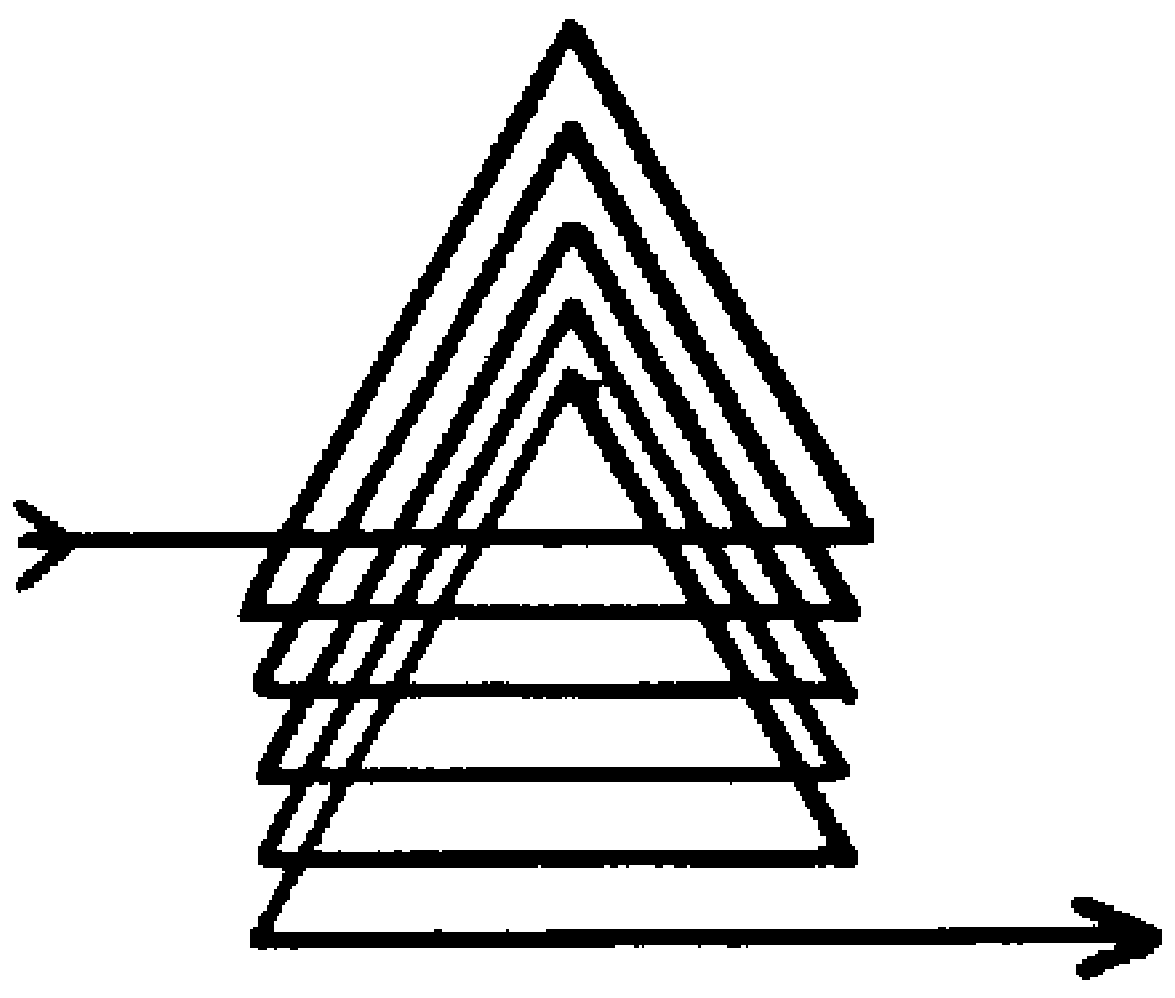

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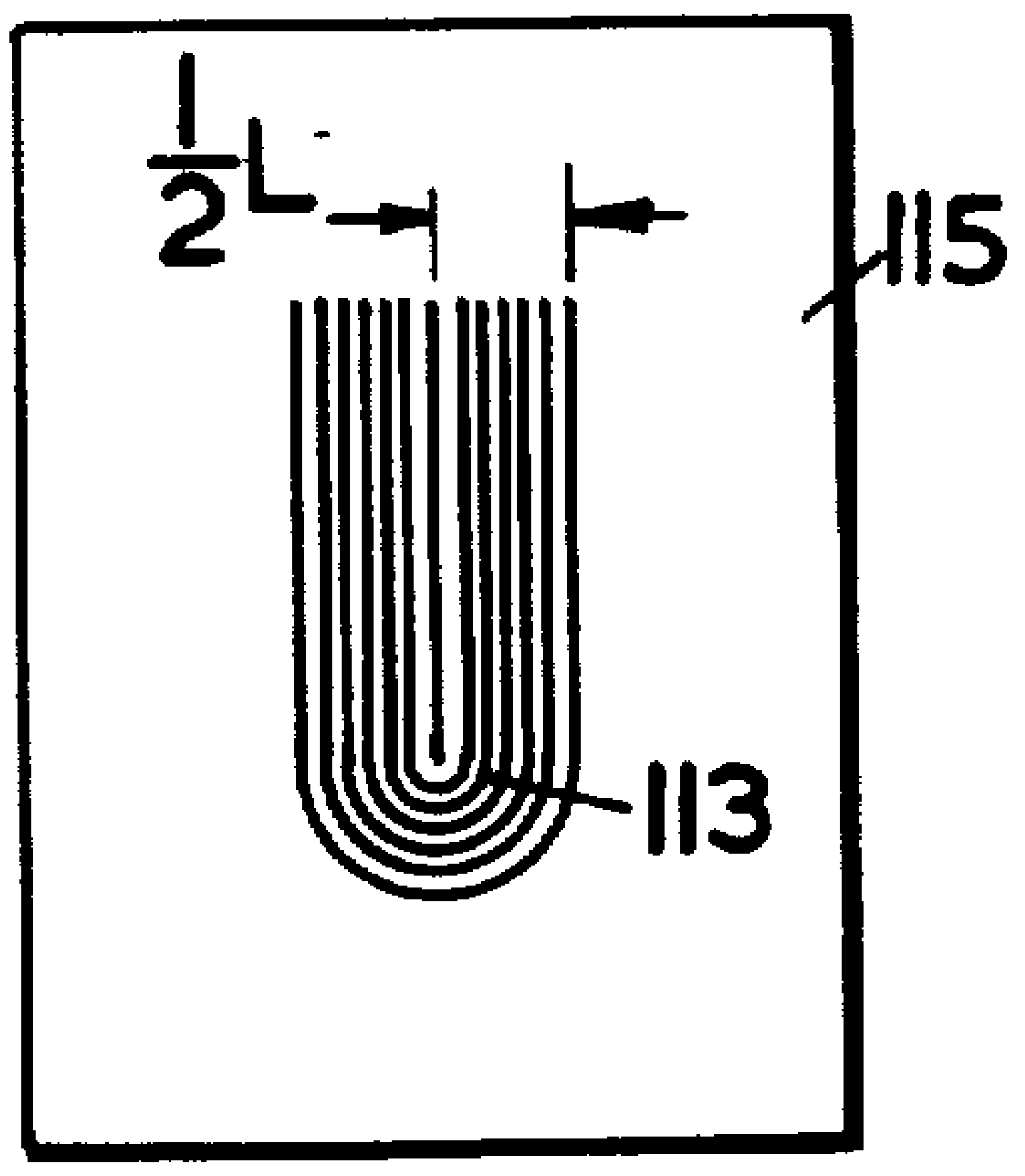

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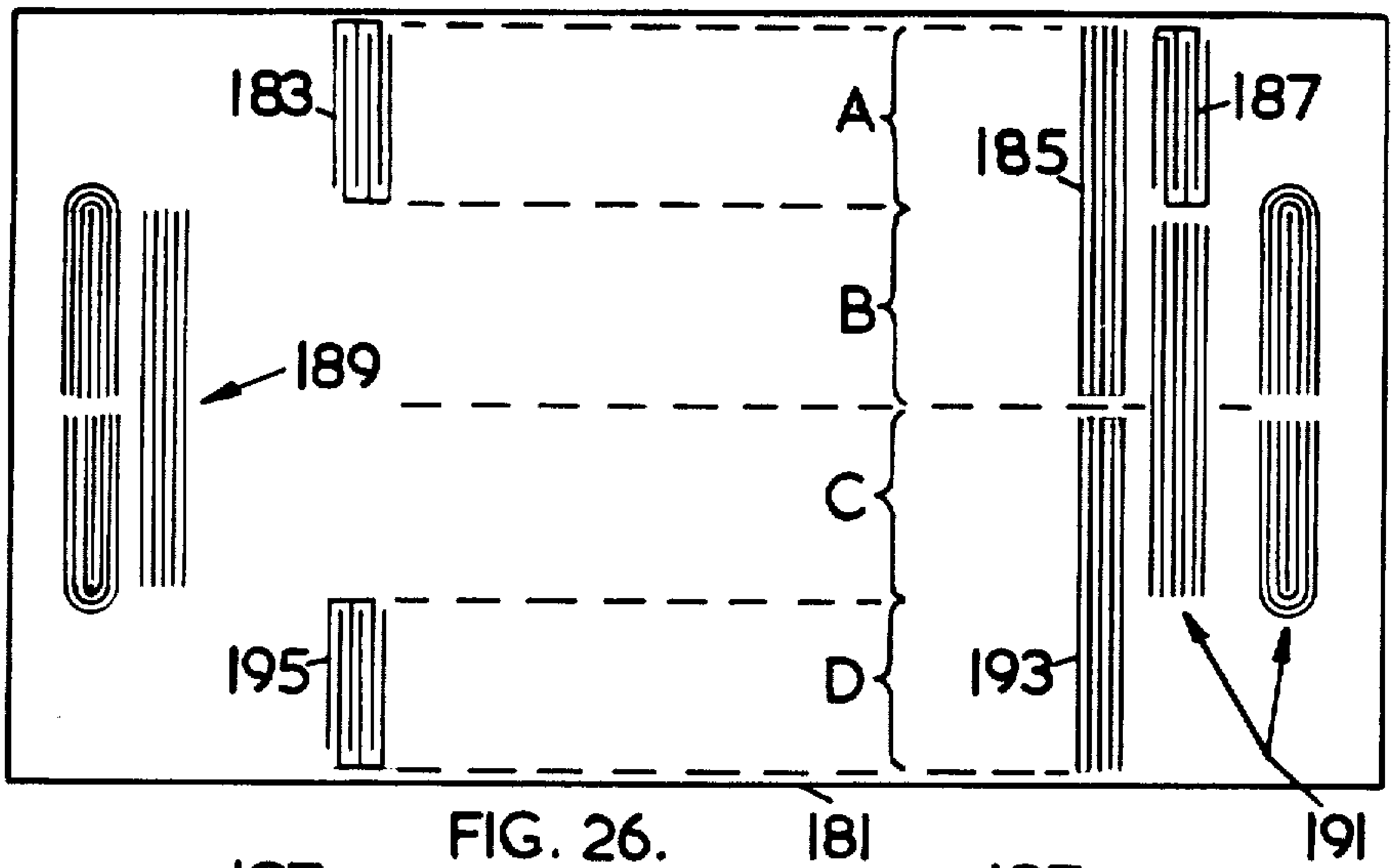

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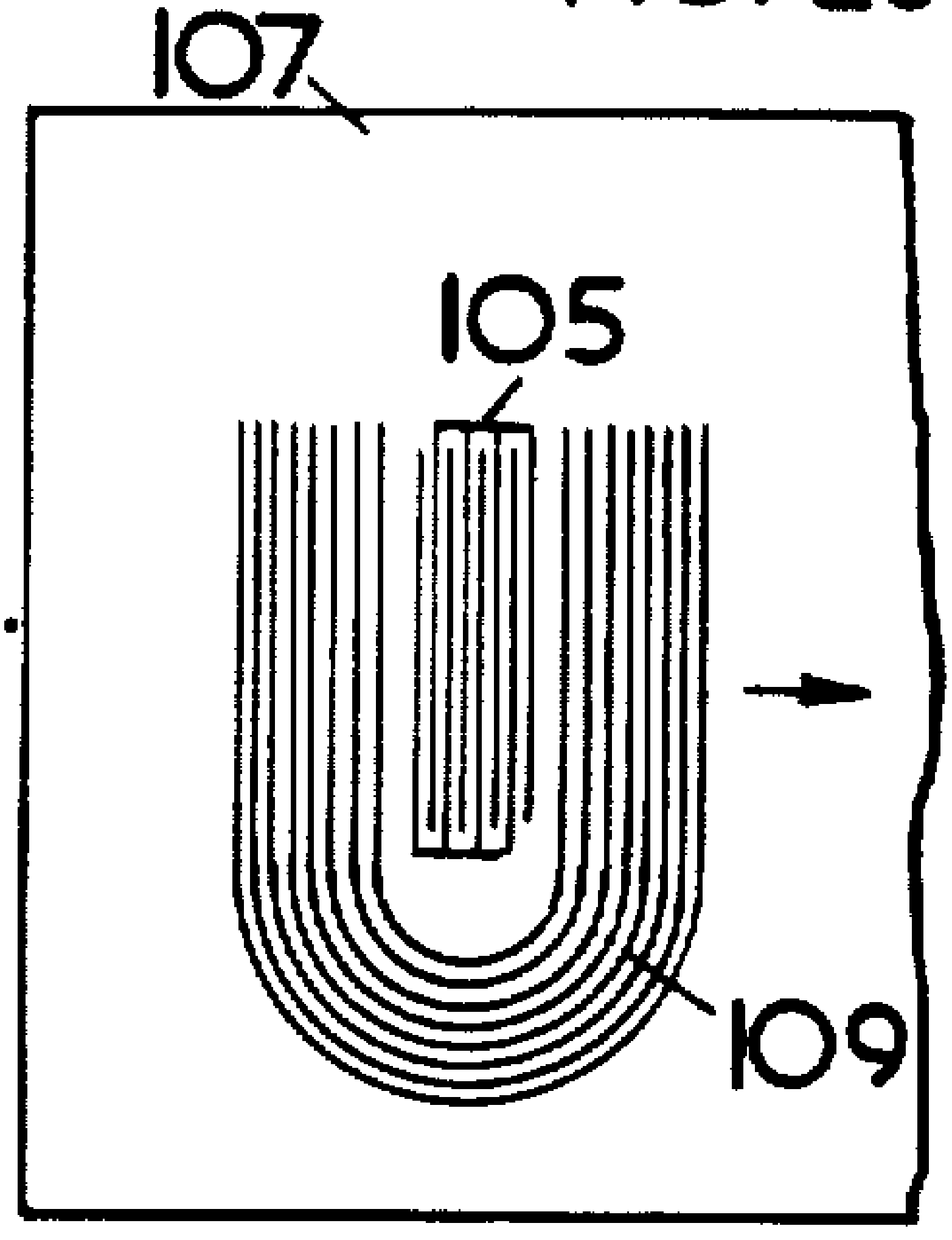

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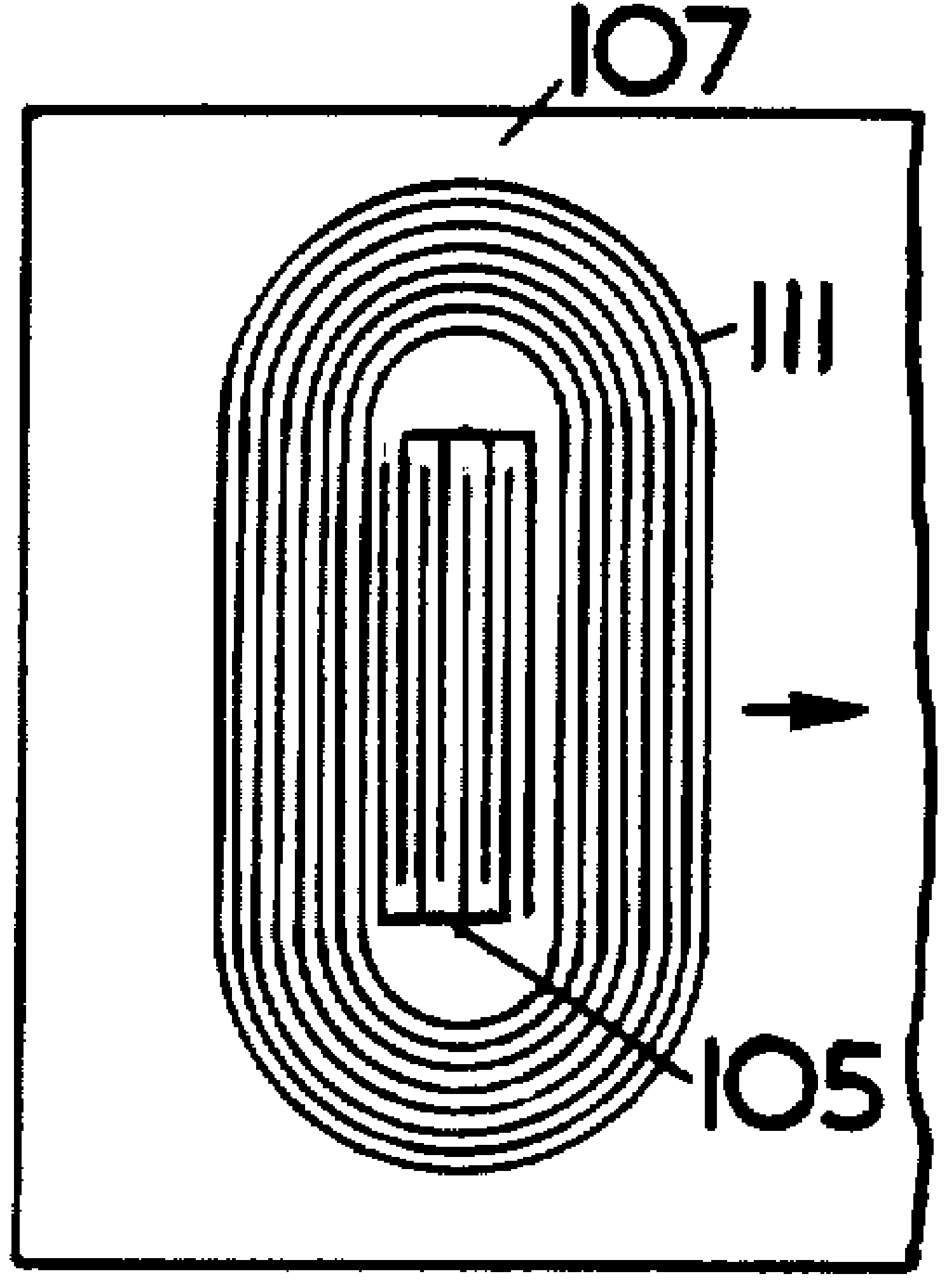

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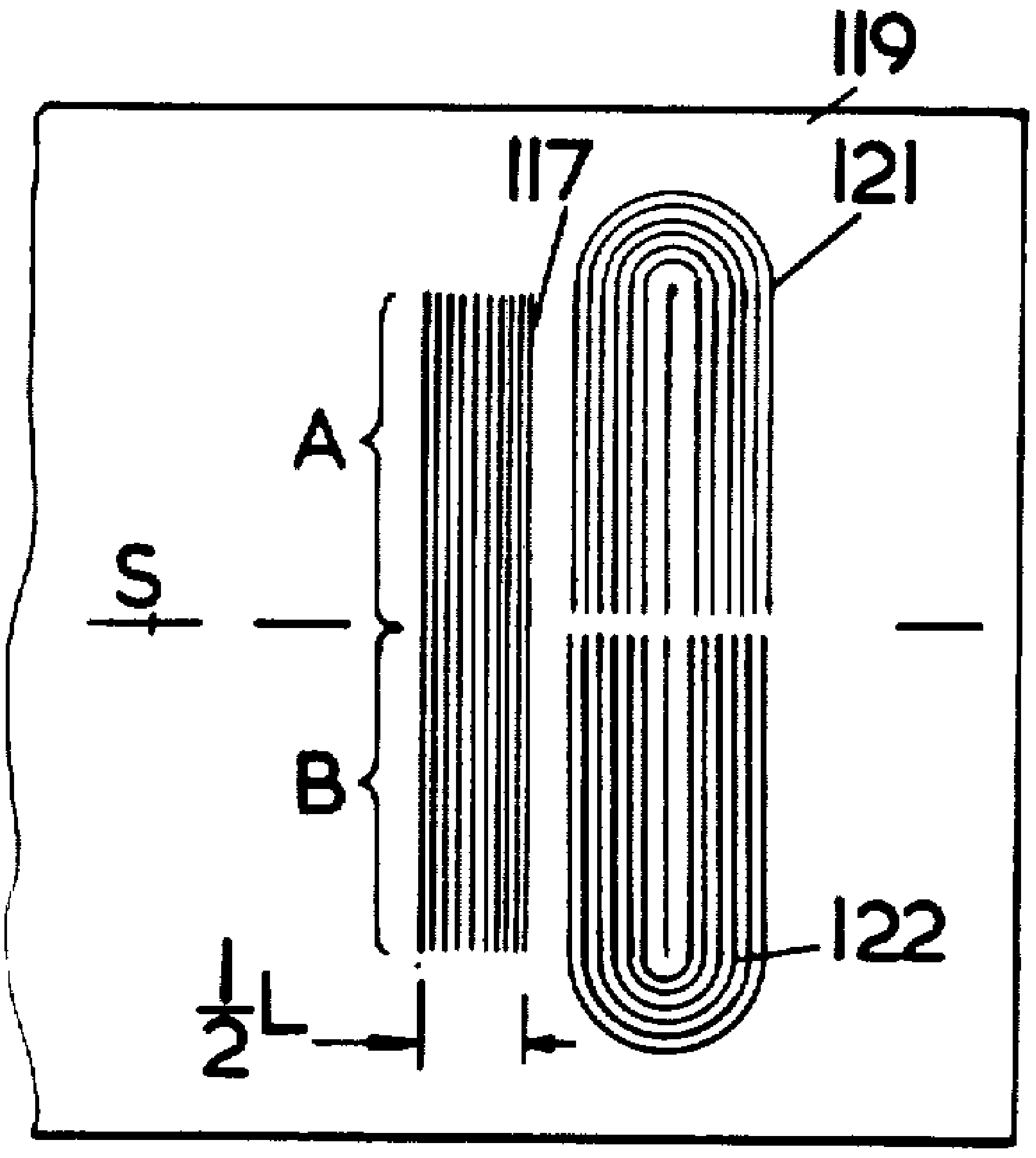

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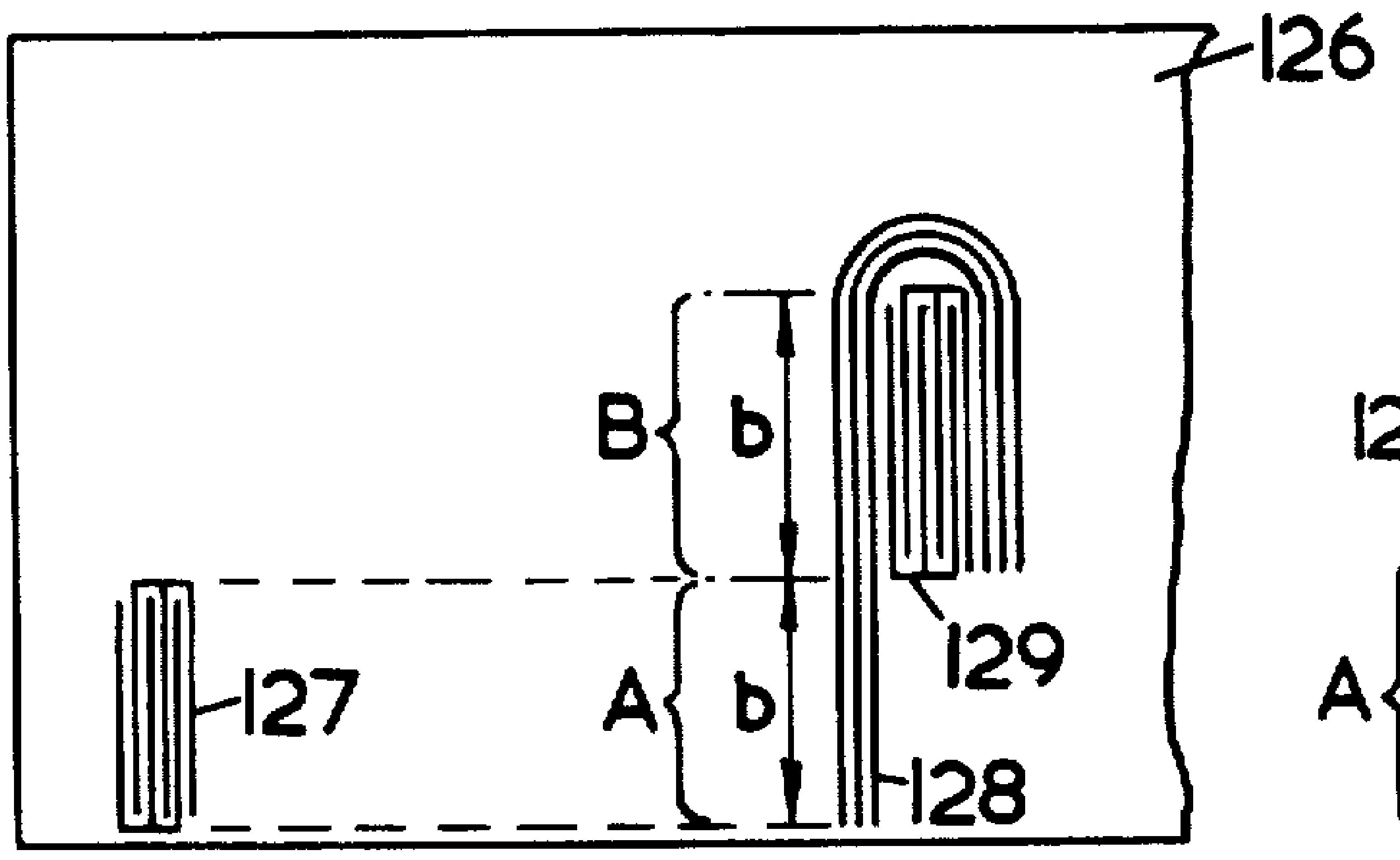

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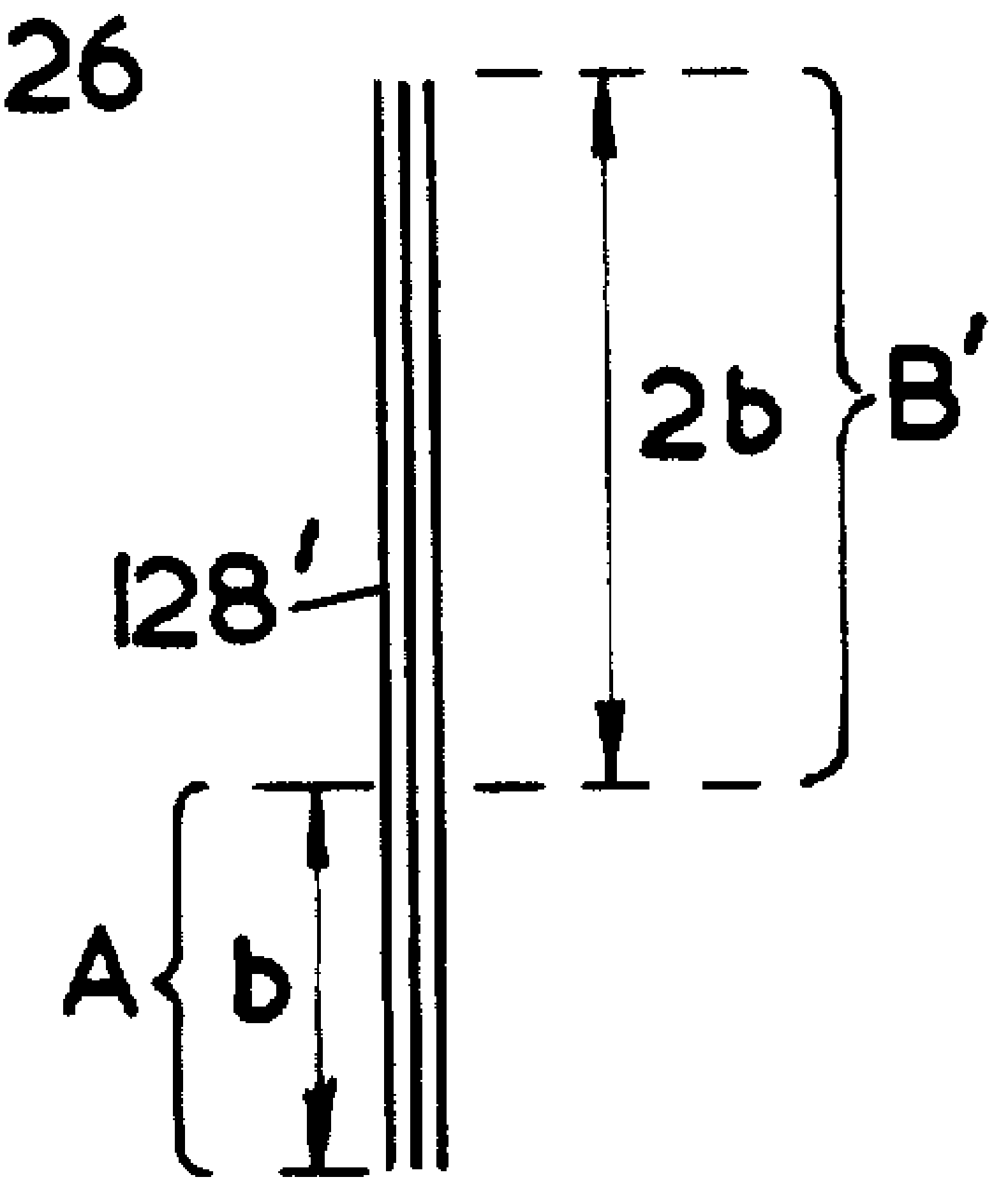

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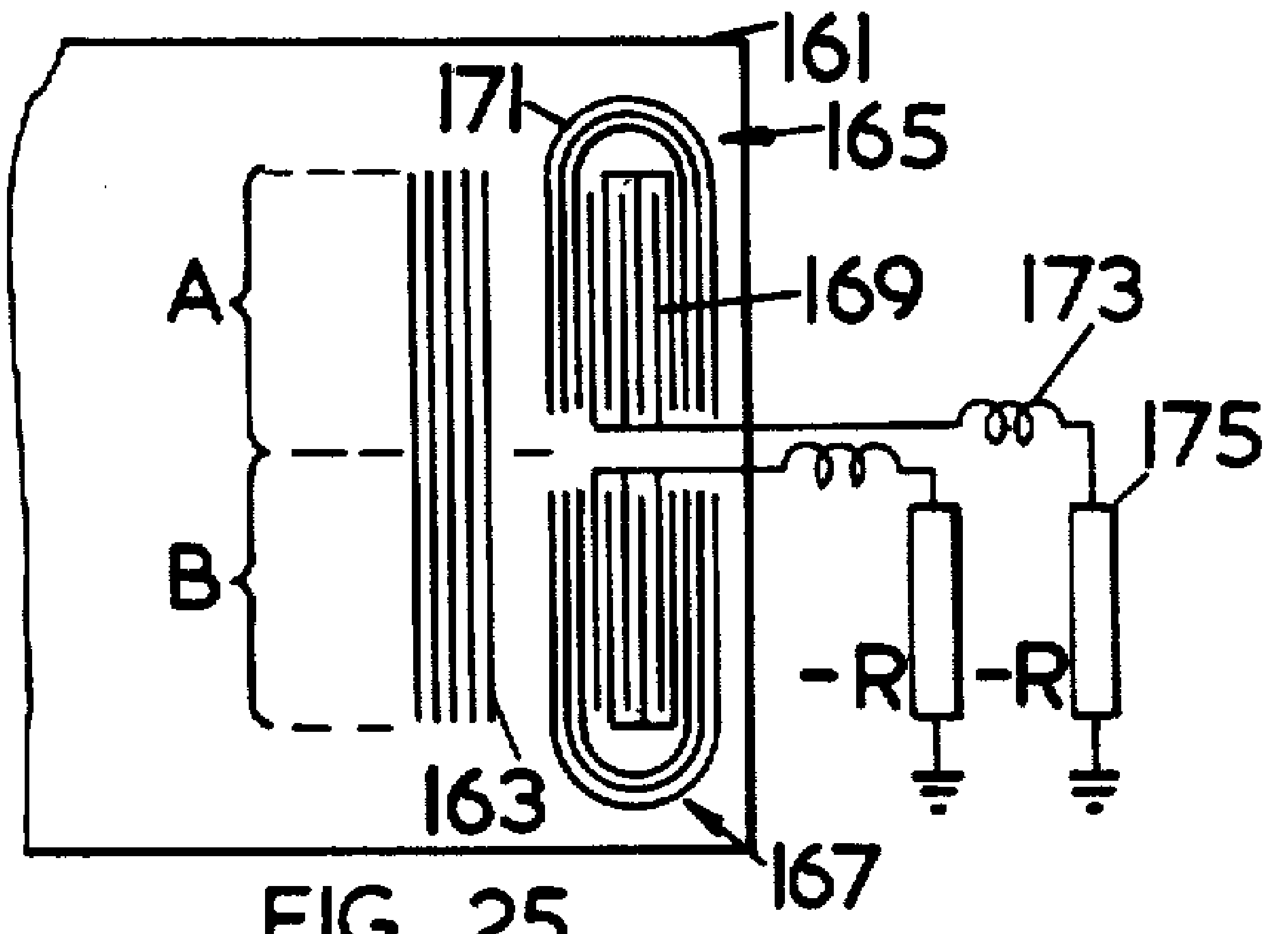

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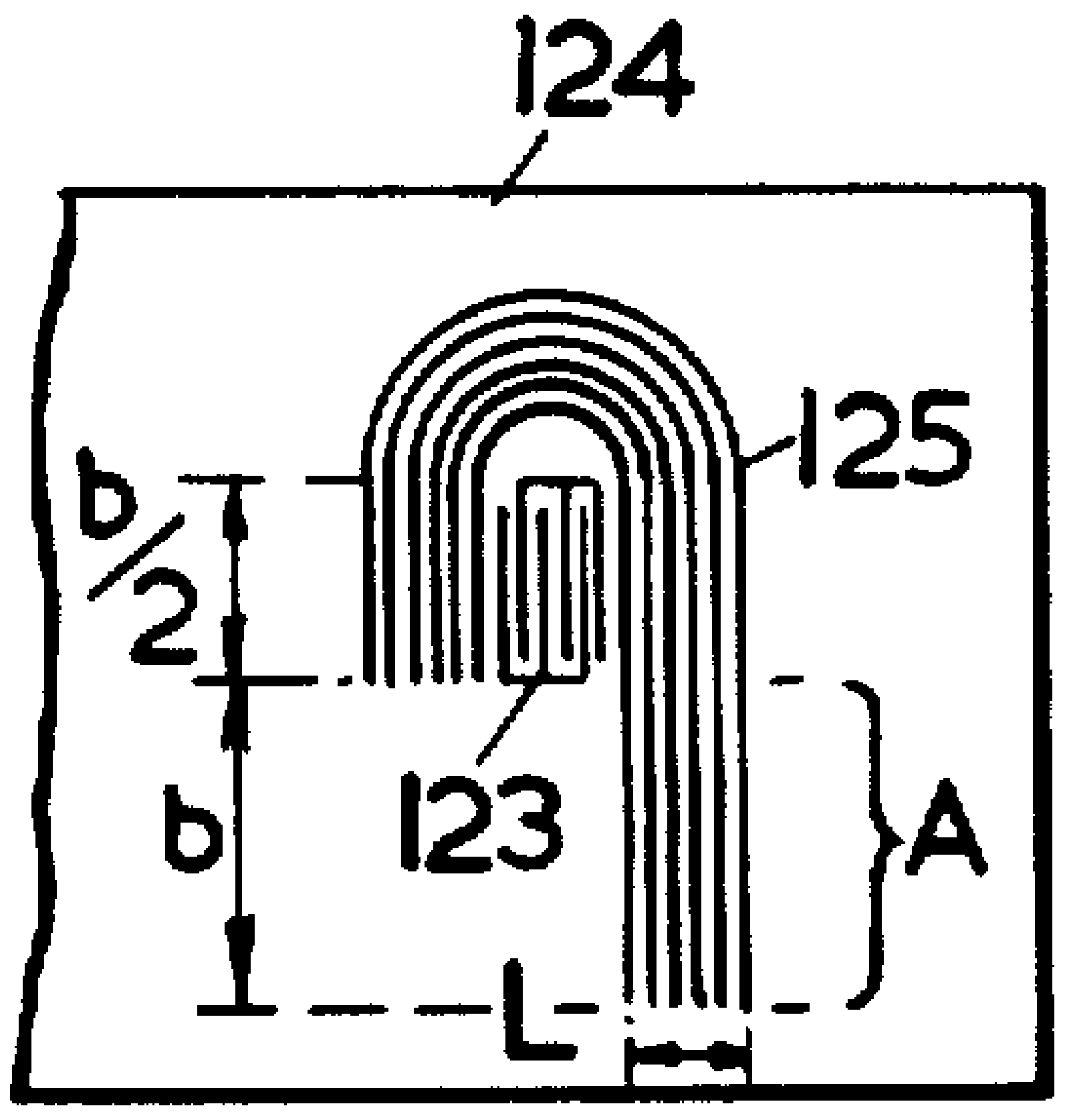

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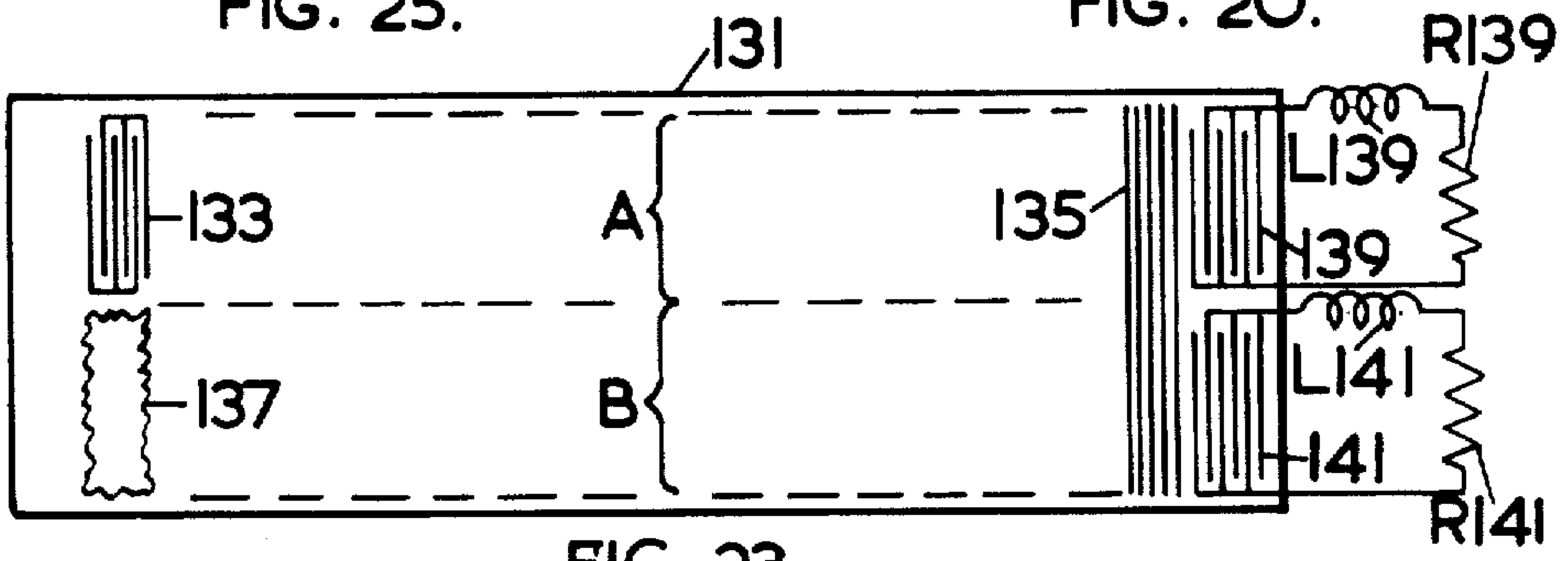

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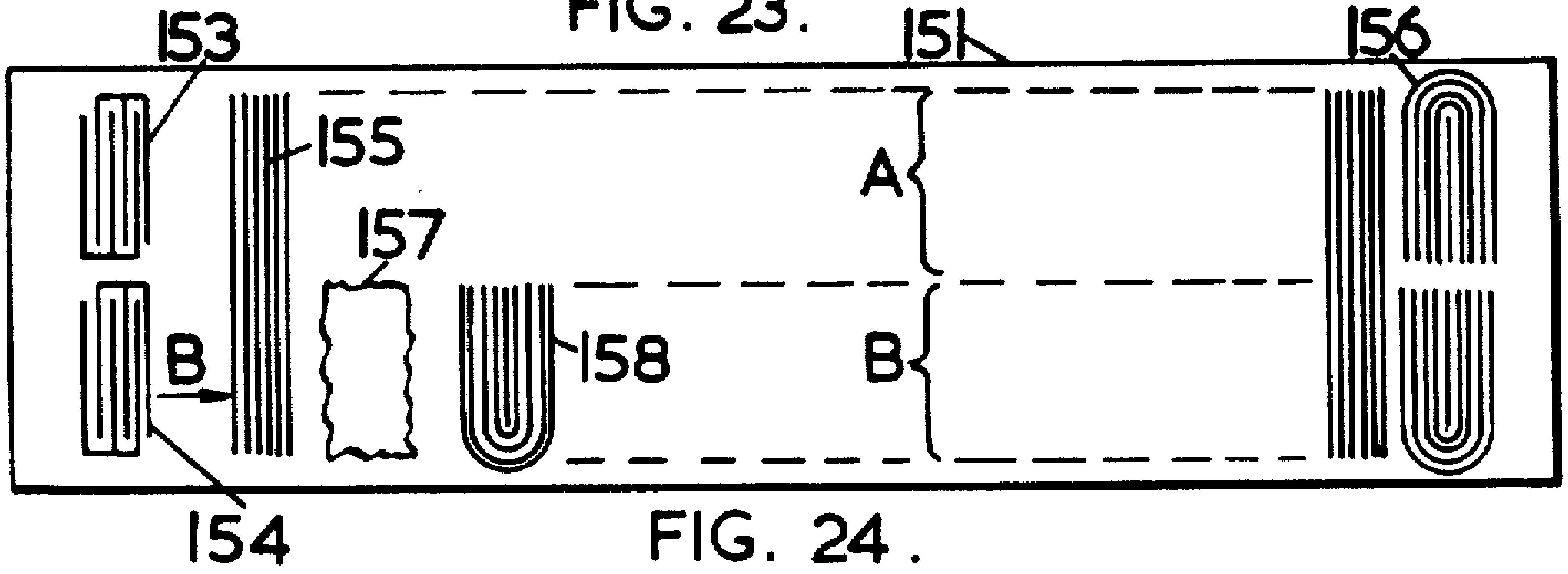

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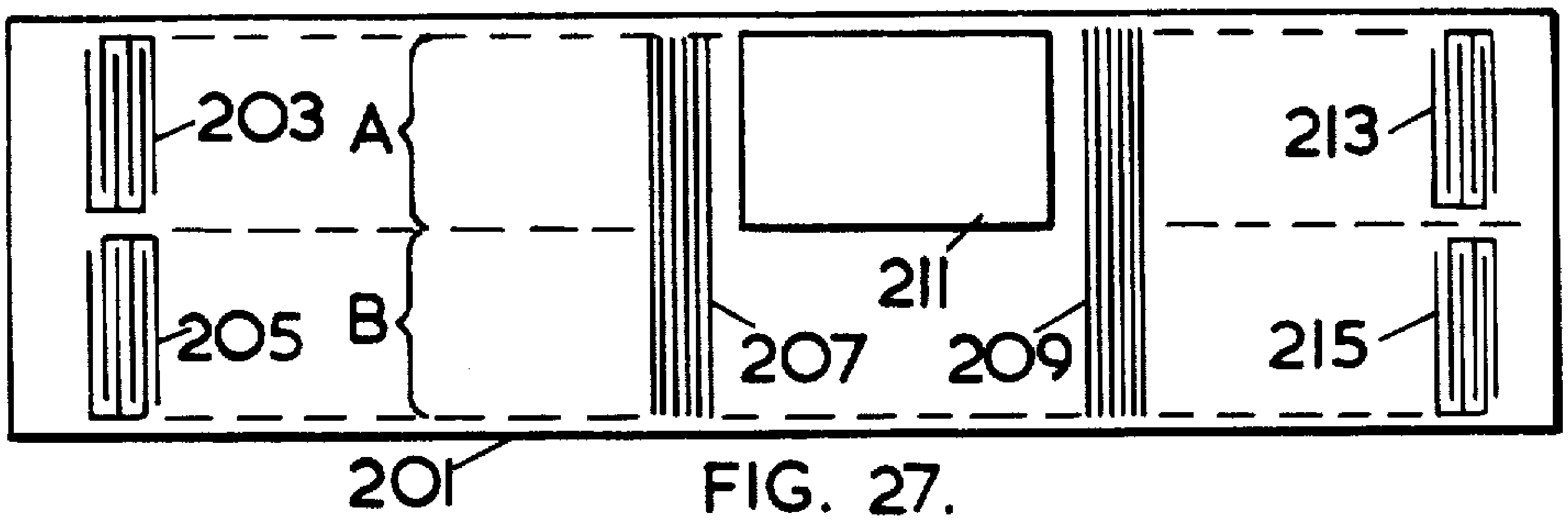

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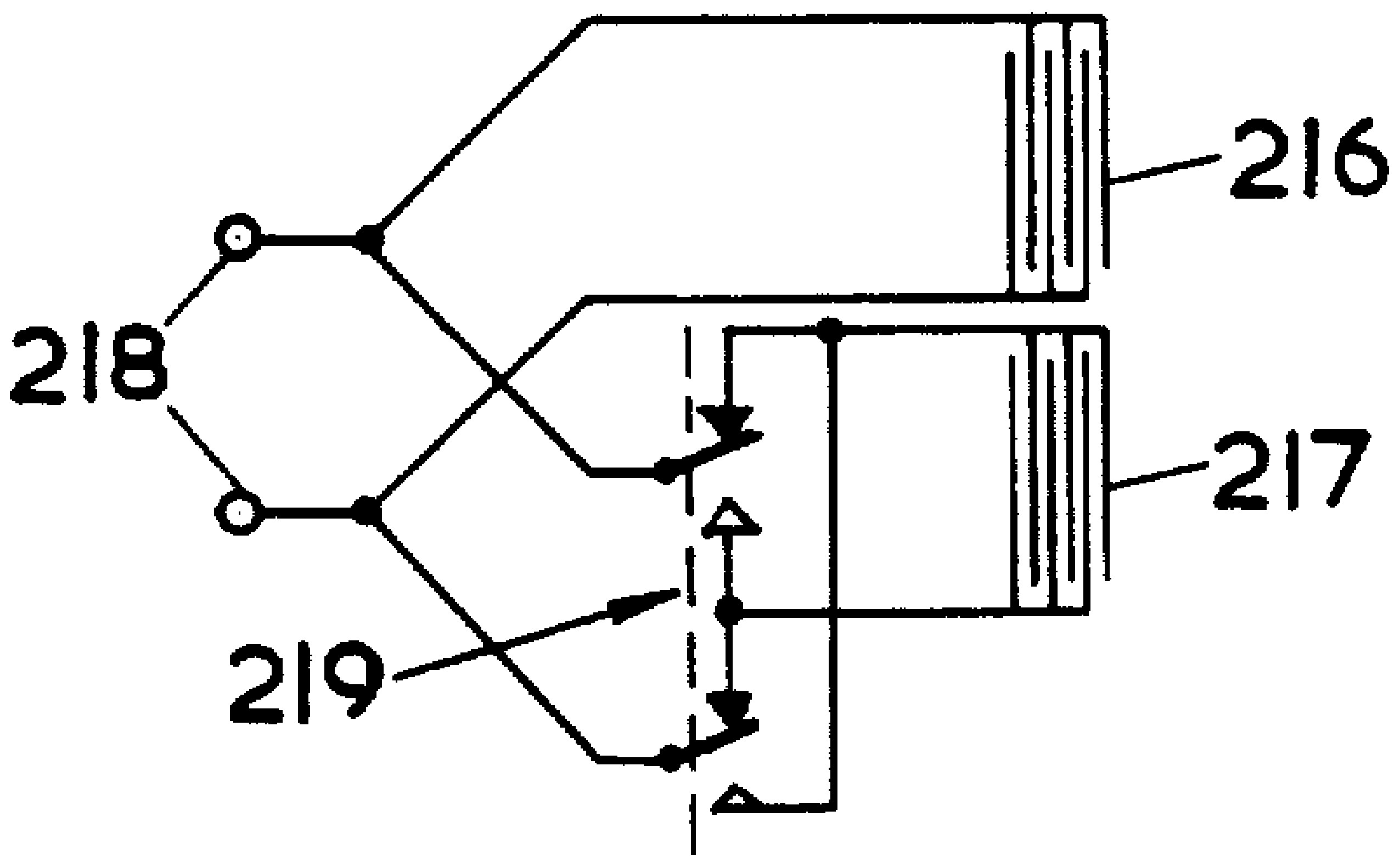

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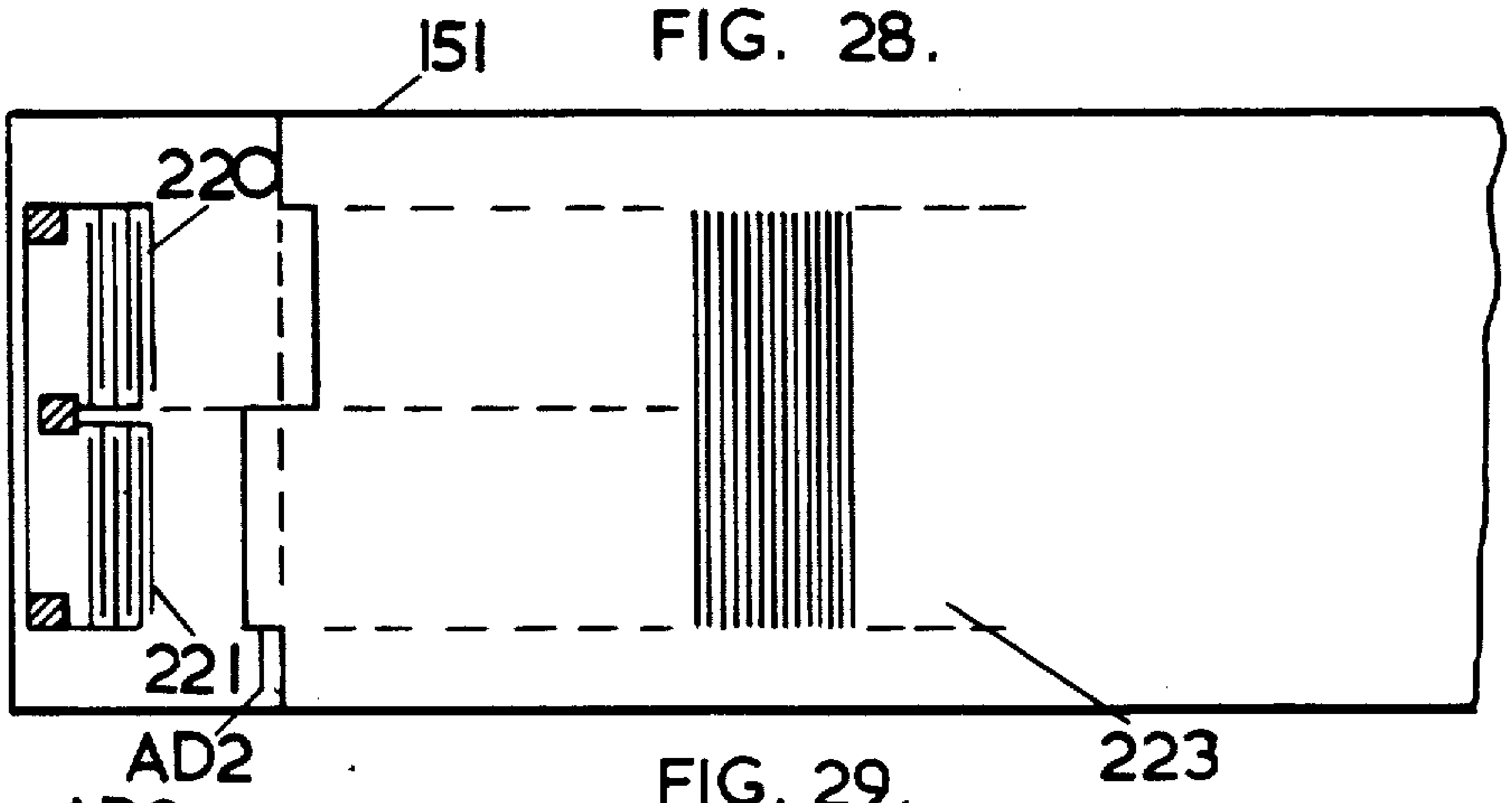

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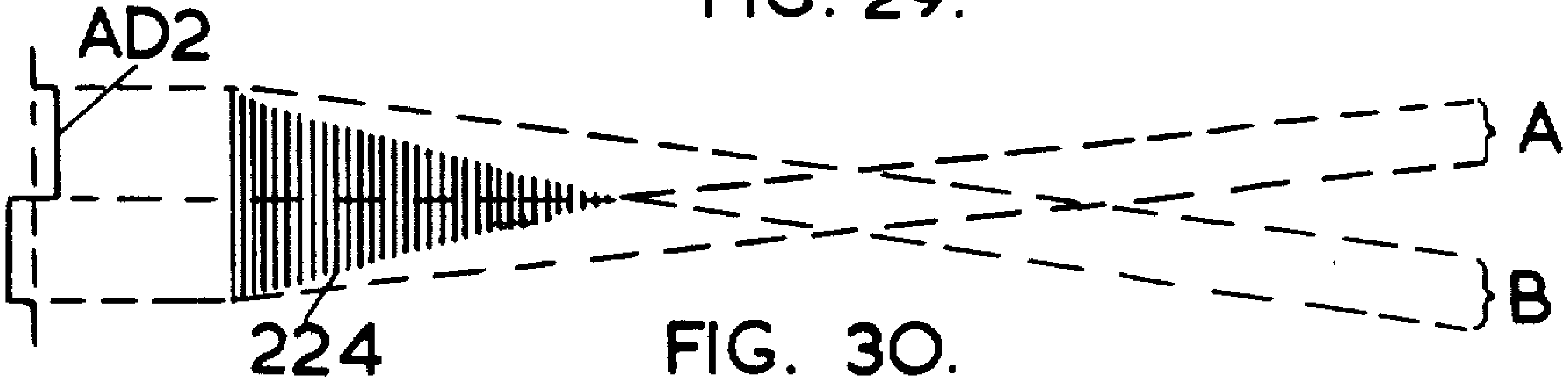
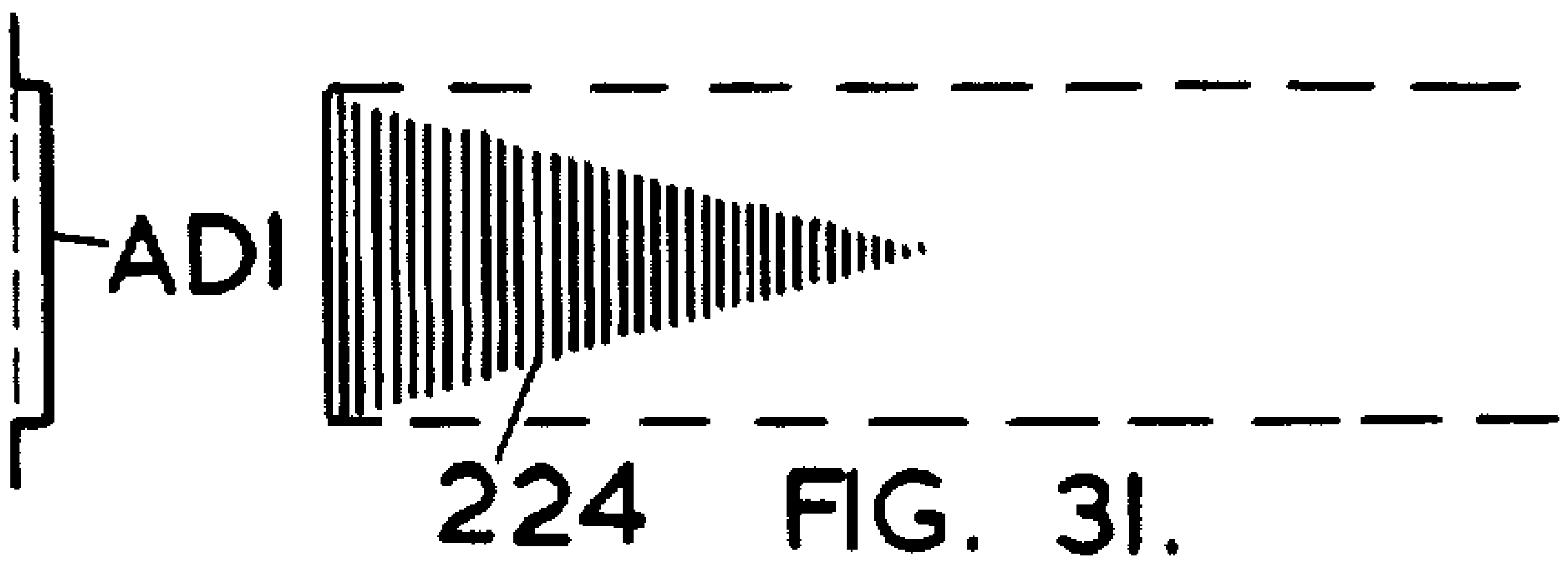


FIG. 30.



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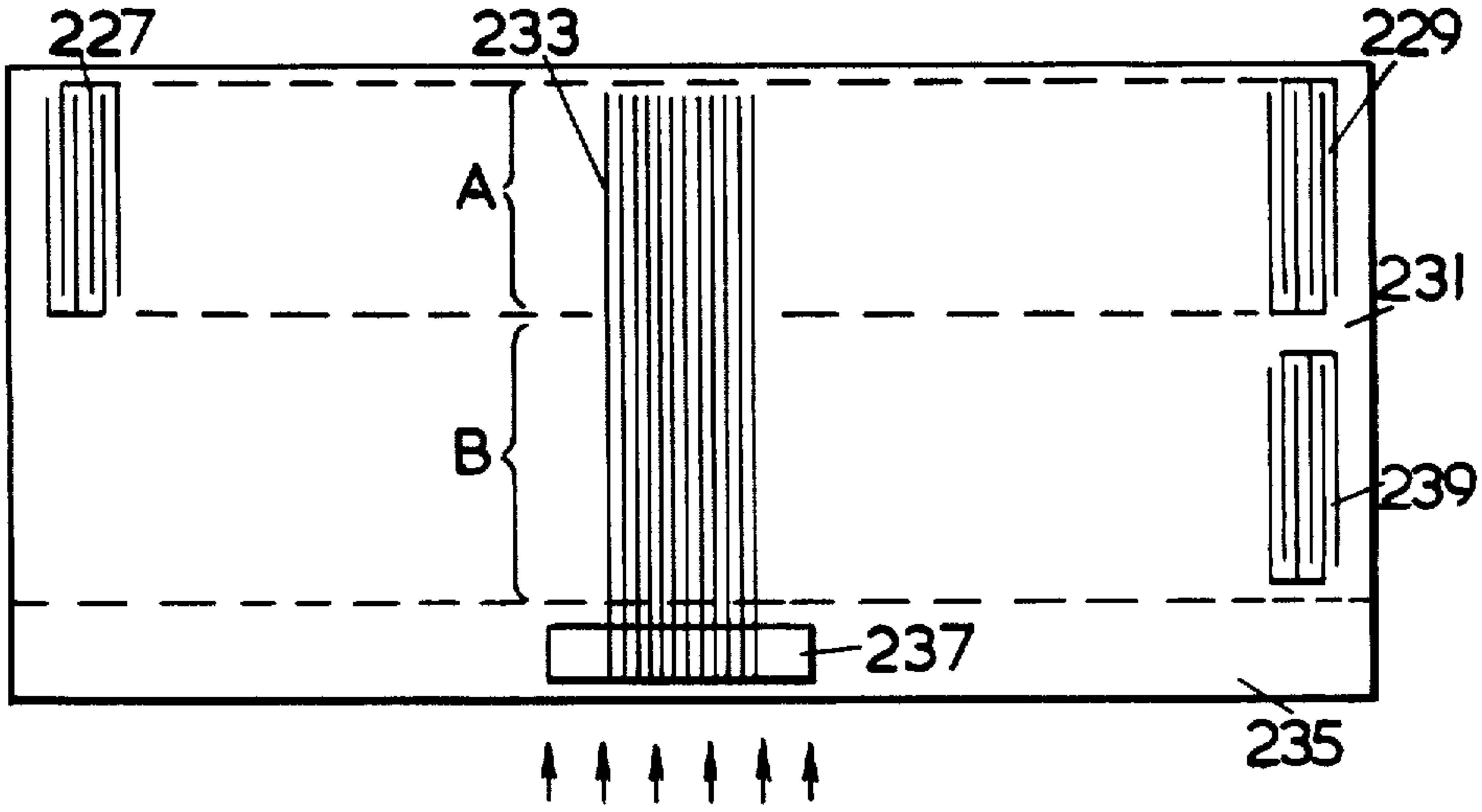
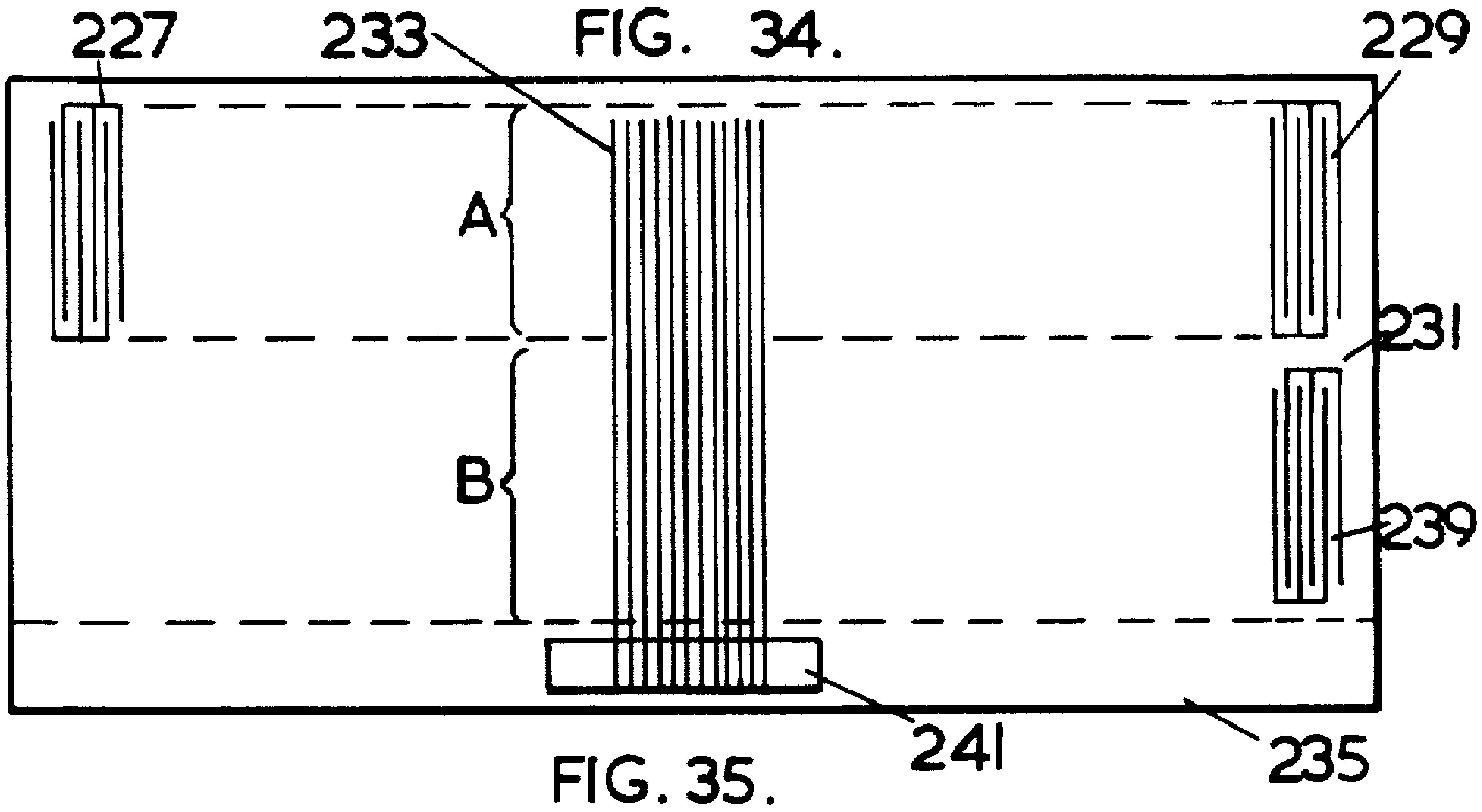


FIG. 34.



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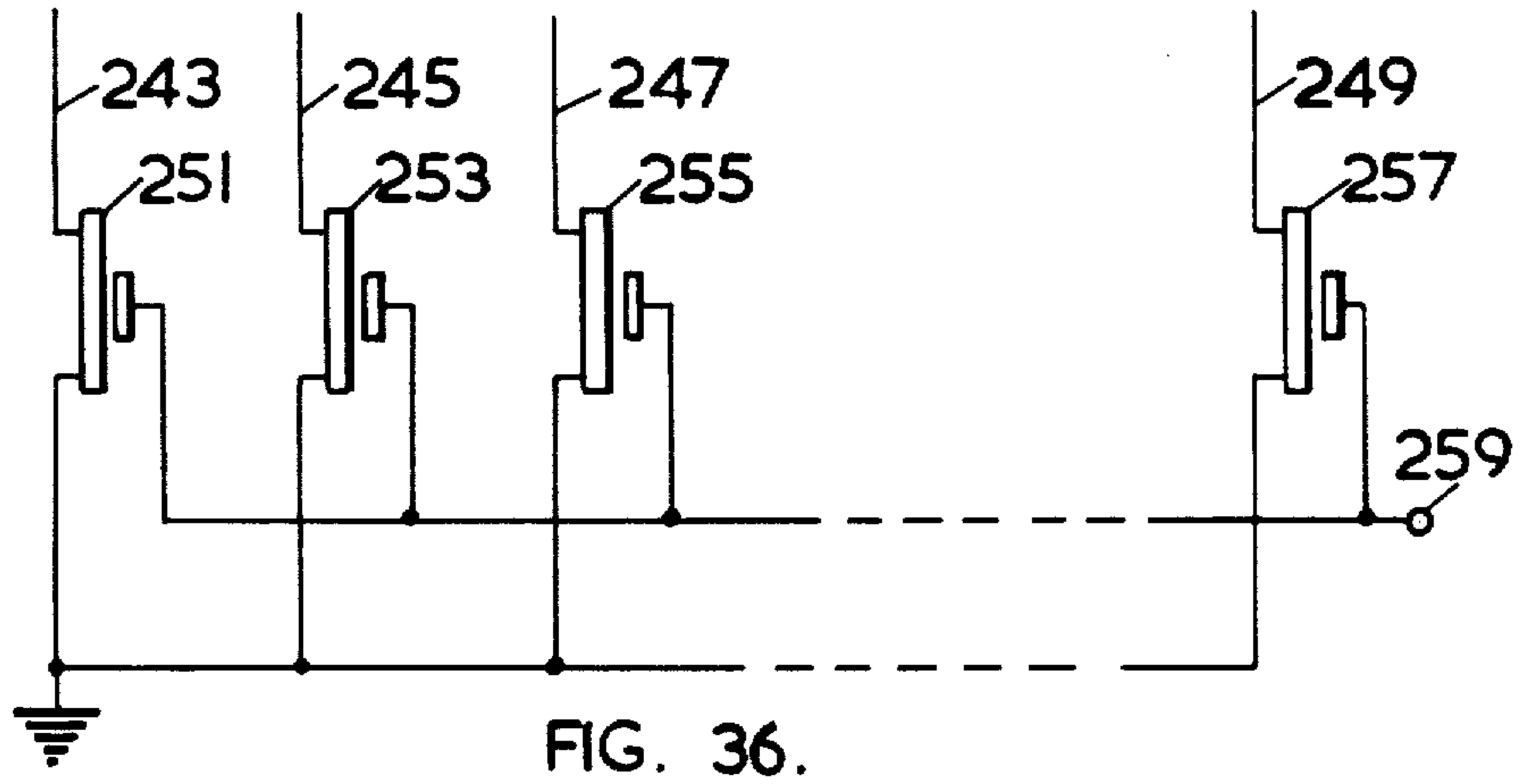

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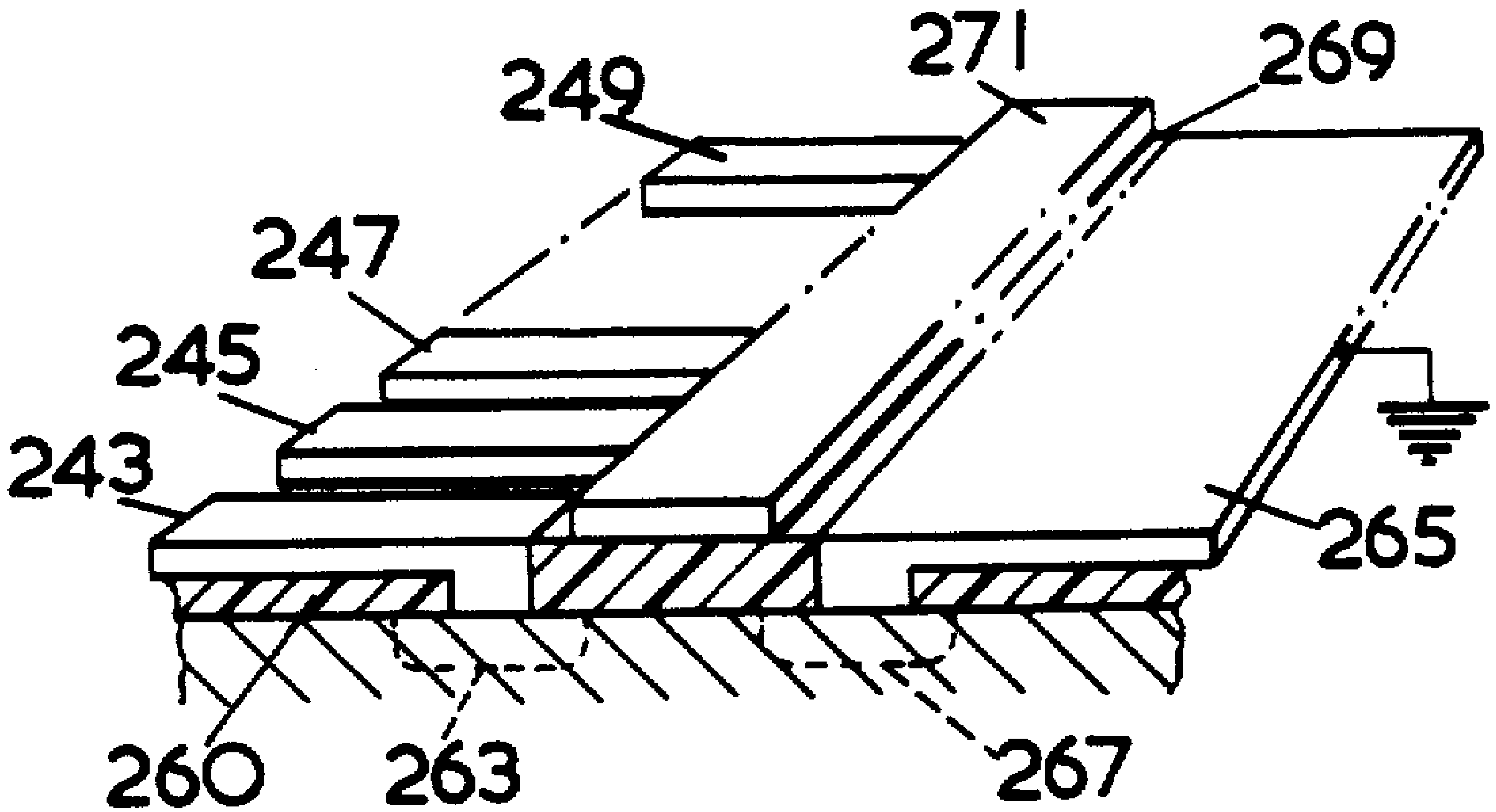

FIG. 37.

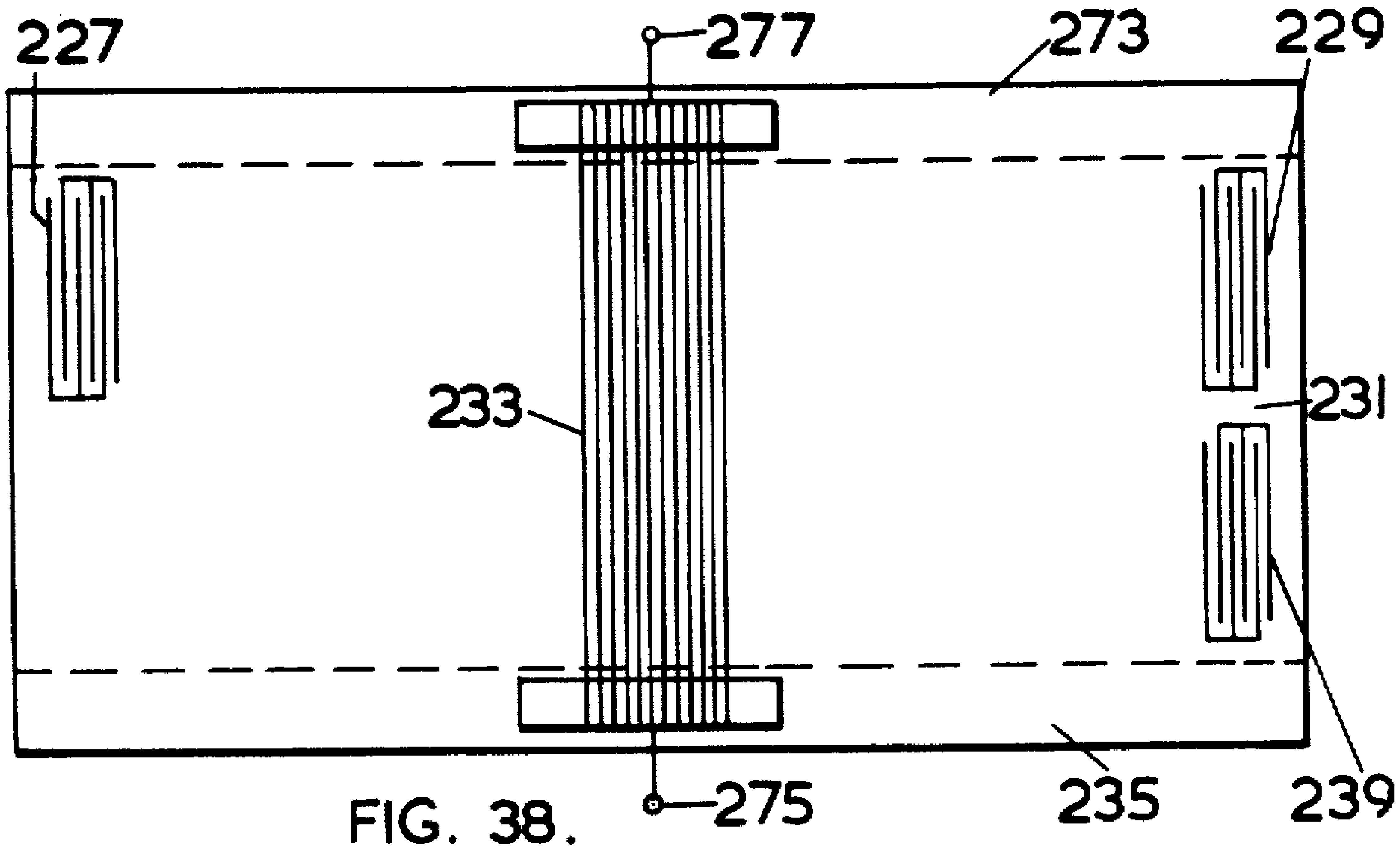

FIG. 38.

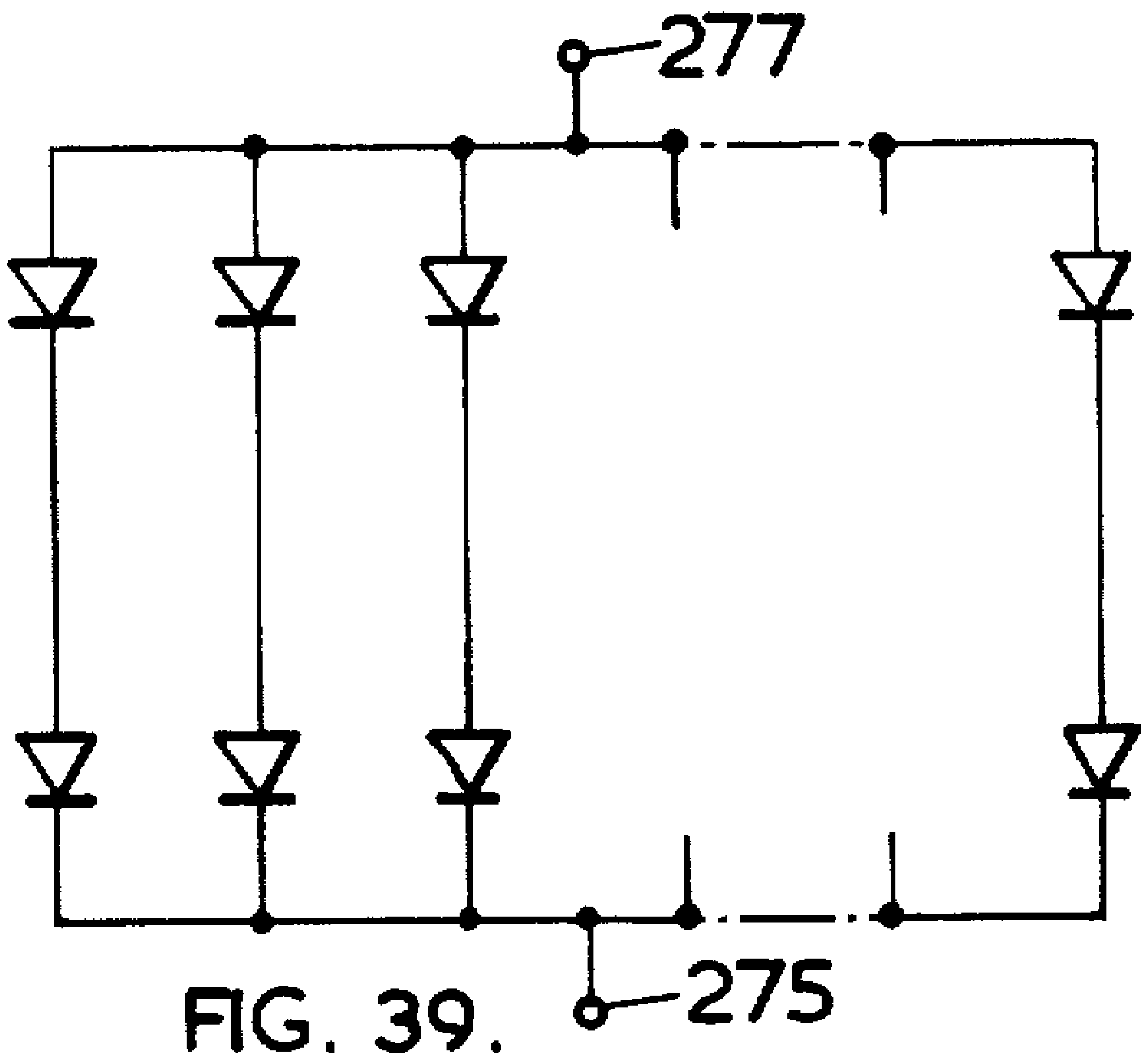

FIG. 39.

ACOUSTIC SURFACE WAVE DEVICES

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

BACKGROUND OF THE INVENTION

The present invention relates to acoustic surface wave and acoustic interface wave devices. The term 'acoustic surface waves' will be used hereinafter to include acoustic interface waves as well as acoustic surface waves.

Acoustic surface wave devices are being proposed for an increasingly large number of electronic purposes, and acoustic surface wave filters and delay lines are likely to find important applications in the future. Such devices commonly comprise a transducer for launching acoustic surface waves along a predetermined track (which must be along a surface or an interface of a material capable of supporting acoustic surface waves, but need not have any other particular configuration or boundaries) and at least one other transducer for detecting the acoustic surface waves and generating electrical signals in response to the acoustic surface waves. The transducers used conventionally comprise interdigitaled comb-like electrodes. If such electrodes are deposited on a piezoelectric material, the application of alternating electric signals of suitable frequency across the electrodes will tend to propagate an acoustic surface wave orthogonal to the interleaved digits of the comblike electrodes. Conversely, the passage of an acoustic surface wave orthogonal to the digits will induce a corresponding alternating electrical signal between the electrodes. It is also known that such transducers can operate effectively on an electrostrictive material, if a biassing electric field is applied to the material under the transducers. The transducers may be designed to achieve filtering effects.

It is an object of the invention to provide means for coupling acoustic surface waves, so that a desired portion or substantially all of the energy in an acoustic surface wave in a first region can be transferred to acoustic surface waves in a second region. A further object of the invention is to form various novel devices incorporating one or more of such coupling means which form components having useful properties, and may be used either to achieve novel or improved technical effects or as alternatives to known electronic components.

SUMMARY OF THE INVENTION

According to the present invention there is provided an acoustic surface wave device including material of the kind able to support acoustic surface waves, the said material extending at least over a first region and over a second region of the device, and including an acoustic surface wave coupling means which comprises at least several spaced filamentary electrical conductors, formed over a surface of the said material and extending over the first region and over the second region, for causing acoustic surface waves propagated in a path crossing the parts of the filamentary conductors in the first region to interact with acoustic surface waves propagated in a path crossing the parts of the filamentary conductors in the second region, by means of alternating electric signals induced between the filamentary electric conductors.

The said material may be a piezo-electric material, in which case the coupling means may simply consist of the plurality of filamentary electrical conductors extending over the first region in a direction orthogonal to the direction of the acoustic surface waves in the first region, and extending over the second region in a direction orthogonal to the acoustic surface waves in the second region. The filamentary electrical conductors need not have any electrical interconnections.

Alternatively, the said material may be an electrostrictive material, in which case the coupling means must also include means for applying a biassing electric field to the material under the filamentary conductors in the first region and in the second region. Arrangements using electrostrictive material in a similar manner have been more fully described in Paige U.S. Pat. No. 3,678,305, issued July 18, 1972, for "Acoustic Surface Wave Devices."

As another alternative the coupling means may utilize the electric motor effect. In this case the filamentary conductors are connected at their ends to form closed circuits, and means are provided for maintaining a magnetic field, orthogonal to the filamentary conductors, over each of the regions where the interactions are required.

As yet another alternative, the coupling may utilize the magnetostrictive effect. In this case the said material must be a magnetostrictive material which does not short-circuit the electrical signals induced on the filamentary conductors, the filamentary conductors are connected at their ends to form closed circuits and means are provided for applying a biasing magnetic field to the material in the first region and the second region.

The device may be formed on a surface of any piece of suitable material, or on a thin layer of suitable material deposited on a substrate, or it may be formed on any substrate able to support acoustic surface waves with a thin film, of suitable material for achieving the desired form of coupling action, deposited on the substrate only over regions where a coupling action is desired.

The device may be covered with a film or layer of protective material, thus covering the surface on which the conductors are deposited. Care should be taken to avoid using any protective material which would cause excessive damping of the acoustic surface waves.

The coupling means may be disposed to couple acoustic surface waves occurring in two regions on a single acoustic surface wave track, or to couple acoustic surface waves occurring in particular regions of two discrete acoustic surface wave tracks, which need not be of equal width, athough coupling between tracks of equal width gives maximum efficiency.

Connecting portions of the plurality of filamentary conductors may be formed over a material which absorbs or does not support acoustic surface waves; this may advantageously be a pad of a material having a low dielectric constant.

The simplest, and preferred form of coupling is the piezoelectric form. The descriptions and explanations hereinafter given refer to emobodiments having piezoelectric coupling, that is to say having at least a layer of piezoelectric material or bulk piezoelectric material over or under each of their transducers and regions where electroacoustic coupling is required, except where a specific reference to some other form of coupling is made. However, it should be remembered that in most cases corresponding structures could be formed using the alternative forms of coupling described hereinabove.

BRIEF DESCRIPTION OF THE DRAWINGS

Various embodiments of the invention using piezoelectric coupling means will now be described by way of example, with reference to the accompanying drawings, of which:

FIG. **1** is a plan view of a coupler designed to transfer the energy of acoustic surface waves from one track to an adjacent track on the same substrate,

FIG. **2** is a plan view of a coupler designed to transfer the energy of acoustic surface waves from one parallel track to form convergent acoustic surface waves in an adjacent track on the same substrate,

FIG. **3** is a plan view of a coupler designed to transfer the energy of acoustic surface waves from one substrate to an adjacent substrate.

FIG. **4** is a plan view of a coupler designed to divide acoustic surface wave power between two discrete output tracks so as to form acoustic surface waves with a quadrature phase relationship in the two tracks,

FIG. **5** is a plan view of an acoustic surface wave beam switch designed to produce an acoustic surface wave output in one or the other of two output tracks depending on the sense of an input quadrature phase difference,

FIG. **6** and FIG. **7** are diagrammatic plan views of alternative acoustic surface wave beam width compressors designed to produce a narrow-beam acoustic surface wave output,

FIG. **8** is a plan view of an acoustic surface wave hybrid junction circuit,

FIG. **9** and FIG. **10** are plan views of alternative acoustic surface wave tapped delay lines,

FIG. **11** and FIG. **12** are plan views of broad-band acoustic surface wave track changers,

FIG. **13** is a plan view of an acoustic surface wave resonator or recirculating delay line incorporating two track changers,

FIG. **14** is a plan view of an acoustic surface wave delay line incorporating angled couplers,

FIG. **15** is a plan view of a folded acoustic surface wave delay line,

FIG. **16** and FIG. **17** are plan views of alternative broad-band acoustic surface wave unidirectional transducers,

FIG. **18** is a plan view of an acoustic surface wave reflector,

FIG. **19** is a plan view of an alternative acoustic surface wave track changer,

FIG. **20** is a plan view of a unidirectional acoustic surface wave conductor,

FIG. **21** is a plan view of an acoustic surface wave tapped delay line,

FIG. **22** is a diagram intended to assist in explaining the operation of the acoustic surface wave tapped delay line described with reference to FIG. **21**,

FIG. **23** is a plan view of an acoustic surface wave delay line incorporating means for suppressing triple transit signals,

FIG. **24** is a plan view of a reflecting acoustic surface wave delay line,

FIG. **25** is a plan view of an amplifying track changer,

FIG. **26** is a plan view of a directional filter,

FIG. **27** is a plan view of a variable directional coupler,

FIG. **28** is a circuit diagram of a transducer arrangement for launching symmetric mode or antisymmetric mode acoustic surface waves,

FIG. **29** is a diagram illustrating an alternative transducer arrangement for launching antisymmetric mode acoustic surface waves;

FIG. **30** is a diagrammatic plan view of an antisymmetric mode beam splitter fed with an antisymmetric mode signal,

FIG. **31** is a diagrammatic plan view of the antisymmetric mode beam splitter of FIG. **30** fed with a symmetric mode signal,

FIG. **32** and FIG. **33** are plan views of coupler matching portions intended to reduce spuriour reflection,

FIG. **34** is a plan view of a light-controlled acoustic surface wave coupler,

FIG. **35** is a plan view of an electrically-controlled acoustic surface wave coupler,

FIG. **36** is a circuit diagram of one form of part of the coupler described with reference to FIG. **35**,

FIG. **37** is a perspective view of an electronic component for the device of which FIG. **36** is a circuit diagram, and

FIG. **38** is a plan view, and FIG. **39** is a circuit diagram of an alternative electrically-controlled acoustic surface wave coupler.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** is a plan view of a coupler designed to transfer acoustic surface waves from one track A to an adjacent parallel track B on the same substrate **1**. The acoustic surface wave substrate **1** may be a piezoelectric material such as quartz, lithium niobate, or lithium germanate; a thin film of aluminium nitride deposited on a non-piezoelectric single-crystal substrate, or a thin film of piezoelectric material, for instance zinc**[,]** oxide sputtered on a non-piezoelectric amorphous substrate, for instance glass. Alternatively the various transducers and coupler elements shown may be formed on a non-piezoelectric substrate which is able to support acoustic surface waves (for instance glass) with a thin film of piezoelectric material, for instance zinc oxide, sputtered or otherwise deposited either over or under the transducers and coupler elements in order to make them effective.

An interdigital comb transducer **3** is formed on the substrate **1** in a position suitable for launching acoustic surface waves along the track A. An acoustic surface wave coupler **5** is deposited on the substrate **1**. The coupler **5** consists of a plurality of vapor-deposited filamentary conductors, each of length 2b, spaced parallel to each other and aligned at right angles to the acoustic tracks A and B. The broken line S represents a line of symmetry bisecting the coupler **5** and extending parallel to the tracks A and B. The filamentary conductors of the coupler **5** may be separated by equal spaces, by monotonically varied spaces, or by spaces varied in any regular or random manner. A second interdigital comb transducer **7** is formed on the substrate **1** in the track B towards the end of the track B which is further from the transducer **3** than the coupler **7**. The transducers **3** and **7** will have conventional electrical connections (not shown) to external circuits, but the filamentary conductors of the coupler **5** need not have any external connections and should be electrically insulated from each other. It should be noted that FIG. 1 and the other plan drawings are schematic, in as much as they do not attempt to show the width of each filamentary conductor or to show the required number of the required number of filamentary conductors accurately.

It has been found that when acoustic surface waves are coupled to an array of filamentary conductors extending across the path of the acoustic surface waves, alternating electric fields are set up between adjacent conductors, which can induce acoustic surface waves in any other acoustic surface wave track crossed by the array of filamentary conductors. In the simplest case of an array such as the coupler 5, the two halves of the array on opposite sides of the line of symmetry S act as coupled structures, and tend to exchange energy from waves propagated under one half to waves propagated under the other half, and then vice versa, as the waves proceed.

This effect can be explained by a theory that acoustic surface waves can propagate in piezoelectric material under an array of filamentary conductors orthogonal to the direction of propagation, in two main modes, namely a symmetric mode and an antisymmetric mode. In the symmetric mode the waves under both halves of the array are in phase with each other and their amplitude is constant across the whole width of the array. In the antisymmetric mode, the signals under the two halves of the array are of equal amplitudes, but have an antiphase relationship with each other. When an antisymmetric mode wave is combined with a symmetric mode wave of the same amplitude, the result resembles an acoustic surface wave under one half of the array only, the two modes having a null effect under the other half. Hence excitation by an acoustic surface wave arriving under one half only of the array is effectively divided equally between the symmetric mode and the antisymmetric mode. However, the antisymmetric mode wave causes currents to flow along the filamentary conductors, and therefore propagates with a slower velocity than the symmetric mode. The phase relationship between the symmetric mode and the antisymmetric mode therefore changes as the signals advance; this has an effect equivalent to a transfer of energy from the acoustic surface wave arriving in track A under one half of the coupler, to form a new acoustic surface wave in track B under the other half of the coupler. When both waves have travelled a distance, hereinafter called L, which is sufficient to cause the phase relationship between the symmetric mode signal and the antisymmetric mode signal to change by π radians, substantially all the energy originally in the track A will be transferred to track B. If the array extends further, and the waves are allowed to continue propagating under it without interference for a further distance L, then (neglecting dissipation in the track) substantially all the energy will be transferred back to the track A again. It follows that for the purpose of the transferring energy from the acoustic surface wave in track A to track B, the coupler 5 should be made to extend for a distance L (or an odd multiple of L) in the direction of propagation of the waves. The length L can be at least approximately calculated as follows, for the case of a coupler having equally spaced conductors, formed on piezoelectric material.

$$L=N_T d$$

$$N_T=\pi/FK^2\theta/1-\cos\theta$$

where

$\theta=\alpha\omega$ d/s,

N_r is the number of conductors required for maximum energy transfer,

ω is angular frequency,

d is the spacing between the centers of adjacent filamentary conductors,

s is the velocity of the acoustic surface waves,

K is the electromechanical coupling constant, and

F and α are factors dependent on the material and on the ratio of the width of the filamentary conductors to the width of the spaces between them.

For Y-cut, lithium niobate with conductors as wide as the spaces between them, arranged to propagate the acoustic surface waves parallel to the crystal Z axis, $\alpha=0.75$ and $F=0.85$.

Under the same conditions the general behaviour of a coupler having N wires is specified by a scattering matrix M:

$$M=\begin{pmatrix} 0 & a & 0 & b \\ a & 0 & b & 0 \\ 0 & b & 0 & a \\ b & 0 & a & 0 \end{pmatrix}$$

where

$a=(1-K_N^2)^{\frac{1}{2}}$

$b=ik_N$

and

$K_N=\sin(\frac{1}{2}NFK^2(1-\cos\theta)$.

This coupling action applies over a wide frequency range limited by a stop band which occurs when the spacing of the conductors becomes approximately equal to one half of the wavelength of acoustic surface waves in the material. (The above formula does not apply in the stop band). The bandwidth may be increased by spacing the conductors unequally or randomly. In such cases the formula for N_T should be slightly modified but still remains approximately true; L will be N_T times the mean spacing of the conductors.

Where electrostrictive coupling, or motor effect coupling is used, different constants will be appropriate. In the electrostrictive case the constants become functions of the biasing field applied.

The coupling action of the array is only slightly modified if the array is curved, or the operative parts of the array spaced apart—that is to say if the filamentary conductors have intermediate portions required to serve only as electrical interconnections between the parts of the array over the first region and the parts of the array over the second region. However a complete transfer of energy is only possible if the operative width of track A is equal to the operative width of track B (assuming that the tracks are in the same material). If the two tracks are unequal in width, a modified theory applies, and similar but less efficient results are achieved.

In some of the devices described hereinafter it is beneficial for intermediate portions of the filamentary conductors to have little or no coupling to the substrate on which they are deposited. Such portions will hereinafter be called connecting-portions, or C-portions.

There are various methods of arranging this. One method which is usable on an anisotropic substrate is to arrange that the electromechanical coupling constant K is large in directions in which it is desired to propagate acoustic surface waves compared with its value in directions perpendicular to the C portions.

Alternatively it may be possible to arrange for K to be zero under the C portions. For example, it is possible to make certain piezoelectric ceramic substrates having selected areas where piezoelectric coupling is absent.

Another alternative method relies on velocity mismatch between acoustic surface waves generated beneath C portions. Such mismatch may arise from anisotropy in the crystal or may be arranged by adjustment of the spacing between the wires in the C portions.

Alternatively the C portions may be deposited over pads of silica or other non-piezoelectric material having a low dielectric constant, the pads themselves being deposited on the substrate.

For additional isolation, the pads of low dielectric constant may be deposited over a metal film on the substrate. This shields the substrate from the electric fields between the filamentary conductors.

These portions of the conductors whose function is to act as electrical conductors only will inevitably impose a capacitive load on the coupler. This extra load may be offset by increasing the number of conductors in the coupler, and full compensation is possible by using this technique. The load can however be reduced by the use of silica pads under the portions of the conductors concerned, which produces the further beneficial effect of reducing the coupling between the conductors and the substsrate, as stated above.

Whatever the actual length of a coupler the symbol L will be used to denote that length which transfers the maximum amount of energy from one track to a further track. In other words the length hereinafter called L should be understood to include any extra length necessary in any given case due to capacitive loading effects of the kind described above. The expression 'full length multistrip coupler' will be used hereinafter to denote a coupler of length L.

It is possible to design a coupler so that the input energy in one track is split equally between two output tracks; this requires a length of ½L. Couplers so designed will hereinafter be called 3dB couplers.

It is also possible to design a coupler of suitable length to transfer any desired proportion of the input energy to another track. Couplers designed to transfer a fraction less than half of the input energy to another track will hereinafter be called fractional couplings.

FIG. 2 is a plan view of a device including a coupling 6, designed to transfer acoustic surface waves from a parallel track A to an adjacent convergent track on the same substrate. This coupling is similar to the coupler 5 of FIG. 1 except that the parts of the filamentary conductors crossing the track B are curved forming a series of circular arcs having a common center O. On an anisotropic substrate it may be better to have curves of some non-circular shape; acoustic surface waves will be generated in directions perpendicular to the conductors.

The action of the device is as follows. Acoustic surface waves launched in the track A by the transducer 3 cause electric fields to be set up between adjacent filamentary conductors in the coupler 6 and these fields are transferred to the circular arcuate parts thereof. This causes acoustic surface waves to be generated and propagated in the track B orthogonal to the circular arcs: thus forming acoustic surface waves converging to a focus at the point O. A fine focus may be achieved at the point O by a suitable choice of the forms of the curves in the wires in the track B. One use for a coupler of this kind is to feed acoustic surface waves into an acoustic surface wave waveguide (not shown) at the point O.

The two operative regions coupled by a multistrip coupler of the kind herein described need not be on the same substrate, as long as the conductors over one region are suitably connected to corresponding conductors over the other region. FIG. 3 shows a plan view of a device including a multistrip coupler arranged to transfer acoustic surface wave energy from one substrate to another. It comprises a first interdigital comb transducer **9** deposited on a first acoustic surface wave substrate **11**, and a second interdigital comb transducer **13** deposited on a second acoustic surface wave substrate **15**. The substrates **11** and **15** are mounted adjacent to one another (for example, by cementing to a common base) and a full length multistrip coupler **17** is formed across the substrates **11** and **15**, between the transducers **9** and **13**. If the substrate **15** is identical to the substrate **11** in all respects, then the spacing between the conductors on both substrates can be identical, but otherwise it may be necessary to have different spacings and length b not identical in each track on the two substrates.

FIG. **4** is a plan view of a device including a coupler **19** designed to divide acoustic surface wave power into two output tracks in quadrature. This is a half length or 3dB coupler. A third interdigital comb transducer **21** is deposited on the substrate **1** towards the end of the track A further from the transducer **3** than the coupler **19**.

The action of the device is as follows. Acoustic surface waves are launched in the track A by the transducer **3**. Let a_3 represent the amplitude of these waves. When they reach the coupler **19**, their energy is split equally between the symmetric mode and the antisymmetric mode. Hence they propagate as a symmetric mode signal of amplitude $\frac{1}{2}a_3$ plus an antisymmetric mode signal of amplitude $\frac{1}{2}a_3$, starting in phase with each other in track A at the leading edge of the coupler **19**. In track B, the antisymmetric mode signal is initially equal and opposite to the symmetric mode signal. The length of the 3dB coupler **19** is just enough to cause the antisymmetric mode signal to be lagging the symmetric mode signal by $\pi/2$ radians when it reaches the trailing edge of the coupler. Hence the resultant acoustic wave signals leaving the coupler in the tracks A and B have amplitudes equal to $a_3/\sqrt{2}$, and the wave in track B leads the wave in track A by $\pi/2$ radinas. The waves in track A are detected and converted into electrical signals by the transducer **21**, and the waves in track B are detected and converted into electrical signals by the transducer 7.

FIG. **5** is a plan view of an acoustic surface wave beam switch designed to produce an acoustic surface wave output in one or the other of two output tracks depending on the sense of a quadrature phase difference between two input signals. This beam switch is similar to the device of FIG. **4** but has a fourth interdigital comb transducer **23**, deposited on the substrate **1** towards the end of the track B remote from the transducer 7.

The beam switch acts as follows. Suppose that the transducers **3** and **23** produce signals of amplitudes a_3 and a_{23} respectively. The action of coupler **19** in response to the signal a_3 produces signals of amplitude $a_3/\sqrt{2}$ in track A and track B, the signal in track B leading the signal in track B by $\pi/2$ radians. Similarly, the signal a_{23} causes the coupler **19** to produce signals in track A and track B of amplitude $a_{23}/\sqrt{2}$, but with the signal in the track A leading by $\pi/2$ radians. Now if the original signals a_3 and a_{23} are of equal amplitudes and have a quadrature phase relationship, the resultant output signals from the coupler **19** will cancel out in one track or the other, depending on whether the signal from transducer **3** leads or lags relative to the signal from the transducer **23**. Hence the output from the switch may be switched from the transducer **21** to the transducer **7** and vice-versa, by reversing the quadrature phase difference between the signals supplied to the transducer **3** and the transducer **23**.

FIG. **6** is a diagrammatic plan view of an acoustic surface wave width compressor designed to produce a narrow-beam acoustic surface wave output. An acoustic surface wave substrate **33** provides two acoustic surface waves A and B, of equal width b, on opposite sides of a line S. A source **25** of width 2b is provided on the substrate **33** so as to launch acoustic surface waves in both track A and track B. A half-lengthy multistrip coupler **35** is deposited on the substrate **33** so as to embrace the track A and the track B. A receiving device **37** is deposited on the substrate **33** in the track B on the farther side of the coupler **35** from the source **25**. The device is so made that the signals arriving at the coupler **35** in the respective tracks A and B are of equal amplitude and in quadrature with one another; this may be arranged in any one of four alternative ways which will now be described.

The first method of ensuring quadrature between the signals is to slow down or speed up acoustic surface waves in one of the tracks by depositing a pad of suitable material, for instance metal, or alternatively any material having elastic properties different from those of the substrate material on one of the tracks.

The second method is to make the source **25** consist of two transducers one being displaced relevant to the other by a quarter wavelength of the acoustic surface waves.

The third method is to make the source **25** consist of two transducers the same distance away from the coupler **35**, but driven in electrical quadrature.

The fourth method is to form the coupler **35** with a step in each of its conductors, so that one half of the coupler is effectively displaced a quarter of an acoustic wavelength along the direction of propagation, as illustrated in the case of the couplers of FIG. **7** described hereinafter.

By any one of these arrangements, it is ensured that the signals reaching the coupler **35** in track B are $\pi/2$ radians in advance of the signals reaching the coupler **35** in track A. By an interaction of the kind described with reference to FIG. **4**, the coupler **35** effectively compresses the energy of the waves from tracks A and B to form a single wave in the track B on the output side of the coupler **35**.

Clearly, several width-compressors can be cascaded in series, to change the width of the acoustic surface wave by a factor of two at each stage. FIG. **7** shows a three-stage width-compressor comprising three couplers **43**, **45** and **[57]** *47*. Each of these couplers has a quarter-wavelength step in the center of each of its filamentary conductors. The block **41** represents a source, and the block **49** represents a receiver of acoustic surface waves. The receiver **49** may be a coupler or a transducer or a waveguide for acoustic surface waves.

By successive width-compressing actions as hereinbefore described, substantially all the energy from the wide source **41** is compressed into a track having one-eighth of the width of the source **41**. The device will work equally well in reverse, as a width expander, if **49** is a narrow source and **41** is a wide receiver. The main utility of such a device is for matching acoustic impedances.

FIG. **8** is a plan view of a coupler device arraned to act as a hybrid junction circuit. Hybrid junction circuits are known both at low frequencies (in the form of inductive circuits) and at microwave frequencies (in the form of magic-tee waveguide junctions), but it is difficult to devise any convenient or practical form for an electrical hybrid junction circuit to operate in a range of commonly used intermediate frequencies. The acoustic surface wave form of hybrid junction circuit should be very useful and convenient in this range of frequenices where the purely electrical or electromagnetic forms of hybrid junction circuit are inconvenient or impractical.

FIG. **8** shows components as in FIG. **5**, except that the half-length coupler **19** is formed with a quarter-wavelength step in the center of each of its conductors, in effect displacing one half of the coupler **19** with respect to the other half, by a distance equal to a quarter-wavelength of the acoustic surface waves, so that when waves are launched in phase with each other in the two tracks A and B, the waves in track A will reach the first conductor of the coupler **19** $\pi/2$ radians ahead of the waves in the track B.

When in-phase signals of amplitude a_3 and a_{23} are propagated from the transducers **3** and **23** respectively, each of the signals a_3 and a_{23} is split to form signals of equal amplitude in the two tracks A and B on the far side of the coupler **19**. Let the phase of the contribution of the signal a_3 to the output signal in track A, at a plane P on the output side of the coupler **19**, be taken as a reference. Relative to this signal, the phase of the contribution of signal a_3 to the output in track B will be advanced $\pi/2$ radians by the step in the coupler **19**, and advanced a further $\pi/2$ radians by the coupler action. The contribution from signal a_{23} to track B will be in phase with the reference signal. The contribution from the signal a_{23} to the output in track A will be set back, or delayed, $\pi/2$ radians by the steps in the coupler, but the $\pi/2$ radians advance caused by the coupler action will exactly compensate for this. Hence the output in track A is a summation of the signals a_3 and a_{23}, but in track B the signal contribution derived from the signal a_3 is inverted and the resultant output signal is the difference of the signals a_3 and a_{23}. Hence the device forms a hybrid junction circuit, in which the transducers **3** and **23** are the input ports, and the transducers **21** and **7** are the sum port and the difference port, respectively.

FIG. **9** is a plan view of an acoustic surface wave tapped delay line. An acoustic surface wave substrate **63** has a line of symmetry S between two acoustic surface wave tracks A, B both of width b and one or either side of the line S. An interdigital comb transducer **65**, of width b, is deposited on the substrate **63** in a position suitable for launching acoustic surface waves along the track A. A series of fractional acoustic surface wave couplers **67a**, **67b**, **67c**, . . . similar to the coupler **5** in FIG. **1**, but having a smaller number of **[**conductrs**]** *conductors*, is deposited on the substrate **63**. An interdigital comb transducer **69** is deposited on the substrate **63** in the track A on the far side of the couplers **67a**, **67b**, **67c** . . . , from the interdigital comb transducer **65**. Other interdigital comb transducers **71a**, **71b**, **71c**, . . . , are deposited on the substrate **63** in the track B on the farther side from the interdigital comb transducer **65** of the couplers **67a**, **67b**, **67c**, . . . , respectively. A set of pads of suitable acoustic absorbing material **72a**, **72b**, **72c**, . . . are placed in the track B between the transducers **71a**, **71b**, **71c**, ...

The action of the device is as follows. Acoustic surface waves launched in the track A by the transducer **65** are received by the transducer **69** after a delay corresponding to the time taken for acoustic surface waves to travel along the track A between the transducer **65** and the transducer **69**, as in a conventional acoustic surface wave delay line. However, as the acoustic surface waves pass the couplers **67a**, **67b**, **67c**, . . . , each coupler transfers a fraction of the wave energy to the track B, which will be detected and converted to provide an electrical output from the adjacent one of the transducers **71a**, **71b**, **71c**, ... The absorbers help to reduce spurious signals. The remaining energy in the track A will provide a signal at the final transducer **69**. The acoustic surface wave path lengths between the transducer **65** and the transducers **71a**, **71b**, **71c**, . . . , determine the relevant delay periods.

FIG. **10** is a plan view of an alternative acoustic surface wave tapped delay line. This tapped delay line resembles the delay line of FIG. **9**, except that the fractional length couplers **67a**, **67b**, **67c**, . . . , having straight conductors are replaced by fractional length couplers **73a**, **73b**, **73c**, . . . , having angled conductors to direct their output waves at an angle to the track A. Output transducers **75a**, **75b**, **75c**, . . . , are deposited to receive the output waves from the couplers **73a**, **73b**, **73c**, . . . , respectively. This arrangement is a way of reducing the amount of acoustic surface wave energy reflected by the transducers which can form spurious signals in previous transducers.

Couplers of the kind herein described may also be used as mode discriminators, since they are highly responsive to acoustic surface waves but comparatively insensitive to bulk surface waves. Thus if the transducer **3** in FIG. **1**, for instance, is liable to generate unwanted bulk acoustic waves, the full length coupler **5** may be utilized simply to separate the acoustic surface waves, which will be transferred to the track B, while the bulk acoustic waves, being comparatively unaffected by the coupler **5**, continue in the track A. Such couplers may also be used, in a similar way, to discriminate between different acoustic surface wave modes which may exist where the acoustic surface waves are propagated in a thin film of material on a substrate of different material.

FIG. **11** is a plan view of a broad-band acoustic surface wave track-changing coupler **79**, deposited on an acoustic surface wave substrate **77**. The track-changing coupler **79** consists of a plurality of J-shaped conductors, nesting inside each other in such a way that all the conductors are straight and parallel to one another at one end, defining a first acoustic surface wave track A, and all the conductors are straight and parallel to one another at the other end, defining a second acoustic surface wave B. The length of the track-changer in both acoustic surface wave tracks is L. The two acoustic surface wave tracks are parallel to one another, but because of the nesting configuration, the order of the conductors in one of the tracks is reversed with respect to their order in the other track. If the substrate **77** is made of anisotropic piezoelectric material, then it may be possible to arrange that the direction of the conductors in any other parts of the track-changing coupler **79** where the conductors happen to be parallel to one another is such that the direction perpendicular to those parts is a piezoelectrically inactive direction, so that no acoustic surface waves will be propagated in that direction.

The action of the track-changing coupler is as follows. Acoustic surface waves incident at the track-changing coupler **78** in the first acoustic surface wave track A cause electric fields to be set up between adjacent conductors. **[**Thses**]** *These* fields are transferred from the first acoustic surface wave A to the second acoustic surface wave track B. Since the order to the conductors in the two acoustic surface waves tracks is reversed, because of the configuration of the conductors constituting the track changer **79**, the acoustic surface wave launched in the second acoustic surface wave track B will travel in the opposite direction to the original acoustic surface wave in the first track A; thus the coupler **79** can be used to transfer energy from the track A to the track B, or vice versa.

FIG. **12** is a plan view of an alternative broad band acoustic surface wave track changing coupler, which incorporates an alternative arrangement for preventing the launching of acoustic surface waves by parts of the track changer between its ends. The substrate **77** is made of glass or some other elastic, non-piezoelectric material, on which the J-shaped conductors constituting the coupler **79** are deposited. A thin film **81** of piezoelectric material such as zinc oxide is sputtered or otherwise deposited over the conductors at one end of the track changer **79** where they cross the track A, and a thin film **83** of zinc oxide is sputtered or otherwise deposited over the conductors at the other end of the coupler **79** where they cross the track B. It is only at the regions covered by the piezoelectric thin films **81** and **83** that there is any coupling between acoustic surface waves and electric fields, so that acoustic surface waves are launched and detected only in these regions and other parts of the conductors of the coupler **79** act simply as electrical conductors.

FIG. **13** is a plan view of an acoustic surface wave resonator or recirculating delay line, incorporating two track-changing couplings hereinafter called track changers. The two track changers **85** and **87**, of the form described above with reference to FIG. **11** or FIG. **12**, are deposited on a substrate **89** in such a way that the two acoustic surface wave tracks C and D coupled by track changer **85** are the same as the two acoustic surface wave tracks coupled by the track changer **87**. A fractional multistrip coupling **84** is placed to couple the track C to another track E, on which there are two transducers **86** and **88**, placed on opposite sides of the coupler **84**.

The action of the device is as follows. The energy of acoustic surface waves launched by the transducer **86** is partially transferred to the track C by the coupler **84**. The acoustic surface waves thus propagated in the track C are coupled into the track D by the track changer **87**, and coupled into track C again by the track changer **85**. The device constitutes a resonator having a period equal to the combined delay of the path C and the path D, signals injected into the loop comprising the tracks C and D and track changers **85** and **87** may go round the loop several times or many times. Each time the signals pass the coupler **84** a fraction of their energy is transferred to the transducer **88** by the coupler **84**. It should be noted that it is the short length of the coupler **84** which makes the device a resonator. If it were replaced by a full length multistrip coupler, then the resonator would become a delay line in which all the energy of the waves launched by the conductor **86** would be injected into the track C by the coupler and would be wholly extracted by the coupler after one single circuit of the delay line.

FIG. **14** is a plan view of an acoustic surface wave delay line incorporating angled couplers. An acoustic surface wave substrate **91** has deposited on it three full-length angled couplers **93, 95** and **97** disposed at the corners of an equilateral triangle, and arranged so that each angled coupler will receive acoustic surface waves from one of the other angled couplers and will retransmit them in the direction of the third angled coupler. The connecting parts of the angled couplers **93, 95** and **97** are deposited over silica pads **94, 96** and **98** respectively to minimize the coupling between the substrate **91** and those parts of the couple **93, 95** and **97** which are not required to receive or launch acoustic surface waves. By itself this arrangement of couplers would constitute a triangular acoustic surface wave resonator, but a fourth angled coupler **99** is provided for launching acoustic surface waves into the delay line and extracting acoustic surface waves from the delay line. The angled coupler **99** is fed by a first interdigital comb transducer **101** and feeds a second interdigital comb transducer **103**.

The action of the device is as follows. Acoustic surface waves launched by the interdigital comb transducer **101** are [recieved] *received* by [th] *the* angled coupler **99** and hence launched in the triangular circuit. The acoustic surface waves are received by the angled coupler **93**, and thence propagated to the angled couplers **95** and **97** in turn. Acoustic surface waves launched by the angled coupler **97** are received again by the angled coupler **99** and launched in the direction of the interdigital comb transducer **103**. By this means a delay line having a delay equivalent to the total path length between the transducers **101** and **103** via the angled couplers **99, 93, 95, 97**, and **99** again respectively, is constituted. It is to be remarked that the coupler **99**, having a strong coupling because it is a full length multistrip coupler, acts to make the device a delay line. If it were replaced by a fractional length multistrip coupler then the delay line would become a resonator in which each signal injected could travel several times round the circuit.

By the use of such angled couplers, even longer folded delay lines can be arranged on reasonably small slices of material. FIG. **15** is a plan view of such a folded acoustic surface wave delay line. In this figure the angled couplers are not illustrated and only the folded acoustic surface wave path is shown, on a much smaller scale than the other diagrams. The path consists of a series of triangles each overlapping the adjacent one by a small amount, in order to achieve a long path length on a comparatively small substrate.

FIG. **16** is a plan view of a broad-hand acoustic surface wave unidirectional transducer. An interdigital comb transducer **105** and an acoustic surface wave coupler **109** are deposited on a piezoelectric substrate **107**. The coupler **109** consists of a plurality of U-shaped filamentary conductors, having long parallel portions at their extremities, all nesting together so that the coupler **109** itself is U-shaped. The interdigital comb transducer **105** is deposited between the arms of the U-shaped coupler **109** so that the long parallel portions of the conductors constituting the coupler **109** are equal in length and parallel to the fingers of the interdigital comb transducer **105**. The coupler **109** is so placed relative to the center line of the interdigital comb transducer **105** that acoustic surface waves propagated by the transducer **105** and travelling in opposite directions will arrive at the innermost edges of the innermost wire of the coupler **109** in a quadrature with each other. This can be arranged by placing the interdigital comb transducer **105** so that one of its fingers is centered on a line one-eighth of an acoustic surface wave length to one side of the axis of symmetry of the coupler **109**. The width of each side of the coupler **109** is the half-transfer length $L_{\frac{1}{2}}$, that is to say the coupler **109** is a folded half-length multistrip coupler.

The action of the device is as follows. The acoustic surface waves propagated by the transducer **105** in both directions reach the innermost wire of the coupler **109** with a quadrature phase relationship, so that the coupler **109** acts like the transducer **35** in FIG. **6**. Hence acoustic surface waves will be propagated from one straight portion only of the coupler **109**. Hence the transducer will be unidirectional, propagating signals only from the side of the U which receives the leading signal.

FIG. **17** is a plan view of an alternative broad-band acoustic surface wave unidirectional transducer. As in the transducer described above with reference to FIG. **16**, an interdigital comb transducer **105** and an acoustic surface wave coupler **111** are deposited on an acoustic surface wave substrate **107**. The coupler **111** consists of a plurality of elongated O-shaped conductors having long parallel portions on each side, all nesting inside each other, so that the coupler **111** itself is O-shaped. The transducer **105** is placed within the coupler **111** as the transducer **105** in FIG. **16** was placed between the arms of the coupler **109**.

This device acts similarly to the device of FIG. **16**, but each straight portion of a conductor of the coupler **111** is joined to a corresponding straight portion on the opposite side of the coupler **111** by two conductors instead of one. This provides current paths of lower resistance, and reduces the deleterious effect of any single unwanted break in any conductor. The disadvantage is that a greater length of conductor is required, and this puts a greater capacitive load on the coupler **111**.

Unidirectional transducers of the kind shown in FIG. **16** or FIG. **17** can advantageously be substituted for the simple interdigitated comb transducers shown in many of the devices herein described, for instance in place of the transducers **3, 23, 21** and **7** of the hybrid junction circuit of FIG. **8**.

FIG. **18** is a plan view of an acoustic surface wave reflector **113**, deposited on an acoustic surface wave substrate **115**. The reflector is a folded 3dB coupler, generally similar to the coupler **109** of FIG. **16** except that it has no gap between the two arms of the U.

The action of the reflector is as follows. It can be regarded as a half-length coupler (like the coupler **19** of FIG. **4**) bent back on itself. Acoustic surface waves incident on the half-length coupler **19** in the path A produce two acoustic surface wave outputs of equal amplitude, in a quadrature phase relationship. In the coupler **113**, these two waves will each be fed into the opposite arm of the U. The coupler is therefore effectively in a similar situation to the coupler of FIG. **5**; its two halves are receiving equal signals in quadrature with each other. Hence it propagates an output wave from one half only, and in the folded form of FIG. **18** it returns the output wave in the opposite direction to the incident wave. Thus it acts as an efficient reflector of acoustic surface waves.

FIG. **19** is a plan view of an alternative acoustic surface wave track changer. An acoustic surface wave substrate **119** has a line of symmetry S between two adjacent acoustic surface wave tracks A and B both of width b. A half-length multistrip coupler **117** is deposited across both tracks A and B, and two acoustic surface wave reflectors **121** and **122**, of the kind shown in FIG. **18**, are deposited in the tracks A and B respectively, both on the same side of the coupler **117**.

The action of the track changer of FIG. **19** is a combination of the effects described with **[**refernece**]** *reference* to FIG. **4**, FIG. **5** and FIG. **18**. When an acoustic surface wave signal reaches the coupler **117** in track A, the coupler **117**, acting like the coupler **19** of FIG. **4**, effectively splits the incident energy between two waves propagated from the output side of the two halves of the coupler **117**. The two reflectors **121** and **122** return these two waves to the two halves of the coupler **117**. The coupler **117** is now in a situation like the coupler **19** of FIG. **5**, receiving signals in quadrature, and therefore passes an output signal in the track which receives the leading signal. Thus the signal received by the track changer in track A is effectively returned in track B, and it can equally well act in the converse sense, taking any acoustic surface wave signal from track B and reflecting it in track A. In effect, it forms a track-changing reflector.

FIG. **20** is a plan view of another form of unidirectional acoustic surface wave transducer. An interdigital comb transducer **123** of ½b, formed on an acoustic surface wave substrate **124**, is coupled to an acoustic surface wave track A by a full length coupler **125**. The coupler **125** consists of a plurality of J-shaped transducers each having two straight mutually parallel arms of unequal length. These conductors are nested inside each other so that the coupler **125** is itself J-shaped. The shorter arm of the J runs parallel to the fingers of the transducer **123** but does not extend into the track A. The track A has width b and does not overlap the transducer **123**. The longer arm of the J runs across the whole of the track A at right angles. The transducer **123** is positioned so that acoustic surface waves launched by the transducer **123** in both directions will arrive at the innermost wire of the coupler **125** in phase with each other.

The coupler **125** is substantially equivalent to the basic coupler **5** of FIG. **1**, with its top half folded back on itself. Though the arrangement looks different, as far as the action of the coupler is concerned it is being stimulated in the same way as the coupler of FIG. **1**, and being a full-length coupler it transfers substantially all the input energy to the other side of its other half. Therefore it propagates the signals from its outer conductor, in track A only.

The coupler of FIG. **20** can equally well be used for receiving acoustic surface waves incident in the track A on the outermost conductor of the coupler **125**. The transducer **123** will not receive acoustic surface waves incident on the innermost wire of the coupler **125**. The unidirectional sensitivity of this arrangement makes it useful in many devices.

If the transducer **123** is omitted, then the coupler **125** will act as a reflector to acoustic surface waves incident on the outermost wire of the coupler **125** as the leading edge, but it will tend to split surface waves incident on the innermost wire of the coupler **125** at the leading edge into two waves propagating in opposite directions from the folded part of the coupler.

Preferably the arcuate portions of the coupler **125**, which do not intersect with the track A or with the track of acoustic surface waves launched or received by the transducer **123**, are connecting-portions as defined above.

FIG. **21** is a plan view of an acoustic surface wave tapped delay line. An acoustic surface wave substrate **126** carries an interdigital comb transducer **127** placed to launch acoustic surface waves on a track A of width b. The substrate **126** also carries a plurality of delay line taps comprising a plurality of couplers, of which one coupler **128** is illustrated. The coupler **128** is a modified form of the coupler **125** described above with reference to FIG. **20** with two significant differences, particularly appropriate for this application. Firstly, the coupler **128** is positioned to transfer some energy into an interdigital comb transducer **129** of width b (rather than ½b) which is positioned in an acoustic surface wave track B parallel and adjacent to the track A. Secondly, the coupler **128** is a fractional coupler. Preferably the portions of the coupler which do not intersect with either of the tracks A or B, are connecting-portions as defined above.

In the delay line of FIG. **21**, acoustic surface waves launched in the track A by the transducer **127** are received after different delays by various delay line taps such as the delay line tap comprising the coupler **128**. Each tap is only required to extract a small amount of energy in order to leave sufficient energy for extraction by subsequent taps. The coupler **128** can be regarded as a folded coupler which if unfolded would be equivalent to a coupler **128'** for coupling waves from a narrow track A into a track B', twice the width of track A. This is illustrated in FIG. **22**. Such a coupler could not be designed to obtain complete transfer of energy, but it should be remembered that delay line taps are not required to obtain complete transfer of energy. It is quite possible and useful to extract a signal say 20 dB lower than that launched by the transducer **127**. Signals from the whole of the wide track B' (FIG. **22**) are launched in phase with each other towards the transducer **129**, so that the transducer **129** will receive a signal 3dB higher than it would have received from a simple coupler of similar length as shown in FIG. **8**. The arrangement is also advantageous because it allows the required amount of energy to be extracted by a coupler having fewer conductors than a comparable simple coupler.

It is possible to extract more power from transducers such as the transducer **129** by tuning them in a known manner with a series inductor to provide a series resonant circuit, the transducer itself providing the capacity. This extra power extracted is at the expense of power normally not absorbed by the transducer, and not at the expense of power propagated down the delay line.

The delay line taps may be so shaped as to allow the transducers to be angled away from the wavefronts of acoustic surface waves travelling down **[**e**]** *the* delay line, like the angled delay line taps hereinbefore described with reference to FIG. **10**.

An important property of delay line taps such as the combination of the coupler **128** and the transducer **129** is that they are unidirectional and will only respond to acoustic surface waves travelling in one direction. This makes delay line taps of this form particularly useful in folded delay lines and similar devices where a signal or an unwanted reflection may return past a tap, for instance if it is required to add taps to the delay line hereinafter described with respect to FIG. **24**.

FIG. **23** is a plan view of an acoustic surface wave delay line incorporating means for suppressing triple transit signals. In a delay line which consists of a signal launcher, a delay medium and a signal receiver, most of the signal launched into the delay medium by the signal launcher will be absorbed by the signal receiver. However experience shows that a fraction of the signal incident on the signal receiver may be reflected and some of this reflected signal may reach the signal launcher. A fraction of the signal incident at the signal launcher may again be reflected and of this signal some may be received once more at the signal receiver. Since this signal will have traversed the delay medium three times it is known as a triple transit signal, and although its power level will be low compared with the original received signal, it may be high enough to form troublesome unwanted echo signals. In FIG. **23** an acoustic surface wave substrate **131** carries two parallel adjacent tracks A and B. An interdigital comb transducer **133** is arranged to launch acoustic surface waves in the track A. A 3 dB coupler **135** is positioned across both the tracks A and B in the path of acoustic surface waves launched by the transducer **133**. An acoustic surface wave absorber **137** is positioned in the track B on the same side of the coupler **135** as the transducer **133**. An interdigital comb transducer **139** is positioned at the end of the track A remote from the transducer **133**. An interdigital comb transducer **141** identical in all respects to the transducer **139** is positioned in the track B at exactly the same distance from the coupler **135** as the transducer **139**. The transducer **139** is electrically connected in series with an inductor L139 and a load resistor R139, and the transducer **141** is electrically connected in series with an inductor L141 which is identical to the inductor L139 and a dummy load resistor R141 which is identical to the load resistor R139.

The action of the device is as follows. Acoustic surface wave signals are launched in the track A by the transducer **133**. These signals are split equally between the track A and the track B, by the action of the 3 dB coupler **135**, and the output signal is taken from the load resistor R139. The 3 dB coupler **135** thus applies signals of equal amplitude but having a relative phase difference of $\pi/2$ radians, which will be incident at the transducers **139** and **141**, and as the transducers **139** and **141** are electrically identical to one another, any signal reflected by the transducer **139** in the track A will have an exact counterpart in a signal reflected by the transducer **141** in the track B. The signal in the track B will retain its $\frac{1}{2}\pi$ phase advance over the signal in the track A and so the action of the 3 dB coupler **135** on these two reflected signals will be to combine them and propagate them back along the track B, where they will be absorbed by the absorber **137**.

The transducers **139** and **141** may advantageously be unidirectional transducers, as hereinbefore described with reference to FIG. **16** or FIG. **17** or FIG. **21**. However, in any case, provided the transducers **139** and **141** are mechanically and electrically identical, all unwanted reflections will be propagated towards the absorber **137**.

FIG. **24** is a plan view of a reflecting acoustic surface wave delay line, which can be used to double the delay time available with a given length of acoustic surface wave substrate.

An acoustic surface wave substrate **151** carries two parallel adjacent tracks A and B. An interdigital comb transducer **153** is arranged to launch acoustic surface waves in the track A. An interdigital comb transducer **154** is positioned in the track B adjacent to the comb transducer **153**. The function of the transducer **154** is to extract the delayed acoustic surface wave. A 3dB coupler **155** is positioned across the track A and B close to the transducer **153** and the transducer **154**. A track changer **156** of the type hereinbefore described with reference to FIG. **19** is positioned across the track A and the track B at the end of the substrate **151** remote from the transducers **153** and **154**. An acoustic surface wave absorber **157** is positioned in the track B adjacent to the coupler **155** and on the side remote from the transducer **154**. A reflector **158** of the type hereinbefore described with reference to FIG. **18** is positioned in the track B adjacent to the absorber **157** and on the side remote from the transducer **154**.

The action of the device is as follows. Signals are launched in the track A by the action of the transducer **153**. By the action of the 3dB coupler **155** the signal energy is split to give rise to equal signals in the track A and the track B. Energy so launched in the track B is absorbed by the action of the absorber **157**. The signals in the track A are coupled into the track B by the action of the track changer **156** reflected by the action of the reflector **158**, coupled back into the track A by the action of the track changer **156** and propagated once more towards the coupler **155**. By the action of the coupler **155** the signal energy returning in track A is again divided between track A and track B, so that signal energy is received by the transducer **154**. Since the signal energy is halved twice, there is a 6dB loss inherent in this device. An alternative is to use a pair of unidirectional transducers and omit the coupler **155**. Unidirectional or bidirectional taps (not shown) can be placed in the track A if desired.

FIG. **25** is a plan view of an amplifying track changer, which may be regarded as an improvement on the track changer hereinbefore described with reference to FIG. **19**.

An acoustic surface wave substrate **161** carries two parallel adjacent tracks A and B. A 3dB coupler **163** is positioned on the substrate **161** across both the track A and the track B, and each track A and B has positioned on it a reflector comprising a unidirectional transducer of the kind hereinbefore described with reference to FIG. **16**. The reflector **165** on track A comprises a U-shaped acoustic surface wave coupler **171**, partially surrounding an interdigital comb transducer **169** which is electrically connected in series with a tuning inductor **173** and a negative resistance device **175**. The negative-resistance device may be a conventional device having a negative-resistance operating characteristic, for instance a tunnel diode circuit. The reflector **167** in track B is similarly constructed and connected. The reflectors **165** and **167** are equidistant from the coupler **163**. The negative resistance devices and tuning inductors are identical.

The action of the amplifying track changer clearly follows similarly to the action of the simple track changer hereinbefore described with respect to FIG. **19**, except that the transducers and the negative-resistance devices connected to them amplify the reflected signals.

FIG. **26** is a plan view of a directional filter. Directional filters are known in the microwave art and are a form of resonator. A known form of microwave directional filter is constructed as follows. A microwave source is connected to a first matched load via a first directional coupler. The first directional coupler is connected to a second directional coupler via a circulating cavity. The second directional coupler couples into a waveguide which feeds a second matched load. Assuming that the source has a broad band output, the frequency spectrum of the output of the first matched load has a series of notches spaced apart by frequency differences dependent on the phase shift in the circulating cavity, because these frequencies are the most strongly accepted by the circulating cavity. They appear as spikes in the frequency spectrum of the output of the second matched load. The width of the notches and the spikes is determined by losses in the circulating cavity and in the two directional couplers. FIG. **26** shows a plan view of an analogous acoustic-surface-wave device.

In FIG. **26** a substrate **181** carries four parallel adjacent tracks A, B, C, D in that order. An interdigital comb transducer **183** is positioned to launch acoustic surface waves in the track A. A coupler **185** is placed across the tracks A and B, so that some of the energy launched by the transducer **183** is propagated along the track B. The remainder of the energy propagated along the track A is incident on an interdigital comb transducer **187**. The tracks B and C have reflecting track changers **189**, **191** at either end, whereby energy in the track B is transferred by the track changer **191** to the track C, and energy in the track C is transferred by the track changer **189** to the track B. A further coupler **193** is placed across the tracks C and C adjacent to the coupler **185**, whereby some of the energy in the track C is launched into the track D. An interdigital comb transducer **195** is positioned to receive energy so launched into the track D.

The action of the device is as follows. The tracks B and C together with the reflecting track changers **189** and **191** constitute a resonator wherein the acoustic surface waves can circulate, and energy is coupled into and out of this resonator by means of the couplers **185** and **193** respectively. The resonator will have a series of resonant frequencies determined by the phase delay in a complete circuit of tracks B **[**an**]** *and* C; these resonant frequencies will build up in the resonator much more than any other frequencies introduced to it, and so the output of the coupler **193**, extracted by the transducer **195**, will have a frequency spectrum which has a series of spikes at the resonator frequencies. The output of the transducer **187** will be the remainder of the output of the transducer **183**, and hence its frequency spectrum will have a series of notches at the resonant frequencies.

The degree of coupling into and out of the circulating cavity is adjusted at the design stage by adjusting the lengths of the couplers **185** and **193** to satisfy the coupling condition desired.

FIG. **27** is a plan view of a variable directional coupler device. An acoustic surface wave substrate **201** carries two parallel adjacent tracks A and B. Two transducers **203** and **205** are placed adjacent to each other at one end of the substrate **201**, with the transducer **203** on track A and transducer **205** on track B. Two more transducers **213** and **215** are placed at the opposite end of the substrate, the transducer **213** in track A and the transducer **215** in track B. Two multistrip couplers **207** and **209** are placed across both tracks A and B, and a region **211** of controllable acoustic velocity is formed over a part of track A between the couplers **207** and **209**. The region **211** may for instance be a region incorporating material having electrically or magnetically controllable piezoelectric or electrostrictive characteristics, in which the velocity of acoustic surface waves can be adjusted by varying a biassing electrical or magnetic field, or other convenient external control.

The action of the variable coupler device is as follows. The region **211** can apply a controllable phase delay to acoustic surface wave signals in the track A relative to signals in the track B between the coupler **207** and the coupler **209**. If both the couplers **207** and **209** are 3dB couplers, and the region **211** is inactive then all the power launched into the track A by the transducer **203** will be fed to the transducer **215** and all power launched in the track B by the transducer **205** will be fed to the transducer **213**. By introducing a phase shift of π radians in the track A by a control of the region **211**, all the power launched into the track B by the transducer **205** will be fed to the transducer **215** in track B. Phase shifts of less than π in the region **211** will produce an intermediate directional coupler action.

Antisymmetric modes and symmetric modes have been mentioned with reference to FIG. **1**. Since the next few devices to be described concern these modes and the action of modes under an array of filamentary conductors, it is appropriate to return to this aspect of the operation of such devices. FIG. **28** is a circuit diagram of a transducer arrangement for producing acoustic surface waves either in a purely symmetric mode or in a purely antisymmetric mode. This comprises two identical interdigital comb transducers **216**, **217** placed end to end so as to propagate acoustic surface waves along adjacent parallel tracks. The transducer **216** is connected directly across electrical signal connection terminals **218**. The transducer **217** is connected to the terminals **218** through a **[**reversihg**]** *reversing* switch **219**. Although the switch **219** is represented conventionally, in practice it is preferably an electronic switch and may be formed as an integrated circuit.

With the switch **219** in the position shown, a signal applied to the terminals **218** will excite both transducers identically, launching a symmetric mode signal. With the switch in the opposite position the transducer **217** is excited in antiphase to the transducer **216**, launching an antisymmetric wave along the pair of adjacent parallel tracks.

FIG. **29** shows an alternative arrangement for launching antisymmetric mode acoustic surface waves, by a pair of identical comb transducers **220**, **221** deposited end to end on a substrate **[222]** *151* so as to launch acoustic surface waves along adjacent parallel tracks. In this arrangement the connections of the interdigitated combs ensure that a signal applied to the pair of transducers will excite acoustic surface waves in antiphase relationship with each other, in other words forming an antisymmetric mode signal. The line AD2 forms a graphical representation of the amplitude of the asymmetric mode signal across the pair of adjacent parallel tracks. FIG. **29** also shows an array of spaced filamentary conductors **223** deposited over the path of the antisymmetric mode signals, aligned orthogonally to the direction of propagation.

It is possible to choose the material of the filamentary conductors and their dimensions so that symmetric mode signals will travel under the array at the same velocity as they travel along a clear part of the surface of the substrate [222] *151*. This is achieved by arranging that the short-circuiting effects of the width of each filamentary conductor on the piezoelectric fields in the direction of propagation is compensated for by mass loading effects. However, the antisymmetric mode signals will always travel more slowly since they cause currents to flow along the filamentary conductors, across the width of the track, and the conductivity of the conductors in this direction significantly reduces the effective piezoelectric stiffness of the material, slowing the antisymmetric mode signals.

FIGS. **30** and **31** are diagrams of an antisymmetric mode signal beam-splitter device comprising a plurality of parallel filamentary conductors **224**, designed to have the velocity-matching adjustment mentioned hereinabove. The leading conductor is the longest and each successive wire is slightly shorter at both ends so that the profile of the beam splitter is an isoceles triangle placed symmetrically on the acoustic surface wave track. When this structure is fed with an antisymmetric mode signal, parts of the acoustic surface waves travelling in material under the structure travel more slowly than parts of the acoustic surface waves travelling in material not under the structure. Hence the effect of the structure is to refract the acoustic surface waves in two beams away from the original direction of propagation of the acoustic surface waves; this is illustrated in FIG. **30**. On the other hand, when symmetric waves are fed to the structure, no velocity change takes place, and hence the acoustic surface waves do not change direction. This is illustrated in FIG. **31**. The line AD2 in FIG. **30** is a graphical representation of the amplitude of the applied antisymmetric waves. The line AD1 in FIG. **31** is a corresponding graphical representation of the amplitude of the applied symmetric mode waves. In this beam-splitter device, the path of the acoustic surface waves is not wholly determined by the layout of the acoustic surface wave components on the surface of the substrate, but is also controlled electronically by the feed to the transducer or pair of transducers from which the acoustic surface waves are launched.

Unfortunately any structure which introduces a velocity discontinuity is likely to cause reflections of acoustic surface waves, which may cause spurious signals. Spurious signals may for example, occur due to reflections from the ends of couplers or similar acoustic waveguide structures. FIG. **32** and FIG. **33** are plan views of coupler matching portions intended to reduce spurious reflections.

In FIG. **32** the leading conductor **225** of a coupler or waveguide array **223** is V-shaped and is symmetrical about the line of symmetry between the two coupled acoustic surface wave tracks. The angle θ which the arms of the V make with a line perpendicular to the direction of propagation of acoustic surface waves is given by the formula tan $\theta=\lambda/$[w] *W* where λ is the wavelength in the substrate of acoustic surface waves and [w] *W* is half the width of the coupler. Subsequent conductors are also V shaped but with angles successively decreasing to zero. The distance d between the apices of the V's may be the same as the mean distance between the conductors in the main part of coupler.

The action of the coupler is as follows. The first conductor **225** will not couple significantly to the wave. Subsequent V shaped conductors couple progressively more strongly as the angle θ becomes [smallr] *smaller* until when $\theta=0$ the conductors become straight. The coupling strength of the conductors near the leading edge of the coupler is thus smoothly tapered to zero. If a sufficient number of intermediate V-shaped conductors is used, between the first conductor **225** and the first straight conductor **226**, then an acceptably small spurious echo signal should result. A similar pattern may be used at the trailing edge of the coupler.

In FIG. **33** the conductors near the leading edge of the coupler are progressively shortened while still remaining symmetric about the line of symmetry between the two coupled acoustic surface wave tracks. Consider one of these shortened conductors. It will be shorter in length than one of its neighbours by a small step at each end. Each step gives a reflection equal to a fraction of the reflection to be expected from a comparable unstepped simple coupler. The reflected acoustic surface wave is the vectorial resultant of the small reflections. It is possible to design the steps so that at a desired frequency (or frequencies) below the stop band frequency, the resultant of the reflections is minimized.

In general the steps will be arranged symmetrically, half the length of the shortest conductor being the same length as the step between each end of the longest conductor and its neighbour, and so on. Thus for a three step transition, (not shown) on each side of the coupler the lengths of the steps will be given by x, y, and x respectively where

$$2x+y=\tfrac{1}{2}w,$$

where w is the width of the coupler. For a four step transition (as shown in FIG. **33**) the lengths of the steps in each of the two tracks will be given by p, q, q, and p respectively, where

$$2p+2q=\tfrac{1}{2}w.$$

A third method of reducing the reflection from a coupler is to adjust the width and position of a sufficient number of conductors at each end of the coupler. Each conductor of the coupler may be regarded as a separate reflecting element, and by adjusting their positions and widths it is possible to adjust the relative phases and amplitudes of the reflections from each of the conductors so that their vectorial resultant is sufficiently small over the required bandwidth.

FIG. **34** is a perspective view of a light-controlled acoustic surface wave coupler. Three transducers **227**, **229**, **239** and a multistrip coupler **233** are deposited on an acoustic surface wave substrate **231** as in the device of FIG. **4**, but the coupler **233** is a full-length multistrip coupler and is extended onto a part **235** of the substrate **231** beyond the acoustic surface wave track B. Photoconducting material **237** is deposited by evaporation or otherwise on the part **235** of the substrate **231** either before or after the coupler **233** is deposited.

The action of the device is as follows, if the photoconducting strip **237** is not illuminated then the coupler **233** acts in a similar way to the coupler **5** described above with reference to FIG. **1**. However, if the photoconducting strip is illuminated then the conductors in the coupler **233** are short-circuited to each other and their coupling action is thereby inhibited so that some of the acoustic surface wave energy from the transducer **227** is received by the transducer **229**. By this means the amount of energy received by the transducer **229** can be controlled by the luminous flux incident on the strip **237** and the energy output of the transducer **229** can be used to measure the luminous flux incident on the strip **237**.

FIG. **35** is a plan view of an electrically-controlled acoustic surface wave coupler device. This differs from the device of FIG. **34** in that the photoconducting strip **237** is replaced by an electrical control device **241**. The electrical control device **241** may consist of (for example) a plurality of P-I-N diodes, or a plurality of bipolar or field effect transistors; it must be able to connect the conductors in the coupler **233** together electrically under the control of an electric signal.

FIG. **36** is a circuit diagram of one possible form for the control [devide] *device* **241**, and FIG. **37** is a perspective view of an integrated circuit form for the device of which FIG. **36** is a circuit diagram. The individual conductors **243, 245, 247**, . . . , **249** in the coupler **233** are separately connected to the source electrodes of a plurality of MOS transistors **251, 253, 255**, . . . , **257** respectively. The MOS transistors **251, 253, 255**, . . . , **257** have their drain electrodes connected together to a ground return connection and their gate electrodes connected together to a terminal **259**. By this means a suitable voltage on the terminal **259** can control the transistors and effectively connect all the conductors of the coupler **233** together and to ground.

The physical arrangement of the device **241** shown in FIG. **37** has all the conductors **243, 245, 247**, . . . , **249** deposited on an insulating layer **260** on a semiconducting substrate [**261**] and each conductor such as **243** making contact with a separate highly doped portion such as **263** of the substrate [**261**]. A single grounded conducting electrode **265** makes contact with a highly doped portion **267** of the substrate [**261**]. A film **269** of insulating oxide is deposited over the ends of the conductors **243, 245, 247**, . . . , **249** the edge of the electrode **265** and the interstitial space and a metal strip electrode **271** is deposited over the film **269**.

The action of the device is that of a conventional MOS transistor. A control voltage of the correct polarity on the metal strip electrode **271** makes a low impedance connection between the conductors **243, 245, 247**, . . . , **249** and the grounded electrode [**261**] *265*, grounding them and so preventing coupler action.

FIG. **38** is a plan view and FIG. **39** is a circuit diagram of an alternative electrically-controlled acoustic surface wave coupler device. This differs from the device of FIG. **35** only in that the substrate **231** has a part **273** adjacent and parallel to the acoustic surface wave track A on the side remote from the acoustic surface wave track B, and the parts **273** and **235** contain a plurality of variable-capacitance diodes, each conductor in the coupler **233** being connected between a variable-capacitance diode in the part **235** and a variable-capacitance diode in the part **273** connected in the same direction, the terminals of the variable-capacitance diodes in the part **235** remote from the coupler **233** being connected to a common terminal **275** and the terminals of the variable capacitance diodes in the part **273** remote from the coupler **233** being connected to a common terminal **277**.

The action of the device is as follows. By applying and varying a voltage between the terminal **275** and the terminal **277** the capacitances between the conductors in the coupler **233** and the terminals **275** and **277** may be varied, and hence the capacitances between the conductors in the coupler **233** themselves. This change in capacitance between the conductors necessarily changes the coupling between them whereby the proportion of energy received by the transducers **229** and **239** is varied in a controllable manner.

I claim:

1. An acoustic surface wave device which comprises *a single substrate having* at least a first track and a second track, said tracks being *located at spaced areas of said substrate each of which areas is* formed of a material able to support acoustic surface waves and having first and second piezoelectric regions respectively across both said first and second tracks, means for launching surface acoustic waves along the first track, and means for receiving and detecting acoustic surface wave energy travelling along the second track, said device further comprising acoustic surface wave coupling means *on said substrate* extending between said tracks and having a first part disposed across said first track and a second part disposed across said second track, said first and second parts of said coupling means comprising a plurality of spaced filamentary electrical conductors *all of which are electrically insulated from one another and* each of which extends in length over the first region and thence without interruption over the second region, those parts of said filamentary conductors which extend across said first region being substantially parallel to another and being oriented substantially orthogonal to the direction of energy travel along said first track, and those parts of said filamentary conductors which extend across said second region being substantially parallel to one another and being oriented substantially orthogonal to the direction of energy travel along said second track, said coupling means being operative to transfer energy between said first and second tracks by transduction whereby energy in said first track comprising at least some of the acoustic surface wave energy traveling in the [travck] *track* is intercepted and converted into electrical energy induced between said conductors by said first part of the coupling means extending across the first track, is then transferred toward said second track along the filamentary electrical conductors of the coupling means as said electrical energy is then converted back to surface acoustic wave energy and relaunched as surface acoustic surface wave energy *traveling substantially in a single direction only* in the second track by said second part of the coupler means extending across the second track.

2. An acoustic surface wave device as claimed in claim **1**, wherein the said material is a piezo-electric material.

3. An acoustic surface wave device as claimed in claim **1**, wherein the said material is an electro-strictive material and the said coupling means also comprises means for applying a biassing electric field to the material under the filamentary conductors in the first region and in the second region.

4. An acoustic surface wave device as claimed in claim **1**, wherein the filamentary conductors are connected to form closed loop circuits, and the coupling means also comprises means for maintaining a magnetic field orthogonal to the filamentary conductors over the first region and means for maintaining a magnetic field orthogonal to the filamentary conductors over the second region.

5. An acoustic surface wave device as claimed in claim **1**, wherein said material is a magneto-strictive material which does not shortcircuit the said alternating electric signals, the filamentary conductors are connected to form closed loop circuits, and the coupling means also comprises means for applying a biassing magnetic field to the material in the first region and means for applying a biassing magnetic field to the material in the second region.

[6. An acoustic surface wave device as claimed in claim **1** formed on a surface of suitable material, and the said first region and the said second region are different areas of the surface.]

7. An acoustic surface wave device as claimed in claim **1** formed on a non-piezoelectric substrate able to support acoustic surface waves, having piezo-electric material deposited to form the said first region and the said second region.

8. An acoustic surface wave device as claimed in claim **1** wherein parts of the said filamentary conductors not over the first region and not over the second region are formed over a material which attenuates or does not support acoustic surface waves.

9. An acoustic surface wave device as claimed in claim **1**, wherein the parts of the filamentary conductors over the second region are curved so as to form convergent acoustic surface waves in the second track.

10. An acoustic surface wave device as claimed in claim **1**, constructed so that acoustic surface waves propagated from one half of the width of the first transducer means will reach the coupling means a quarter of a period in advance of the acoustic surface waves propagated from the other half of the width of the first transducer means.

11. An acoustic surface wave device as claimed in claim **1**, wherein each filamentary conductor has two substantially equal parts, of which one part is a quarter of an acoustic wavelength nearer to the first transducer means than the other part.

12. An acoustic surface wave device as claimed in claim **1**, also comprising a third transducer means disposed to launch acoustic surface waves in the second track towards the coupling means, and a fourth transducer means disposed to receive and detect acoustic surface waves propagated from the coupling means in the first track, constructed so that signals launched in phase with each other from the first transducer means and the third transducer means will reach the coupling means in a quadrature phase relationship, and the device will therefore act as a hybrid junction circuit.

13. An acoustic surface wave device as claimed in claim **12**, wherein each filamentary coupler has a quarter-wavelength step substantially at its center, effectively advancing one half of the coupling means by a quarter-wavelength in one track, relative to the other half of the coupling means in the other track.

14. An acoustic surface wave device as claimed in claim **1**, forming a tapped delay line, comprising a plurality of fractional coupling means extending across successive parts of the first track, and a plurality of transducer means disposed in the second track, comprising one transducer means disposed between each fractional coupling means and the next fractional coupling means.

15. An acoustic surface wave device forming a tapped delay line as claimed in claim **14**, having a plurality of deposits of acoustic surface wave attenuating material disposed in the second track between each transducer means and the next fractional coupling means.

16. An acoustic surface wave device forming a tapped delay line as claimed in claim **14**, wherein each of the fractional coupling means has its part in its second track disposed at an angle to its part in the first track, so that each fractional coupling means will transfer signals into a distinct track.

17. An acoustic surface wave device comprising a plurality of coupling means as claimed in claim **1**, disposed to direct acoustic surface wave signals around a circuit of acoustic surface wave tracks, and at least one additional coupling means for coupling signals in the circuit to a separate track, and an input transducer means and an output transducer means disposed in the said separate track.

18. An acoustic surface wave device, as claimed in claim **1**, forming a unidirectional transducer means wherein the said first region and the said second region lie in a common acoustic surface wave track and a transducer means is disposed between the first region and the second region so that signals propagated from the transducer means in opposite directions will reach the coupler means in a quadrature phase relationship with each other.

19. An acoustic surface wave device as claimed in claim **18**, wherein the filamentary conductors are U-shaped.

20. An acoustic surface wave device as claimed in claim **18**, wherein each filamentary conductor is a separate elongated O shape.

21. An acoustic surface wave device as claimed in claim **1**, forming a reflector for acoustic surface waves, wherein the said first region and the said second region lie in a common acoustic surface wave track and the coupling means is a 3dB coupler as hereinbefore defined.

22. An acoustic surface wave device forming a track changer, comprising a coupling means as claimed in claim **1** wherein the coupling means is a 3dB coupler as hereinbefore defined, and two reflectors are provided on one side of the 3DB coupler, one of the reflectors being disposed in the first track and the other being disposed in the second track.

23. An acoustic surface wave device as claimed in claim **1**, forming a unidirectional transducer means, wherein the filamentary conductors are separate J shapes, the said first region comprises two equal parts in a common acoustic wave track, and a transducer means is disposed between the two equal parts of the first region so that acoustic surface wave signals propagated from the transducer means in opposite directions will reach the two equal parts of the first region in phase with each other.

24. An acoustic surface wave device as claimed in claim **1**, forming a tapped delay line and comprising a plurality of unidirectional transducers wherein the coupling means are fractional coupling means as hereinbefore defined and the long ends of the J-shaped filamentary conductors extend over successive parts of the delay line track.

25. An acoustic surface wave device as claimed in claim **1**, wherein the coupling means is a 3db coupler as hereinbefore defined, a third transducer means identical to the second transducer means is provided to receive acoustic surface wave signals passed by the coupling means in the first track, the second and the third transducer means are connected to equivalent circuits, and acoustic surface wave absorbing material is deposited in the part of the second track on the opposite side of the coupling means from the second and third transducer means.

26. An acoustic surface wave delay line device including a track changer as claimed in claim **23** and a reflector.

27. An acoustic surface wave device, forming an amplifying track changer, as claimed in claim **1**, wherein the coupling means is a 3dB coupler as hereinbefore defined, the second transducer means is a unidirectional transducer, an identical unidirectional transducer is disposed to receive acoustic surface wave signals passed by the coupling means in the first track, and the transducer means of both unidirectional transducers are connected to similar negative-resistance amplifying circuits.

28. An acoustic surface wave device for use as a directional filter comprising a plurality of transducer means as claimed in claim **1**, disposed to direct acoustic surface wave signals around a circuit of acoustic surface wave tracks, a plurality of additional coupling means extending over separate parts of the circuit, an input transducer means for launching acoustic surface wave signals towards one of the additional coupling means, and at least one output transducer means disposed for receiving acoustic surface wave signals from one of the additional coupling means.

29. An acoustic surface wave device as claimed in claim **1** wherein there are two separate coupling means each extending over the first track and the second track, and a region of controllable acoustic velocity is formed in one of the tracks between the two separate coupling means.

30. An acoustic surface wave device as claimed in claim **1** wherein successive filamentary conductors of the coupling means are of linearly decreasing length, for beam-splitting antisymmetric mode signals.

31. An acoustic surface wave device as claimed in claim **1**, wherein the leading filamentary conductors of the coupling means are V-shaped with angles which are successively increased towards 180°.

32. An acoustic surface wave device as claimed in claim **1**, wherein the leading filamentary transducers of the coupling means increase monotonically in length.

33. An acoustic surface wave device as claimed in claim **1**, wherein the filamentary conductors of the coupling means also extend over a region of controllable electrical impedance.

34. An acoustic surface wave device as claimed in claim **34**; wherein the said region of controllable electrical impedance is formed of a photoconductive material.

35. An acoustic surface wave device as claimed in claim **1**, wherein the filamentary transducers of the coupling means are electrically connected to an array of field effect transistors.

36. An acoustic surface wave device as claimed in claim **1**, wherein two arrays of diodes are connected to opposite ends of the filamentary transducers, thereby forming a plurality of connections each comprising two diodes connected in series by a filamentary conductor of the coupling means.

37. An acoustic surface wave device as claimed in claim 1 wherein the filamentary conductors in said first and second regions are spaced apart by equal amounts.

38. An acoustic surface wave device as claimed in claim 1 wherein the filamentary conductors in said first and second regions are spaced apart by randomly varying amounts.

39. An acoustic surface wave device as claimed in claim 1 wherein the filamentary conductors in said first and second regions are spaced apart by regularly varying amounts.

40. An acoustic surface wave device as claimed in claim 1 wherein the filamentary transducers in said first and second regions are spaced apart by monotonically varied amounts.

41. An acoustic surface wave device as claimed in claim 1 wherein said first and second tracks are formed on a flat surface of a piezo electric substrate, said means for launching surface acoustic waves along the first track comprising an input interdigital transducer for launching surface waves along the first track on said surface, said means for receiving and detecting acoustic surface wave energy traveling along the second track comprising an output interdigital transducer on said surface located to receive surface waves from said second track, said second track being separate from and parallel to said first track, said coupling means comprising a plurality of electrically separate filamentary conductors each of which is arranged with one end portion thereof orthogonally across said first track and another end portion thereof orthogonally across said second track, said conductors being spaced uniformly and parallel to one another at their said end portions.

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