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Mohwinkel

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[54] **MINIATURE ACTIVE CONVERSION BETWEEN MICROSTRIP AND COPLANAR WAVE GUIDE**

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[73] Assignee: **Endgate Corporation**, Sunnyvale, Calif.

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Related U.S. Patent Documents

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Filed: **Jun. 12, 1995**

[51] **Int. Cl.**^{6} **H01P 5/08**

[52] **U.S. Cl.** **333/33**; 333/247

[58] **Field of Search** 333/33, 246, 247, 333/32; 257/664, 728, 778; 330/307

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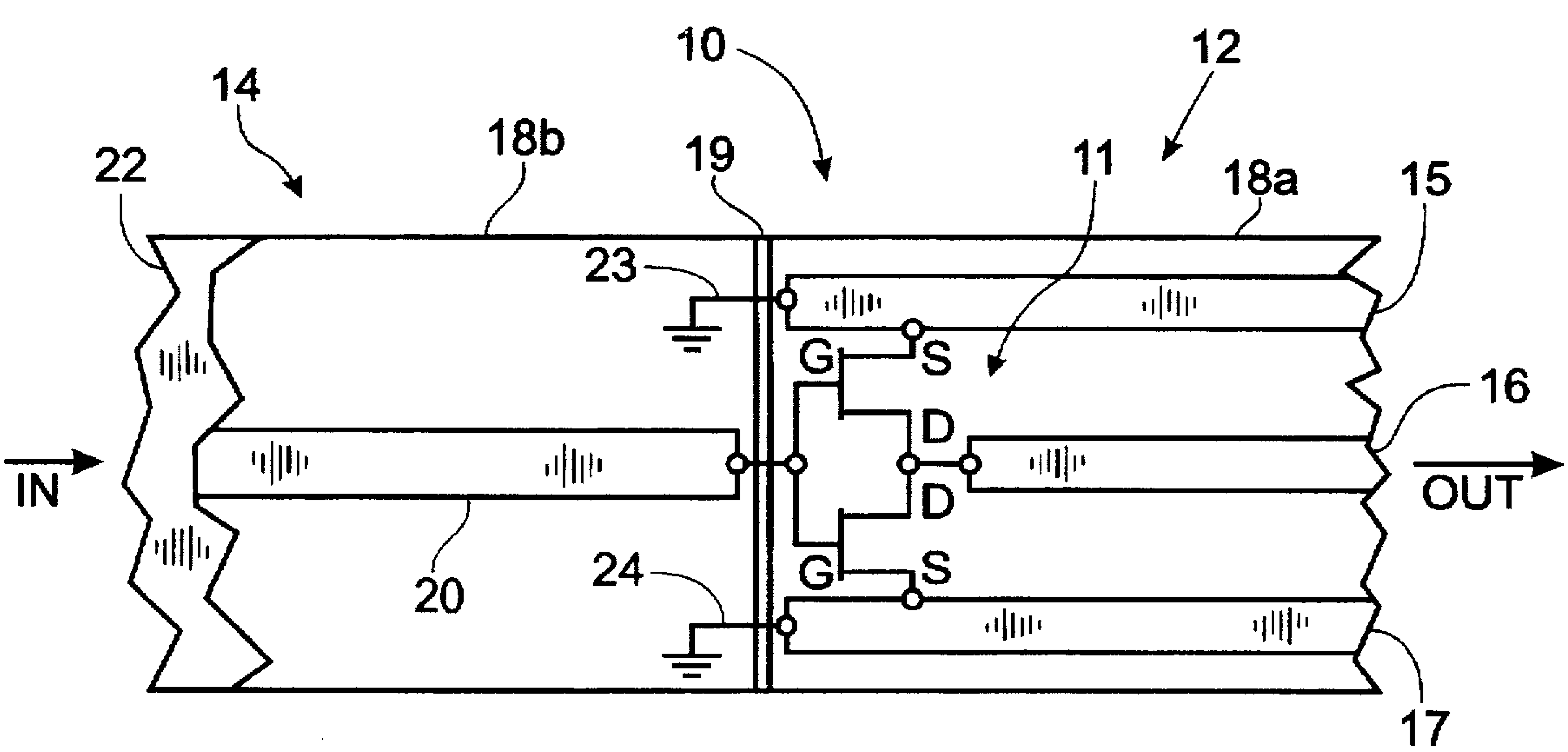
Attorney, Agent, or Firm—Edward B. Anderson

[57] **ABSTRACT**

An active device, such as a field effect transistor ("FET") or MMIC, converts microwave signals between a microstrip transmission line ("microstrip") and a coplanar wave guide ("CPW"). In microstrip-to-CPW conversion using a simple FET, a gate connection is made to the microstrip signal conductor. A drain connection is made to the center conductor on the CPW. Two FET source terminals are connected respectively to each CPW ground strip. The ground strips are electrically coupled to the microstrip ground plane with a minimum length connection so the inductance common to the FET input and output is minimized. The FET can be reconnected so as to reverse the input and output, providing for conversion of signals from CPW to microstrip. Conversion from microstrip to an intermediate CPW and back to microstrip provides for mounting an intermediate circuit, such as an amplifier or other MMIC, directly on the CPW.

18 Claims, 5 Drawing Sheets



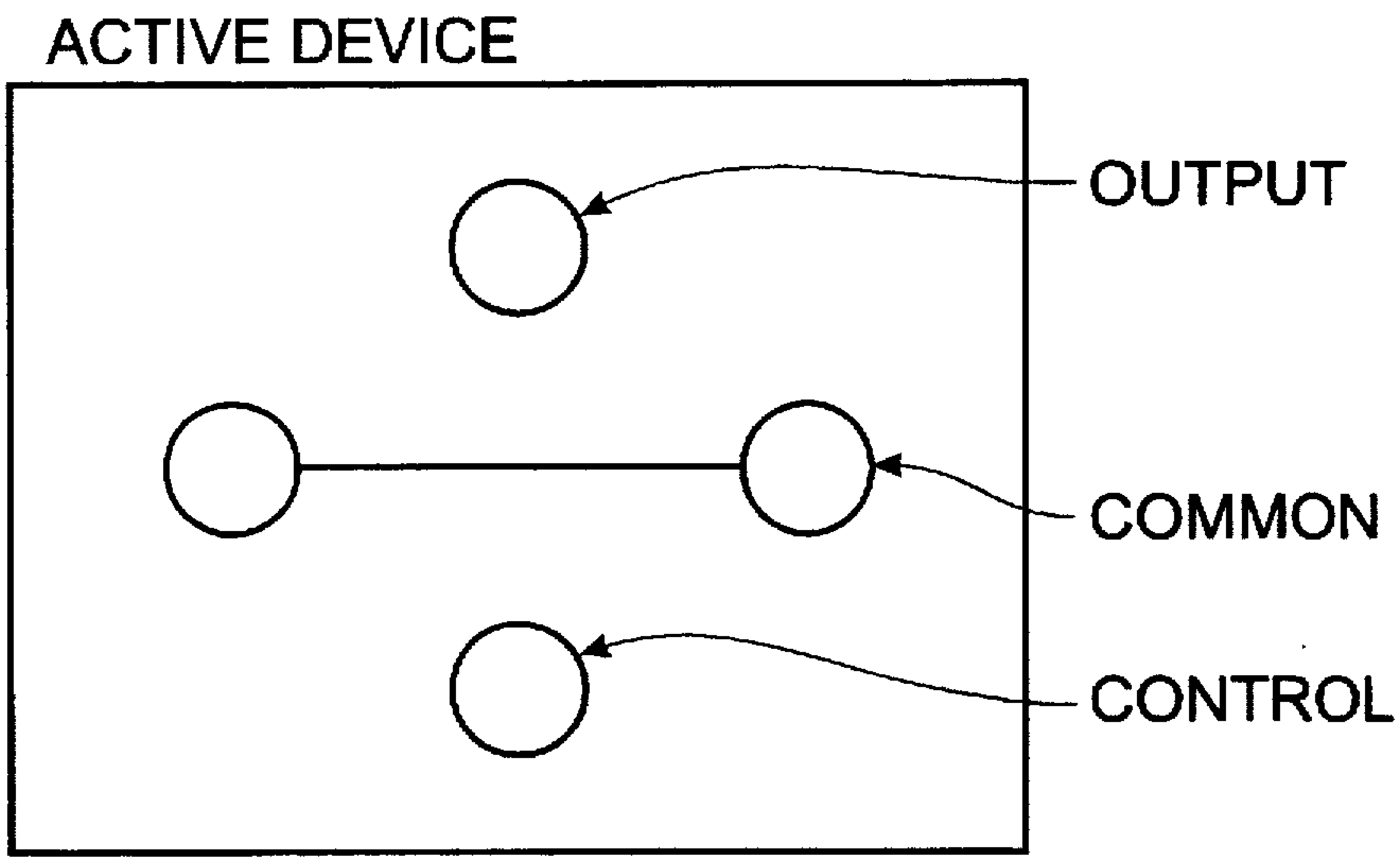


Fig. 1

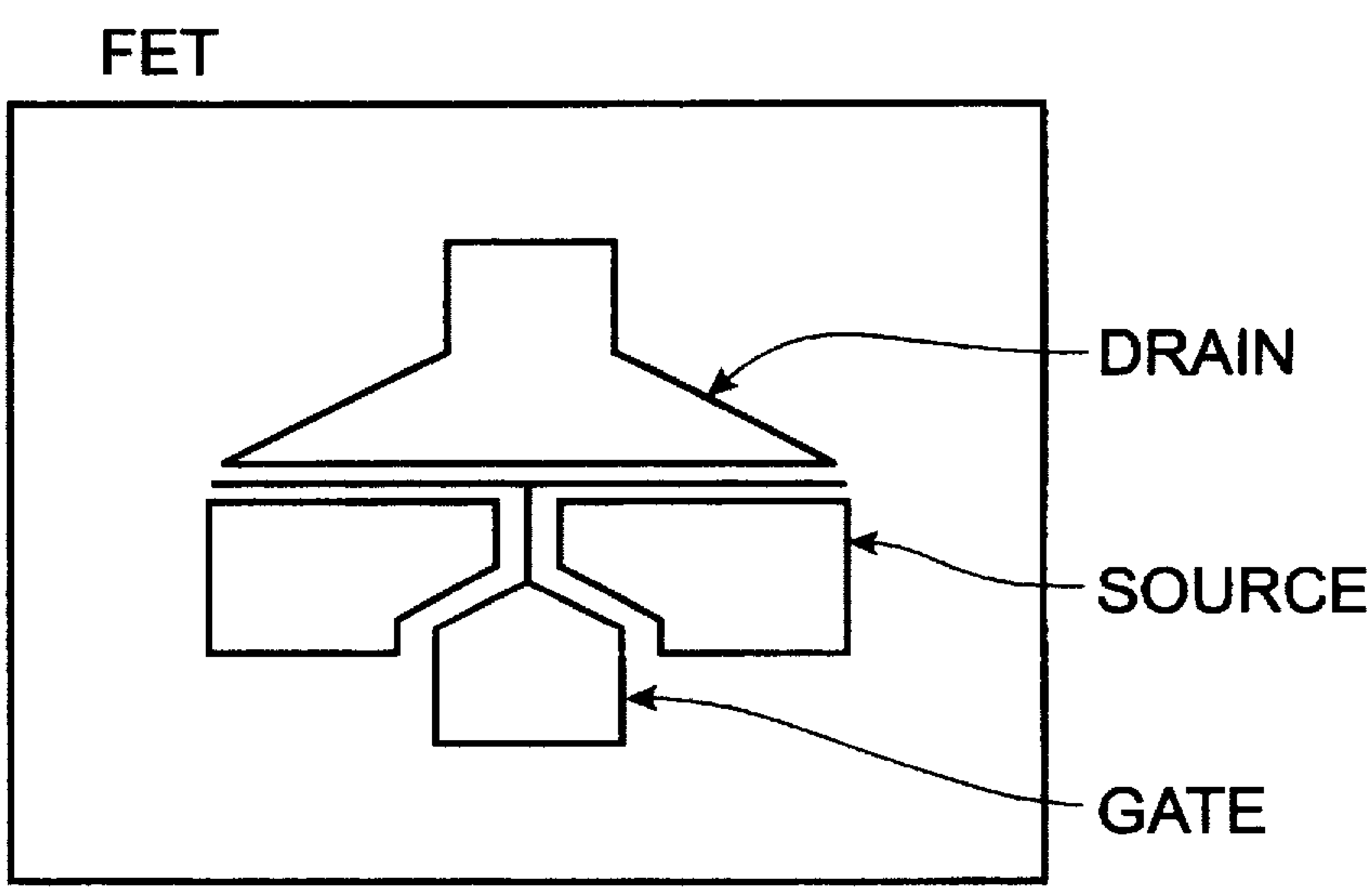
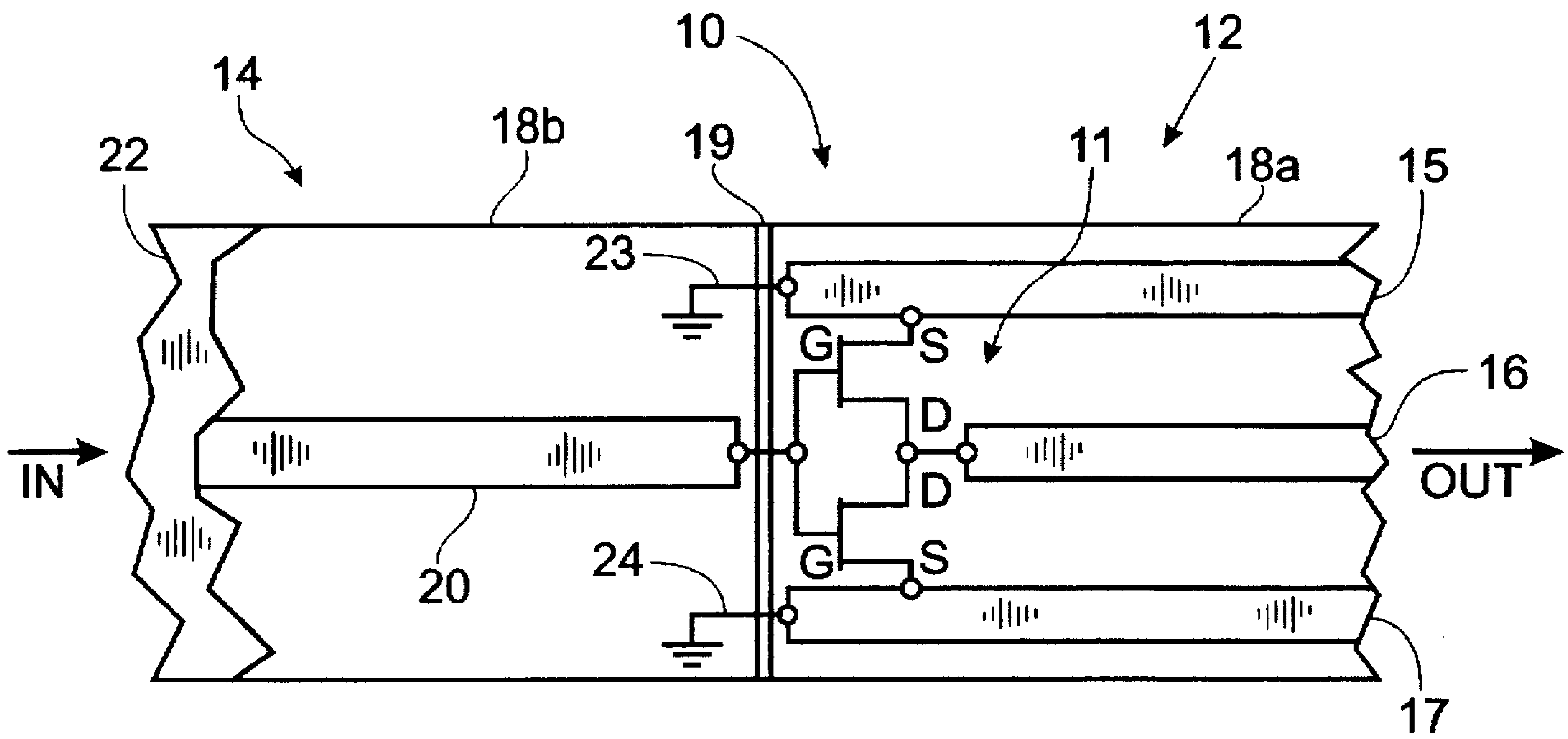


Fig. 2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12
14
18b
19
11
18a
15
22
23
G
S
D
16
IN
OUT
D
24
G
S
20
17

Fig. 3

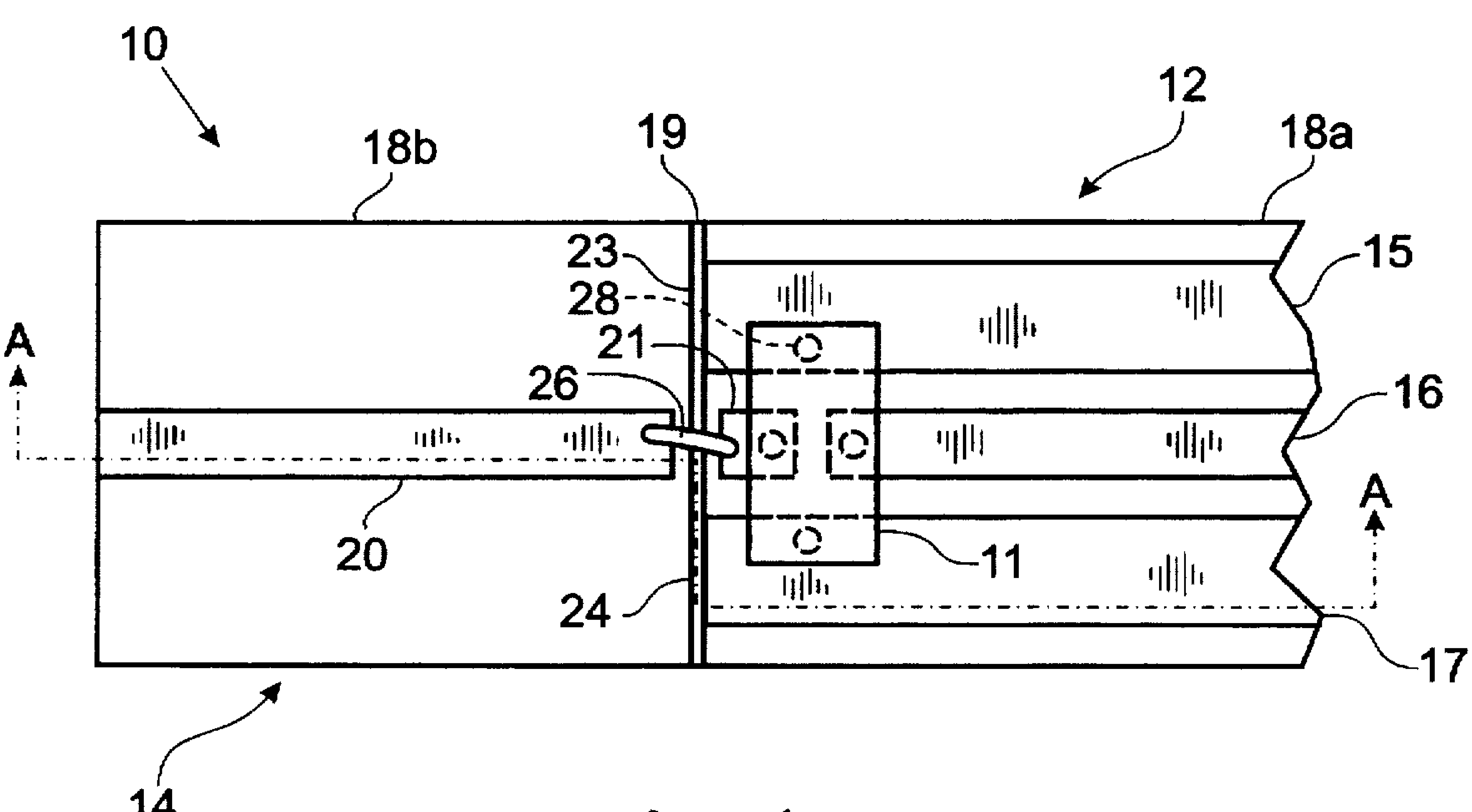

10
12
18b
19
18a
23
15
28
21
A
26
16
20
11
A
24
17
14

Fig. 4

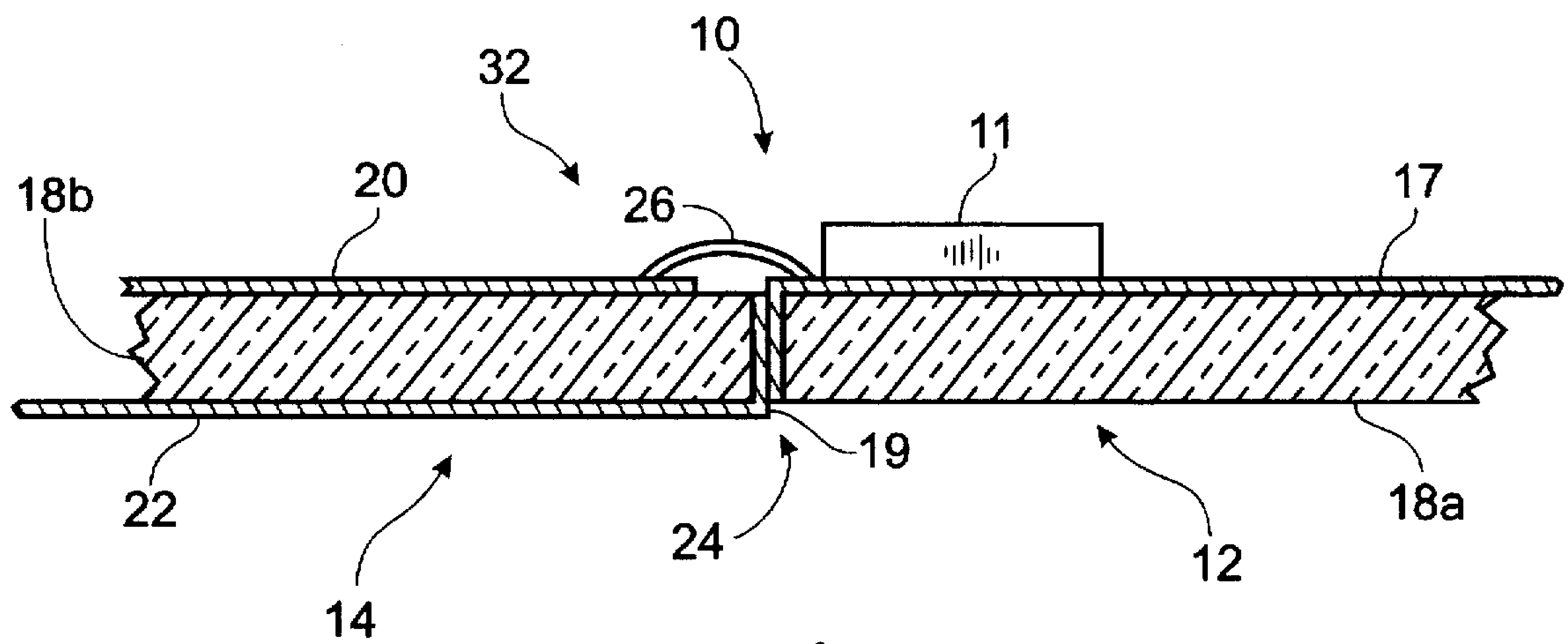

10
32
11
18b
20
26
17
19
22
24
12
18a
14

Fig. 5

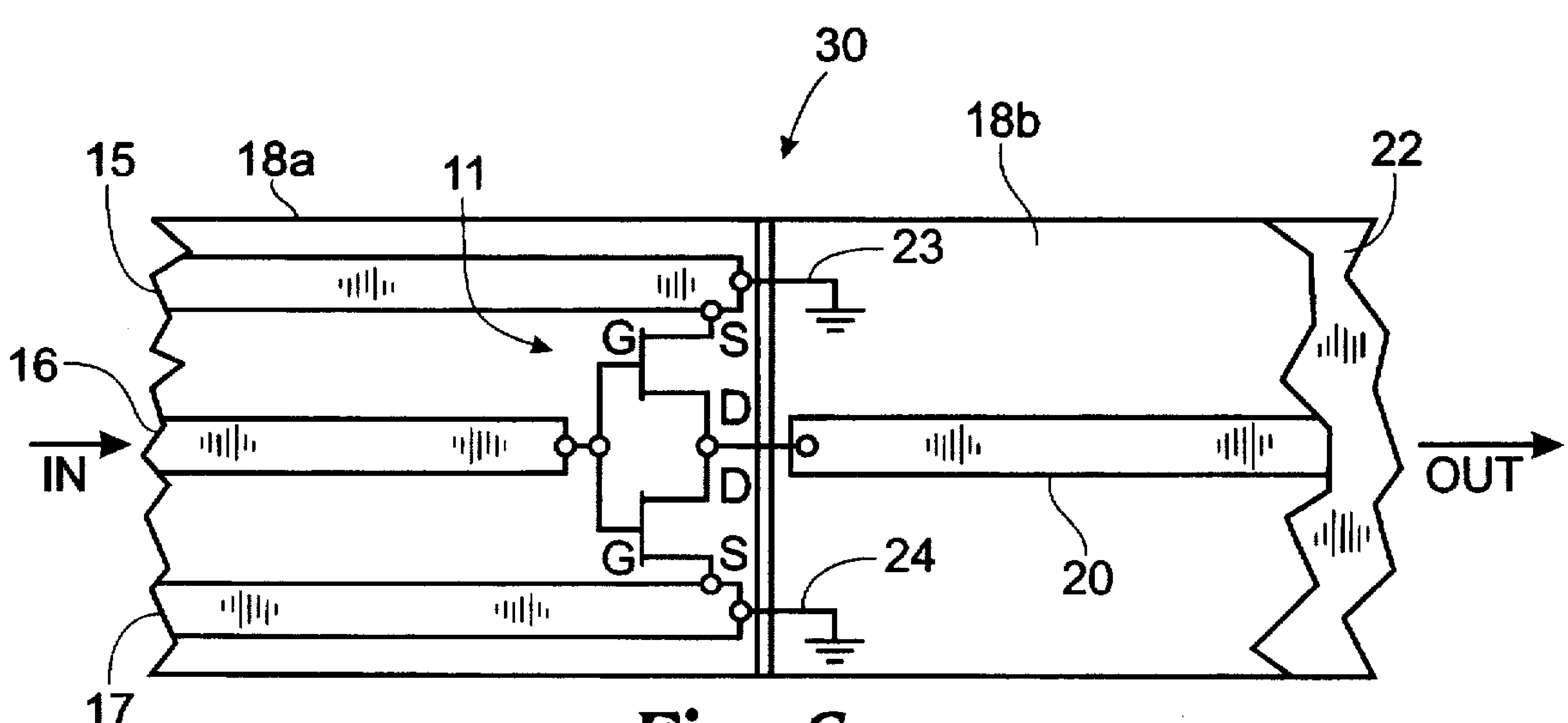

30
18b
15
18a
11
22
23
16
G
S
D
IN
OUT
D
G
S
24
20
17

Fig. 6

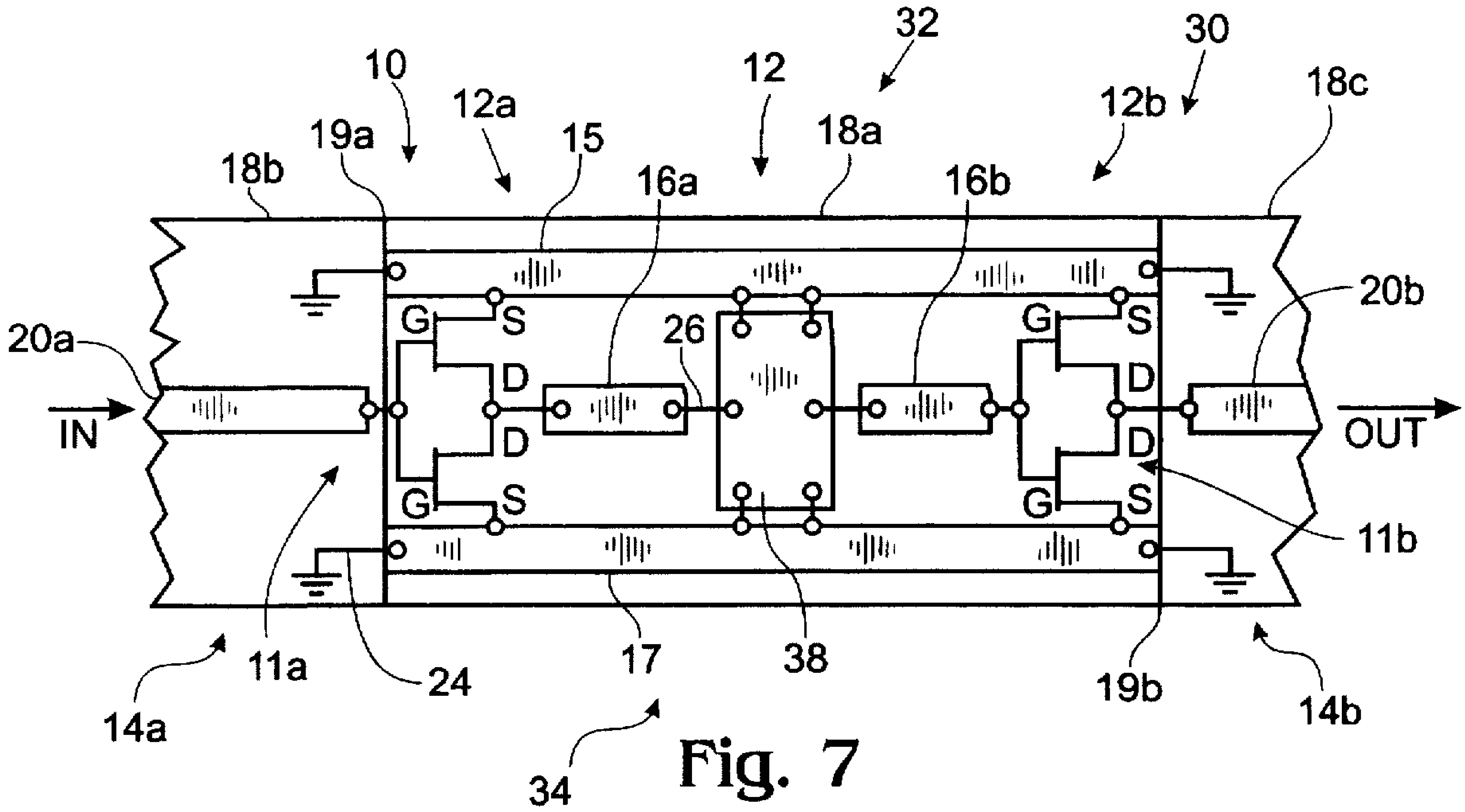
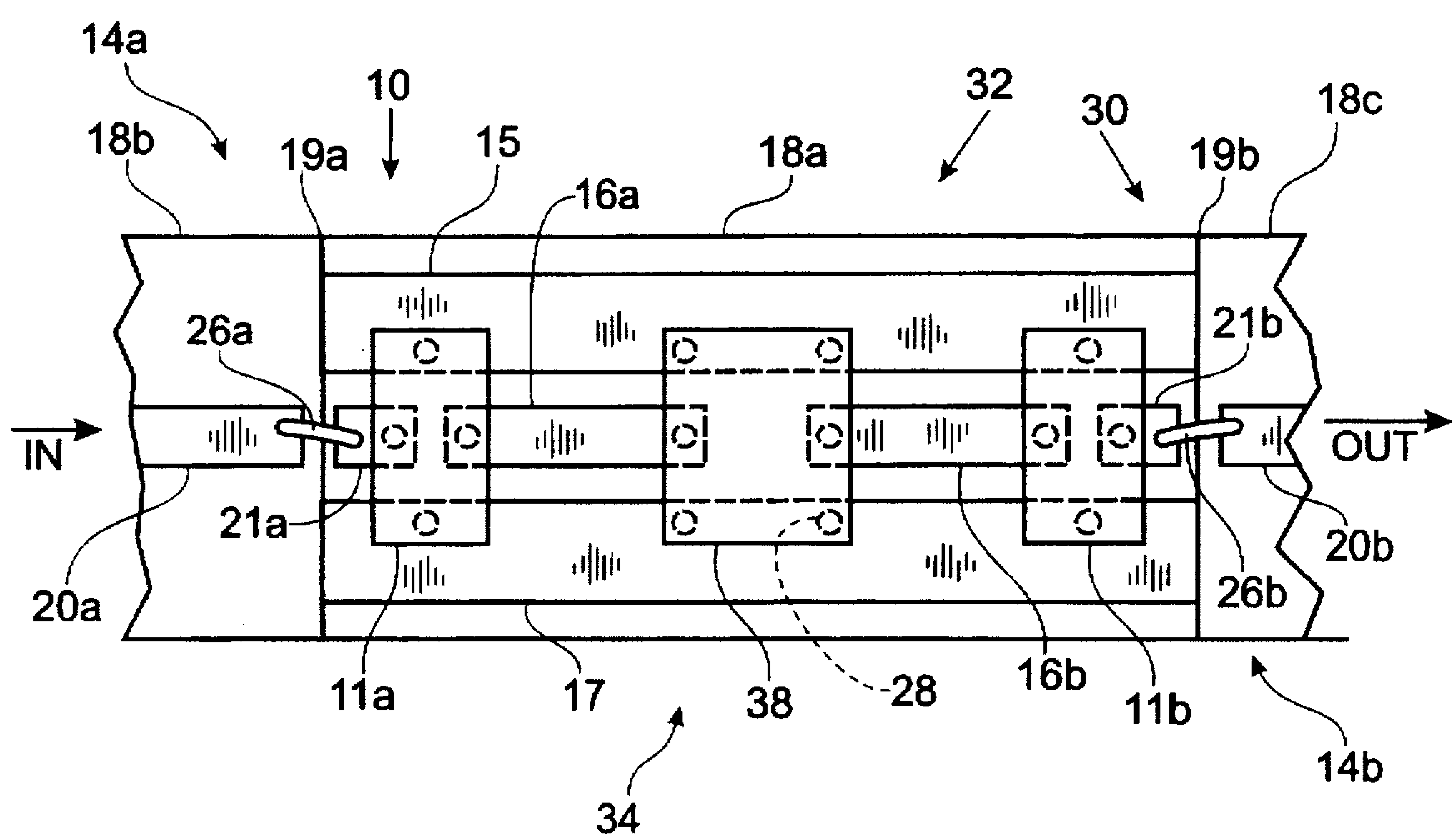

32
30
10
12
12a
12b
18c
19a
15
18a
18b
16a
16b
20b
20a
26
G
S
D
D
G
S
IN
OUT
11b
11a
24
17
38
19b
14a
14b
34

Fig. 7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10
32
30
18c
18b
19a
15
18a
19b
16a
26a
21b
IN
OUT
21a
20b
20a
26b
11a
17
38
28
16b
11b
14b
34

Fig. 8

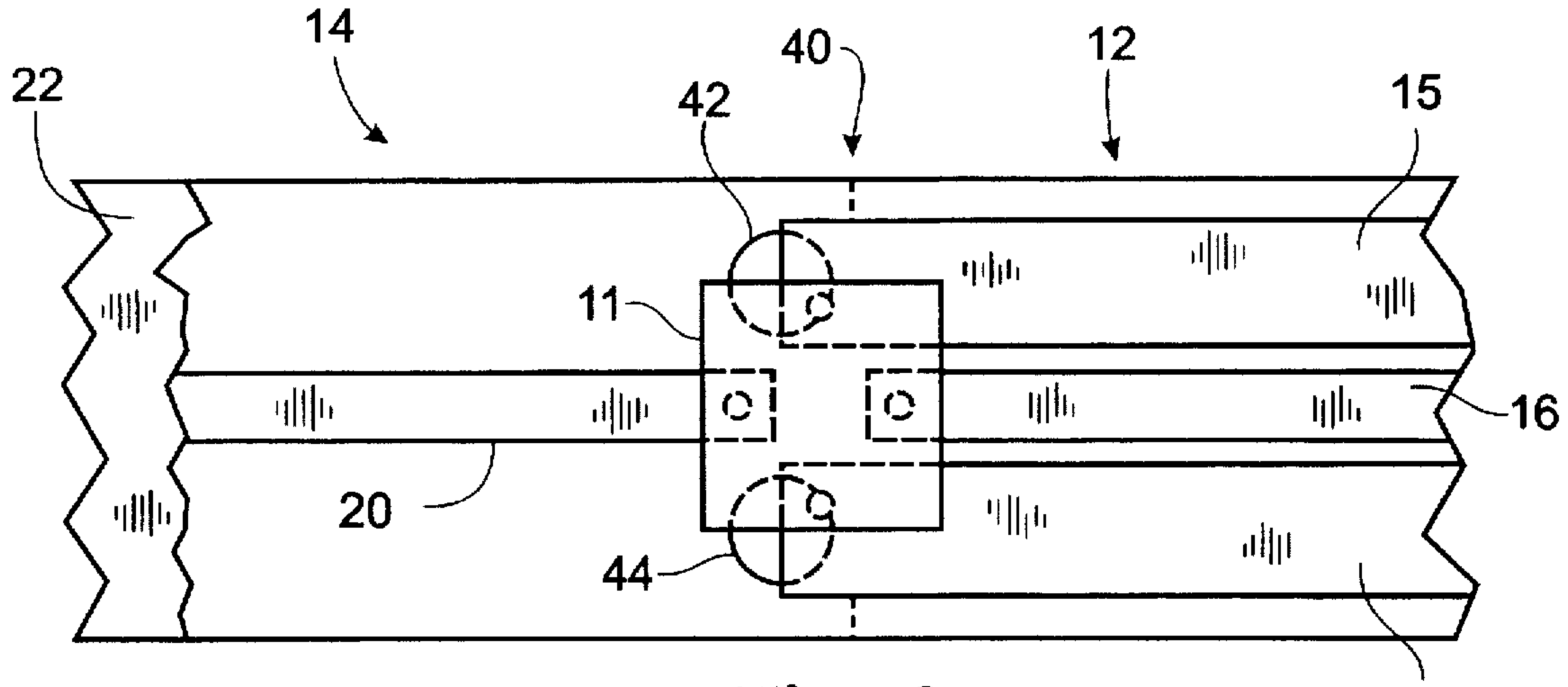
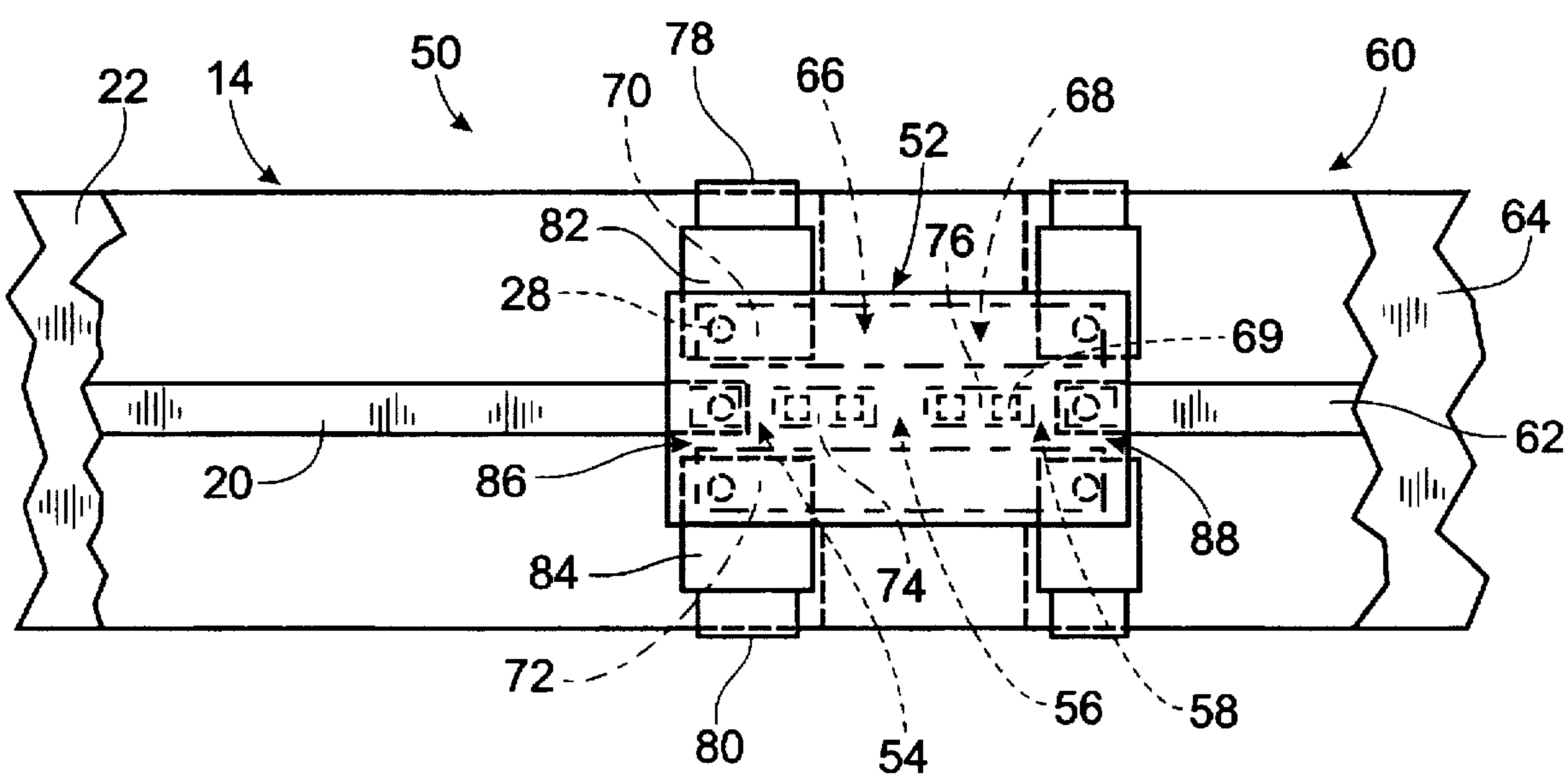

14
22
42
40
12
15
11
16
20
44
17

Fig. 9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50
66
60
22
14
70
68
52
64
82
76
28
69
62
86
20
88
84
74
72
56
58
80
54

Fig. 10

MINIATURE ACTIVE CONVERSION BETWEEN MICROSTRIP AND COPLANAR WAVE GUIDE

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.

FIELD OF THE INVENTION

The present invention relates to the field of signal transmission circuits, and in particular to conversions between microstrip and coplanar wave guide transmission lines.

BACKGROUND OF THE INVENTION

Microstrip transmission lines provide low-loss transmission of microwave and millimeter wave signals, particularly over extended distances as for example in antenna transmission lines. Coplanar wave guides are useful in microwave and millimeter wave circuits for transmitting microwave signals over one face of a substrate. They are ideally suited, for example, for flip chip mounted amplifiers.

Conversion between microstrip transmission mode and coplanar wave guide mode offers the circuit designer the advantages of low loss transmission of microstrip with extra-low common lead inductance associated with amplifiers, oscillators, or other circuits having active devices flip-chip mounted onto coplanar wave guides. Low common lead inductance is very important in amplifier design in particular principally because the inductance common to the input and output circuit reduces the stable gain of the amplifier.

Connecting a microstrip transmission line to a coplanar wave guide in the usual, passive way introduces loss due to the fact that the conversion usually takes several quarter wavelengths of transmission line to achieve. It is desirable to "launch" a microwave signal input supplied in a microstrip transmission line mode to a coplanar wave guide transmission mode with no loss of gain and have the Signal leave the coplanar wave guide with no loss in gain. It would be further desirable if such connection could be in the form of a monolithic microwave integrated circuit (MMIC), occupying a small space with few parts and therefore costing less to produce than current connection methods.

SUMMARY OF THE INVENTION

The present invention provides a small, easily implemented active "launch" or conversion between a microstrip transmission line and a coplanar wave guide that is economical and may readily be implemented in a form having a small size.

In an apparatus according to the present invention, an active device, which may be as simple as a BJT or a FET, or a more complex device, such as a MMIC, converts a microwave or millimeter wave signal conducted by a microstrip transmission line (hereinafter "microstrip") to a signal conducted by a coplanar wave guide (hereafter "CPW"), or a signal conducted by a CPW to one conducted by a microstrip.

In a first embodiment providing a microstrip-to-CPW launch using a FET as the active device, a gate connection is made to a microStrip signal conductor. A drain connection is made to the center conductor of the CPW. Preferably the FET is formed on a chip with two spaced common source terminals, with both source terminals connected to a CPW ground strip. The microstrip and CPW preferably have contiguous ends with the ground plane on the reverse side of the microstrip electrically coupled to the CPW ground strips with a minimum length connection. One method of making this connection is by ground vias. Also, wraparound grounds can be used with the two substrates to achieve low common lead inductance.

Similarly, a second embodiment provides a CPW-to-microstrip launch embodiment also using a FET as the mode converting device. In this embodiment, the gate connection is made to the center conductor of the CPW. The drain connection is made to the microstrip signal conductor. Each of two FET source terminals is connected respectively to one of the ground strips of the CPW and to the ground plane of the microstrip with minimum inductance. connectors.

By constructing microstrip-to-CPW interfaces in this manner, the inductance common to the input and output of the active device is minimized. This active microstrip to CPW or CPW to microstrip launch also can provide gain.

A particularly advantageous feature of this invention is that amplifiers, filters, mixers, etc. can be constructed in CPW with microstrip launchers on the input and output terminals. These circuits may be mounted on the CPW using flip chip die attachment, and MMICs may be formed with low and very controllable common lead inductance, since they are not dependent on the use of back side vias.

An appreciation of other advantages of the present invention and a more complete understanding of this invention may be achieved by studying the following description of preferred embodiments and by referring to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a general diagram showing distribution of terminals on an active device usable in a preferred embodiment of the invention.

FIG. **2** is a diagram similar to FIG. **1** for a FET.

FIG. **3** is a schematic diagram of an embodiment of the invention used for launch from microstrip mode to coplanar wave guide mode utilizing a FET.

FIG. **4** is a plan view illustration of the embodiment of FIG. **3** using flip-chip mounting of the FET.

FIG. **5** is a cross-section taken along line A—A of FIG. **4**, illustrating chip bonding and ground-plane to ground-strip coupling.

FIG. **6** is a schematic diagram of another embodiment of the invention used for launch from coplanar wave guide mode to microstrip transmission line mode, also utilizing a FET.

FIG. **7** is a schematic diagram illustrating use of the invention for conversion from microstrip mode to coplanar wave guide mode and reconversion back to microstrip mode.

FIG. **8** is a plan view of the embodiment of FIG. **7** using flip-chip mounting of conversion FETs and an intermediate integrated circuit.

FIG. **9** is a plan view illustrating an embodiment similar to the embodiment of FIG. **4** except that it is made using a unitary substrate with vias for ground connections to the microstrip ground plane.

FIG. **10** is a plan view of an embodiment having a single substrate with lateral edge wraparounds for ground connections and a single MMIC.

SPECIFICATION OF PREFERRED EMBODIMENTS

As has been mentioned, the invention provides for low-loss conversion between microstrip and coplanar wave guide

(CPW) transmission lines by the use of an active device at the interface. The invention works well when the active device is configured as shown in FIG. 1. An active device typically has a control terminal, an output terminal, and a common terminal, as shown. The common terminal is preferably brought out in two places in bilateral symmetry.

One or more field effect transistors (FETs) may be used to form the active device, as is shown in FIG. 2. A FET has opposing gate and drain terminals, and preferably an associated source terminal formed on each side of the gate. The bilateral symmetry shown falls out of the basic structure of the FET as well as the need to reduce common lead inductance by doubling the number of common terminals.

Although the preferred form of the active devices for the invention are shown herein as FETs, other forms of active devices, such as a bipolar junction transistor, can also be used when the terminals are properly configured.

FIG. 3 shows in schematic form a launch **10** that converts a microstrip transmission line (microstrip) **14** to a coplanar wave guide (CPW) **12** using an active device **11**. A pair of FETs, configured as shown in FIG. 2, form the active device. Note that the FET shown in FIG. 2 can be thought of as two FETs, each with its independent gate and source, and a common connected drain. That is, each source pad has its associated gate and portion of a common connected drain. As used herein, then, the term "active device" is intended to be considered in the general sense as a device having one or more active elements, such as FETs. When more than one element is used, the elements may be joined, as in the case of the FETs of FIG. 2, or may be independent. Collectively, regardless of the particular configuration used, they are referred to as an active device. This active device may have any reasonable form. For instance, it may be resident on a MMIC.

CPW **12** is formed by ground conductor strips **15** and **17** which flank a center signal conductor strip **16**, all mounted on a substrate **18a**. Correspondingly, microstrip **14** is formed by a planar signal conductor strip **20** mounted on a substrate **18b**, and a ground plane **22** mounted on the underside of substrate **18b**. Substrates **18a** and **18b** are also collectively and individually referred to as substrate means. One end of CPW substrate **18a** is positioned against an associated end of microstrip t **4** in a butt joint **19**. Ground plane **22** is electrically coupled to CPW ground strips **15** and **17** with minimum length connections **23** and **24**.

The structure of the CPW can have various forms. The ground conductors may be indefinitely wide, for instance; there may be ground or other conductors on the other side of the substrate; or there may be cavities in the substrate. Other variations are also possible.

The common connected gates G of the FETs are connected to conductor strip **20** as close to the butt joint **19** as possible. Common connected drains D are connected to center conductor **16** on CPW substrate **18a**. The FET sources S are connected respectively to a respective one of ground strips **15** and **17** as close to joint **19** as possible on the CPW substrate.

FIG. 4 illustrates a particular form of microstrip-to-CPW launch **10** of FIG. 3 in which active device **11** is a FET formed in a chip flip mounted over substrate **18a** to the metalization of CPW **12**. A conductor stub **21** mounted in line with conductor strip **16** adjacent to butt joint **19** provides a pad for connection of microstrip conductor **20** to the gate terminal of FET **11** via an air bridge or bond wire **26**. The gate terminal of the FET is mounted onto stub **21**. The drain terminal is mounted onto an end of conductor strip **16** adjacent to butt joint **19**, and the source terminals are bonded to ground strips **15** and **17**, as shown. Conventional flip-mounting techniques, such as thermocompression bonding or solder reflow, may be used. The flip-mounted connections are identified generally by bonds **28**.

Ground plane **22** must be connected to ground strips **15** and **17**. FIG. 5 shows, in cross section taken along line A—A in FIG. 4, one method of making the ground connection. This is achieved by wrapping the microstrip ground plane **22** around the end of the microstrip substrate **18b** in joint **19**, and wrapping ground strips **15** and **17** around the end of CPW substrate **18a**, also in joint **19**. When the respective substrates are butted together to form joint **19**, the wrap-around portions of the ground plane and ground strips are placed in intimate contact. Mechanical and electrical connection can be made with solder or the connection can be made by welding gold ribbon (or other suitable metal) around the substrate. Additionally, these strips could be patterned onto the substrate using photo lithographic methods.

FIG. 6 shows a CPW-to-microstrip launch **30**, again using a FET or MMIC as the active device **11**. The gate G and drain D connections are reversed from the microstrip-to-CPW launch **10** embodiment of FIG. 3. That is, the gate terminals G are commonly connected to center conductor **16** of CPW **12** and the drain terminals D are commonly connected to planar conductor strip **20** on microstrip **14**. The source terminals S are connected respectively to a corresponding one of ground strips **15** and **17** as close to joint **19** as possible, in the same manner as for microstrip-to-CPW launch **10**. The CPW ground strips are likewise connected to the microstrip ground plane in the same manner. Thus, launch **30** is essentially a mirror image of launch **10**.

FIG. 7 is a schematic diagram illustrating a compound circuit structure **32** made according to the invention. Structure **32** includes an intermediate circuit apparatus **34** structured in an intermediate CPW transmission mode. This structure also includes an input launch **10** from microstrip mode to CPW mode, as was described with reference to FIG. 3. Similarly, the structure includes an output launch **30**, structured as shown in FIG. 6, providing conversion from the intermediate CPW mode back to microstrip mode.

As indicated in FIG. 7, the previously commonly identified elements of launches **10** and **30** are assigned respective identifiers "a" and "b". Thus, the active devices of launches **10** and **30** are identified as devices **11a** and **11b**, respectively. Similarly, launch **10** includes microstrip **14a** and CPW **12a**, and launch **30** includes microstrip **14b** and CPW **12b**. The substrates are labeled the same as described previously except for the output substrate **18c** of launch **30**. Input and output CPW sections **12a** and **12b** form a composite CPW **12**, and have associated respective signal conductors **16a** and **16b**. An intermediate circuit **38** is connected to adjacent ends of CPW signal conductors **16a** and **16b**, as well as to ground strips **15** and **17**, as shown, to form intermediate circuit apparatus **34**. It will be appreciated that the circuits on substrate **18a**, including both input and output launches and the intermediate circuit, could all be on a single MMIC.

The particular structure of intermediate circuit **38** is undefined, as it can be any appropriate circuit. An example would be an amplifier, and with appropriate gain from the active devices in launches **10** and **30**, compound circuit structure **32** would constitute a three-stage amplifier. Similarly, additional circuitry could be provided in place of, or in addition to, CPW signal conductors **16a** and **16b**. Said in another way, intermediate circuit apparatus **34** could contain several devices separately or jointly connected to associated CPW sections.

In the structure shown, a microwave signal is input on input microstrip **14a**, conducted through launch **10** to input CPW **12a**. The signal on the input CPW is processed by intermediate circuit **38** and applied to output CPW **12b**. It then passes through launch **30** to output microstrip **14b**.

FIG. **8** illustrates circuit structure **32** using flip mounting of active devices **11a** and **11b**, and intermediate circuit **38**. Connection of active devices **11a** and **11b** are as described previously with reference to FIG. **4**. The reference numbers applied in FIG. **7** are applied to the same elements in this embodiment, with the addition of input and output microstrip stubs **21a** and **21b** and associated air bridges or bond wires **26a** and **26b**.

Connection of the ground planes of the input and output microstrip transmission lines also may be at butt joints **19a** and **19b**, as illustrated in FIG. **5**. FIGS. **9** and **10** show two-other structures for accomplishing the same result, but with the further advantage of building the launch on a single unitary substrate **18**.

FIG. **9** shows a launch **40** having a microstrip **14** coupled to a CPW **12** by an active device **11**. Ground plane **22** of the microstrip is connected to ground strips **15** and **17** of the CPW by vias **42** and **44**. The chip shown as active device **11** could also be configured as a MMIC containing active device **11** and an intermediate circuit, such as circuit **38** shown in FIG. **8**. In such an embodiment, the CPW between active device **11** and circuit **38** could be formed on the MMIC as well.

FIG. **10** shows as yet another embodiment of the invention, a circuit structure **50**. This circuit structure includes an input microstrip **14** coupled to a MMIC **52**. This MMIC includes, for purposes of illustration, an input active device **54**, and intermediate circuit **56**, and an output active device **58**. It is thus equivalent to the three chips shown in FIG. **8** containing devices **11a** and **11b**, and intermediate circuit **38**. Certainly many other circuit configurations are possible, depending on the application for which it is designed.

Output active device **58** is connected to an output microstrip **60**. The output microstrip has a signal conductor **62** and a ground plane **64** on opposite faces of substrate **18**, as shown. MMIC **52** further has a first CPW **66** extending between active device **54** and circuit **56**. Similarly, a second CPW **68** extends between circuit **56** and active device **58**. The resident connections between the circuits and the CPWs on the MMIC are represented by pads **69**. The active devices and CPWs are all contained on the MMIC. CPWs **66** and **68** are formed by common ground strips **70** and **72** and separate respective center conductors **74** and **76**.

Ground plane **22** of the input microstrip is connected to ground strips **70** and **72** of the CPW by wraparounds **78** and **80** extending around the lateral edges of substrate **18**, connected respectively, to land pads **82** and **84**, and associated bonds **28**, as shown. Similarly, ground plane **64** of the output microstrip is connected to the CPWs on the MMIC via associated ground strips, land pads and bonds. It will thus be understood that input active device **54** and output active device **58**, and the respective associated connections form respective input and output launches **86** and **88**. The launches to and from the CPWs are thus resident on MMIC **52**.

It will be appreciated that the use of vias and wraparounds, made using conventional techniques, may also be used in the dual-substrate embodiments described previously, with appropriate use of air bridges or bond wires to connect across the substrate joint(s).

The use of the unitary substrate also simplifies the connection between microstrip signal conductor and the active device. In FIGS. **9** and **10**, rather than having a stub to which the microstrip signal conductor is connected via an air bridge, the active device is flip mounted directly to the end of the microstrip signal conductor.

Although the present invention has been described in detail with reference to a particular preferred embodiments, persons possessing ordinary skill in the art to which this invention pertains will appreciate that various modifications and enhancements may be made without departing from the spirit and scope of the claims that follow. The above disclosures are intended to educate the reader about preferred embodiments, and are not intended to constrain the limits of the invention or the scope of the claims.

What is claimed is:

1. An electrical circuit apparatus for converting transmission of signals between a microstrip transmission line and a coplanar wave guide transmission line comprising:

substrate means having opposite faces;

a microstrip transmission line having a signal conductor mounted on one face of the substrate and a ground plane mounted to the other face of the substrate;

a coplanar wave guide having a center conductor and two coplanar ground strips mounted on the one face of the substrate means;

means coupling the ground plane to the two ground strips; and

an active device having a control terminal, an output terminal, and a common terminal, the active device being [mounted adjacent to the substrate] *flip-mounted to the coplanar wave guide* with the control terminal and the output terminal each coupled to a different respective one of the signal conductor and the center conductor, and with the at least one common terminal coupled to one of the ground strips, so that the active device couples a signal between the signal conductor and the center conductor.

2. An apparatus according to claim **1** in which the active device is a field effect transistor.

3. An apparatus according to claim **1** in which the active device is a MMIC.

4. An apparatus according to claim **3** in which the coplanar waveguide is formed on the MMIC.

[**5**. An apparatus according to claim **1** wherein the active device is flip-mounted to the coplanar wave guide.]

6. An apparatus according to claim [**5**] *1* wherein the active device iS also flip-mounted to the signal conductor.

7. An apparatus according to claim **6** wherein the substrate means comprises first and second coplanar substrates, with the microstrip transmission line mounted on the first substrate and the coplanar wave guide mounted on the second substrate.

8. An apparatus according to claim **7** wherein the microstrip transmission line includes a signal conductor extension mounted on the second.substrate and connected to the signal conductor mounted on the first substrate.

9. An apparatus according to claim **1** wherein the substrate means comprises first and second substrates, with the microstrip transmission line mounted on the first substrate and the coplanar wave guide mounted on the second substrate.

10. An apparatus according to claim **9** wherein the first and second substrates have adjacent edges and the coupling means comprises conductor means extending between the adjacent edges.

11. An apparatus according to claim 1 wherein the substrate means comprises a unitary substrate.

12. An apparatus according to claim 11 wherein substrate has opposing lateral edges and the coupling means comprises a conductive strip extending around each lateral edge.

13. An electrical circuit apparatus for processing signals comprising:

substrate means having opposite faces;

an input microstrip transmission line having an input signal conductor mounted on one face of the substrate and an input ground plane mounted to the other face of the substrate;

an input coplanar wave guide having an input center conductor and two coplanar input ground strips mounted on the one face of the substrate means;

means coupling the input ground plane to the two input ground strips;

an input active device having a control terminal, an output terminal, and two common terminals, the active device being mounted adjacent to the substrate with the control terminal coupled to the input signal conductor and the output terminal coupled to the input center conductor, and the two common terminals coupled to respective ones of the input ground strips;

an output coplanar wave guide having an output center conductor and two coplanar output ground strips mounted on the one face of the substrate means;

an intermediate circuit mounted to the input coplanar wave guide and the output coplanar wave guide for processing a signal received on the input coplanar wave guide and outputting the processed signal on the output coplanar wave guide;

an output microstrip transmission line having an output signal conductor mounted on one face of the substrate and an output ground plane mounted to the other face of the substrate;

an output active device having a control terminal, an output terminal, and two common terminals, the output active device being mounted adjacent to the substrate with the control terminal coupled to the output center conductor and the output terminal coupled to the output signal conductor, and the two common terminals coupled to respective ones of the output ground strips;

means coupling the two output ground strips to the output ground plane;

whereby a signal input on the input microstrip transmission line is transmitted to and from the intermediate circuit via coplanar wave guides, and output on the output microstrip transmission line.

14. An apparatus according to claim 13 wherein the intermediate circuit is on a chip flip mounted to the input and output coplanar wave guides.

15. An apparatus according to claim 13 wherein the input device and the output device are on a single MMIC.

16. An apparatus according to claim 15 wherein the input and output coplanar waveguides are also on the MMIC.

17. An apparatus according to claim 16 wherein the MMIC is flip mounted to the input and output microstrip transmission lines.

18. An apparatus according to claim 16 wherein the intermediate circuit is also on the MMIC.

19. An apparatus according to claim 15 wherein the intermediate circuit is also on the MMIC.

* * * * *