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(54) **Thin-structure aerial**

(57) A thin-structure aerial suitable for flush-mounting on the outside of an aircraft comprises a dielectric sheet substrate (1) whose major surfaces are covered with conductive layers (2, 3), the layer (3) on the front surface having at least one radiating slot (4) surrounded by means (5), such as a series of plated-through holes, for simulating lateral conductive walls between the major surfaces. In order to increase the bandwidth over which good matching can be obtained, at least one feed slot (10) is formed in the conductive layer on the front surface, the feed slot (10) being parallel to and near the radiating slot (4).

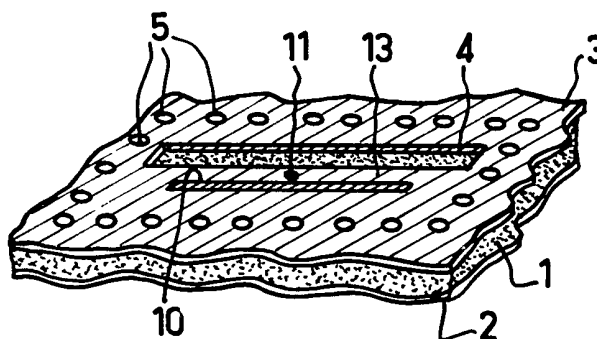


FIG.1

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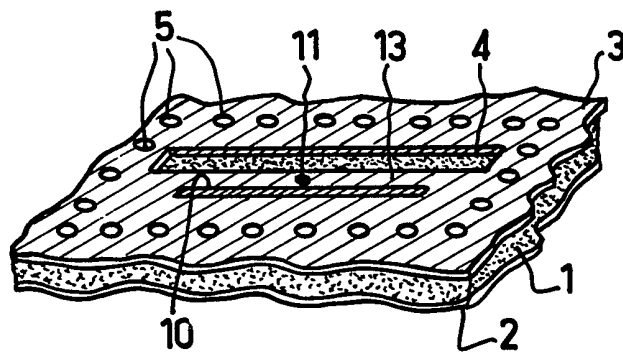


FIG. 1

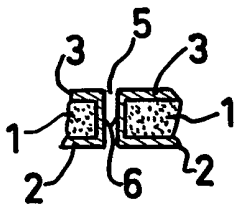


FIG. 2

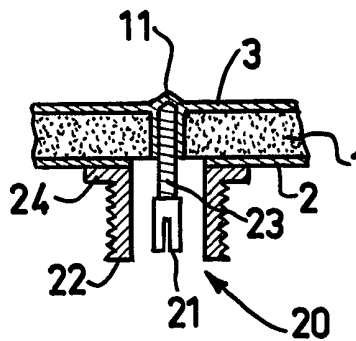


FIG. 3

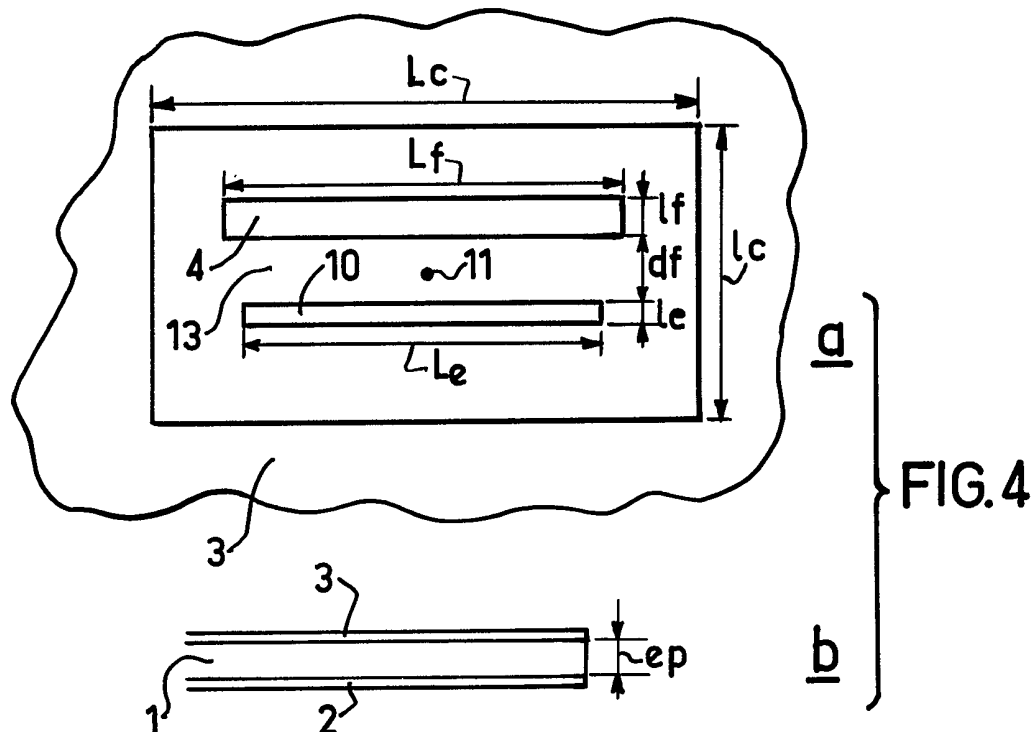


FIG. 4

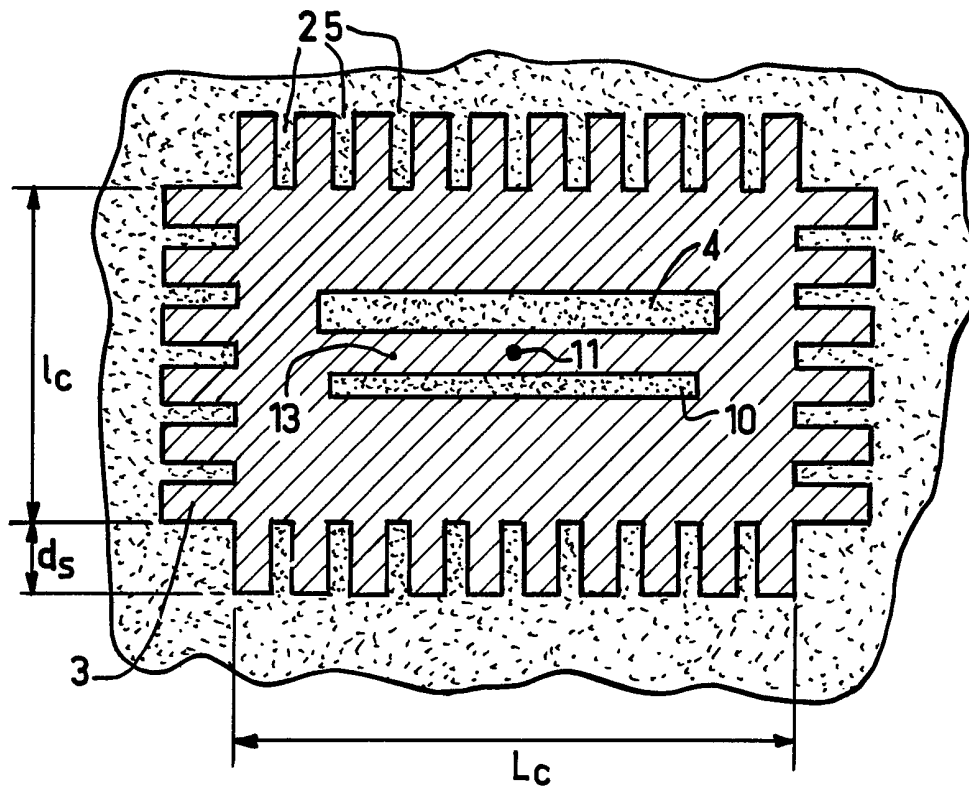


FIG. 5

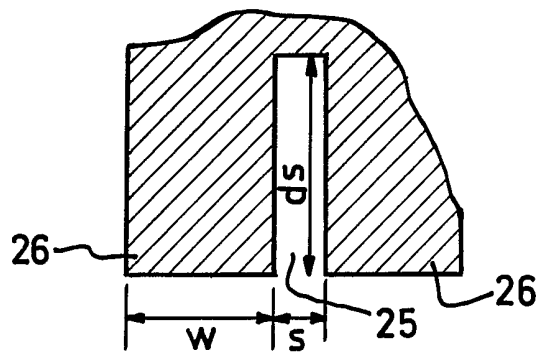


FIG. 6

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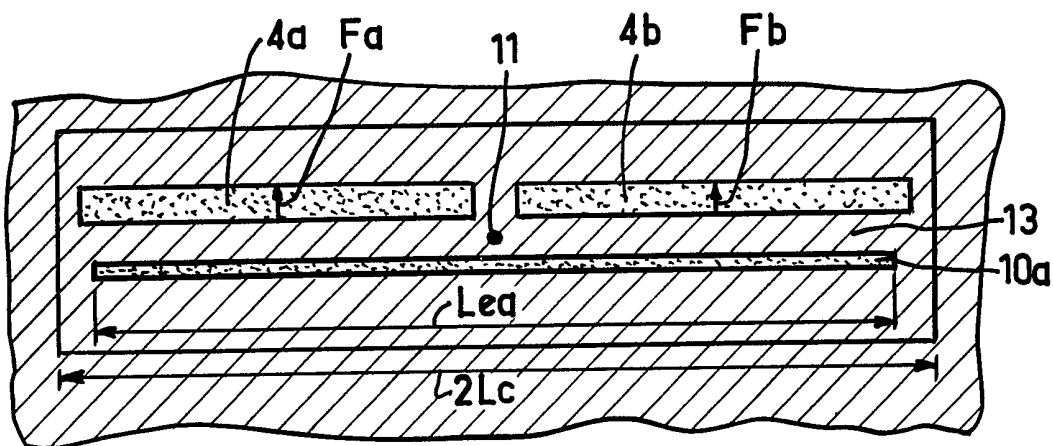


FIG. 7

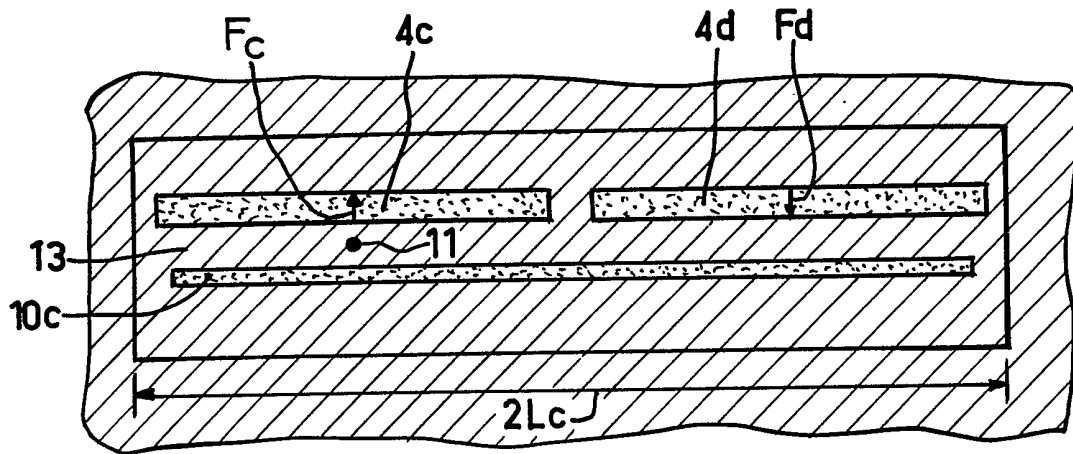


FIG. 8

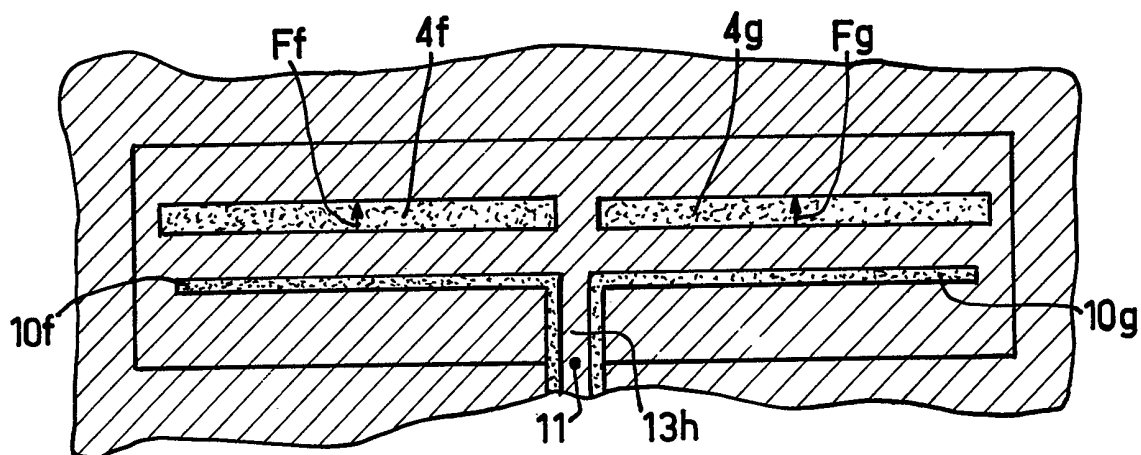


FIG. 9

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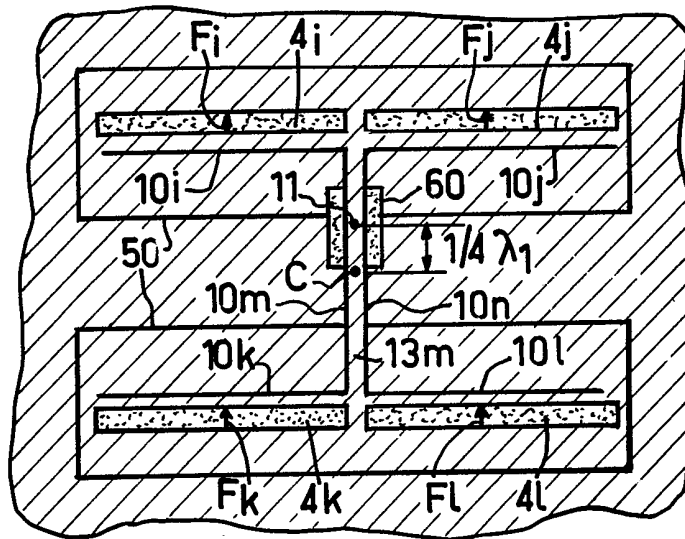


FIG. 10

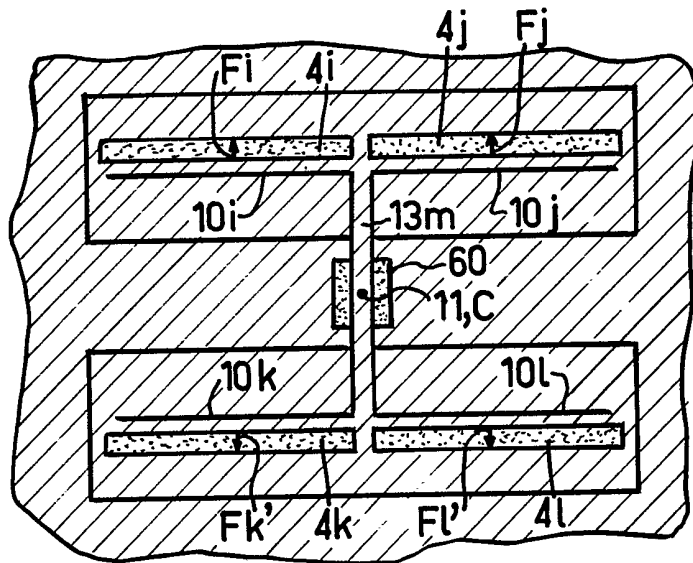


FIG. 11

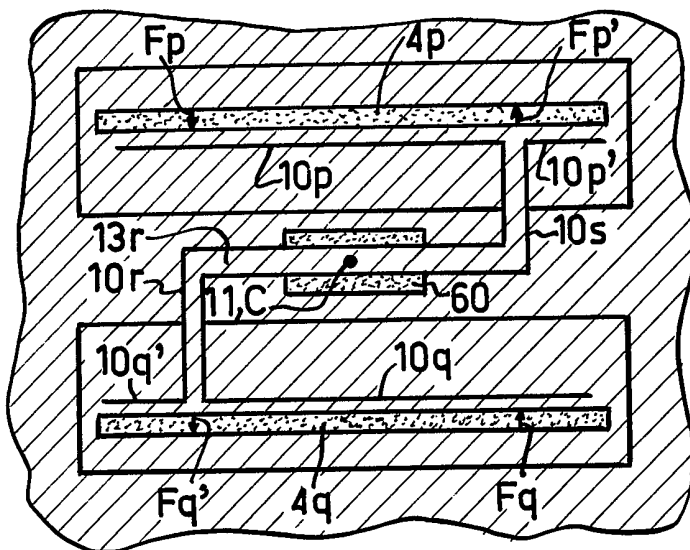


FIG. 12

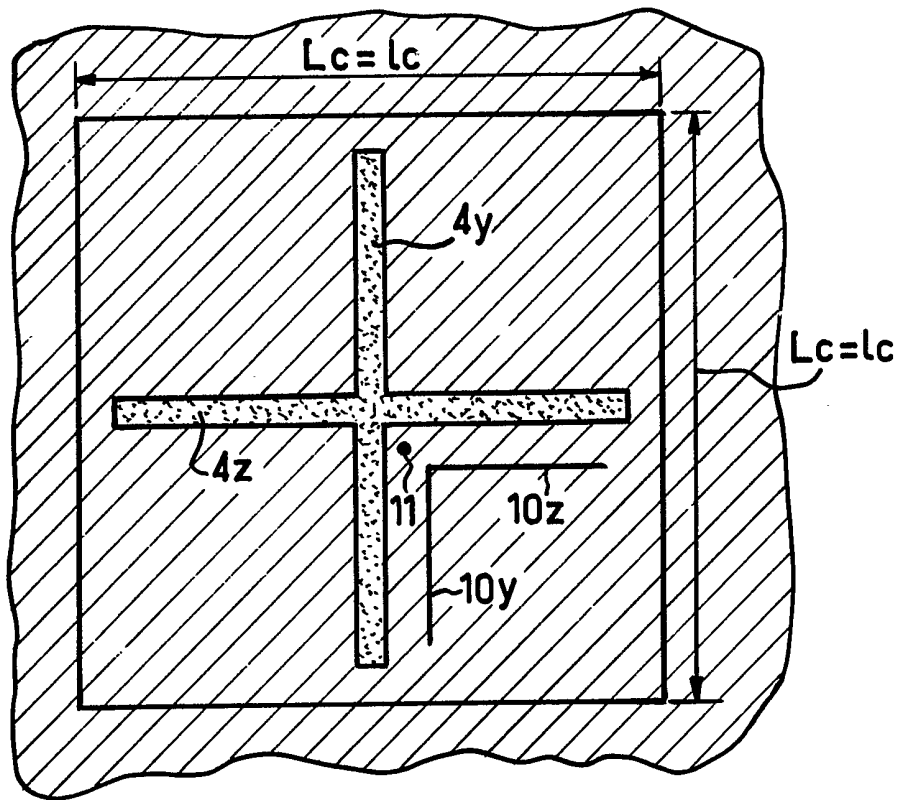


FIG.13

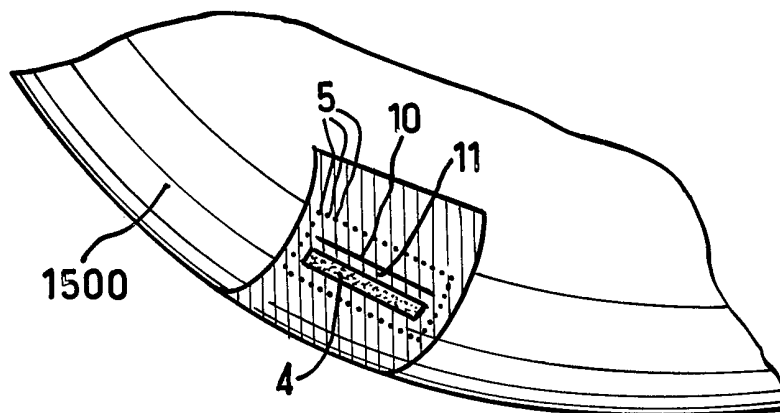


FIG.14

SPECIFICATION

Thin-structure aerial

- 5 The present invention relates to a thin-structure aerial comprising a dielectric sheet substrate having on one major surface a first layer of conductive material and on the other major surface a further layer of conductive material with a radiating slot formed therein and means for simulating lateral conductive walls extending between the conductive layers and surrounding the radiating slot. 5
- Aerials of this type are frequently used, especially for aircraft. Owing to their small thickness, said aerials may be shaped for flush-mounting to any suitable aircraft contour, so that the aerodynamic shape of said aircraft is not affected. 10
- United States Patent Specification No. 4,110,751 describes such an aerial. This known aerial has the drawback that the impedance at its feed connector only has a suitable value for a range of frequency variation which is too narrow for wide-band operation.
- 15 The invention proposes an aerial of the type mentioned in the opening paragraph, which can exhibit good matching over a wide band of substantially 10% of the nominal frequency and which can provide various radiation patterns in conformity with the requirements of the user. According to the invention, an aerial as set forth in the opening paragraph is characterised in that there is provided a feed slot which is formed in said further layer of conductive material on said other major surface and which is disposed parallel to and near the radiating slot. 20
- Said feed slot has a resonant frequency which, in combination with that of the radiating slot and that of the cavity formed by the front surface, the rear surface and the means for simulating lateral walls, yields an extended frequency range over which suitable matching can be obtained.
- The following description of embodiments of the invention with reference to the accompanying drawings, given by way of example, enables the invention to more fully understood. In the drawings:- 25
- Figure 1* represents a first aerial embodying the invention comprising a radiating slot;
- Figure 2* is a detail of the aerial of *Figure 1* and represents a hole used for simulating the lateral walls of the aerial;
- Figure 3* is a detail of the aerial of *Figure 1* and represents the feed arrangement of the aerial;
- 30 *Figures 4a* and *4b* show in plan and in side view respectively various dimensions of the aerial shown in *Figure 1*; 30
- Figure 5* shows a second embodiment of the invention, employing crenellations for simulating the lateral walls;
- Figure 6* represents a crenellation in detail;
- 35 *Figure 7* represents a third embodiment of the invention, comprising two radiating slots which are fed in phase; 35
- Figure 8* represents a fourth embodiment of the invention, comprising two radiating slots fed in phase opposition;
- Figure 9* represents a fifth embodiment of the invention, which is similar to the third embodiment, comprising two radiating slots which are fed in phase, but whose feed point is shifted; 40
- 40 *Figure 10* represents a sixth embodiment of the invention, comprising four radiating slots which are fed in phase;
- Figure 11* represents a seventh embodiment of the invention, comprising four radiating slots, two of which are fed in phase opposition to the other two;
- 45 *Figure 12* represents an eighth embodiment of the invention, comprising two double-length radiation slots fed in phase opposition; 45
- Figure 13* represents a ninth embodiment of the invention, comprising two slots disposed perpendicularly to each other, and
- Figure 14* represents an aerial embodying the invention, which is flush-mounted to an arbitrary contour.
- 50 *Figure 1* is a perspective view of an aerial embodying the invention. This aerial is formed by means of a sheet 1 of a dielectric substrate. A layer 2 of conductive material covers the rear surface of said substrate and a further layer 3 covers the front surface. In said further layer 3 a slot 4 is formed for radiating r.f. power. In accordance with Babinet's principle such a slot will behave as a doublet. In this embodiment the means for simulating the lateral walls are constituted by a series of holes 5. In this way the boundary of the four lateral walls of a parallelepiped cavity is defined, whose fifth wall is constituted by the layer 2 and whose sixth wall is constituted by the layer 3, the radiating slot 4 being parallel to the large side of the rectangle bounded by the holes 5. 55
- Figure 2* shows how said holes are formed. Their interior is covered with a layer 6 of a conductive material, in such a way that the layers 2 and 3 are electrically interconnected. Said holes 5 are disposed sufficiently close to each other to behave as a continuous metal wall at the wavelength of the radiation for which the aerial is designed. 60
- In accordance with the invention, the thin-structure aerial is provided with a feed slot 10 which is formed in said layer 3 of a conductive material covering the front surface and which is disposed parallel to and near the radiating slot 4.
- 65 The aerial of *Figure 1* is fed at a point 11 disposed in the centre of the portion 13 of the conductive material 65

separating the slots 4 and 10. Said centre point substantially corresponds to the point of intersection of the diagonals of the rectangle defined by the holes 5. It is to be noted that said portion 13 constitutes an element of a line of the type known by the name of "coplanar line". Information concerning this type of line will be found in the following publication: MICROWAVE TRANSMISSION LINE IMPEDANCE DATA by M.A.R.

5 GUNSTON, VAN NOSTRAND Reinhold Cy, LONDON. 5

Hereinafter this type of line will be referred to as: "coplanar line".

Figure 3 shows as an example how a connection may be made to the feed point 11 by means of a coaxial socket 20 comprising a pin 21 which has a blind bore and which is surrounded by a metal part 22 formed with an external screw-thread, enabling a standard coaxial plug to be fitted. A pin 23 in line with and supporting
10 the pin contact 21 connects the latter to point 11 on the layer 3. The part 22 has a flange 24 connected to the layer 2. 10

In Figure 4 various dimensions are indicated which are of importance for the design of an aerial in accordance with the invention. These quantities depend on the nominal operating frequency F_0 .

" L_c " is the length of the cavity and " l_c " its width. For reasons of simplicity the boundaries of the cavity are
15 represented by solid lines. 15

" e_p " is the thickness of the cavity, that is the thickness of the substrate 1.

" L_f " and " l_f " respectively are the length and the width of the radiating slot 4.

" L_e " and " l_e " are the length and width of the feed slot 10.

" ϵ_r " is the dielectric constant of the substrate 1.

20 " df " is the distance between the slots 10 and 4. 20

The point 11 in the centre of the portion 13 is disposed at the intersection of the diagonals (not shown) of the rectangle $L_c \times l_c$.

The frequency F_0 corresponds to a wavelength λ_0 :

25 (1) $\lambda_0 = c/F_0$, where c is the velocity of light. 25

When a waveguide is considered which is filled with a dielectric whose dielectric constant is ϵ_r and whose transverse dimensions are " l_c " and " e_p ", the wavelength of the guided wave g in the fundamental mode is:

30 (2) $\lambda_g = \lambda_0 / \sqrt{\epsilon_r - (\lambda_0/2 l_c)^2}$ 30

The requirement for resonance of the cavity is:

(3) $L_c = k_1 (\lambda_g/2)$ 35

On the other hand, the elementary aerial corresponds to a resonant slot of length $k_2 (\lambda_0/2)$, which implies:

(4) $L_c \approx k_2 (\lambda_0/2)$ 40

40 k_1 and k_2 being positive integers. 40

With the aid of equation (2) it is found that for the fundamental mode, i.e. $k_1 = k_2 = 1$,

(5) $l_c = \lambda_0/2 \sqrt{\epsilon_r - 1}$ 45

The resonant frequency is related to the cavity parameters by the equation:

(6) $F_0 = c \sqrt{[1 + (L_c/l_c)^2] / 2 L_c \epsilon_r}$ 50

50 On the other hand, the portion 13, as already stated, constitutes a coplanar line. With this type of line the impedance calculations and the calculations of the velocity propagation should allow for a fictitious dielectric constant ϵ_f , whose value is: 50

(7) $\epsilon_f = (\epsilon_r + 1)/2$ 55

Thus, the resonant frequency F_1 of the coplanar line portion is equal to:

(8) $F_1 = (c/L_e) \sqrt{[2/(\epsilon_r + 1)]}$ 60

60 Finally, the resonant frequency F_2 of the radiating slot 4 is: 60

(9) $F_2 = c/(2L_f)$.

Thus, it will be evident that the aerial has three resonant frequencies.

the first one is that of the parallelepiped cavity; the value of this first frequency is given by formula (6).
 the second one is that of the coplanar line; it is given by formula (8).
 the third one is that of the radiating slot 4 and it is in conformity with formula (9).

- 5 The other parameters which do not occur in the above formulas *inter alia* define the coupling coefficients of these different resonators. By varying all the parameters, it is possible to obtain a comparatively wide frequency band over which a satisfactory matching is obtained. 5

The Applicant has found that for an aerial whose parameters have the following values:

- 10 $L_c = 36 \text{ mm}$ 10
 $l_c = 18.5 \text{ mm}$
 $L_f = 35 \text{ mm}$
 $L_e = 21 \text{ mm}$
 $l_e = 0.15 \text{ mm}$
 15 $d_f = 2 \text{ mm}$ 15
 $e_p = 3 \text{ mm}$
 $\epsilon_r = 4.5 \text{ mm (epoxy-glass)}$

- a standing-wave ratio smaller than or equal to 2 is obtained for a frequency from 4.1 GHz to 4.5 GHz.
 20 Starting from the basic structure of the aerial described, it is possible to realize several variants within the scope of the invention. Thus, the means for simulating the lateral walls may be realized in a manner other than that indicated for the aerial of Figure 1. It is evident that said means may be constituted by conductive sheets. Particularly advantageous means are used for the aerial of Figure 5: said means are easy-to-realize, whilst for the remainder said aerial is identical to that of Figure 1. In order to define the lateral walls of the
 25 aerial of Figure 5, there are provided (as shown in greater detail in Figure 6) crenellations 25 situated between solid portions 26 which form part of the metal layer 3 deposited on the front surface of the aerial. The overall dimensions of the conductive layer are then: $(L_c + 2ds) \times (l_c + 2ds)$ where "ds" is the depth of the crenellation. 25

- Said solid portions in combination with layer 2 form microstrip lines. By a suitable choice of the value "ds" an impedance of substantially zero is obtained at the bottom of the crenellations. Said impedance will more closely approximate to zero as the width w of the solid portion (see Figure 6) becomes greater relative to the thickness "ep" of the dielectric substrate. For this subject reference is made to the said publication by GUNSTON and more particularly to sections 3.6 and 6.3. With respect to determining the value "ds" this value should be such that:
 30 30

- 35 $ds = \lambda_{\mu}/4$ 35

λ_{μ} being the wavelength in the microstrip lines.

- Figure 7 shows another aerial embodying the invention. This aerial comprises two radiating slots 4a and 4b arranged in line with each other and a rectilinear feed slot 10a disposed parallel to the slots 4a and 4b; the
 40 feed point 11 is disposed in the centre of the portion 13 of the layer of a conductive material, which portion separates the slots 4a and 4b from the slot 10a. The cavity which is bounded by solid lines in said Figure has the dimensions "lc", $2L_c$ and a depth: "ep". This means that a cavity is obtained which is two times as long as that of the aerial of Figure 1. The slots 4a and 4b have the same length as the slot 4. The slot 10a has a
 45 length "Lea" whose order of magnitude is $2 \times L_f$. 45

In this embodiment the slots 4a and 4b are fed in phase, which is schematically represented by the arrows Fa and Fb, which point upwards in the Figure. In this case the maximum radiation is obtained in a direction perpendicular to the front surface of the aerial.

- The aerial shown in Figure 8 has a radiation pattern which differs from that of the aerial of Figure 7.
 50 Although the aerial of Figure 8 has slots 4c, 4d and 10c which are arranged and dimensioned identically to those of Figure 7, the radiating slots are energized in phase opposition, which is indicated by the arrow Fc relating to the slot 4c and pointing upwards in the Figure and by the arrow Fd relating to the slot 4d and pointing downwards. The energization in phase opposition is obtained by the special arrangement of the feed point 11, which is disposed in the centre of the portion 13 between the slot 4c and the slot 10c. This
 55 arrangement promotes an asymmetrical distribution of the electric field inside the cavity. The cavity is then excited in the $H_{1,0,2}$ mode and the radiation pattern of the aerial of Figure 8 will exhibit a radiation minimum in the direction in which the aerial of Figure 7 exhibits a maximum. 55

- Figure 9 shows another embodiment of the invention. This aerial has two radiation slots 4f and 4g. Each of said slots is associated with a feed slot 10f and 10g respectively. The feed point 11 is disposed on a coplanar line formed by a conductive portion 13h disposed perpendicularly to the aligned slots 4f and 4g and bounded
 60 by the two feed slots 10f and 10g. The feed slots 10f and 10g may extend (downwards in the Figure) beyond the feed point 11, ending to provide the coplanar line with a short-circuit termination at a distance from point 11 such that the impedance of the coplanar line at point 11 is appropriate for a feeder connected to that point. The radiating slots 4f and 4g are thus excited in phase which is indicated by the arrows Ff and Fg, which point
 65 upwards in the Figure. The radiation pattern is therefore identical to that of the aerial of Figure 7. 65

Figure 10 represents a preferred embodiment of the invention. This aerial comprises four radiating slots 4i, 4j, 4k and 4l; the slots 4i and 4j, which are arranged in line with each other, are surrounded by lateral walls or equivalent means (holes or crenellations) arranged in accordance with a rectangle. The slots 4k and 4l, which are also arranged in line with each other, are surrounded in a similar manner. The slots 4k and 4l are arranged underneath (as drawn) the slots 4i and 4j. Associated with said four slots are four feed slots 10i, 10j, 10k and 10l, which are respectively disposed underneath (as drawn), the radiating slots. (In this and the succeeding Figures, each feed slot is mainly depicted by a solid line.) The slots 10i and 10k are connected by a slot 10m, which is perpendicular thereto and the slots 10j and 10l are similarly interconnected by a slot 10n. The feed 11 point is shifted relative to the centre C of a conductive portion 13m situated between the slots 10m and 10n. The off-centre distance is chosen to equal $\lambda_1/4$, λ_1 being the wavelength guided in the coplanar line, so that a phase lead of 180° is introduced between the energizing voltages of the slots 10i and 10j on the one hand and those of the slots 10k and 10l on the other hand. When allowance is made for the geometry of the coplanar lines, this results in an in-phase energization of the four radiating slots 4i, 4j, 4k and 4l, which is indicated by the arrows Fi, Fj, Fk and Fl in the respective slots 4i, 4j, 4k and 4l, which arrows all point upwards in the Figure. Thus, a radiation pattern is obtained having a maximum in a direction perpendicular to the front surface in the Figure. In order to obtain suitable matching, there is provided a pair of quarter-wave transformers 60. Said pair of transformers is constituted by a widening of the slots 10m and 10n over a length which is equal to a quarter of the wavelength in the coplanar line measured from the feed point 11. This widening is such that said coplanar line section then has a characteristic impedance equal to the geometric mean of the impedance to be matched and the desired impedance on point 11. Although the use of a quarter-wave line for matching is well-known in the art, it is to be noted that its use is particularly suitable for the aerial of Figure 10, because no additional material is required.

The aerial shown in Figure 11 is constructed in the same way as that of Figure 10, except that the feed point 11 is disposed in the centre of symmetry C of the aerial. Thus, an anti-phase feed is obtained between the slots 4i and 4j, and the slots 4k and 4l. The arrows Fk' and Fl' consequently have a direction which differs from that of the arrows Fk and Fl of Figure 10. This results in a radiation pattern which cancels itself in the plane of symmetry perpendicular to the electric field whose direction is indicated by the arrows Fi, Fj, Fk', Fl'. On opposite sides of said plane the value of the radiated field is of opposite sign.

The aerial of Figure 12 has two slots 4p and 4q disposed parallel to each other. Said slots have a length which is two times that of the preceding one, in such a way that the first half of the aerial radiates in phase opposition with respect to the second half; for the slot 4p this is indicated by the arrows Fp and Rp', which are directed oppositely, and for the slot 4q by the arrows Fq and Fq', which are also directed oppositely. Moreover, the arrows Fp and Fq have opposite directions. Associated with the slot 4p is a parallel feed slot formed by two portions 10p and 10' and with the slot 4q a feed slot formed by the portions 10q and 10q'. The slots 10p and 10q' are interconnected by slot 10r in the form of a staircase. Said slot joins the slots 10p and 10q' at right angles. In a similar way the slots 10p' and 10q are interconnected by a slot 10s, which is arranged parallel to the slot 10r. The conductive portion 13r situated between the two slots 10r and 10s comprises a portion parallel to the feed slots 10p and 10q, the feed point 11 being disposed in the centre of said portion, which in this case coincides with the centre of symmetry C of the aerial. In this case there is also provided a quarter-wave transformer 60. The radiation pattern cancels itself in the plane of symmetry which passes through point C and which is parallel to the directions given by the arrows Fp, Fp', Fq, Fq'. The radiated field is of opposite sign on opposite sides of said plane. With respect to polarity the aerial of Figure 12 is the complement of that of Figure 8.

Figure 13 shows an interesting aerial in accordance with the invention. Here, use is made of a dielectric substrate whose dielectric constant is chosen so that $L_c = l_c = \lambda_0/2$, allowance being made for the aerial dimensions. Thus, radiating slots can be obtained in two orthogonal directions, that is the slots 4y and 4z. In order to excite said slots two feed slots 10y and 10z are disposed parallel to the radiating slots. These slots are interconnected arranging the feed point 11 near said interconnection and by selecting different lengths for said slots in such a way that the energization of the slots 4y and 4z is in phase quadrature, a circularly polarized radiation field is obtained.

Figure 14 by way of example represents the manner in which an aerial in accordance with the invention, for example the aerial of Figure 1, can be flush-mounted to the curved contour 1500 of, specifically, an aircraft.

55 CLAIMS

1. A thin-structure aerial comprising a dielectric sheet substrate having on one major surface a first layer of conductive material and on the other major surface a further layer of conductive material with a radiating slot formed therein and means for simulating lateral conductive walls extending between the conductive layers and surrounding the radiating slot, characterised in that there is provided a feed slot which is formed in said further layer of conductive material on said other major surface and which is disposed parallel to and near the radiating slot.

2. A thin-structure aerial as claimed in Claim 1, characterised in that the means for simulating lateral walls comprise conductive sheets which interconnect the layers of conductive material on the major surfaces.

3. A thin-structure aerial as claimed in Claim 1, characterised in that the means for simulating lateral walls comprise holes which extend through the substrate from one major surface to the other and the walls of which are covered by a layer of conductive material interconnecting the layers on the major surfaces.
4. A thin-structure aerial as claimed in Claim 1, characterised in that the means for simulating lateral walls comprise crenellations formed between solid portions in the periphery of said further layer, the depth of the crenellations being such that an impedance of substantially zero is obtained at the bottom of said crenellation. 5
5. A thin-structure aerial as claimed in any of Claims 1 to 4, characterised in that a feed point is arranged in the portion of the further layer of conductive material between the radiating slot and the feed slot.
- 10 6. A thin-structure aerial as claimed in any of Claims 1 to 4, characterised in that a feed point is disposed on a coplanar line connecting it to the feed slot. 10
7. A thin-structure aerial as claimed in Claim 5 or 6, characterised in that it comprises adjacent the feed point a coaxial connector on said one major surface, a central contact pin thereof being connected to the feed point and an outer conductor thereof being connected by a flange to the first layer of conductive material.
- 15 8. A thin-structure aerial as claimed in any of Claims 1 to 7, adapted to radiate a circulatory polarized wave, characterised in that it comprises two radiating slots disposed perpendicularly to each other with respective feed slots and in that lengths of the feed slots are selected so as to obtain phase-quadrature energization of the two radiating slots. 15
9. An aerial substantially as herein described with reference to Figures 1 and 4 or Figures 5 and 6 or to any of Figures 7 to 13 of the accompanying drawings. 20