

- [54] **MICROSTRIP RING-SHAPED  
RESONATORS AND MICROWAVE  
GENERATORS USING THE SAME**
- [72] Inventor: **Gerard E. Forterre**, Colombes,  
France
- [73] Assignee: **Lignes Telegraphiques et Telephoni-  
ques**, Paris, France
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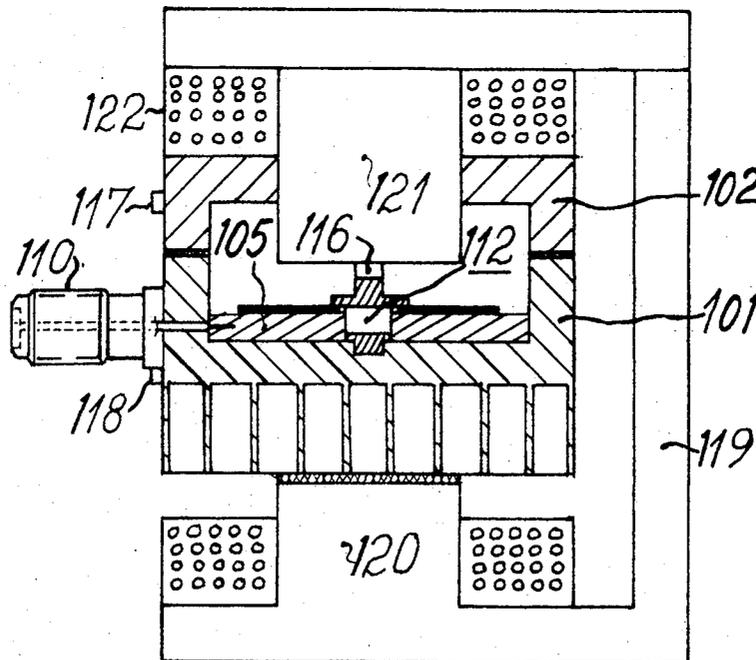
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- [51] Int. Cl.....**H03b 7/06**
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*Primary Examiner*—John Kominski  
*Attorney*—Abraham A. Saffitz

[57] **ABSTRACT**

A microwave resonator comprising an insulating substrate plate with a metallized coating entirely covering one of its faces and a metallized ring on its other face, and a microstrip transmission line on the same plate capacitively coupled with said ring. Microwave generators using such a resonator for determining their working frequency and having a Gunn diode located in the central hole of the ring are also described. The substrate plate can be made of a non-magnetic material or, if a variable frequency is desired, of a magnetic material adjustably polarized by D.C. field producing means.

**5 Claims, 14 Drawing Figures**



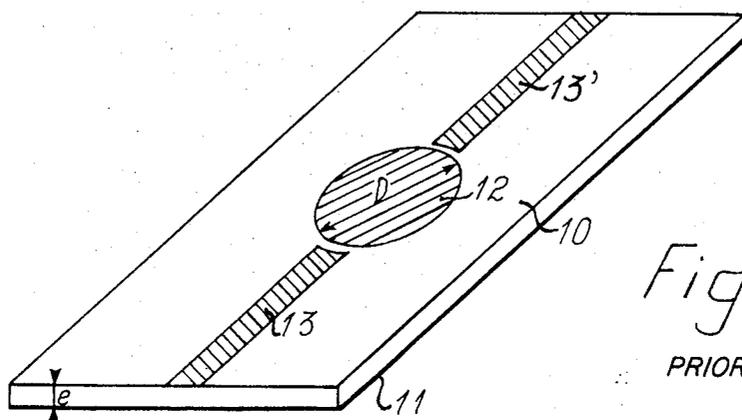


Fig. 1

PRIOR ART

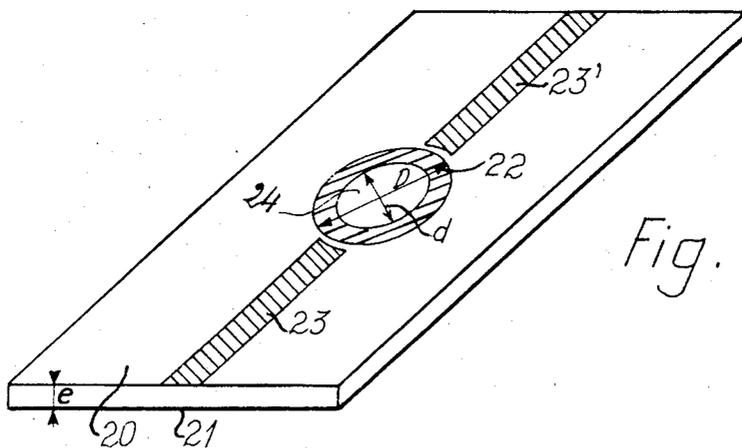
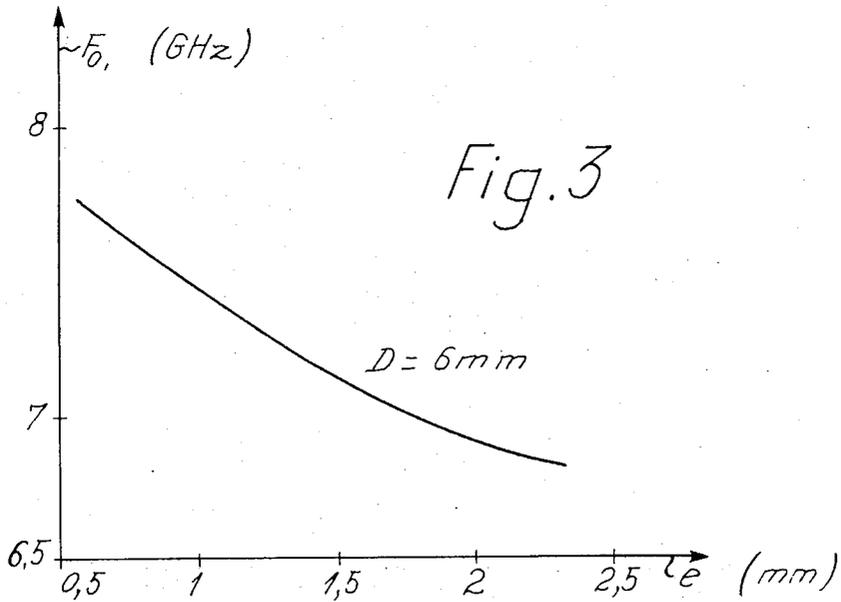
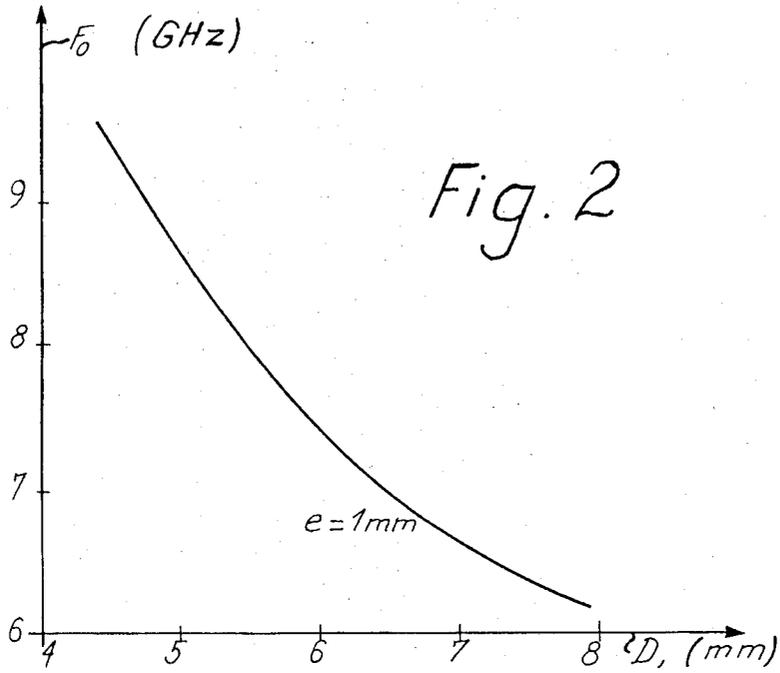


Fig. 6

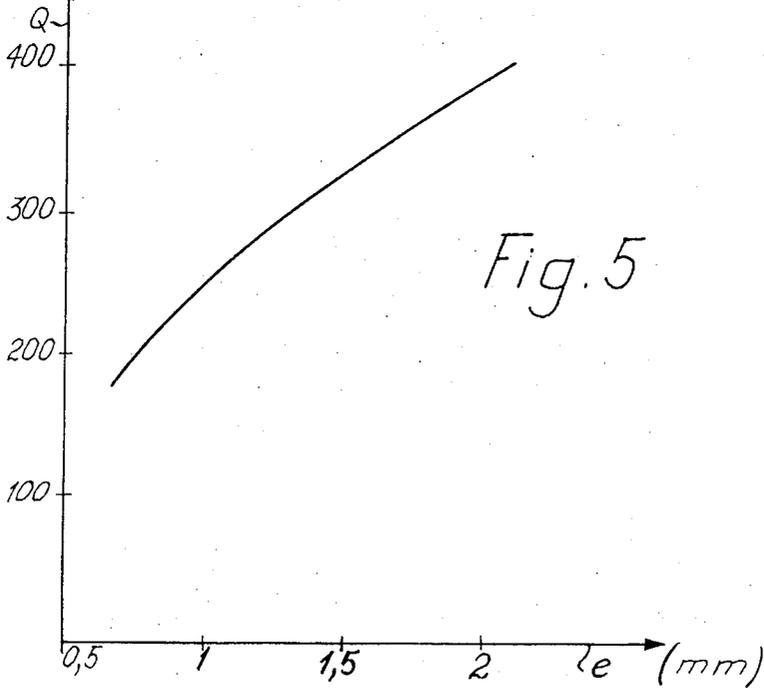
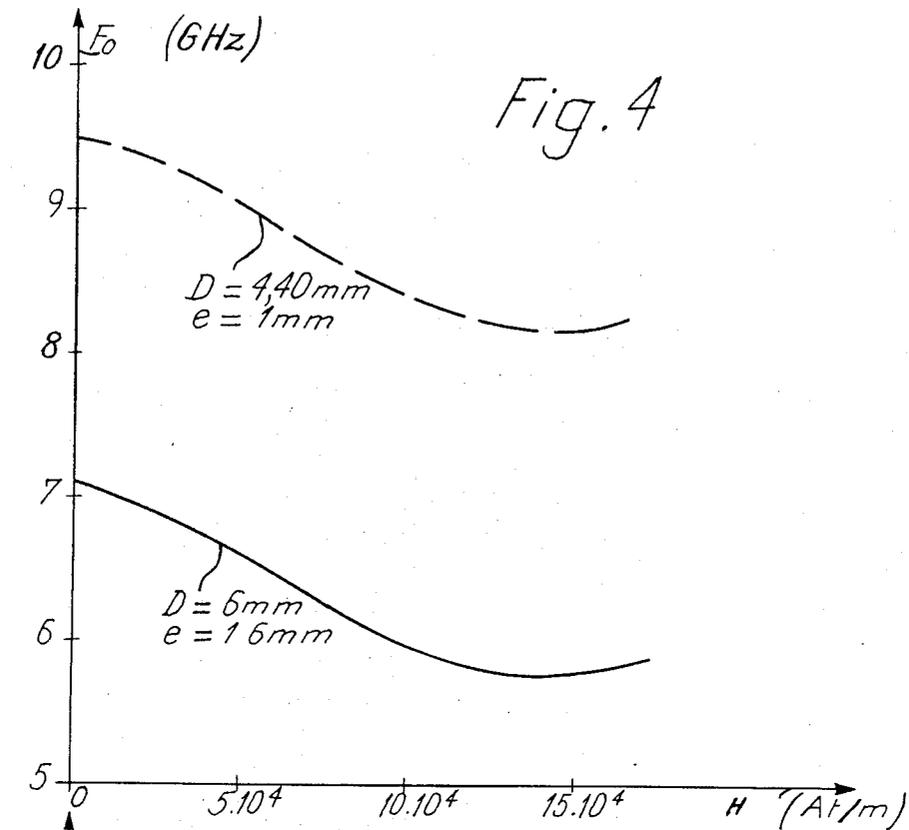
Inventor  
GERARD E. FORTERRE

By *Arden A. Saffitz*  
Attorney



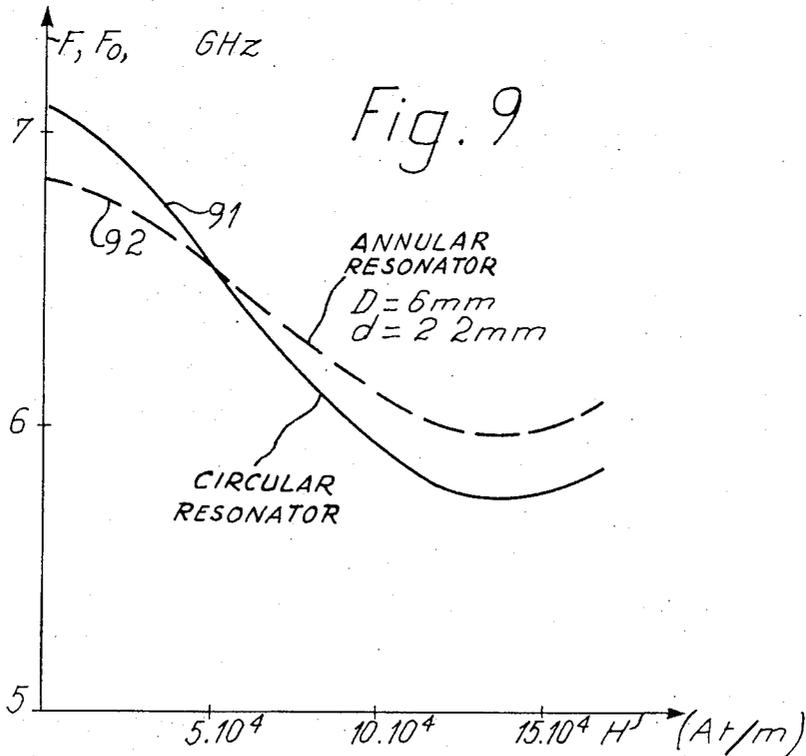
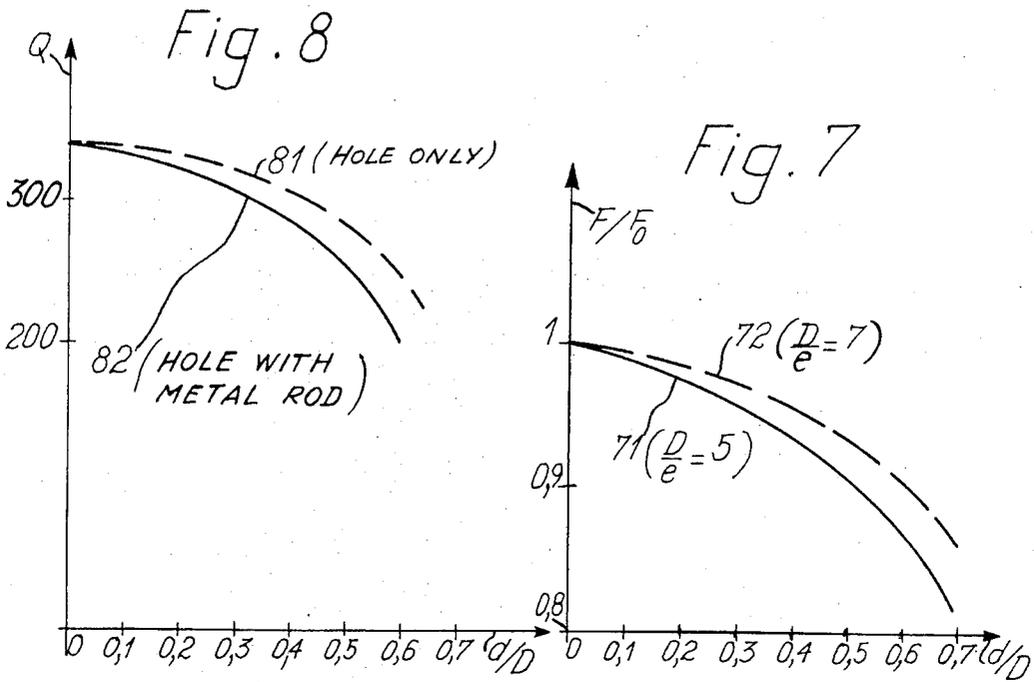
Inventor  
GERARD E. FORTERRE

By *Abraham A. Leffitz*  
Attorney



Inventor  
GERARD E. FORTERRE

By *Abraham A. Siffert*  
Attorney



Inventor  
GERARD E. FORTERRE

By *Abraham A. Schiff*  
Attorney

Fig.11

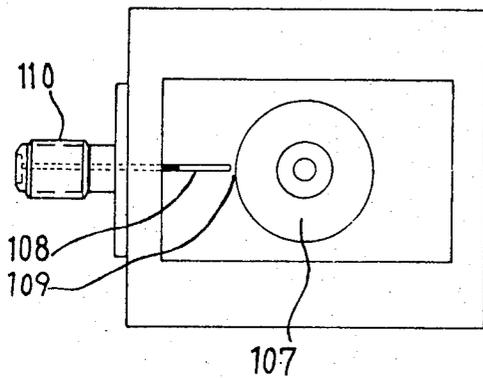


Fig.10

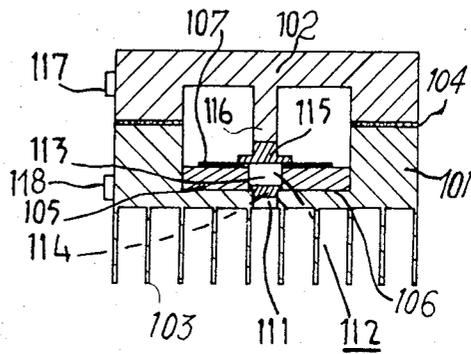
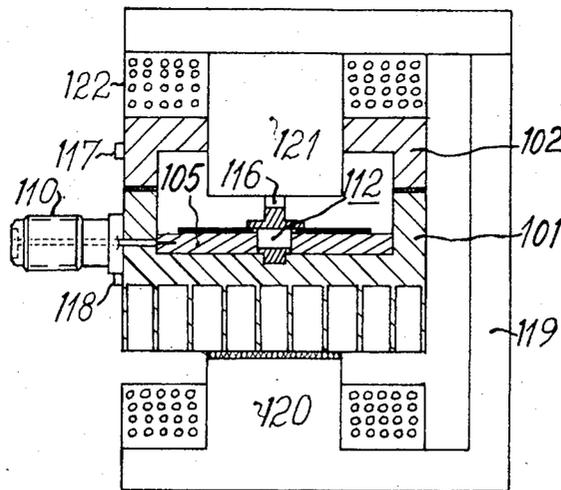
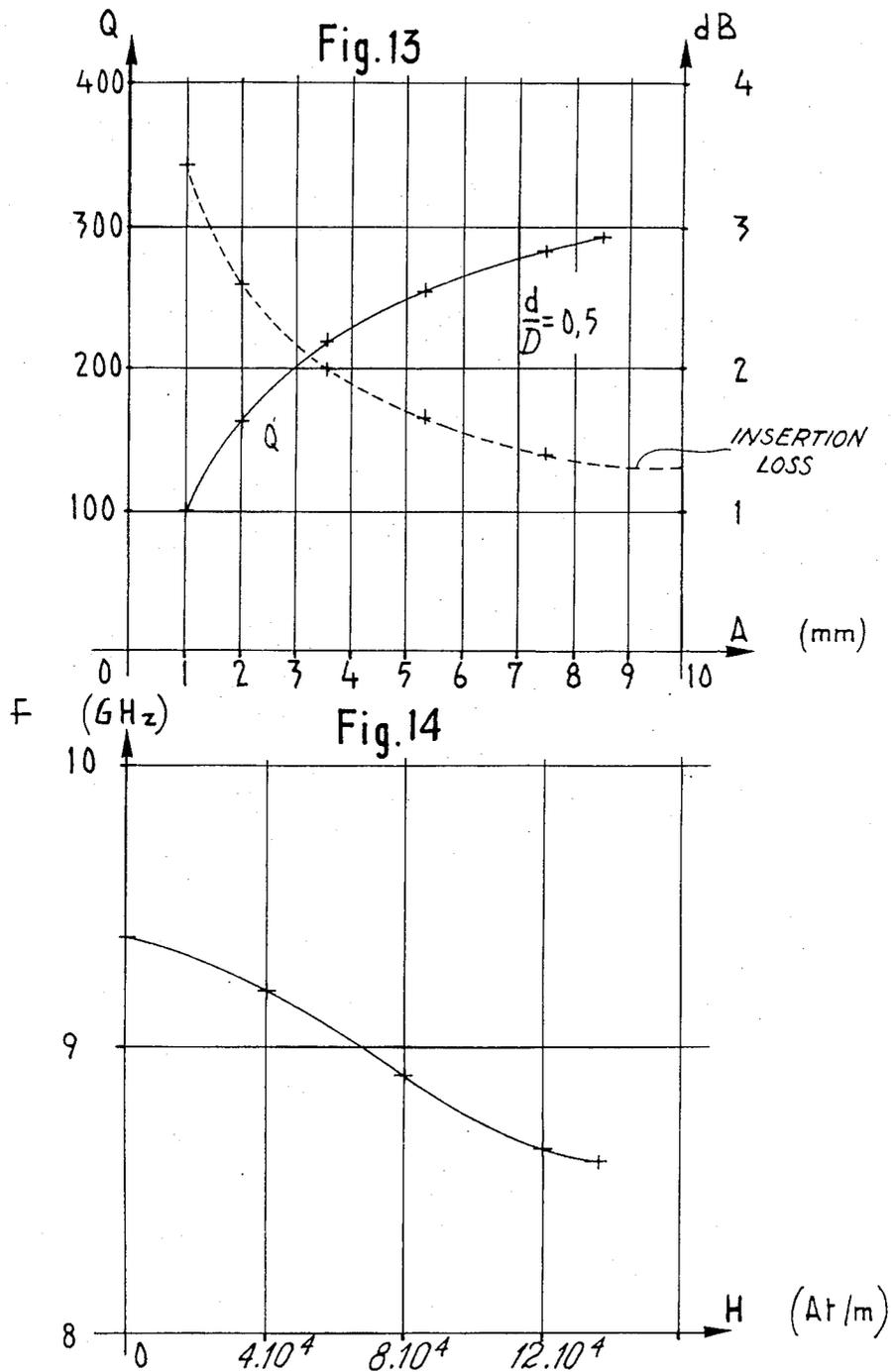


Fig.12



Inventor  
GERARD E. FORTERRE

By *Abraham C. Saffitz*  
Attorney



Inventor  
GERARD E. FORTERRE

By *Abraham A. Siffity*  
Attorney

## MICROSTRIP RING-SHAPED RESONATORS AND MICROWAVE GENERATORS USING THE SAME

The present invention relates to microwave resonators of the "microstrip" type and to microwave generators using such resonators.

Microstrip microwave generators are already known in the art, consisting of a plate or substrate of a thickness  $e$  completely metallized on one side and having on the other side a circular metallized coating of diameter  $D$  coupled with a microstrip transmission line by two capacitive gaps. The central resonant frequency of the apparatus is given by the expression:

$$F_0 = \frac{cK'}{2D\sqrt{\epsilon_{\text{eff}}\mu_{\text{eff}}}} \quad (1)$$

where  $c$  is the speed of light and  $\epsilon_{\text{eff}}$  and  $\mu_{\text{eff}}$  are given by the expressions:

$$\epsilon_{\text{eff}} = 1 + q(\epsilon_r - 1);$$

$$1/\mu_{\text{eff}} = 1 + q(1/\mu_r - 1);$$

wherein  $\epsilon_r$  and  $\mu_r$  are the relative permittivity and permeability of the substrate, and  $q$  is a factor known as the filling factor, depending on  $D/e$ . Further,  $K'$  is a function of  $D/e$  approaching unity.

According to the present invention, there is provided a microstrip microwave resonator comprising an electrically insulating substrate plate, a metallic coating entirely covering one face of said plate, and a metallized circuit covering a part of the other face of said plate, wherein said circuit is ring-shaped and a microstrip transmission line is capacitively coupled with said ring-shaped circuit.

According to the present invention, there is also provided a microwave generator comprising a metal box forming a resonating cavity and resonating at a frequency at least equal to twice the working frequency of the said microwave generator and containing within the said cavity an annular resonator consisting of an insulating substrate plate, one face of which is completely metallized and the other face of which carries a metallized ring provided with a control hole containing a solid state oscillating element, such as a Gunn diode connected with the said ring, with an output terminal passing through the said box and capacitively coupled with the said ring, and a biasing connection consisting of a cylindrical rod rigidly secured to the cover of the box, arranged in the axis of the metallized ring and making contact with the aforesaid oscillating element.

An object of the invention is thus a microstrip resonator different from the known ones in that, instead of being circular, it is of annular shape with an external diameter  $D$  and an internal diameter  $d$ .

For such resonators, the resonance frequency is given by

$$F = \frac{cK'[1 - K''(d/D, D/e)]}{2D\sqrt{\epsilon_{\text{eff}}\mu_{\text{eff}}}} \quad (2)$$

where all symbols have the same significance as in Eq. (1), and  $K''$  is a function of both  $d/D$  and  $D/e$ .

The annular form of resonator presents the advantage of allowing a hole to be made in the substrate plate, inside the ring, receiving a solid-state oscillator such as a Gunn diode and means for polarizing or feed-

ing the latter in a manner which will be explained later on.

The invention further relates to an annular resonator of the microstrip type wherein the substrate plate is made of a magnetic material associated with means for generating a magnetic field of variable intensity for variably adjusting the resonant frequency of the resonator.

The invention finally relates to an annular resonator of the microstrip type wherein the substrate plate is pierced by a hole inside the metallized ring, the said hole being either unoccupied or containing a metal rod passing through it.

The invention will now be described in detail under reference to the accompanying drawings, in which:

FIG. 1 shows a circular resonator of the microstrip type, built according to the prior art;

FIG. 2 to 5 are graphs representing the value of the resonant frequency of a resonator according to FIG. 1 as a function of the various geometrical parameters of the system and the intensity of the magnetic field applied thereto, if the plate is of magnetic material;

FIG. 6 is a ring resonator of the microstrip type according to the present invention;

FIG. 7 shows curves representing for particular values of the ratio  $D/e$  the ratio  $F/F_0$  of the resonant frequency  $F$  of a ring resonator to the resonant frequency  $F_0$  of a circular resonator, for the same values of  $D$ , as a function of the ratio  $d/D$ .

FIG. 8 is a graph representing the variations of the quality factor (Q-factor) of a ring resonator as a function of the ratio  $d/D$ , for a ring resonator pierced with a hole either unoccupied or occupied by a penetrating metal rod;

FIG. 9 shows graphs respectively representing for circular and annular resonators of the microstrip type, the variation of the resonant frequency as a function of the intensity of the magnetic field applied to the substrate.

FIG. 10 is a sectional view of a fixed-frequency microwave generator according to the invention;

FIG. 11 is a top view in plan with the cover of the box removed, of the generator according to FIG. 10;

FIG. 12 is a sectional view of a variable-frequency microwave generator according to the invention;

FIG. 13 is a graph showing the change in the generator frequency as a function of the height of the box cavity; and

FIG. 14 is a graph showing the change in the generator frequency with changing intensity of the magnetic field applied to the substrate.

Referring to FIG. 1, 10 is a plate of insulating material, either magnetic or non-magnetic. This material may be aluminum, a ferrite, a garnet, or the like. In the exemplary embodiments which will follow, this plate is made of YIG garnet, i.e. an yttrium-iron garnet such as made by the French Company "Lignes Telegraphiques et Telephoniques" under the designation LTT 6901 or the product made by the U.S. Company TRANSTECH INC. under the designation G 113. One side of the plate is coated with a metallized layer 11 of metallic gold, and the other side carries a metallized ring 12, also of gold, of circular shape and a diameter  $D$ , coupled with a microband transmission line 13, 13'. The resonant frequency of the resonator is thus determined by Eq.(1), as above.

FIG. 2 shows the resonant frequency  $F_0$  in GHz of the circular resonator according to FIG. 1, depending on the diameter of the resonator in mm for a substrate with a thickness  $e$  of 1 mm.

FIG. 3 shows the resonant frequency in GHz of the circular resonator according to FIG. 1, depending on the thickness of the substrate in mm, for a diameter  $D=6$ mm.

FIG. 4 shows the resonant frequency in GHz of the circular resonator according to FIG. 1, depending on the intensity of the magnetic polarization in  $A/t$  (ampere-turns/meter), the two curves being related to a diameter of 4.4 mm. and a thickness of 1 mm; and a diameter of 6 mm and a thickness of 1.6 mm, respectively.

FIG. 5 represents the Q-factor in terms of the substrate thickness  $e$  in 11.

From the curves of FIGS. 2 to 5 it will be seen that the resonant frequency and Q-factor can be determined from known values of the dimensional characteristics  $e$  and  $D$  of the resonator, and, in the case of a magnetic substrate, the intensity of the magnetic polarizing field.

Referring now to FIG. 6, 20 is the substrate of thickness  $e$ , 21 the metallized coating forming the ground plane, and 22 an annular resonator with external and internal diameters  $D$  and  $d$  respectively. This resonator is coupled with a microstrip transmission line 23, 23'. The resonant frequency of this resonator is determined by the formula (2), as explained above.

The part of the plate inside the ring 22 is pierced by a hole 24 which is intended to receive a solid-state oscillator or a conductor rod, as it will be explained later on.

The curves 71 and 72 in FIG. 7 show, for the values 5 and 7 of the ratio  $D/e$ , the variation of  $F/F_0$  depending on  $d/D$  for the case of the resonator according to FIG. 6. It will be seen that if  $d/D$  remains below 0.7, the resonant frequency  $F$  of the annular resonator pierced by a central hole deviates by not more than 20 percent from the resonant frequency  $F_0$  of the circular resonator of diameter  $D$ .

The curves 81 and 82 in FIG. 8 show the variations in the Q-factor in relation to the ratio  $d/D$  respectively for the case of an annular resonator pierced with a central hole, and the same resonator when fitted with a conducting rod passing through the said hole, of any suitable length larger than the thickness of the substrate.

The curves 91 and 92 in FIG. 9 show the variation of the resonant frequency, respectively of a circular resonator and an annular resonator, as a function of intensity of the polarizing magnetic field.

It will be appreciated from the curves shown that if the loss in the Q-factor is relatively reduced when passing from a circular to an annular form of resonator, the variation of the frequency as a function of the magnetic field is less in the case of an annular resonator. The tunable band-width of such an annular resonator is somewhat less than that of the circular form thereof. However, this band-width remains above 15 percent of the central frequency, which in practice provides some interesting resonator constructions which are easily adaptable for use with solid-state oscillators.

The annular resonators according to the present invention can also be usefully connected in series or in parallel to construct band-pass filters for microwave generators.

Referring to FIGS. 10 and 11, 101 is a metal box, suitably of copper, with a cover 102 and cooling fins 103. The cover and the box are separated from each other when assembled by an insulating film 104. The box cavity 101 contains an insulating plate or base 105 of magnetic or non-magnetic material, metallized on its face 106 in contact with the box, and carrying on its upper surface a metallized ring 107 coupled with a transmission line 108 of the microstrip type over a capacitive gap 109. This microstrip transmission line is coupled with the internal conductor of a coaxial cable 110.

The plate 105 and the body of the box 101 are penetrated by a hole 111 coaxial with the ring 107 and of the same or lesser diameter than the inside diameter of the ring. This hole 111 contains a Gunn diode 112 e.g. of the kind made by "American Microwave Associates" under the designation MA. 49114.

This diode 112 comprises a ceramic body 113 with metal terminals 114 and 115. The terminal 114 is located inside the hole 111 and is in contact with the body of the resonator box 101; the terminal 115 is in contact with a pin 116 projecting from the cover towards the inside of the box. The cover and the box also have two terminals 117 and 118, between which a D.C. voltage of the order of 112 volts is applied.

If the generator is desired to work at a fixed frequency, the plate 105 is non-magnetic.

If the generator is wished to work at a variable frequency, it is located in the gap of an electromagnet 119 the pole pieces 120 and 121 whereof enclose the plate 105, which is in such case made a magnetic material such as a ferrite or a garnet. The resonant frequency of the ring resonator is then varied by altering the current intensity in the winding 122 of the electromagnet.

A suitable material for the plate 105 is a YIG yttrium-iron garnet.

In order to increase the magnetic polarization field of the plate 105 the pole piece 121 passes through a hole in the box cover and is placed in electrical contact with the said cover. This pole piece 121 carries the biasing pin 116 of the diode 112.

FIG. 13 illustrates the influence of the height  $A$  of the resonator box on the Q-factor and the insertion loss of the resonator for the case in which the base plate is made of YIG garnet.

FIG. 14 is a graph showing the frequency in GHz of the generator resonator depending on the intensity of the magnetic field for the case of a resonator with a ring of 4.4-mm external and 2.2-mm internal diameter.

What is claimed is:

1. A microwave generator comprising a metal box forming a cavity resonating at a frequency definitely higher than the working frequency of the microwave generator, within such a cavity an annular microstrip resonator consisting of an insulating substrate plate completely metallized on one side and having on its other side a metallized ring within which the plate is provided with a hole containing a solid-state oscillator element connected with the said metallized ring, an output terminal, means for capacitively coupling said output terminal with said ring, and a biasing connection comprising a cylindrical pin secured to the box cover of the resonator and so arranged along the axis

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line of the said ring as to make contact with the aforesaid oscillator element.

2. A microwave generator in accordance with claim 1 wherein said solid-state oscillator element consists of a Gunn diode.

3. A microwave generator in accordance with claim 1 wherein said means for capacitively coupling said output terminal with said metallized resonator ring consist of a microstrip transmission line located on the same said substrate plate and capacitively coupled with said ring.

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4. A variably-frequency microwave generator in accordance with claim 1 wherein said annular resonator is fitted in the gap between the pole-pieces of a magnetic circuit generating a magnetic field of adjustably-variable intensity.

5. A variable-frequency microwave generator in accordance with claim 4 wherein one of said pole-pieces of said magnetic circuit projects into the resonator box through a hole in the cover thereof.

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