(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number : **0 598 580 A1**

(12) **EUROPEAN PATENT APPLICATION**

(21) Application number : **93309103.5**

(22) Date of filing : **15.11.93**

(51) Int. Cl.^{5} : **H01Q 13/10,** H01Q 21/00

(30) Priority : **16.11.92 US 976599**

(43) Date of publication of application : **25.05.94 Bulletin 94/21**

(84) Designated Contracting States : **DE ES FR GB IT**

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(54) **Cross-slot microwave antenna.**

(57) A microwave antenna (20) comprises a stripline microwave element including an outer conductor (36) having a radiating face (22) and an oppositely disposed backing face (30), an inner linear conductor (28) lying parallel to the radiating face within the outer conductor (36), and a dielectric between the outer conductor (36) and the linear conductor (28). There is a pair of slots (24, 26) in the radiating face of the outer conductor (22), the pair of slots (24, 26) being oriented at 90 degrees to each other and being of unequal length. The inner linear conductor (28) is oriented such that it is not parallel to either of the slots (24, 26). A dielectric (33) resides between the outer conductor (36) and the inner linear conductor (28).

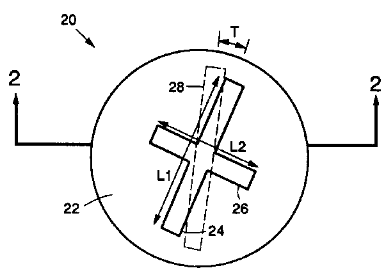


FIG. 1.

EP 0 598 580 A1

This invention relates to microwave antennas, and, more particularly, to a microwave antenna for producing or receiving circularly polarized microwave signals.

Microwaves (including millimeter waves as the term is used herein) are used in communications applications because of the high density of information that they can convey. In such applications, the microwaves can either be propagated through free space or conducted along waveguides. The present invention relates to microwave antennas used to radiate or receive microwave signals propagated through free space.

The polarization of a microwave signal is described by the locus of the field vector of the microwave as it propagates. When a microwave antenna is driven by two orthogonally polarized elements, the emitted free space microwave is generally elliptically polarized. Under some conditions, the major and minor axes of the ellipse may be made identical, and the microwave is said to be circularly polarized. The use of circularly polarized microwaves is particularly desirable in many types of general-purpose and special-purpose microwave communications systems, because it is not necessary to align the receiving antenna to the radiating antenna in order to maximize the power of the received signal. Microwave antennas optimized for radiating and receiving circularly polarized microwaves are therefore important and widely used in communications and other applications.

Many types of microwave antennas are known. In one approach, two unequal length dipoles are driven in parallel by a single coaxial line. See M.F. Bolster, "A New Type of Circular Polarizer Using Crossesd Dipoles", IRE Trans. Microwave Theory and Techniques, vol. MTT-9, No. 5, pages 385-388 (1961). While operable, this type of antenna suffers from the shortcomings that it has a high profile and is fragile and bulky, inasmuch as the dipoles and their support extend outwardly from a backing ground plane. Antenna arrays made using such dipoles have the same problems.

In another approach, these problems may be overcome using a patch antenna, such as described in Y.T. Lo and S.W. Lee, "Antenna Handbook, Theory, Applications, and Design," Van Nostrand Reinhold Company, pages 10-57 to 10-61 (1989). The patch antenna is formed from a planar array of radiating elements. However, the patch antenna has the shortcomings of narrow band width, excitation of spurious modes, and, in some cases, the need for two excitation feeds.

Thus, there continues to be a need for an improved microwave antenna that achieves the benefits of other prior approaches without their drawbacks. The present invention fulfills this need, and further provides related advantages.

SUMMARY OF THE INVENTION

The present invention provides a microwave antenna for radiating and receiving circularly polarized microwaves propagated through free space. The antenna of the invention is compact with a low profile, rugged because it has no projecting elements that can be readily broken, and requires only a single feed. The microwave antenna does not produce surface mode excitations and has a broad bandwidth of radiation and reception. The antenna can be fabricated either singly or in small or large arrays, using in part microelectronic techniques that permit close control of sizes and tolerances of the elements while maintaining economic construction costs. The microwave antenna of the invention is also readily designed and optimized for optimal performance.

In accordance with the invention, a microwave antenna comprises a radiating plate made of an electrically conducting material and having two slots cut therein, the slots being oriented at 90 degrees to each other and being of unequal length, and linear means for cooperating with the radiating plate to produce microwave excitations in the radiating plate. The linear means is preferably a linear conductor lying parallel to the radiating plate but not parallel to either of the slots. There is desirably provided a backing plate positioned parallel to and spaced apart from the radiating plate, with the linear means disposed between the radiating plate and the backing plate. The space between the linear means and the radiating and backing plates may be filled with air or some other material of differing dielectric strength.

In a preferred embodiment, the microwave antenna is configured with stripline-fed crossed slots of unequal length. In accordance with this aspect of the invention, a microwave antenna comprises a stripline microwave element including an outer conductor having a radiating face and an oppositely disposed backing face, an inner linear conductor lying parallel to the radiating face within the outer conductor, and a dielectric between the outer conductor and the inner conductor. There is further a pair of slots in the radiating face of the outer conductor, the pair of slots being oriented at 90 degrees to each other and being of unequal length. This stripline-fed device is sturdy and compact, and requires only a single feed.

The microwave antenna of the invention may be used singly or in arrays. The structure of each element of an array is similar to that just described, with the addition of means for reducing internal coupling between the radiating elements. Such means can be a conducting fence placed around each element of the array, to prevent coupling that produces spurious modes which can be radiated or received.

The present invention provides an advance in the art of microwave antennas. The antenna of the invention radiates or receives circularly polarized microwaves, is compact and rugged, and has no undesirable characteristics such as production of spurious modes. Other features and advantages of the invention will be apparent from the following more detailed description of the preferred embodiments, taken in conjunction with the accompanying drawings which illustrate, by way of examples, the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a plan view of a microwave antenna according to the present invention, with the linear inner conductor indicated in phantom lines;
Figure 2 is a sectional view of the microwave antenna of Figure 1, taken along line 2-2;
Figure 3 is a plan view of a planar active phased microwave array constructed using the microwave antenna of the invention;
Figure 4 is a sectional view of the microwave antenna of Figure 3, taken along line 4-4; and
Figure 5 is the circular polarization pattern for an S-band antenna constructed according to the approach of the invention for a range of frequencies of (a) 6.6 GHz, (b) 6.7 GHz, (c) 6.8 GHz, (d) 6.9 GHz, (e) 7.0 GHz, and (f) 7.1 GHz.

DETAILED DESCRIPTION OF THE INVENTION

A microwave antenna 20 according to the present invention is illustrated in Figures 1 and 2 as a cavity-backed cross slot fed by a stripline. The antenna includes a radiating plate 22 in which two intersecting slots 24 and 26 are provided. The slots 24 and 26 are oriented at 90 degrees to each other, and are of different lengths, L1 and L2, respectively. (Equivalently, the two slots 24 and 26 may be characterized as a "cross slot".)

Below the radiating plate 22 is a linear means that cooperates with the radiating plate to produce microwave excitations in the radiating plate. The linear means is preferably a linear conductor 28 separated from and disposed parallel to the radiating plate 22. In operation, a microwave driving signal is applied to the radiating plate 22 and the linear conductor 28, with the result that a microwave is radiated from the radiating plate 22.

A backing plate 30 is separated from and disposed parallel to the radiating plate 22 and the linear conductor 28. Preferably, the linear conductor 28 is symmetrically positioned between the radiating plate 22 and the backing plate 30. The backing plate 30 functions as a ground plane to cause the microwave antenna 20 to radiate only in a single radiating direction 32 rather than in both directions. Energy emitted opposite to the direction 32 is reflected back by the backing plate 30 in the radiating direction 32.

The space between the radiating plate 22 and the backing plate 30 comprises a dielectric 33 may be filled with air as a dielectric. Alternatively, other dielectrics such as other gases, ceramics, or glasses may fill the space between the plates 22 and 30 to alter the emission characteristics of the antenna 20.

In the form of the antenna 20 illustrated in Figures 1 and 2, the radiating plate 22 and the backing plate 30 are conveniently connected by a side plate 34 to form a unitary outer conductor 36 having a circular plan view (Figure 1) and hollow rectangular cross section (Figure 2). The linear conductor 28 thus forms an inner conductor centered within the interior of the outer conductor within the dielectric. This structure, without the slots 24 and 26, may be viewed as a stripline conductor comparable in function with a coaxial conductor.

As shown in Figure 1, the slots 24 and 26 are rotated or tilted through a non-zero angle T from the axis of the linear conductor 28. That is, neither of the slots 24 or 26 may be aligned parallel to the axis of the linear conductor 28. A preferred approach for selecting the angle T and the lengths L1 and L2, to produce a circularly polarized microwave, will be discussed subsequently. However, critical conditions for operability of the antenna are that the slots 24 and 26 are perpendicular to each other when viewed in the plan view of Figure 1, that the slot lengths L1 and L2 are different, and that T is not zero (or 90 degrees, which would align the other slot with the axis of the linear conductor 28).

The operable condition of the antenna 20 to produce circularly polarized microwave radiation is that the real parts of the admittances of the two slots 24 and 26 must be the same, and that the angle of the input admittances differs by 90 degrees. The angle T and the lengths L1 and L2 are adjusted to meet these conditions. To determine these values experimentally, a radiating plate 22 is made with two slots 24 and 26 of unequal length at 90 degrees to each other.

To determine the preferred slot lengths and tilt angle for this structure, one of the slots (illustrated as slot 24) is initially made slightly longer than one-half (for air dielectric) of the wavelength of the intended microwave radiation, and the other of the slots (illustrated as slot 26) is made slightly shorter than one-half of the wavelength of the intended microwave radiation. One of the slots is taped closed, and the radiated microwave energy through the other slot is measured. The first slot is opened, the second slot is taped closed, and the power radiated through the first slot is measured. The total radiated power through a slot depends upon the angle T. The radiating plate 22 is rotated with respect to the axis of the linear conductor 28 and the measurements repeated until the power output of each slot is the same. This fixes the value of T. Studies to date have indicated that T is often about 15 degrees, but there is no such limitation on the invention.

Next, the relative lengths of the slots are adjusted by shortening or lengthening the slot lengths with tape, and measuring the degree of circularity of the polarization of the radiated microwave. The slot lengths are adjusted until the radiated microwave is determined to be circularly polarized. Then the radiated power through each slot is again measured, and the angle T readjusted so that the power radiated through each slot is the same. In practice, the value of T changes little with variations in L1 and L2, and this iterative procedure has converged on the correct values of T, L1, and L2 to produce a circularly polarized radiated microwave in 1 or 2 iterations.

The antenna 20 as described may be used by itself, or as one element of an antenna array 40, as shown in Figures 3 and 4 for a 3 X 3 antenna array. The antennas 20 are arranged on an appropriate grid. Active driving elements 42, such as gallium arsenide integrated circuits used to drive the individual antennas, may be placed between the individual antennas 20. The construction of such active elements for use in driving antenna arrays using other types of microwave radiator antennas is well known in the art.

One potential problem with such an antenna array 40 is internal coupling between the individual antennas 20. Such internal coupling can produce other propagation modes than that intended in the radiated microwave signal. To prevent internal coupling, conducting fences are placed between the individual antennas 20 to prevent signal leakage between the individual antennas. In the preferred embodiment of Figure 2, the side plate 34 which defines the generally circular shape of the antenna 20 when viewed in the plan view of Figure 1, constitutes the required fence that confines the microwave energy to the interior of the outer conductor 36. In the absence of the side plates 34, separate fences may be added to isolate the individual antennas 20 from each other.

The present invention has been implemented as a single element antenna 20 for an S-band (of frequency approximately 7 GHz (Gigahertz)) antenna, and a 2 X 2 antenna array for a K-band (of frequency 20 GHz) antenna. For the S-band antenna, L1 was 2.54 cm (centimeters), L2 was 1.3 cm, and T was 15 degrees. For each of the antenna elements making up the K-band antenna array, L1 was about 0.7 cm, L2 was about 0.33 cm, and T was 15 degrees degrees.

By way of example of the results attained with this approach, Figure 5 is a polarization pattern for the S-band, single element antenna operated at a range of frequencies near 6.9 GHz. The polarization pattern is generally good and indicates nearly perfect circular polarization. Similar results were obtained with the K-band antenna array operated at about 21.8 GHz.

The present invention provides an advance in the art of microwave antennas. The antenna of the present approach is rugged and compact, with no projecting features that can be easily broken. It produces good quality circularly polarized microwave radiation. Although particular embodiments of the invention have been described in detail for purposes of illustration, various modifications may be made without departing from the spirit and scope of the invention. Accordingly, the invention is not to be limited except as by the appended claims.

Claims

1. A microwave antenna, comprising:
   a radiating plate made of an electrically conducting material and having two slots cut therein, the slots being oriented at 90 degrees to each other and being of unequal length; and
   linear means for cooperating with the radiating plate to produce microwave excitations in the radiating plate.

2. The microwave antenna of claim 1, wherein the linear means includes a linear conductor lying parallel to the radiating plate.

3. The microwave antenna of claim 2, wherein the linear conductor is not parallel to either of the slots.

4. The microwave antenna of claim 1, further including a backing plate positioned parallel to and spaced apart from the radiating plate.

5. A microwave antenna, comprising:
   a stripline microwave element including
   an outer conductor having a radiating face and an oppositely disposed backing face,
   an inner linear conductor lying parallel to the radiating face within the outer conductor, and
   a dielectric between the outer conductor and the inner conductor; and
   a pair of slots in the radiating face of the outer conductor, the pair of slots being oriented at 90 degrees to each other and being of unequal length, with neither of the slots parallel to the inner linear conductor.

6. The microwave antenna of claim 5, wherein the dielectric is a nonconducting material other than air.

7. The microwave antenna of claim 5, wherein the slots are of lengths such that the real part of their admittances are equal and the angle of the input admittances differs by 90 degrees.

8. A microwave array antenna, comprising:

a first plurality of radiating elements, each element including

a radiating plate having two slots cut therein, the slots being oriented at 90 degrees to each other and being of unequal length, and

linear means for cooperating with the radiating plate to produce microwave excitations in the radiating plate; and

means for reducing internal coupling between the radiating elements.

9. The microwave antenna of claim 8, wherein the means for reducing internal coupling includes a plurality of fences of conducting material separating the individual radiating elements.

10. The microwave antenna of claim 8, wherein the respective slots of the respective radiating elements are geometrically congruent.

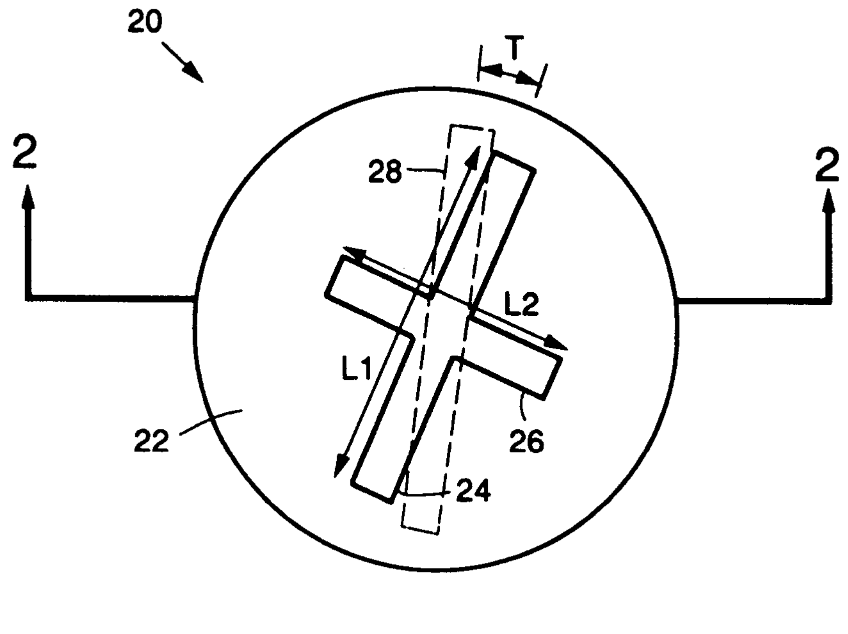
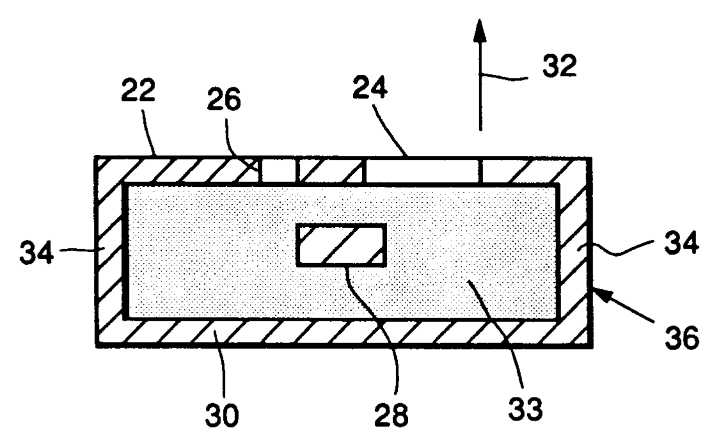


FIG. 1.

FIG. 2.



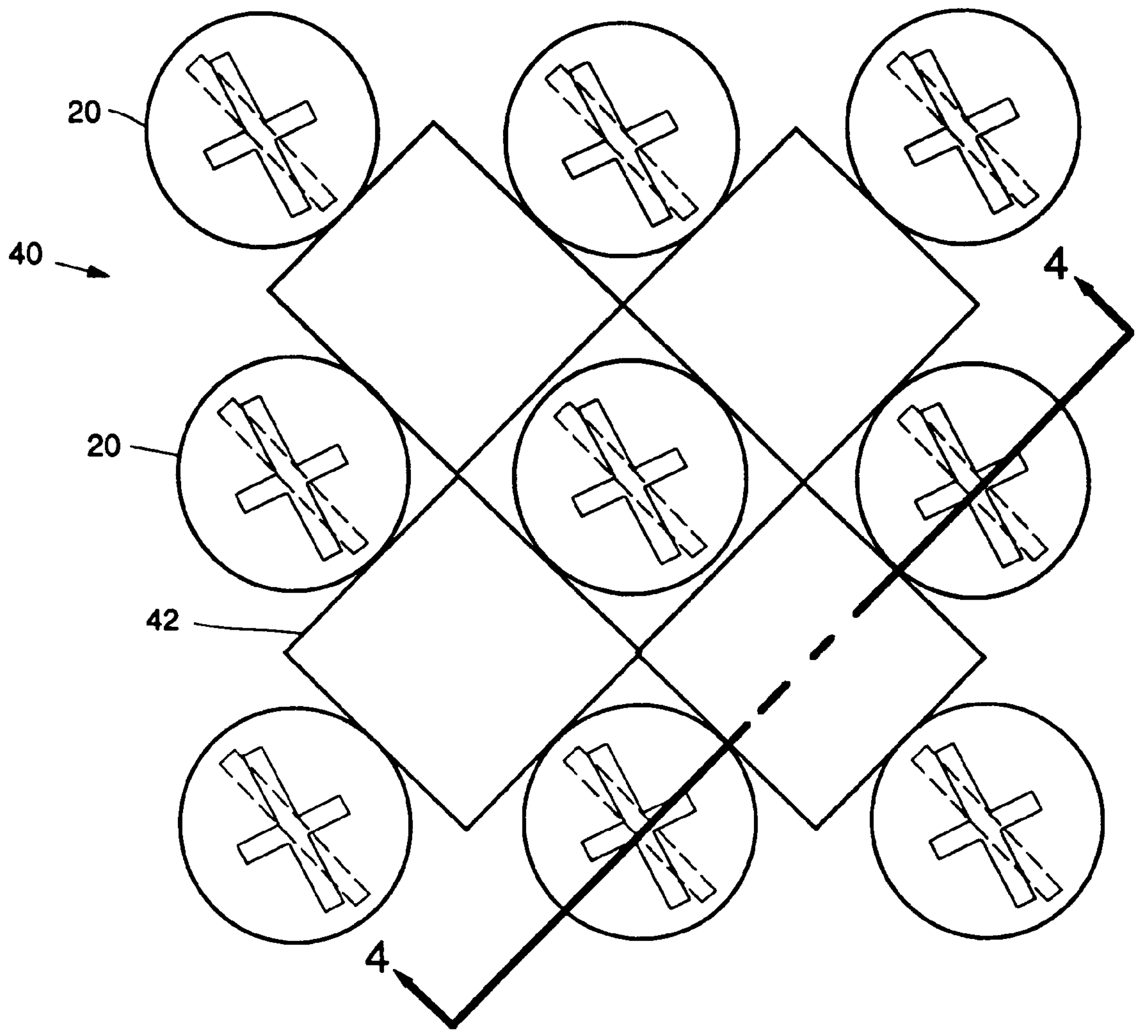
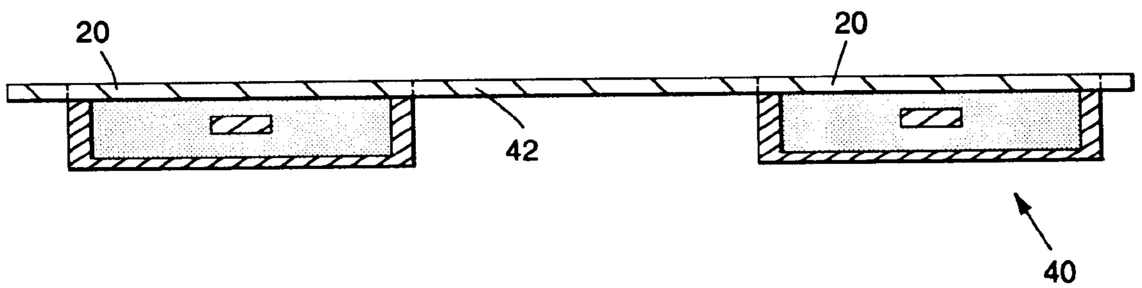


FIG. 3.

FIG. 4.



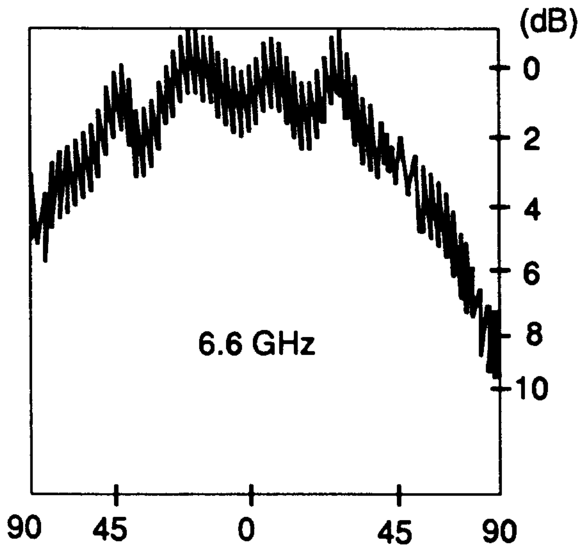


FIG. 5a.

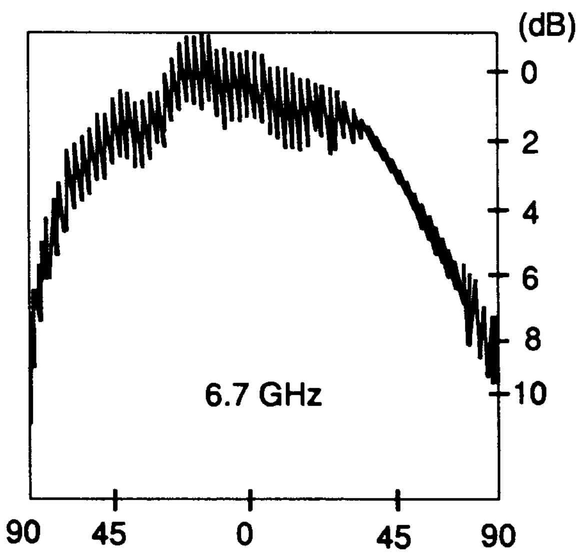


FIG. 5b.

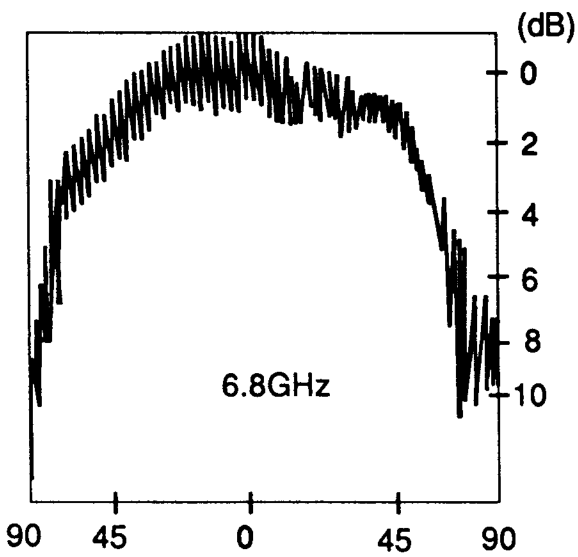


FIG. 5c.

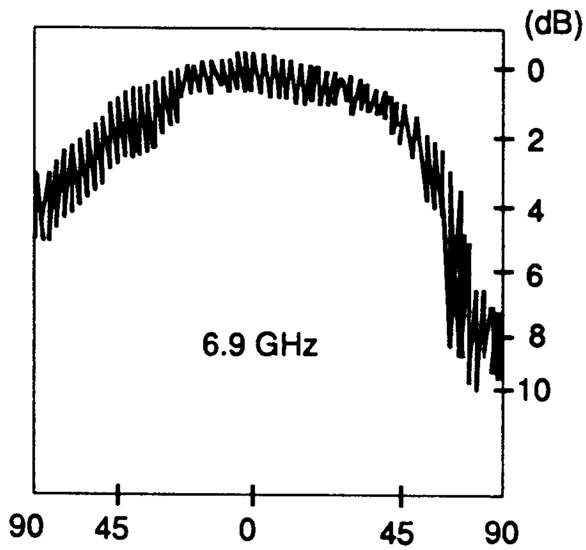


FIG. 5d.

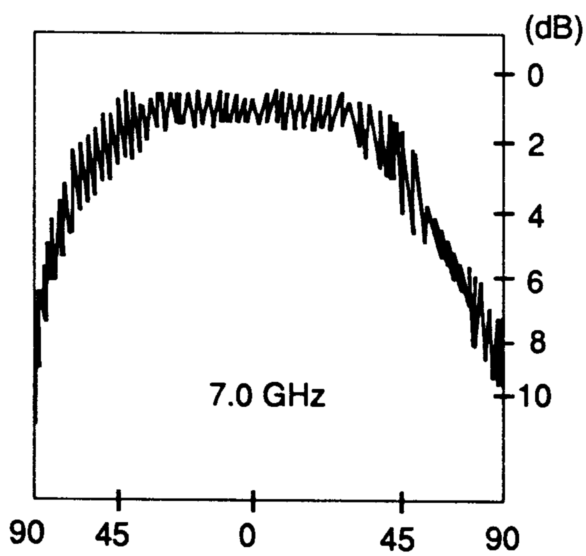


FIG. 5e.

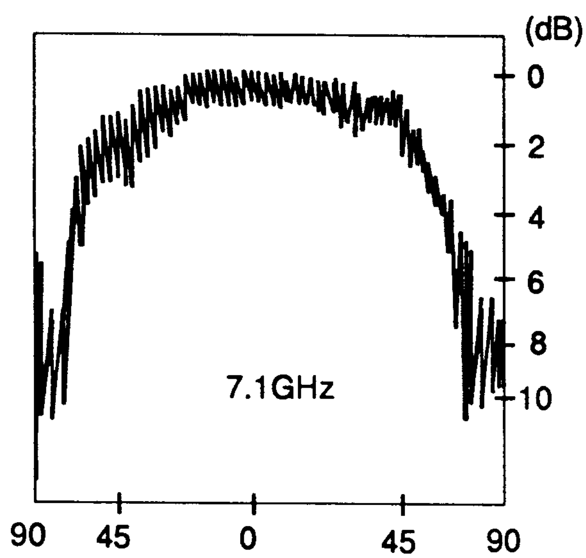


FIG. 5f.

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 93 30 9103

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.5)
X	EP-A-0 295 003 (THORN EMI) * column 5, line 27 - column 6, line 46; claims 1-5; figures 1,2 *	1,5,8	H01Q13/10 H01Q21/00
X	* column 6, line 18 - line 31; figure 5 *	8	
A	US-A-4 242 685 (G. G. SANFORD) * column 2, line 33 - column 3, line 34; figure 1 * & EP-A-0 018 476	1	
P,A	EP-A-0 527 417 (ALCATEL ESPACE) * claim 6; figure 8 *	3	
A	US-A-4 916 457 (WONG FOY ET AL) * column 3, line 50 - column 4, line 57; figures 1-3 *		
A	GB-A-2 251 520 (THOMSON-CSF) * abstract; claim 4; figure 6 *		
A	US-A-4 443 802 (P. E. MAYES) * abstract; figure 4 *		TECHNICAL FIELDS SEARCHED (Int.Cl.5) H01Q

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
BERLIN	22 February 1994	Breusing, J

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
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