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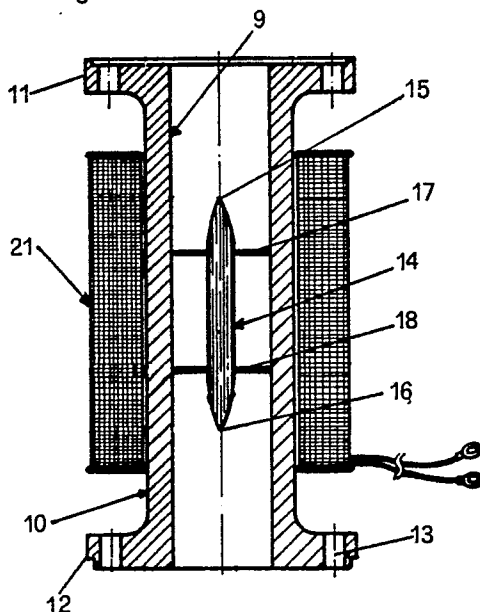
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⑤④ **Rotator for antennas receiving transmissions from satellite.**

⑤⑦ The rotator for antennas receiving from satellite is substantially formed of a waveguide segment (10) of circular shape in cross-section, a cylindrical rod of ferrite (14) arranged within the waveguide segment along the longitudinal axis thereof and supported by small discs (17, 18) of a material having good mechanical and electrical characteristics, and an inductor (21) arranged outside the waveguide segment and connected to an electric power supply in order to cause the polarization rotation of the incoming signal in presence of the magnetic field generated along the waveguide axis.



**FIG. 1**

## ROTATOR FOR ANTENNAS RECEIVING TRANSMISSIONS FROM SATELLITE

This invention generally relates to antennas for receiving transmissions from satellite in linear polarization and, more particularly, to a rotator permitting the antennas to receive both X-polarized and Y-polarized signals.

As known, the transmission of signals from satellite is usually made in linear or circular polarization. In the former case the electric field vector (assuming the Z-axis as propagation direction in the X,Y,Z Cartesian axes) rotates about the Z-axis by maintaining its absolute value constant.

Of course, we can speak of right or left polarization according to the rotation direction, either clockwise or counterclockwise, with respect to a viewer looking the vector to move away in the direction of the increasing Z-axis values.

In the latter case, the electric field vector maintains itself, during the propagation, parallel to the X-axis or Y-axis. In the practice the satellites operating in linear polarization will transmit to earth both X-polarized signals and Y-polarized signals.

Referring for example to the ECS (European Communications Satellite) it will be noted that the satellite is equipped with 12 transponders for earth transmissions (however, only a maximum of 9 transponders can simultaneously transmit) one half of which operates in X-polarization, whereas the other half is preset for the transmission of Y-polarized signals.

In a conventional parabolic antenna for receiving transmissions from satellite the illuminator orientation will determine in univocal manner the possibility of receiving either of the X-polarized and Y-polarized signals.

In other words, once the illuminator has been mounted so as to receive the Y-polarized signals and it is desired to receive the X-polarized signals, the illuminator will have to be rotated by  $90^\circ$  (suppose that it is preferred to rotate all the paraboloid).

A simpler system consists in inserting within the illuminator a pair of movable plates of a dielectric material, which have a predetermined length and are inclined in a suitable manner with respect to the incident field. The change of polarization will require in this case the simple rotation by  $90^\circ$  of one of the pair of plates. This is a relatively simple and effective approach which requires, however, for the remote control, the use of electro-mechanical components and therefore the presence of movable mechanical elements.

This can be a disadvantage in terms of reliability of the system, principally if it is considered that the antenna can be installed in positions accessible with difficulty by the user and exposed to the inclemency of the weather.

The present invention aims at obviating the disadvantages concerning the known antennas for receiving transmissions from satellite, by providing a static device to be applied to receiving parabolic antennas of known construction and of any type in order to permit them to receive both X-polarized signals and Y-polarized signals and which can be operatively mounted also by unskilled labour.

More particularly, the rotator for antennas receiving transmissions from satellite is characterized in that it comprises a waveguide segment of circular cross-section, containing along its longitudinal axis a cylindrical rod of ferrite, supporting means for this ferrite rod and an inductor arranged outside the waveguide segment and intended, when excited, to cause the rotation of polarization of the incoming signals, this waveguide segment being provided with means for fastening it to the illuminator of the receiving antenna.

The present invention will be now described in more detail in connection with a preferred embodiment thereof, given by way of example only and therefore not intended in a limiting sense, illustrated in the accompanying drawings, wherein:

Fig.1 is a diametral section view of the rotator according to the present invention;

Fig.2 is a plan view of the rotator of Fig.1;

Fig.3 is a diagram in which the diameter of the ferrite rod vs. the length thereof is plotted;

Fig.4 is a diagram showing the reflection coefficient of the waveguide segment;

Fig.5 is a diagram showing the insertion loss of the rotator; and

Fig.6 shows the insertion loss of the rotator for three different values of the inductor excitation current.

The rotator according to the present invention relies upon the Faraday's effect on its operation, this effect being here concisely explained.

The Faraday's effect is well known as responsible of the field rotations found in the propagation of the linearly polarized electromagnetic waves in the high layers of the atmosphere (ionosphere).

The same effect has been later used for producing several microwave devices (insulators, gyrators and so on).

The Faraday's rotation occurs when a linearly polarized plane wave TEM propagates in an anisotropic dielectric medium.

5 A simple definition of isotropy of a medium presupposes that, once a cause in form of a vectorial quantity is assumed, the resulting effect must be aligned with the cause itself which has produced it. In the case of isotropic medium, in relations such as:  $\vec{D} = \epsilon \vec{E}$  or  $\vec{B} = \mu \vec{H}$ , which relate the electric induction to the electric field and the magnetic induction to the magnetic field, the quantities such as  $\epsilon$  and  $\mu$  - (dielectric constant and magnetic permeability) are in terms of scalar numbers in the real or more generally

10 complex field. This is not valid for anisotropic media in which the same quantities must be in terms of tensors and the above mentioned equations will assume forms of the type:

$$15 \begin{vmatrix} B_x \\ B_y \\ B_z \end{vmatrix} = \begin{vmatrix} \mu_{xx} & \mu_{xy} & \mu_{xz} \\ \mu_{yx} & \mu_{yy} & \mu_{yz} \\ \mu_{zx} & \mu_{zy} & \mu_{zz} \end{vmatrix} \begin{vmatrix} H_x \\ H_y \\ H_z \end{vmatrix}$$

more simply indicated as follows:

$$20 \quad 2) \quad \vec{B} = \hat{\mu} \vec{H}.$$

A conventional example of magnetic anisotropy is offered by the ferritic materials immersed in continuous magnetic fields. In this case the magnetic permeability will assume a tensorial form and the component, for example along the X-axis of the induction vector, will be determined not only by the component relating to the same axis of the field vector but also by the components of this vector along the

25 Y-and X-axes.

Intuitively, it is possible to think of the electrons within the ferrite as elemental carriers of magnetic moment (essentially due to the rotation of the electron about its axis (spin moment)).

In the absence of outer magnetic field the various moments which are randomly oriented because of the thermal agitation will be annulled and the material exhibits a zero total magnetization.

30 On the contrary, in the case that an outer field is applied, the elemental dipoles will tend to align themselves along the direction of the field and, in so doing, will initiate a precession movement having as its axis just this direction.

The movement will occur in a counterclockwise direction looking in the direction of  $\vec{H}_0$  and will be characterized by an angular velocity  $\vec{\omega}_0 = |\gamma| \vec{H}_0$ , where  $\gamma$  is a negative constant called gyromagnetic ratio and for the electron assumes the value:

$$\gamma = -2,2 \cdot 10^5 \frac{\text{Rad/sec}}{\text{A/m}}$$

40 Assuming now that a circularly polarized electromagnetic field propagates in the direction of  $H_0$  within the ferrite rod, it is intuitive that it will be influenced in a manner quite different in accordance to whether the magnetic field vector rotates in the same direction as or in opposite direction of the proper rotation direction of the elemental magnetic moments within the material. After all, the anisotropy of the ferrite will be manifested by the fact that electromagnetic fields which are circularly polarized, but in opposite directions, will have different values of magnetic permeability ( $\mu_1 \neq \mu_2$ ). Of course, till now only an intuitive explanation

45 of a phenomenon has been given, which however is largely explained in the microwave literature.

It is possible now to explain also intuitively which is on the contrary the magnetized ferrite effect on an electromagnetic field propagating in the same direction already considered, but linearly polarized.

50 It is first at all to be remembered that a linearly polarized vector can be always interpreted as the addition of two vectors which are circularly polarized in opposite directions, and each of which has an amplitude which is one half of the original vector amplitude.

$$3) H e^{-iKz} = H/2 e^{-iKz} (ix + jiy) + H/2 e^{-iKz} (ix - jiy)$$

55 In the equation 3)  $Kz$  is the propagation constant in the medium. However, it should be noted that, in this specific case, the values of  $Kz$  for two opposite circular polarizations will be different because, as already said, the values of the magnetic permeability are different. The equation 3) will be therefore rewritten as follows:

$$4) H e^{-iKz} = HE/2 e^{-iKz1} (ix + jiy) + H/2 e^{-iKz2} (ix - jiy)$$

where:

$$5) \quad K_{z1} = \omega \sqrt{\epsilon_0 \epsilon_f} \sqrt{\mu_1 + \mu_2}$$

$$K_{z2} = \omega \sqrt{\epsilon_0 \epsilon_f} \sqrt{\mu_1 - \mu_2}$$

5:

In the equation 5)  $\epsilon_f$  is the dielectric constant of the ferrite. The expressions for  $\mu_1$  and  $\mu_2$  derived from the theory are the following:

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$$6) \quad \mu_1 = \mu_0 \left( 1 + \frac{\omega_0 \omega_M}{\omega_0^2 - \omega^2} \right)$$

$$\mu_2 = \mu_0 \frac{\omega \omega_M}{\omega_0^2 - \omega^2}$$

where

$$\bar{\omega}_0 = -\gamma H_0, \quad \bar{\omega}_M = -\gamma \bar{M}$$

15

$\bar{M}$  is the magnetisation intensity vector and  $\omega$  is the pulsation of the incident electromagnetic field. After all, the different value of  $K_z$  for the two circular polarization will cause, at the outlet of the ferrite rod, the original linearly polarized vector to undergo a rotation of polarisation which is in direct proportion with the length of the ferrite rod itself.

20

This rotation can be expressed as follows:

$$7) \quad \theta = - \frac{K_{z1} - K_{z2}}{2} Z$$

or

25

$$8) \quad \frac{\theta}{Z} = - \frac{\omega \sqrt{\epsilon_0 \epsilon_f \mu_0}}{2} \left[ \sqrt{1 + \frac{\omega_M}{\omega_0 - \omega}} - \sqrt{1 + \frac{\omega_M}{\omega_0 + \omega}} \right]$$

where  $\theta$  is measured in radians and  $Z$  in meters.

Note that:

for  $\omega_0 > \omega$  there will be two ordinary real waves;

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for  $\omega_0 < \omega < \omega_0 + \omega_M$  there will be a fading wave and an ordinary wave;

for  $\omega > \omega_0 + \omega_M$  an extraordinary real wave and an ordinary wave.

35

In the third case which relates to this invention, the rotation or polarization will be directed in clockwise direction for a viewer looking the wave to move away in the direction of the increasing  $Z$ -axis values. Till now the ferrite losses and the physical dimensions of the ferrite have been taken into account. There are mathematical means for computing the former, whereas it is possible to apply the Maxwell's equations suitably conditioned for modifying the equation 8) according to the latter.

In any case, for a circular waveguide wherein the fundamental mode  $TE_{11}$  is propagated, the equation 8) can be rewritten with a good approximation as:

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$$9) \quad \frac{\theta}{Z} \approx -1,4 \frac{\Delta S}{S} \omega \sqrt{\epsilon_0 \mu_0 \epsilon_f} \frac{\omega \omega_M}{(\omega_0 + \frac{\omega_M}{2})^2 - \omega^2}$$

where  $\Delta S$  is the cross-section of the ferrite rod in  $m^2$ , and

$S$  is the cross-section of the waveguide in  $m^2$ .

45

As can be seen from Figs.1 and 2, the rotator according to the invention is formed of a waveguide segment, generally indicated at 10, having a circular cross-section and at its ends a flange 11 and 12, respectively, each of these flanges being provided with four holes 13 for securing the rotator to the usual illuminator of a parabolic antenna for receiving signals coming from satellite. Arranged along the longitudinal axis of the waveguide segment 10 is a ferrite rod 14 having a circular cross-section and critical dimensions which will be given in the description of the various components and which, at its ends, terminates in two points 15 and 16. The ferrite rod is held in position within the waveguide segment 10 by two discs 17 and 18 of a material exhibiting good mechanical and electrical characteristics, as well as a good dimensional stability, the discs being provided centrally with a hole 19 having substantially the same diameter as the ferrite rod 14. The ferrite rod 14 is fastened by means of an adhesive on the two discs which are then secured within the waveguide segment in the desired positions.

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The supporting discs 17 and 18 have holes 20 which are spaced apart the same distance along a circumference and which have been provided for the purpose of minimizing the interferences between the dielectric material and the incident electromagnetic field.

Arranged outside the waveguide segment is an inductor 21 connected to a power supply and which is intended, when excited, to rotate the polarization of the signal entering the waveguide segment.

The dimensions of the ferrite rod 10 have been selected so as to obtain field rotations wider than  $\pm 90^\circ$  so as to be sure to have a good reception also in the case that the antenna parabola has been rotated in the polar plane to track a satellite, with relative rotation of the illuminator.

The purpose of the inductor 21 is to generate a constant magnetic field within the waveguide segment 10, directed along the axis thereof.

The various described components will be now further examined.

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#### a) WAVEGUIDE SEGMENT

The material used is aluminium anticorodal paralluman 7.

The inside diameter of the waveguide is 17,5 mm. The fundamental mode  $TE_{11}$  has therefore a cut-off frequency of about 10 GHz, while the first upper mode  $TH_{01}$  has a cut-off frequency of 13,2 GHz.

The selected working band ranges from 10,9 to 11,7 GHz. In the case of the ECS this band includes the working frequencies of the first 10 transponders. Nothing prevents, however, without making particular changes to the design, of widening the band up to 12,6 GHz so as to include also the remaining two transponders (12,50-12,58 GHz).

The length of the waveguide segment is 80 mm exclusive of the flange thickness but, since this is not a critical parameter, it cannot be excluded that in the manufacturing stage, different dimensions can be adopted.

#### 25 b) INDUCTOR

The inductor is formed of a coil of about 55 mm in length and which is arranged around the waveguide body so as to generate a magnetic field  $H_0$  directed along the waveguide axis.

The magnetic field values have been experimentally evaluated: it has been noted that with a field  $H_0$  of about 6000 Ampere.turns/m it is possible to obtain rotations wider than  $90^\circ$  over the entire band with the used ferrite rod.

The indicated field value has been obtained by winding 3500 turns over 55 mm and employing excitation currents of a maximum of  $\pm 100$  mA.

Note (see equation 9) that the rotation effect is affected by the value of  $\omega$  (microwave signal pulsation). Actually, at high frequencies lower currents are employed with the same rotation angle with respect to the lowest frequencies in the band.

The physical dimensions of the inductor are relatively reduced and the thickness is such as to be below the flange limits.

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#### c) FERRITE

The used material is an yttrium-gadolinium-aluminium garnet having a saturation magnetization of about 150 kA/m, a Curie temperature of  $205^\circ\text{C}$ , a  $\epsilon_f$  of 15,5 (relative dielectric constant). Other significant parameters are the loss tangent  $< 2 \times 10^{-4}$  and the line length  $\Delta H$  of 0,8 kA/m.

The determination of the ferrite rod dimensions has been experimentally evaluated.

Starting from the theoretical curve of Fig.3 in which the diameter versus the length values are plotted which curve has been drawn from the equation 9), several approaches have been made.

The nowadays used ferrite rod is 42 mm in length and 4,5 mm in diameter.

It has been decided to point the ends thereof as shown in 15 and 16 since it has been found that in so doing it is possible to obtain better matching values.

#### d) SUPPORTING ELEMENTS

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As already said, in order to support the ferrite rod within the waveguide, two thin discs of rexolite are employed. The rexolite has been selected for its very good mechanical and electrical characteristics ( $\epsilon_R = 2,6$ ; loss tangent = 0,0005; very good dimensional stability).

The measures have been carried out in laboratory at a temperature of 20°C.

The measured ROS value over all the band (see Fig.4) is always lower than 1,3 (reflection coefficient better than -18 dB).

The insertion losses of the waveguide with ferrite rod with respect to the same waveguide without ferrite rod and without excitation are in the order of 0,25 dB.

In excited conditions the greatest insertion loss is about 0,30 dB (see Fig.5).

The field polarization rotation of 90° is obtained with current values ranging from 40 mA for the higher frequencies to 80-90 mA for the lower frequencies (see Fig.6).

The maximum rotation which can be obtained with the nowadays dimensions of the ferrite rod are in the order of  $\pm 100^\circ$ .

From the foregoing it is evident that the rotator according to the present invention allows both X-polarized signals and Y-polarized signals to be received from a satellite, which signals are at present usually transmitted in linear polarization.

This rotator, when experimentally mounted on an antenna having a parabola of 1,5 m of diameter aimed at the satellite ECS, has proved to operate in a very effective manner. This device is also simple in construction, does not contain moving mechanical elements, requires low supply powers and can readily be applied without the intervention of skilled labour to the usual parabolic antennas for receiving from satellite linearly polarized signals.

## Claims

1) Rotator for antennas receiving from satellite transmitting in linear polarization, characterized in that it comprises a waveguide segment of circular shape in cross-section, which contain a cylindrical rod of ferrite arranged along its longitudinal axis, supporting means for the ferrite rod and an inductor arranged outside the waveguide and intended, when excited, to cause the rotation of polarization of the incoming signals, said waveguide segment being provided with means for securing it to the illuminator of the receiving antenna.

2) Rotator according to claim 1, characterized in that the cylindrical rod of ferrite has its ends pointed in order to obtain better matching values.

3) Rotator according to claims 1 and 2, characterized in that said supporting means of the ferrite rod are formed of a pair of thin discs of a material exhibiting very good mechanical and electrical characteristics as well as a good dimensional stability, said ferrite rod being secured by means of an adhesive to said pair of discs which are secured within the waveguide in the desired position.

4) Rotator according to claim 3, characterized in that said thin discs supporting the ferrite rod are preferably formed of rexolite.

5) Rotator according to claims 3 and 4, characterized in that said supporting discs are provided with holes circumferentially spaced in order to minimize the interferences between the dielectric material and the incident magnetic field.

6) Rotator according to claim 1, characterized in that said inductor is formed of a coil wound around the waveguide body so as to generate a magnetic field directed along the waveguide axis, said coil being connected to an excitation power supply.

7) Rotator according to claim 1, characterized in that said means for securing the waveguide segment to the illuminator of the receiving antenna are formed of a pair of end flanges provided with holes intended to receive usual fastening means.

8) Rotator according to anyone of the preceding claims, characterized in that when said inductor is unexcited, X-polarized signals or Y-polarized signals are received and, when said inductor is excited, Y-polarized signals or X-polarized signals are received.

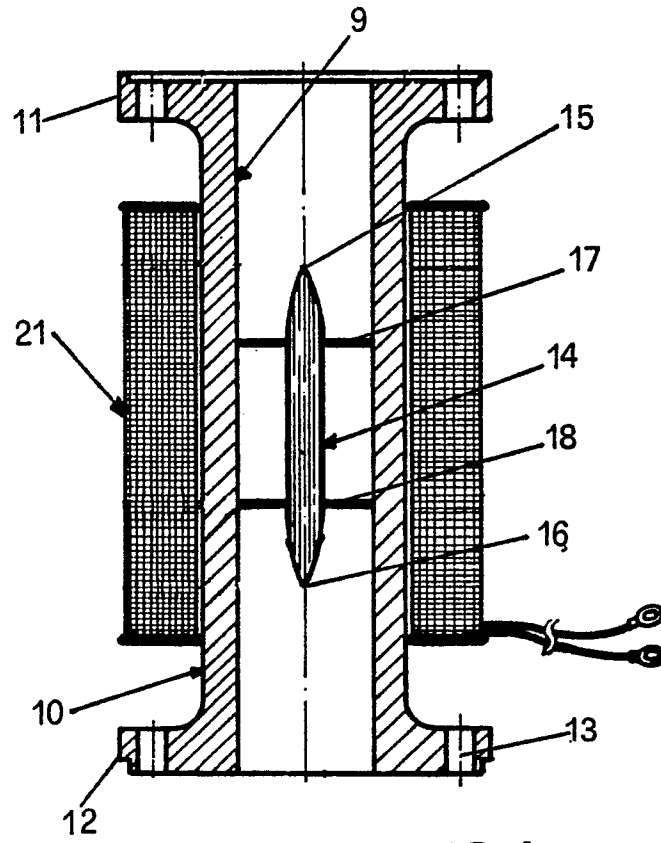


FIG. 1

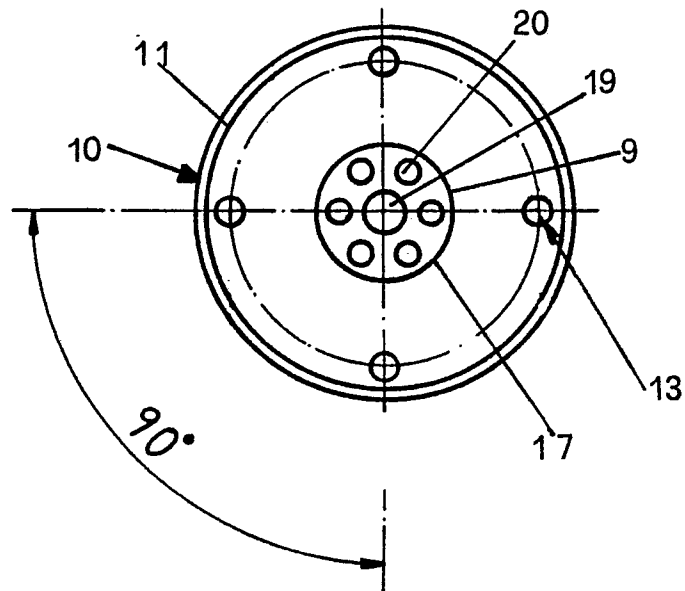
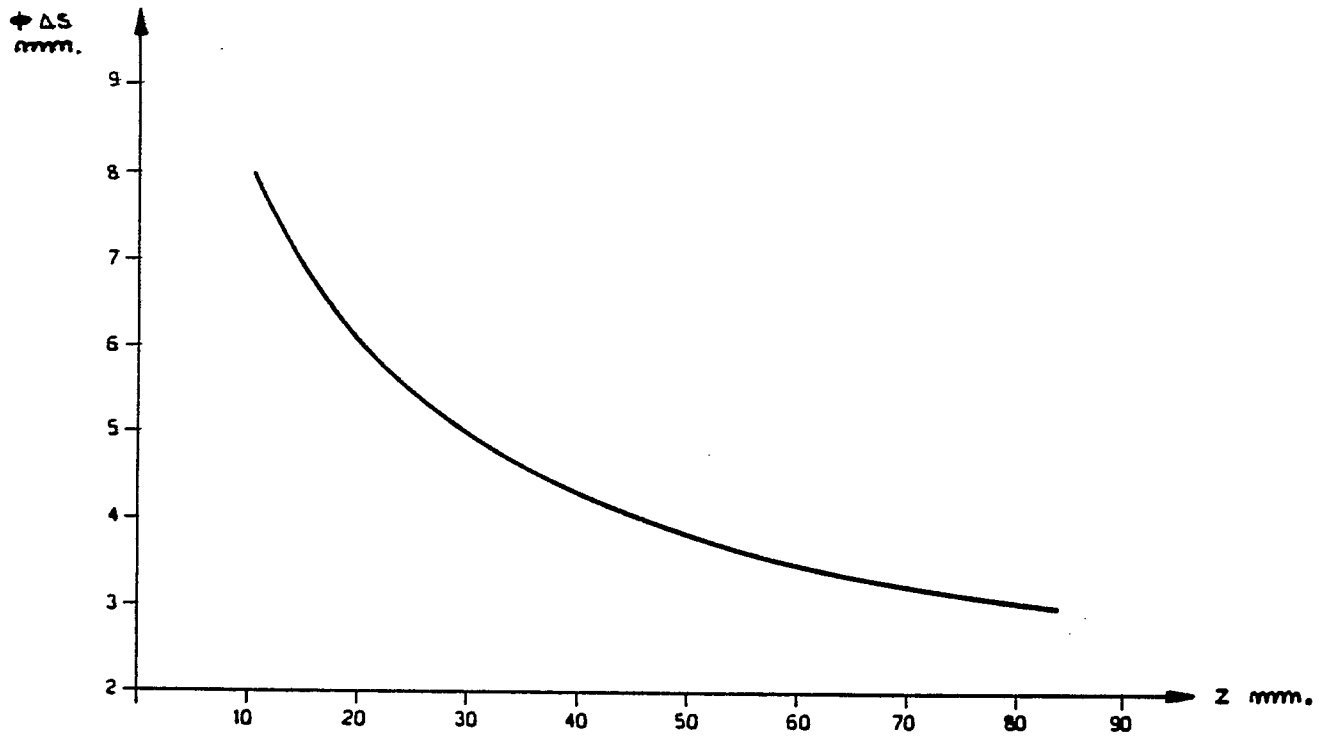
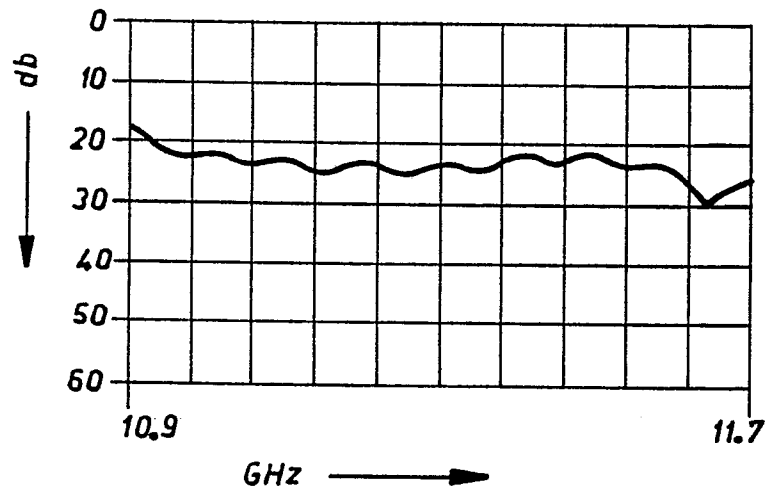
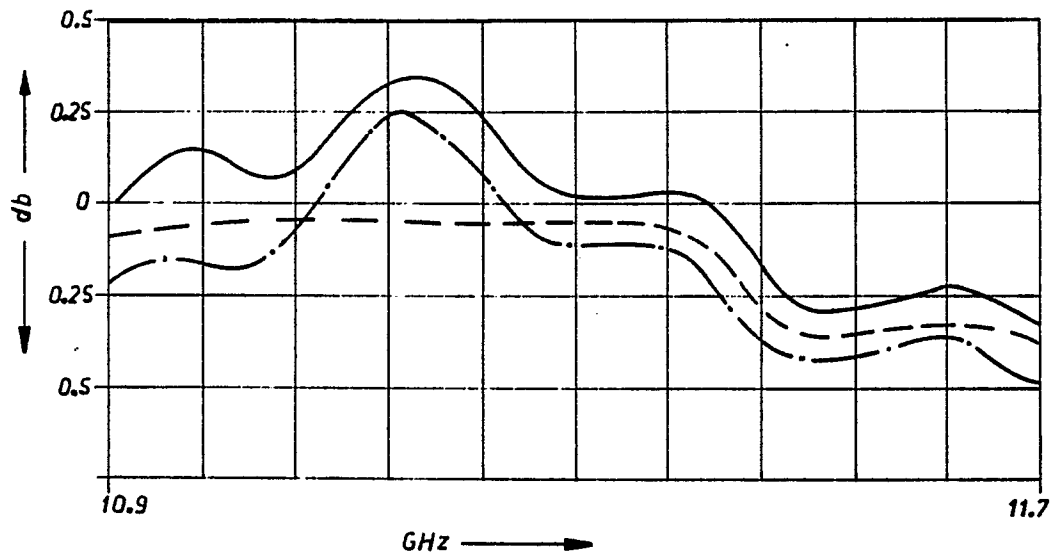
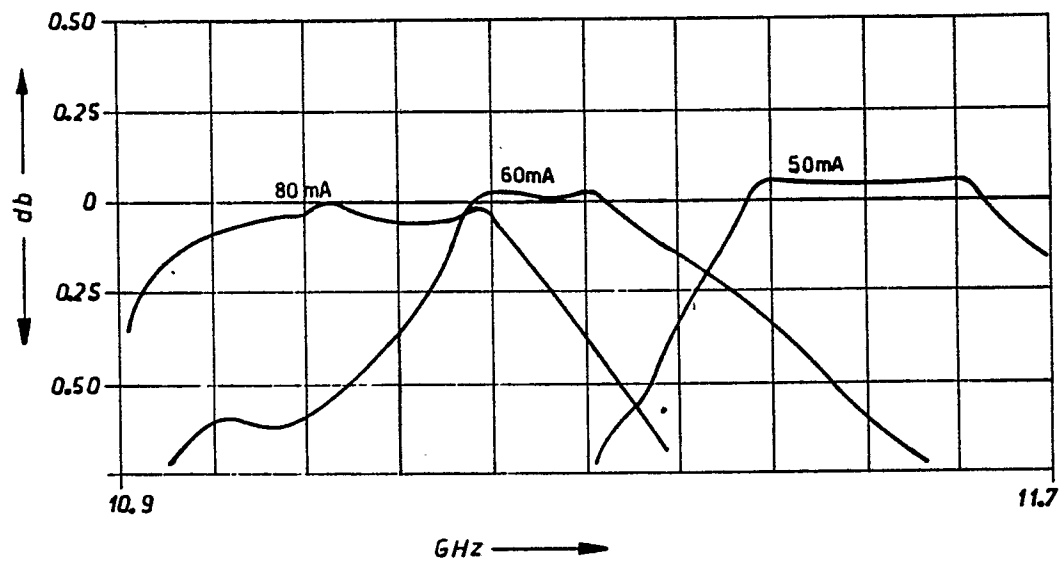


FIG. 2

FIG.3FIG.4

FIG. 5FIG. 6



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| DOCUMENTS CONSIDERED TO BE RELEVANT                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                            |                                                |                                               |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------|-----------------------------------------------|
| Category                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Citation of document with indication, where appropriate, of relevant passages                                                              | Relevant to claim                              | CLASSIFICATION OF THE APPLICATION (Int. Cl.4) |
| X                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | PATENT ABSTRACTS OF JAPAN, vol. 3, no. 153 (E-159), 15th December 1979, page 56 E 159; & JP - A - 54 133 049 (MITSUBISHI DENKI) 16-10-1979 | 1,6                                            | H 01 Q 15/24<br>H 01 P 1/175                  |
| Y                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | ---<br>DE-C-1 152 453 (PHILIPS)<br>* figure 1; column 4, lines 1-5 *                                                                       | 2                                              |                                               |
| Y                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | ---<br>US-A-3 023 165 (LE GRAND G. VAN UITERT)<br>* figure 1; column 2, lines 11-25 *                                                      | 2                                              |                                               |
| A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | ---<br>DE-A-1 591 362 (PHILIPS)<br>* figure 1; page 4, lines 1-6 *                                                                         | 3,5                                            |                                               |
| A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | ---<br>US-A-3 938 158 (J.D. BIRCH et al.)<br>* figure 1; abstract *                                                                        | 1                                              |                                               |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | -----                                                                                                                                      |                                                |                                               |
| The present search report has been drawn up for all claims                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                                                                                            |                                                |                                               |
| Place of search<br>BERLIN                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                            | Date of completion of the search<br>16-06-1987 | Examiner<br>BREUSING J                        |
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