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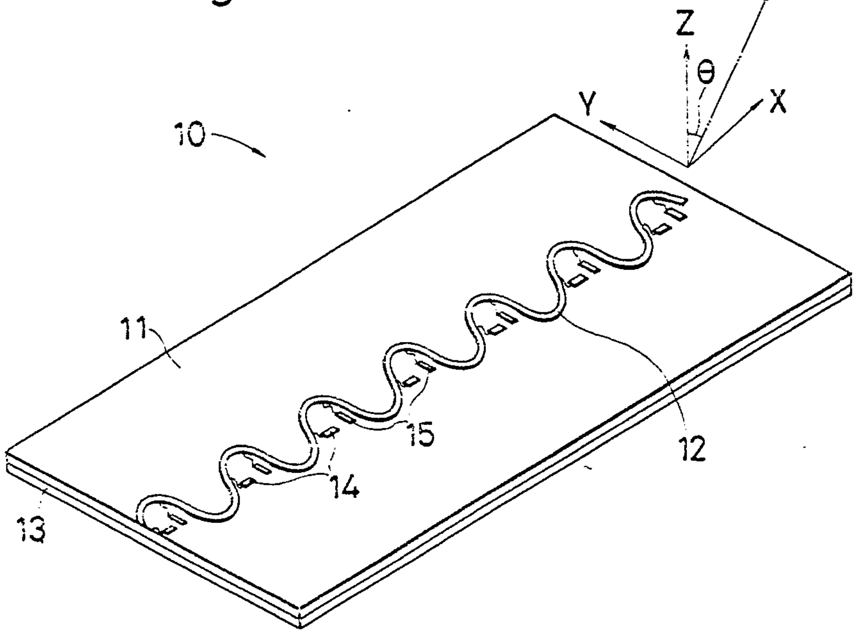
(54) **Phase control microstripline antenna.**

(57) A phase control microstripline antenna (10, 10a, 10e, 10f) comprises a dielectric substrate (11), singular or plural strip conductors being bent periodically and a ground conductor (13). A single or a plurality of resonance elements (14, 15, 20, 21, 32, 38, 42, 49, 50, 53) for being supplied with electric current from a predetermined position of singular or plural strip conductors (12, 30, 31, 40, 41) in every period of the strip conductors (12, 30, 31, 40, 41) are disposed to control phase of electric wave being radiated from the strip conductors (12, 30, 31, 40, 41).

Fig. 2



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PHASE CONTROL MICROSTRIPLINE ANTENNA

This invention relates to a microstripline antenna generally known as a plane antenna, and more particularly to a phase control microstripline antenna designed to restrict the changes in the directivity of generated beams, if the excitation frequency varies, by controlling the phase of the generated beams.

Conventionally, for example, in satellite communications, microwave communications or radar, beam antenna of high gain in circularly polarized waves has been needed. As such beam antennas, the microstripline antennas are widely used as plane antennas. Such microstripline antennas had such a problem that the beam generation direction changes as the excitation frequency varies as described below.

Fig. 1 is a diagram explaining a strip conductor 1 of a typical conventional microstripline antenna. In this drawing, dielectric substrate and ground conductor are omitted. A case is illustrated herein when a beam is generated in a direction shifted by angle θ (indicated by arrow A1 in Fig. 1) with respect to the normal 2 of a dielectric substrate on which the strip conductor 1 is mounted. When said strip conductors 1 are disposed at array pitched (array period) L, said arrow A1 is assumed at every part (called antenna unit) 3 in every repetitive period of the strip conductors 1 in the following explanation.

At an adjacent arrow A1, when a leg 4 of a perpendicular line is set on the start end of the arrow at the right side from the left side in Fig. 1, the distance d from the intersection of said perpendicular line leg 4 and said left side arrow to the start point of the left side arrow is expressed as

$$d = L\sin\theta \qquad (1)$$

If, at this time, a beam is generated from the strip conductor 1 in the direction of said arrow A1, concerning the number of waves k of the excitation frequency of the strip conductor 1, the spatial phase difference between the start end terminal end of one period is

$$kL\sin\theta \qquad (2)$$

and the number of waves k is expressed as

$$k = 2\pi/\lambda \qquad (2\,a)$$

where λ is the free space wavelength.

On the other hand, an electric current I is flowing in the strip conductor 1, and the intensity of this current I is assumed as

$$I = I_0 e^{-j\beta s} \qquad (3)$$

where I0 is the maximum amplitude, and symbol s denotes the length of the strip conductor 1 measured along the strip conductor 1, and variable β is

$$\beta = 2\pi/\lambda g \qquad (4)$$

where λg is the wavelength of current I. As for β in equation (4), the following relations are established.

$$\beta = \delta k \qquad (4\,a)$$

$$\delta = \beta/k = \lambda/\lambda g \qquad (4\,b)$$

Between the start point 3a and the terminal point 3b of said antenna unit 3 of the strip conductor 1, the phase of said current I is shifted by βL_2 (L_2 is the overall length measured along the strip conductor 1 in the antenna unit 3 of the strip conductor 1). Therefore, together, with equation (2), a phase difference of

$$\beta L_2 - kL\sin\theta \qquad (5)$$

is caused in the spatial wave generated from the strip conductor 1. At the same time, the beam is generated in the direction of the angle θ in which

$$\beta L_2 - kL\sin\theta = 2n\pi \qquad (6)$$

is established, where n is an integer.

Putting equations (4a), (4b) into equation (6) yields

$$k(\delta L_2 - L\sin\theta) = 2n\pi \qquad (7)$$

In equation (6), the number of waves k is a value which varies with the excitation frequency as indicated in equation (4), and therefore in the conventional microstripline antenna using strip conductors 1 shown in Fig.1, the beam generating direction was changed, though not desired, when the excitation frequency varied.

It is hence a primary object of this invention to present a phase control microstripline antenna improved so as to prevent the beam generation direction from being deviated undesirably if the excitation frequency varies by solving the above-discussed problems.

To achieve the above object, this invention presents a phase control microstripline antenna comprising a dielectric substrate, singular or plural strip conductors being bent periodically and a ground conductor characterized in that:

a single or a plurality of resonance elements for being supplied with electric current from a predetermined position of singular or plural strip conductors in every period of the strip conductors are disposed to control phase of electric wave being radiated from the strip conductors.

In a preferred embodiment, the resonance elements are formed in pairs and like rectangular plates, each having a length of half period of exciting current.

In another preferred embodiment, each of the resonance elements is connected with each of the strip conductors through a supplying line having a length of quarter period of the exciting current.

In still another preferred embodiment, a length from a start end of the period to an electric supplying point of the resonance element most adjoining to the start end is selected to be a half period of the exciting current, and a length from a terminal end of the period to a connection point of the resonance element most adjoining to the terminal end is selected to be three quarter period.

In a further preferred embodiment, a single or a plurality of the resonance elements in every period are supplied with electric current through a plurality of the strip conductors.

Further, to achieve the object this invention presents a phase control microstripline antenna comprising a dielectric substrate, singular or plural strip conductors being bent periodically and a ground conductor characterized in that:

a single or a plurality of resonance elements being electrically coupled, in every period of the strip conductors, which the strip conductors within the period through the dielectric substrate are disposed to control the phase of electric wave being radiated from the strip conductors.

In a preferred embodiment, the resonance elements are partially overlapped with the strip conductors in the direction that the strip conductors are extending, the dielectric substrate being interposed therebetween.

According to this invention, in a microstripline antenna disposing periodically bent strip conductors on the surface of one side of a dielectric substrate and ground conductors on the entire surface of the other side, one or plural resonance elements being supplied with electric current from a predetermined position of one or plural strip conductors in every period of said strip conductors are disposed. As a result, it is possible to control the phase of the excitation current flowing in the constitution in every period of said strip conductors and said resonance elements, and therefore it is possible to prevent the beam direction from changing if the excitation frequency varies.

Moreover, in every period of strip conductors, either singular or plural resonance elements electrically coupled by way of strip conductors and dielectric in said period are disposed. In this constitution, too, the phase of the excitation current can be controlled.

These and other objects of this invention, along with the characteristics and advantages thereof, will be more clearly understood and appreciated in the following detailed description made in conjunction with the drawings.

Fig. 1 is a plan showing a typical prior art;

Fig. 2 is a perspective view of an antenna 10 in an embodiment of this invention;

Fig. 3 is a plan of one repetitive period of the antenna 10;

Fig. 4 is a plan showing the constitution concerning a strip conductor 12 possessing a crank shape in an embodiment of this invention;

Fig. 5 is a drawing to explain the principle of this invention;

Fig. 6 is an equivalent circuit diagram of the constitution shown in Fig.5;

Fig. 7 to Fig.9 are graphs to explain the characteristics of the antenna 10 of this embodiment;

Fig. 10 is a plan showing the constitution of other embodiment of this invention;

Fig. 11 is a plan showing the constitution of a further different embodiment of this invention;

Fig. 12 is an equivalent circuit diagram of the constitution shown in Fig.11;

Fig. 13 is a graph to explain the characteristics of the constitution shown in Fig. 11;

Fig. 14 to Fig.16 are perspective views to explain the shape of strip conductors 12 in other embodiments of this invention;

Fig. 17 and Fig.18 are plans to explain the shape of the strip conductor 12 for realizing a linearly polarized wave;

Fig. 19 is a plan showing the connected state of parts in another embodiment of this invention;

Fig. 20 is a plan showing a constitution example of antenna 10e of a further different embodiment of this invention;

Fig. 21 is a drawing to explain the principle of generation of a circularly polarized wave beam by the antenna 10e shown in Fig. 20;

Fig. 22 is a plan showing a constitution example of antenna 10f of still another embodiment of this invention;

Fig. 23 is a plan of resonance element 38 of a different embodiment of this invention;

Fig. 24 is a plan of an antenna unit 22 of another embodiment of this invention;

Fig. 25 is a plan of an antenna unit 22 of still another embodiment of this invention;

Fig. 26 is an equivalent circuit diagram of antenna unit 22 shown in Fig. 25;

Fig. 27 is an equivalent circuit diagram of an impedance unit 55 shown in Fig. 26;

Fig. 28 is a plan showing a constitution of a still different embodiment of this invention;

Fig. 29 is a plan showing a constitution of a further still different embodiment of this invention;

Fig. 30 is a perspective view showing a constitution of another embodiment of this invention;

Fig. 31 is a sectional view along section line XXXI-XXXI in Fig. 30; and

Fig. 32 and Fig. 33 are plans each showing constitution of further different embodiments of this invention.

Referring now to the drawings, some of the preferred embodiments of this invention are described herein.

Fig. 2 is a perspective view of a phase control microstripline antenna (hereinafter abbreviated as antenna) 10 in one of the embodiments of this invention. The basic structure of the antenna 10 is described below by reference to Fig.2. The antenna 10 includes a substrate 11 made of a flat dielectric material, and a strip conductor 12, for example, realized by a periodically bent copper as shown in Fig. 2, is formed on the surface of one side thereof. On the other side (back side) the strip conductor 12 of the substrate 11, a ground conductor 13 is adhered on the whole surface. On the surface of the strip conductor 12 on the substrate 11, for example, rectangular first resonance elements 14 and second resonance elements 15 are disposed as described below, in every period of the bent shape of the strip conductor 12.

Fig. 3 is a magnified plan of one period portion (hereinafter called an antenna unit) 22 of the strip conductor 12. Referring also to Fig. 2, the constitution of the antenna 10 is described in details below. The bent shape of the strip conductor 12 may be an arbitrary shape, and various shapes such as crank shape descirbed below are freely selected. This strip conductor 12 is periodically curved in an array period L at every antenna unit 22, and a power feed line 16 for feeding power to the first resonance element 14 is disposed at the position of length L1 along the strip conductor 12 from the start end 12a of each period. From the terminal end 12b of said repetitive period to the start end 12a, a power feed line 17 for feeding power to the second resonance element 15 is disposed at the position of length L2 along the strip conductor 12.

The lengths of these power feed line 16, 17 measured along their shape are respectively L3 and L4, and the lengths of the approximately rectangular resonance elements 14, 15 are selected at L5, L6. The start end 12a and terminal end 12b of the strip conductor 12 are distinguished so that the power feeding side to the strip conductor 12 is the start end.

The antenna 10 having such construction emits a circularly polarized beam by the strip conductor 12, transforms the beam released from the resonance elements 14, 15 into circularly polarized waves, and synthesizes them. As a result, the irradiation efficiency of the beam emitted from the antenna 10 is improved, and the direction of the generated beam is not changed excessively if the excitation frequency varies. The principle for obtaining such characteristic is described below.

Concerning the enhancement of irradiation efficiency mentioned above, generally, the microstripline antenna containing a strip conductor having a periodically bent shape is known to be relatively low in the irradiation efficiency. On the other hand, a wave source of stationary wave type, for example, the resonance elements 14, 15 used in this embodiment are known to be outstandingly high in the irradiation efficiency.

Therefore, the antenna 10 of this embodiment realizing by combining them can accomplish a very high irradiation efficiency not experienced in the conventional microstripline antenna.

Hereinafter, for the sake of simplicity of explanation of the operating principle of the antenna 10 of this invention shown Fig. 2 having the above characteristics, the bent shape of the strip conductor 12 is described as crank shape as shown in Fig. 4, but it is evident, that the conclusion and various effects of action of this embodiment may be similarly applied to the antenna 10 of arbitrarily bent shape shown in Fig. 2.

Fig. 5 is a drawing to describe the principle that the antenna unit 22 shown in Fig. 4 can generate beams of circularly polarized wave. Referring to Fig. 2 to Fig. 5, this principle is explained below. Here, said lengths L1 to L6 are defined as follows. The following parameters are used:

1. Lateral length x_0 in Fig. 4 from start end 12a to connection point 19 to strip conductor 12 of power feed line 17;
2. Lateral length s_0 in Fig. 4 from terminal end 12b to connection point 19;
3. Length 2 × a of the part along the array direction (lateral direction in Fig. 4) A1 of strip conductor 12, being the part enclosing the resonance elements 14, 15 of strip conductor 12;
4. Length b in the direction vertical to said array direction A1 of strip conductor 12; and
5. Overall length L from start end 12a to terminal end 12b of strip conductor 12

$$L = 2a + c \quad (8)$$

Using these parameters, the length L1, L2 are defined as follows.

$$L1 = x_0 + b \quad (9)$$
$$L2 = s_0 + c/2 \quad (10)$$

Variables of the right side of equations (9) and (10), and said lengths L3 to L6 are defined as follows.

$$x_0 + b = \lambda g/2 \quad (11)$$
$$s_0 + c/2 = 3\lambda g/4 \quad (12)$$
$$L3 = L4 = \lambda g/4 \quad (13)$$
$$L5 = L6 = \lambda g/2 \quad (14)$$

In this condition of defining the lengths, the principle of realization of circularly polarized wave by the antenna unit 22 shown in Fig. 4 is described below. From the start end 12a side of the strip conductor 12, an electric current with wavelength of λg is passed at time $t = 0$, the direction of the current flowing in the strip conductor 12 is shown in Fig. 5(1). From start end 12a to the connection point 18, the half period portion of the current is assumed to be in the direction indicated by arrow B1. Therefore, in the power feed line 16, an electric current in the direction of arrow B2 toward the connection point 18 flows, in which the length L3 of the power feed line 16 is λ g/4 as shown in equation (13), and the current in the direction of arrow B2 is present as indicated by arrow B3 by the portion of the half of the first resonance element 14 in the longitudinal direction. In the remaining portion of the first resonance element 14 (length $\lambda g/4$), a current of $\lambda g/4$ indicated by arrow B2 in the opposite direction to the arrow B3 appears.

Between the connection points 18, 19 of the strip conductor 12, there is a length of 3 $\lambda g/4$, and hence in part of this area, the half period portion of the current indicated by arrow B5 appears. In the remaining part, passing through the connection point 19, an electric current of the half period portion indicated by arrow B6 reading to the part of the strip conductor 12 in the vertical direction in Fig. 5 appears. Part of this current flows into the power feed line 17 by the length of $\lambda g/4$. Therefore, in the resonance element 15, as indicated by arrow B7, a current for the portion of half period appears. On the other hand, opposite to the current of the arrow B6 at strip conductor 12, a current for the portion of half period indicated by arrow B8 appears toward the terminal end 12b. At this time, as shown in Fig. 5(1), the component in the lateral direction of Fig. 5 is canceled to be zero, and only the component in the vertical direction in Fig. 5 is left over. Thus, at the moment of Fig. 5(1), the generated beam is deflected in the direction of arrow F1.

The state after lapse of time 1/4fo from the time in Fig. 5(1) is shown in Fig. 5(2). At this time, the directions of currents at strip conductor 12, power feed lines 16, 17, and resonance elements 14, 15 are indicated by arrows C1 to C10 in Fig. 5 (2). In this case, according to the principle explained in reference to Fig. 5(1), the deflection direction of the generated beam is, as indicated by arrow F2, 90 degrees rotated from the stage in Fig. 5(1).

After further lapse of time 1/4fo from the moment in Fig. 5(2), that is, 2/4fo after Fig. 5(1), the direction of current in each part of the strip conductor 12 becomes as shown in Fig. 5(3), and the generated beam is deflected in the direction of arrow F3.

In time 1/4fo from the moment in Fig. 5(3), that is, 3/4fo after Fig. 5(1), the current in the strip conductor 12 is as shown in Fig. 5(4). In this case, the electric current in each half wavelength at the strip conductor 12 is indicated by arrows E1 to E10, and the deflection direction of the generated beam obtained by synthesizing them is indicated by arrow F4.

Thus, as shown in Fig. 5(1) to Fig. 5(4), concerning the period 1/fo of the current flowing in the strip conductor 12, the constitution shown in Fig. 4 generates a clockwise circularly polarized beam in each period.

Fig. 6 is an equivalent circuit diagram of the antenna unit 22 shown in Fig.4. Relating to resonance elements 14, 15, impedances Z1, Z2 are assumed, and an impedance Z0 is assumed for the remaining strip conductor 12. Besides, at input voltage of Vi, input impedance of Zi and excitation current of Vi, input impedance of Zi and excitation current of Ii, suppose output voltage Vout, output current Iout are obtained. At this time, the following relation is established among the four terminal circuit constants A, B, C, D.

$$\begin{pmatrix} Vi \\ Ii \end{pmatrix} = \begin{pmatrix} A & B \\ C & D \end{pmatrix} \cdot \begin{pmatrix} Vout \\ Iout \end{pmatrix} \quad \cdots (15)$$

By the way, the repetitive propagation constant θ is expressed as follows, relating to the attenuation αi and phase βi of the antenna 10.

$$\Theta = \alpha i + \beta i \quad (16)$$

Relating to such repetitive propagation constant Θ, the following relations are established.

$$e^{\Theta} = (A+D)/2 + \sqrt{[(A+D)/2]^2 - 1} \quad \cdots (17)$$

$$e^{-\Theta} = (A+D)/2 - \sqrt{[(A+D)/2]^2 - 1} \quad \cdots (18)$$

The graph in Fig. 7 shows the result of measurement, in the condition shown in Table 1 below, of the attenaution αi and variation $\Delta(\beta i)$ of phase βi described below, obtained by solving the above equations (16) to (18). The axis of abscissas in Fig. 7 refers to the normalized figure of variation Δf of the center frequency fo being divided by the center frequency fo. Line ℓ1 shows the change in the phase variation Δ-(βi) of the strip conductor 12 only in the antenna unit 22 in Fig.4, and lines ℓ2, ℓ3 denote the phase variation $\Delta(\beta i)$ and change of attenuation αi of the antenna 10.

Here, the direction of the beam generated from the antenna 10 is determined by the priciple stated in relation to the prior art above, and is practically generated in the direction to satisfy the condition of equation (6). Concerning equation (6), if the center frequency fo varies, the number of waves k is also changed. In such a case, the condition corresponding to equation (6) is expressed as follows.

$$[\beta L_2 + \Delta(\beta L_2)] - (k + \Delta k)L_1 \sin(\theta + \Delta\theta) = 2n\pi \quad (19)$$

At this time, setting an approximation condition of

$$|\Delta\theta| \ll 1 \quad (20)$$

when equation (19) is solved by the direction variation $\Delta\theta$, we obtain

$$\Delta\theta = [\Delta(\beta L_2) - \Delta k L \sin\theta] / kL\cos\theta \quad (21)$$

Assuming the direction of the beam to be emitted from the antenna at $\theta = 90$ degrees, the direction variation $\Delta\theta$ is obtained as follows:

$$\Delta\theta = \Delta(\beta L_2)/kL \quad (22)$$

The antenna 10 of this embodiment includes resonance elements 14, 15 in addition to strip conductor 12, and the calculated direction variation $\Delta\theta$ is obtained as follows:

$$\Delta\theta = \Delta\beta\, i/kL \qquad (23)$$

Therefore, to restrict the direction variation $\Delta\theta$ of the irradiation beam at the antenna 10 in this embodiment, it is required that the relation

$$|\Delta\beta i| \ll |\Delta(\beta L_2)| \qquad (24)$$

be established.

The condition in equation (24) above appears, in a graph as shown in Fig. 7, as the tendency of the inclination of the curve to express the obtained phase amount to approach to zero as far as possible. It is preferable, of course, when the attenuation αi is smaller.

The antenna 10 in the above condition of this embodiment brought about very excellent results as shown by line $\ell 2$.

Fig. 8 is a graph showing the changes in said attenuation αi and phase variation $\Delta(\beta i)$ when the overall length ℓ of the strip conductor 12 along the extending direction is slightly increased or decreased and the lengths L3, L4 of the power feed lines 16, 17 are slightly shortened from the dimensions in Fig. 7, in the antenna 10 shown in Fig. 4. Solid lines $\ell 1$, $\ell 7$ refer to the strip line 12 only, and broken lines $\ell 5$, $\ell 8$ represent the slightly decreased overall length ℓ, and dotted lines $\ell 6$, $\ell 9$ relate to the overall length ℓ slightly extended, respectively showing the attenuation α i and phase variation $\Delta(\beta$ i).

In this condition, it is understood that a characteristic different from that in Fig. 7 be obtained. Fig. 9 is a graph showing the data when the value Q of the antenna 10 is decreased in the same condition basically as in Fig. 8. The curves in Fig. 9 correspond to those in Fig. 8, and the corresponding curves are identified with the subscript "a" attached the reference codes $\ell 4$ to $\ell 9$ used in Fig. 8.

A similar phenomenon to the explanation about the antenna 10 having the basic constitution of Fig. 4 is not limited to the crank shape of the strip conductor 12, but it can be realized also by a strip conductor 12 having an arbitrary periodic shape as shown in Fig. 3. In such a case, the shape of the resonance elements 14, 15 provided in connection to the strip conductor 12 is not limited to the shape shown in Fig. 3, but it is possible to realize similarly in a cross overlapped shape, that is, a resonance element 20 shaped as shown in Fig. 10. The resonance element 20 is fundamentally obtained by cutting off the four corners of a rectangular metal plate in a square shape.

Besides, this invention may be similarly realized by using a resonance element 21 shaped as shown in Fig. 11. The resonance element 21 is formed by cutting off the tops on the diagonal lines of a rectangular metal plate, and it is connected to the strip conductor 12 by a single power feed line 22.

The antenna 10a as shown in Fig. 11 is equivalently indicated by a circuit shown in Fig. 12. As the equations corresponding to said equations (15) to (18) in such equivalent circuit, the following equations (25) and (26) are known.

$$\begin{pmatrix} V_1 \\ I_1 \end{pmatrix} = \begin{pmatrix} A & B \\ C & D \end{pmatrix} \cdot \begin{pmatrix} V_2 \\ I_2 \end{pmatrix} \qquad \cdots (25)$$

$$\begin{aligned} \Theta &= \alpha i + j\beta i \\ &= \ell n\, V_1/V_2 \\ &= \ell n\, I_1/I_2 \qquad (26) \end{aligned}$$

Concerning equations (17) and (18), the same numerical expressions are used.

Relating to the constitution shown in Fig. 11, the data of measuring the attenuation αi and phase variation $\Delta(\beta i)$ by the similar calculating procedure as in the previous embodiment are shown in Fig. 13. Line ℓ 1 of Fig. 13 refers to the data of the strip conductor 12 only, and lines $\ell 10$, $\ell 11$ represent the phase variation $\Delta(\beta i)$ and attenuation αi of the constitution shown in Fig. 11.

Thus, this invention is not intended to limit the shape of the strip conductor 12 to the crank shape, but the crank shape strip conductor 12 was used in the above descriptions only for the simplicity's sake of explanation. That is, if the strip conductor 12 of this invention is shaped as shown in Fig. 14 to Fig. 16, it is possible to realize similarly.

The beam generated by the phase control microstripline antenna of this invention is not limited to a circularly polarized wave, but by setting up the strip conductor 12 as shown in Fig. 17 and Fig 18, it is possible to realize linearly polarized waves in the directions of arrow F5 and arrow F6. The repetitive shape of the strip conductor 12 of this embodiment is explained as the crank shape, but it is of course possible that it may be any arbitary repetitive shape same as in the above embodiments.

In the constitution in Fig. 17, by selecting the lengths H1 to H3 of each side to compose the crank shaped strip conductor 12 at $\lambda g/2$ with respect to the wavelength λg of the current being applied, it is confirmed that linearly polarized waves in the direction of arrow F5 are realized by the same discussion as in the explanation of Fig. 5.

In Fig. 18, by selecting the lengths H1 to H3 of parts to compose the crank shaped strip conductor 12 as

$$H1 = H2 = \lambda g/4 \quad (27)$$
$$H3 = 5\lambda g/4 \quad (28)$$

it is confirmed that linearly polarized waves in the direction of arrow F6 are realized by the same discussion as above.

At this time, length H4 of the resonance element 21 is selected at $\lambda g/2$, and the setting position on the strip conductor 12 is selected so that the length H5 in Fig. 18 may be $\lambda g/2$. In this constitution, too, the same effects as mentioned in the above embodiments are obtained.

The mode of connection of the strip conductor and resonance elements in this invention is not limited to the above embodiments, but, in Fig.19 for example, it is possible to dispose power feed lines 33, 34 for feeding power to the resonance element 32 on two mutually adjoining strip conductors 30, 31. Here, according to the principle described in the above embodiments, the disposing position of the power feed line 33 relating to the resonance element 32 to the strip conductor 30 is located at the position of length L10 along the strip conductor 30 from the power feed point 37 to the strip conductor 30.

At this time, the length along the strip conductor 31 between the connecting position 35 of the strip conductor 31 for connecting the power feed line 34 and the power feed point 36 for feeding power to the strip conductor 31 in the same phase as the power feed point 37 is selected at L 10. As a result, the phase of the current flowing into the power feed line 34 from the strip conductor 31 is in phase with that of the strip conductor 30. In such constitution, too, it is possible to obtain the same effects as mentioned in the above embodiments.

Fig. 20 is a plan showing a constitution example of an antenna 10e of a further different embodiment of this invention. In the antenna 10e, as shown in Fig. 20, power feed lines 44, 44 for feeding power to a resonance element 42 are respectively disposed on two mutually adjoining strip conductors 40, 41. According to the principle stated in each of the above embodiments, the disposing position of the power feed line 43 relating to the resonance element 42 to the strip conductor 40 is located at the position of length L11 along the strip conductor 40 from the power feed point 45 to the strip conductor 40.

At this time, length L12 along the strip conductor 41 between the connecting position 46 of the strip conductor 41 for connecting the power feed line 44 and the power feed point 47 for feeding power to the strip conductor 41 in phase with the power feed point 45 is selected as

$$L12 = \frac{L11}{2} (2n + 1) \quad (29)$$

Fig. 21 is a diagram to show the principle of generation of beam of circularly polarized wave by the antenna 10e shown in Fig. 20. This principle is described below while referring to Fig. 20 and Fig. 21. The dimensions of the parts of the antenna 10e correspond to those of the antenna unit 22 in Fig. 5.

The principle of capability of such antenna 10e to realize circularly polarized waves if explained below. When an electric current with wavelength λg is passed at time $t = 0$ from the start ends 45, 47 side of the strip conductors 40, 41, the current flow direction on the strip conductor 42 becomes as shown in Fig. 21 (1). From start ends 45, 47 to the connection point 48, it is assumed that the half period portion of the current is in the direction indicated by arrow F1. Therefore, in the power feed line 43, an electric current flows in the direction of arrow F2 toward the connection point 48, but since the length L3 of the power feed line 43 is $\lambda g_1/4$ as shown in equation (13), the current in the direction of arrow F2 is present only for the half portion of the length in the longitudinal direction of the first resonance element 49 as indicated by arrow F3. In the remaining portion (length $\lambda g_1/4$) of the first resonance element 49, a current of $\lambda g_1/4$ indicated by arrow F4 in the opposite direction of arrow F3 appears.

Between connection points 48, 46 of the strip conductors 40, 41, there is a length of 5 λ g/4, and in this part, therefore, the half period portion of the current indicated by arrow F5 appears. In the remaining portion, the current of half period portion each indicated by arrows F6, F7 appears. Part of this current F7 flows into the power feed line 44 by the length of λ g/4. Therefore, at the resonance element 50, the current of the half period portion appears as indicated by arrow F8.

At this time, as shown in Fig. 21(1), the component in the lateral direction in Fig. 21 is canceled to be zero, and only the component in the vertical direction in Fig. 21 is left over, and thus at the moment of Fig. 21(1), the generated beam is deflected in the direction of arrow G1.

The state of the time 1/4fo after the moment of Fig. 21(1) is shown in Fig. 21(2). At this time, the direction of each current in the strip conductors 40, 41, power feed lines 43, 44, and resonance elements 49, 50 is indicated by arrows H4 to H10 in Fig. 21 (2). In this case, following the principle explained by reference to Fig. 21(1), the deflection direction of the generated beam is 90 degrees rotated from the state in Fig. 21(1) as indicated by arrow G2.

In further 1/4fo time after the moment in Fig. 21 (2), that is, 2/4fo from Fig. 21 (1), the direction of current in each part of strip conductors 40, 41 is as shown in Fig. 21 (3), and the generated beam is deflected in the direction of arrow G3.

In another 1/4fo time after the moment in Fig. 21 (3), that is, 3/4fo from Fig. 21(1), the mode of current in strip conductors 40, 41 is as shown in Fig. 21(1). In this case, the current in each half wavelength in strip conductors 40, 41 is indicated by arrows J4 to J8, and the deflection direction of the generated beam obtained by synthesizing them is indicated by arrow G4.

Thus, as shown in Fig. 21 (1) to Fig. 21(4), relating to the period 1/fo of the current flowing in the strip conductors 40, 41, a clockwise circularly polarized beam is generated in every period.

Fig. 22 is a plan showing a constitution example of an antenna 10f in a further different embodiment of this invention. This antenna 10f in Fig. 22, in addition to the constitution disposed in the power feed line 40 in the embodiment explained in Fig. 21, has a similar construction disposed at the power feed line 41 connected in parallel. In such constitution, too, the same effects as in the preceding embodiments can be realized.

The resonance element used in this invention is not limited to the shapes used in the above embodiments, but, as shown in Fig. 23, a resonance element of approximately ellipsoidal shape may be used. When feeding power to one point of this resonance element 38, it is designed to feed power at other positions than the points on the major axis and minor axis of the ellipsoidal shape shown in Fig. 23. The angle ϕ formed between this one-point power feed position 39 and the major axis may be selected, for example, somewhere between 35° and 45°. By thus feeding power, an electric current in the direction of arrows G1, G2 flows in the resonance element 38, so that, for example, a circularly polarized wave may be realized.

When feeding power to two points of the resonance elements 38, it is designed to feed power at power feed positions 40, 41 on the major axis and minor axis of the ellipsoidal shape shown in Fig. 23. By thus feeding power, an electric current in the direction of arrows G1, G2 flows in the resonance element 38, so that, similarly, a circularly polarized wave or the like may be realized.

Fig. 24 is a plan of an antenna unit 22 of another embodiment of this invention. This embodiment is similar to, for example, the embodiment shown in Fig. 10. and same reference codes are attached to the corresponding parts. What is to be noted in this embodiment is that the strip conductor 12 is formed in a crank shape, and that concave portions 50, 51 are formed at the mounting position of a resonance element 20 to which power feed lines 16, 17 extending from the strip conductor 12 are attached.

Generally, in a patch antenna having the shortest distance d2 to the central position 52 as shown in Fig. 24, if the patch antenna without concave portion 50, 51 possesses an impedance Z, and impedance Z1 possessed by a patch antenna with concave portion 50, 51 of depth of d1 is known to be obtained in the following equation.

$$Z1 = (d2 - d1)\, Z/d2 \qquad (30)$$

Therefore, by properly selecting the depth d1 of the concave portion 50, 51, a desired impedance for the patch antenna may be easily realized.

Fig. 25 is a plan of an antenna unit 22 of still another embodiment of this invention. This embodiment is explained in relation to Fig. 25. This embodiment is similar to the preceding ones, and corresponding parts are identified with the same reference codes. What is of note in this invention is that a strip conductor 12 is formed in a crank shape, and that strip-shaped resonance elements 53a, 53b, 53c are disposed in the regions enclosed by strip parts 12a, 12b, 12c of the strip conductor 12 at distances $\alpha 1$, $\alpha 2$, $\alpha 3$ from the strip conductors 12a, 12b, 12c. The resonance element 53a is disposed parallel to the strip part 12a, the resonance element 52b parallel to the strip part 12b, and the resonance element 53c parallel to the strip part 12c. The length of the resonance elements 53a, 53b, 53c is selected at λ g/2.

In gaps 54a, 54b, 54c at said distances α1, α2, α3 between these strip parts 12a, 12b, 12c and resonance elements 53a, 53b, 53c, virtually, electrostatic capacitances C1, C2, C3, resistances R1, R2, R3, and inductances H1, H2, H3 are generated due to the synthetic resin film to coat the antenna unit 22 or the like.

Fig. 26 is an equivalent circuit diagram of the antenna unit 22 shown in Fig. 25. Referring to Fig. 25 and Fig. 26, the antenna unit 22 is electrically coupled with the strip conductor 12 and strip part 53 in its overall length by electrostatic induction and electromagnetic induction, and its equivalent impedance is assumed to have plural impedance units 55 connected parallel, relating to the strip conductor 12.

Fig. 27 is an equivalent circuit diagram of the impedance unit 55 shown in Fig. 26. Referring to Fig. 25 to Fig. 27, since said electric constants are assumed in the gaps 54 in the constitution in Fig. 25, electrostatic capacitance C, resistance R and inductance H are assumed for the impedance unit 55.

In the antenna unit 22 shown in Fig. 25, as expressions corresponding to said equation (15) and (16), said equations (25) and (26) are known, whereas same expressions are used as for equations (17) and (18). In this case, the four terminal circuit constant A, B, C, D in equation (25) include said electric constants C, R, H specific to this embodiment.

Fig. 28 is a plan showing a constitution example of a different embodiment of this invention. This embodiment is described while referring to Fig. 28. This embodiment is similar to the preceding ones, and corresponding parts are identified with the same reference codes. What is of note in this embodiment is that the length of strip-shaped resonance elements 53a, 53b, 53c is selected at λ g/4. In this constitution, too, the same effects as shown in the above embodiments can be realized, but in the case of this embodiment the resonance elements 53a, 53b, 53c must be grounded at one end of each.

Fig. 29 is a plan showing a constitution example of a further different embodiment of this invention. This embodiment is similar to the preceding ones, and corresponding parts are identified with the same reference codes. What is of note in this embodiment is that the resonance element 53 is a rectangular patch. In this constitution it is also possible to compose gaps 54a, 54b, 54c for realizing electric constants derived from the electric coupling between the strip conductor 12 and resonance element 53. In this constitution, too, the same effects as shown in the above embodiments can be realized.

Fig. 30 is a perspective view showing the constitution of another embodiment of this invention, and Fig. 31 is a sectional view seen from the section XXXI-XXXI of Fig. 30. Referring now to Fig. 30 and Fig. 31, this embodiment is described below. This embodiment is similar to the preceding ones, and corresponding parts are identified with the same reference codes. What is of note in this embodiment is that a strip conductor 12, for example, is formed at the opposite side of the ground conductor 13 of the dielectric substrate 11 composing an antenna 10, and that a dielectric layer 55 is formed thereon, and still that a patch 53 is formed on this dielectric layer 55.

In this embodiment, the portion corresponding to the gap 54 in the above embodiments is the dielectric portion 56 at interval of t1 and overlapping width of s1 between the patch 53 and the strip conductor 12. That is, the gap 54 in the above embodiments was the interval on the plane between the strip conductor 12 and patch 53 formed on the same plane, but in this embodiment it is the gap in the direction orthogonal to the plane. In this constitution, too, the electric coupling of said strip conductor 12 and patch 53 is realized, and the same effects as in the above embodiments will be realized.

In this embodiment, furthermore, since the strip conductor 12 and patch 53 are disposed in the vertical direction, an ample degree of freedom is permitted in their configuration, and varied types of antenna 10 can be fabricated.

Fig. 32 and Fig. 33 are plans showing the constitution of further different embodiments of this invention. Referring to these drawings, the respective embodiments are described below. The constitution shown in Fig. 32 is similar to that in Fig. 11 and Fig. 29. What is characteristic of this embodiment is that the patch 53 formed distant from the strip conductor 12 in the region enclosed by the strip conductor 12 is shaped by cutting off a pair of corners on a diagonal line thereof.

The constitution in Fig. 33 is similar to that in Fig. 25. What is characteristic of this embodiment is that, in the constitution shown in Fig. 25, a resonance element 53d of an approximately L-shape is provided by integrally combining the resonance elements 53b, 53c. The overall length of this resonance elements 53d is selected, for example at λg/2. In this constitution, too, the same effects as mentioned in the above embodiments will be realized.

In the above embodiments, meanwhile, the power is fed to the strip conductors 12, 30, 31 from upper left part of the drawings, and clockwise circularly polarized waves are formed, but it is obvious that counterclockwise circularly polarized waves may be easily realized by feeding power from the right part of the drawings.

Claims

1. A phase control microstripline antenna (10, 10a, 10e, 10f) comprising a dielectric substrate (11), singular or plural strip conductors being bent periodically and a ground conductor (13) characterized in that:
a single or a plurality of resonance elements (14, 15, 20, 21, 32, 38, 42, 49, 50, 53) for being supplied with electric current from a predetermined position of singular or plural strip conductors (12, 30, 31, 40, 41) in every period of the strip conductors (12, 30, 31, 40, 41) are disposed to control phase of electric wave being radiated from the strip conductors (12, 30, 31, 40, 41).

2. A phase control microstripline antenna as claimed in claim 1, wherein the resonance elements (14, 15, 49, 50) are formed in pairs and like rectangular plates, each having a length of half period of exciting current.

3. A phase control microstripline antenna (10) as claimed in claim 1, wherein each of the resonance elements (14, 15, 20, 21, 32, 38, 42, 49, 50, 53) is connected with each of the strip conductors (12, 30, 31, 40, 41) through a supplying line (16, 17, 23, 33, 34, 43, 44) having a length of quarter period of the exciting current.

4. A phase control microstripline antenna as claimed in claim 1, 2 or 3, wherein a length from a start end (12a, 36, 37, 45, 47) of the period to an electric supplying point (18, 19, 35, 46, 48) of the resonance element (14, 15, 32, 42) most adjoining to the start end is selected to be a half period of the exciting current, and a length from a terminal end (12b) of the period to a connection point (18, 19, 35, 46, 48) of the resonance element (14, 15, 32, 42) most adjoining to the terminal end is selected to be three quarter period.

5. A phase control microstripline antenna as claimed in claim 1, wherein a single or a plurality of the resonance elements (32, 38, 42, 49, 50) in every period are supplied with electric current through a plurality of the strip conductors (30, 31, 40, 41).

6. A phase control microstripline antenna (22) comprising a dielectric substrate (11), singular or plural strip conductors (12) being bent periodically and a ground conductor (13) characterized in that:
a single or a plurality of resonance elements (53, 54) being electrically coupled, in every period of the strip conductors (12); with the strip conductors (12) within the period through the dielectric substrate (11, 55) are disposed to control the phase of electric wave being radiated from the strip conductors (12).

7. A phase control microstripline antenna as claimed in claim 6, wherein the resonance elements (53) are partially overlapped (56) with the strip conductors (12) in the direction that the strip conductors (12) are extending, the dielectric substrate being interposed therebetween.

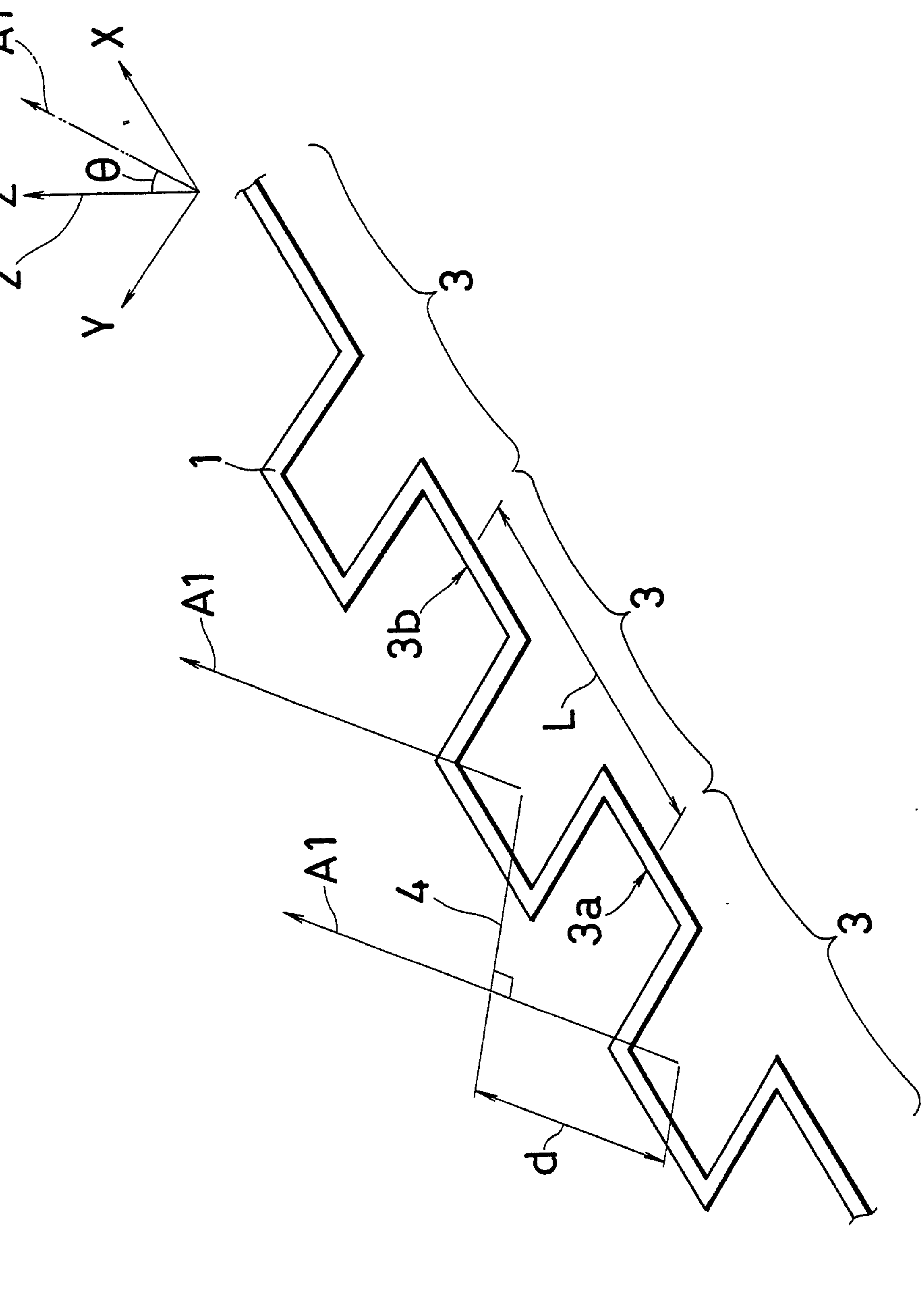


Fig. 1

Fig. 2

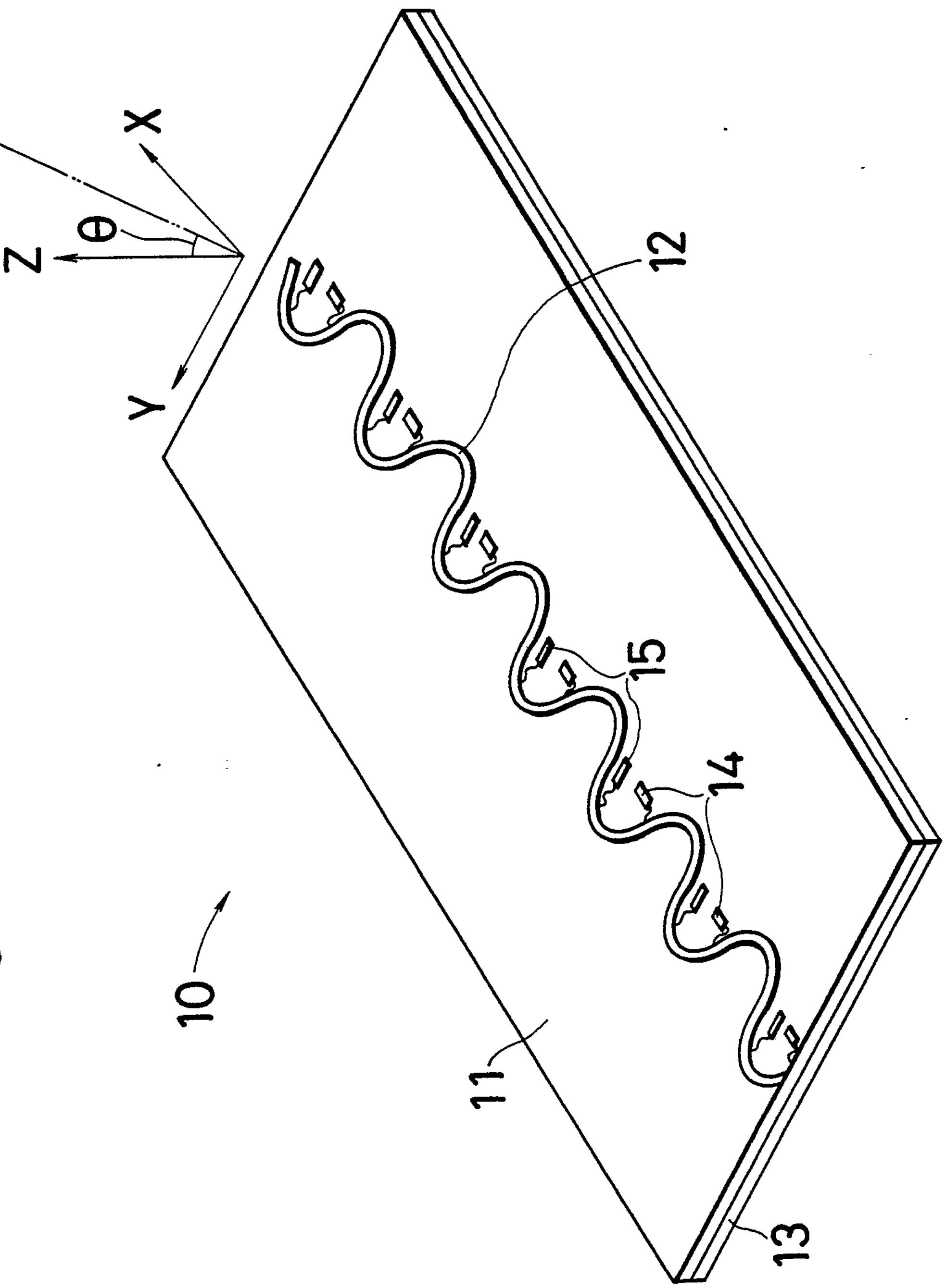


Fig. 3

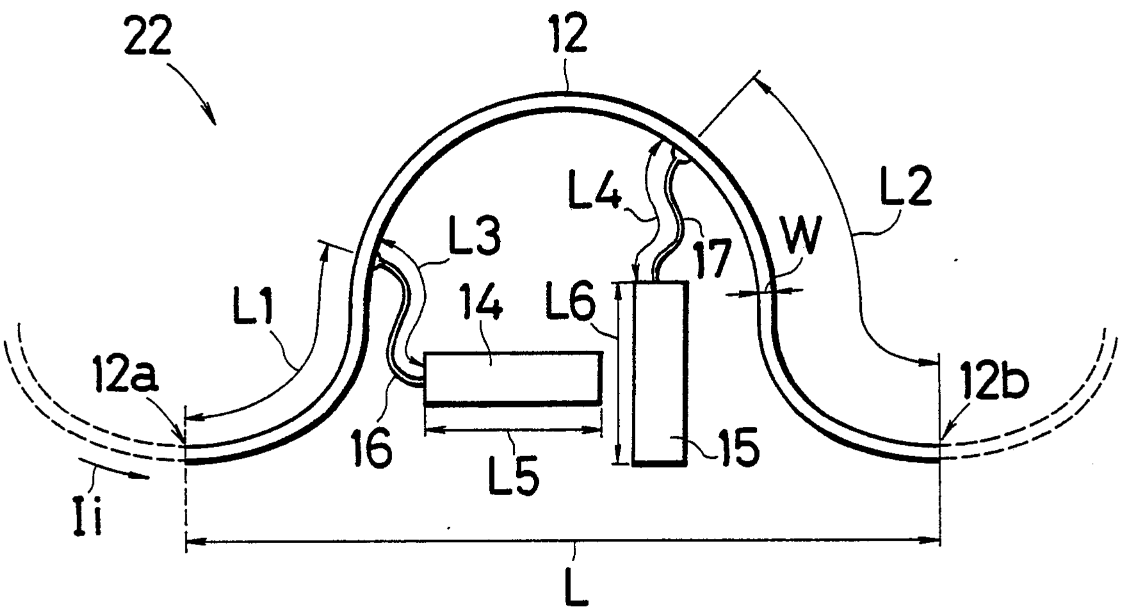

22
12
L4
L2
L3
W
17
L1
14
L6
12a
12b
16
15
L5
Ii
L

Fig. 4

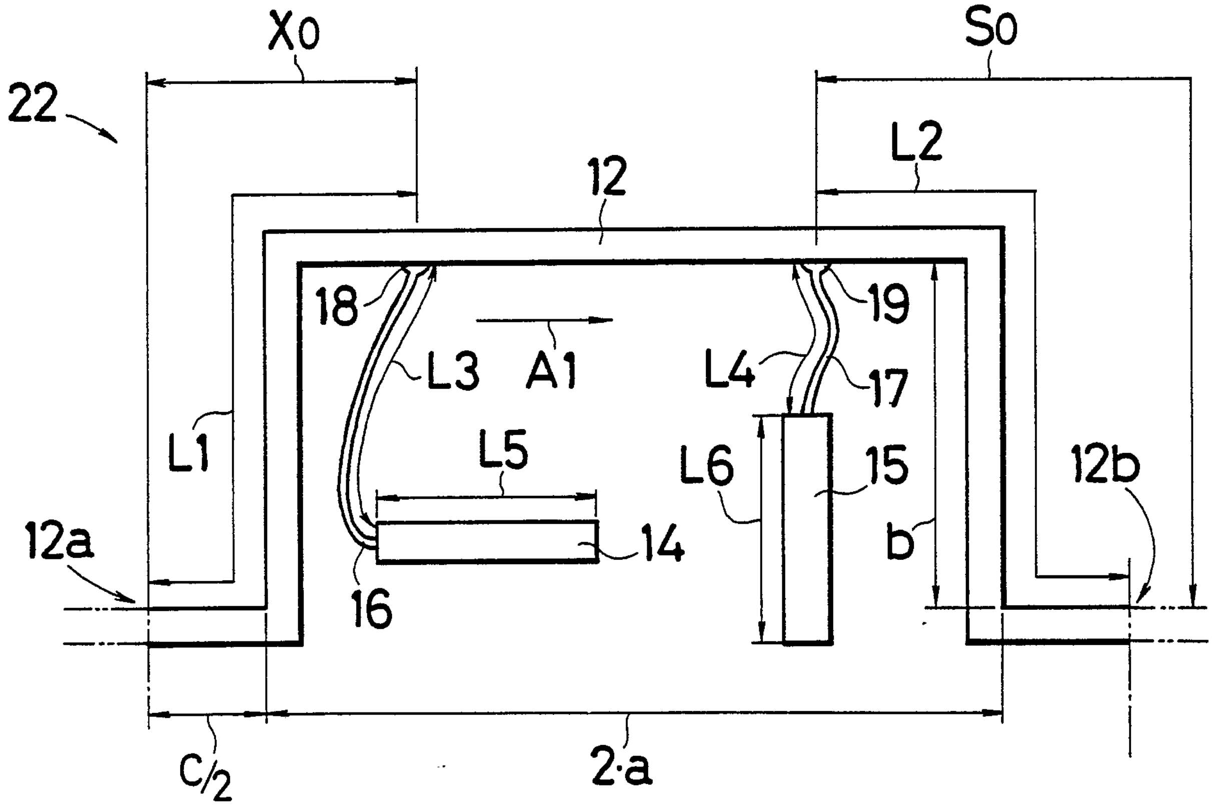

X0
S0
22
L2
12
18
19
L3
A1
L4
17
L1
L5
L6
15
12b
12a
14
b
16
C/2
2·a

Fig. 5 (1) (t=0)

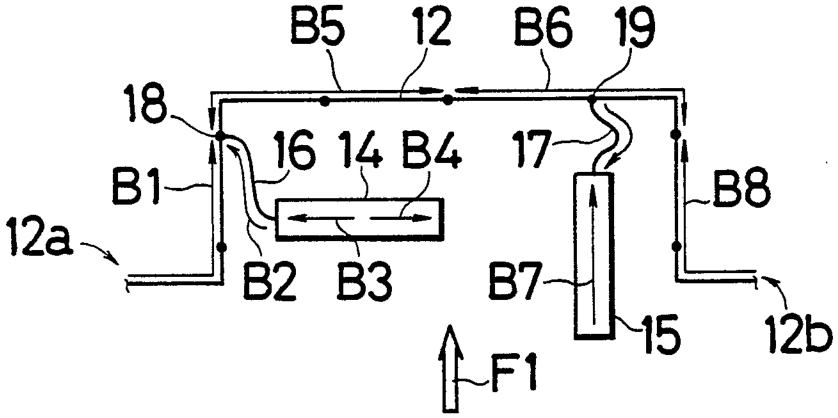


Fig. 5 (2) (t=¼ f0)

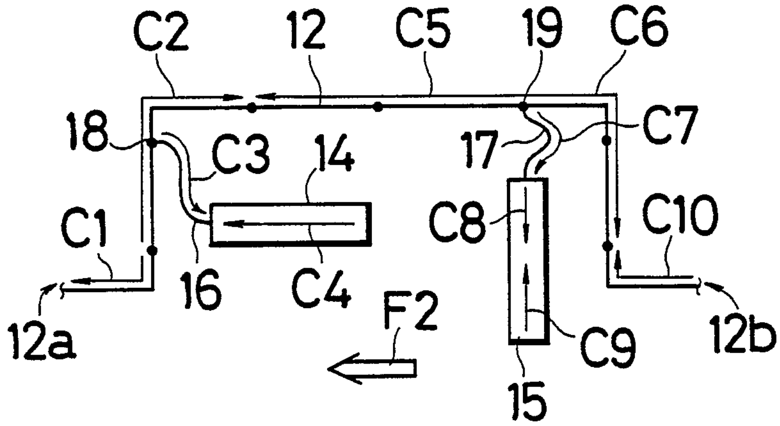


Fig. 5 (3) (t=2/4 fo)

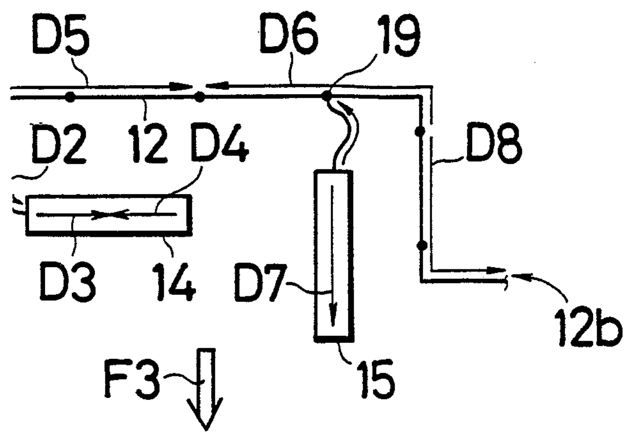


Fig. 5 (4) (t=3/4 fo)

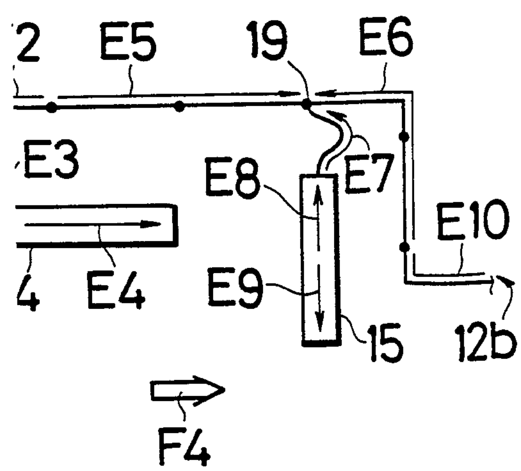


Fig. 6

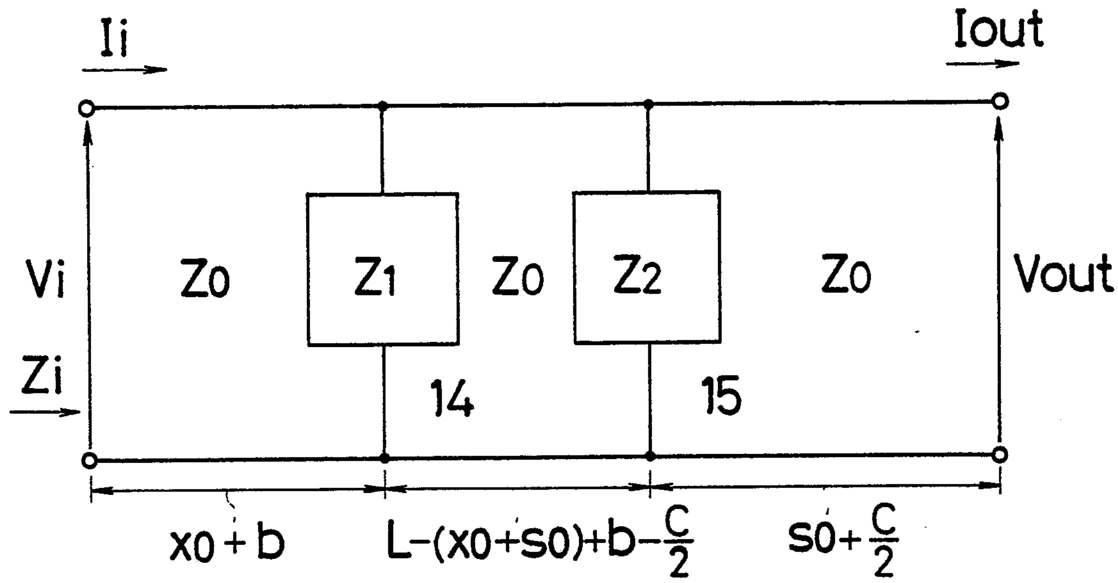

Ii
Iout
Vi
Z0
Z1
Z0
Z2
Z0
Vout
Zi
14
15
x0 + b
L-(x0+s0)+b-C/2
s0+C/2

Fig. 7

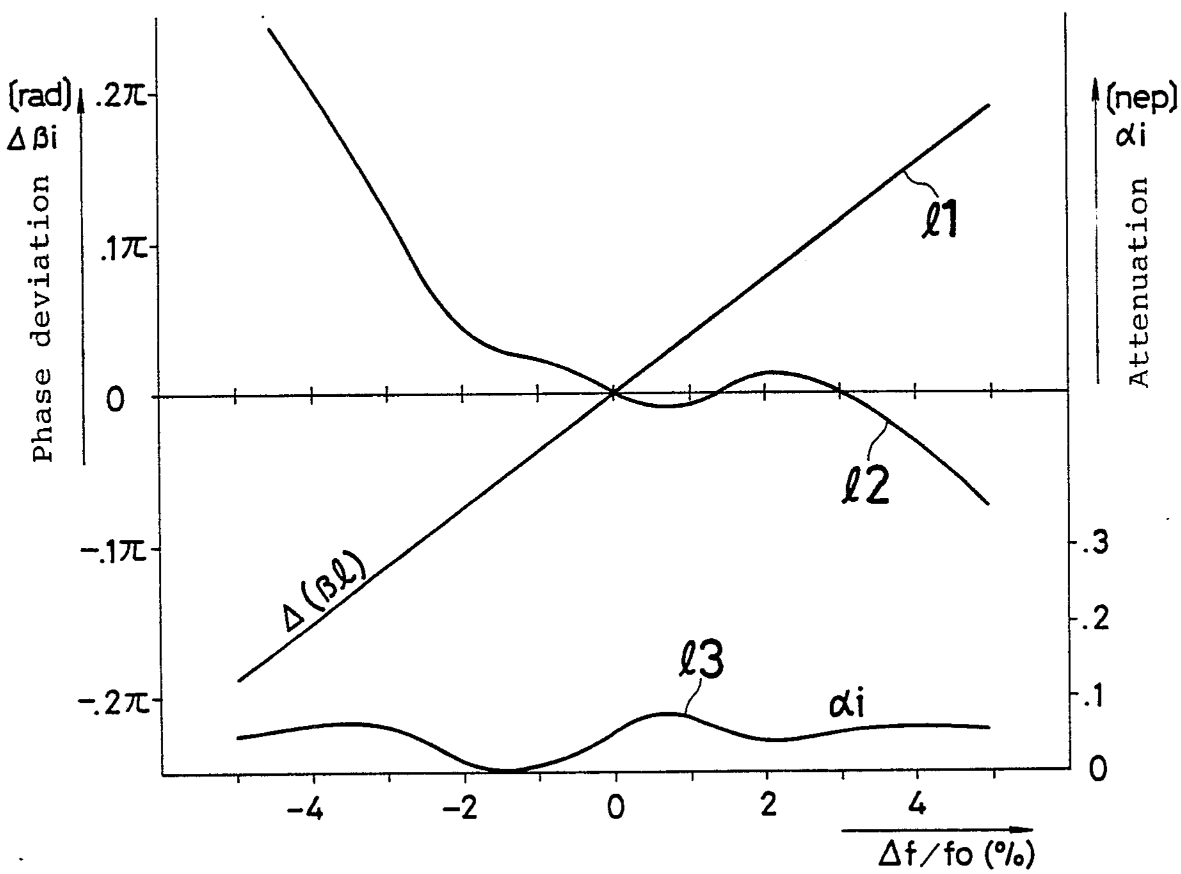

(rad)
Δβi
Phase deviation
.2π
.1π
0
-.1π
-.2π
(nep)
αi
Attenuation
.3
.2
.1
0
ℓ1
ℓ2
ℓ3
Δ(βℓ)
αi
-4
-2
0
2
4
Δf/fo (%)

Fig. 8

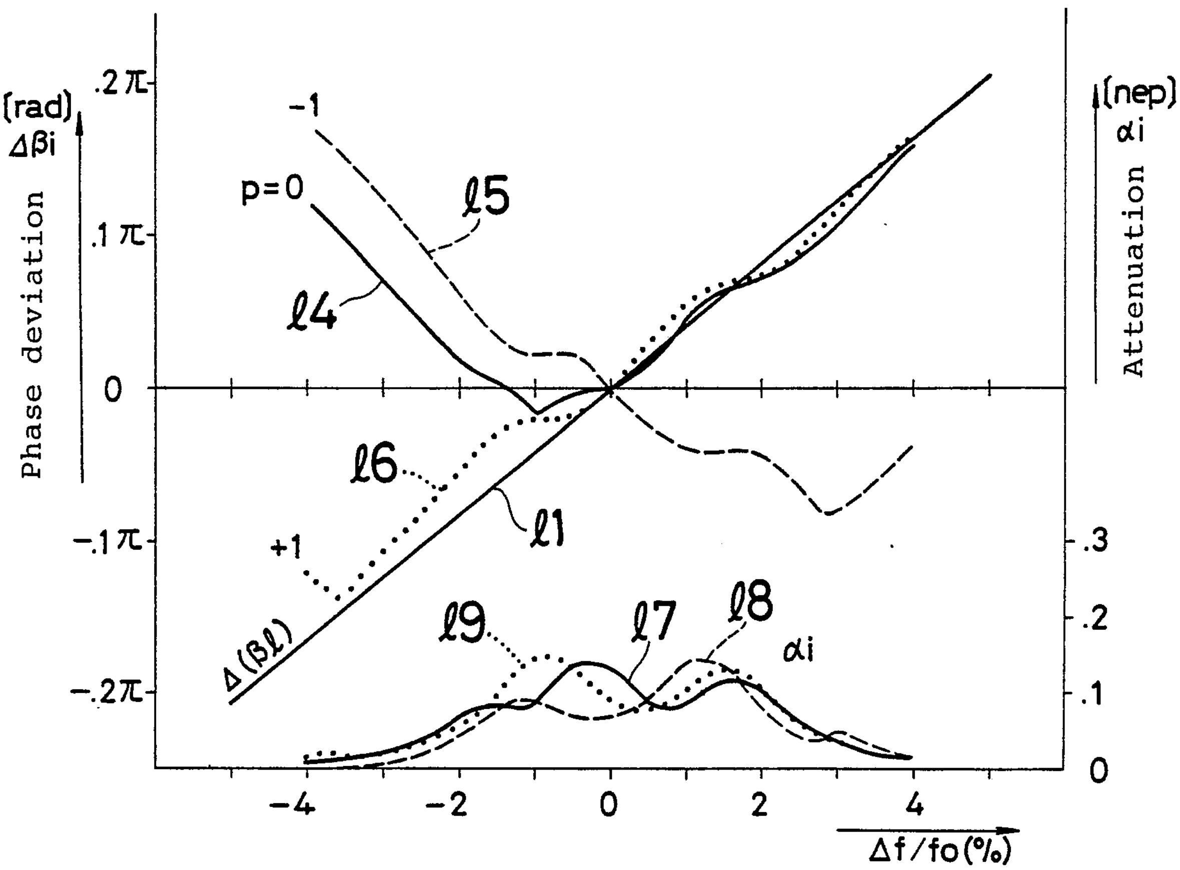

(rad)
Δβi
Phase deviation
.2π
.1π
0
-.1π
-.2π
-1
p=0
+1
ℓ5
ℓ4
ℓ6
ℓ1
Δ(βℓ)
ℓ9
ℓ7
ℓ8
αi
(nep)
αi
Attenuation
.3
.2
.1
0
-4
-2
0
2
4
Δf/fo(%)

Fig. 9

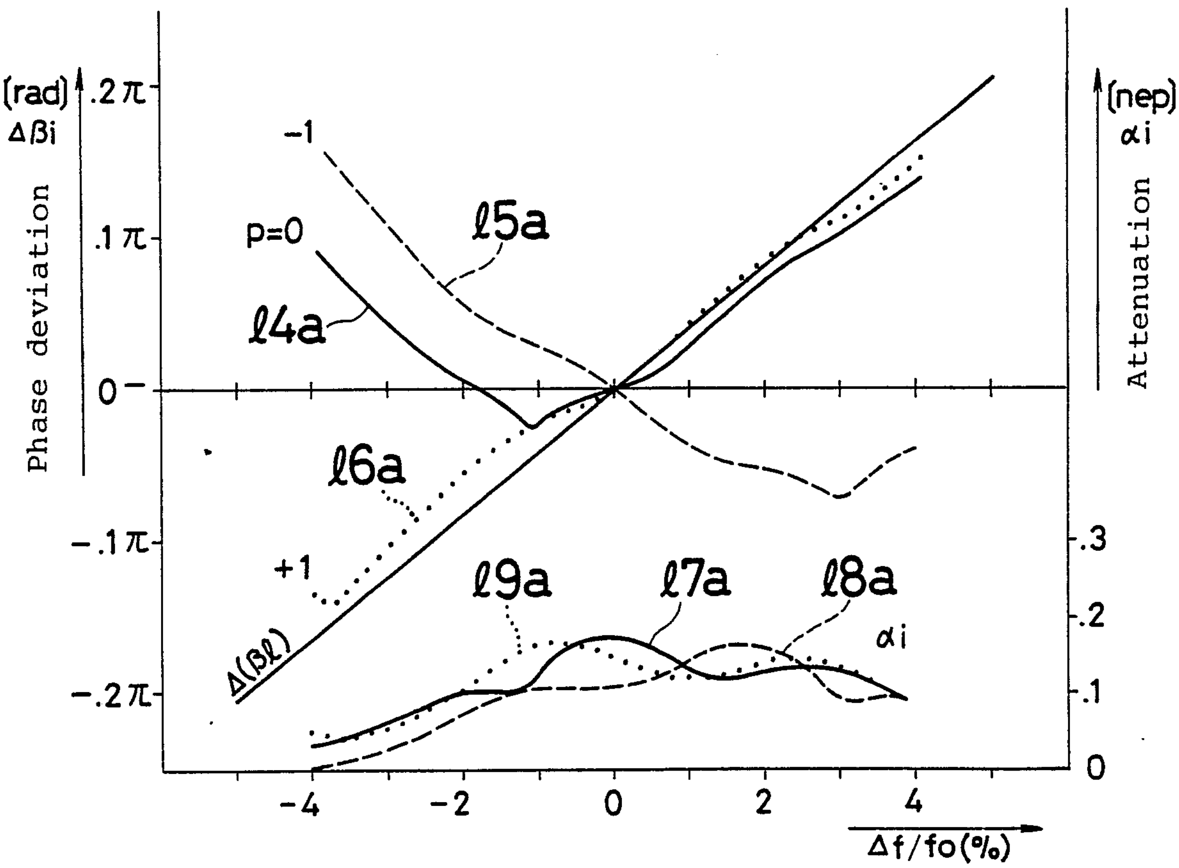

(rad)
ΔβI
Phase deviation
.2π
.1π
0
-.1π
-.2π
(nep)
αi
Attenuation
.3
.2
.1
0
-1
p=0
+1
ℓ4a
ℓ5a
ℓ6a
ℓ7a
ℓ8a
ℓ9a
Δ(βℓ)
αi
-4
-2
0
2
4
Δf/fo(%)

Fig.10

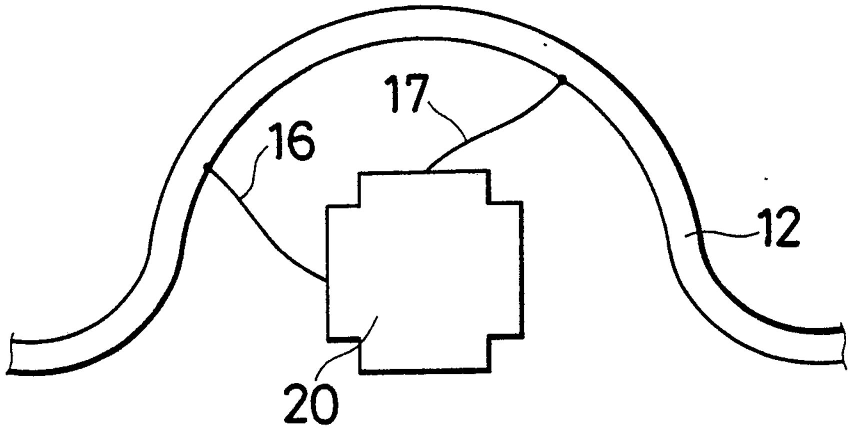


Fig.11

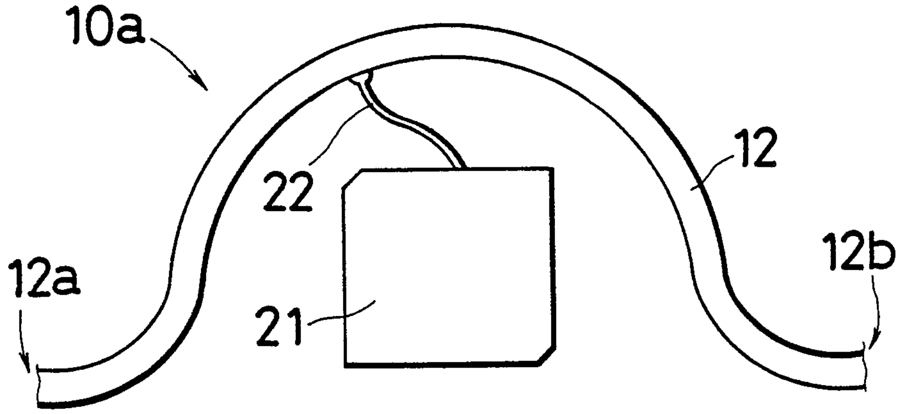
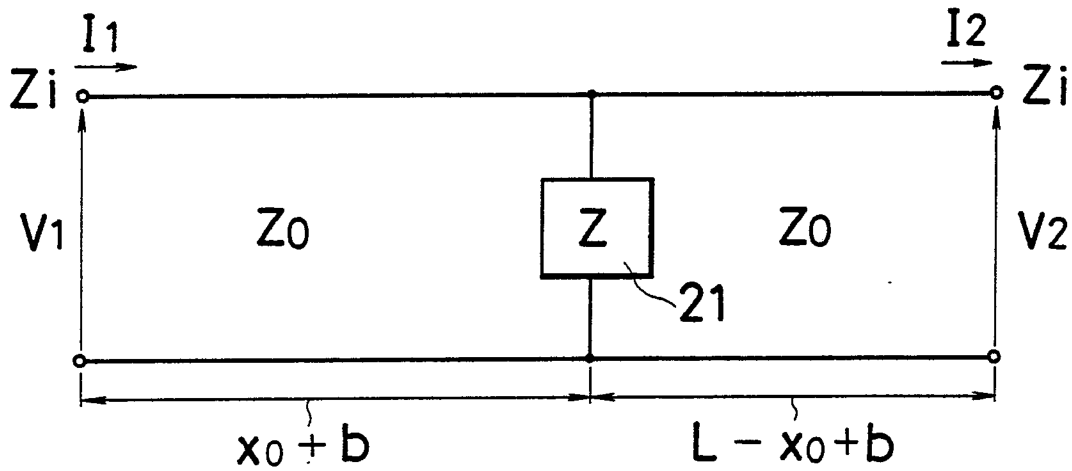
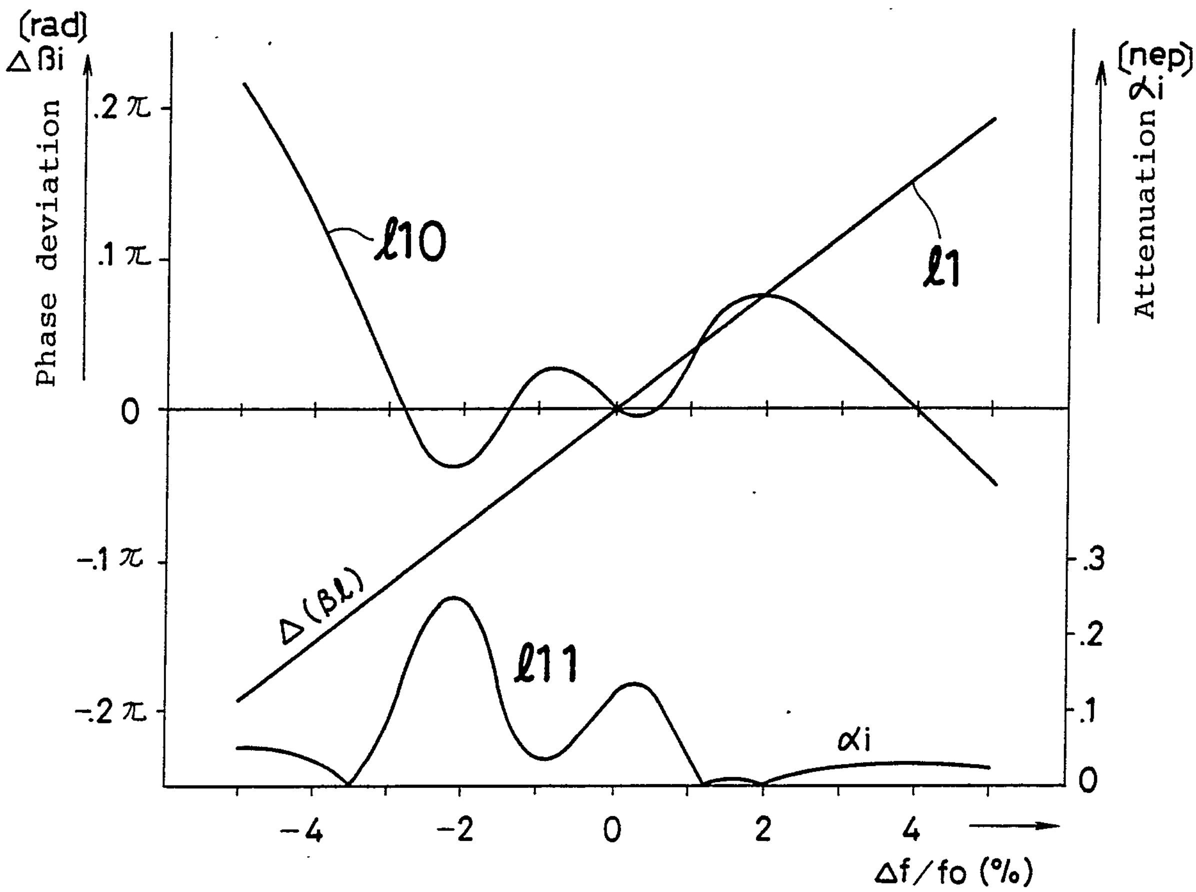


Fig. 12



I1
I2
Zi
Zi
V1
Z0
Z
Z0
V2
21
x0 + b
L - x0 + b

Fig. 13



(rad)
ΔβI
Phase deviation
.2 π
.1 π
0
-.1 π
-.2 π
ℓ10
ℓ1
Δ(βℓ)
ℓ11
αi
(nep)
αi
Attenuation
.3
.2
.1
0
-4
-2
0
2
4
Δf/fo (%)

Fig. 14

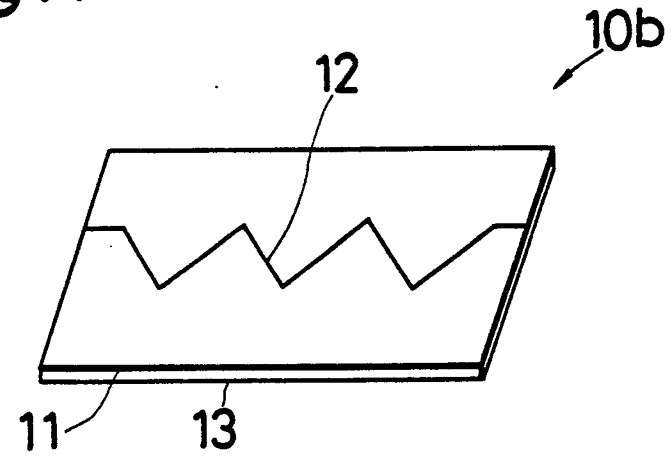


Fig. 15

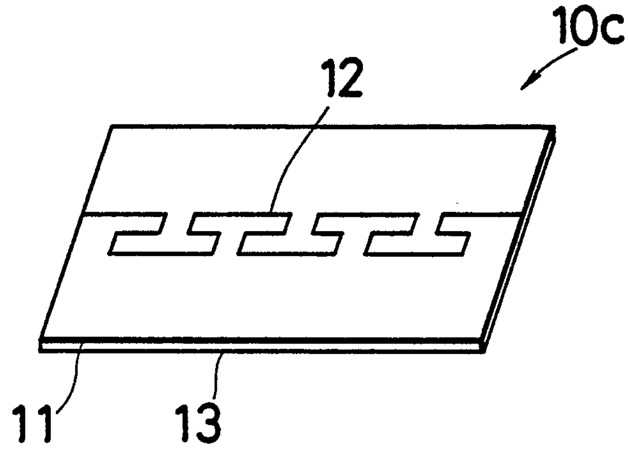


Fig. 16

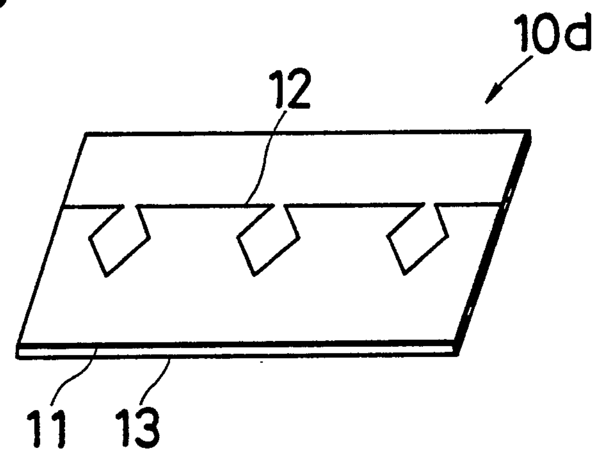


Fig. 17

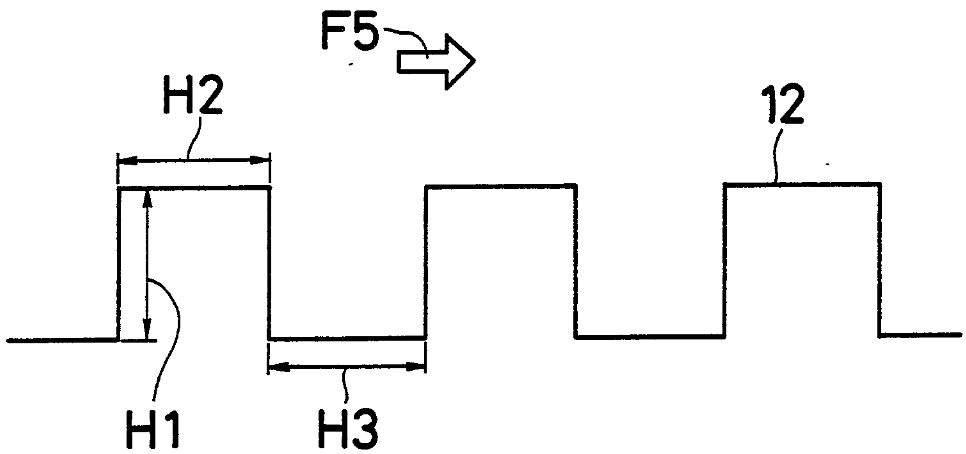


Fig. 18

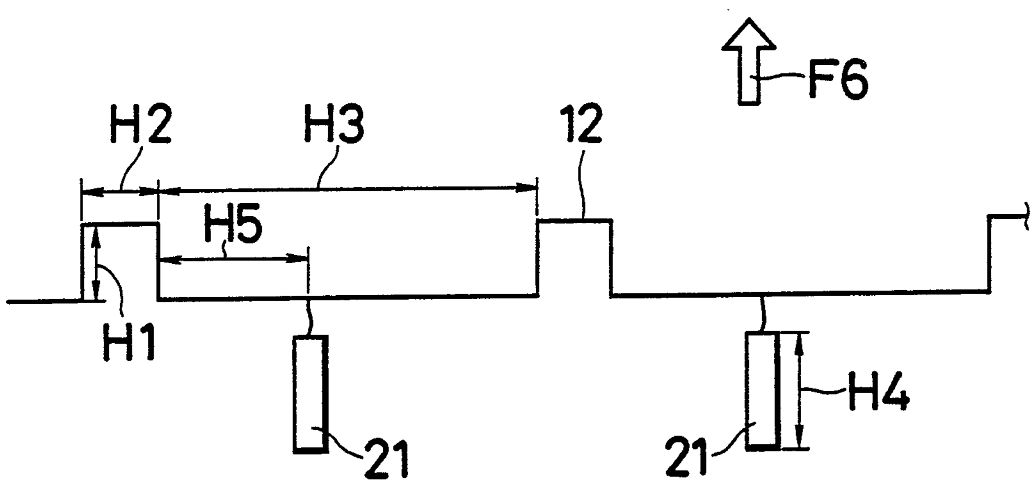


Fig. 19

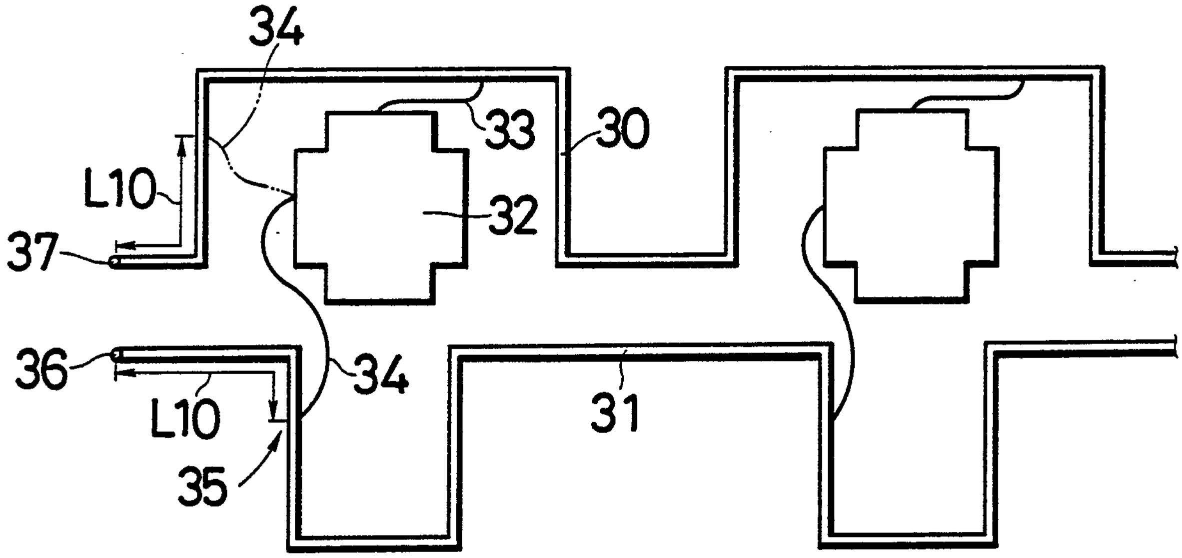


Fig. 20

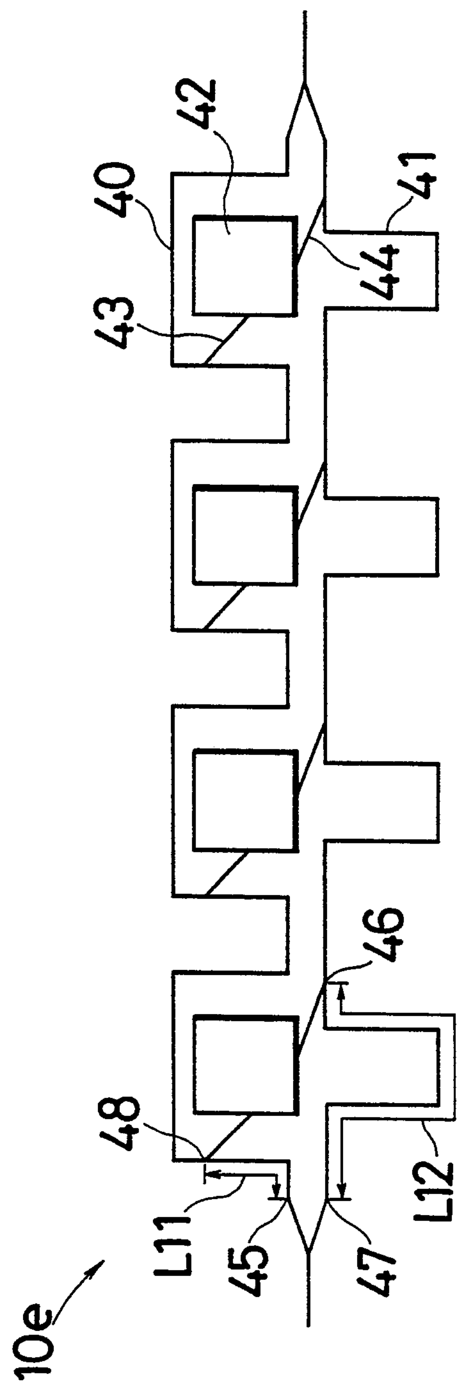


Fig. 22

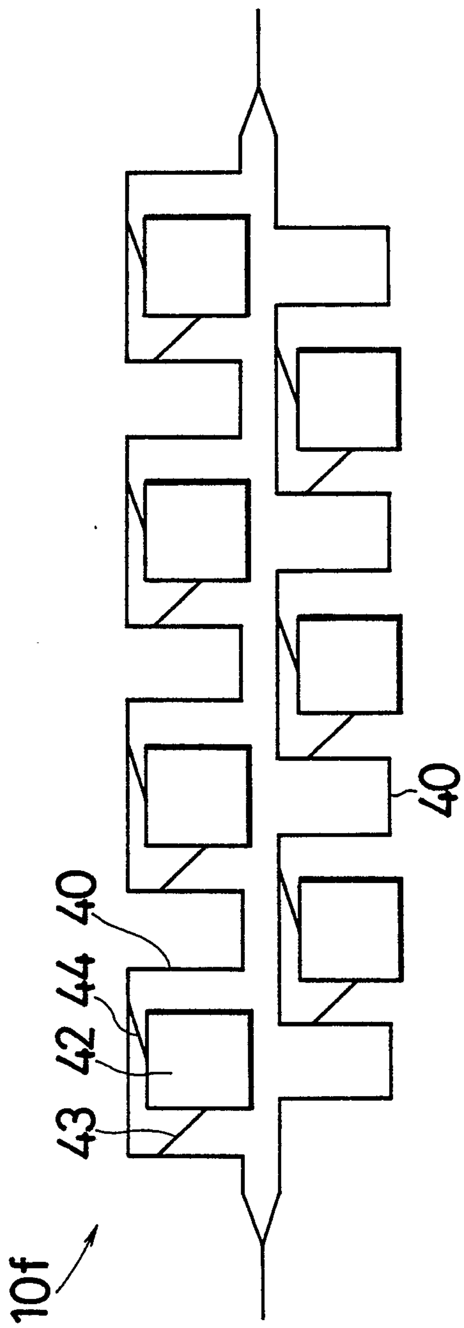


Fig. 21 (1) (t=0)

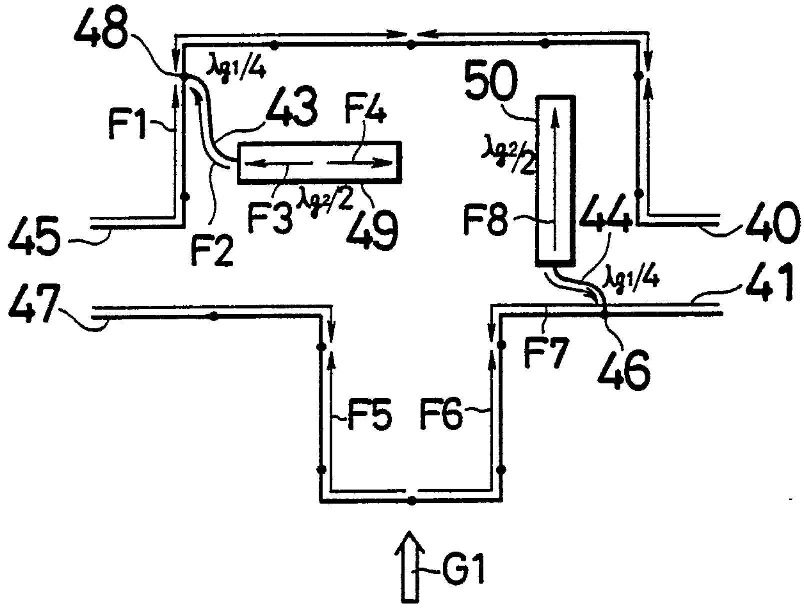


Fig. 21 (2) $(t=\frac{1}{4f})$

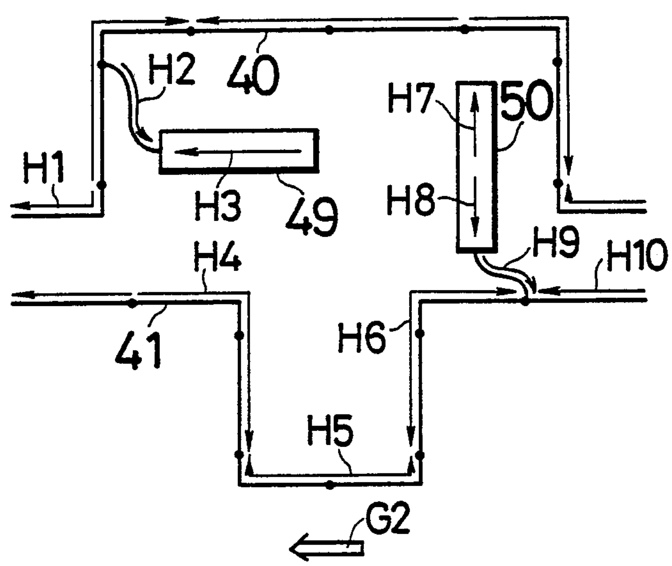


Fig. 21 (3) $(t=\frac{2}{4f})$

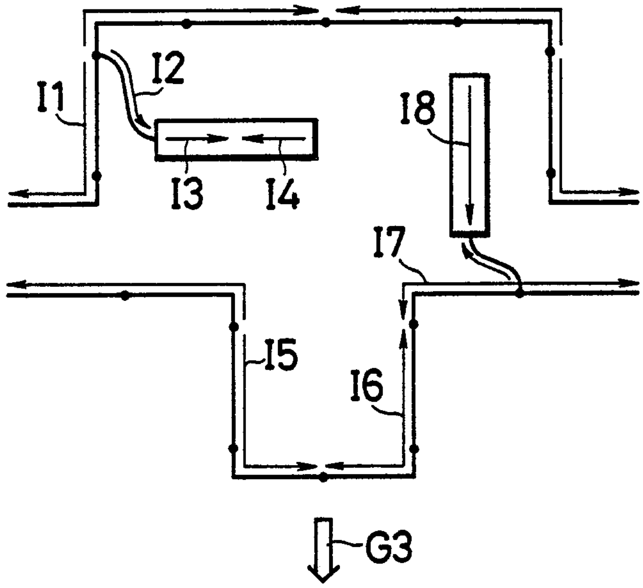


Fig. 21 (4) $(t=\frac{3}{4f})$

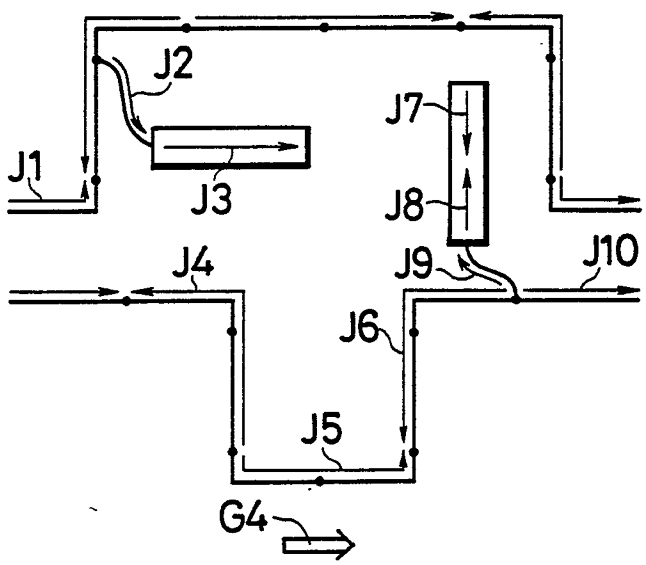


Fig. 23

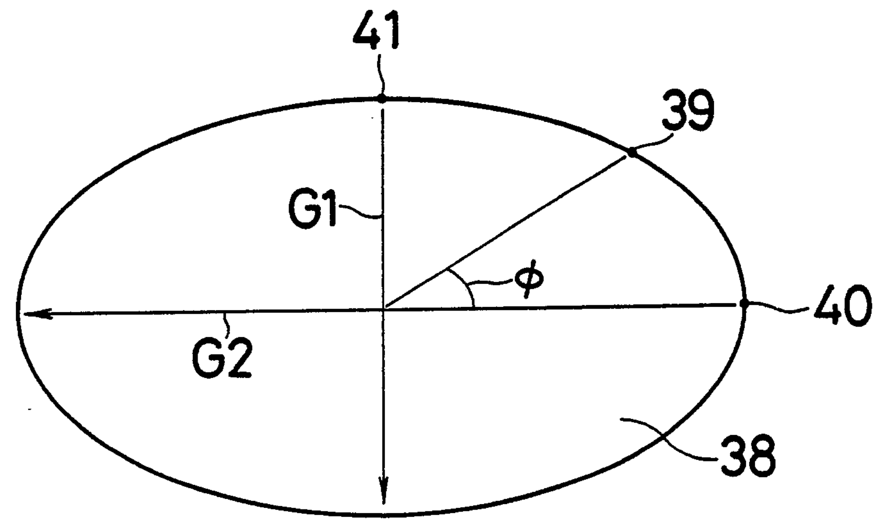


Fig. 24

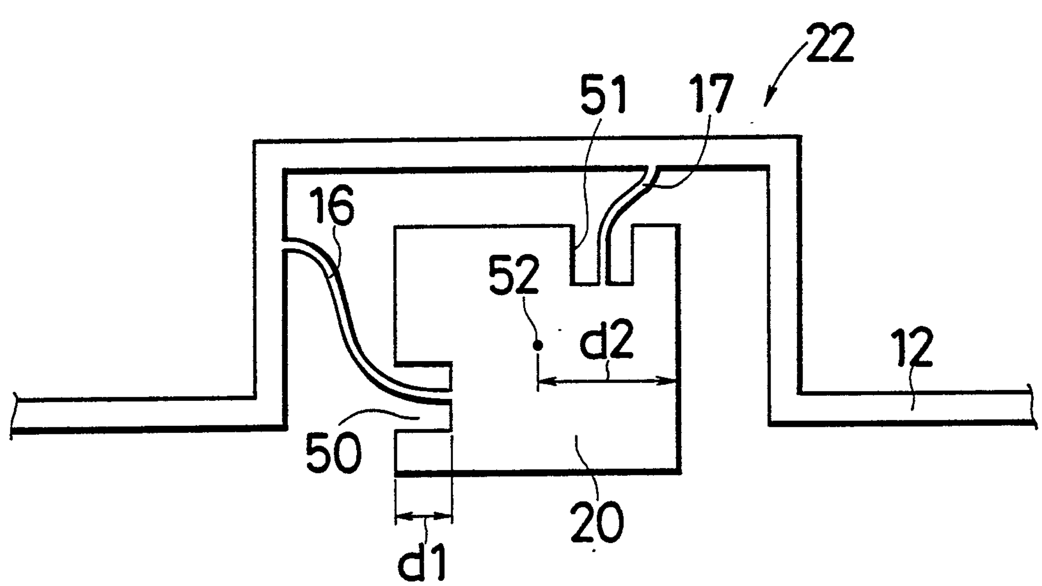


Fig. 25

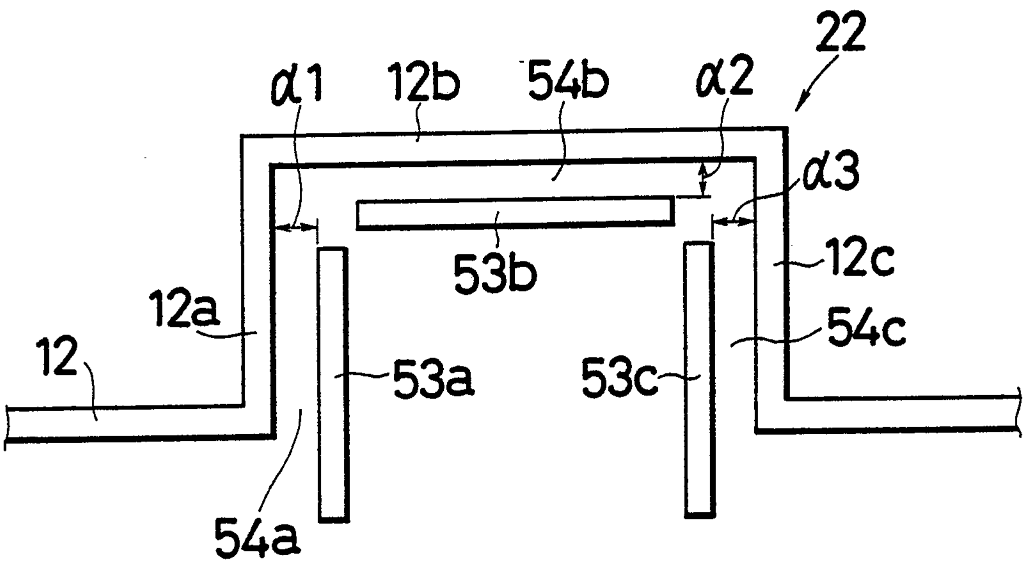

22
α1
12b
54b
α2
α3
12c
53b
12a
54c
12
53a
53c
54a

Fig. 26

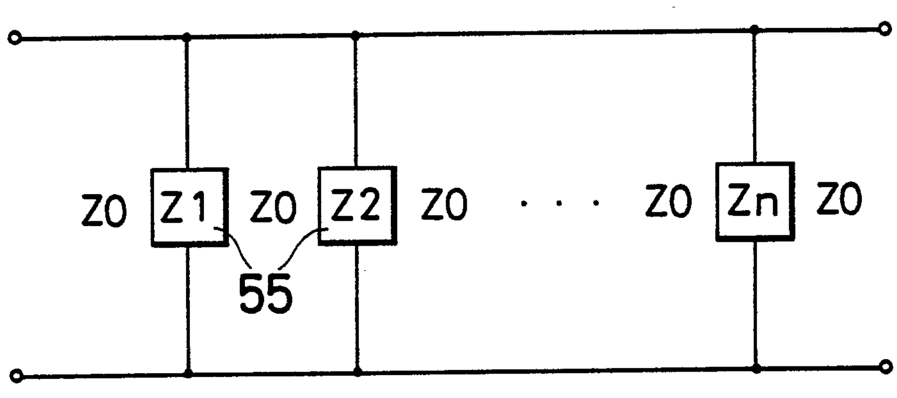

Z0
Z1
Z0
Z2
Z0
· · ·
Z0
Zn
Z0
55

Fig. 27

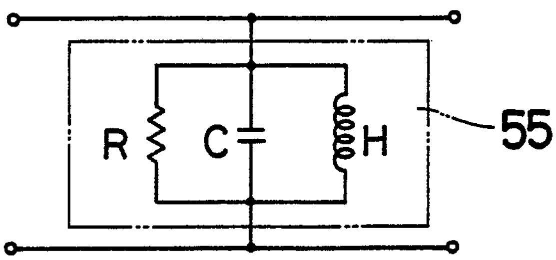


Fig. 28

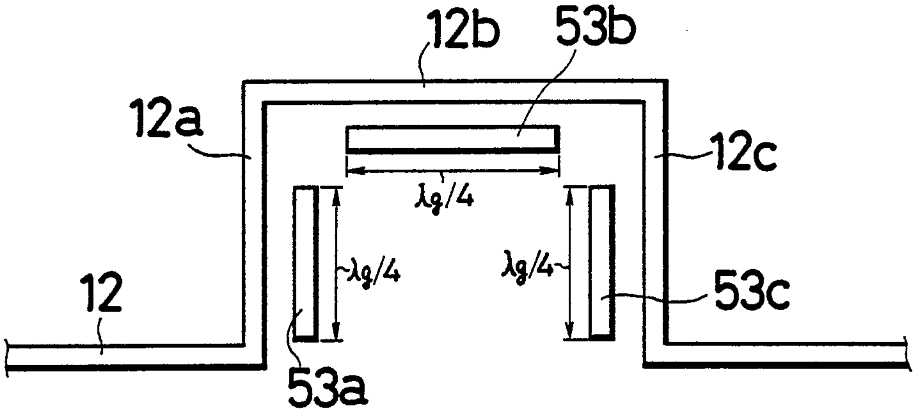


Fig. 29

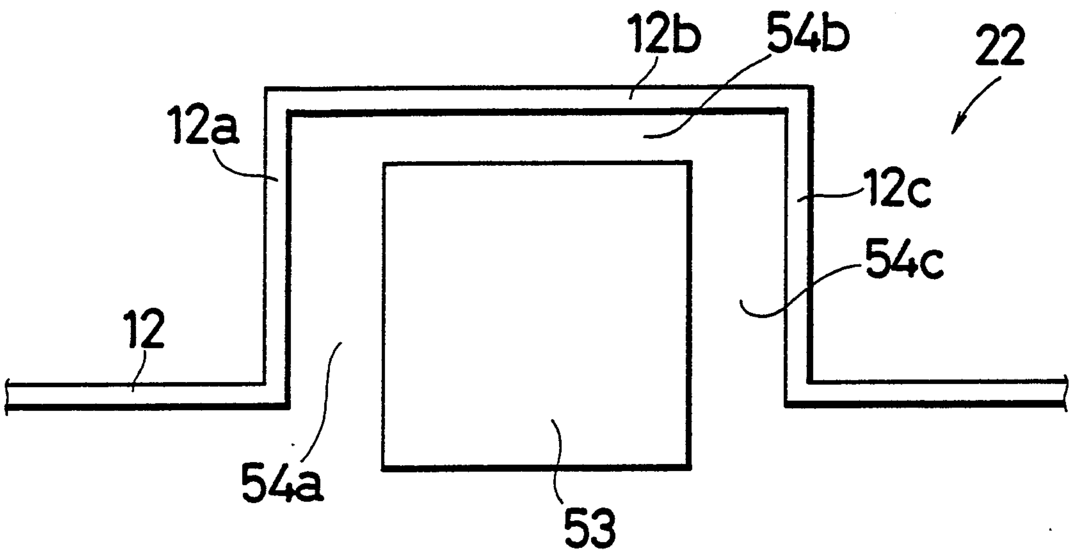


Fig. 30

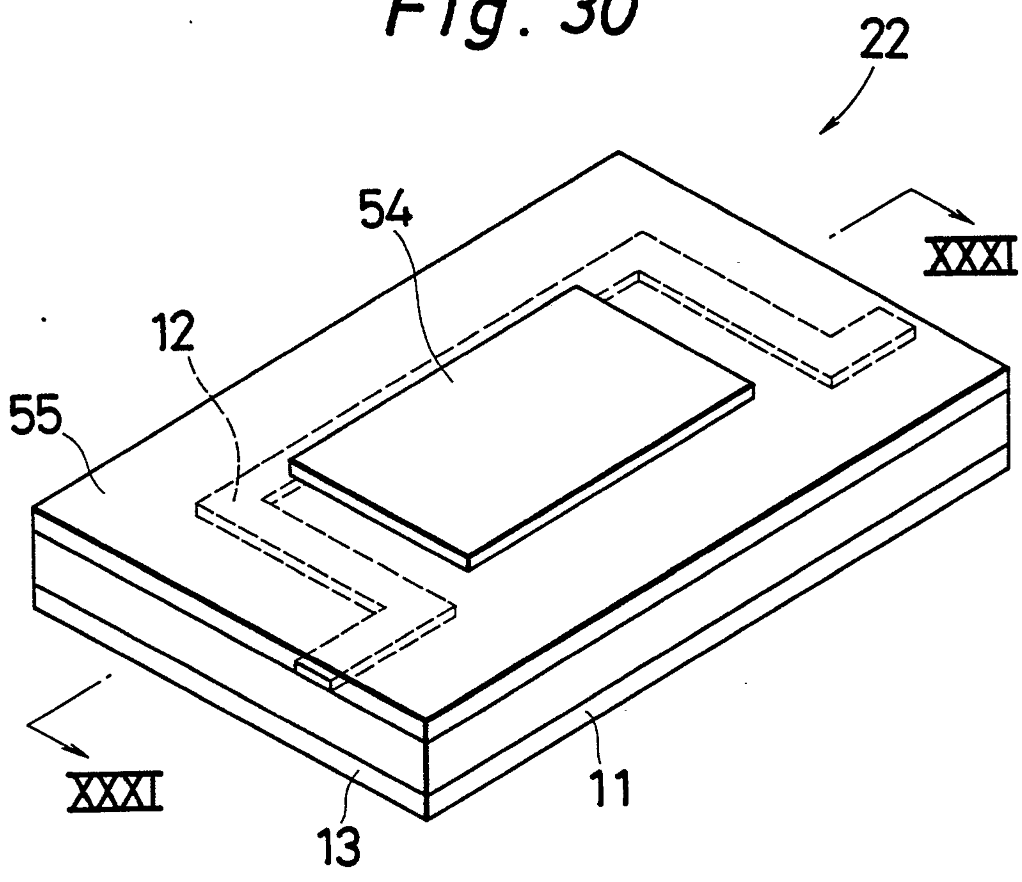


Fig. 31

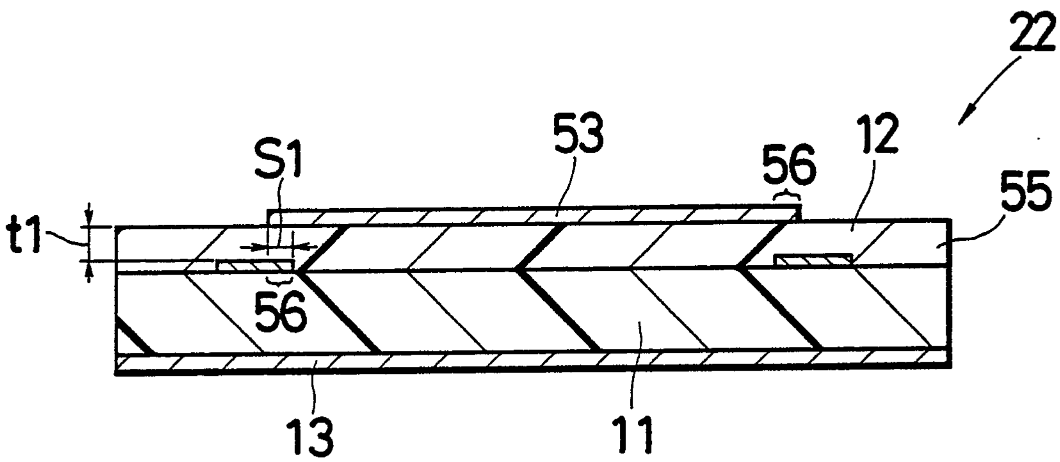


Fig. 32

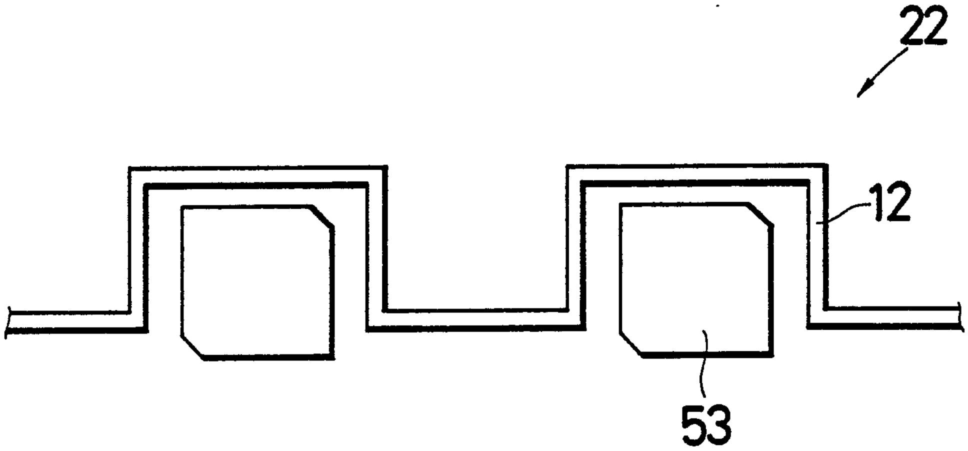


Fig. 33