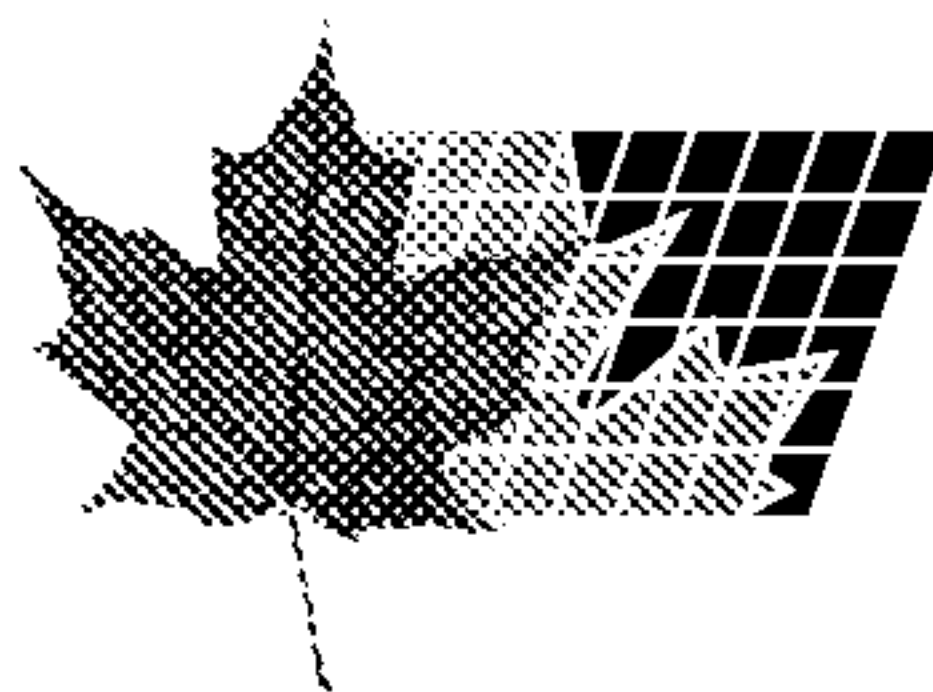




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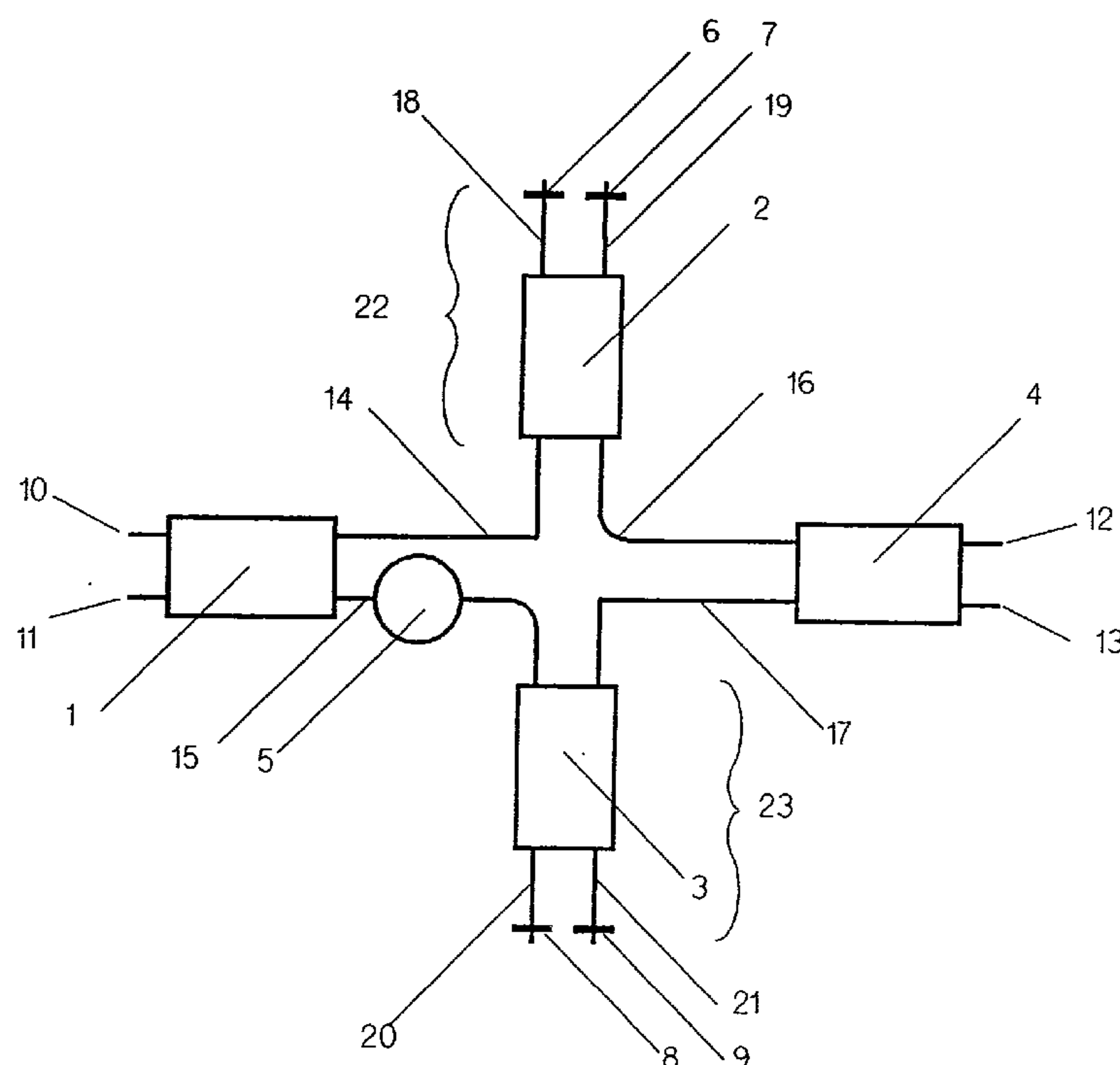
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(54) **REPARTITEUR DE PUISSANCE VARIABLE DE TYPE PLANAR**

(54) **PLANAR VARIABLE POWER DIVIDER**



(57) Microwave variable power divider, comprising (Fig. 1) a 3 dB directional coupler (1) (called hybrid circuit), followed on one output leg by a variable phase shifter, obtained by assembling a -3dB directional coupler (2) with its outlets closed on movable short-circuits (6; 7) that can ensure its variability, and on the other by a 90-degree differential phase shifter (5) and an analogous variable phase shifter consisting of directional coupler (3) and movable short-circuits (8; 9), followed by another directional coupler (4). The device makes it possible to vary the power on the two output legs (12; 13) in a complementary manner by regulating the movement of the movable short-circuits. The particular solution proposed allows the use of a planar-type technology, which can assure considerable advantages in terms of construction, dimensions and integration in more complex networks. In addition, the operating bandwidth ($\geq 16\%$) associated with low losses (0.15 dB) and minimal inband variation of amplitude at the outputs in relation to any desired power division value constitute the peculiar characteristics of this device. Lastly, the low level of passive intermodulation products allows the device to operate in multicarrier systems and the particular movable short-circuit solution adopted allows it to be used for medium-high powers (300 W in continuous wave radiofrequency).



ABSTRACT

Microwave variable power divider, comprising (Fig. 1) a 3 dB directional coupler (1) (called hybrid circuit), followed on one output leg by a variable phase shifter, obtained by assembling a -3dB directional coupler (2) with its outlets closed on movable short-circuits (6; 7) that can ensure its variability, and on the other by a 90-degree differential phase shifter (5) and an analogous variable phase shifter consisting of directional coupler (3) and movable short-circuits (8; 9), followed by another directional coupler (4). The device makes it possible to vary the power on the two output legs (12; 13) in a complementary manner by regulating the movement of the movable short-circuits. The particular solution proposed allows the use of a planar-type technology, which can assure considerable advantages in terms of construction, dimensions and integration in more complex networks. In addition, the operating bandwidth ($\geq 16\%$) associated with low losses (0.15 dB) and minimal inband variation of amplitude at the outputs in relation to any desired power division value constitute the peculiar characteristics of this device. Lastly, the low level of passive intermodulation products allows the device to operate in multicarrier systems and the particular movable short-circuit solution adopted allows it to be used for medium-high powers (300 W in continuous wave radiofrequency).

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PLANAR VARIABLE POWER DIVIDER

The technical field in which this invention is situated is that of passive microwave components and its application field is that of microwave systems in which it is necessary to vary the amplitude and phase of the output signals.

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DESCRIPTION

The present invention relates to a variable microwave power divider of an electromechanical type.

5 The technical field in which this invention is situated is that of passive microwave components and its application field is that of microwave systems in which it is necessary to vary the amplitude and phase of the output signals.

10 At the present state of the art, the solutions employed for the realisation of a wave-guide variable power divider were generally based on two possible operation models:

(A) The first model employed two hybrid circuits and two complementary variable phase shifters. The
15 first hybrid circuit, with orthogonal output gates ("T" type), generated from the input signal two signals of equal amplitude at its outputs, which were subjected to a relative phase shift by the variable phase shifters. The second circuit then
20 recombined these signals, so that one of the two outputs gave the sum and the other the difference between the input signals. In this manner two signals were generated, whose amplitudes depended on the electric phase-shifting angle introduced by
25 the variable phase shifters according to two sine functions in quadrature to each other. The critical feature of this solution resides in the fact that the actuating element for power regulation was the electrical phase-shift angle,
30 which by nature depends on the frequency, and this fact inevitably limited the variable power divider's inband performance.

(B) The variable power divider model employed a
35 variable polarisation rotator between two linear polarisation separators known as "OMT" (Ortho Mode

Transducers). Since the output gates were disaligned, dividers of this type could not be easily integrated into more complex planar networks.

- 5 The variable power divider that is the subject of the invention described here can be considered a further development of those described with reference to model (A) above. This divider is characterised in that the variable phase shifters are realised by means of two
- 10 hybrid circuits with outputs closed by the movable short-circuits of a particularly innovative type. The aim of the proposed invention is to provide an easily integratable, low-loss, broad-band variable power divider operating at medium-high powers (300 to 600 W).
- 15 The innovative features of this invention, as compared to the model (A) type described above, and its relative advantages are indicated below. The device is designed to be constructed employing planar (or clam shell) technology, whereby the various
- 20 component parts are made in two specular halves (half-shells) that are subsequently joined up. In particular, the hybrids used are all "H" type, i.e., they consist of directional couplers of the type with the coupling cavity in the plane containing electrical field E ("E plane") of the fundamental mode (mode TE_{10}) of electromagnetic propagation with input and output in the same plane. This technology offers the following advantages from the electrical functional standpoint:
- 25
- minimisation of the ohmic losses of the various
- 30 components constituting the device, since separation into their two constituent halves occurs in a zone where currents are not excited for the fundamental mode (mode TE_{10}) propagated in the rectangular waveguide;
- 35
- low level of passive intermodulation products, in

the event that several carriers are utilised, since non-linearity phenomena are not excited.

With reference to the mechanical and constructional aspects of the device, its advantages are as follows:

- 5 - it is easily integrated in more complex microwave networks, such as antenna beam forming networks used to produce radiation beams of variable shape (reconfigurable beams) and networks devoted to
- 10 channelling multi-carrier radiofrequency (RF) systems (these networks are used before or after the multiplexers to direct the channels towards different output gates);
- the whole assembly is machined in two half-shells using numerical control machine tools, with
- 15 consequent cost savings;
- very limited dimensions, thanks to the particular component layout (Fig. 2), based on hybrids set side by side in pairs, with the use of curved
- 20 waveguide stretches having a particularly small bending radius.

The technical solution adopted for the movable short-circuits, which together with the hybrid constitute the variable phase shifter, consists of a movable metal body kept centred and at an appropriate distance (≥ 1 mm) from the walls of the rectangular waveguide containing it, with the consequent advantage of avoiding sliding contact between the metal body that constitutes the movable part of the short-circuit and the waveguide that contains it, preventing the

25 occurrence of multipactor effect discharges or breakdown discharges in the event that the device is used in medium-high power apparatus (≤ 8 KW peak).

30 To perfect the movable short-circuit, the waveguide containing the movable body of the said circuit has

35 been provided with resonant cavities on the "E plane"

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and a discontinuity introduced by widening the dimensions of the waveguide in the plane orthogonal to the preceding one in relation to the guide's dimensions in the rest of the device, with the following advantages:

- minimising radiofrequency power losses from the short-circuit that could pass beyond the movable body, thus avoiding fixed or sliding contacts;
- minimising inband phase variation in relation to the central frequency value of the variable phase shifter constituted by the short-circuited transmission line (waveguide), consequently optimising the device's inband response and limiting its amplitude dispersion.

Other advantages connected with to the solutions adopted are:

- the adaptability of the device to all frequency bands using a rectangular waveguide (for typical frequencies from 6 GHz to 60 GHz);
- the possibility of actuating the movement of the short-circuit's movable bodies by a motor with an opposed stirrup or a linear actuator of the stepping motor type.

The solutions regarding model (A) have the following disadvantages, which this invention has eliminated:

- the first input hybrid is of the "T" type, i.e., with one of the two gates outside the plane containing the device's circuitry development, and therefore it does not allow the planar development of the device; in the solution proposed by this invention, this hybrid has been replaced by an "H" type hybrid, as already described, and by a 90-degree differential phase shifter, thus obtaining electrical functions equivalent to those of the "T" hybrid, but with the advantage due to the fact

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that the output gates lie on the same plane;

- the circuitry layout of the proposed components, in the event that the variable phase shifters are constituted by hybrids short-circuited at the output, is generally of the "cross" type, i.e., with the 4 hybrids set out perpendicularly to one another; this makes it impossible to optimise the dimensions and limits the possibility of integrating the device in beam-forming networks;
- the movable short-circuits, made with sliding contacts or small distances in relation to the waveguide containing them, can cause discharge or radio frequency power loss phenomena when high powers are used; in the device proposed here the particular solution adopted, namely non-sliding movable short-circuits with resonant cavities, makes it possible to avoid the aforementioned phenomena;
- the phase response obtainable from variable phase shifters is closely linked to the scatter from the short-circuited line segment, and this entails considerable amplitude and phase variations in the device's inband output in relation to the central frequency value; in the device proposed here, scatter is reduced by introducing the resonant cavities and discontinuity previously described.

The solutions applying to model (B) have the disadvantage of preventing the integration of the device in more complex planar networks.

We shall now proceed to describe the invention, for illustrative and not limitative purposes, with reference to the attached drawings. It must be noted that the configuration described is the one preferred by the inventors at present, but it could as well be realised in a different manner without altering its

basic concept.

With reference to Fig. 1, we shall first of all describe how the invention operates. The signal at input 10 is divided by type "H" hybrid 1 equally between the two lines 14 and 15. The signal on line 15 has a 90-degree phase delay in relation to the one on line 14. Phase shifter 5 and an appropriate lengthening of line 14 make up this delay, so that the two signals' phases coincide at the input of their respective hybrids 2 and 3. The signal on line 14 is split equally by hybrid 2 into two signals travelling along lines 18 and 19, where they are reflected by short-circuits 6 and 7, and pass back through the same hybrid 2, recombining so that all the power is channelled onto line 16. Likewise, the signal on line 15 is split equally by hybrid 3 into two signals travelling along lines 20 and 21, where they are reflected by short-circuits 8 and 9, and pass back through the same hybrid 3, recombining so that all the power is channelled onto line 17. The phase of the signal on line 16 is proportionate to the length of the line between the outputs of hybrid 2 and movable short-circuits 6 and 7. Likewise, the phase of the signal on line 17 is proportional to the length of the line between the outputs of hybrid 3 and movable short-circuits 8 and 9. The position of the movable short-circuits is adjusted in such a manner that when short-circuits 6 and 7 approach, by a certain distance, the outputs of hybrid 2, short-circuits 8 and 9 move , by the same distance, from the outputs of hybrid 3. Consequently, the variable phase shifters 22 and 23, each of which consists of a hybrid plus a movable short-circuit, ensure that the phases of their output signals are equal but opposite in sign.

The signals on lines 16 and 17 are finally combined by

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hybrid 4 on outputs 12 and 13 so as to obtain the division of all the power entering the device in a complementary manner. The power at outputs 12 and 13 is proportionate to the phase of the signals on lines 16 and 17. It therefore depends on the position of the movable short-circuits pair 6 and 7 in relation to pair 8 and 9.

With reference to Fig. 2, we shall now describe the construction solution for the proposed invention. This drawing refers to the interconnection section of the two half-shells of which the device is made up. This section coincides with "plane E", the propagation plane of the electromagnetic field's fundamental mode in a rectangular waveguide.

All the hybrids are of the branch guide coupler type, i.e. directional couplers with coupling cavities on "plane E" between two parallel waveguides running along the wide side of their section. Hybrids 1 and 3 are parallel and opposite to hybrids 2 and 4. The parallel hybrids are connected through the "U" bends 27, which have an internal step to optimise electrical performance with a minimal bending radius. Again with reference to Fig. 2, the 90-degree stationary phase shifter 5 is located in the straight line stretch of waveguide connecting hybrid 3 to hybrid 4. This phase shifter, in the function scheme diagram shown in Fig. 1, is located between hybrids 1 and 3. Fig. 2 shows the variable power divider's working configuration. The reason for moving phase shifter 5 to the position located between hybrids 3 and 4 is due to the need to reduce overall dimensions. Phase shifter 5 is of the type with resonant cavities in "plane E", with an extremely flat inband differential electric phase constant (± 0.2 degrees).

The movable short-circuits are located at the outer end

of hybrids 2 and 3, and they are moved by a mechanical arm and a motor, not shown in Fig. 2, which ensure that movable bodies 24 and movable bodies 30 move by the same distance but in opposite directions.

5 The movable short-circuits are made up of the following parts (Fig. 3):

- 10 - a metal movable body (24) kept centred inside the waveguide at the necessary distance from the sides to prevent discharge phenomena (≥ 1 mm in "plane E" and 0.2 mm in the orthogonal plane);
- a rectangular waveguide whose larger side is greater than the larger side of the waveguide in which the remainder of the device is located, so that the variation in dimension produces a step
15 discontinuity (26) in the guide;
- four cavities, in two symmetrical pairs in "plane E", which may be either of the bent L-shaped type (this is the solution preferred at present by the inventors, and is shown in detail 25 in Fig. 3a),
20 or of the I-shaped type; in the second case these may be air cavities or may contain dielectric material (alternative solution shown in detail 28 in Fig. 3b).

25 The movable part of the short-circuit, consisting of metal body 24, is located between step discontinuity 26 in the guide and cavities 25 (Fig. 3a), or else, in the alternative solution shown in Fig. 3b, between discontinuity 26 and cavities 28. The reciprocal distances between the cavities, the discontinuity and
30 the various positions that the movable body must assume to accomplish the desired phase shift are optimised so as to:

- 35 (1) minimise the inband phase shift variation of the signal coming from the short-circuit in relation to the value desired at the central frequency;

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- (2) minimise the radiation losses due to the fact that movable body 24 is not in contact with the waveguide containing it.

As regards point (1), if the particular solution based on the use of a movable short-circuit had not been developed and the past solutions had been adopted, the inband phase dispersion would have been related to the variation in the length of the transmission line from output 31 of the short-circuit (shown in Fig 3a or 3b) to the position of movable body 24. With the solution adopted here, this dispersion is compensated for by the effect of step discontinuity 26 and cavities 25 or 28 located in the waveguide. In fact the variable distance between discontinuity 26 and movable body 24 assures both the desired phase shift (because of the variation in the length of the transmission line) and the phase dispersion compensation effect, since discontinuity 26 introduces a phase with an opposite inband shape to the phase shape introduced by the distance between discontinuity 26 and movable body 24.

It follows that the differential phase shift between variable phase shifters 22 and 23 shown in Fig. 2, consisting of hybrids 2 and 3 short-circuited at their outputs by the movable short-circuits shown in Fig. 3a or 3b, is sufficiently constant along the entire band of interest. The maximum phase dispersion between variable phase shifters 22 and 23, obtained with the use of these short-circuits, is ± 2 degrees in the case of a desired differential phase of 90 degrees, instead of ± 13 degrees as is the case with the short-circuits used at present. Since the device's inband power division is a function of the said differential phase, the reduction of phase dispersion brings about a substantial improvement in the electrical performance of the device.

The peculiar characteristics of the device are:

- the use of the components employed, which allows the device's special planar construction in two specular half-shells joined to one another ("clam shell" technology), with advantages in terms of easy integration, minimisation of ohmic losses, and easy manufacture;
- the solution proposed for the movable short-circuits, which makes it possible to minimise inband phase dispersion (minimising output amplitude variation as a function of frequency), and the use of the variable power divider for medium-high powers.

List of drawings:

Fig. 1: Functional diagram of the power divider:

- 1 -3 dB input directional coupler (hybrid circuit);
- 2 -3 dB directional coupler (hybrid circuit) part of variable phase shifter 22;
- 3 -3 dB directional coupler (hybrid circuit) part of variable phase shifter 23;
- 4 -3 dB output directional coupler (hybrid circuit);
- 5 stationary 90-degree phase shifter;
- 6 short-circuit on line 18;
- 7 short-circuit on line 19;
- 8 short-circuit on line 20;
- 9 short-circuit on line 21;
- 10 variable power divider's input;
- 11 closed gate on variable power divider's matched load;
- 12 variable power divider's first output;
- 13 variable power divider's second output;
- 14 connection line between input hybrid and variable phase shifter 22 consisting of a

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- straight stretch of rectangular waveguide;
- 15 connection line between input hybrid and
variable phase shifter 23;
- 16 connection line between variable phase
5 shifter 22 and directional coupler 4;
- 17 connection line between variable phase
shifter 23 and directional coupler 4;
- 18 connection line between the direct gate of
directional coupler 2 and movable short-
10 circuit 6;
- 19 connection line between the coupled gate of
directional coupler 2 and movable short-
circuit 7;
- 20 connection line between the direct gate of
15 directional coupler 3 and movable short-
circuit 8;
- 21 connection line between the coupled gate of
directional coupler 3 and movable short-
circuit 9;
- 20 22 set consisting of directional coupler 2 and
movable short-circuits 6 and 7;
- 23 set consisting of directional coupler 3 and
movable short-circuits 8 and 9.

Fig. 2: General configuration of the power divider:

- 25 1 -3 dB input directional coupler (hybrid
circuit);
- 2 -3 dB directional coupler (hybrid circuit)
part of variable phase shifter 22;
- 30 3 -3 dB directional coupler (hybrid circuit)
part of variable phase shifter 23;
- 4 -3 dB output directional coupler (hybrid
circuit);
- 5 stationary 90-degree phase shifter with 3
cavities in electrical plane E;
- 35 22 variable phase shifter consisting of hybrid

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- 2, movable body 24, resonant cavities 25, and discontinuity 26;
- 23 variable phase shifter consisting of hybrid 3, movable body 30, resonant cavities 25, and discontinuity 26;
- 24 movable metal body of the short-circuit constituting part of variable phase shifter 22;
- 25 L-type resonant cavities;
- 26 discontinuity in plane H (orthogonal to the plane containing the electrical field of the fundamental mode of electromagnetic propagation TE_{10});
- 27 180-degree bend in "plane E" with matching step;
- 29 matched closing load of the unused input gate;
- 30 movable body of the short-circuit constituting part of variable phase shifter 23.

Fig. 3a: Details of the movable short-circuit (plan and cross-section):

- 24 movable metal body of the short-circuit;
- 25 L-type resonant cavities;
- 26 discontinuity in plane H (orthogonal to the plane containing the electrical field of the fundamental mode of electromagnetic propagation TE_{10});
- 31 output of the movable cross-section.

Fig. 3b: Details of the movable short-circuit (plan and cross-section):

- 24 movable metal body of the short-circuit;
- 26 discontinuity in plane H (orthogonal to the plane containing the electrical field of the fundamental mode of electromagnetic

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propagation TE_{10});
29 I-type resonant cavities filled with
dielectric material;
31 output of the movable cross-section.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A variable power divider circuit for use in
5 microwave systems, comprising:
first, second, third and fourth waveguide
transmission lines;
first and second variable phase shifting means, each
of said variable phase shifting means including: an
10 output, a directional coupling means, and a pair of
movable non-sliding short circuits, each of the movable,
non-sliding short circuits being coupled through the
directional coupling means to the output of the
respective variable phase shifting means; and
15 third and fourth directional coupling means,
respective outputs of said third directional coupling
means being coupled, through the first and second
waveguide transmission lines, to corresponding inputs of
said first variable phase shifting means and said second
20 variable phase shifting means, and respective inputs of
said fourth directional coupling means being coupled
through said third and fourth waveguide transmission
lines, to corresponding outputs of said first and second
variable phase shifting means.
- 25 2. The variable power divider circuit of claim 1,
wherein said microwave system is an antenna beam forming
network.
3. The variable power divider circuit of claim 1,
wherein said microwave system is a multi-carrier RF
30 channeling network.
4. The variable power divider circuit of claim 1, 2 or
3, wherein said movable short circuits are dimensioned
and arranged for operation in a medium high power range
of 300 W to 600 W.

5. The variable power divider circuit of any one of claims 1 to 4, wherein each of said movable short-circuits comprises an empty L-shaped resonant cavity and a step discontinuity.
- 5 6. The variable power divider circuit of any one of claims 1 to 4, wherein each of said movable short circuits comprises an I-shaped resonant cavity.
7. The variable power divider circuit of claim 6, wherein at least one of said I-shaped cavities contains
10 dielectric material.
8. The variable power divider circuit of any one of claims 1 to 7, further including a 90 degree phase shifter interconnected between an output of said third directional coupling means and an input of one of said
15 variable phase shifting means.
9. The variable power divider circuit of any one of claims 1 to 8, wherein said variable phase shifting means and directional coupling means are defined by coupling cavities disposed between parallel waveguides.
- 20 10. The variable power divider circuit of claim 9, wherein said variable phase shifting means and directional coupling means are disposed in coplanar relation.
11. The variable power divider circuit of claim 9,
25 wherein said third directional coupling means and said second variable phase shifting means are disposed parallel to one another and are disposed opposite said first variable phase shifting means and said fourth directional coupling means, respectively.
- 30 12. The variable power divider circuit of claim 9, wherein said third directional coupling means and said second variable phase shifting means, and said first variable phase shifting means and said fourth directional

coupling means are connected by first and second U-shaped waveguide sections, respectively.

13. The variable power divider circuit of claim 12, wherein each of said U-shaped waveguide sections defines
5 a step discontinuity.

14. The variable power divider circuit of claim 12, wherein each of said short-circuits comprises a metal member having a first section movable within a leg of respective U-shaped wavelength section and a second
10 section movable within a corresponding one of said parallel waveguides.

15. The variable power divider circuit of claim 12, wherein each of said short circuits defines a plurality of resonant cavities disposed in symmetrical pairs, said
15 resonant cavities being disposed in a fundamental mode propagation plane.

16. The variable power divider circuit of claim 15, wherein said cavities are filled with a dielectric material.

20 17. The variable power divider circuit of claim 15, wherein said cavities are L-shaped in cross section.

18. The variable power divider circuit of claim 15, wherein said cavities are I-shaped in cross section.

19. The variable power divider circuit of claim 15,
25 wherein a first short-circuit of each of said variable phase shifting means is disposed in a corresponding one of said parallel waveguides.

20. The variable power divider circuit of claim 19, wherein a second short-circuit of each of said variable
30 phase shifting means is disposed in a corresponding U-shaped waveguide section.

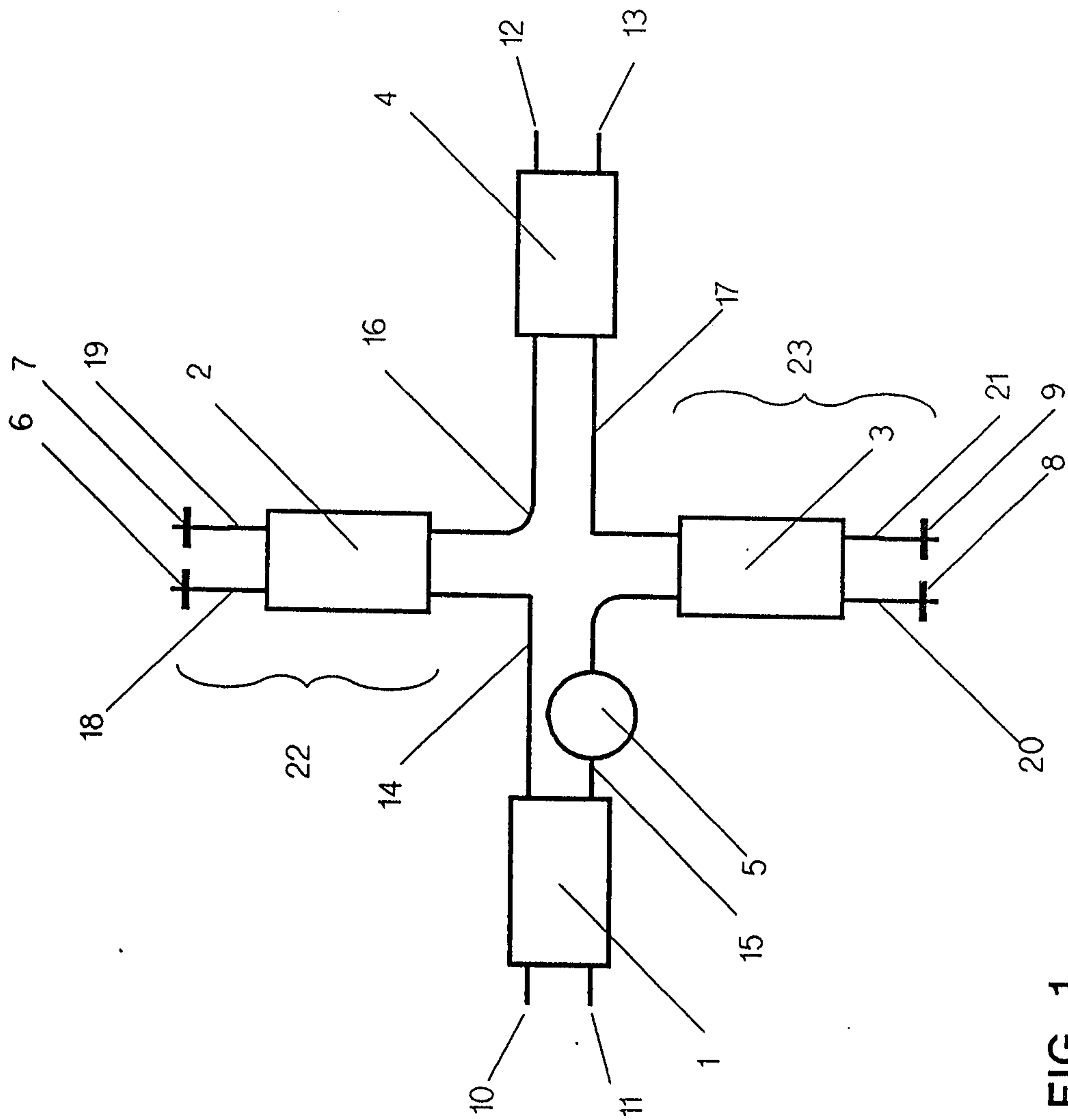


FIG. 1

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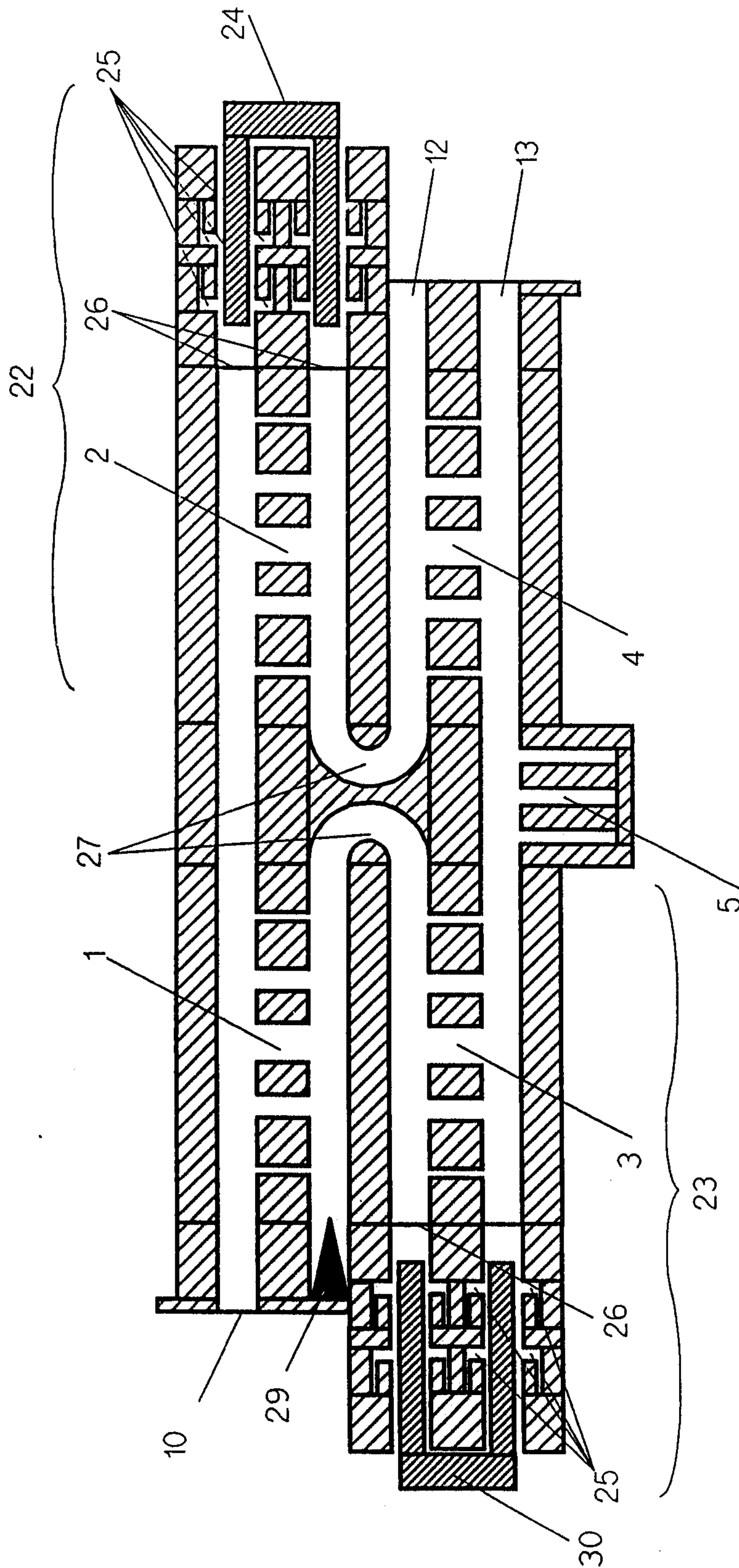
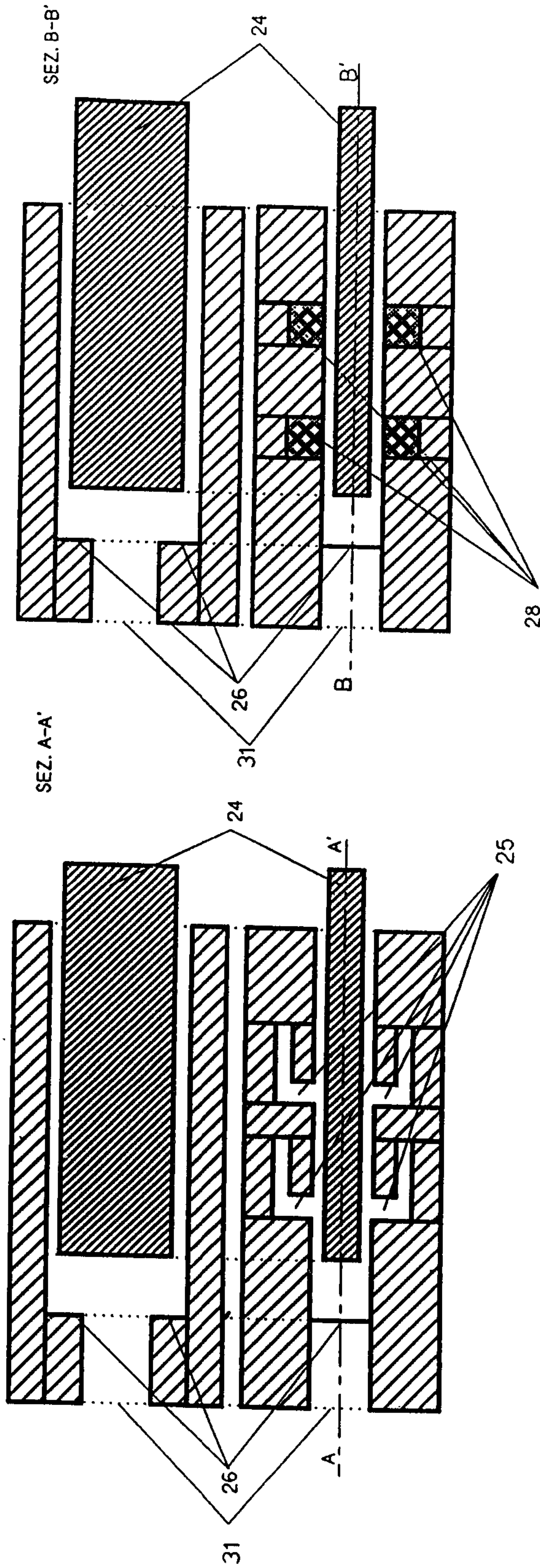


FIG. 2

Sim. M. Bureau



(A)

(B)

FIG. 3

Sim. M. Bureau