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Iio et al.

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(45) **Date of Patent: Jan. 15, 2013**

(54) **HARMONIC SUPPRESSION RESONATOR, HARMONIC PROPAGATION BLOCKING FILTER, AND RADAR APPARATUS**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 972 days.

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(22) Filed: **Dec. 23, 2008**

(65) **Prior Publication Data**

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(30) **Foreign Application Priority Data**

Dec. 28, 2007 (JP) 2007-340542
Dec. 28, 2007 (JP) 2007-340560
Sep. 18, 2008 (JP) 2008-238947

(51) **Int. Cl.**
H01P 7/06 (2006.01)

(52) **U.S. Cl.** **333/230**; 333/212

(58) **Field of Classification Search** 333/211, 333/227, 208, 212, 135, 230, 202
See application file for complete search history.

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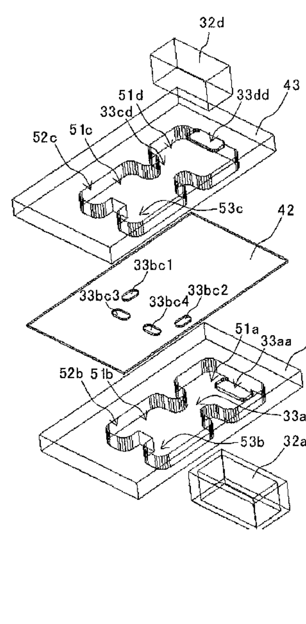
Primary Examiner — Dean O Takaoka
Assistant Examiner — Alan Wong
(74) *Attorney, Agent, or Firm* — Birch, Stewart, Kolasch & Birch, LLP

(57) **ABSTRACT**

A harmonic suppression resonator comprises a plurality of waveguide resonators that resonate in TE mode, in which harmonic suppression resonator, adjoining resonators are coupled via a plurality of coupling windows. Four coupling windows **33*bc*1**, **33bc2**, **33*bc*3** and **33*bc*4** are provided between a resonant region **51*b*** and a resonant region adjoining the resonant region **51*b***. These coupling windows allow fundamental wave modes of the adjoining resonators to be coupled mainly by magnetically coupling. The coupling windows **33*bc*3** and **33*bc*4** allow second harmonic modes of the adjoining resonators to be electrically coupled, and the coupling windows **33*bc*1** and **33*bc*2** allow the second harmonic modes of the adjoining resonators to be magnetically coupled. By causing the amount of the electrically coupling and the amount of the magnetically coupling to be substantially equal, the coupling of the second harmonic modes is negated, whereby propagation of the second harmonic is blocked.

15 Claims, 24 Drawing Sheets



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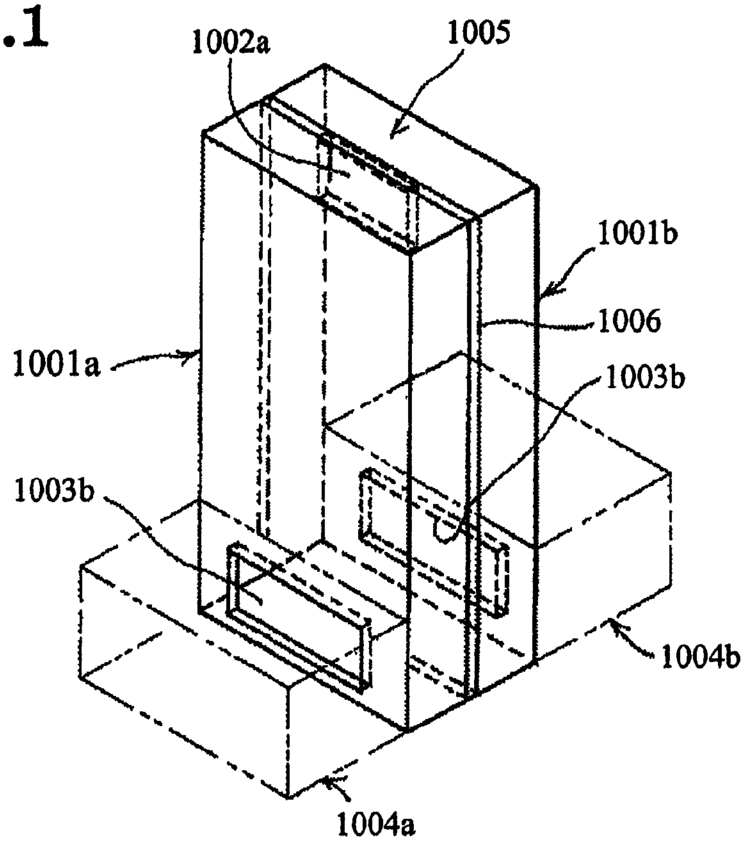
CONVENTIONAL ART

Fig.1



CONVENTIONAL ART

Fig.2(A)

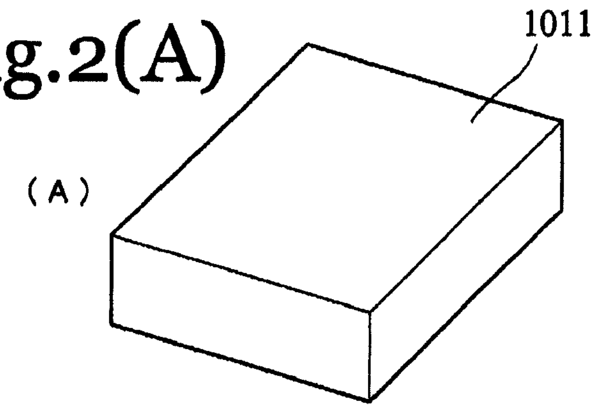


Fig.2(B)

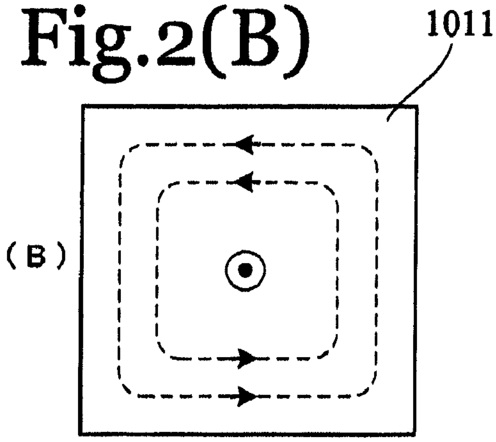


Fig.2(C)

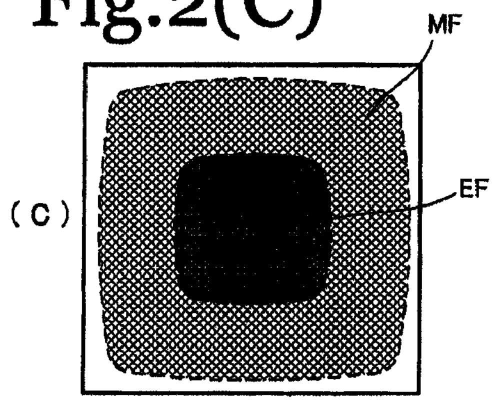


Fig.2(D)

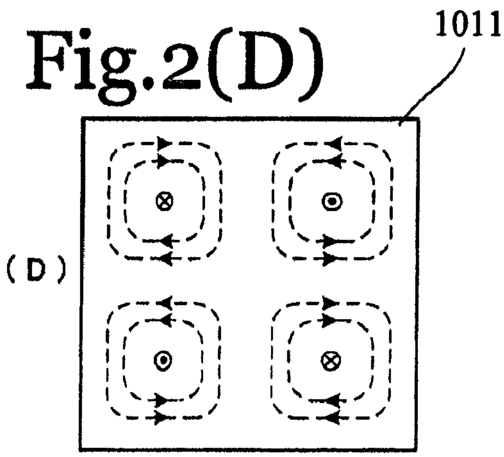


Fig.2(E)

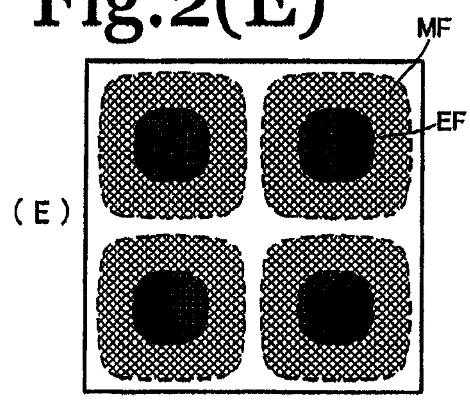


Fig.3

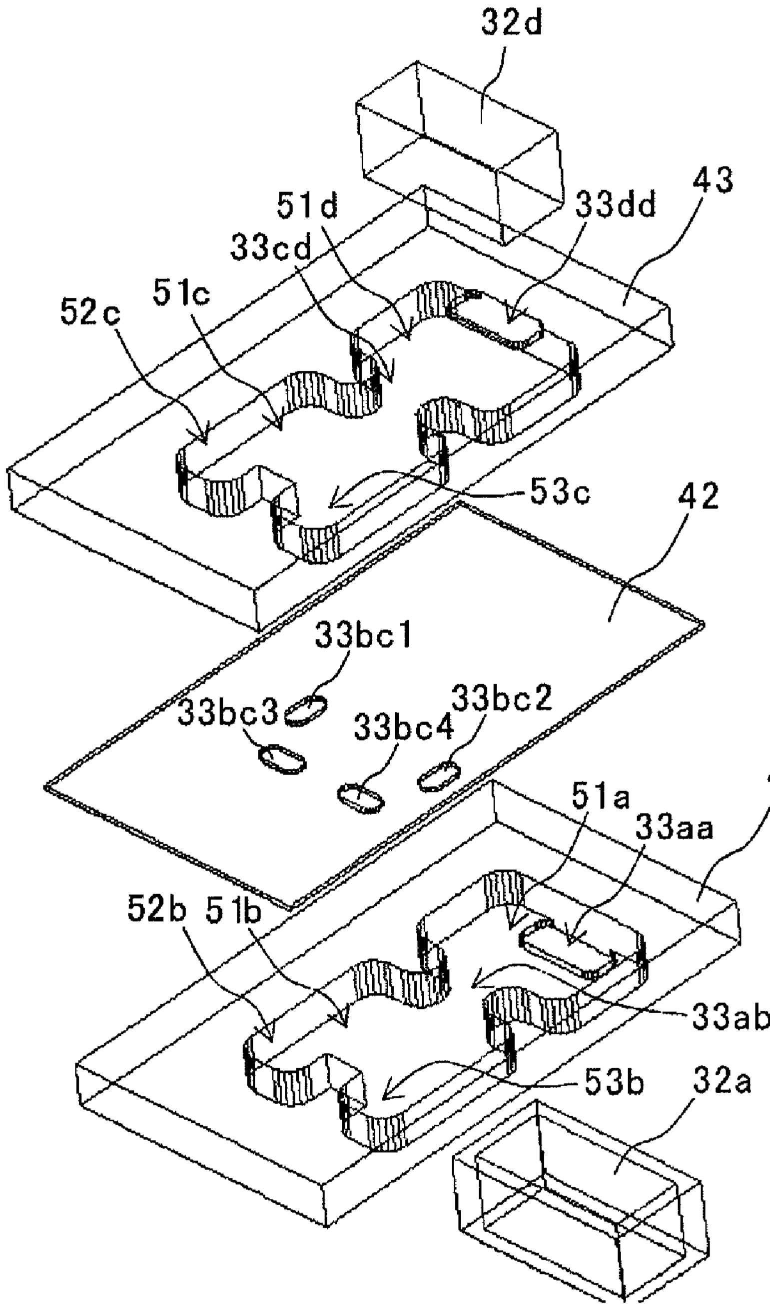

32d
43
51d
33dd
33cd
51c
52c
53c
42
33bc1
33bc3
33bc2
33bc4
41
51a
33aa
52b
51b
33ab
53b
32a

Fig.4(A)

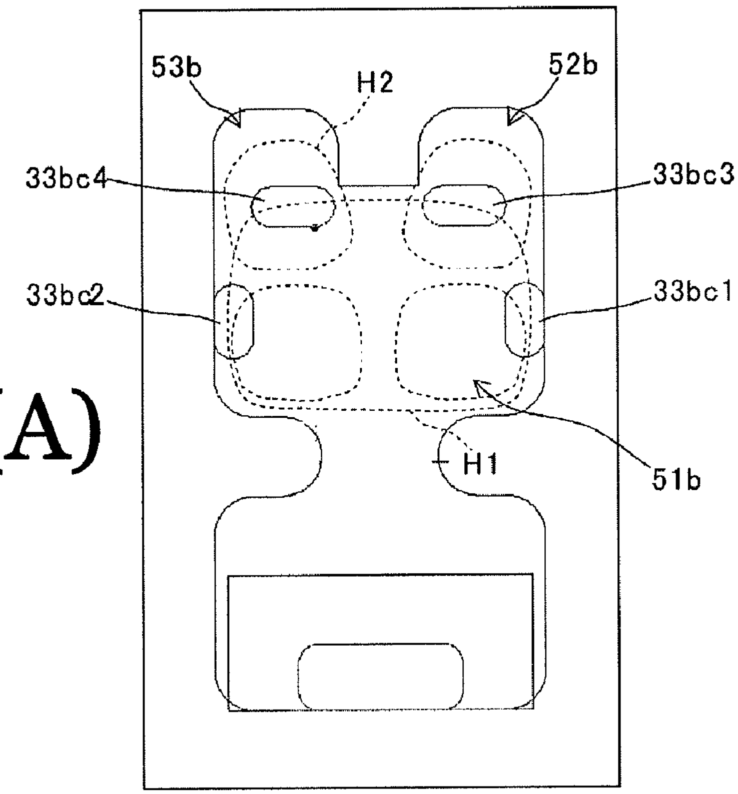


Fig.4(B)

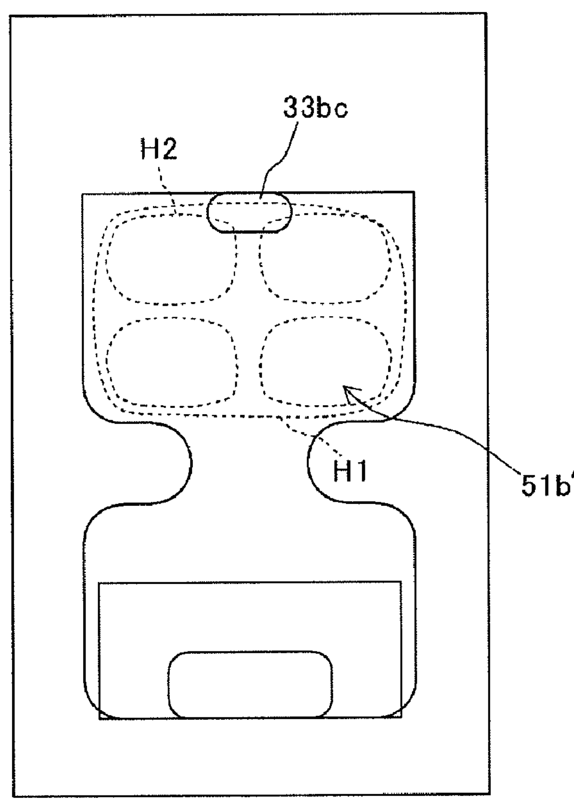


Fig.5

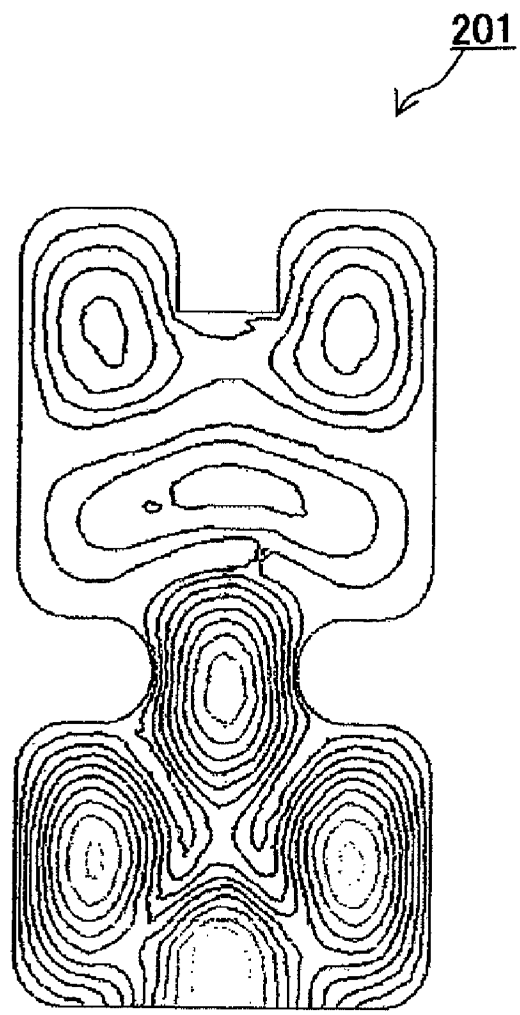


Fig.6(A)

(A)

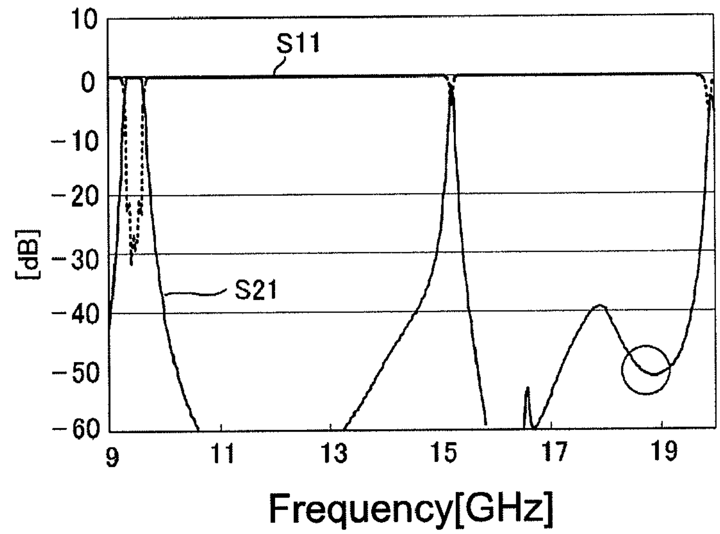


Fig.6(B)

(B)

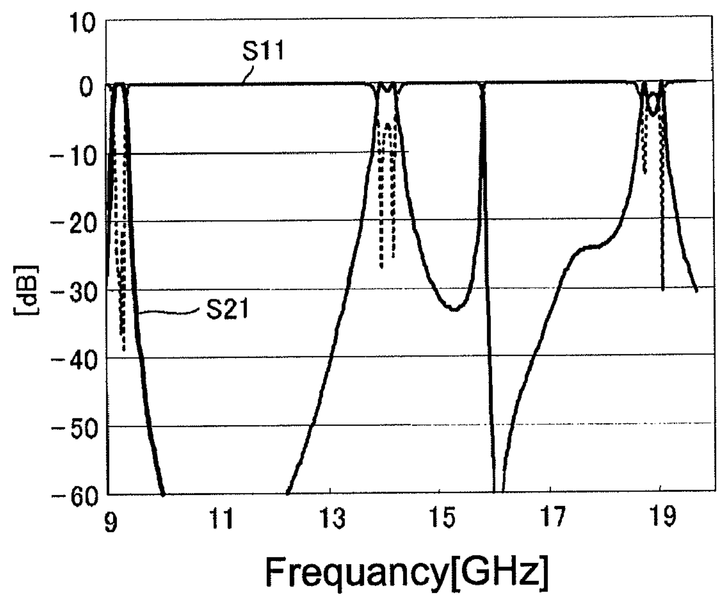


Fig.7

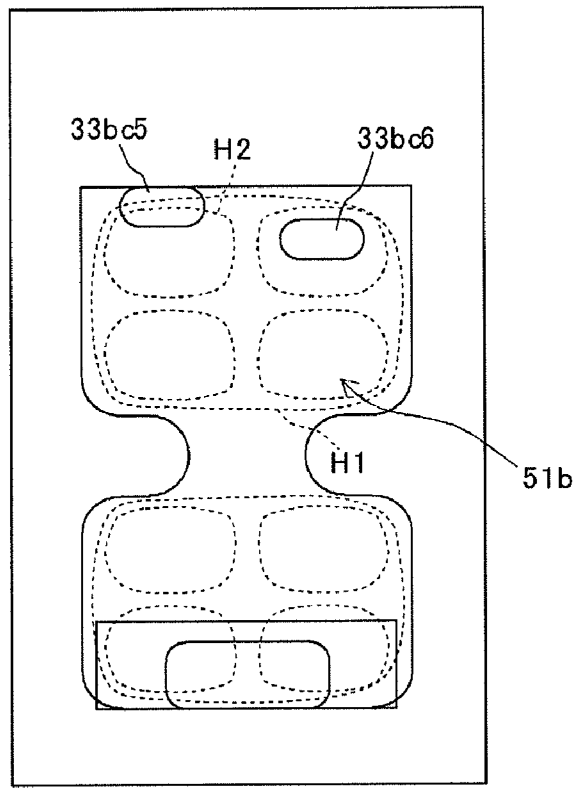

33bc5
H2
33bc6
H1
51b

Fig.8

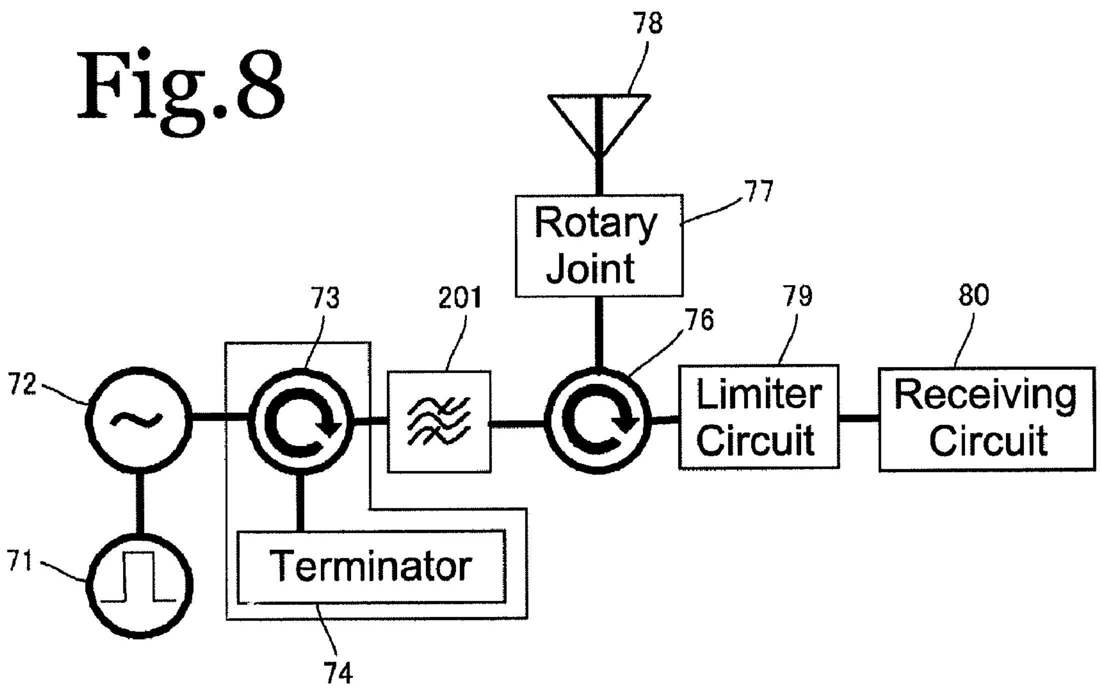

78
Rotary Joint
77
73
201
76
79
80
72
Limiter Circuit
Receiving Circuit
71
Terminator
74

Fig.9(A)

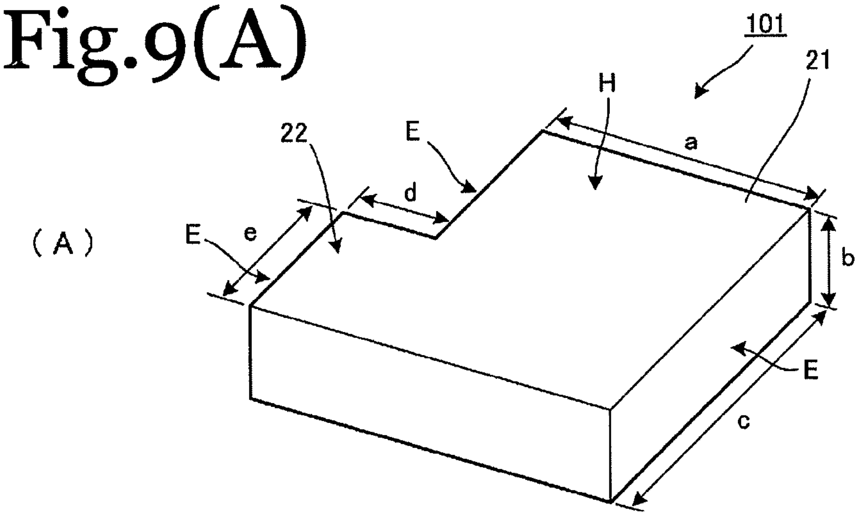


Fig.9(B)

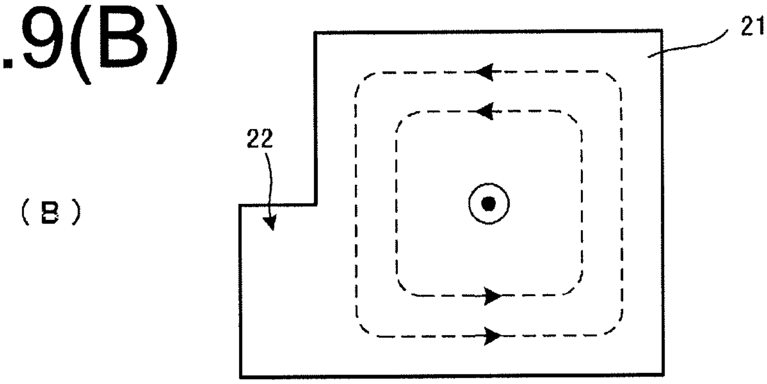


Fig.9(C)

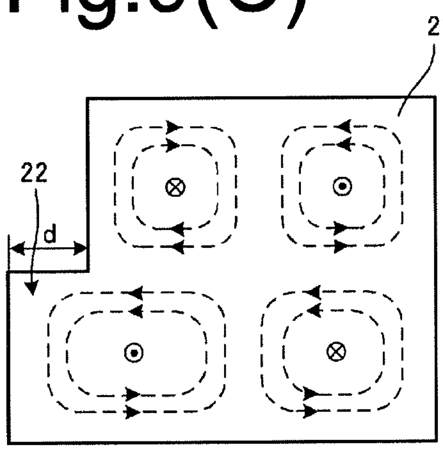
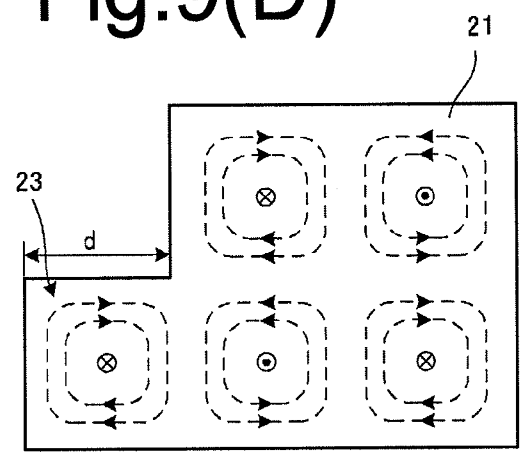


Fig.9(D)



(C)

(D)

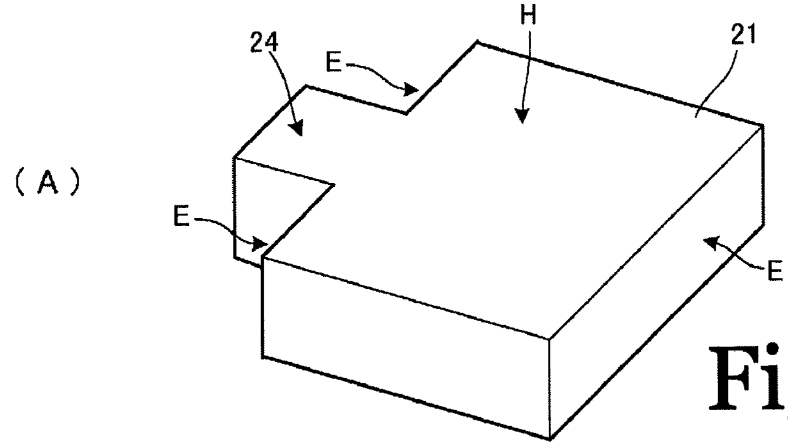
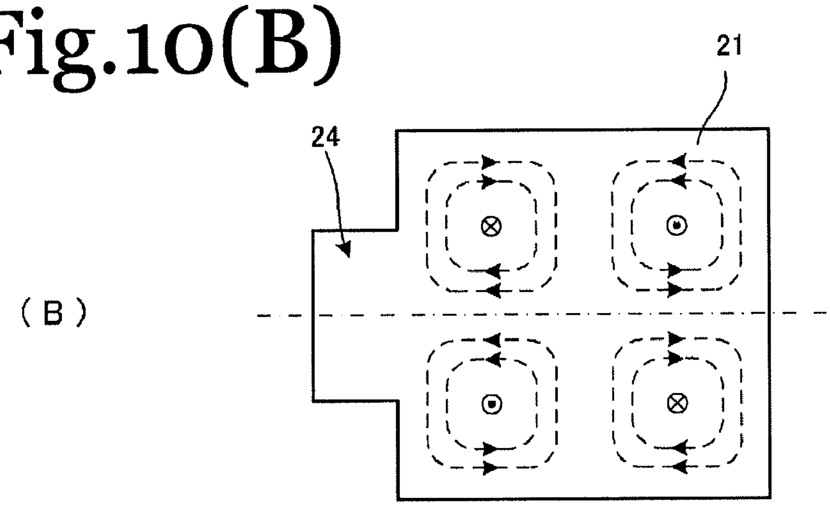


Fig.10(A)

Fig.10(B)



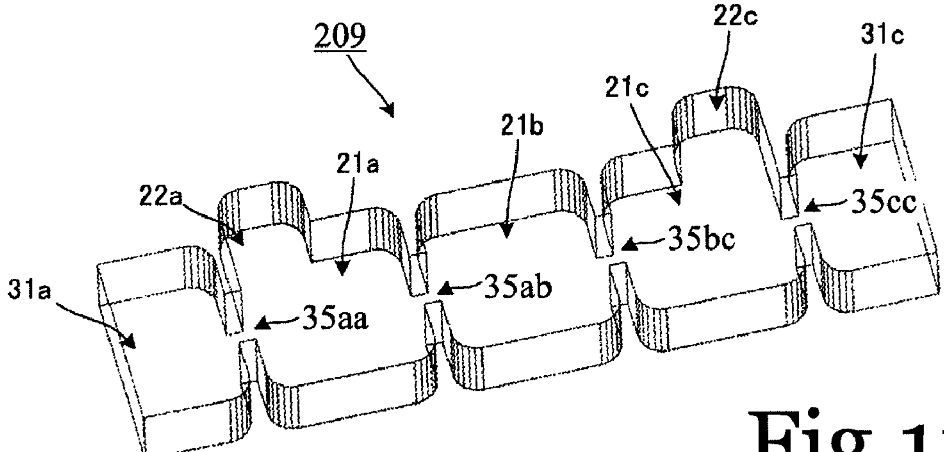


Fig.11

Fig.12(A)

(A)

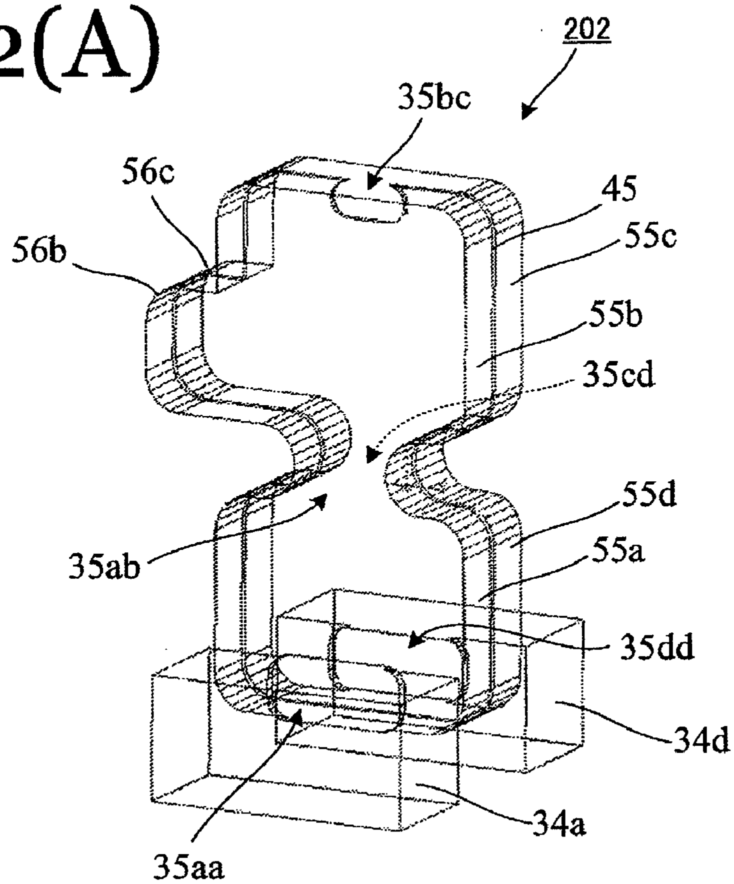


Fig.12(B)

(B)

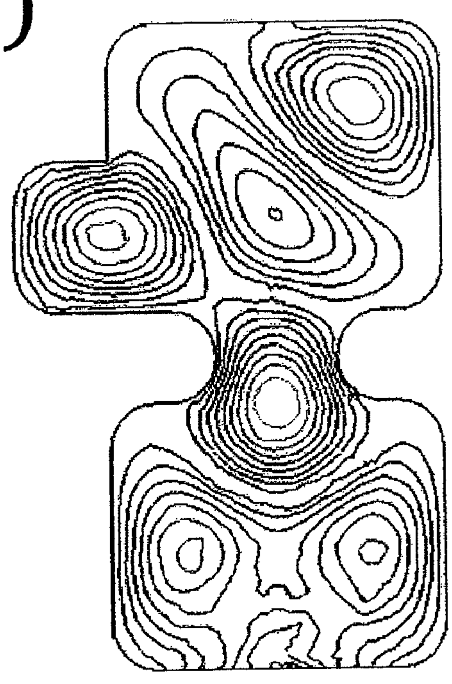
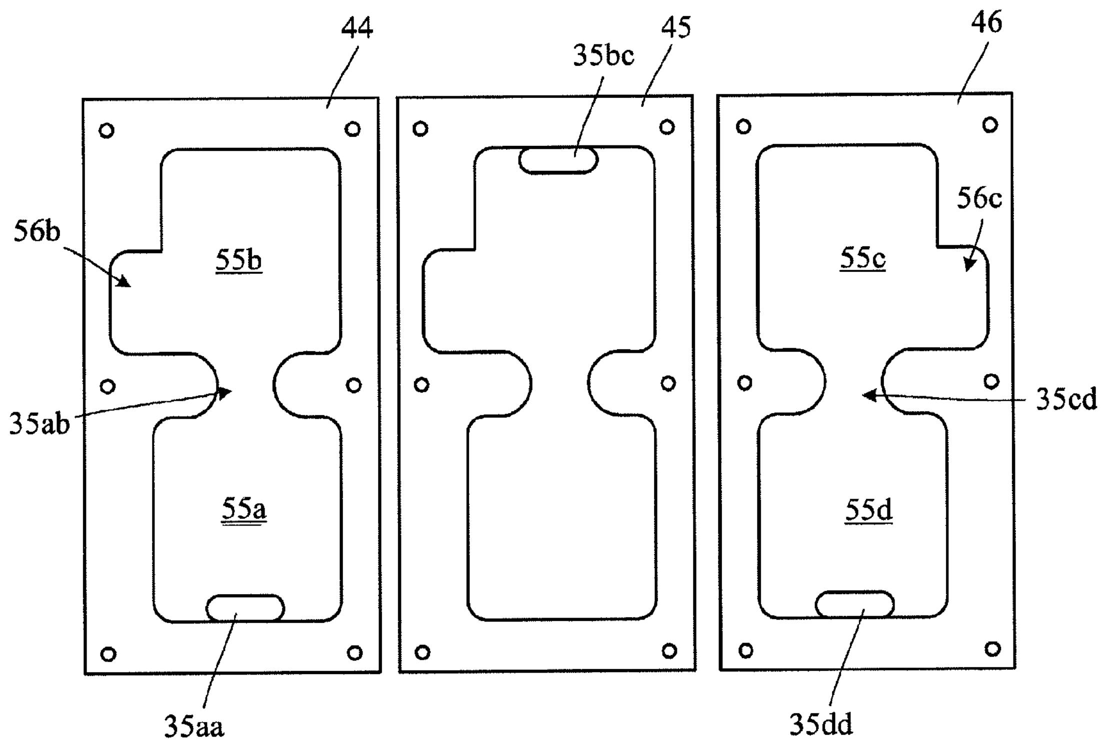


Fig.13(A) Fig.13(B) Fig.13(C)



(A) (B) (C)

Fig.14(A)

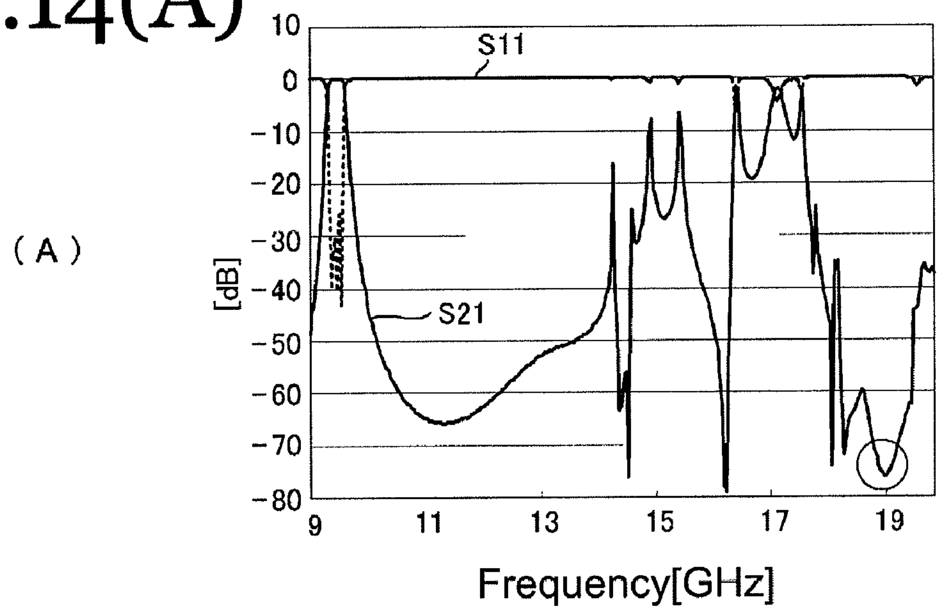


Fig.14(B)

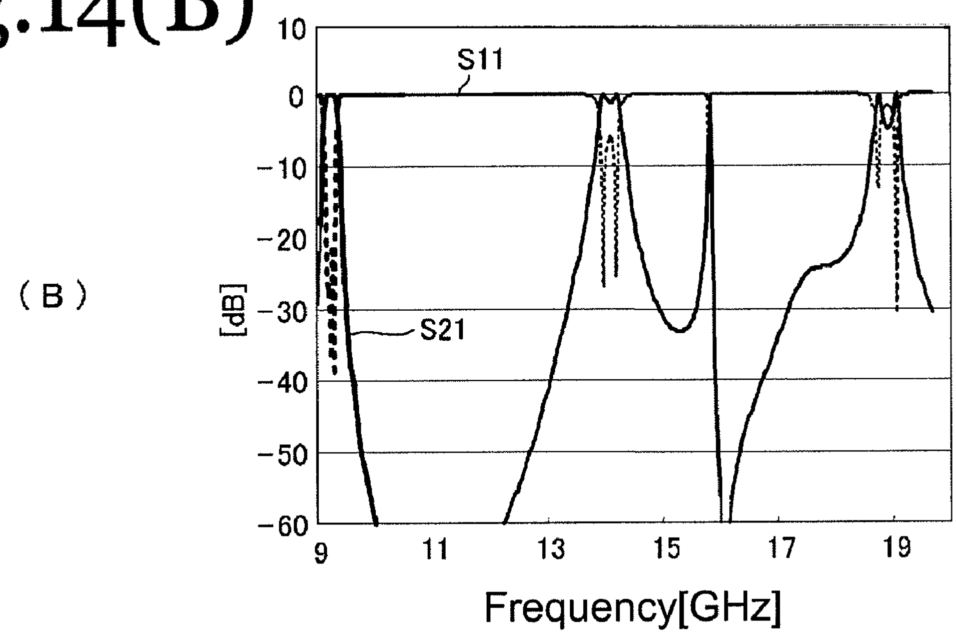


Fig.15

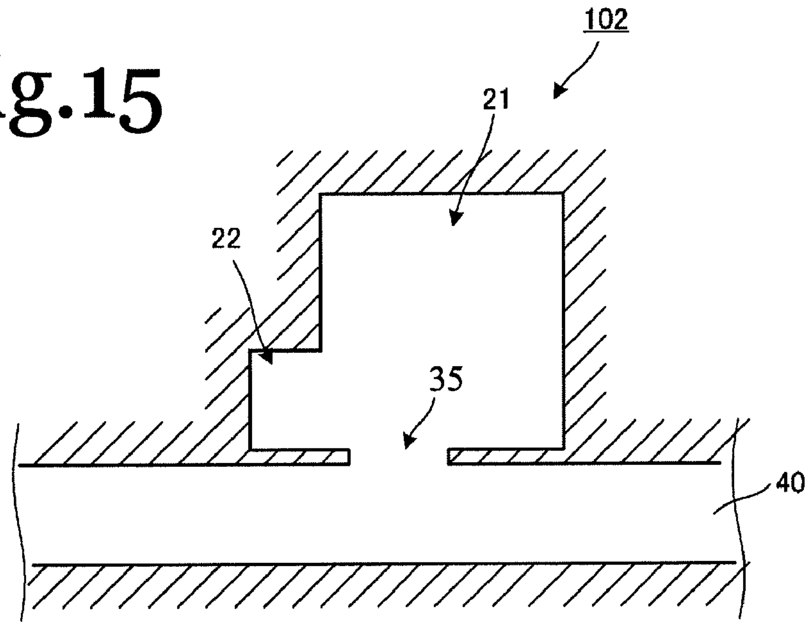


Fig.16

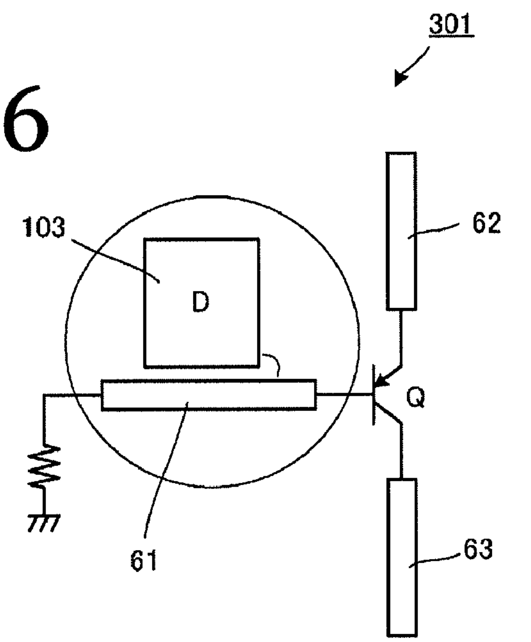


Fig.17

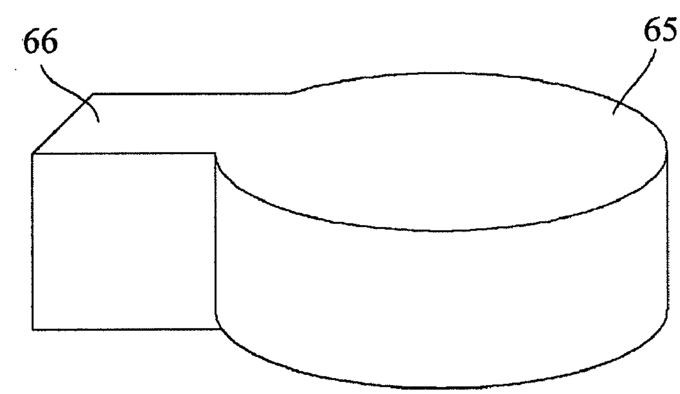
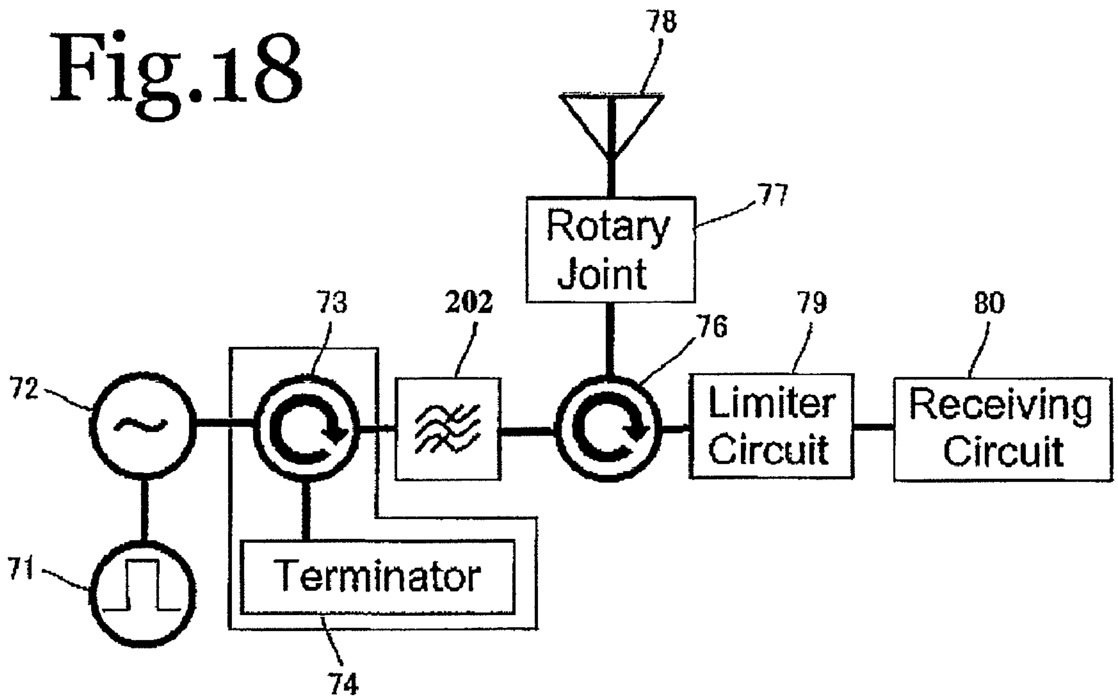


Fig.18


78
77
Rotary
Joint
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202
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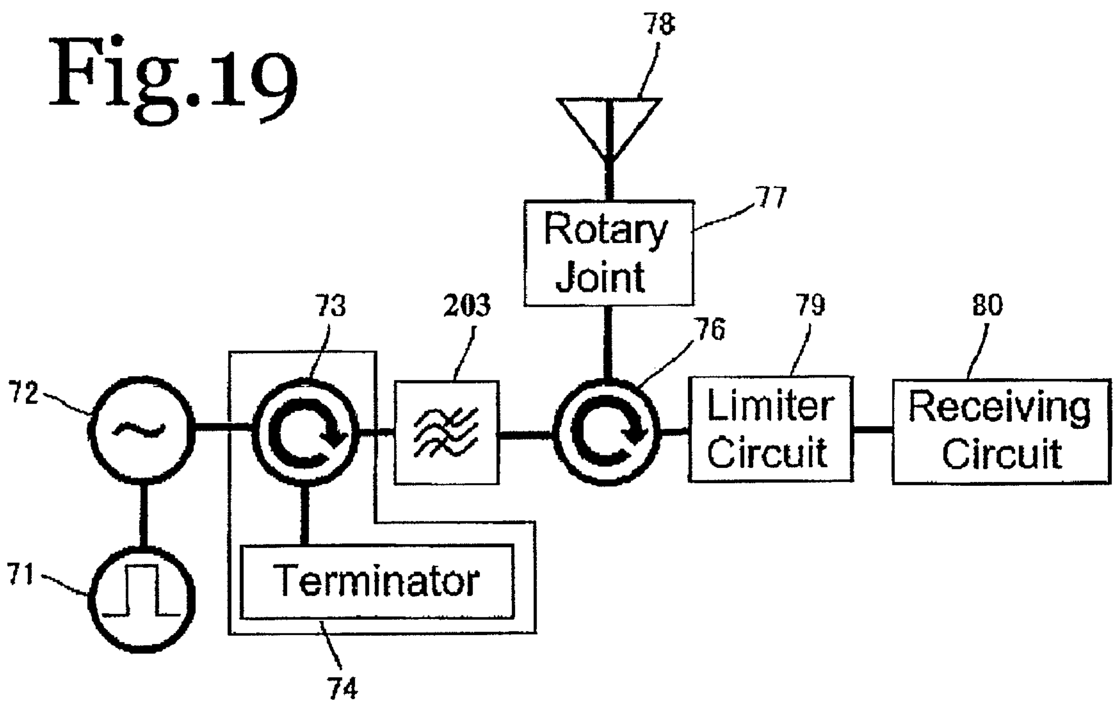
79
80
72
Limiter
Circuit
Receiving
Circuit
71
Terminator
74

Fig.19


78
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Limiter Circuit
Receiving Circuit
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Terminator
74

Fig.20(A)

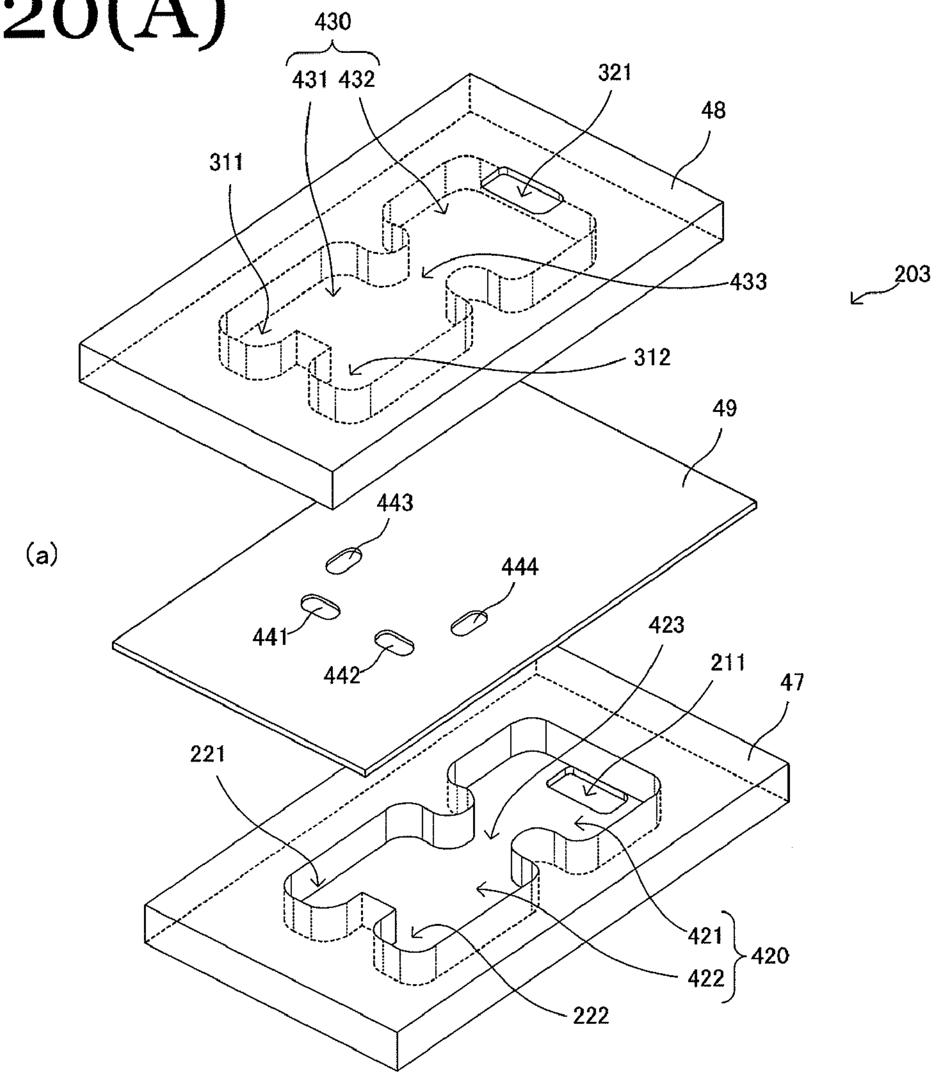


Fig.20(B)

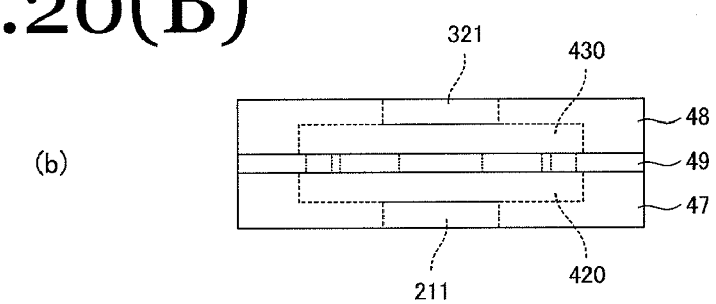


Fig.21

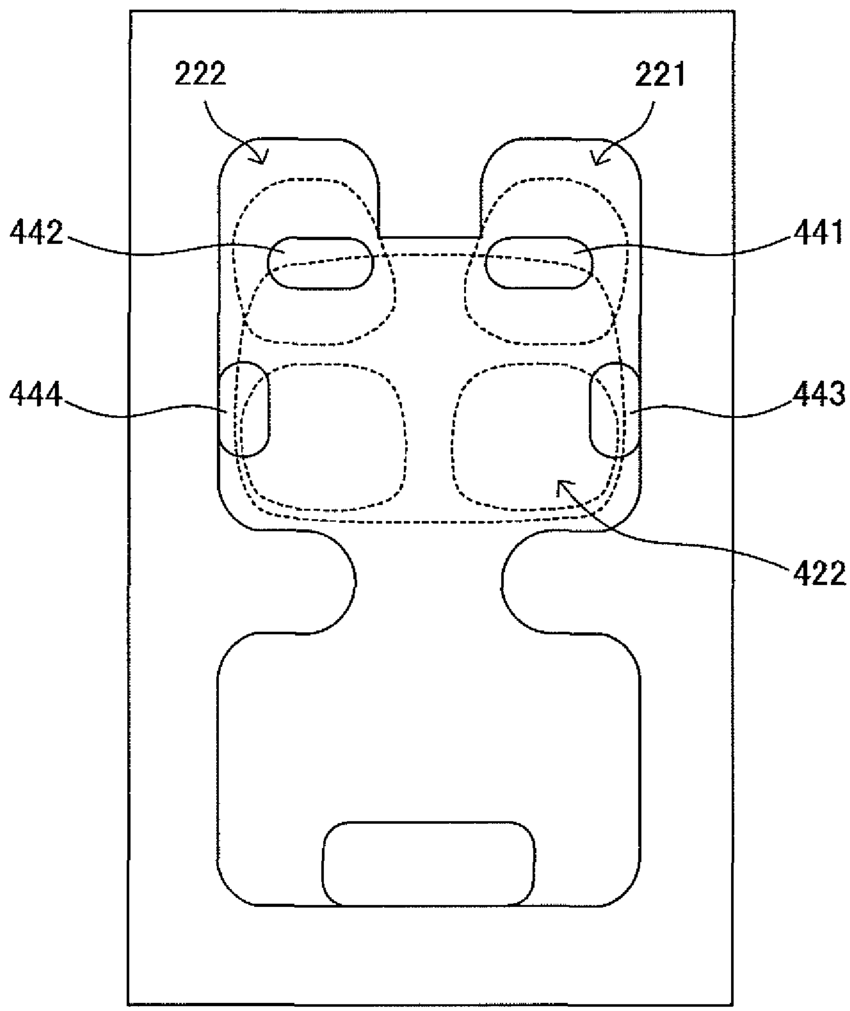


Fig.22

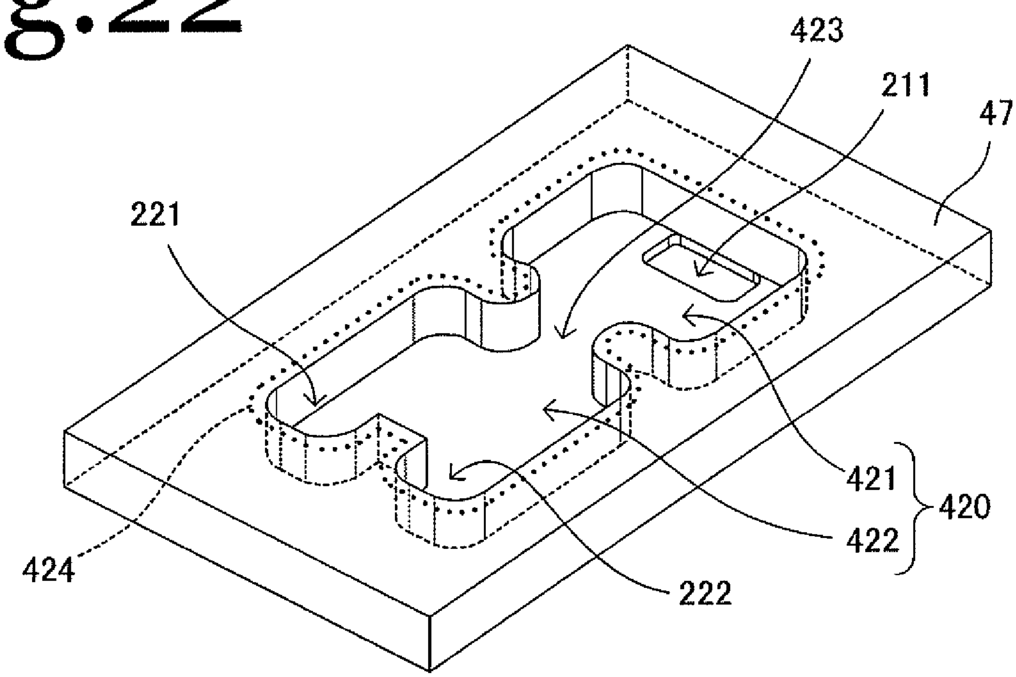


Fig.23

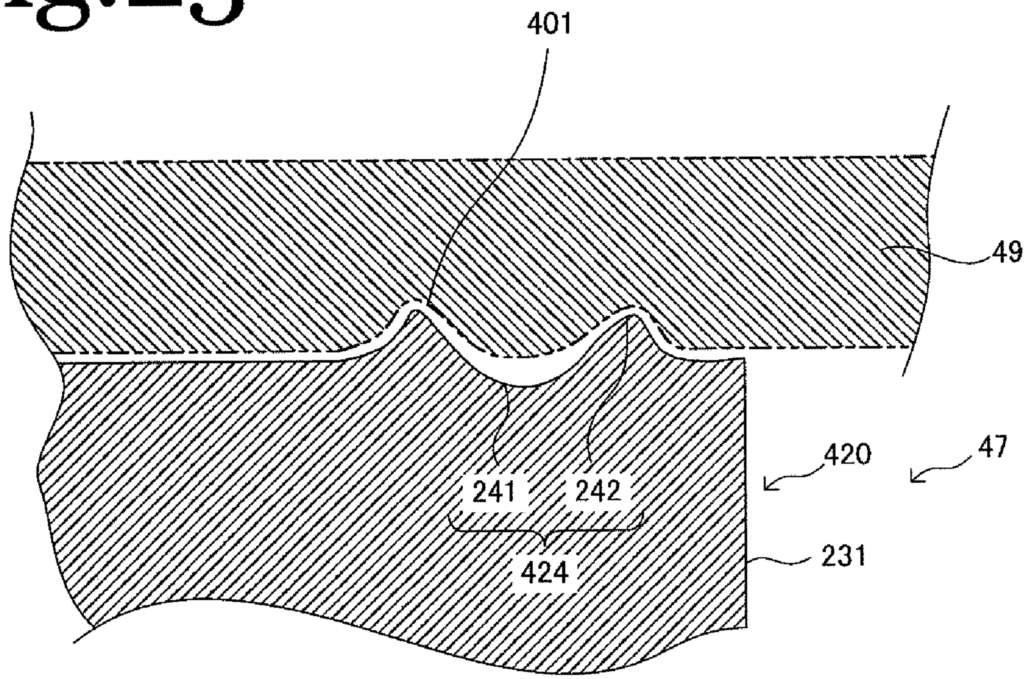
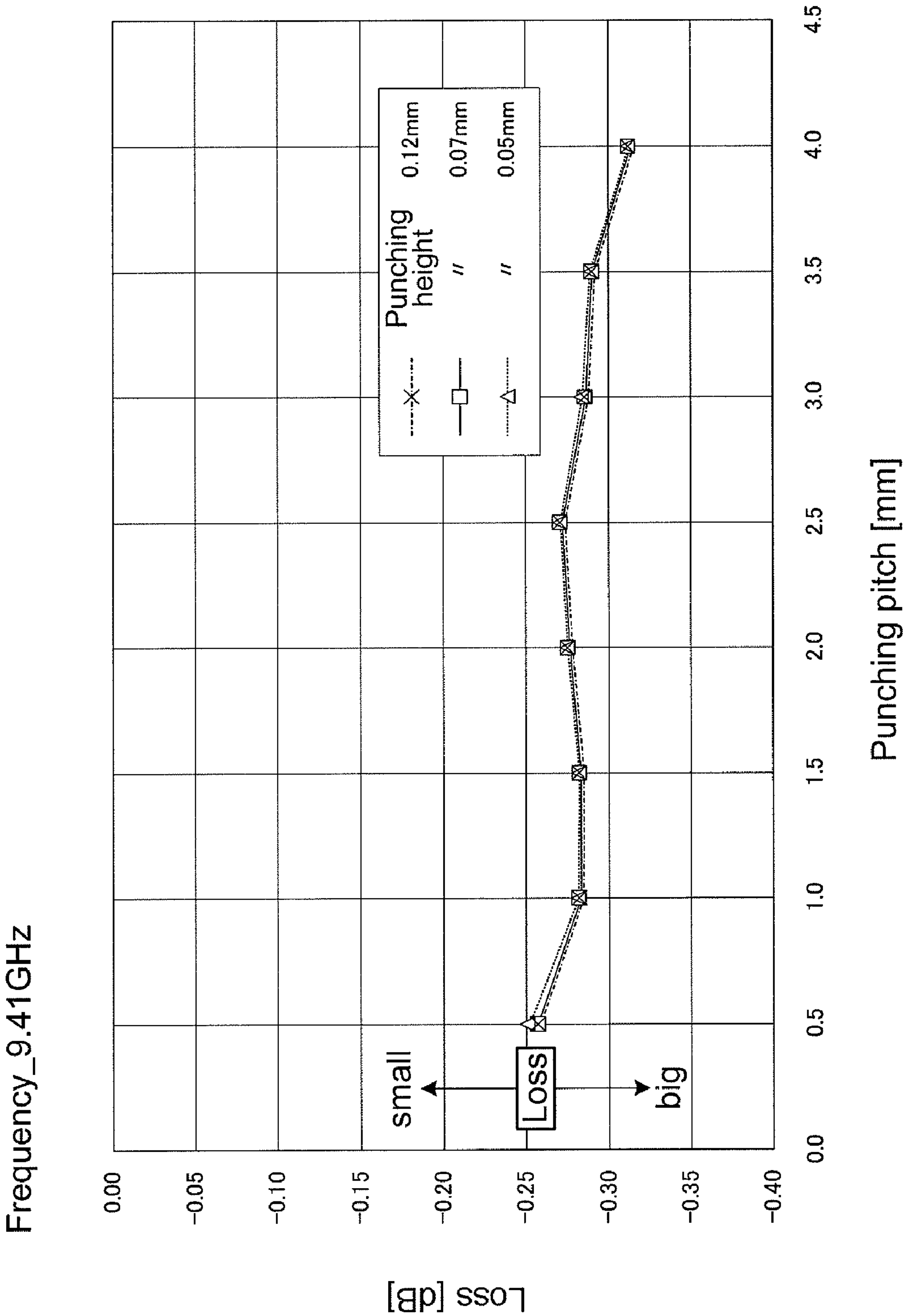


Fig.24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Loss [dB]
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
-0.30
-0.35
-0.40
small
Loss
big
Punching height 0.12mm
〃 0.07mm
〃 0.05mm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Punching pitch [mm]

Fig.25

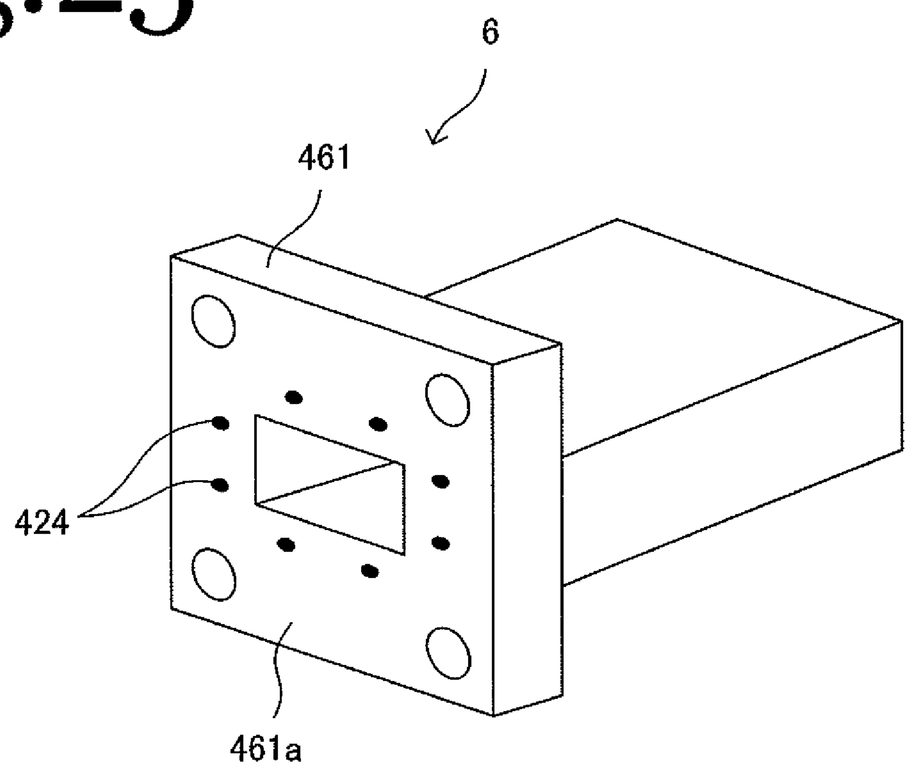


Fig.26

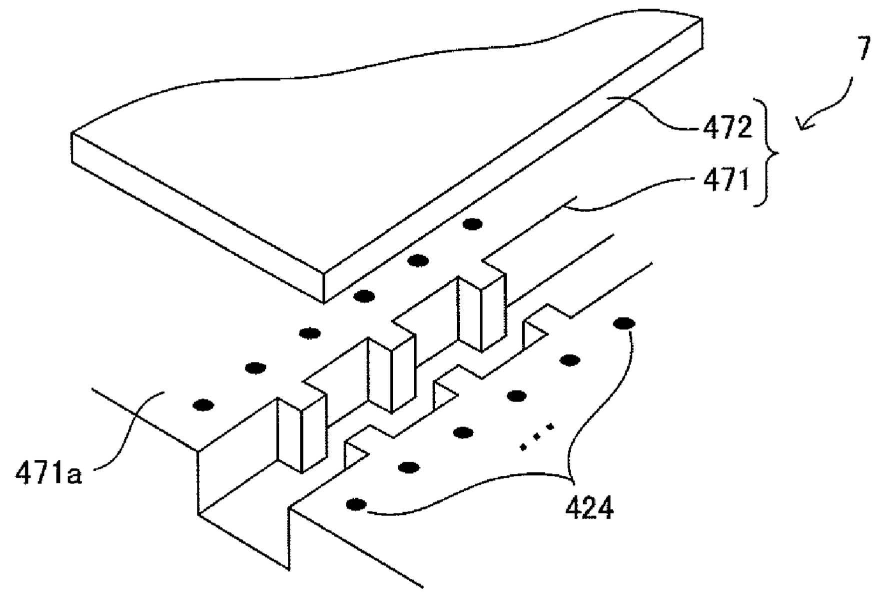


Fig.27

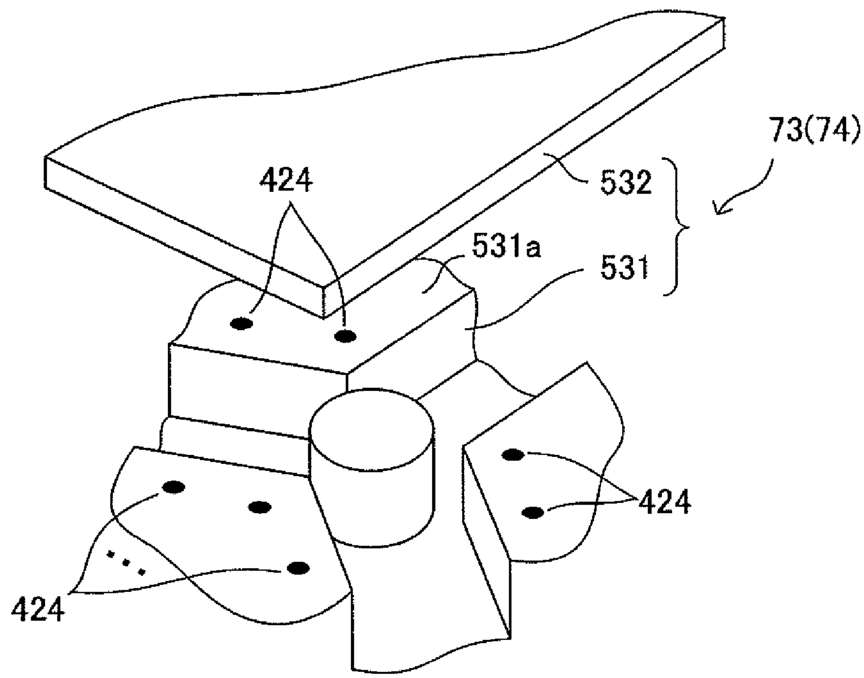
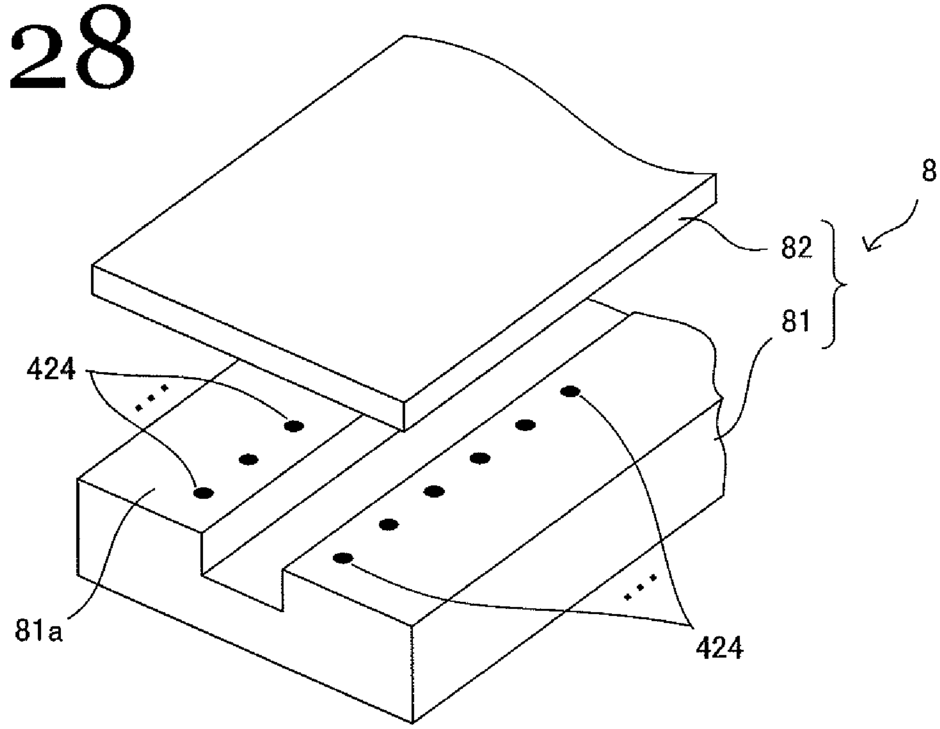


Fig.28



HARMONIC SUPPRESSION RESONATOR, HARMONIC PROPAGATION BLOCKING FILTER, AND RADAR APPARATUS

CROSS-REFERENCE TO RELATED APPLICATION(S)

This application claims priority under 35 U.S.C. §119 to Japanese Patent Application No. 2007-340542 which was filed on Dec. 28, 2007, Japanese Patent Application No. 2007-340560 which was filed on Dec. 28, 2007, and Japanese Patent Application No. 2008-238947 which was filed on Sep. 18, 2008, the entire disclosure of which is hereby incorporated by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a harmonic suppression resonator for suppressing, in a circuit using high frequency signals, a harmonic component having a different frequency from a fundamental wave frequency. The present invention also relates to a high-frequency device such as a harmonic propagation blocking filter, radar apparatus or the like, which comprises the harmonic suppression resonator.

2. Description of the Background Art

Conventionally, for the purpose of efficient use of radio wave resources, high-frequency devices are regulated and recommended so as not to cause unnecessary radiation in a frequency band which is remote from a frequency band used by the high-frequency devices.

Japanese Laid-Open Patent Publication No. 2004-274341 (hereinafter, referred to as Patent Document 1) describes a band-pass filter for improving a spurious characteristic of a microwave generating source.

FIG. **1** shows a structure of a waveguide band-pass filter of Patent Document 1. In the waveguide band-pass filter, waveguide resonators **1001***a* and **1001***b*, which have TE102 mode that is a fundamental mode of a rectangular waveguide, are provided so as to be connected to each other in a direction in which an electric field component E is orthogonal to a main propagation direction of TE10 mode that is a fundamental mode of a rectangular waveguide. The waveguide resonators **1001***a* and **1001***b* are connected such that a wide face, which is one of waveguide walls, of each waveguide resonator, is connected to the wide face of the other waveguide resonator so as to form a two-part structure. A turnaround section **1005** is provided at the connection between both the waveguide resonators **1001***a* and **1001***b*, which connection is a part of the connected waveguide resonators **1001***a* and **1001***b*. A coupling hole **1002***a* for coupling the waveguide resonators **1001***a* and **1001***b* is provided at a waveguide wall **1006** of the turnaround section **1005**, which waveguide wall **1006** is formed by the wide waveguide faces dividing the waveguide resonators **1001***a* and **1001***b*. Input/output coupling holes **1003***a* and **1003***b*, which are respectively formed at one end and the other end of the connected waveguide resonators **1001***a* and **1001***b*, are separated from each other by the waveguide wall **1006** formed with the wide faces of the waveguide resonators **1001***a* and **1001***b*, and do not couple with each other. Input/output waveguides **1004***a* and **1004***b* are respectively connected, in a direction orthogonal to an electric field component, to the input/output coupling holes **1003***a* and **1003***b* that are respectively formed at one end and the other end of the connected waveguide resonators **1001***a* and **1001***b*.

Another technique for suppressing unnecessary radiation contained in radio waves radiated from a radar using a large amount of power, is disclosed by Japanese Laid-Open Patent Publication No. 2007-81856 (hereinafter, referred to as Patent Document 2).

For a transmitter tube of a shipboard radar, a magnetron is used. The magnetron basically oscillates in π mode to generate a microwave having a fundamental wave frequency. At the same time, however, a frequency component of π-1 mode and a frequency component of a frequency-doubled wave (i.e., a second harmonic) occur as unnecessary radiation. In Patent Document 2, in order to suppress this unnecessary radiation, a rotary joint of a pedestal section is used, in which a spurious suppression filter (LPF) is provided in a coaxial tube on a central axis of the rotary joint.

In general, in a high-frequency device using a waveguide as a transmission path, a waveguide resonator is provided as a filter in order to allow only a fundamental wave component to propagate.

Further, Japanese Laid-Open Patent Publications No. 2004-274341 (hereinafter, referred to as Patent Document 3) and No. 2007-81856 (hereinafter, referred to as Patent Document 4) disclose techniques in which metallic blocks, which are obtained from dividing a metallic block along a longitudinal plane thereof, are combined to form a waveguide. Although this type of waveguide has advantages in manufacturing, it is necessary to provide a countermeasure for radio wave leakage (electrical loss) from a gap between planes, which face each other, of the combined metallic blocks. Patent Document 3 proposes to interpose a soft metallic foil between a metallic block, on which a waveguide groove is formed, and a metallic block, which covers the groove. In this manner, a gap between portions, which face each other, of the metallic blocks is eliminated by a tight contact between the metallic foil and the metallic blocks. Patent Document 4 proposes to silver-plate a vicinity of a groove of a plane of one metallic block, which plane faces a plane of the other metallic block, or to form a protrusion by using a metallic block or a different member, whereby a gap between the facing planes of the blocks is eliminated.

As mentioned above, a magnetron is used for a transmitter tube of a shipboard radar. The magnetron basically oscillates in π mode to generate a microwave having a fundamental wave frequency. At the same time, however, a frequency component of $\pi-1$ mode and a frequency component of a frequency-doubled wave (i.e., a second harmonic) occur as unnecessary radiation.

In a structure comprising a waveguide resonator as a filter, if a waveguide filter, which resonates in, for example, TE101 mode of a rectangular waveguide, is provided, not only a fundamental wave is transmitted but also a second harmonic is transmitted since the waveguide filer also resonates in TE202 mode. For this reason, it has been impossible to use a waveguide filter as a harmonic propagation blocking filter. This is described below using FIG. **2**.

FIG. **2** shows a structure of a conventional waveguide resonator that does not have a harmonic-suppressing function. FIG. **2**(A) is an external perspective view of the conventional waveguide resonator. Basically, the waveguide resonator has a shape which is formed in the following manner: a rectangular waveguide is cut such that wide planes thereof become square planes; and front and rear openings thereof are closed using conductive materials.

FIG. **2**(B) schematically shows electromagnetic field distribution of a fundamental wave. FIG. **2**(D) schematically shows electromagnetic field distribution of a second harmonic. Here, solid arrows represent lines of electric force at a given moment, and dot marks and cross marks represent directions of magnetic fields. In this manner, electromagnetic field intensity distribution is represented.

FIG. **2**(C) shows, in relation to the electromagnetic field distribution of the fundamental wave, intensity distribution of electric field energy and magnetic field energy. FIG. **2**(E) shows, in relation to the electromagnetic field distribution of the second harmonic, intensity distribution of electric field energy and magnetic field energy. In these diagrams, EF represents a region where the electric field energy is dominant, and MF represents a region where the magnetic field energy is dominant.

As shown herein, the waveguide resonator that resonates in the TE101 mode also resonates in the TE202 mode. Therefore, the second harmonic in the case where the fundamental wave is in the TE101 mode, cannot be suppressed.

Accordingly, even if the waveguide band-pass filter disclosed by Patent Document 1 is used in order to suppress the aforementioned unnecessary radiation, there is a problem that an effect to suppress the second harmonic component, which is crucial, is low.

In such a structure as disclosed in Patent Document 2 where a low-pass filter is used, harmonic components can be suppressed over a relatively wide frequency band within a frequency band that is higher than a fundamental wave frequency band. However, there is a problem that an attenuation characteristic in the frequency band higher than the fundamental wave frequency band is not steep, and an effect to suppress the second harmonic, which is crucial, is low.

Further, in the structure comprising a waveguide resonator as a filter, if a waveguide filter, which resonates in, for example, TE□101 mode of a rectangular waveguide (hereinafter, simply referred to as "TE101 mode"), is provided, not only a fundamental wave is transmitted but also a second harmonic is transmitted since the waveguide filter also resonates in TE□202 mode (hereinafter, simply referred to as "TE202 mode"). For this reason, it has been impossible to use a waveguide filter as a harmonic propagation blocking filter. This is described below with reference to FIG. **2**.

FIG. **2** shows a configuration of a conventional waveguide resonator that does not have a harmonic-suppressing function. FIG. **2**(A) is an external perspective view of the conventional waveguide resonator. Basically, the waveguide resonator has a shape which is formed in the following manner: a rectangular waveguide is cut such that wide planes thereof become square planes; and front and rear openings thereof are closed using conductive materials.

FIG. **2**(B) schematically shows electromagnetic field distribution of a fundamental wave. FIG. **2**(D) schematically shows electromagnetic field distribution of a frequency-doubled wave of the fundamental wave. Here, solid arrows represent lines of electric force at a given moment, and dot marks and cross marks represent directions of magnetic fields. In this manner, electromagnetic field intensity distribution is represented.

As shown herein, the waveguide resonator that resonates in the TE101 mode also resonates in the TE202 mode. Therefore, the second harmonic in the case where the fundamental wave is in the TE101 mode, cannot be suppressed.

Further, in Patent Document 3, since the soft metallic foil is used, the foil needs to be handled carefully, and it is questionable whether flatness or the like of the foil can be maintained in the long term. Thus, the technique disclosed in Patent Document 3 is not sufficient in terms of workability and reliability. Still further, in Patent Document 4, a new problem arises in relation to flatness of a surface of the formed protrusion, and thus, there is a limit to completely eliminate the gap.

SUMMARY OF THE INVENTION

Therefore, an object of the present invention is to provide a harmonic suppression resonator having a high harmonic-suppression effect, and to provide a harmonic suppression high frequency device comprising the same.

The present invention has the following features to attain the object mentioned above. A first aspect of the present invention is a harmonic suppression resonator comprising a plurality of waveguide resonators which resonate in TE mode, the harmonic suppression resonator having adjoining resonators therein coupled with each other via a coupling window.

In the harmonic suppression resonator, harmonic modes of a predetermined order of the adjoining resonators are magnetically and electrically coupled with each other via the coupling window, whereby coupling of the harmonic modes is negated.

According to this structure, the harmonic modes are not coupled. Even if, between the adjoining two resonators, a fundamental wave of one resonator and a harmonic of the other resonator are coupled via the coupling window, the harmonic modes of the adjoining two resonators are negated due to the above magnetically and electrically coupling. Accordingly, propagation in the harmonic modes is blocked.

In this manner, an n-th order harmonic to be suppressed can be effectively suppressed, and propagation of an unnecessary harmonic can be blocked substantially.

In a second aspect of the present invention based on the first aspect, a plurality of coupling windows are provided, and fundamental wave modes of the adjoining resonators are mainly electrically coupled or magnetically coupled with each other via a part or all of the plurality of coupling windows.

According to this structure, coupling of the harmonic modes is blocked by means of the coupling windows that allow the fundamental wave modes of the adjoining resonators to be coupled. Accordingly, propagation in the harmonic modes is blocked.

In a third aspect of the present invention based on the first aspect: a coupling window for causing the harmonics of the adjoining resonators to be magnetically coupled with each other, may be provided; an additional region, whose width is no longer than a half wavelength of the fundamental wave and no shorter than a half wavelength of the harmonics, may be provided at any position on an E-plane of at least one of the plurality of waveguide resonators; and a coupling window for causing the harmonics to be electrically coupled with each other may be provided near the additional region.

According to this structure, the harmonics of the adjoining resonators are relatively strongly electrically coupled via the coupling window provided near the additional region. Accordingly, magnetically coupling via the other coupling window is negated, and thus, coupling of the harmonics is more securely suppressed.

If, without providing the additional region, a coupling window is provided in such a position as to allow the harmonic modes to be electrically coupled, the position of the coupling window is in an area where electric field intensity of the fundamental wave modes is high. Accordingly, electric discharge is likely to occur at an opening of the coupling window or between the coupling window and a conductor side facing the coupling window, that is, power-withstanding capability deteriorates. However, the above-described structure does not cause this problem.

In a fourth aspect of the present invention based on the first aspect, in the harmonic suppression resonator, at least one of the plurality of waveguide resonators, which respectively include the resonant regions and in each of which the fundamental wave resonates in the TE mode, includes an additional region in which the fundamental wave is blocked and whose size is such that an n-th order harmonic to be suppressed [n is an integer no less than 2] is propagated therein.

According to this structure, the additional region does not affect the fundamental wave. Therefore, a resonance frequency of the fundamental wave does not vary. However, a resonance frequency of the n-th order harmonic lowers. Accordingly, the n-th order harmonic (n-multiplication wave) to be suppressed does not resonate at a resonance frequency of an n-th order harmonic (n-times frequency wave) of the resonators. In other words, the harmonic suppression resonator acts as a harmonic suppression resonator that resonates at the fundamental wave and which does not resonate at the harmonic to be suppressed.

In a fifth aspect of the present invention based on the fourth aspect, the resonant regions respectively act as substantially rectangular waveguide resonators, in each of which the fundamental wave resonates in the TE mode. The additional region has such a shape as to protrude from an E-plane of at least one of the substantially rectangular waveguide resonators such that a width, along a longitudinal direction of the E-plane, of the additional region is no longer than ½ of a wavelength of the fundamental wave and no shorter than ½ of a wavelength of the n-th order harmonic, and a depth of the additional region is different from m/2 of the wavelength of the n-th order harmonic [m is an integer no less than 1].

According to this structure, the n-th order harmonic to be suppressed can be effectively suppressed, and thus the unnecessary harmonic can be substantially suppressed.

In a sixth aspect of the present invention based on the fifth aspect, the depth of the additional region is set to be, in particular, substantially (1+2 m)/4 of the wavelength of the n-th order harmonic [m is an integer no less than 0].

According to this structure, the n-th order harmonic to be suppressed can be suppressed more effectively, and thus the unnecessary harmonic can be substantially suppressed. Further, a size of the additional region can be kept small, which prevents the harmonic suppression resonator from becoming large sized.

In a seventh aspect of the present invention based on the fourth aspect, the additional region is provided such that a center of the additional region is positioned so as to deviate from an extension of a line that connects centers, in a longitudinal direction, of E-planes of at least one of the resonant regions.

As a result, an n-th order harmonic standing wave easily occurs in the additional region, and a harmonic suppression effect is improved, accordingly.

In an eighth aspect of the present invention based on the first aspect, the plurality of waveguide resonators constitute a waveguide structure comprising a first block which is a metallic block and whose predetermined face has a radio-wave-propagating groove formed thereon, and the predetermined face of the first block is covered by a cover member, and a plurality of first protrusions are formed, on the predetermined face, in positions along the groove with predetermined pitches.

According to the eighth aspect, by covering the predetermined face of the first block with the cover member, a wave guide is formed in which a space, which is formed with the groove of the first block and the cover member, acts as a waveguide path. When the groove of the first block is covered with the cover member, the protrusions formed on the predetermined face are deformed in accordance with relative strength between the first block and the cover member, whereby the first block and the cover member tightly contact each other. In this manner, a gap between the first block and the cover member is eliminated, and radio wave leakage is prevented to the utmost extent.

In a ninth aspect of the present invention based on the eighth aspect, the cover member is formed from a material that is as hard as, or softer than, the first block.

According to this structure, a degree of contact between the first block and the cover member is increased due to deformation of a surface of the relatively soft cover member. As a result, the gap between the first block and the cover member is eliminated, whereby radio wave leakage is prevented to the utmost extent.

In a tenth aspect of the present invention based on the eighth aspect, the harmonic suppression resonator comprises a second block which is a metallic block provided to be positioned at an opposite side to the first block with respect to the cover member interposed between the second block and the first block and which has a radio-wave-propagating groove formed on a face thereof facing the cover member. The second block has a plurality of second protrusions, formed on the face thereof facing the cover member, in positions along the groove with predetermined pitches.

According to this structure, waveguides are respectively formed at both sides to the cover member, and the degree of contact between the first block and the cover member, as well as the degree of contact between the second block and the cover member, is increased. This consequently eliminates the gap between the first block and the cover member as well as the gap between the second block and the cover member. As a result, radio wave leakage from both the waveguides is blocked to the utmost extent.

In an eleventh aspect of the present invention based on the tenth aspect, the grooves formed on the first and second blocks are mirror-symmetrical to each other, and positions of the first protrusions and positions of the second protrusions deviate from each other by substantially half a pitch.

According to this structure, both the faces of the cover member are in tight contact with the protrusions, at substantially every half a pitch. As a result, radio wave leakage from both the grooves is blocked to the utmost extent.

In a twelfth aspect of the present invention based on the tenth aspect, holes are drilled through the first block, the second block and the cover member such that the holes at respective faces of the first block, the second block and the cover member are aligned, and the first block, the second block and the cover member are fastened together with fastening means through the holes.

According to this structure, the cover member is pressure-bonded to the first block and to the second block with a same required pressure by means of fastening means, for example, bolts and nuts, which required pressure is obtained by a degree of fastening.

In a thirteenth aspect of the present invention based on the tenth aspect, the first and second protrusions are swell portions surrounding recesses that are formed by pressing operations performed with a needle-like body.

According to this structure, the protrusions can be relatively easily formed by a so-called punching process.

A fourteenth aspect of the present invention is a harmonic propagation blocking filter comprising the harmonic suppression resonator and input/output sections for guiding a propagation signal into/out of the resonant regions.

By providing the harmonic propagation blocking filter, for example, in a path of a waveguide, propagation of the n-th order harmonic to be suppressed is blocked.

A fifteenth aspect of the present invention is a radar apparatus comprising: a magnetron which oscillates in π mode to generate the fundamental wave; an antenna; and the harmonic propagation blocking filter provided on a propagation path between the magnetron and the antenna.

According to this structure, a radio microwave generated by a microwave generator is propagated to the antenna while leakage thereof from the waveguide is blocked to the utmost extent. Thus, the microwave is efficiently transmitted into the air from the antenna.

These and other objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description of the present invention when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a structure of a waveguide band-pass filter of Patent Document 1;

FIG. **2** shows a structure of a waveguide resonator and an example of electromagnetic field distributions of a fundamental wave mode and a second harmonic mode;

FIG. **3** is a perspective view showing a main part of a harmonic propagation blocking filter according to a first embodiment;

FIG. **4** shows a configuration of resonant regions and coupling windows of the harmonic propagation blocking filter according to the first embodiment, and shows an example of electromagnetic field distribution of each mode;

FIG. **5** shows an example of electromagnetic field distribution of a second harmonic mode of the harmonic propagation blocking filter according to the first embodiment;

FIG. **6** shows a frequency characteristic of the harmonic propagation blocking filter;

FIG. **7** is a plane view showing a structure of a main part of a harmonic propagation blocking filter according to a second embodiment;

FIG. **8** is a block diagram showing a structure of a radar according to a third embodiment;

FIG. **9** shows a structure of a harmonic suppression resonator and an example of electromagnetic field distribution of each mode, according to a fourth embodiment;

FIG. **10** shows an example of a position in which an additional region of the harmonic suppression resonator is formed;

FIG. **11** is a perspective view showing a main part of a harmonic propagation blocking filter according to a fifth embodiment;

FIG. **12** shows a perspective view showing a main part of a harmonic propagation blocking filter according to a sixth embodiment, and shows an example of electromagnetic field distribution;

FIG. **13** is a plane view of components of the harmonic propagation blocking filter;

FIG. **14** shows a frequency characteristic of the harmonic propagation blocking filter;

FIG. **15** is a horizontal sectional view showing a structure of a harmonic suppression resonator according to a seventh embodiment;

FIG. **16** is a circuit diagram of a harmonic suppression oscillator according to an eighth embodiment;

FIG. **17** shows a structure of a harmonic suppression resonator according to a ninth embodiment;

FIG. **18** is a block diagram showing a structure of a radar according to a tenth embodiment;

FIG. **19** is a block diagram showing a structure of a radar apparatus that is an example of a microwave transmission/reception apparatus in which a waveguide structure according to the present invention is applied;

FIG. **20**(A) is an exploded perspective view of a main part of a filter, and FIG. **20**(B) is a side view showing that components of the main part are assembled;

FIG. **21** is a plane view illustrating a positional relationship, in a resonant region, between electromagnetic field distribution and coupling windows;

FIG. **22** illustrates a structure of an upper surface of a metallic block;

FIG. **23** shows cross-sectional shapes of protrusions and a partition plate;

FIG. **24** shows a relationship between a height of the protrusions (a punching height) and a level of radio wave leakage;

FIG. **25** is a partial structural view illustrating an embodiment where the present invention is applied to a flange portion of a waveguide;

FIG. **26** is a partial structural view illustrating an embodiment where the present invention is applied to a filter;

FIG. **27** is a partial structural view illustrating an embodiment where the present invention is applied to a circulator; and

FIG. **28** is a partial structural view illustrating an embodiment where the present invention is applied to a normal waveguide.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

First Embodiment

FIG. **3** is an exploded perspective view of a main part of a harmonic propagation blocking filter according to a first embodiment.

Basically, the harmonic propagation blocking filter comprises: two metallic blocks **41** and **43**; a partition plate **42** provided between the two metallic blocks; and input/output spaces **32***a* and **32***d* (end portions of a rectangular waveguide).

Recessed portions having a predetermined depth are formed on the first metallic block **41**, whereby resonant regions **51***a* and **511** are formed on the first metallic block **41**. Additional regions **52***b* and **53***b* are provided at the resonant region **51***b*. Further, a coupling window **33***ab* is formed between the two resonant regions **51***a* and **51***b*. Also, a coupling window **33***aa* is formed at the resonant region **51***a* so as to be open to rearward of FIG. **3**.

Resonant regions **51***c* and **51***d*, additional regions **52***c* and **53***c*, and coupling windows **33***cd* and **33***dd* are formed on the second metallic block **43** such that the structure of the second metallic block **43** is mirror-symmetrical to that of the first metallic block **41**.

The partition plate **42** is a metallic plate interposed between resonant-region-forming planes of the metallic blocks **41** and **43**, and have coupling windows **33***bc***1**, **33***bc***2**, **33***bc***3** and **33***bc***4** that are openings which allow the resonant regions **51***b* and **51***c* to communicate with each other.

The above five components are combined in a layered manner to form a harmonic propagation blocking filter **201**.

Owing to the above structure, an electromagnetic wave is propagated through the following path: the input/output space **32***a*→the coupling window **33***aa*→the resonant region **51***a*→the coupling window **33***ab*→the resonant region **51***b*→the coupling windows **33***bc*→the resonant region

51*c*→the coupling window **33***cd*→the resonant region **51***d*→the coupling window **33***dd*→the input/output space **32***d.*

FIG. **4**(A) shows an example of electromagnetic field distribution of each mode of predetermined resonators of the harmonic propagation blocking filter **201** according to the first embodiment, and FIG. **4**(B) shows, for comparison with the harmonic propagation blocking filter **201**, an example of electromagnetic field distribution of each mode of predetermined resonators of a filter.

FIG. **5** shows density distribution of second harmonic standing waves generated within the resonant regions of the harmonic propagation blocking filter **201** according to the first embodiment.

In the resonant region **51***b* and a resonant region **51***b*' shown in FIGS. **4**(A) and **4**(B), a loop H**1** indicated by a dashed line represents a magnetic field loop in the electromagnetic field distribution of a fundamental wave mode, and four loops H**2** indicated by dashed lines represent magnetic field loops in the electromagnetic field distribution of a second harmonic mode. Similarly, the electromagnetic field distributions of the fundamental wave mode and the second harmonic mode are present in a resonant region adjoining the resonant region **51***b* (i.e., the resonant region **51***c* shown in FIG. **3**).

Also in the filter shown in FIG. **4**(B) of the comparison example, similar magnetic fields of the fundamental wave mode and the second harmonic mode to those shown in FIG. **4**(B) are distributed in a resonant region adjoining the resonant region **51***b'*.

In the filter of the comparison example, as shown in FIG. **4**(B), a coupling window **33***bc* is positioned in an area where magnetic field energy of the fundamental wave modes of the adjoining resonators is high, the fundamental wave modes of the two resonators are magnetically coupled. In the area in which the coupling window **33***bc* is positioned, magnetic field energy of the second harmonic modes of the adjoining resonators is also relatively high. Accordingly, the second harmonic modes of the two resonators are magnetically coupled.

As a result, the filter shown in FIG. **4**(B) of the comparison example resonates not only in the fundamental wave mode but also in the second harmonic mode, and the fundamental wave and the second harmonic are both propagated, accordingly.

Meanwhile, as shown in FIG. **4**(A), in the harmonic propagation blocking filter according to the first embodiment, coupling windows **33***bc***1**, **33***bc***2**, **33***bc***3** and **33***bc***4** are positioned in areas in each of which magnetic field energy of the fundamental wave modes of the adjoining resonators is high. For this reason, the fundamental wave modes of the two resonators are strongly magnetically coupled with each other.

Since the coupling windows **33***bc***3** and **33***bc***4** are positioned in areas in each of which electric field energy of the second harmonic modes of the adjoining resonators is high, the second harmonic modes of the two resonators are prompted to be electrically coupled to each other. It is clear from the electromagnetic field distribution shown in FIGS. **2**(E) and **5** that the coupling windows **33***bc***3** and **33***bc***4** are present in the areas in each of which the electric field energy of the second harmonic modes is high.

However, since the coupling windows **33***bc***1** and **33***bc***2** are positioned in the areas in each of which magnetic field energy of the second harmonic modes of the adjoining resonators is high. For this reason, the second harmonic modes of the two resonators are prompted to be magnetically coupled to each other. By causing the amount of the electric field coupling between the second harmonic modes and the amount of the magnetic field coupling between the second harmonic modes to be substantially equal, the second harmonic modes of the adjoining resonators are rarely coupled.

Note that, the aforementioned additional regions **52***b* and **53***b* (**52***c* and **53***c*) each have such a shape as to be a partial protrusion of an E-plane of the resonant region **51***b* (**51***c*) such that a width, in a longitudinal direction of the E-plane, of each additional region is no longer than a half wavelength of the fundamental wave and no shorter than a half wavelength of the second harmonic. As a result, the second harmonic magnetic fields are distributed so as to enter the additional regions **52***b* and **53***b* (**52***c* and **53***c*). For this reason, the coupling windows **33***bc***3** and **33***bc***4** can each be provided at the position where the electric field energy of the second harmonic modes is high and electric field energy of the fundamental wave modes is low.

When a coupling window is provided at a position where the electric field energy of the fundamental wave modes is high, electric discharge is likely to occur at an opening of the coupling window or between the coupling window and a conductor side facing the coupling window. However, according to the first embodiment, this problem does not occur. Thus, power-withstanding capability does not deteriorate.

As described above, the harmonic propagation blocking filter **201** is a four-resonator filter in which the four resonators are sequentially connected. In the filter, the resonator section formed with the resonant region **51***b* and the resonator section formed with the resonant region **51***c* block the coupling and propagation of the second harmonic mode. In other words, the filter acts as a band-pass filter having a function to pass the fundamental wave frequency band and having a function to block the second harmonic.

FIG. **6**(A) shows a frequency characteristic of the harmonic propagation blocking filter according to the first embodiment. FIG. **6**(B) shows a frequency characteristic of the filter shown in FIG. **4**(B) of the comparison example. Both the frequency characteristics show that the fundamental wave frequency is 9.4 GHz. However, in the filter that does not have the harmonic blocking function, a passband occurs near 13.8 GHz and 18.8 GHz as shown in FIG. **6**(B). On the other hand, in the harmonic propagation blocking filter according to the first embodiment, insertion loss is great at 18.8 GHz as indicated by a circle in FIG. **6**(A). This indicates that the second harmonic is blocked.

Second Embodiment

A harmonic propagation blocking filter according to a second embodiment is, similarly to the harmonic propagation blocking filter according to the first embodiment, formed such that a partition plate is interposed between two metallic blocks. FIG. **7** is a plane view showing shapes of resonant regions and arrangement of coupling windows, which are included in the harmonic propagation blocking filter according to the second embodiment. This diagram is shown in a manner corresponding to that of FIG. **4**(A) of the first embodiment.

In the example shown in FIG. **7**, the additional regions **52***b* and **53***b* as shown in FIG. **4**(A) are not provided. Only two coupling windows **33***bc***5** and **33***bc***6** are provided at the resonant region **51***b*.

In FIG. **7**, the loop H**1** indicated by a dashed line is a magnetic field loop in electromagnetic field distribution of a fundamental wave mode, and the four loops H**2** indicated by dashed lines represent magnetic field loops in electromagnetic field distribution of a second harmonic mode. Similarly, the electromagnetic field distributions of the fundamental wave mode and the second harmonic mode are present in a resonant region adjoining the resonant region **51***b*, the resonant regions having the partition plate interposed therebetween.

Since the coupling window **33***bc***5** is positioned in an area where magnetic field energy of the fundamental wave modes of the two adjoining resonators is high, and the coupling window **33***bc***6** is positioned in an area where magnetic field energy of the fundamental wave modes of the two resonators is relatively high, the fundamental wave modes of the two resonators are magnetically coupled.

In the area in which the coupling window **33***bc***5** is positioned, magnetic field energy of the second harmonic modes of the adjoining resonators is also high. Accordingly, the second harmonic modes of the two resonators are prompted to be magnetically coupled. However, since the coupling window **33***bc***6** is positioned in the area where electric field energy of the second harmonic modes of the adjoining resonators is high, the second harmonic modes of the two resonators are prompted to be electrically coupled. By causing the amount of the electric field coupling between the second harmonic modes and the amount of the magnetic field coupling between the second harmonic modes to be substantially equal, the second harmonic modes of the adjoining resonators are rarely coupled.

As described above, the harmonic propagation blocking filter according to the second embodiment is a four-resonator filter in which four resonators are sequentially connected. In the filter, the resonator section formed with the resonant region **51***b* and the resonator section formed with the resonant region adjoining the resonant region **51***b* block the coupling and propagation of the second harmonic mode. In other words, the filter acts as a band-pass filter having a function to pass the fundamental wave frequency band and having a function to block the second harmonic.

Third Embodiment

FIG. **8** is a block diagram showing a structure of a radar that is an example of a microwave transmitter according to a third embodiment. A high-frequency circuit section of the radar comprises: a magnetron **72** which oscillates to generate a microwave; a drive circuit **71** for pulse-driving the magnetron **72**; a circulator **73** for propagating, to a subsequent stage, an oscillation signal generated by the magnetron **72**; a terminator **74**; the harmonic propagation blocking filter **201** for suppressing a second harmonic; a circulator **76** for propagating a transmission signal to a rotary joint side and propagating a received signal to a receiving circuit side; a rotary joint **77**; an antenna **78**; a limiter circuit **79** for limiting power of the transmission signal so as not to reach the receiving circuit side; and a receiving circuit **80**.

As a result of the drive circuit **71** pulse-driving the magnetron **72**, a pulse microwave signal of 9.4 GHz is outputted. Then, the signal propagated through the following path is radiated into the air: the circulator **73**→the harmonic propagation blocking filter **201**→the circulator **76**→the rotary joint **77**→the antenna **78**. Meanwhile, the signal, which has reflected at a target, is received by the antenna **78**, and the signal propagated through the following path is received: the rotary joint **77**→the circulator **76**→the limiter circuit **79**→the receiving circuit **80**.

When the transmission signal travels through the harmonic propagation blocking filter **201** in this manner, the second harmonic is blocked. Therefore, unnecessary radiation of the second harmonic from the antenna **78** is suppressed. Since the harmonic propagation blocking filter **201** is provided at a subsequent stage to the circulator **73**, the harmonic propagation blocking filter **201** is effective to block not only the second harmonic occurring at the magnetron **72** but also the second harmonic occurring at the circulator **73**.

Note that, the second harmonic, which reflects without being transmitted through the harmonic propagation blocking filter **201**, reaches the terminator **74** through the circulator **73**, and is then consumed at the terminator **74**. Therefore, the magnetron **72** does not receive negative effect.

Note that, although in the above embodiments the resonant regions of the fundamental wave are each formed using a cavity resonator, the resonant regions are not necessarily filled with air, but may each be filled with a solid dielectric material. Alternatively, the resonant regions may each be formed by forming an electrode film on an exterior surface of a dielectric block. Waveguide resonators of the present invention may be formed in such a manner.

Further, in the above embodiments, coupling windows are provided at an H-plane that partitions adjoining waveguide resonators. However, the coupling windows may be provided at an E-plane in accordance with a positional relationship between the adjoining resonators. In other words, a plurality of coupling windows may be provided at any positions as long as, via a part or all of the plurality of coupling windows, fundamental wave modes of the adjoining resonators are coupled, and predetermined-order harmonic modes of the adjoining resonators are magnetically and electrically coupled so as to negate the coupling of the predetermined-order harmonic modes.

Fourth Embodiment

FIG. **9** shows a perspective view showing a fundamental structure of a harmonic suppression resonator according to a fourth embodiment, and shows an example of electromagnetic field distribution of each mode.

As shown in FIG. **9**(A), a harmonic suppression resonator **101** comprises a resonant region **21** and an additional region **22** that is a protruding portion of the resonant region **21**. In FIG. **9**, a plane indicated by “E” is an E plane, and a plane indicated by “H” is an H plane. This resonator may be seen as a cavity resonator that has an additional space therein.

The additional region **22** has such a shape as to be a partial protrusion of the E-plane of the resonant region **21** such that: a width, in a longitudinal direction of the E-plane of the resonant region **21**, of the additional region **22** is no longer than ½ of a wavelength of a fundamental wave and no shorter than ½ of a wavelength of an n-th order harmonic; and a depth of the additional region **21** is substantially ¼ of the wavelength of the n-th order harmonic.

In the case where a frequency of the fundamental wave is 9.4 GHz, measurements of respective portions in FIG. **9**(A) are as follows: a is 22.9 mm; b is 5 mm; c is 20 mm; d is 5 mm; and e is 10 mm. FIG. **9**(B) shows electromagnetic field distribution of the fundamental wave, and FIG. **9**(C) shows electromagnetic field distribution of a frequency-doubled wave mode (pseudo TE202 mode). Since the fundamental wave is blocked from entering the additional region **22**, there is little change in a resonance frequency of the fundamental wave as shown in FIG. **9**(B) even if there is the additional region **22**. On the other hand, as shown in FIG. **9**(C), the frequency-doubled wave enters the additional region **22**. Therefore, the additional region **22** acts as a part of the resonant region. Consequently, an effective resonant space for the frequency-doubled wave is expanded, and the resonance frequency of the frequency-doubled wave becomes lower as compared to a case where the additional region **22** is not provided. Therefore, resonance does not occur at a second harmonic frequency (i.e., at a doubled frequency of the fundamental wave frequency).

Note that, as shown in FIG. **9**(D), if an additional region **23**, which protrudes from the resonant region **21**, is formed such that a depth of the additional region **23** is ½ of the wavelength of the second harmonic, standing waves as shown in FIG. **9**(D) occur and resonance occurs at the doubled frequency of the fundamental wave. Therefore, it is crucial to properly set the measurement of the depth d of the additional region. The amount, by which the resonance frequency of the frequency-doubled wave becomes lower, is greatest when the measurement of the depth d is set to be substantially ¼ of the wavelength of the second harmonic. Accordingly, the second harmonic suppression effect is optimized.

FIG. **10** shows an example where an additional region **24** of the resonant region **21** is formed such that the center of the additional region **24** is positioned at an extension of a line that connects central positions, in a length direction along a longitudinal direction, of E-planes. In this case, as shown in FIG. **10**, a frequency-doubled standing wave does not enter the additional region **24** sufficiently, and an effective resonant space is not expanded. Accordingly, the resonance frequency lowering effect for the second harmonic is small.

Therefore, the additional region **24** is provided such that the center of the additional region **24** deviates from the extension of the line that connects the central positions, in the length direction along the longitudinal direction, of the E-planes.

Fifth Embodiment

FIG. **11** is a perspective view showing a structure of a harmonic propagation blocking filter according to a fifth embodiment. Only a space where electromagnetic field distribution occurs is extracted from the filter and shown here. In FIG. **11**, a harmonic propagation blocking filter **209** comprises three resonant regions **21***a*, **21***b* and **21***c*. Additional regions **22***a* and **22***c* are provided for the resonant regions **21***a* and **21***c*, respectively. Further, the harmonic propagation blocking filter **209** comprises input/output spaces **31***a* and **31***c*. A coupling window **35***aa* is provided between the input/output space **31***a* and the resonant region **21***a*. Similarly, a coupling window **35***cc* is provided between the input/output space **31***c* and the resonant region **21***c*. Further, a coupling window **35***ab* is provided between the resonant regions **21***a* and **21***b*, and a coupling window **35***bc* is provided between the resonant regions **21***b* and **21***c*.

As described above, a three-resonator filter is formed by sequentially connecting the three resonators that comprise the three resonant regions **21***a*, **21***b* and **21***c* and the additional regions **22***a* and **22***c*. This filter acts as a band-pass filter having a function to pass the fundamental wave frequency band and having a function to block the second harmonic.

Sixth Embodiment

FIG. **12** shows a perspective view of a main part of a harmonic propagation blocking filter **202** according to a sixth embodiment. FIG. **13** is an exploded plane view of components constituting the main part.

The harmonic propagation blocking filter **202** is basically formed with two metallic blocks **44** and **46**, and with a partition plate **45** interposed therebetween.

FIG. **13**(A) is a plane view of the first metallic block **44**. Recessed portions having a predetermined depth are formed on the first metallic block **44**, whereby resonant regions **55***a* and **55***b* are formed on the first metallic block **44**. An additional region **56***b* is provided at the resonant region **55***b*. A coupling window **35***ab* is formed between the two resonant regions **55***a* and **55***b*. Also, a coupling window **35***aa* is formed at the resonant region **55***a* so as to be open to rearward of FIG. **13**(A).

Resonant regions **55***c* and **55***d*, an additional region **56***c*, and coupling windows **35***cd* and **35***dd* are formed on the second metallic block **46** such that the structure of the second metallic block **46** is mirror-symmetrical to that of the metallic block **44**.

The partition plate **45** is a metallic plate interposed between resonant-region-forming planes of the metallic blocks **44** and **46**, and have a coupling window **35***bc* that is an opening which allows the resonant regions **55***b* and **55***c* to communicate with each other.

FIG. **12**(A) shows resonant regions which are formed by combining the three components shown in FIG. **13** in a layered manner. Here, input/output spaces **34***a* and **34***d* are provided so as to be respectively connected to the coupling windows **35***aa* and **35***dd*. The input/output spaces **34***a* and **34***d* are end portions of a rectangular waveguide.

Owing to the above structure, an electromagnetic wave is propagated through the following path: the input/output space **34***a*→the coupling window **35***aa*→the resonant region **55***a*→the coupling window **35***ab*→(the resonant region **55***b*, the additional region **56***b*)→the coupling window **35***bc*→(the resonant region **55***c*, the additional region **56***c*)→the coupling window **35***cd*→the resonant region **55***d*→the coupling window **35***dd*→the input/output space **34***d*.

FIG. **12**(B) shows density distribution of frequency-doubled standing waves occurring within the above resonant regions. As shown herein, a part of the frequency-doubled waves occurs in the additional regions **56***b* and **56***c*, and a resonance frequency of the frequency-doubled waves becomes lower than the twice of a fundamental wave frequency.

This filter is a four-resonator filter which is formed by sequentially connecting four resonators. In this filter, the resonator section, which is formed with the resonant region **55***b* and the additional region **56***b*, and the resonator section, which is formed with the resonant region **55***c* and the additional region **56***c*, block the resonance of the second harmonic.

In this manner, the filter acts as a band-pass filter having a function to pass the fundamental wave frequency band and having a function to block the second harmonic.

FIG. **14** shows a frequency characteristic of the harmonic propagation blocking filter shown in FIGS. **12** and **13**, and shows a frequency characteristic of a filter in which the additional regions are not provided. FIG. **14**(A) shows a characteristic of the harmonic propagation blocking filter according to the sixth embodiment. FIG. **14**(B) shows, for comparison with the harmonic propagation blocking filter, a characteristic of the filter in which the additional regions **56***b* and **56***c* are not provided. Both the frequency characteristics show that the fundamental wave frequency is 9.4 GHz. However, in the filter that does not have the harmonic blocking function, a passband occurs near 13.8 GHz and near 18.8 GHz as shown in FIG. **14**(B). On the other hand, in the harmonic propagation blocking filter according to the sixth embodiment, insertion loss is great at 18.8 GHz as indicated by a circle in FIG. **14**(A). This indicates that the second harmonic is blocked.

Seventh Embodiment

FIG. **15** is a horizontal sectional view showing a structure of a harmonic suppression resonator **102** according to a seventh embodiment. The harmonic suppression resonator **102** comprises the resonant region **21** and the additional region **22** which are described in the fourth embodiment. The resonant region **21** and the additional region **22** are formed within a metallic block. A waveguide section **40** is formed on the metallic block, and a coupling window **35** is provided between the resonant region **21** and a predetermined position of the waveguide section **40**.

Owing to this structure, an electromagnetic wave propagating through the waveguide section **40** is, via the coupling window **35**, coupled with the harmonic suppression resonator **102** that is formed with the resonant region **21** and the additional region **22**. A fundamental wave is coupled with the harmonic suppression resonator **102**, and almost the entire fundamental wave is reflected. Meanwhile, a second harmonic is not coupled with the harmonic suppression resonator **102**. Therefore, the second harmonic is transmitted through the waveguide section **40**. Thus, the harmonic suppression resonator **102** can be used as a circuit that traps a desired fundamental wave and which allows a second harmonic to be transmitted.

Eighth Embodiment

FIG. **16** is a circuit diagram of a harmonic suppression oscillator **301** according to an eighth embodiment. The harmonic suppression oscillator **301** comprises: a transmission line **61**, one end of which is reflection-free terminated; a harmonic suppression resonator **103** coupled to the transmission line **61**; an active element Q which acts as a negative resistance element to be coupled to a signal propagating through the transmission line **61**; and stubs **62** and **63**.

By having the above structure, the harmonic suppression oscillator **301** acts as a band-reflection oscillation circuit. The harmonic suppression resonator **103** resonates at a fundamental wave frequency and does not resonate at a second harmonic frequency. Accordingly, an oscillation signal having a high C/N ratio, which does not resonate at the second harmonic frequency and which does not cause a second harmonic component to occur, can be obtained. Note that, a mode, in which a frequency-doubled wave resonates, occurs in the harmonic suppression resonator **103**. However, since the harmonic suppression resonator **103** is coupled with the transmission line **61** at such a position as to satisfy oscillation requirements at the fundamental wave frequency, the oscillation requirements are not satisfied at a resonance frequency of the aforementioned frequency-doubled wave. Consequently, a resonance frequency component of the frequency-doubled wave does not occur.

In the case where the transmission line **61** is formed with a waveguide, the harmonic suppression resonator **102** described in the seventh embodiment can be used as the harmonic suppression resonator **103**.

Ninth Embodiment

FIG. **17** is a circuit diagram of a harmonic suppression resonator according to a ninth embodiment. The harmonic suppression resonator is formed with a round-shaped resonant region **65** and an additional region **66**. In the foregoing embodiments, the shape of the resonant regions of the fundamental wave is substantially rectangular parallelepiped. However, as shown in FIG. **17**, the resonant regions of the fundamental wave may be in a cylindrical shape. A resonant mode of a fundamental wave of the resonant region **65** is TM○010 mode, and a resonant mode of a frequency-doubled wave of the resonant region **65** is TM○210 mode. Accordingly, a function and effect of the additional region **66** are the same as those shown in FIG. **9**.

Tenth Embodiment

FIG. **18** is a block diagram showing a structure of a radar that is an example of a microwave transmitter according to a tenth embodiment. A high-frequency circuit section of the radar comprises: the magnetron **72** which oscillates to generate a microwave; the drive circuit **71** for pulse-driving the magnetron **72**; the circulator **73** for propagating, to a subsequent stage, an oscillation signal generated by the magnetron **72**; the terminator **74**; the harmonic propagation blocking filter **202** for suppressing a second harmonic; the circulator **76** for propagating a transmission signal to a rotary joint side and propagating a received signal to a receiving circuit side; the rotary joint **77**; the antenna **78**; the limiter circuit **79** for limiting power of the transmission signal so as not to reach the receiving circuit side; and the receiving circuit **80**.

As a result of the drive circuit **71** pulse-driving the magnetron **72**, a pulse microwave signal of 9.4 GHz is outputted. Then, the signal propagated through the following path is radiated into the air: the circulator **73**→the harmonic propagation blocking filter **202**→the circulator **76**→the rotary joint **77**→the antenna **78**. Meanwhile, the signal, which has reflected at a target, is received by the antenna **78**, and the signal propagated through the following path is received: the rotary joint **77**→the circulator **76**→the limiter circuit **79**→the receiving circuit **80**.

When the transmission signal travels through the harmonic propagation blocking filter **202** in this manner, the second harmonic is blocked. Therefore, unnecessary radiation of the second harmonic from the antenna **78** is suppressed. Since the harmonic propagation blocking filter **202** is provided at a subsequent stage to the circulator **73**, the harmonic propagation blocking filter **202** is effective to block not only the second harmonic occurring at the magnetron **72** but also the second harmonic occurring at the circulator **73**.

Note that, the second harmonic, which reflects without being transmitted through the harmonic propagation blocking filter **202**, reaches the terminator **74** through the circulator **73**, and is then consumed at the terminator **74**. Therefore, the magnetron **72** does not receive negative effect.

Note that, although in the above embodiments the resonant regions of the fundamental wave are each formed using a cavity resonator, the resonant regions are not necessarily filled with air, but may each be filled with a solid dielectric material. Alternatively, the resonant regions may each be formed by forming an electrode film on an exterior surface of a dielectric block. Waveguide resonators of the present invention may be formed in such a manner.

Eleventh Embodiment

FIG. **19** is a block diagram showing a structure of a radar apparatus as an example of a microwave transmission/reception apparatus in which a waveguide structure according to the present invention is applied. A high-frequency circuit section of the radar apparatus has the magnetron **72** that oscillates to generate, for example, a microwave of 9.4 GHz as a fundamental wave. The pulse-drive circuit **71** intermittently drives the magnetron **72** with a predetermined cycle, thereby causing the magnetron **72** to generate a pulse transmission signal having a predetermined width. The circulator **73** propagates the pulse transmission signal, which is provided from the magnetron **72**, to a predetermined circuit side. The terminator **74** is connected to the circulator **73**, and causes unnecessary power to be consumed. A filter **203** suppresses transmission of a harmonic of the fundamental wave. The suppressed harmonic reaches the terminator **74** via the circulator **73**, and is then consumed at the terminator **74**.

The circulator **76** is provided for propagating the transmission signal to a transmitting end and propagating a received signal to a receiving end. The rotary joint **77** is provided for electrically connecting a static system and a rotating system. The antenna **78** is caused by a motor (not shown) to rotate at a constant speed, and transmits to the outside the transmission signal as a radio wave pulse. The limiter circuit **79** suppresses a power signal level of a high level, which occurs immediately after reception has started, so as to protect the receiving circuit **80**. The receiving circuit **80** receives a signal received by the antenna **78**. Note that, the components from the magnetron **72** to the antenna **78**, and the components from the antenna **78** to the limiter circuit **79**, are formed with waveguides.

FIG. **20**(A) is an exploded perspective view of a main part of the filter **203**. FIG. **20**(B) is a side view showing that components of the main part are assembled. The filter **203** is formed with two metallic blocks **47** and **48**, and with a partition plate **49** interposed there between. Note that, in the present embodiment, structures of the metallic blocks **47** and **48** are mirror-symmetric to each other.

The metallic block **47** is formed from conductive metal having a required thickness, such as aluminum (Al) or the like. A recessed portion (groove) **420**, which has a predetermined depth that is determined based on a frequency of an electromagnetic wave to be used, is formed on an upper face (predetermined face) of the metallic block **47**, which is a plane face portion. The recessed portion **420** has resonant regions **421** and **422**. A coupling window **423** is formed between the resonant regions **421** and **422**. A coupling window **211** is holed through the resonant region **421**, as shown in the bottom part of FIG. **20**. The coupling window **211** acts as an input port for an electromagnetic wave provided from an upstream side. Further, the resonant region **422** has additional regions **221** and **222**.

The metallic block **48** is formed from conductive metal having a required thickness, such as aluminum (Al) or the like. A recessed portion (groove) **430**, which has a predetermined depth that is determined based on a frequency of an electromagnetic wave to be used, is formed on a plane face portion at a lower face of the metallic block **48**. The recessed portion **430** has resonant regions **431** and **432**. A coupling window **433** is formed between the resonant regions **431** and **432**. A coupling window **321** is holed through the resonant region **432**, as shown in the upper part of FIG. **20**. The coupling window **321** acts as an output port for an electromagnetic wave to be provided to a downstream side. Further, the resonant region **431** has additional regions **311** and **312**. Note that, the positions of the coupling windows **211** and **321** are not limited to those shown in FIG. **20**, but may be any positions that are favorable for the coupling windows **211** and **321** to act as input and output ports for the electromagnetic wave.

The partition plate **49** is conductive, and acts as a covering member for both the metallic blocks **47** and **48**. Waveguide portions formed with the resonant regions **421**, **422**, **431**, **432** and the partition plate **49**, each act as a resonator in the present embodiment. Hardness of the partition plate **49** is preferred to be, at least, at a same level as that of the metallic blocks **47** and **48**. More preferably, the partition plate **49** is softer than the metallic blocks **47** and **48**. The partition plate **49** is formed from, for example, aluminum (Al). Alternatively, the partition plate may be formed by plating, with copper(Cu)-gold(Au) alloy, a surface of a base material. Four coupling windows **441** to **444** are holed through the partition plate **49** such that the coupling windows, each having a required shape, are respectively provided at required positions. Although not shown in FIG. **20**, a required number of through-holes are drilled through the metallic blocks **47**, **48** and the partition plate **49** so as not to drill through the recessed portions **420** and **430**, such that the through-holes are aligned. Bolts are inserted into the through-holes and fastened by nuts with a required pressure, whereby the metallic blocks **47**, **48** and the partition plate **49** are connected to each other, and thus a waveguide structure is formed. Fastening members for connecting the metallic blocks **47**, **48** and the partition plate **49** with a required pressure, are not limited to bolts and nuts. Other publicly-known fastening members may be used.

FIG. **21** is a plane view illustrating a positional relationship, in a resonant region, between electromagnetic field distribution and the coupling windows **441** to **444**.

As shown in FIG. **21**, the coupling windows **441** to **444** are formed so as to be positioned in areas in each of which magnetic field energy of fundamental wave modes of the adjoining resonant regions **422** and **431** is high. For this reason, the fundamental wave modes of the resonant regions **422** and **431** are strongly magnetically coupled with each other. Meanwhile, the coupling windows **443** and **444** are formed so as to be positioned in areas in each of which electric field energy of second harmonic modes of the resonant regions **422** and **431** is high. For this reason, the second harmonic modes of the resonant regions **422** and **431** are prompted to be electrically coupled to each other.

However, the coupling windows **441** and **442** are formed so as to be positioned in the areas in each of which magnetic field energy of the second harmonic modes of the resonant regions **422** and **431** is high. For this reason, the second harmonic modes of the resonant regions **422** and **431** are prompted to be magnetically coupled to each other. By causing the amount of the electric field coupling between the second harmonic modes and the amount of the magnetic field coupling between the second harmonic modes to be substantially equal, the second harmonic modes of the resonant regions **422** and **431** are rarely coupled.

Note that, the additional regions **221** and **222** (**311** and **312**) each have such a shape as to be a partial protrusion of an E-plane of the resonant region **422** (**431**) such that a width, in a longitudinal direction of the E-plane, of each additional region is no longer than a half wavelength of the fundamental wave and no shorter than a half wavelength of the second harmonic. As a result, the second harmonic magnetic fields are distributed so as to enter the additional regions **221** and **222** (**311** and **312**). For this reason, the coupling windows **441** and **442** can each be provided at a position where the electric field energy of the second harmonic modes is high and electric field energy of the fundamental wave modes is low.

As described above, the filter **203** is a four-resonator filter in which the four resonators are sequentially connected. In the filter, the resonator corresponding to the resonant region **422** and the resonator corresponding to the resonant region **431** block the coupling and propagation of the second harmonic mode. In other words, the filter **203** has a function to pass the fundamental wave frequency band and a function to block the second harmonic. As shown in FIG. **6**(A), the passband occurs near 13.8 GHz in relation to the fundamental wave frequency of 9.4 GHz. However, the second harmonic of 18.8 GHz is blocked.

FIG. **22** illustrates a structure of an upper surface of at least one of the metallic blocks **47** and **48**. Here, a structure of an upper surface of the metallic block **47** is described. In FIG. **22**, a plurality of protrusions **424** are formed, along the recessed portion **420** with predetermined pitches, on the upper surface of the metallic block **47**, which upper surface is a plane face portion. The protrusions **424** are positioned near the recessed portion **420**. The predetermined pitches may be in a range of, at least, 0.5 mm to 4 mm. It has been discovered from an experiment that by using this range, radio wave leakage is favorably blocked.

FIG. **23** shows cross-sectional shapes of the protrusions **424** and the partition plate **49**. The protrusions **424** shown in FIG. **23** are formed by punching. To be specific, a fine needle-shaped punching jig is pressed against the plane face portion of the metallic block **47** to form a recess **241**, whereby swell portions **242** are formed around the recess **241**. These swell portions **242** act as protrusions.

A height of the swell portions **242** (i.e., a punching height) may be in a range of, at least, 0.05 mm to 0.12 mm. As shown in FIG. **24**, by using this range, radio wave leakage can be favorably blocked. Thus, the amount of radio wave leakage is not greatly affected even if the height of the projected portion **242** varies in a wide range. Accordingly, precise fastening of the metallic blocks **47** and **48** with the partition plate **49** is not necessary.

The partition plate **49** is fastened, between the metallic blocks **47** and **48**, by fastening members with a required pressure, and the partition plate is formed from a material which is as hard as, or preferably softer than, the metallic blocks **47** and **48**. Therefore, the partition plate **49** is deformed, such as recesses **401**, in accordance with the shape of the swell portions **242**. Engagement between the swell portions **242** and the recesses **401** allows the metallic block **47** and the partition plate **49** to firmly and tightly contact each other, whereby a gap therebetween is eliminated. In addition, the engagement between the swell portions **242** and the recesses **401** maintains a fixed positional relationship between the metallic block **47** and the partition plate **49**. Therefore, a gap due to displacement of the metallic block **47** and the partition plate **49** does not occur, and as a result, the radio wave leakage blocking function can be stabilized.

Twelfth Embodiment

The present invention may be in a form described below.

In the case where the protrusions **424** are provided on the metallic block **47**, protrusions may also be formed on the metallic block **48**. In this case, radio wave leakage can be prevented at both the recessed portions **420** and **430**. Further, pitches and a height with which the protrusions are formed may be identical, or may be different, between the metallic blocks **47** and **48**. The pitches may not necessarily be precisely constant. In the case where the pitches are set to be substantially identical between the metallic blocks **47** and **48**, by forming the pitches such that positions of those formed on the metallic block **47** and positions of those formed on the metallic block **48** deviate from each other by half a pitch, the partition plate **49** is practically engaged with the metallic blocks every half a pitch. This increases a degree of contact between the partition plate **49** and the metallic blocks **47** and **48**, and as a result, radio wave leakage is prevented more favorably.

Although the resonators, with which the filter is formed, have been described as one form of a waveguide structure, the present invention is not limited thereto. The present invention is similarly applicable in a microwave circuit element that propagates radio waves, such as a normal waveguide portion, flange portion, filter portion, or a circulator. It is conceivable that the radio waves, to which the present invention is applied, are mainly microwaves used by a ship radar or the like. However, the radio waves may be the one used by a vehicle-mounted obstacle detection radar or a vehicle-mounted anti-collision radar.

FIG. **25** shows a joint surface **461***a* of a flange portion **461** of a waveguide **6**, in which the protrusions **424** are formed near a waveguide path with predetermined pitches. FIG. **26** shows a filter **7** comprising: a waveguide section **471** in which a waveguide path is formed by digging a filter groove on a predetermined face **471***a* of one member; and a cover member **472** covering the predetermined face **471***a*. In the filter **7**, the protrusions **424** are formed, on the predetermined face **471***a*, around the groove of the waveguide path with predetermined pitches. FIG. **27** is a circulator **73** (or **76**) in which: a waveguide section **531** is formed by digging branched waveguide paths on a predetermined face **531***a* of one member **531**; and the protrusions **424** are formed near the waveguide paths on the predetermined face **531***a* with predetermined pitches. FIG. **28** shows a waveguide **8** comprising: a waveguide section **81** in which a waveguide path is formed by digging a filter groove on a predetermined face **81***a* of one member; and a cover member **82** covering the predetermined face **81***a*. In the waveguide **8**, the protrusions **424** are formed near the groove of the waveguide path on the predetermined face **81***a* with predetermined pitches.

Although it is described above that the protrusions **424** are formed by the punching process, the manner of forming the protrusions is not limited thereto. The protrusions may be formed by a different process, for example, a process in which pressure is applied to areas surrounding a central area so as to project the central area. In another form, the protrusions may be formed by bonding, or fusion-bonding, minute objects, e.g., sphere-shaped minute objects, to a plane face portion.

A distance from the protrusions **424** to a side wall **231** of the recessed portion **420** may be, as is clear from FIG. **23**, in a range of a few tenths of a millimeter to a few millimeters. The protrusions **424**, whose distance to the side wall **231** is within this range, are not too close to the side wall **231** to cause unnecessary deformation of the sidewall **231**, and are not too distant from the sidewall **231** to deteriorate the radio wave leakage blocking capability.

While the invention has been described in detail, the foregoing description is in all aspects illustrative and not restrictive. It is understood that numerous other modifications and variations can be devised without departing from the scope of the invention.

What is claimed is:

1. A harmonic suppression resonator comprising:

a plurality of waveguide resonators respectively including resonant regions in each of which a fundamental wave resonates in TE mode, the harmonic suppression resonator having adjoining waveguide resonators therein coupled with each other via a coupling window, wherein

harmonics of a predetermined order of the adjoining waveguide resonators are magnetically and electrically coupled with each other via the coupling window to weakened coupling of the harmonics.

2. The harmonic suppression resonator according to claim 1 further comprising:

a plurality of coupling windows, wherein

fundamental waves of the adjoining resonators are mainly electrically or magnetically coupled with each other via a part or all of the plurality of coupling windows.

3. The harmonic suppression resonator according to claim 1 further comprising:

an additional region, whose width is no longer than a half wavelength of the fundamental wave and no shorter than a half wavelength of the harmonics, at any position on an E-plane of at least one of the plurality of waveguide resonators, wherein

a first coupling window for causing the harmonics of the adjoining waveguide resonators to be magnetically coupled with each other; and

a second coupling window for causing the harmonics to be electrically coupled with each other near the additional region.

4. The harmonic suppression resonator according to claim 1 further comprising:

an additional region whose size being configured to block the fundamental wave and to propagate an n-th order harmonic, wherein n is an integer no less than 2.

5. The harmonic suppression resonator according to claim 4, wherein

the resonant regions respectively act as substantially rectangular waveguide resonators, in each of which the fundamental wave resonates in the TE mode; and

the additional region has such a shape as to protrude from an E-plane of at least one of the substantially rectangular waveguide resonators such that a width, along a longitudinal direction of the E-plane, of the additional region is no longer than ½ of a wavelength of the fundamental wave and no shorter than ½ of a wavelength of the n-th order harmonic, and a depth of the additional region is different from m/2 of the wavelength of the n-th order harmonic, wherein m is an integer no less than 1.

6. The harmonic suppression resonator according to claim 5, wherein

the depth of the additional region is substantially (1+2m)/4 of the wavelength of the n-th order harmonic, wherein m is an integer no less than 0.

7. The harmonic suppression resonator according to claim 4, wherein

the additional region is provided such that a center of the additional region is positioned so as to deviate from an extension of a line that connects centers, in a longitudinal direction, of E-planes of at least one of the resonant regions.

8. The harmonic suppression resonator according to claim 1 further comprising:

a first metallic block with a radio wave-propagating groove on a side of the waveguide resonator and is covered with a plurality of first protrusions being formed on the side along the groove with the predetermined pitches.

9. The harmonic suppression resonator according to claim 8, wherein

the cover member is formed from a material that is as hard as, or softer than, the first block.

10. The harmonic suppression resonator according to claim 8 further comprising:

a second block which is a metallic block provided to be positioned at an opposite side to the first block with respect to the cover member interposed between the second block and the first block and which has a radio-wave-propagating groove formed on a face thereof facing the cover member, wherein

the second block has a plurality of second protrusions, formed on the face thereof facing the cover member, in positions along the groove with predetermined pitches.

11. The harmonic suppression resonator according to claim 10, wherein

the grooves formed on the first and second blocks are mirror-symmetrical to each other, and positions of the first protrusions and positions of the second protrusions deviate from each other by substantially half a pitch.

12. The harmonic suppression resonator according to claim 10, wherein

holes are drilled through the first block, the second block and the cover member such that the holes at respective faces of the first block, the second block and the cover member are aligned, and

the first block, the second block and the cover member are fastened together with fastening means through the holes.

13. The harmonic suppression resonator according to claim 10, wherein

the first and second protrusions are swell portions surrounding recesses that are formed by pressing operations performed with a needle-like body.

14. A harmonic propagation blocking filter comprising:

the harmonic suppression resonator according to claim 1; and

input/output sections for guiding a propagation signal into/out of the resonant regions.

15. A radar apparatus comprising:

a magnetron which oscillates in π mode to generate the fundamental wave;

an antenna; and

the harmonic propagation blocking filter according to claim 14 on a propagation path between the magnetron and the antenna.

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