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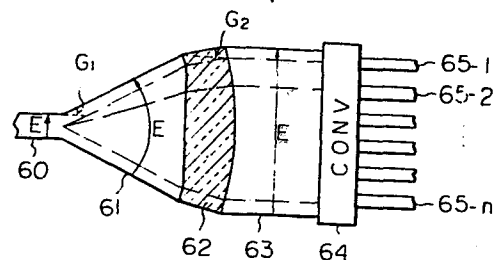
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54 **Device for distributing and/or combining microwave electric power.**

57 This device for distributing and/or combining microwave electric power is used, for example, in a high power microwave amplifier and combines or distributes microwave electric power between a first microwave path such as a standard waveguide (60) and a plurality of second microwave paths such as a plurality of waveguides or MIC transmission lines (65-1,...65-n). The device comprises a horn (61) having a throat portion which is coupled to the first microwave path, and an oversized waveguide (63) coupled at one end to the open end of the horn and at the other end to the plurality of second microwave paths. It further comprises means such as a dielectric lens (62), one or more reflectors, or a plurality of MIC transmission lines of different lengths, for uniformizing the phases of the microwave signals distributed by the horn or for adjusting the phases of the microwave signals fed from the second microwave paths into the horn.

Fig. 6



DEVICE FOR DISTRIBUTING AND/OR COMBINING
MICROWAVE ELECTRIC POWER

This invention relates to a device for distributing and/or combining microwave electric power between a single waveguide and a plurality of microwave transmission paths.

5 In recent years, it has been attempted to use semiconductor amplifier elements such as gallium-arsenic (GaAs) field effect transistors (FETs) instead of conventional travelling-wave tubes, in order to amplify signals in the microwave band. However, the semiconductor
10 amplifier element has an output power of several watts at the most. When it is necessary to amplify a high frequency signal of high electric power, such elements must be operated in parallel. For this reason, it is accepted practice to distribute input signals in the
15 microwave band into a plurality of channels by a microwave distributor, to amplify the signals of each channel by the above-mentioned semiconductor amplifier element, and to combine the amplified output signals of each of the channels into a signal of one channel by a microwave
20 combiner, thereby obtaining a high power high frequency signal. However, electric power is lost when the phases of the microwave electric signals distributed by the microwave distributor are not in agreement, or when the microwave signals are not combined in phase by the
25 microwave combiner. It is, therefore, desired that phases of microwave signals be uniformly distributed in the microwave distributor and in the microwave combiner. It is also necessary that the distributor or combiner itself lose as little electric power as possible.

30 Figure 1A of the accompanying drawings shows a conventional microwave power amplifier, in which a high-

- 2 -

frequency input signal IN is divided into four 3-dB hybrid circuits, the divided input signals are individually amplified by four solid state amplifier elements 2 to 5, and the amplified output signals are combined by hybrid circuits 6, thereby obtaining an amplified high-frequency output signal OUT. In the amplifier of Fig.1A, when the microwave electric power is distributed from a single waveguide to a plurality of transmission paths or is combined in the opposite direction, branching points which branch at a ratio of 1:2 or combining points must be provided at each of the places as denoted by reference numeral 1 in Fig.1B. The distribution of electric power from a single waveguide 7 directly into many transmission paths (such as waveguides) 8-1, 8-2,..., or vice versa, is not possible. In the conventional amplifier of Fig.1A, each of the hybrid circuits 1 or 6 consists of a magic T as shown in Fig.1C. Therefore, if magic T's are used at a plurality of branching points, the whole amplifier becomes very bulky and complex in construction. Furthermore, the amplifier element and the waveguide are usually connected via a structure which consists of the following interconnected components: a waveguide - a ridge waveguide - an amplifier element with strip lines which serve as input and output terminals - a ridge waveguide - a waveguide. Therefore, the construction is complicated and, moreover, its reliability is not good, since the strip lines are connected to the ridge waveguides simply by a press fit.

An object of the present invention is to provide a device for distributing and/or combining microwave electric power between a single waveguide and a plurality of microwave transmission paths which is capable of uniformizing the phase distribution of microwave electric power when it is to be distributed or combined.

According to the present invention a device for

- 3 -

distributing and/or combining microwave electric power between a first microwave path and a plurality of second microwave paths comprises a horn having a throat portion which is coupled to the first microwave path; an
5 oversized waveguide coupled at one end to the open end of the horn and at the other to the plurality of second microwave paths; and phase compensating means for uniformalizing the phases of the microwave signals distributed by the horn or for adjusting the phases of
10 the microwave signals fed out from the plurality of second microwave paths, the phase compensating means being arranged at the portion from the horn to the oversized waveguide.

Embodiments of the invention will now be described,
15 by way of example, with reference to the accompanying drawings, in which:

Figure 1A is a block circuit diagram of a microwave amplifier which uses a conventional distributor and a conventional combiner of microwave electric power;

20 Figure 1B is a diagram of a conventional distributor or combiner used in the amplifier of Fig.1A;

Figure 1C is a perspective view of a magic T used in a conventional distributor or combiner of Figure 1B;

Figure 2 is a perspective view of a microwave
25 amplifier which uses a distributor and a combiner according to the present invention;

Figure 3 is a perspective view of part of the microwave amplifier of Figure 2;

Figure 4 is a partial perspective view of another
30 embodiment of the present invention;

Figure 5A is a perspective view of a microwave amplifier which uses a distributor and a combiner according to the present invention;

Figure 5B is an enlarged view of part of the
35 microwave amplifier of Figure 5A;

- 4 -

Figure 6 is a diagram of another distributor or combiner according to the present invention;

Figure 7 is a view of an example of the shape of a dielectric lens used in the device of Figure 6;

5 Figure 8 shows a coupling circuit used in the device of Figure 6,

Figure 9 is a schematic view of part of another distributor or combiner according to the present invention;

10 Figures 10 and 11 are schematic views of other distributors or combiners according to the present invention;

Figure 12 is a graph of the phase distribution characteristics of the devices of Figures 10 and 11;

15 Figures 13 to 16 are perspective views of wave-guide-MIC converters used in distributors or combiners according to the present invention;

Figures 17 to 20 are diagrams of further distributors or combiners according to the present invention;

20 Figure 21 is a graph illustrating the phase distribution characteristics of the devices of Figures 17 to 20;

Figures 22 and 23 are diagrams showing dimensions relevant to the phase characteristics of the devices of Figures 17 to 20;

25 Figure 24 is a schematic view of a conventional microwave power amplifier;

Figure 25 is a schematic partially cut-away view of a microwave power amplifier used in a distributor or a combiner according to the present invention;

30 Figure 26 shows partial plan and side views of the microwave power amplifier of Figure 25 in detail;

Figure 27 is a block circuit diagram of an equivalent circuit of the device of Figure 26;

35 Figure 28 is a perspective view of the structure of a microstrip line; and

- 5 -

Figure 29 is a graph of the frequency-gain characteristics of the circuit of Figure 27.

Figure 2 illustrates a microwave amplifier which uses a distributor and a combiner according to the present invention. The amplifier includes an input waveguide 20, a distributing electromagnetic horn (E-plane horn) 21, an oversized waveguide 22 which has a broad E-plane, a combining electromagnetic horn (E-plane horn) 23, and an output waveguide 24. In the oversized waveguide 22 a plurality of amplifiers 30 is arranged, each amplifier being made up of an input dipole antenna 25, a solid state amplifier 26 constructed in the form of a microwave integrated circuit (MIC) employing one or more stages of solid state amplifier elements, and a dipole antenna 27 on the output side.

Figure 3 illustrates a concrete example of an amplifier 30, comprising a dielectric substrate 31 with a metal block 32 on its back surface. The metal block is secured to the bottom of the waveguide 22. One side (segment) of the dipole antenna 25 having an overall length of $\lambda/2$, is formed by a pattern 25a on the front surface, and the other side thereof is formed by a pattern 25b on the back surface. A matching circuit 33 is provided, wherein small squares represent electrically conductive patterns for adjusting the impedance, these patterns being wire-bonded to a base portion of the antenna according to need. Reference numeral 34 denotes

- 6 -

an amplifier element (such as an FET) with its gate being connected to the pattern 25a. The source of the FET 34 is grounded, and its drain is connected to an amplifier element 35 of the next stage. Reference
5 numerals 36, 37, --- denote amplifier elements of the subsequent stages, and the output of the final stage is connected to the antenna 27 of the output side. When the electromagnetic horn 21 is an E-plane horn, segments of the antennas 25 (the same holds true for the antennas
10 27) are arrayed along the direction of electric field E as shown in Fig. 2, and the antennas are all arrayed in series along the electric field. When the electromagnetic horn 21 is an H-plane horn, the antenna elements are turned by 90° toward the direction of electric
15 field E as shown in Fig. 4, whereby the antennas are all arrayed in a direction at right angles to the direction of electric field E, i.e., parallel with the direction of electric field E.

Figure 5A illustrates a microwave amplifier using a
20 distributor and a combiner as another embodiment of the present invention in which slot antennas are employed as small antennas. Namely, a unit amplifier 30 comprises slot antennas 41, 42 on the input and output sides, an amplifier 26, and slot/strip line converters 43, 44.
25 Slot antennas 41a, 41b, 41c, --- and 42a, 42b, 42c, --- on the input side and output side are arrayed in series along the direction of electric field E. With this construction, electromagnetic waves emitted from an antenna 41b are not mixed into the electromagnetic waves
30 emitted from the other antenna 41a as shown in Fig. 5B, so that an isolation effect between the antennas is performed. In Fig. 5B, reference numeral 45 denotes a dielectric substrate, and 46a, 46b, --- denote electrically conductive patterns which form horned slots
35 for antennas 41a, 41b, ---. Converters 43, 44 of Fig. 5A comprise electrically conductive patterns formed on the opposite surface of the substrate. It should be

noted that the above-mentioned isolation effect results from the fact that the electric lines of force 47 of the slot antenna 41b are evenly absorbed by the conductors 46a, 46b constituting the slot antenna 41a. Like the case of Fig. 4, the slot antennas may be arrayed in a direction at right angles to the direction of electric field, that is, parallel with the direction of the electric field. In this case, however, the isolation effect cannot be expected.

10 In the above-mentioned microwave amplifier, a high-frequency input is distributed into a plurality of input antennas by the distributing electromagnetic horn, and outputs amplified by amplifiers coupled to the input antennas are combined into one output by the output
15 antennas and the combining electromagnetic horn. Therefore, the high power microwave amplifier can be realized in a compact and simplified construction without requiring hybrid devices such as magic T's. Furthermore, a reliable connection between the amplifiers
20 and the waveguides is obtained.

Figure 6 is a diagram which illustrates still another embodiment of the present invention, in which reference numeral 60 denotes a waveguide (WG) and reference numerals 65-1, 65-2, ---, 65-n denote a
25 plurality of transmission paths such as MIC's. The microwave electric power is distributed or combined between the waveguide 60 and these transmission paths. Reference numeral 61 denotes an E-plane horn having a uniform thickness which expands the width of the
30 waveguide at an angle G_1 , 62 denotes a two-dimensional dielectric lens having a uniform thickness made of, for example, polytetrafluoroethylene, polystyrene, or polycarbonate, 63 denotes an oversized waveguide having a broad width, and 64 denotes a converter circuit
35 between the oversized waveguide 63 and the transmission paths 65-1, 65-2, ---, 65-n. A device for distributing and combining the microwave electric power is constituted

by the above-mentioned members. The transmission paths 65-1, 65-2, ---, 65-n, will be made up of waveguides, coaxial cables, or MIC's. The E-plane horn 61 is widened from the waveguide 60 toward the dielectric lens 62, and the inner electric field E forms a wave surface, i.e., a cylindrical surface emerging from one point.

The dielectric lens 62 is disposed at the joint portion between the E-plane horn 61 and the oversized waveguide 63, and converts the electric field forming the wave surface into a parallel electric field E in the oversized waveguide 63. The dielectric lens 62 has a nearly plane surface on the side of the E-plane horn 61 and an arcuate surface on the side of the oversized waveguide 63. It is necessary to design the lens 62 so that both the phase and amplitude of the electric field E are uniform. Since the dielectric lens 62 has two surfaces and, therefore, two degrees of freedom, it is capable of satisfying this requirement. The angle G_2 at both ends of the dielectric lens 62 is not zero but is set at about $G_1/2$. This is because the curvature of the electric field in the dielectric lens 62 becomes small and the cylinder-plane conversion is smoothly carried out, thereby reducing the reflection of microwave signals. In order to further reduce the reflection, a lens may be arranged between the waveguide 60 and the E-plane horn 61. In this case, a concave lens is used.

The shape of the dielectric lens is determined by the method based on geometrical optics in the following conditions:

- (a) The opening area of the dielectric lens is sufficiently larger than the wavelength of the microwave signal.
- (b) Only the electromagnetic waves of the fundamental mode of the E-plane horn are incident to the dielectric lens. Therefore, the electromagnetic waves

are radiated from the throat portion of the E-plane horn, and have a uniform power distribution with regard to the angle of radiation. Each of the in-phase planes of the electromagnetic waves becomes a cylinder whose central axis penetrates the throat of the E-plane horn.

5 (c) The path length from the throat portion of the dielectric lens to the cross section of the oversized waveguide at the output side of the dielectric lens is constant regardless of the position along the direction of the electric field E (Condition of
10 equiphase).

(d) The distribution of the energy of electromagnetic waves within the E-plane horn with regard to the radiation angle is equal to the distribution of the energy of electromagnetic waves
15 within the cross section of the oversized waveguide (Condition of equimagnitude).

Figure 7 illustrates an example of a shape of the dielectric lens used in the device for distributing and combining microwave electric power of a 14 GHz band,
20 which shape is determined by the above-mentioned conditions. In Fig. 7, the width W_E of a standard waveguide 60 along the electric field E is 7.9 mm and the width W_H thereof along the magnetic field H is 15.8 mm. The opening angle of an E-plane horn 61 is 60° , and the
25 length L of the E-plane horn 61 is about 410 mm. The maximum width W of a dielectric lens 62 along the electric field E is 500 mm.

Table 1 shows the coordinates of the points on each of the planes A and B of the dielectric lens 62 shown in
30 Fig. 7. The dielectric constant ϵ_r of the dielectric lens 62 is assumed to be 2.1.

Table 1

A plane		B plane	
<u>x (mm)</u>	<u>y (mm)</u>	<u>x (mm)</u>	<u>y (mm)</u>
7.81	493.53	31.95	500.0
4.40	436.29	63.70	450.0
2.10	373.25	93.65	387.5
0.55	315.66	112.08	325.0
0	260.84	119.63	262.5
0	239.16	119.63	237.5
0.55	184.34	112.08	175.0
2.10	126.75	93.65	112.5
4.40	63.72	63.70	50.0
7.81	6.47	31.95	0

Figure 8 illustrates a detailed structure of a converter circuit 64, i.e., a waveguide/MIC converter circuit used in the device of Fig. 6. The circuit of Fig. 8 is provided in each of the transmission paths 25 65-1, 65-2, ---, 65-n. That is, the circuits are arrayed in a plurality in parallel at the end of the waveguide 63. Reference numeral 80 denotes a dielectric substrate. The electromagnetic field is trapped between back-surface patterns 81 and 82 which form a terminal 30 slot line, taken out by a front-surface pattern 83, and fed to an amplifier element such as an FET. Other coupling elements such as printed-board antennas may be used for receiving the input signal. In the case of the transmission, it is possible to use the above-mentioned 35 converter circuit. In the case of the oversized waveguide/waveguide conversion, it is only necessary to insert a separator board in the end of the oversized

waveguide 63, to suitably obtain the impedance matching.

The E-plane horn 61 may be replaced by an H-plane horn which widens the H-plane. The dielectric lens 62 in Fig. 6 may be replaced by reflectors, as illustrated 5 in Fig. 9. That is, the phase and amplitude of the microwave signal in the oversized waveguide can be maintained constant by two reflectors 95 and 96. Although the device can be constructed using only one reflector, in this case, it becomes difficult to maintain 10 the amplitude constant, and the efficiency decreases as well.

In the embodiments mentioned above, the microwave electric power can be directly distributed at a ratio of 1:n, or can be directly combined at the same ratio. 15 Therefore, the size of the device can be decreased.

Figure 10 illustrates a device for distributing microwave electric power as still another embodiment of the present invention. The distributor of Fig. 10 comprises an E-plane horn 102 coupled to a standard 20 waveguide 101 through which microwave signals are introduced, an oversized waveguide 103 coupled to the E-plane horn 102, and an MIC device 104 coupled to transmission paths of the oversized waveguide 103. The MIC device 104 comprises a plurality of waveguide-MIC 25 converters 105a, 105b, ---, 105e arrayed in the direction of electric field vector, i.e., in the direction of vector E indicated by arrows E in the oversized waveguide 103, MIC transmission paths 106a, 106b, ---, 106e connected to the waveguide-MIC converters, and microwave 30 amplifiers 107a, 107b, ---, 107e connected to the MIC transmission paths. The waveguide-MIC converters 105a, 105b, ---, 105e are composed of dipole antennas formed on a dielectric substrate 108 and linearly arrayed in the widthwise direction of the oversized waveguide, 35 i.e., in the direction of vector E. Further, the MIC transmission paths 106a, 106b, ---, 106e are composed of microstrip lines formed on the dielectric substrate 108,

and their lengths are changed depending upon the positions along the widthwise direction of the oversized waveguide 103. That is, the lengths of the MIC transmission paths 106a, 106b, ---, 106e increase toward
5 the central portion in the widthwise direction of the oversized waveguide 103, and decrease toward the peripheral portions.

In the microwave distributor of Fig. 10, microwave signals introduced via the standard waveguide 101 are
10 dispersed in the direction of vector E by the E-plane horn 102 and received by the waveguide-MIC converters 105a, 105b, ---, 105e via oversized waveguide 103. Microwave signals received by the waveguide-MIC converters 105a, 105b, ---, 105e are transmitted via MIC
15 transmission paths 106a, 106b, ---, 106e to amplifiers 107a, 107b, ---, 107e and amplified. In this case, the input microwave signals are distributed into a plurality of waveguide-MIC converters 105a, 105b, ---, 105d by the E-plane horn 102 and the oversized waveguide 103. Here,
20 however, distance from a throat portion of the E-plane horn 102 to the waveguide-MIC converters 105a, 105b, ---, 105e via oversized waveguide 103 vary depending upon the positions in the widthwise direction of the E-plane horn 102, i.e., depending upon the positions in
25 the widthwise direction of the oversized waveguide 103. Accordingly, microwave electric power received by the waveguide-MIC converters has different phases. However, since the MIC transmission paths 106a, 106b, ---, 106e have different lengths depending upon the positions in
30 the widthwise direction of the oversized waveguide 103, different phases are uniformalized, and microwave electric power having the same phase is input to the amplifiers 107a, 107b, ---, 107e.

Figure 11 shows a device for distributing microwave
35 electric power according to another embodiment of the present invention, which is different from the embodiment of Fig. 10 with respect to construction of an MIC

device 104' that is coupled to the oversized waveguide 103. The MIC device 104' comprises waveguide-MIC converters 105a', 105b', ---, 105e' formed on a dielectric substrate 108', MIC transmission paths 106a', 106b', ---, 106e', and microwave amplifiers 107a, 107b, ---, 107d. Here, however, depending upon the positions in the widthwise direction of the oversized waveguide 103, the waveguide-MIC converters 105a', 105b', ---, 105e' are arrayed at different positions in the lengthwise direction of the oversized waveguide 103. Unlike the case of Fig. 10, furthermore, MIC transmission paths 106a', 106b', ---, 106e' are formed straight to connect the waveguide-MIC converters 105a', 105b', ---, 105e' to the amplifiers 107a, 107b, ---, 107e. Due to this construction, the lengths of the MIC transmission paths 106a', 106b', ---, 106e' can be increased toward the center portion in the widthwise direction of the oversized waveguide and decreased toward the peripheral portions, in order to uniformize the phase distribution of microwave electric powers input to the amplifiers 107a, 107b, ---, 107e. In this case, differences in the signal transmission distances from the throat portion of the E-plane horn 102 to the waveguide-MIC converters via the oversized waveguide between the central portion and peripheral portions of the waveguide become larger than those of the distributor of Fig. 10. However, since microwave signals propagate in the space in the oversized waveguide 103 at a speed faster than when they propagate on the dielectric substrate 108', it is possible to adjust the lengths of the MIC transmission paths 106a', 106b', ---, 106e' so that the phase distribution can be perfectly uniformized.

Below the phase distribution characteristics of the E-plane horn are described. As illustrated in Fig. 12, central axis of the E-plane horn is set on the x-axis so that the y-axis passes through the throat portion of the E-plane horn. In this case, the phase distribution on

an opening plane of the E-plane horn, i.e., the phase distribution at a given point P on a line which passes through a point (r, o) in Fig. 12 which is perpendicular to the x-axis, is given by the following equation:

$$5 \quad \varphi = \frac{2\pi r}{\lambda g} \left(\frac{1}{\cos \theta} - 1 \right) \quad (\text{rad}) \quad \dots (1)$$

In the above equation, φ represents a phase distribution at a given point P when the phase at the point (r, o) is 0 rad., λg represents a guide wavelength
 10 in the E-plane horn, θ represents an angle between the x-axis and the line segment connecting the point P to the origin O.

Below, the case in which the phase difference generated by the E-plane horn is corrected by changing
 15 the lengths of strip lines as shown in Fig. 10 or 11 is discussed. In the device for distributing microwave electric power of, for example, Fig. 11, if the plane which includes a connection portion between the E-plane horn and the oversized waveguide is denoted by AA', the
 20 plane which is closest to the E-plane horn 102 which includes the waveguide-MIC converters is denoted by BB', and the plane which is remotest from the E-plane horn 102 which includes the waveguide-MIC converters is denoted by CC', the phase difference on the plane AA' is found
 25 from the equation (1). In the portion between the plane AA' and the plane BB', the phase difference generated by the E-plane horn is almost maintained provided the distance is short between the plane AA' and the plane BB'. Therefore, it is the portion between the
 30 plane BB' and the plane CC' which contributes to correct the phase. Here, the wavelength λg_2 of a strip line is given by the following equation:

$$\lambda g_2 = \frac{\lambda}{\sqrt{\epsilon_{\text{eff}}}} \quad \dots (2)$$

35 where λ denotes a free-space wavelength, and ϵ_{eff} denotes an effective dielectric constant of a dielectric

material on which strip lines are formed.

Further, if a guide wavelength of the waveguide is denoted by λ_g , and the length of the waveguide by L , the quantity of phase shift φ_1 is given by:

$$\varphi_1 = \frac{2\pi L}{\lambda_g} \quad \dots (3)$$

In Fig. 11, therefore, if the distance between the waveguide-MIC converters and the plane BB' is denoted by ℓ , the phase distribution φ_2 on the plane CC' is given by:

$$\varphi_2 = \frac{2\pi \ell}{\lambda_g} - \frac{2\pi \ell}{\lambda g_2} = 2\pi \ell \left(\frac{1}{\lambda_g} - \frac{\sqrt{\epsilon_{eff}}}{\lambda} \right) \quad \dots (4)$$

with the quantity of the phase shift at an intersecting point of the central axis OO' and the plane CC' as a reference. Here, the sum of φ_2 of the equation (4) and φ of the equation (1) should be brought to zero. Therefore, the phase distribution can be uniformalized by finding distances ℓ which satisfy an equation:

$$\frac{r}{\lambda_g} \left(\frac{1}{\cos \theta} - 1 \right) + \ell \left(\frac{1}{\lambda_g} - \frac{\sqrt{\epsilon_{eff}}}{\lambda} \right) = 0 \quad \dots (5)$$

with regard to various angles θ . Similarly, lengths of strip lines from the waveguide-MIC converters to the amplifiers can also be found in the device for distributing microwave electric power of Fig. 10.

Although the above description has dealt with the device for distributing microwave electric power, it will be obvious that the phase distribution is uniformalized even for a device for combining microwave electric power by using the same construction. That is, in the device for combining microwave electric power having the same construction as that of Fig. 10 or 11, microwave signals of a plurality of channels are introduced from the side of strip lines, combined through the oversized waveguide 103 and the E-plane horn 102, and the combined signals are sent into the standard waveguide 101. In this case, the microwave

signals can be combined maintaining a uniform phase by changing the lengths of the strip lines depending upon the positions in the widthwise direction of the oversized waveguide.

5 In the embodiments mentioned above, the phase distribution can be uniformalized in a device for distributing and combining microwave electric power relying upon a very simple construction. Moreover, since hybrid circuits are not employed, a device for
10 distributing and combining microwave electric power can be realized featuring greatly reduced transmission losses.

Figure 13 illustrates the construction of a waveguide-MIC converter used in a device for distributing
15 and combining microwave electric power according to the present invention. In an oversized rectangular waveguide 131, the distance of a set of opposing walls is made greater than a distance between the walls of a standard waveguide. In this embodiment, the distance between the
20 walls is increased in the direction of electric field vector indicated by arrow E, i.e., increased in the direction of vector E. On a dielectric substrate 132 a plurality of, e.g. four in the case of Fig. 13, MIC antennas 133-1, 133-2, 133-3, and 133-4 are formed.
25 Each of the MIC antennas 133-1, 133-2, -- is a so-called slot antenna obtained by forming electrically conductive patterns on the dielectric substrate 132 as indicated by the hatched areas. Further, the MIC antennas 133-1, 133-2, -- are arrayed in the direction of electric field
30 vector E of the oversized waveguide 131 and coupled to the transmission path of the oversized waveguide 131 at an end portion thereof.

In the waveguide-MIC converter of Fig. 13, microwave signals introduced from the side of the oversized
35 waveguide 131, i.e., introduced from the direction of arrow A, are received by the array of MIC antennas 133-1, 133-2, -- at the end of oversized waveguide 131

and transmitted to a plurality of MIC channels. In this case, a standard waveguide is coupled to the input side of the oversized waveguide 131 via, for example, a horn element. Microwave power amplifiers comprising gallium-
5 -arsenic FET's are connected to the plurality of MIC antennas 133-1, 133-2, --. When the microwave electric power is combined by the waveguide-MIC converter of Fig. 13, microwave signals are input to the MIC antennas from the direction of arrow B. The microwave signals
10 are emitted from the MIC antennas into the transmission path in the oversized waveguide 131 and combined into microwave electric power.

In the waveguide-MIC converter of Fig. 13, if microwave signal input from the side of arrow A is
15 transmitted in a TE 10 mode through the oversized waveguide 131, the electric field is established by the microwave signal in a direction indicated by arrow E in Fig. 13, whereby potential differences develop among the conductors constituting the slot antennas 133-1, 133-2,
20 --, and microwave electric power is transmitted. In this case, the magnetic field in the oversized waveguide 131 is established in a direction perpendicular to the arrow E, i.e., established in a direction perpendicular to slot planes of the MIC antennas or perpendicular to
25 the plane of the dielectric substrate 132.

Figure 14 shows the construction of another waveguide-MIC converter. In the waveguide-MIC converter of Fig. 14, dipole antennas 145-1, 145-2, 145-3, and 145-4 are formed on a dielectric substrate 144 in place
30 of the slot antennas 133-1, 133-2, -- employed in the converter of Fig. 13. The dipole antennas 145-1, 145-2, -- comprise conductive patterns formed on the front surface of the dielectric substrate 144 as indicated by solid lines and conductive patterns formed on the back
35 surface as indicated by dotted lines. Conductors 146-1, 146-2, 146-3, and 146-4 forming MIC transmission paths are coupled to the dipole antenna elements formed on the

front surface of the dielectric substrate 144. To the dipole antenna elements formed on the back surface of the dielectric substrate 144 are coupled balanced-to-unbalanced transformer portions 147-1, 147-2, 147-3, 5 and 147-4 which have gradually increasing pattern widths. Patterns formed on the back surface of the dielectric substrate 144 stretching over the whole width are coupled to the subsequent stage of the balanced-to-unbalanced transformer portions.

10 Even in the waveguide-MIC converter of Fig. 14, microwave signal input from the side of the oversized waveguide 141 is received separately by the dipole antennas 145-1, 145-2, -- formed on the MIC substrate and taken out via transmission paths 146-1, 146-2, -- in
15 a similar manner to the case of Fig. 13. Further, the microwave signals input from the side of transmission paths 146-1, 146-2, -- on the side of MIC substrate, are emitted from dipole antennas 145-1, 145-2, -- into the transmission path in the oversized waveguide 141 and
20 transmitted being combined together. Even in this case, the oversized waveguide 141 is connected to the standard waveguide via, e.g., an E-plane horn. In the embodiment of Fig. 14, also, a microwave signal is transmitted in the TE 01 mode through the oversized waveguide 141 in a
25 similar manner to the embodiment of Fig. 13. As indicated by arrow E in Fig. 14, therefore, the electric field vector is generated in a direction perpendicular to the direction in which the signal travels through the oversized waveguide 141.

30 Figure 15 illustrates still another waveguide-MIC converter. In the waveguide-MIC converter of Fig. 15, the oversized waveguide 158 has a larger width in the direction of the magnetic field vector as indicated by arrow H. Further, MIC antennas 159-1, 159-2, ---, 159-n
35 coupled to the oversized waveguide 158, are so arrayed that their substrate surfaces are perpendicular to the magnetic field vector H. Therefore, the microwave

signal in the oversized waveguide 158 assumes the form of, for example, TE waves of such as the TE 10 mode. In the waveguide-MIC converter of Fig. 15, therefore, TM waves in the oversized waveguide 158 are separately
5 transmitted to the MIC antennas 159-1, 159-2, ---, 159-n, or microwave signals from the MIC antennas 159-1, 159-2, ---, 159-n are emitted into the oversized waveguide 158 and combined and transmitted in the form of TM waves.

10 Figure 16 shows still another waveguide-MIC converter. In the waveguide-MIC converter of Fig. 16, an MIC substrate 163 having a plurality of dipole antenna elements 162-1, 162-2, 162-3, 162-4 is coupled to an end of the oversized waveguide 161 which is the
15 same as that of Fig. 13 or 14. Here, however, the MIC substrate 163 is disposed at right angles to the direction in which the electromagnetic waves travel through the oversized waveguide 161, unlike the device of Fig. 13 or 14. The dipole antenna elements 162-1,
20 162-2, 162-3, 162-4, however, are arrayed in the oversized waveguide 161 in a direction of electric field vector E of the microwaves. In the construction of Fig. 16, the microwaves in the oversized waveguide 161 are transmitted, for example, in the TE 10 mode, received
25 by the dipole antenna elements 162-1, 162-2, ---, and distributed into MIC transmission paths 164-1, 164-2, 164-3, and 164-4. Conversely, microwave signals input from the MIC transmission paths 164-1, 164-2, 164-3, and 164-4 are emitted into the oversized waveguide 161
30 through the MIC antennas, i.e., through the dipole antennas 162-1, 162-2, 162-3, and 162-4 and transmitted being combined into one signal. According to the construction of Fig. 16, the oversized waveguide 161 and the MIC transmission paths 164-1, 164-2, 164-3, and
35 164-4, can be set at right angles of each other or at any desired angle, thereby increasing the degree of freedom for arraying the transmission paths.

In the above-mentioned waveguide-MIC converters, the mode of electromagnetic field can be converted between the waveguide and the MIC transmission paths relying upon a very simply constructed device, thereby
5 enabling distribution and combination of microwave electric power. In the above-mentioned converters, furthermore, microwave electric power can be distributed and combined without using hybrid circuits. In distributing and combining microwave electric power,
10 therefore, transmission losses can be reduced strikingly.

Figure 17 illustrates a construction of a device for distributing and combining microwave electric power in still another embodiment of the present invention. The device of Fig. 17 comprises an E-plane horn 172
15 coupled to a standard waveguide 171, an oversized waveguide 173 coupled to the E-plane horn 172, and a plurality of waveguides 174-1, 174-2, 174-3, ---, 174-n which are coupled to the transmission path of the oversized waveguide 173. The E-plane horn 172 has a
20 width which gradually increases in the direction of the electric field vector indicated by arrow E, and the oversized waveguide 173 has a width which is enlarged in the direction of the electric field vector E and coupled to the opening portion of the E-plane horn 172. The
25 width of the oversized waveguide 173 in the direction of magnetic field vector H changes toward the end portion where it is coupled to the waveguides 174-1, 174-2, 174-3, ---, 174-n, depending upon the positions in the direction of electric field vector E. That is, the
30 oversized waveguide 173 has the greatest width in the direction of magnetic field vector at the central portion of the oversized waveguide 173, and becomes gradually narrow toward both ends thereof. To meet the above-mentioned shape of the oversized waveguide 173,
35 widths of the waveguides 174-1, 174-2, 174-3, ---, 174-n are greatest in the direction of magnetic field vector near the central portion of the oversized waveguide 173,

and become gradually small toward both ends of the oversized waveguide 173.

In the device of Fig. 17, microwave signals of, for example, the TE 10 mode which are input from the side of the standard waveguide 171, i.e., from the side of arrow A, are dispersed in the direction of electric field vector E by the E-plane horn 172 and distributed to the waveguides 174-1, 174-2, 174-3, ---, 174-n through the oversized waveguide 173. In this case, therefore, the device of Fig. 17 works to distribute microwave electric power. Conversely, microwave signals input from the side of waveguides 174-1, 174-2, 174-3, ---, 174-n, i.e., input from the side of arrow B, are combined by the oversized waveguide 173 and the E-plane horn 172 and transmitted into the standard waveguide 171. In this case, therefore, the device of Fig. 17 works to combine microwave electric power.

When the device of Fig. 17 is used for distributing microwave electric power, the microwave signals input from the side of standard waveguide 171 are distributed to the waveguides 174-1, 174-2, 174-3, ---, 174-n via the E-plane horn 172 and the oversized waveguide 173. Here, however, the distance from the throat portion of the E-plane horn to the opening portion differs depending upon the positions of the oversized waveguide 173 in the direction of electric field vector E. Therefore, phases of the microwave signals become nonuniform on the opening plane Q-Q' of the E-plane horn 172. The phase can be corrected and uniformized by changing the width of the oversized waveguide 173 and widths of the waveguides 174-1, 174-2, 174-3, ---, 174-n in the direction of magnetic field vector H, depending upon the positions in the direction of electric field vector E. That is, as will be mentioned later in detail, the phase delay of signal in the opening plane of the E-plane horn 172 becomes large as it moves away from the central portion toward the direction of vector E. Furthermore, in the

waveguide, in general, the amount of phase rotation decreases with the decrease in the width. Therefore, the phase can be corrected by selecting the widths of the waveguides 174-1, 174-2, 174-3, ---, 174-n to be
5 greatest in the central portion, and to be decreased as they separate away from the central portion along the direction of vector E.

Figure 18 shows a device for distributing and combining microwave electric power according to still
10 another embodiment of the present invention. In the device of Fig. 18, width of the oversized waveguide 185 coupled to the E-plane horn 182 is constant in the direction of magnetic field vector H, and lateral widths of the plurality of waveguides 186-1, 186-2, 186-3, ---,
15 186-n coupled to the oversized waveguide 185, change depending upon the positions of the oversized waveguide 185 in the direction of electric field vector E. In the embodiment of Fig. 18, furthermore, a maximum lateral width of the waveguides 186-1, 186-2, 186-3, ---, 186-n
20 is the same as the width of the oversized waveguide 185 in the direction of magnetic field vector H, and gradually decreases toward both ends in the direction of electric field vector E.

The device for distributing and combining microwave
25 electric powers shown in Fig. 18 operates in the same manner as the embodiment of Fig. 17. Namely, the phase characteristics are uniformized by changing the widths of the waveguides 186-1, 186-2, 186-3, ---, 186-n depending upon the positions in the direction of
30 vector E.

Figure 19 shows a device for distributing and combining microwave electric power according to still
another embodiment of the present invention. In this embodiment, the oversized waveguide 195 has a width
35 which remains nearly constant in the direction of magnetic field vector H like in the embodiment of Fig. 18. Here, however, waveguides 197-1, 197-2, 197-3,

---, 197-n having different lateral widths are coupled to an end of the oversized waveguide 195 via H-plane horns 198-1, 198-2, 198-3, ---, 198-n, respectively. In this case, the waveguide 197-4 coupled to the central
5 portion of the oversized waveguide 195 in the direction of vector E has the same width as that of the oversized waveguide 195 in the direction of magnetic field vector H and, hence, is directly coupled to the oversized waveguide 195 without using H-plane horn. Widths of
10 waveguides successively arrayed on both sides of the waveguide 197-4 become gradually narrower than the width of the waveguide 197-4, and H-plane horns have such widths that these waveguides are coupled to the oversized waveguide 195 without developing steps.

15 The device for distributing and combining microwave electric power of Fig. 19 operates in the same manner as the devices of Figs. 17 and 18. Phase characteristics produced by the E-plane horn 192 can be corrected by suitably setting the widths of the waveguides 197-1,
20 197-2, 197-3, ---, 197-n, thereby to uniformize the phase distribution of the distributed signals on the plane separated away from the end surface of the oversized waveguide 195 by predetermined distances. In the device of Fig. 19, unlike the device of Fig. 18, the
25 waveguides 197-1, 197-2, 197-3, ---, 197-n are coupled to the oversized waveguide 195 through H-plane horns 198-1, 198-3, ---, 198-n, without developing steps. Therefore, the electromagnetic waves are not reflected at the coupling portions, and transmission losses are
30 reduced.

Figure 20 illustrates a device for distributing and combining microwave electric power according to still another embodiment of the present invention. In the embodiment of Fig. 20, the oversized waveguide 209 is
35 not coupled to a plurality of waveguides as are the aforementioned devices, but is coupled to a plurality of dipole antenna elements 211-1, 211-2, 211-3, ---, 211-n

that are formed on an MIC substrate 210. The individual MIC dipole antenna elements 211-1, 211-2, 211-3, ---, 211-n are coupled to MIC elements, such as microwave amplifiers (not shown), via strip lines 212-1, 212-2, 212-3, ---, 212-n formed on the MIC substrate 210. Further, lateral width of the oversized waveguide 209, i.e., the width in the direction of magnetic field vector H, changes in the portion where it is coupled to the MIC dipole antenna elements depending upon the positions in the direction of electric field vector E. Namely, lateral width is the greatest at the central portion and gradually decreases toward both ends in the direction of electric field vector E. This shape makes it possible to correct the phase characteristics produced by the E-plane horn 202.

In the device for distributing and combining microwave electric power of Fig. 20, the microwave electric power input through the standard waveguide 201, propagates through the E-plane horn 202 and oversized waveguide 209, received by the MIC dipole antenna elements 211-1, 211-2, 211-3, ---, 211-n, and is transmitted through the strip lines 212-1, 212-2, 212-3, ---, 212-n. On the other hand, the microwave signals input through the strip lines 212-1, 212-2, 212-3, ---, 212-n are emitted from the MIC dipole antenna elements 211-1, 211-2, 211-3, ---, 211-n into the transmission path in the oversized waveguide 209, combined by the E-plane horn 202, and taken out through the standard waveguide 201. In the embodiment of Fig. 20, the phase distribution characteristics produced by the E-plane horn 202 can be corrected by changing the width of the oversized waveguide 209 in the direction of magnetic field vector H depending upon the positions in the direction of electric field vector E. Namely, the phase distribution characteristics can be uniformalized at the moment when the microwave signals are received by the MIC dipole antenna elements 211-1, 211-2, 211-3, ---,

211-n. According to this embodiment, furthermore, the device can be simply constructed since it does not use a plurality of waveguides that are employed in the preceding embodiments.

5 Phase distribution characteristics of the E-plane horn are explained below. As shown in Fig. 21, central axis of the E-plane horn is set on the x-axis so that the y-axis passes through the throat portion of the E-plane horn. In this case, the phase distribution on an
10 opening plane of the E-plane horn, i.e., the phase distribution at a given point P on a line Q-Q' which passes through a point (r, o) in Fig. 21 which is perpendicular to the x-axis, is given by the following equation:

$$15 \quad \varphi = \frac{2\pi r}{\lambda g} \left(\frac{1}{\cos \theta} - 1 \right) \quad \dots (6)$$

where φ represents a phase distribution at a given point P when the phase at the point (r, o) is 0 rad., λg represents a guide wavelength in the E-plane horn, and θ
20 represents an angle between the x-axis and the line segment connecting the point P to the origin O.

Below phase characteristics, with regard to lateral width of the waveguide are described. Figure 22 shows in cross section the waveguide, in which a guide
25 wavelength λg_1 and a cut-off wavelength λc are determined by the lateral width a of the waveguide. Namely, if a free-space wavelength is denoted by λ , the cut-off wavelength λc and the guide wavelength λg_1 are given by:

$$\lambda c = 2a \quad \dots (7)$$

30

$$\lambda g_1 = \frac{\lambda}{\sqrt{1 - \left(\frac{\lambda}{\lambda c}\right)^2}} \quad \dots (8)$$

Therefore, if the length of the waveguide is
35 denoted by l , the phase shift φ_1 is given by:

$$\varphi_1 = \frac{2\pi l}{\lambda g_1} \quad \dots (9)$$

In a standard waveguide, $a = 2b$ in the cross
5 section of Fig. 22.

From the equations (7) to (9), when the lateral
width of the waveguide is narrower than that of the
standard waveguide, the guide wavelength λg_1 lengthens;
i.e., the amount of phase rotation decreases. When the
10 lateral width of the waveguide is broader than that of
the standard waveguide, the guide wavelength λg_1 shortens;
i.e., the amount of phase rotation increases.

As apparent from the above-mentioned explanation,
in order to correct the phase difference generated by
15 the E-plane horn by changing lateral widths of the
waveguides in the aforementioned embodiments, waveguides
having broad widths should be used in the central
portion of the E-plane horn to obtain large phase
rotation, and widths should be gradually narrowed from
20 the central portion toward both ends in order to reduce
the phase rotation. In the embodiments of Fig. 18
or 19, therefore, lateral widths of the waveguides
186-1, 186-2, 186-3, ---, 186-n or 197-1, 197-2, 197-3,
---, 197-n coupled to the oversized waveguide 185
25 or 195, should be broadened in the central portion of
the oversized waveguide and narrowed toward both ends
along the direction of vector E.

In the embodiment of Fig. 17 or 20, the lateral
width of the oversized waveguides 173 and 209 is
30 broadened in the central portion and narrowed toward
both ends thereof. The oversized waveguides 173, 209
have lateral widths which are constant in the portions
where they are coupled to the E-plane horn 172 or 202,
and lateral widths that change depending upon the
35 positions in the direction of electric field vector E in
the portions where they are coupled to the waveguides
174-1, 174-2, 174-3, ---, 174-n and to the MIC dipole

antenna elements 211-1, 211-2, 211-3, ---, 211-n. For easy comprehension, lateral widths are found below at each of the positions in the case when the oversized waveguide has lateral widths that are uniformly distributed in the lengthwise direction thereof, as shown in Fig. 23. From the equation (8), if the length of the waveguide is denoted by l , lateral width at the center by b' , and the phase quantity at the central position by φ' , the phase distribution φ_1 of the oversized waveguide in the direction of electric field vector E is given by:

$$\varphi_1 = \frac{2\pi l}{\lambda} \left[\sqrt{1 - \left(\frac{\lambda}{2b}\right)^2} - \sqrt{1 - \left(\frac{\lambda}{2b'}\right)^2} \right] \dots (10)$$

with the phase quantity at the center as a reference.

To correct the phase difference produced by the E-plane horn, the sum of phase quantity φ found by the equation (6) and phase quantity φ_1 found by the equation (10) should be brought to zero. For this purpose, the following equation holds true:

$$\frac{r}{\lambda g} \left(\frac{1}{\cos \theta} - 1 \right) + \frac{l}{\lambda} \left[\sqrt{1 - \left(\frac{\lambda}{2b}\right)^2} - \sqrt{1 - \left(\frac{\lambda}{2b'}\right)^2} \right] = 0 \dots (11)$$

Therefore, characteristics of lateral width distribution of the oversized waveguide can be obtained by finding the values b relative to various angles θ relying upon the equation (11).

According to the above-mentioned embodiments, phase characteristics of microwaves in the waveguides can be uniformized at predetermined distances from the opening plane of the oversized waveguide. Therefore, phase characteristics of the distributed microwave signals can be uniformized by providing waveguide-MIC converters or microwave amplifiers at the above-mentioned positions. In the case of the device for combining microwave electric power, the microwave signals can be efficiently combined maintaining the same phase by supplying microwave signals of the same phase from the above-mentioned positions.

Also in the embodiments mentioned above, the phase distribution can be uniformalized in combining or distributing microwave signals relying upon a very simply constructed device. Moreover, since hybrid
5 circuits are not employed, transmission losses can be greatly reduced at the time of distributing or combining microwave electric power.

Figure 24 illustrates a conventional power amplifier in which an amplifier 241 of a microwave integrated
10 circuit (MIC) is inserted in waveguides 244, 245 of the transmission path via mode-converting ridge waveguides 242, 243 being interposed on the input and output sides of the amplifier 241. With this system, however, increased space is required for inserting the waveguides
15 242, 243, mode conversion losses are increased, and connection between the amplifier 241 and waveguides 242, 243 is not so reliable since the conductor pieces 241c of the input and output terminals of the amplifier are simply brought into contact with ridges 242a, 243a of
20 the waveguides 242, 243. In Fig. 24, reference numeral 241b denotes an amplifier element such as an FET.

Figure 25 illustrates a power amplifier which can be adaptable to the device for distributing and combining microwave electric power according to the present
25 invention. In Fig. 25, reference numeral 250 denotes a short waveguide that is inserted between waveguides 255 and 256 which constitute a signal transmission path, 251 denotes a metal block secured to the bottom surface 250a of the waveguide 250, 252 denotes a high-frequency power
30 amplifier of the MIC construction secured onto the metal block 251, and 253 and 254 denote terminals for biasing the amplifier element.

Figure 26 illustrates in detail the amplifier 252, in which reference numeral 260 denotes an amplifier
35 element such as a packaged-type FET, 261 and 262 denote dielectric substrates divided into two (the element 260 may be mounted on the center of a piece of substrate.),

263 and 264 denote surface patterns, i.e., conductors, and 265 denote a back-surface pattern which stretches to the side of the conductor 264.

Base portions of the surface patterns 263, 264, 5 i.e., the sides of the amplifier element 260, constitute a microstrip line together with the back-surface pattern 265 as shown in Fig. 28, whereby ends thereof serve as the transmitting antenna and a receiving antenna, respectively. Gate electrode G and drain electrode D of 10 the FET 260 are soldered or wire-bonded to the base portions of the surface patterns 263 and 264. Matching adjusting elements 267 and 268 are provided in the base portions of the surface patterns 263 and 264 to properly match the impedance with regard to the FET 260. That 15 is, the amplifier element have different S-parameters even when they have the same ratings, and the frequency f vs. gain G characteristics are often deviated from a predetermined curve C_1 as shown by C_2 in Fig. 29. To correct the deviation, a plurality of thin conductive 20 films represented by small squares in Fig. 26 are suitably wire-bonded onto the surface patterns 263 and 264 to adjust the electrostatic capacity with respect to the back-surface pattern. Figure 27 is a diagram of an equivalent circuit, in which $-V_g$ denotes a 25 negative bias voltage applied to the gate electrode G, and $+V_d$ denotes a positive bias voltage applied to the drain electrode D. The source electrode S is grounded via the metal block 251. Choke coils 270 and 271 are established by branched patterns 269 of the surface 30 patterns 263 and 264.

The tapered end of the back-surface pattern 265 works to adjust the impedance so that the surface pattern 263 will effectively serve as an antenna. In the ordinary MIC construction, the back surface has a 35 uniform earth pattern. According to the present invention, however, the end of the pattern 265 is narrowed to adjust the capacity relative to the surface

pattern 263, i.e., the width of the pattern gradually increases from the end to realize an optimum matching condition with the least amount of reflection.

The above-mentioned high-frequency power amplifier
5 presents the following advantages:

(1) Reduced space is required since two ridge waveguides are not needed to convert the mode.

(2) The amplifier element features improved input and output efficiency due to the use of a micro-
10 strip matching circuit which is based upon a tapered back-surface pattern and surface patterns.

(3) Since the amplifier is coupled to the transmission path through antennas, high reliability is maintained in the connection portions.

15 (4) When the amplifiers are to be connected in a plurality of stages, a plurality of waveguides 250 containing amplifiers should be connected in cascade. In this case, the amplifiers are connected through antennas which have a function to cut off direct current.
20 Therefore, there is no need to use capacitors for cutting off the direct current, i.e., for cutting off the bias voltage, unlike the case of connecting the transistors in a plurality of stages.

- 31 -

CLAIMS

1. A device for distributing and/or combining microwave electric power between a first microwave path (60) and a plurality of second microwave paths (65-1, ... 65-n), characterised by an electromagnetic horn (61) having a throat portion which is coupled to the first microwave path (60); an oversized waveguide (63) coupled at one end to the open end of the horn and at the other end to the plurality of second microwave paths; and phase compensating means (62) for uniformalizing the phases of the microwave signals distributed by the horn or for adjusting the phases of the microwave signals fed out from the plurality of second microwave paths, the phase compensating means being arranged at the portion from the horn to the oversized waveguide.
2. A device according to Claim 1, characterised in that the phase compensating means comprises a dielectric lens (62) made of a dielectric substance.
3. A device according to Claim 2, characterised in that the dielectric lens (62) is disposed at the junction between the horn (61) and the oversized waveguide (63).
4. A device according to Claim 1, characterised in that the phase compensating means comprises one or more reflectors (95,96).
5. A device according to Claim 4, characterised in that the reflectors are disposed at the junction between the horn (71) and the oversized waveguide (73).
6. A device according to any preceding claim, characterised in that each of the plurality of second microwave paths comprises an MIC transmission line (106a,...106e) and a waveguide/MIC converting element (105a,...105e) which is coupled to the MIC transmission line and disposed at the end portion of, or within, the oversized waveguide (103), the MIC transmission lines being

- 32 -

of different lengths in accordance with the position of the corresponding waveguide/MIC converting element along the direction of enlargement (E) of the oversized waveguide.

5 7. A device according to Claim 6, characterised in that the length of the MIC transmission line (106c) corresponding to the waveguide/MIC converting element (105c) disposed at the central position along the direction of enlargement (E) of the oversized waveguide (103) is the
10 largest, and the lengths become smaller as the distances from the central position become larger.

8. A device according to Claim 6, characterised in that the positions of the waveguide/MIC converting elements (105a', ... 105e') along the direction of propagation of
15 the microwave signals vary in accordance with the position thereof along the direction of enlargement (E) of the oversized waveguide (103).

9. A device according to any preceding claim, characterised in that the width of the oversized waveguide (173)
20 varies in accordance with the position along the direction of enlargement (E) of the horn (172).

10. A device according to Claim 9, characterised in that the width of the oversized waveguide (173,209) is largest at the central position along the direction of enlargement
25 of the horn (172,202) and becomes smaller in accordance with the distance from the central position.

11. A device according to any preceding claim, characterised in that each of the second microwave paths (33) comprises an MIC transmission line (106a, ... 106e)
30 connected to a waveguide/MIC converting element (105a,... 105e) which is disposed at the end portion of or within the oversized waveguide (102), each of the waveguide/MIC converting elements being an MIC dipole antenna formed on the sides of a dielectric substrate (108).

35 12. A device according to any one of Claims 1 - 10, characterised in that each of the second microwave paths

- 33-

comprises an MIC transmission line connected to a waveguide/MIC converting element which is disposed at the end portion of or within the oversized waveguide (131), each of the waveguide/MIC converting elements (133-1,...133-4) being an MIC slot antenna formed on one side of a dielectric substrate (132).

13. A device according to Claim 12, characterised in that each of the waveguide/MIC converting elements comprises a conductor line pattern (43) formed on the substrate on the opposite side to the MIC slot antenna, the conductor line pattern being formed along the direction perpendicular to the direction of the slot line portion of the MIC slot antenna (41a,...41c).

14. A device according to any preceding claim, characterised in that each of the second microwave paths is equipped with a microwave power amplifier comprising a metal block (251) secured and disposed in a waveguide (250); dielectric substrates (261,262) secured on the metal block; a pair of strip conductors (263,264) formed on the surfaces of the substrates; at least one antenna element formed at the end of at least one of the pair of strip conductors; an amplifier element (260) having an input terminal (G) and an output terminal (D) connected to the strip conductors, respectively; and back surface patterns (265) which are provided on the back surfaces of said substrates, each of which constitutes a microstrip line together with the strip conductor for impedance matching with the amplifier element, at least one of the back surface patterns having a narrowed end to obtain impedance matching with the antenna.

15. A device according to Claim 1 or Claim 14, ^{characterised} in that the phase compensating means comprises, in each of the second microwave paths, a waveguide (186-1,...186-n) the width of which is determined in accordance with its position along the direction of enlargement of the oversized waveguide (185).

- 34 -

16. A device according to Claim 15, characterised in that the width of each waveguide (186-1,...186-n) of the second microwave path is largest at the central position along the direction of enlargement of the oversized
5 waveguide (185) and becomes smaller in accordance with the distance from the central position.

17. A device according to Claim 15 or Claim 16, characterised in that each of the second microwave paths comprises an MIC transmission line connected to a wave-
10 guide/MIC converting element which is disposed in the corresponding waveguide (186-1,...186-n) each of the waveguide/MIC converting elements being an MIC dipole antenna formed on the sides of a dielectric substrate.

18. A device according to Claim 15 or Claim 16,
15 characterised in that each of the second microwave paths comprises an MIC transmission line connected to a waveguide /MIC converting element which is disposed in the corresponding waveguide (186-1,...186-n) each of the waveguide/MIC converting elements being an MIC slot antenna formed
20 on one side of a dielectric substrate.

19. A device according to Claim 15, characterised in that each of the waveguide/MIC converting elements comprises a conductor line pattern formed on the opposite side of the MIC slot antenna, the conductor line pattern
25 being formed along the direction perpendicular to the direction of slot line portion of the MIC slot antenna.

20. A microwave power amplifier, characterised by a first electromagnetic horn (21) having a throat portion which is coupled to an input microwave path (20) and which
30 radially disperses a microwave input signal; an oversized waveguide (22) coupled at one end to the open end of the first electromagnetic horn; a second electromagnetic horn (23) the open end of which is coupled to the other end of the oversized waveguide and which combines microwave
35 signals from the oversized waveguide; a plurality of

- 35 -

- amplifier units (26) which are arranged in the oversized waveguide (22), each of the amplifier units receiving and amplifying the microwave signal from the first electromagnetic horn after converting it into an MIC mode signal, 5 and the output signal of each of the amplifier units being transmitted into the second electromagnetic horn after it is converted into a waveguide mode signal; and phase compensating means for uniformalizing the phases of the microwave signals distributed by the first electro- 10 magnetic horn or for adjusting the phases of the microwave signals fed out from the plurality of amplifier units, the phase compensating means being arranged at the portion from the first electromagnetic horn to the oversized waveguide or at the portion from the oversized waveguide 15 to the second electromagnetic horn.
21. An amplifier according to Claim 20, characterised in that the phase compensating means comprises a dielectric lens (62) made of a dielectric substance.
22. An amplifier according to Claim 21, characterised 20 in that the dielectric lens (62) is disposed at the joint portion of the first horn (21) and the oversized waveguide (22).
23. An amplifier according to Claim 20, characterised in that the phase compensating means comprises one or more 25 reflectors (95,96).
24. An amplifier according to Claim 23, characterised in that the reflectors (95,96) are disposed at the joint portion between the first or second electromagnetic horn (21,23) and the oversized waveguide (22).
- 30 25. An amplifier according to any one of Claims 20-24, characterised in that each of the plurality of amplifier units (26) comprises an MIC transmission line (106a,... 106e) and a waveguide/MIC converting element (105a,...105e) which is coupled to the MIC transmission line and which is 35 disposed within the oversized waveguide (22), the MIC transmission lines being of different lengths in accordance

- 36 -

with the position of the corresponding waveguide/MIC converting element along the direction of enlargement of the oversized waveguide.

26. An amplifier according to Claim 25, characterised in
5 that the length of the MIC transmission line (106c) corresponding to the waveguide/MIC converting element (105e) disposed at the central position along the direction of enlargement of the oversized waveguide (22) is the largest, and the lengths become smaller as the distances
10 from the central position become large.

27. An amplifier according to Claim 26, characterised in that the positions of the waveguide/MIC converting elements along the direction of propagation of the microwave signals vary in accordance with the position thereof along
15 the direction of enlargement of the oversized waveguide (22).

28. An amplifier according to any one of Claims 20-27, characterised in that the width of the oversized waveguide (22) varies in accordance with the position along the
20 direction of enlargement of the horns (21,23).

29. An amplifier according to Claim 28, characterised in that the width of the oversized waveguide (22) is largest at the central position along the direction of enlargement of the horns, and becomes smaller in accordance with the
25 distance from the central position.

30. An amplifier according to any one of Claims 20-29, characterised in that each of the amplifier units (26) comprises an MIC transmission line connected to a waveguide/MIC converting element which is disposed at the end
30 portion of or within the oversized waveguide (22), each of the waveguide/MIC converting elements being an MIC dipole antenna (25) formed on the sides of a dielectric substrate.

31. An amplifier according to any one of Claims 20-29, characterised in that each of the amplifier units (30)
35 comprises an MIC transmission line connected to a waveguide/MIC converting element (41a-41c; 42a-42c) which is

- 37 -

disposed at the end portion of or within the oversized waveguide (22), each of the waveguide/MIC converting elements being an MIC slot antenna formed on one side of a dielectric substrate.

5 32. An amplifier according to Claim 31, characterised in that each of the waveguide/MIC converting elements (43,44) comprises a conductor line pattern formed on the opposite side of the MIC slot antenna, the conductor line pattern being formed along the direction perpendicular to the
10 direction of the slot line portion of the MIC slot antenna.

33. An amplifier according to any one of Claims 20-32, characterised in that each of the amplifier units (26,30) is equipped with a microwave power amplifier comprising a metal block (251) secured and disposed in a waveguide (250);
15 dielectric substrates (261,262) secured on the metal block; a pair of strip conductors (263,264) formed on the surfaces of the substrates; at least one antenna element formed at the end of at least one of the pair of strip conductors; an amplifier element (260) having an input terminal (G)
20 and an output terminal (D) connected to the pair of strip conductors, respectively; and back surface patterns (265) which are provided on the back surfaces of the substrates, each of which constitutes a microstrip line together with the strip conductor for impedance matching with the ampli-
25 fier element, at least one of the back surface patterns having a narrowed end to obtain impedance matching with the antenna.

34. An amplifier according to any one of Claims 20-33, characterised in that each of the amplifier units is
30 located in a respective one of a plurality of waveguides coupled with the oversized waveguide (22), the width of each of the waveguides being dependent upon its position along the direction of enlargement of the oversized waveguide.

35 35. An amplifier according to Claim 34, characterised in that the width of the waveguides of the amplifier units is

- 38 -

largest at the central position along the direction of enlargement of the oversized waveguide (22), and becomes smaller in accordance with the distances from the central position.

5 36. A device for distributing and combining microwave electric power between a first microwave path and a plurality of second microwave paths, characterised by a horn having a throat portion which is coupled to the first microwave path; and an oversized waveguide coupled at one
10 end to the open end of the horn, the other end of the oversized waveguide being coupled to the plurality of second microwave paths, and the width of the oversized waveguide varying in accordance with the position along the direction of enlargement of the horn.

15 37. A device for distributing and combining microwave electric power between a first microwave path and a plurality of second microwave paths, characterised by a horn having a throat portion which is coupled to the first microwave path; and an oversized waveguide coupled
20 at one end to the open end of the horn, the other end of the oversized waveguide being coupled to the plurality of second microwave paths; each of the second microwave paths including a waveguide the width of which is determined in accordance with the position along the direction of
25 enlargement of the oversized waveguide.

38. A microwave power amplifier, characterised by a first electromagnetic horn having a throat portion which is coupled to an input microwave path and which radially disperses a microwave input signal; an oversized waveguide
30 coupled at one end to the open end of the first electromagnetic horn; a second electromagnetic horn the open end of which is coupled to the other end of the oversized waveguide and which combines microwave signals from the oversized waveguide; and a plurality of amplifier units
35 which are arranged in the oversized waveguide, each of the amplifier units receiving and amplifying the microwave

- 39 -

signal from the first electromagnetic horn after converting it into an MIC mode signal, and the output signal of each of the amplifier units being transmitted into the second electromagnetic horn after it is converted into a waveguide mode signal; the width of the oversized waveguide varying in accordance with the position along the direction of enlargement of the first or second electromagnetic horn.

39. A microwave power amplifier, characterised by a first electromagnetic horn having a throat portion which is coupled to an input microwave path and which radially disperses a microwave input signal; an oversized waveguide coupled at one end to the open end of the first electromagnetic horn; a second electromagnetic horn the open end of which is coupled to the other end of the oversized waveguide and which combines microwave signals from the oversized waveguide; and a plurality of amplifier units each of which is arranged in a respective one of a plurality of waveguides coupled to the oversized waveguide, each of the amplifier units receiving and amplifying the microwave signal from the first electromagnetic horn after converting it into an MIC mode signal, and the output signal of each of the amplifier units being transmitted into the second electromagnetic horn after it is converted into a waveguide mode signal; the width of each of the waveguides coupled to the oversized waveguide varying in accordance with the position along the direction of enlargement of the oversized waveguide.

40. A device according to Claim 15, characterised by, in each of the second microwave paths, a respective horn (198-1, ... 198-n) which opens out transversely of the oversized waveguide (195) and couples the oversized waveguide to the respective waveguide (197-1, ... 197-n) in the second microwave path.

Fig. 1A

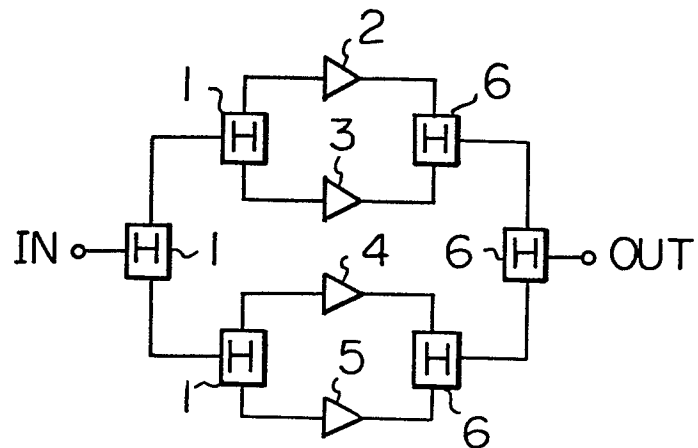


Fig. 1B

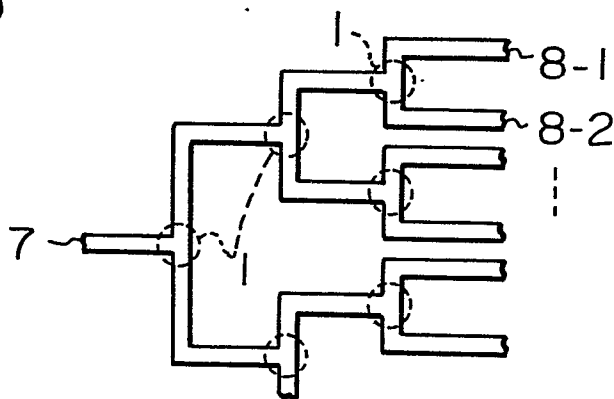


Fig. 1C

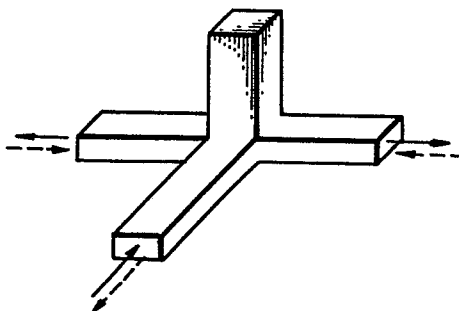


Fig. 2

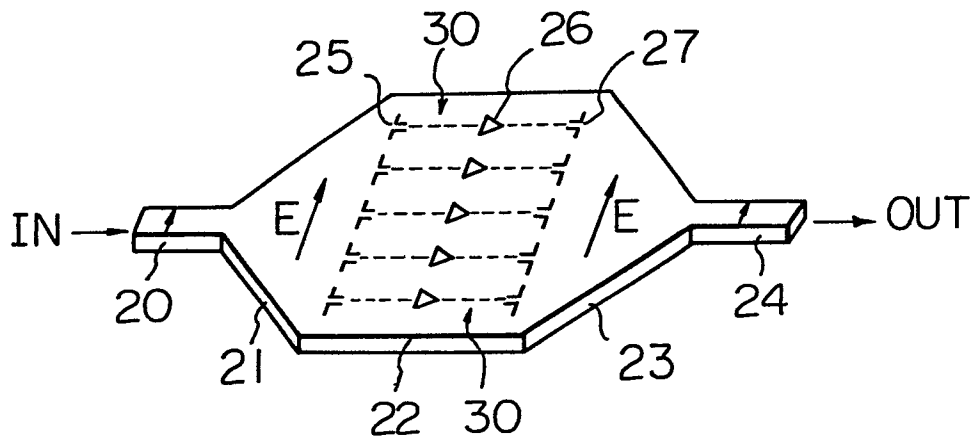


Fig. 6

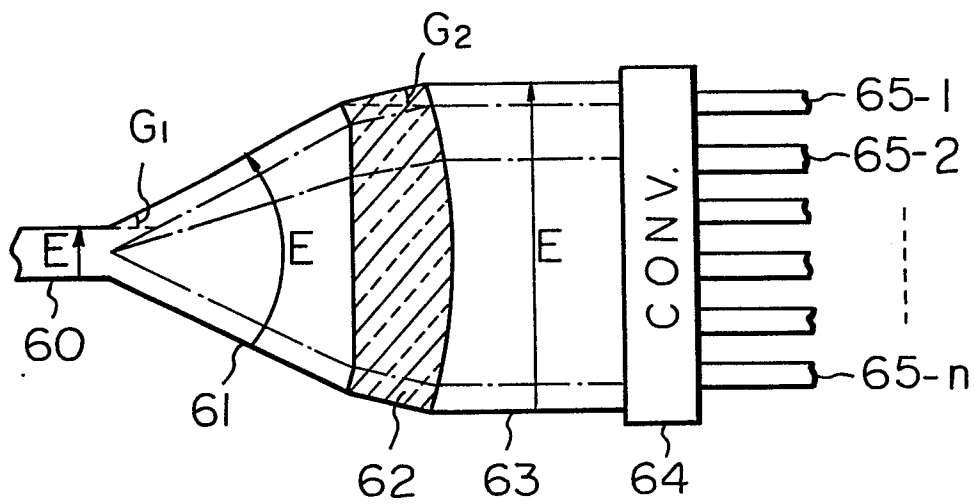
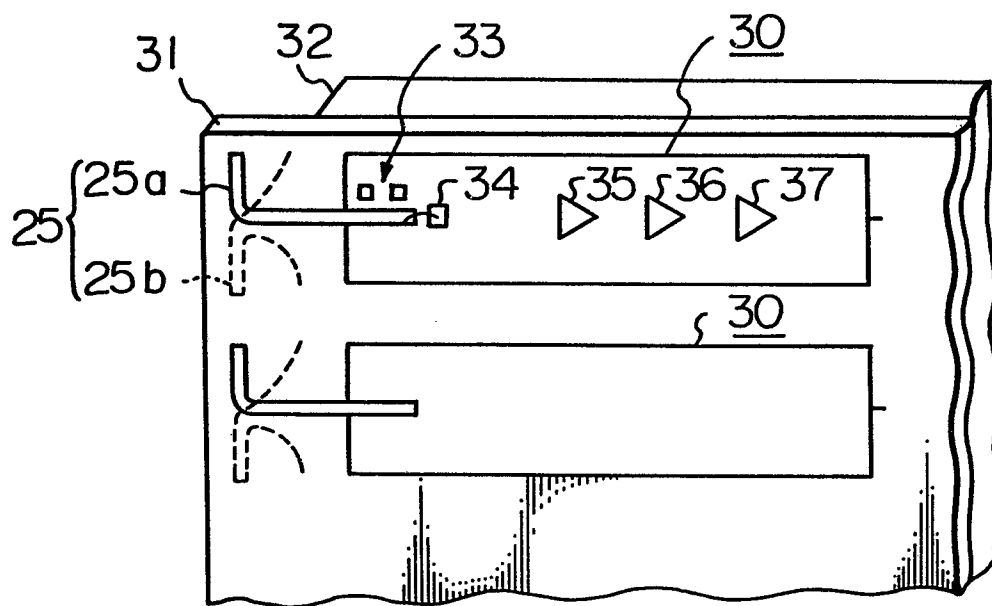
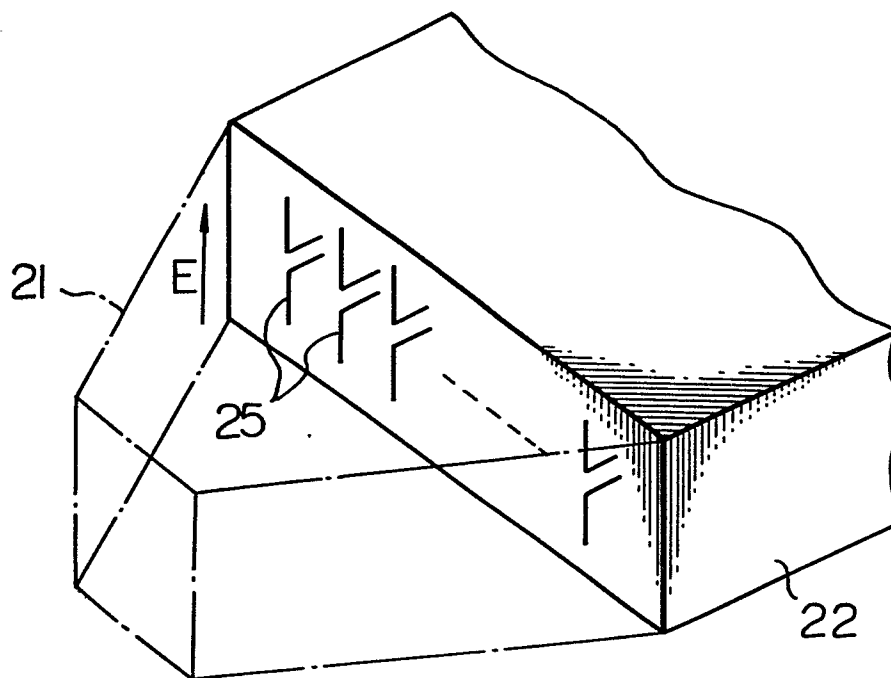
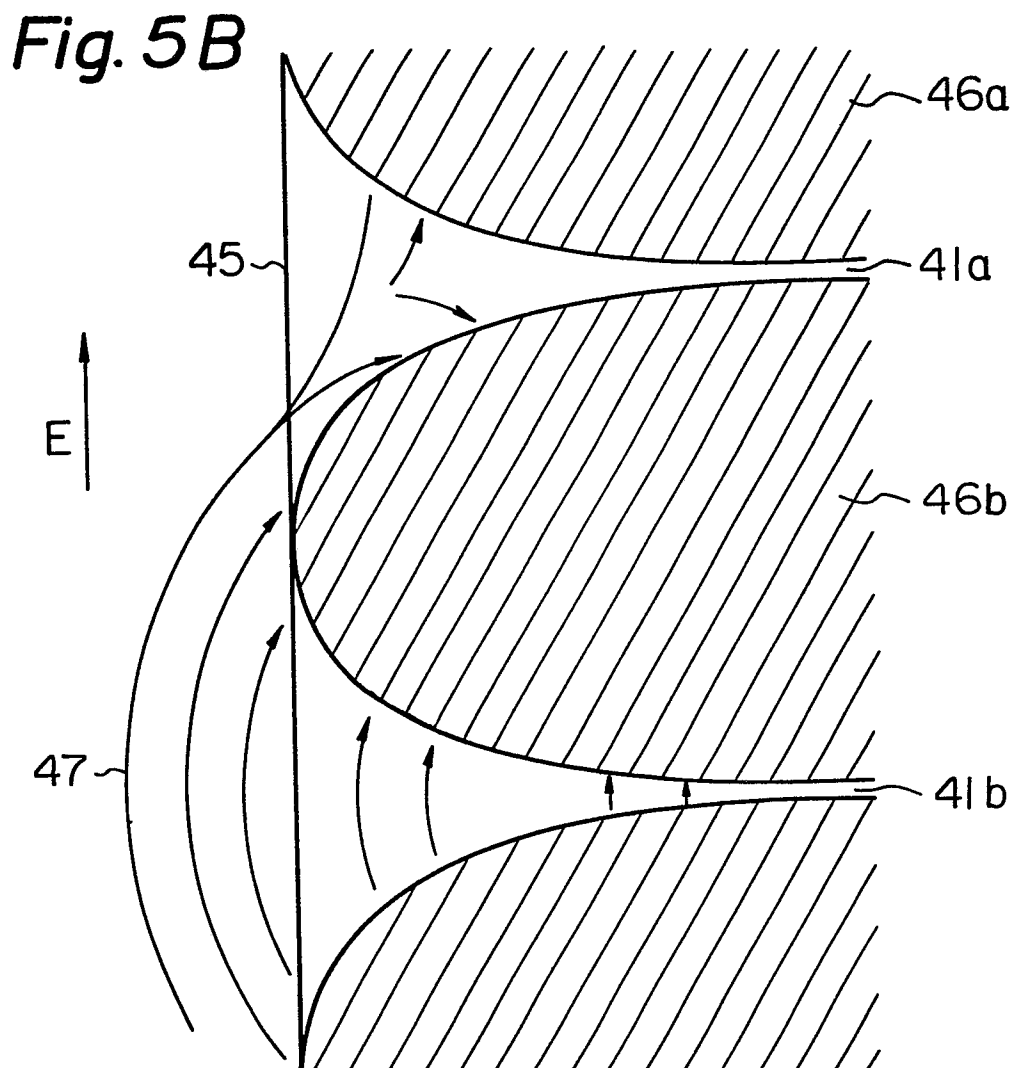
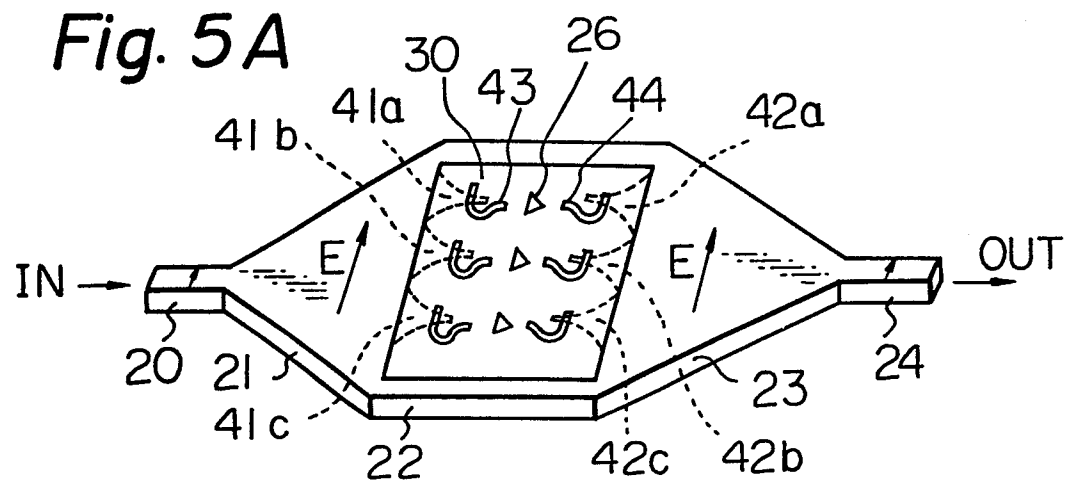


Fig. 3*Fig. 4*



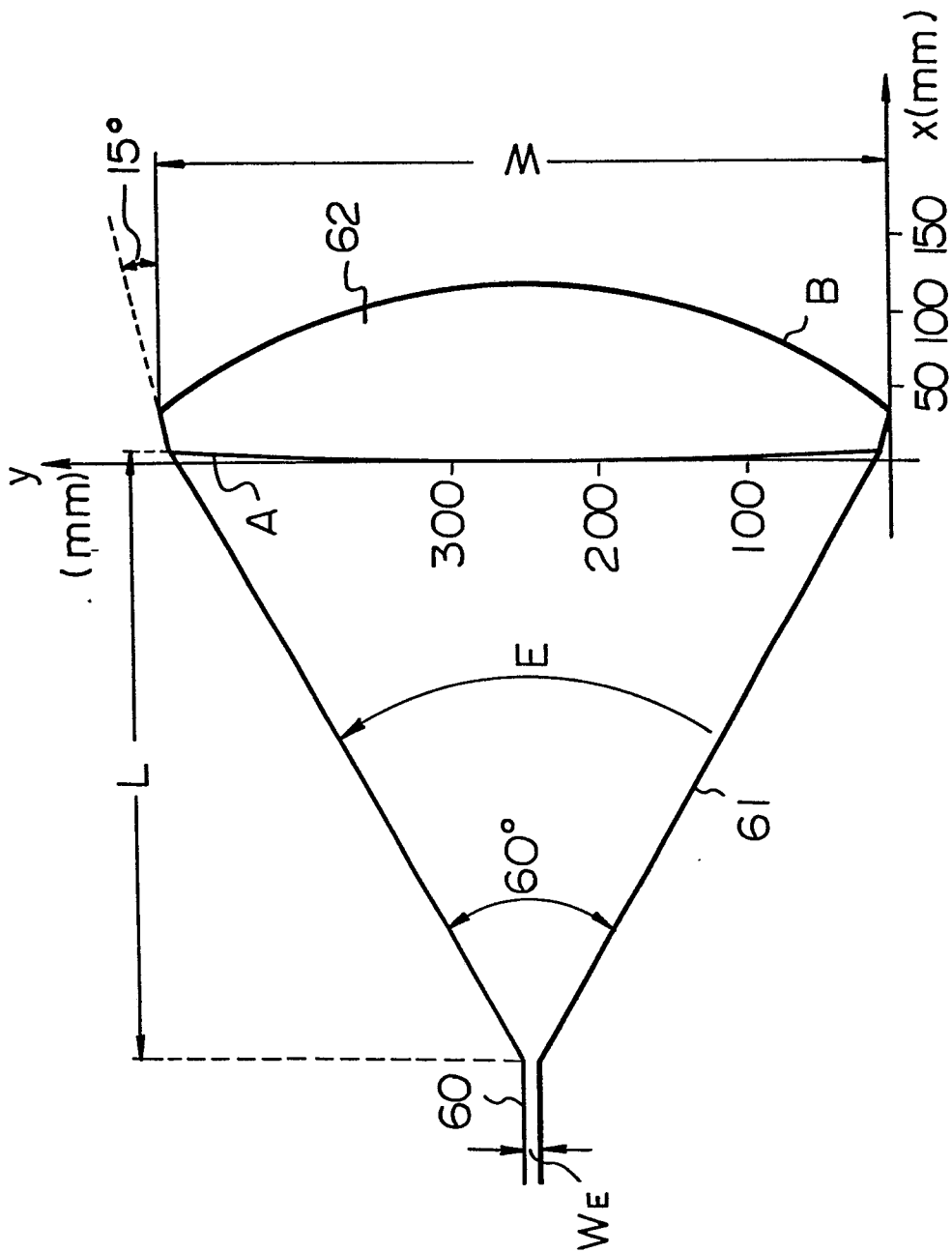


Fig. 7

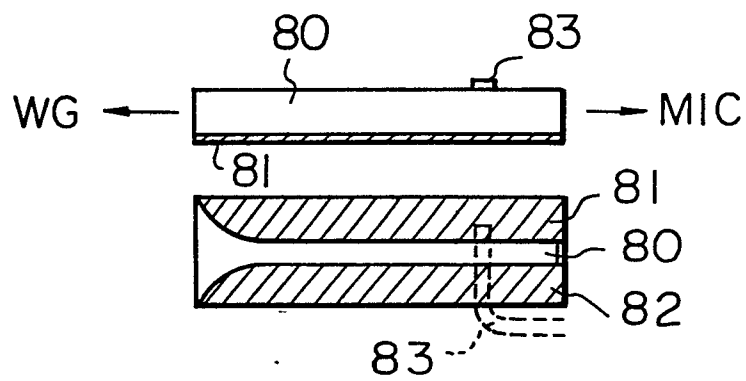
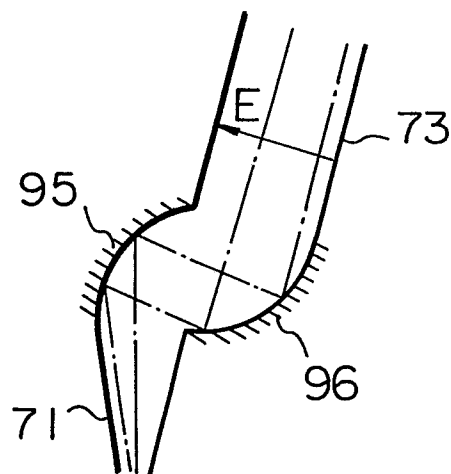
Fig. 8*Fig. 9*

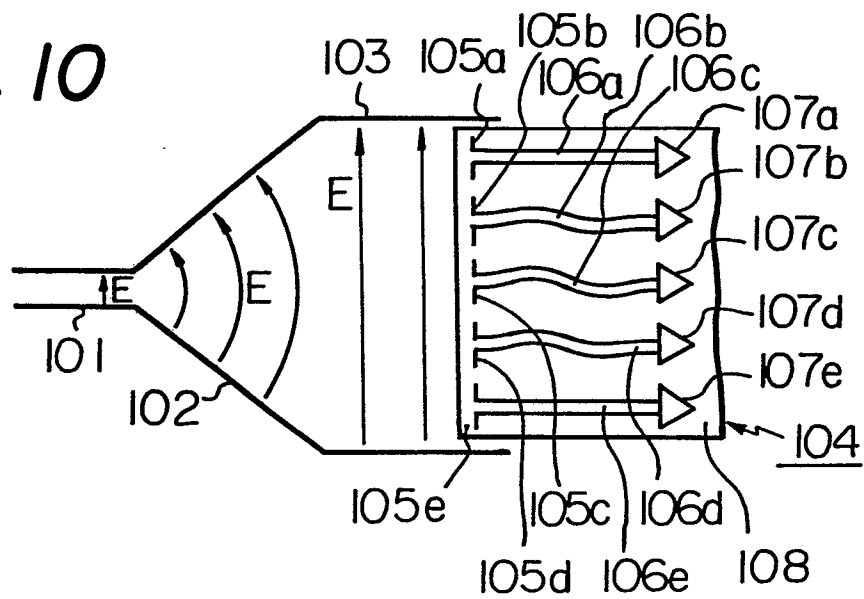
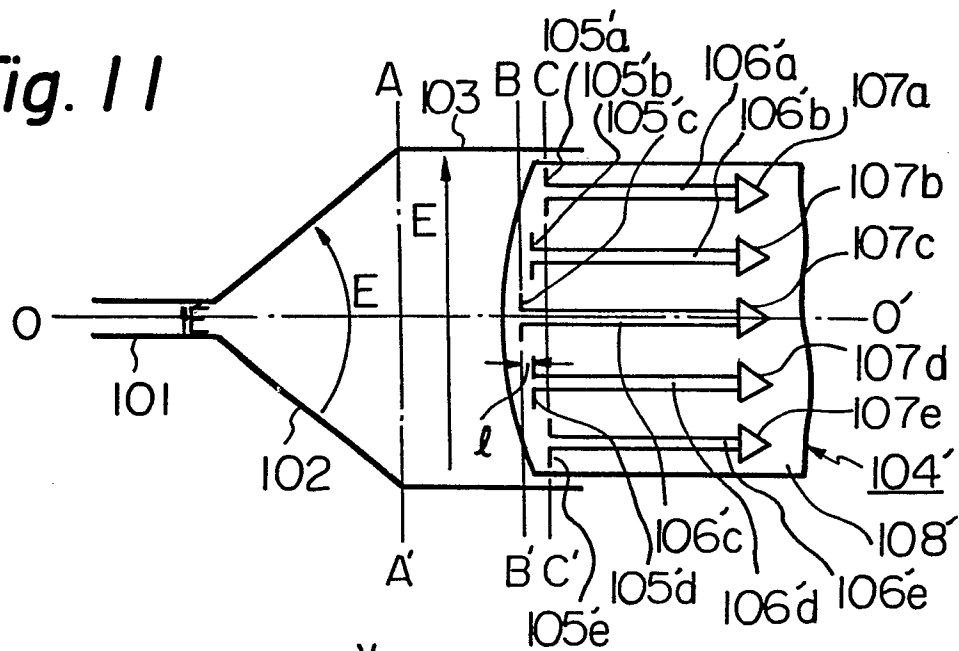
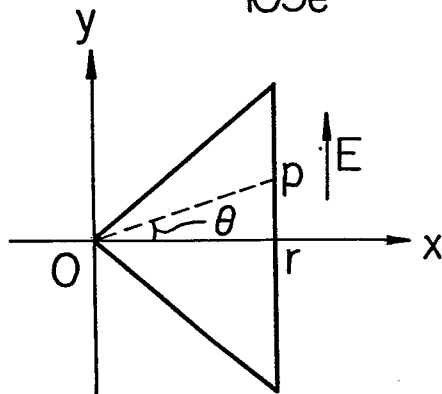
Fig. 10**Fig. 11****Fig. 12**

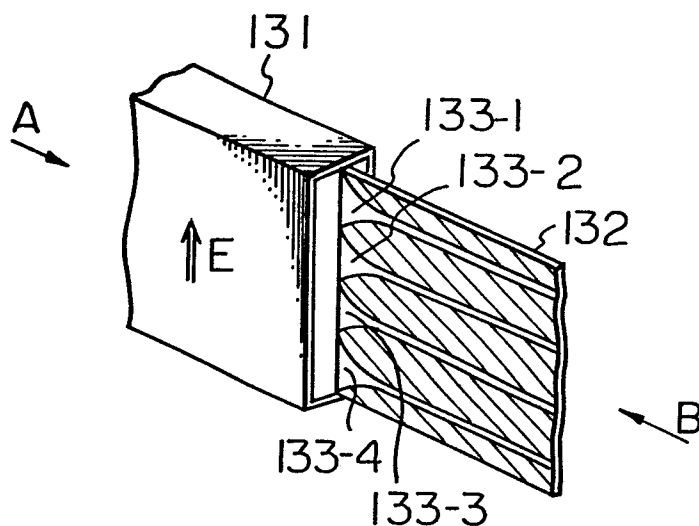
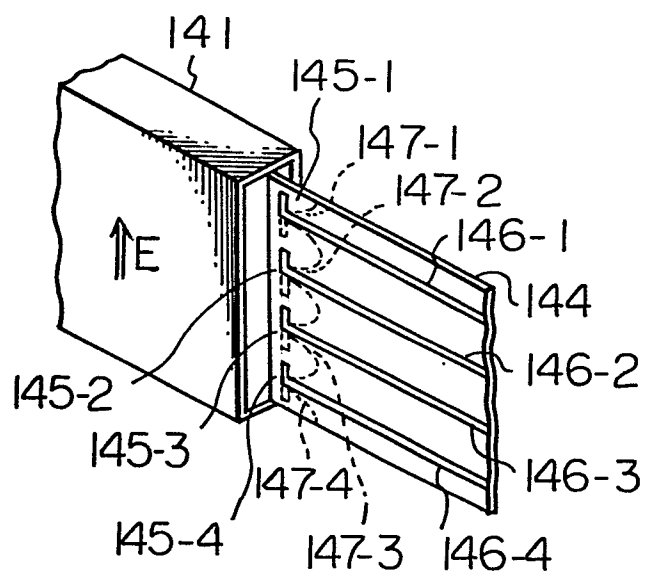
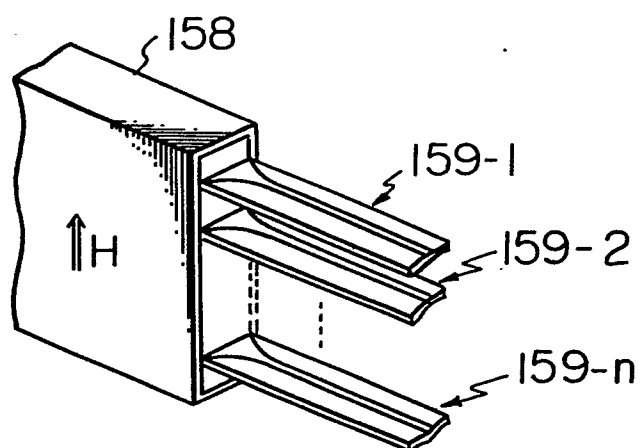
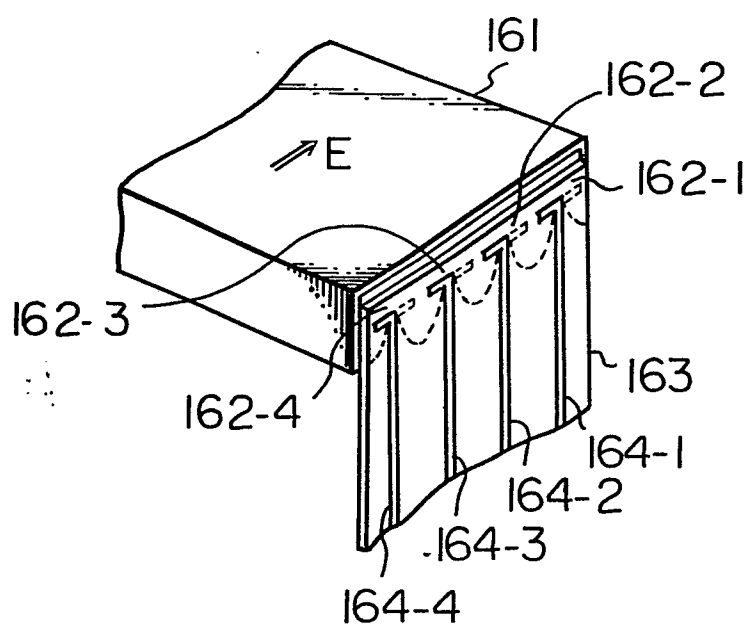
Fig. 13*Fig. 14*

Fig. 15*Fig. 16*

10/14

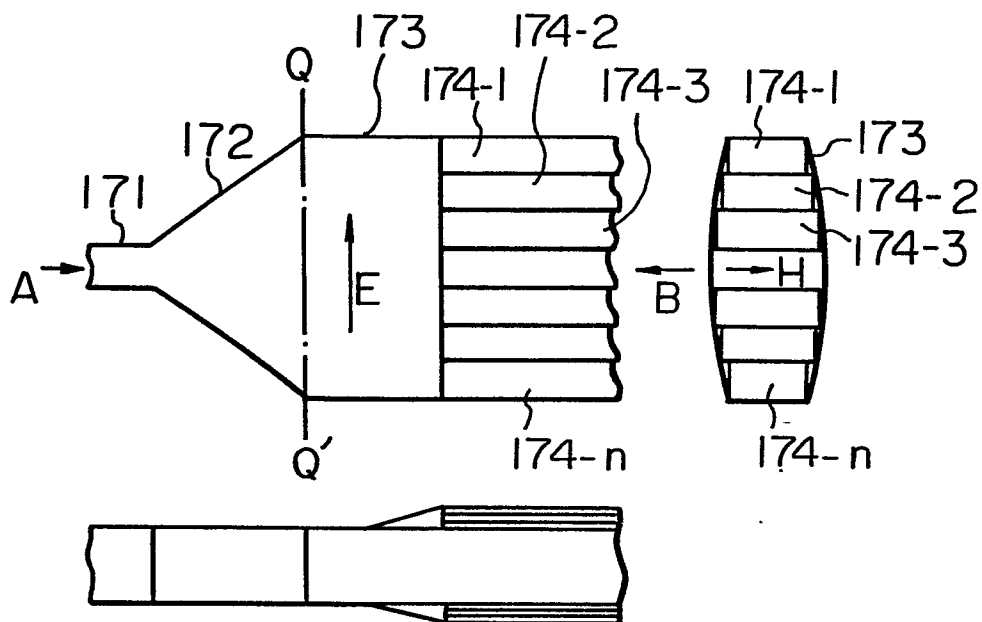
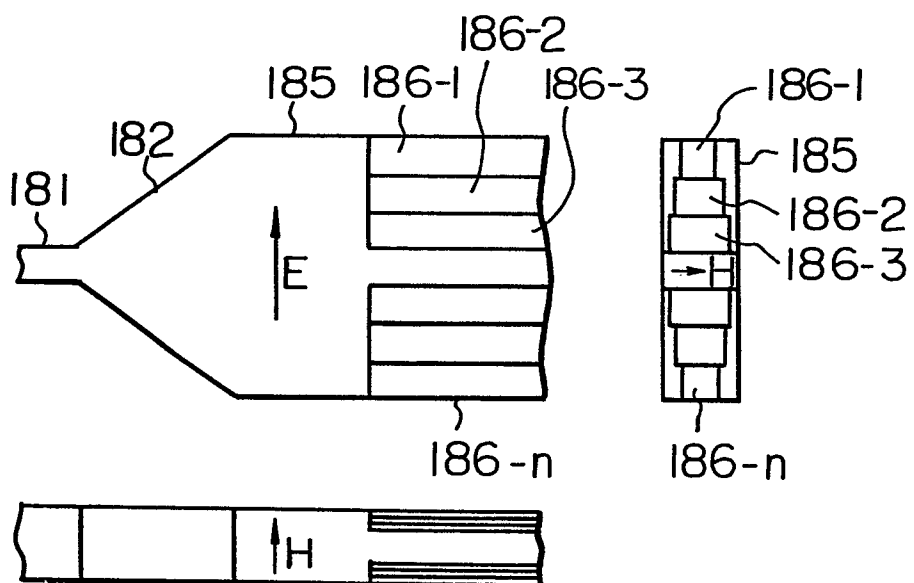
Fig. 17*Fig. 18*

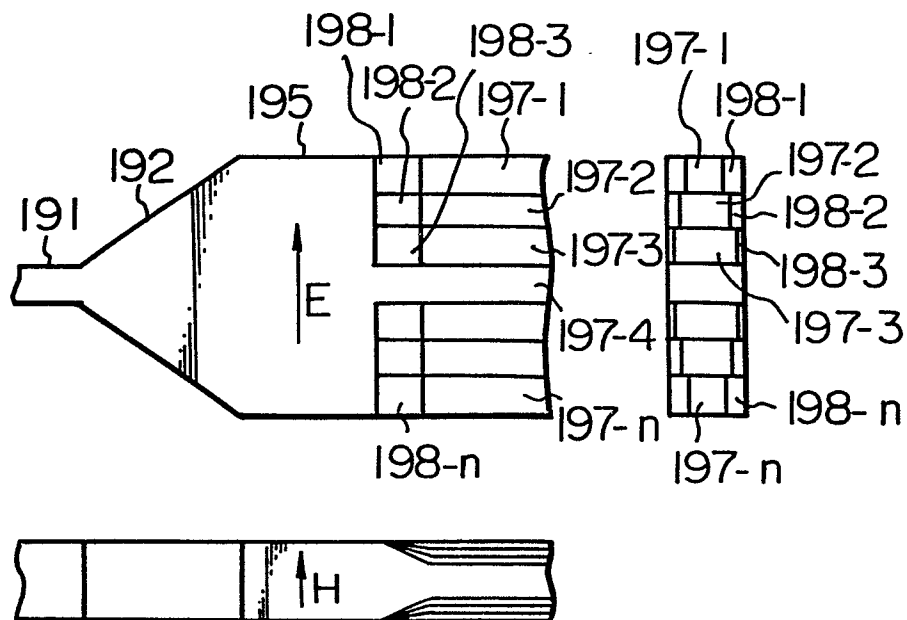
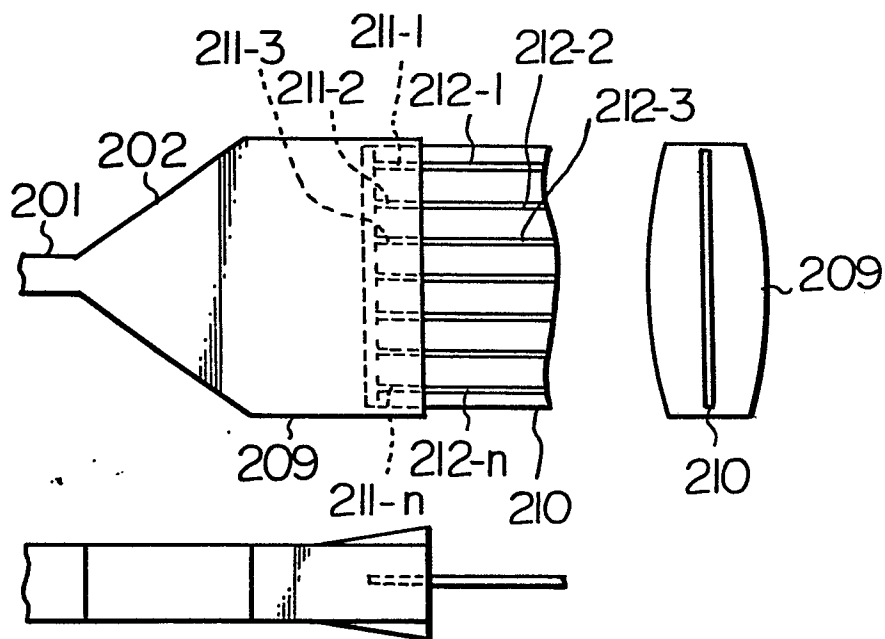
Fig. 19*Fig. 20*

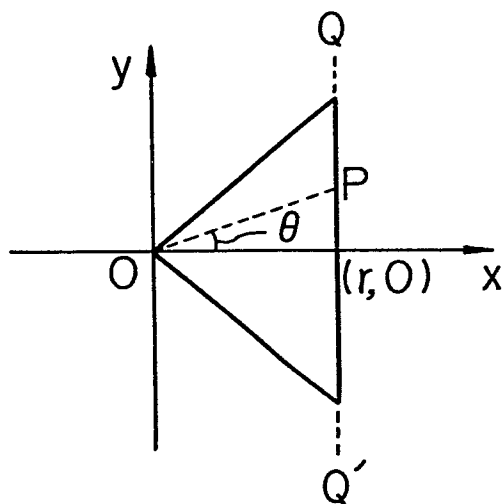
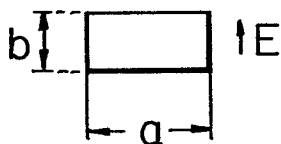
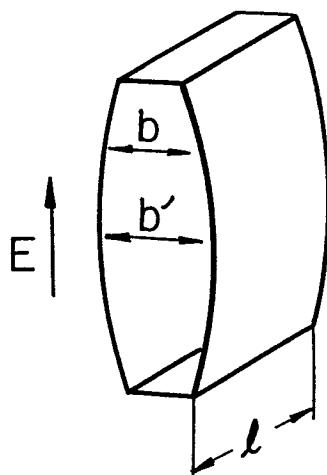
Fig. 21*Fig. 22**Fig. 23*

Fig. 24

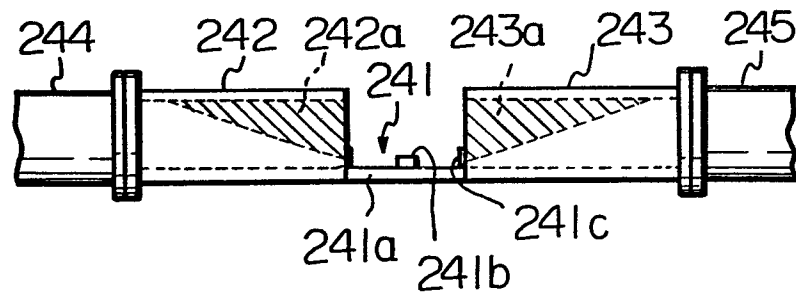


Fig. 25

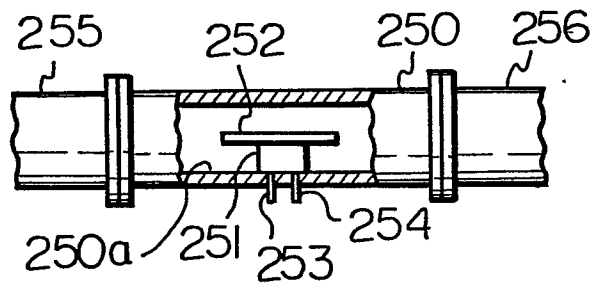


Fig. 26

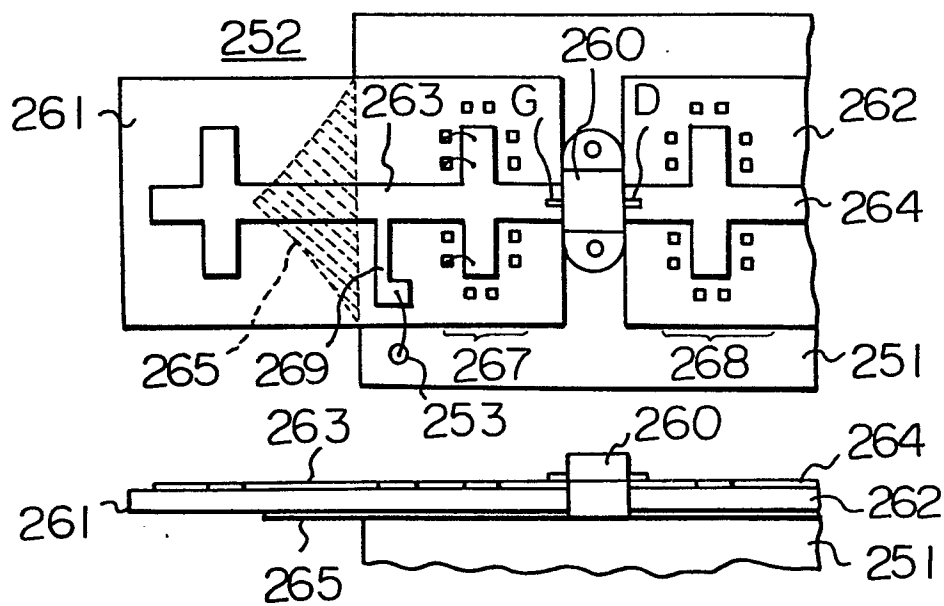
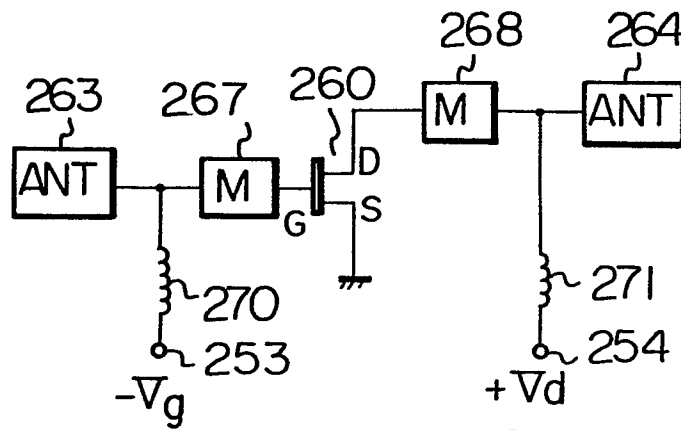
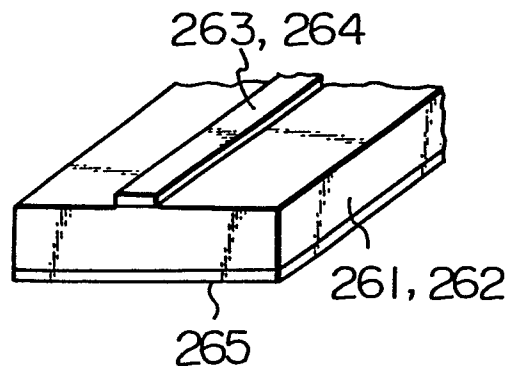


Fig. 27*Fig. 28**Fig. 29*