

EXHIBIT C

U.S. Patent No. 6,317,083



US006317083B1

(12) **United States Patent**
Johnson et al.

(10) **Patent No.:** **US 6,317,083 B1**
(45) **Date of Patent:** **Nov. 13, 2001**

(54) **ANTENNA HAVING A FEED AND A SHORTING POST CONNECTED BETWEEN REFERENCE PLANE AND PLANAR CONDUCTOR INTERACTING TO FORM A TRANSMISSION LINE**

5,268,702	12/1993	Amano .	
5,631,660	5/1997	Higashiguchi .	
5,764,190	*	6/1998 Murch et al.	343/702
5,896,109	*	4/1999 Hachiga et al.	343/702
6,034,636	*	3/2000 Saitoh	343/700 MS
6,081,728	*	6/2000 Stein et al.	455/523

(75) Inventors: **Alan Johnson**, Camberley; **Joseph Modro**, Hants, both of (GB)

FOREIGN PATENT DOCUMENTS

(73) Assignee: **Nokia Mobile Phones Limited**, Espoo (FI)

720252A1	7/1996	(EP) .
2191045A	12/1987	(GB) .

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

* cited by examiner

(21) Appl. No.: **09/355,019**

Primary Examiner—Don Wong

(22) Filed: **Jul. 16, 1999**

Assistant Examiner—Ephrem Alemu

Related U.S. Application Data

(74) *Attorney, Agent, or Firm*—Antonelli, Terry, Stout & Kraus, LLP

(63) Continuation of application No. PCT/EP99/03715, filed on May 28, 1998.

(57) **ABSTRACT**

(30) **Foreign Application Priority Data**

An antenna comprises a reference plane **204**, a conductive polygonal lamina **202** disposed opposing the reference plane, and a feed section **206** coupled to the reference plane and the lamina. The feed section **206** is arranged as a transmission line. The feed section may comprise at least two planar conductors **208** arranged parallel to each other, one of the planar conductors **208b** being connected to the feed and the other of the conductors **208a** being connected to the reference. The feed section may be in the form of a coplanar strip.

May 29, 1998 (GB) 116692/98

(51) **Int. Cl.⁷** **H01Q 1/38**

(52) **U.S. Cl.** **343/700 MS; 343/702; 343/846**

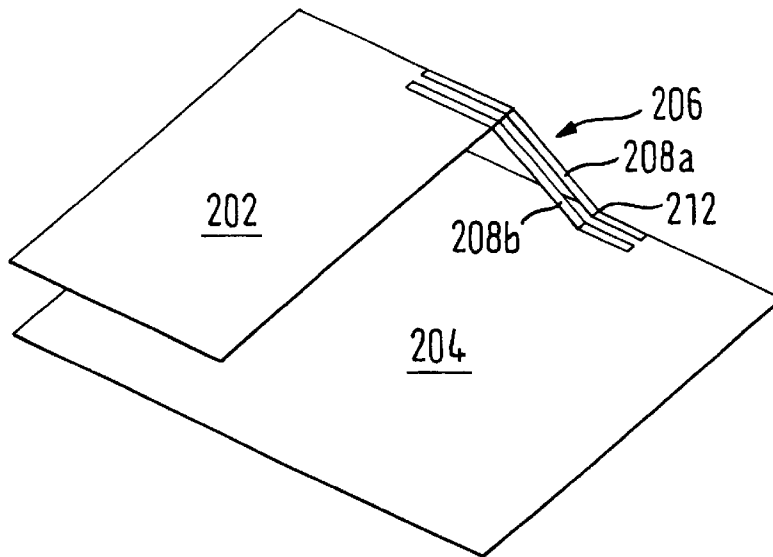
(58) **Field of Search** 343/829, 830, 343/846, 700 MS, 702

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,701,763 * 10/1987 Yamamoto et al. 343/700 MS

25 Claims, 4 Drawing Sheets



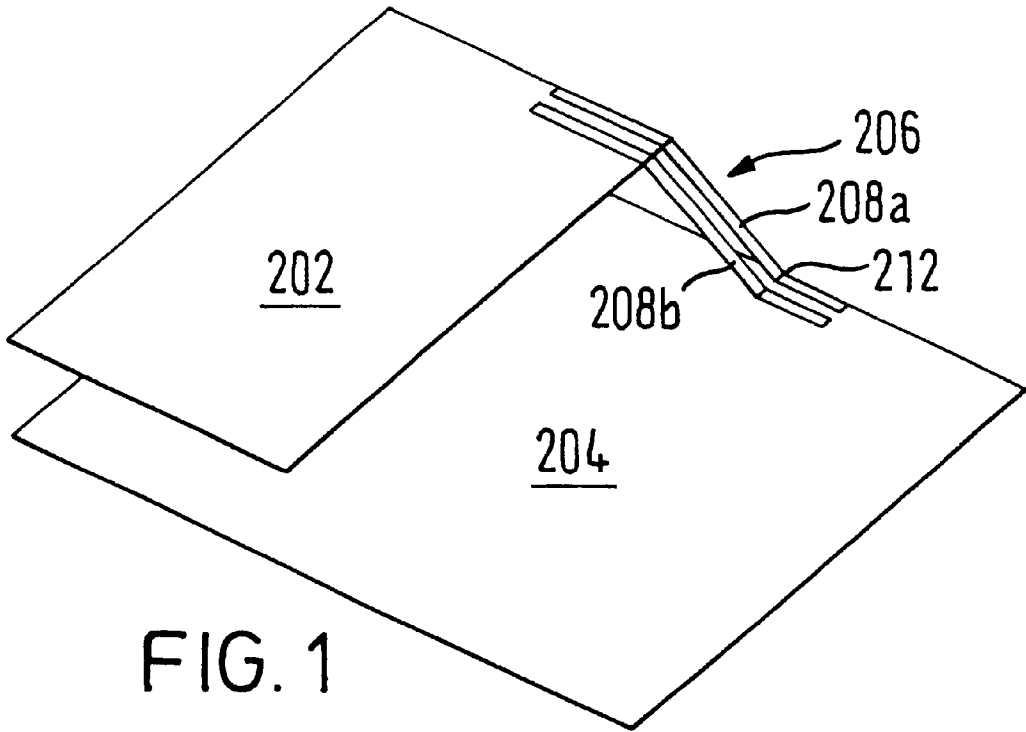


FIG. 1

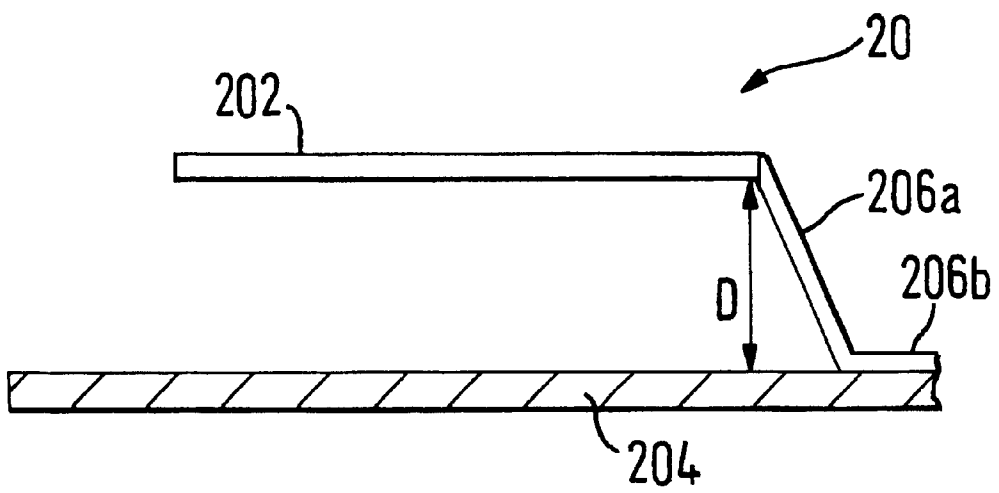


FIG. 2

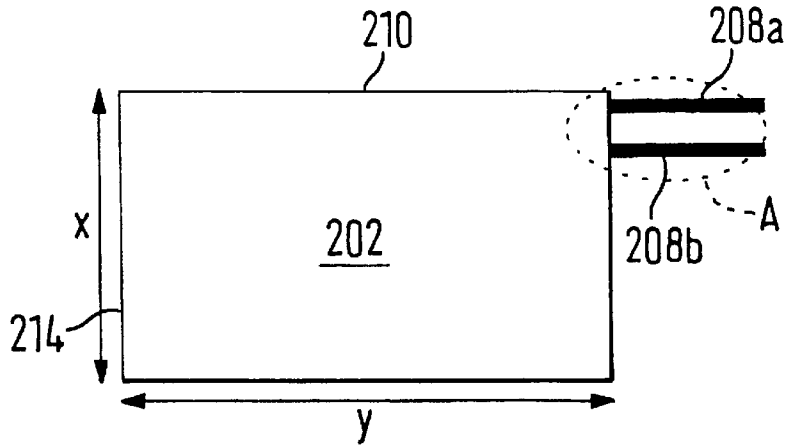


FIG. 3

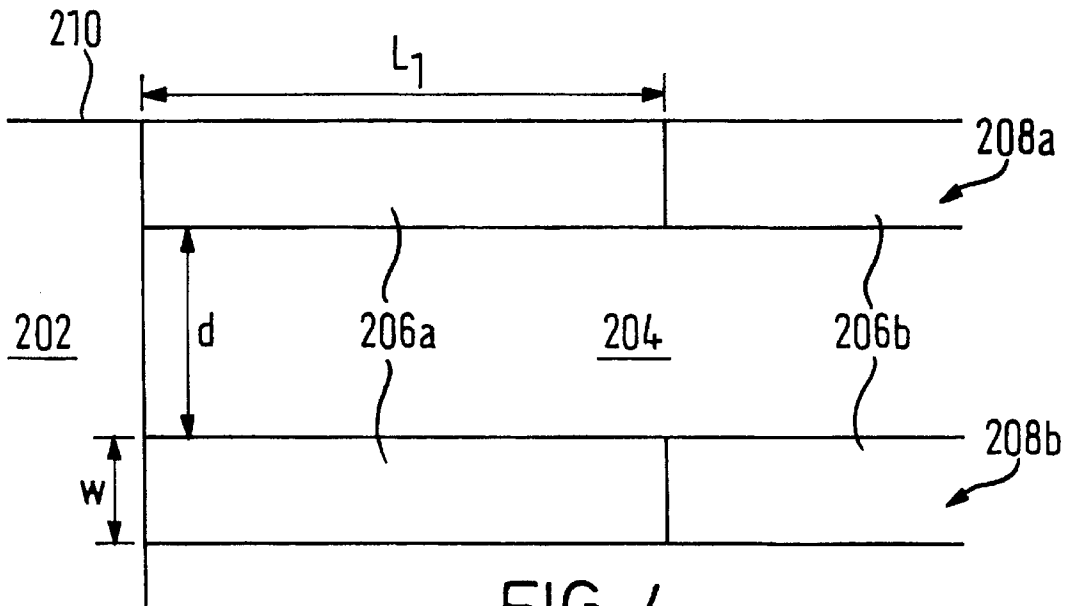


FIG. 4

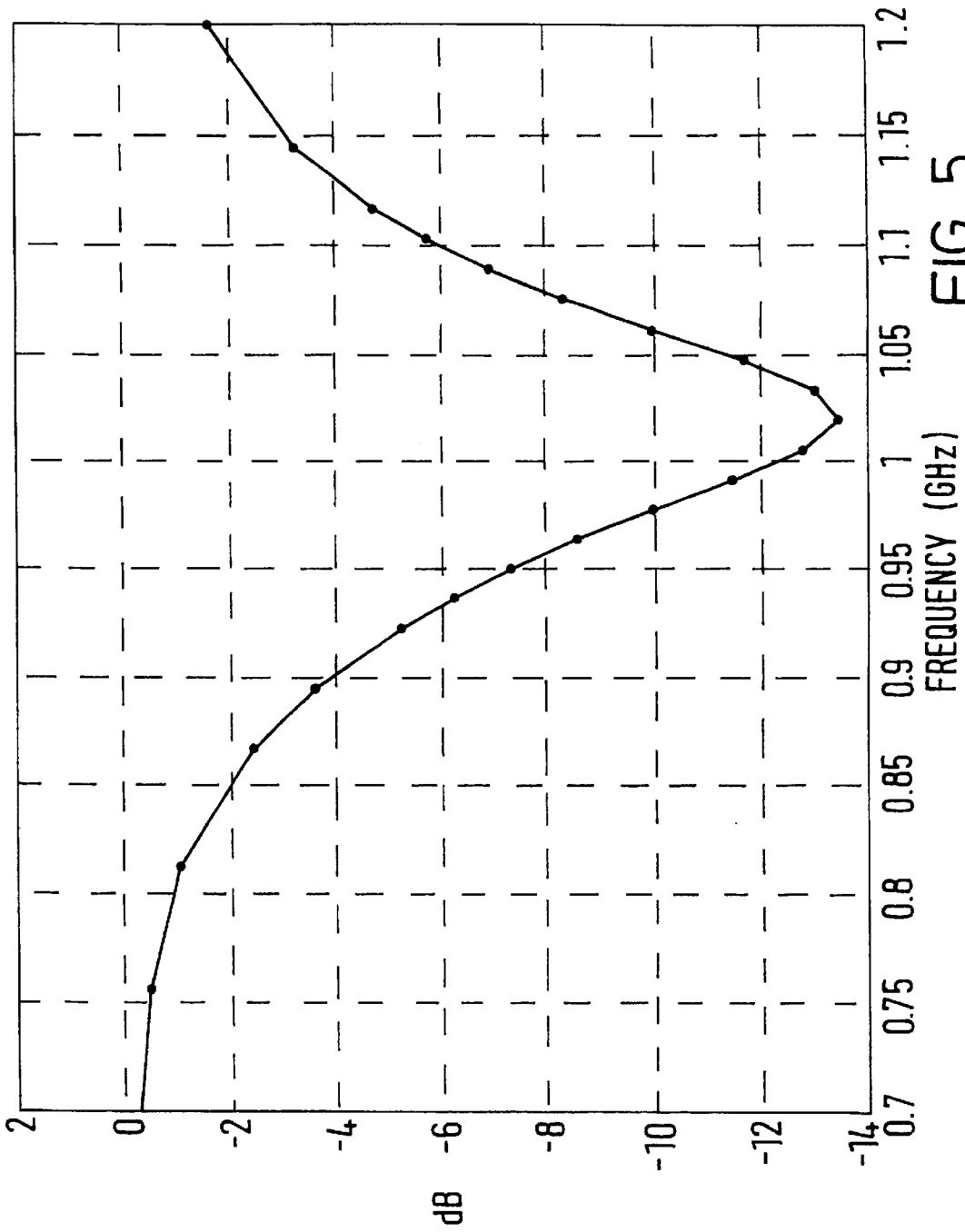


FIG. 5

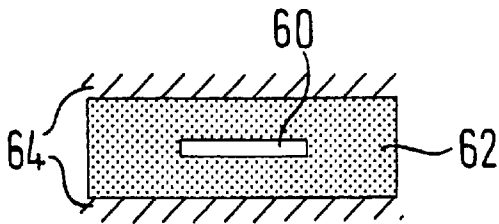


FIG. 6(a)

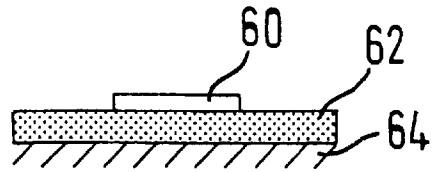


FIG. 6(b)

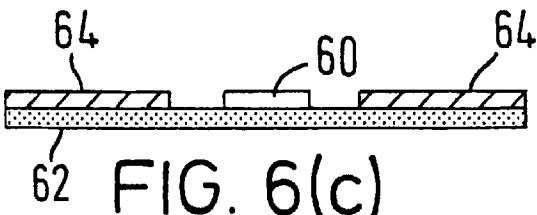


FIG. 6(c)

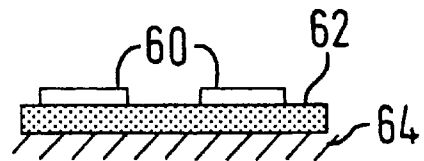


FIG. 6(d)

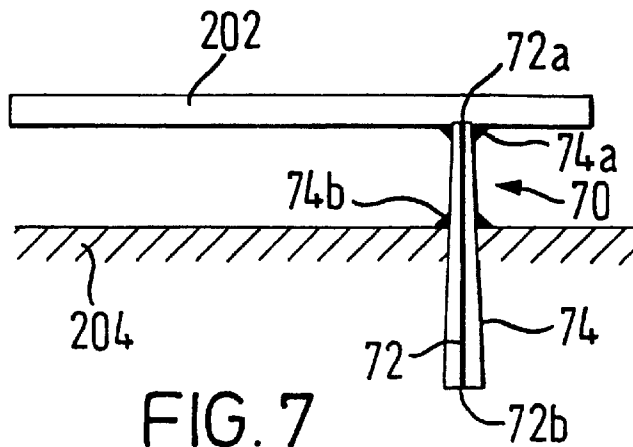
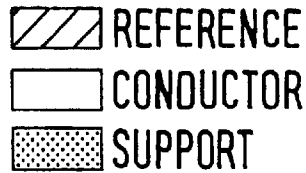


FIG. 7

**ANTENNA HAVING A FEED AND A
SHORTING POST CONNECTED BETWEEN
REFERENCE PLANE AND PLANAR
CONDUCTOR INTERACTING TO FORM A
TRANSMISSION LINE**

This is a Continuation of International Application PCT EP99/03715, with an international filing date of May 28, 1998.

This invention relates to antennas and in particular to flat plate or planar antennas.

As electronics and communications technologies have advanced, there has been a drive to increase the performance and decrease the size of consumer devices. In particular, in the field of mobile communications, there has been continual demand for increasingly smaller communications devices, such as telephones, computers and personal organisers, but without a decrease in performance.

One area in which size and weight design goals may be counter to performance design goals is in the design of antennas. The performance of an antenna can be measured by various parameters such as gain, specific absorption rate (SAR), impedance bandwidth and input impedance. Conventionally, mobile telephones have been provided with a rod antenna. These provide good performance relative to cost. However, since the antennas extend from the housing of the device, they are prone to breakage. Furthermore, as the size of a rod antenna decreases, the gain also decreases which is undesirable. As communication devices become smaller, rod antennas are therefore unlikely to provide a convenient antenna solution.

It is desirable therefore to develop an antenna which could be located within the device. An example of such an antenna is a flat plate or low profile antenna such as planar inverted-F antennas (PIFAs) which are well known in antenna art. A PIFA comprises a flat conductive sheet supported a height above a reference voltage plane such as a ground plane. The sheet may be separated from the reference voltage plane by an air dielectric or supported by a solid dielectric. A corner of the sheet is coupled to the ground via a grounding stub and provides an inductive load to the sheet. The sheet is designed to have an electrical length of $\pi/4$ at the desired operating frequency. A feed is coupled to an edge of the flat sheet adjacent the grounded corner. The feed may comprise the inner conductor of a coaxial line. The outer conductor of the coaxial line terminates on and is coupled to the ground plane. The inner conductor extends through the ground plane, through the dielectric (if present) and to the radiating sheet. As such the feed is shielded by the outer conductor as far as the ground plane but then extends, unshielded, to the radiating sheet.

The PIFA forms a resonant circuit having a capacitance and inductance per unit length. The feed point is positioned on the sheet a distance from the corner such that the impedance of the antenna at that point matches the output impedance of the feed line, which is typically 50 ohms. The main mode of resonance for the PIFA is between the short circuit and the open circuit edge. Thus the resonant frequency supported by the PIFA is dependent on the length of the sides of the sheet and to a lesser extent the distance and the thickness of the sheet.

Planar inverted-F antennas have found particular applications in portable radio devices, e.g. radio telephones, personal organisers and laptop computers. Their high gain and omni-directional radiation patterns are particularly suitable. Planar antennas are also suitable for applications where good frequency selectivity is required. Additionally, since

the antennas are relatively small at radio frequencies, the antennas can be incorporated into the housing of a device, thereby not distracting from the overall aesthetic appearance of the device. In addition, placing the antenna inside the housing means that the antenna is less likely to be damaged.

However it is difficult to design a planar antenna that offers performance comparable to that of a rod antenna, in particular as far as the bandwidth characteristics of the device are concerned. Loss in an antenna is generally due to two sources: radiation, which is required; and energy which is stored in the antenna, which is undesirable. Planar antennas have an undesirably low impedance bandwidth.

In accordance with the invention there is provided an antenna comprising a reference plane, a conductive polygonal lamina disposed opposing the reference plane; and a feed section coupled to the reference plane and the lamina, the feed section being arranged as a transmission line.

Since the feed section is arranged as a transmission line (otherwise known as a waveguide), energy is contained and guided between the conductors of the transmission line. This results in a low Q factor and hence a higher impedance bandwidth compared with conventionally-fed planar antennas. The bandwidth is increased considerably while retaining the efficiency, size and ease of manufacture of planar antennas. The feed section should be as low-loss as possible.

At the end of the feed section adjacent the reference plane, the feed section preferably has an impedance which matches the impedance of the feed (typically a 50 Ω line). At the end of the feed section adjacent the lamina, the feed section preferably has an impedance which matches the impedance of the antenna. Thus the feed section acts as an impedance transformer, matching the impedance characteristics of the feed at one end and the characteristics of the radiating lamina at the other. The feed section generally has a graded impedance characteristic along its length and provides an inductive load for the antenna. The impedance advantageously varies along the length of the feed section in a uniform manner.

The feed section generally comprises a first conductor for providing the feed signal to the conductive lamina and a second conductor connected to the reference plane, the first and second conductors together forming a transmission line. Thus the conductors of the feed section are e.m. coupled and operate as a waveguide. The energy is guided along the two conductors rather than being stored in the shorting post connected to the reference plane as is the case with conventional planar antennas. Thus the resulting antenna is very efficient compared with known antennas.

Preferably the width of the two conductors are of a similar order of magnitude.

Preferably the feed section comprises a microstrip line and/or a coplanar strip. In a particularly preferred embodiment, the feed section comprises a first part comprising a microstrip line parallel to the reference plane and a second part comprising a coplanar strip which extends at an angle from the reference plane to the conductive lamina. However, other transmission lines may be used e.g. coaxial line.

Thus an antenna according to the invention has an increased impedance bandwidth compared with known planar antennas without a sacrifice in efficiency. There is little radiation from the feed section because the energy is guided along the conductors of the transmission line feed section. In addition the resulting antenna is easy, and therefore relatively inexpensive, to manufacture.

The first conductor provides an inductive load to the conductive lamina.

The invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

FIG. 1 shows a perspective view of one embodiment of an antenna according to the invention;

FIG. 2 shows a side view of the antenna of FIG. 1;

FIG. 3 shows a plan view of the antenna shown in FIG. 1;

FIG. 4 shows an expanded view of part A of the antenna shown in FIG. 3;

FIG. 5 shows the gain of an antenna according to the invention;

FIG. 6 shows examples of transmission line which may form the feed section of an antenna according to the invention; and

FIG. 7 shows a second embodiment of the invention in which the feed section comprises a coaxial line.

The antenna **20** of FIG. 1 comprises a lamina **202** made from a conductive material. The lamina is disposed opposing a reference plane **204** which is commonly a ground plane. A feed section **206** provides both the feed to excite the lamina into resonance and also the grounding point of the antenna. The feed section comprises a transmission line having two planar metal conductors **208** and has a first part **206a** comprising a coplanar coupled strip and second part **206b** comprising a microstrip transmission line. The conductor **208a** nearest the edge **210** of the sheet **202** adjacent the feed section is grounded by connection to the ground plane **204** at the end remote from the sheet **202**. The remote conductor **208b** is the feed. The feed section introduces a propagation mode transition as well as an impedance transition.

The transmission line **206** conveys power from one point (the source of the feed signal) to another (the radiating antenna) and is arranged in such a manner that the properties of the lines must be taken into account i.e the feed section operates as a low-loss waveguide. The conductors of the transmission line are close-coupled narrow lines and able to support more than one mode of propagation.

At the end of the feed section **206** adjacent the ground plane **204**, the feed section has an impedance which matches the impedance of the line of the ground plane (typically 50 Ω). At the end of the feed section **206** adjacent the lamina **202**, the feed section matches the impedance at the feed point of the antenna, typically of the order of 200 Ω . The impedance varies along the length of the feed section in a uniform manner.

Thus feed into the lamina **202** is balanced. In section **206b** the field is confined between the conductors **208** and the ground plane. In section **206a** the field is confined between the conductors **208**.

The centre frequency of the antenna is determined by the electrical length of the resonant circuit which extends from the open circuit on an edge **214** of the antenna sheet **202**, along the feed section **206** and to the point **212** at which the feed section meets the ground plane. This electrical length is usually designed to be a quarter wavelength of the desired frequency.

Referring to FIGS. 2, 3 and 4, for an antenna with a resonant frequency of around 1.1 GHz and a sheet **202** having dimensions $x=7.8$ mm, $y=33$ mm, the distance D from the ground plane is 8 mm; the width w of the conductors **208** is 0.6 mm; the distance d between the conductors **208** is 0.6 mm; and the length l_1 of the first part **206a** is 11.3 mm. The feed section extends from the ground plane **204** to the lamina **202** at an angle of 45°. For a co-planar strip (CPS) line the track width-to-gap (w,d) measurements may be calculated using well known formulae

to achieve the desired impedance transformation. This is also so with other forms of transmission line.

The antenna may be produced using conventional printed circuit board techniques thus making manufacture economical.

The impedance bandwidth of an antenna is calculated as follows:

$$B_z = B_{-6dB} / f_0 \times 100$$

where

B_z is the impedance bandwidth;

B_{-6dB} is the bandwidth at 6dB; and

f_0 is the centre frequency

As can be seen in FIG. 5, the bandwidth of the antenna at -6 dB is 166 MHz which results in an impedance bandwidth of 16%. This is a substantial increase compared with conventionally fed planar antennas which typically have a maximum impedance bandwidth of around 7%. Using a feed section as described herein has been found to provide an impedance bandwidth of the order of 23% and up to 31% if loading is also used to improve the characteristics.

FIG. 6 shows four examples of strip transmission line which may be used to form the feed section **206**. FIG. 6(a) shows stripline comprising a conductor **60** embedded within a support of dielectric **62**. A reference plane **64** is provided either side of the conductor **60**. The electric field is confined between the conductor **60** and the reference planes **64**. In this embodiment, the conductor **60** forms the feed and one of the reference planes forms the grounding point as has been described earlier. Thus the plate **202** is connected to the reference plane **64**.

FIG. 6(b) shows microstrip which comprises a single conductor **60** separated from a ground plane **64** by dielectric **62**. The electrical field is confined between the conductor **60** and the reference plane **64**. In this embodiment, the conductor **60** forms the feed and the reference plane **64** forms the ground point as has been described earlier. Thus the plate **202** is connected to the reference plane **64**.

FIG. 6(c) shows a co-planar waveguide which comprises a single conductor **60** located on the surface of a dielectric material **62**. Located on either side of the conductor **60** on the surface of the dielectric is a reference plane **64**. The electrical field is confined between the conductor **60** and the reference planes **64**. In this embodiment, the conductor **60** forms the feed and one of the reference planes forms the ground point as has been described earlier. Thus the plate **202** is connected to the reference plane **64**.

FIG. 6(d) shows a co-planar strip (CPS) which comprises two conductors **60** located on the surface of a dielectric material **62**. Located on the other side of the dielectric **62** is a reference plane **64**. The electrical field is confined between the two conductors **60**. In this embodiment, one of the conductors **60** forms the feed and the other of the conductors **60** forms the grounding point, an end of which remote from the sheet **202** is coupled to the reference plane **64**.

FIG. 7 shows a further embodiment of the feed section. The feed section **70** comprises a coaxial line having an inner conductor **72** and an outer conductor **74**. The gap between the inner conductor **72** and the outer conductor **74** is filled with dielectric (not shown). One end **72a** of the inner conductor **72** is connected to the lamina **202** and the other end **72b** of the inner conductor **72** is connected to the source of the feed signal (not shown). One end **74a** of the outer conductor **74** is connected to the lamina **202** and part **74b** of the outer conductor remote from the end **74a** is connected to the ground plane **204**. The profile of the coaxial cable is

5

graded to provide an impedance transformer. At the end of the feed section 70 adjacent the ground plane 204, the feed section has an impedance which matches that of the feed (typically 50 Ω). At the end of the feed section 70 adjacent the lamina 202, the feed section matches the impedance at the feed point of the antenna, typically of the order of 200 Ω. The impedance preferably varies along the length of the feed section in a uniform manner although a non-uniform variation may be chosen.

What is claimed is:

1. An antenna comprising:

- a reference plane;
- a conductive polygonal lamina disposed opposing the reference plane; and
- a feed section extending from the reference plane to the lamina and coupled to the reference plane and the lamina;

wherein the feed section comprises:

- a first conductor for providing a feed signal to the conductive lamina, and
- a second conductor connected to the reference plane, wherein first and second conductors together interact to form a transmission line to contain and guide said feed signal between said first and second conductors.

2. An antenna according to claim 1 wherein the feed section comprises at least two planar conductors arranged parallel to each other, one of the planar conductors being connected to the feed and the other of the conductors being connected to the reference plane.

3. An antenna according to claim 1 wherein the feed section is connected to the conductive lamina adjacent an edge thereof, the conductor adjacent the edge being connected to the reference plane and the conductor remote from the edge being connected to the feed.

4. An antenna according to claim 3 wherein the feed section is connected adjacent a corner edge of the conductive lamina.

5. An antenna according to claim 1 wherein the feed section comprises a stripline.

6. An antenna according to claim 1 wherein the feed section comprises microstrip.

7. An antenna according to claim 1, wherein the feed section comprises two strips coplanar to each other strip.

8. An antenna according to claim 1, wherein the feed section comprises a first part comprising a microstrip line parallel to the reference plane and a second part comprising two strips coplanar to each other which extend at an angle from the reference plane to the conductive lamina.

9. A mobile telephone handset incorporating an antenna according to claim 1.

10. A portable radio device incorporating an antenna according to claim 1.

6

11. A planar inverted-F comprising:

- a planar conductor arranged to resonate at $f=N\lambda/4$, where n is odd;
- a shorting post coupled to the planar conductor and a reference plane to provide a short circuit between the planar conductor and the reference plane;
- a feed to provide a feed signal to the planar conductor; wherein the feed and the shorting post are arranged to interact as a transmission line to contain and guide the feed signal between the feed and the shorting post.

12. An antenna according to claim 2 wherein the feed section is connected to the conductive lamina adjacent an edge thereof, the conductor adjacent the edge being connected to the reference plane and the conductor remote from the edge being connected to the feed.

13. An antenna according to claim 3 wherein the feed section is connected to the conductive lamina adjacent an edge thereof, the conductor adjacent the edge being connected to the reference plane and the conductor remote from the edge being connected to the feed.

14. An antenna according to claim 2 wherein the feed section comprises a stripline.

15. An antenna according to claim 3 wherein the feed section comprises a stripline.

16. An antenna according to claim 2 wherein the feed section comprises microstrip.

17. An antenna according to claim 3 wherein the feed section comprises microstrip.

18. An antenna according to claim 2 wherein the feed section comprises two strips coplanar to each other.

19. An antenna according to claim 3 wherein the feed section comprises two strips coplanar to each other.

20. An antenna according to claim 2 wherein the feed section comprises a first part comprising a microstrip line parallel to the reference plane and a second part comprising two strips coplanar to each other which extend at an angle from the reference plane to the conductive lamina.

21. An antenna according to claim 3 wherein the feed section comprises a first part comprising a microstrip line parallel to the reference plane and a second part comprising two strips coplanar to each other which extend at an angle from the reference plane to the conductive lamina.

22. A mobile telephone handset incorporating an antenna according to claim 2.

23. A mobile telephone handset incorporating an antenna according to claim 3.

24. A portable radio device incorporating an antenna according to claim 2.

25. A portable radio device incorporating an antenna according to claim 3.

* * * * *