



Europäisches Patentamt
European Patent Office
Office européen des brevets



(11)

EP 1 276 170 A1

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:

15.01.2003 Bulletin 2003/03

(51) Int Cl.7: **H01Q 1/36**, H01Q 1/38,
H01Q 9/04, H01Q 5/00

(21) Application number: **01202677.9**

(22) Date of filing: **12.07.2001**

(84) Designated Contracting States:

**AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU
MC NL PT SE TR**

Designated Extension States:

AL LT LV MK RO SI

(72) Inventor: **Simon Dunlop**
Belfast BT9 5AH (GB)

(74) Representative: **O'Connell, Maura, Dr. et al**
F. R. Kelly & Co.,
9, University Street
Belfast, BT7 1FY, Northern Ireland (GB)

(71) Applicant: **TDK Corporation**
Chuo-ku, Tokyo (JP)

(54) **Multi-band antenna**

(57) An antenna comprising a conductive patch arranged to resonate when excited by an electromagnetic signal, and a feed mechanism arranged to provide electromagnetic signals to the conductive patch. For a generally rectangular patch, the feed mechanism is arranged to feed electromagnetic signals to a point substantially on, or in-line with, a diagonal of the patch.

Feeding the conductive patch in this manner enables the patch to resonate in a plurality of discrete frequency bands. This means that the antenna is capable of multi-band operation without the need for additional resonating patches, shorting pins, matching circuits or multiple feed points. In a preferred embodiment, the patch includes one or more slots for manipulating the performance of the antenna.

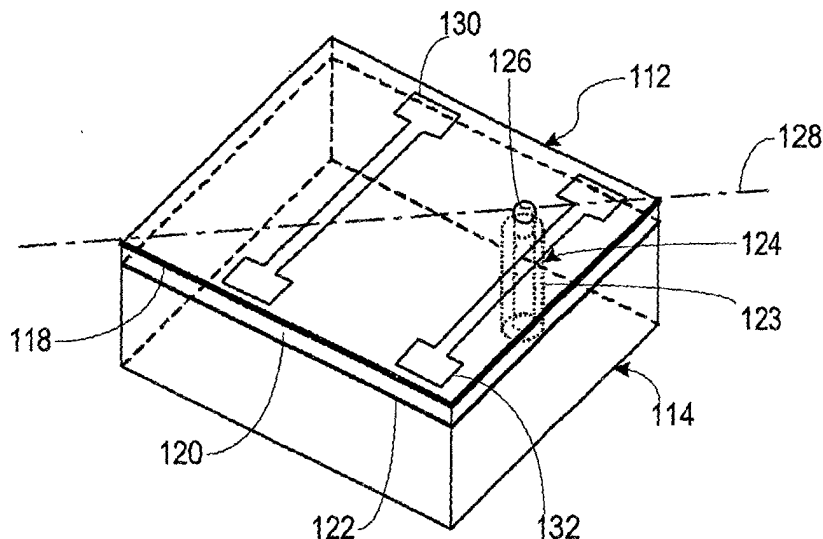


FIG. 2

EP 1 276 170 A1

Description

Field of the Invention

[0001] The present invention relates to multi-band antennas, and in particular to multi-band planar antennas.

Background to the Invention

[0002] Many applications require that an antenna is able to transmit and receive signals in two or more discrete frequency bands. For example, in the field of mobile telecommunications, mobile telecommunications networks may operate in one or more different frequency bands which may vary from country to country. Hence mobile telephones (cellular telephones) are required to be able to operate in more than one frequency band if they are to be compatible with more than one mobile network using different frequency bands (this is sometimes referred to as having roaming functionality). A multi-band antenna is an antenna capable of operating in more than one frequency band.

[0003] Planar antennas, such as microstrip patch antennas, are an increasingly popular form of antenna. Planar antennas are relatively compact in structure, relatively lightweight, relatively simple to manufacture and hence relatively inexpensive. Moreover, planar antennas are suitable for internal use, i.e. they can be incorporated within a telecommunications apparatus, for example a mobile telephone handset. Not only does this improve the aesthetic appeal of the apparatus, but it also protects the antenna making it less susceptible to damage. A further advantage of planar antennas is that they may be arranged within, say, a telephone handset in such manner that the radiation emitted during use is primarily directed away from the user of the handset.

[0004] Previous attempts have been made to provide multi-band planar antennas. These attempts include combining two planar antennas one on top of the other, or side-by-side, or using a matching network. Such antennas suffer in terms of size and complexity and can therefore be relatively difficult and expensive to manufacture. Other attempts have involved the combination of slots and shorting pins, but such antennas are required to be relatively large and are unsuitable for incorporation into modern telecommunication devices, particularly telephone handsets, for this reason. The problem of size is exacerbated by the fact that many mobile telecommunications networks operate in relatively low frequency bands, low frequency operation normally requiring a large planar antenna.

[0005] There is a need therefore for improved multi-band planar antennas.

Summary of the Invention

[0006] Accordingly, a first aspect of the invention provides an antenna comprising a multi-sided conductive

patch arranged to resonate when excited by an electromagnetic signal; and a feed mechanism arranged to provide electromagnetic signals to said conductive patch, wherein said feed mechanism is arranged to feed electromagnetic signals to a point substantially on, or in-line with, a notional line through a corner and the centre of the conductive patch

[0007] Feeding the conductive patch in this manner enables the patch to resonate in a plurality of discrete frequency bands. This means that the antenna is capable of multi-band operation without the need for additional resonating patches, shorting pins, matching circuits or multiple feed points.

[0008] Preferably, the feed mechanism is arranged to provide a direct feed to the conductive patch. The feed mechanism may alternatively feed the patch by indirect coupling.

[0009] Preferably, the conductive patch is generally rectangular in shape and the feed point is substantially on, or in-line with, a diagonal of the patch.

[0010] Preferably, the antenna further comprises a dielectric substrate having first and second oppositely disposed surfaces, said patch being provided on said first surface, and a conductive layer provided on said second surface and arranged to act as a ground plane. More preferably, the antenna is formed from microstrip.

[0011] Preferably, one or more slots are formed in the conductive patch, at least one of said slots being arranged to increase the current density in one or more areas of the patch during resonance in one or more frequency bands thereby lowering said one or more frequency bands.

[0012] More preferably, at least one of said slots is arranged to adjust the effective impedance of the conductive patch in one or more resonant frequency bands in order to improve the Return Loss value of the patch in said one or more frequency bands.

[0013] Preferably, at least part of at least one of said slots is positioned in close proximity with an edge of the patch so that said at least one slot part radiates electromagnetic energy in a frequency band other than the natural resonant frequency bands of the patch.

[0014] Preferably, at least one slot includes a first and a second non-parallel slot portions. More preferably, said first and second slot portions are substantially perpendicular with each other. Further preferably, said at least one slot is substantially "I"-shaped.

[0015] In a preferred embodiment, the conductive patch is generally rectangular in shape and includes a first and a second slot, one on either side of the feed point, each slot having an elongate body portion with a respective foot portion at, or adjacent, either end of the body portion, the slots being arranged so that the respective elongate body portions are substantially parallelly disposed with respect to one pair of opposing edges of the patch and that the respective foot portions are located in close proximity with the other pair of opposing patch edges. Preferably, said one pair of opposing patch

edges are the patch edges that radiate electromagnetic energy during resonance in a frequency band in respect of which the conductive patch is designed primarily to resonate. Preferably, said first and second slots are substantially "I"-shaped and said respective foot portions are arranged to be substantially parallelly disposed to said other opposing patch edges.

[0016] Preferably, the patch includes a third slot located between, and substantially perpendicularly with, said first and second slots. More preferably, the third slot is substantially centrally located in the conductive patch.

[0017] A second aspect of the invention provides a method for designing a multi-band planar antenna comprising a multi-sided conductive patch arranged to resonate when excited by an electromagnetic signal; and a feed mechanism arranged to provide electromagnetic signals to said conductive patch, the method including providing a feed point substantially on, or in-line with, a notional line through a corner and the centre of the conductive patch so that the conductive patch is capable of resonance in more than one frequency band; and providing one or more slots in the patch to manipulate the frequency bands in which resonance occurs.

[0018] Further advantageous aspects of the invention will become apparent to those ordinarily skilled in the art upon review of the following description of specific embodiments of the invention and with reference to the accompanying drawings.

Brief Description of the Drawings

[0019] Specific embodiments of the invention are now described by way of example and with reference to the accompanying drawings in which:

Figure 1 is a perspective view of a planar antenna in situ within a mobile telephone handset;

Figure 2 is a perspective view of a planar antenna according to a first aspect of the invention mounted on a Front End Module (FEM) for a radio transceiver;

Figure 3 is a side view of the antenna of Figure 2;

Figure 4 is a plan view of an unslotted planar antenna arranged in accordance with the invention;

Figures 5a to 5c are plots of the current density across the unslotted antenna of Figure 4 at different feed frequencies;

Figure 6 is a plot of Return Loss (dB) against Frequency (GHz) for said unslotted planar antenna;

Figure 7 is a plan view of a slotted planar antenna according to a preferred embodiment of the invention;

Figures 8a to 8e are plots of the current density across the slotted planar antenna of Figure 7 at different feed frequencies;

Figure 9 is a plot of Return Loss (dB) against Frequency (GHz) for said slotted planar antenna; and

Figure 10 shows a set of equations for use in the design of a planar antenna.

Detailed Description of the Invention

[0020] Referring now to Figure 1 of the drawings, there is shown, generally indicated at 10, a perspective view of a mobile telecommunications handset. The handset 10 is shown in general outline only for reasons of clarity. The handset 10 includes a planar antenna in the preferred form of a microstrip patch antenna 12. The patch antenna 12 is mounted on a radio module, or Front End Module (FEM) 14, which in turn is mounted on a printed circuit board (PCB) 16 in conventional manner. The antenna 12 comprises a dielectric substrate 20 having a first conductive layer, or patch 18, on one face and a second conductive layer, or ground plane 22, on the opposite face. A feed mechanism (not shown in Figure 1) is provided for communication between the FEM 14 and the antenna 12. The feed mechanism may be connected directly to the patch (direct feed) or may be coupled indirectly to the patch.

[0021] In use, the FEM 14 sends and receives electromagnetic signals, including radio frequency signals, via the antenna 12 as is conventional. During transmission, the FEM 14 feeds an electrical signal to the antenna 12 via the feed mechanism. The signal excites the patch 18 to cause the radiation of electromagnetic energy, or waves, therefrom. More particularly, when the patch 18 is excited by a feed signal, a charge distribution is established on the reverse side, or underside, of the patch 18 and the ground plane. At a particular instant in time, the underside of the patch is positively charged and the ground plane is negatively charged. The attractive forces between these charges tend to hold a large percentage of the charge between the two reverse surfaces.

[0022] However, the repulsive forces between positive charges on the patch push some of these charges towards the edges of the patch resulting in large charge density, or current density, at some of the edges (normally two opposing edges). These areas of large charge density are the source of fringing fields at the edges of the patch 18 and the corresponding radiation from the patch 18.

[0023] A planar, or patch, antenna radiates energy only in frequency bands where resonance occurs. The location of the resonant, or operational, frequency band of a patch antenna depends primarily on its dimensions and composition. Thus, when a patch is fed with a signal in the resonant frequency band, the patch radiates en-

ergy in that frequency band.

[0024] The efficiency at which the patch radiates energy depends on, amongst other things, whether or not there is an impedance match between the patch 18 and the feed mechanism. Typically, a coaxial feeder has an impedance of 50 Ohms and it is important therefore to position the feed point such that the effective impedance presented by the patch at the feed point matches the feeder impedance. Radiation efficiency may be measured in terms of Return Loss (typically in decibels(dB)) or Voltage Standing Wave Ratio (VSWR). A Return Loss Value (RLV) of approximately -10dB or better, which corresponds to a VSWR of approximately 2 or less, is usually considered to be desirable in an operational frequency band, although poorer efficiency can be satisfactory.

[0025] Normally, a patch antenna 12 is considered as a single band structure with narrow bandwidth i.e. a structure having only one, relatively narrow, resonant frequency band. In order to design a patch antenna for operation in a desired frequency band and for a given dielectric constant and substrate thickness, equations [1] to [4] of Figure 10 may be used to determine the approximate required length and width of the patch 18. Normally some fine tuning is then required in order to finalise patch dimensions to suit the application in question.

[0026] The next step in the design of the patch antenna 12 is to determine the position of the point at which the feed mechanism feeds the antenna. Conventionally, the feed point is on a notional straight line perpendicular to the patch 18 edges and running through the centre of the patch. Such a feed position is hereinafter referred to as a central, or symmetrical, feed position. A common way to determine the best position for the feed point is to simulate the operation of the antenna 12 for various feed positions starting on a patch edge moving towards the patch centre along the notional centre line. A suitable feed point is found when there is an impedance match between the feed mechanism and the patch (it is noted that in some cases an impedance match is not found on the centre line. In such cases, the normal solution is to enlarge the size of the patch 18 or to provide an impedance matching network between the feed mechanism and the patch 18).

[0027] When fed with a signal in the resonant, or operational, frequency band, the current density on the surface of the patch 18 increases significantly along two opposing edges of the patch 18 causing electromagnetic waves to radiate from those edges. The current density also increases across the surface of the patch 18 between the two radiating edges and this causes further electromagnetic radiation from between the two radiating edges. The resulting radiation pattern is substantially symmetrical with respect to the patch 18 and this optimises the gain of the antenna. This is the main reason why patch antennas are conventionally fed from a central position.

[0028] However, a centrally fed patch antenna provides only one resonant frequency band. Previous attempts have been made to provide multi-band planar antennas, including multi-band patch antennas. These attempts include stacking or layering two patch antennas one on top of the other, or side-by-side, or using a matching network. Other attempts have involved the combination of slots and shorting pins, or providing multiple feed points. It is considered that such earlier attempts suffer in terms of size and/or complexity. As a result they can be relatively difficult and expensive to manufacture. Moreover, it is considered that the size of such antennas makes them unsuitable for incorporation into modern telecommunication devices, particularly telephone handsets. The problem of size is exacerbated by the fact that many mobile telecommunications networks operate in relatively low frequency bands, low frequency operation normally requiring a large antenna.

[0029] As is now described, one aspect of the invention provides a single layer planar, or patch, antenna capable of multi-band operation without the use of shorting pins, matching networks or multiple feed points.

[0030] Figures 2 and 3 illustrate a patch antenna 112, arranged in accordance with a preferred embodiment of the invention, mounted on an FEM 114. The antenna 112 comprises a multi-sided patch 118 in the form of a layer of conductive material, particularly conductive metal such as copper or copper alloy. The patch 118 coats one face of a substrate 120 made of a dielectric material such as duroid, ceramic or alumina. A second conductive layer 122 coats the opposite face of the dielectric substrate 120. The second conductive layer 122, which is typically made from the same material as the patch 118, serves as a ground plane for the antenna 112.

[0031] The antenna 112 includes a feed mechanism 124 for supplying electromagnetic signals (such as radio or microwave signals) in the form of electrical signals between the antenna 112 and the FEM 14. In Figure 2, the feed mechanism 124 takes the form of a coaxial feeder although a skilled person will appreciate that other forms of conventional feed mechanism, such as microstrips, striplines and waveguides, may alternatively be used. The feeder 124 is preferably arranged to provide a direct feed to the patch 118 and so is fixed to a feed point 126 on the patch 118 itself. A non-conductive sleeve 123, formed for example from polytetrafluoroethylene (PTFE), surrounds the body of the feeder 124.

[0032] In accordance with the invention, the feed point 126 is positioned on, or substantially on, a notional straight line 128 passing through a corner of the patch 118 and the centre of the patch 118. When the patch is a straight-sided figure, such as the generally rectangular patch 118 shown in the example of Figure 2, the feed point 126 is positioned on, or substantially on, a diagonal of the patch.

[0033] When the feed point 126 is positioned on, or approximately on, a diagonal, it is found that the patch

118 resonates in a plurality of different frequency bands. This phenomenon is believed to occur because all sides of the patch are presented to the excitation signal as possible areas from which radiation may emanate. Thus, for the generally rectangular patch 118 of Figure 2, all four sides of the patch 118 are available as possible radiating elements as a result of the diagonally positioned feed point 126. Since the frequency at which radiation occurs depends on patch dimensions, and since the respective opposing sides of the patch 118 are different lengths, the respective resonant states occur in different frequency bands.

[0034] The patch 118 includes two slots 130, 132 for manipulating the performance of the antenna 112 as is described in more detail below.

[0035] Firstly, the operation of an unslotted patch is considered. Figure 4 shows a plan view of an unslotted patch 218 provided with a diagonally positioned feed point 226 in accordance with the invention. The patch 218 dimensions are calculated using equations [1] to [4] of Figure 10 for a desired operational frequency, f_r , of approximately 1800 MHz, where the substrate thickness, t , is approximately 1.2 mm and the dielectric constant, ϵ_r , is approximately 10. Accordingly, the length, l , of the patch 218 is approximately 34.20 mm, and the patch width, w , is approximately 23.37 mm. The optimal position of the feed point 226 was determined by simulating the operation of the patch 218 with the feed point first positioned at or near a corner 234 of the patch 218 and then subsequently positioned at points progressively nearer the patch centre along the diagonal. For the present design, an impedance match was found when the feed point 226 was positioned 5.70 mm from the longer edge 236 of the patch 218 and 7.98 mm from the shorter edge 238 of the patch 218 as shown in Figure 4. It will be understood that the feed point 226 may equally be positioned along the respective diagonal from any corner of the patch 218.

[0036] In Figures 5a to 5c and 8a to 8e, the current density on the respective patches 218, 318 is shown. It will be noted that only areas of relatively high, or significant, current density are shown by the dashed lines. In general, the current density on a patch may range from 0 to 1500 A/m, or higher. In Figures 5 and 8, only areas where the current density is approximately 400 A/m and above are depicted. Current density of approximately 500 A/m and higher is considered to be particularly significant.

[0037] Figures 5a to 5c show plots of the current density across the patch 218 at different feed frequencies where resonance occurs. Figures 5a to 5c thus show the current density of patch 218 in three different resonant states in three different frequency bands. In Figure 5 (and also in Figure 8) current density is indicated by short dashes on the patch 218 surface, the density of the dashes corresponds to the current density. Figure 5a shows the current density when patch 218 is fed with an excitation signal of approximately 1389MHz. The

main area of high current density is indicated approximately by dashed line 501. This area corresponds to the area of most significant electromagnetic radiation from the patch 218 in this resonant state, the radiation being in a frequency band centred at approximately 1389 MHz. As can be seen from Figure 5a, in this frequency band the key areas of high current density occur at and around the mid-sections of the opposing longer edges 236, 240, and across the patch 218 between the two edges 236, 240. Consequently, the main radiation of electromagnetic energy occurs at and around the mid-sections of the edges 236, 240 and from the patch surface between the edges 236, 240 in this resonant state (and therefore in the 1389 MHz frequency band).

[0038] A second resonant state occurs when the excitation signal is approximately 1971MHz, and the corresponding current density plot is shown in Figure 5b. The main area of high current density is indicated approximately by dashed line 503. In this state, the key areas of high current density are at and around the mid-sections of the remaining two opposing edges 238, 242 and across the patch 218 between the two edges 238, 242. Consequently, the main radiation of electromagnetic energy in the frequency band around 1971 MHz occurs at and around the mid-sections of the edges 238, 242 and from the patch surface between the edges 238, 242.

[0039] A third resonant state occurs when the excitation signal is approximately 2476 MHz, and the corresponding current density plot is shown in Figure 5c. The main area of high current density is indicated approximately by dashed lines 505. In this state, the key areas of high current density are at and around the mid-sections of all four edges 236, 238, 240, 242. Consequently, the main radiation of electromagnetic energy in the frequency band around 2476 MHz occurs at and around the four edges 236, 238, 240, 242. It will also be seen that there is a null point for current density at and around the centre of the patch 218 and that the level of current density increases towards the edges of the patch 318. The current density/radiation pattern shown in Figure 5c is dual linear or circularly polarised, meaning that high current density and hence radiation is occurring simultaneously at all four edges in this frequency band.

[0040] It will be noted from Figures 5a to 5c that, as a result of the diagonal feed position, the patch 218 is able to radiate energy from all four of its edges 236, 238, 240, 242 in contrast to a conventional centre feed patch which only radiates energy from two opposing edges. This enables the patch 218 to resonate in more than one frequency band.

[0041] Figure 6 shows the Return Loss (dB) for each of the resonant states illustrated in Figures 5a to 5c. The first Return Loss Peak 601 represents a resonant, or operational, frequency band centred at approximately 1389 MHz and corresponds with the resonant state shown in Figure 5a. The second Return Loss Peak 602 represents a resonant frequency band centred at ap-

proximately 1971 MHz and corresponds with the resonant state shown in Figure 5b. The third Return Loss Peak 603 represents a resonant frequency band centred at approximately 2476 MHz and corresponds with the resonant state shown in Figure 5c. The second Return Loss Peak 602 is significantly better (approximately -13dB) than the first and third Return Loss Peaks 601, 603 (approximately -4dB and -4.5dB respectively). This is expected since the patch 218 was designed particularly for resonance at around 1800 MHz and the feed point 226 was selected to provide a good impedance match in this frequency range. Nonetheless, the first and third Return Loss Peaks 601, 603 are significant and, as is described in more detail below, can be developed to provide additional operating frequency bands for an antenna into which it is incorporated.

[0042] Thus, the unslotted patch 218 with diagonal feed may be incorporated into an antenna of the general type illustrated in Figures 2 and 3 and the resulting antenna is capable of operating in a number of different frequency bands. This is achieved using only a single conductive layer for the patch 218, using only a single feed mechanism and without the need for shorting pins or a matching circuit. However, the relatively poor Return Loss Peaks 601, 603 for the first and third frequency bands, are normally considered to be unsatisfactory for commercial use. Moreover, the three illustrated Return Loss Peaks 601, 602, 603 are in frequency bands that are not currently in commercial use in the mobile telecommunication industry. In this connection, four key frequency bands that are in current use in the mobile telecommunications market are GSM (Global System for Mobile telecommunications - approx. 890 to 960 MHz), GPS (Global Positioning System - approx. 1.57 to 1.58 GHz), DCS (Digital Communication System - approx. 1.71 to 1.88 GHz) and Bluetooth (approx. 2.4 to 2.48 GHz).

[0043] It is proposed, therefore, to provide one or more slots in the patch 218 in order to manipulate the performance of the antenna. In particular, it is proposed to provide a planar antenna capable of satisfactory operation in at least two commercially used frequency bands.

[0044] The provision of slots increases the current density in the patch around at least some of the slot edges. An increase in current density has the effect of making the patch electrically larger and this makes the patch behave as if it were physically larger even though the actual length and width of the patch are unchanged. By careful arrangement of a slot (including slot shape, slot size and slot position) one or more of the frequency bands in which the patch resonates can be adjusted. In particular, by placing at least part of a slot in or adjacent an area of the patch that has a relatively high current density during resonance in a given frequency band, the frequency band can be lowered (i.e. resonance occurs at a lower frequency). This is because the increase in current density caused by the presence of the slot caus-

es the patch to behave as if it were larger - and larger patches generally resonate at lower frequencies.

[0045] The slots also provide a further effect when arranged in accordance with the invention. The increased surface current density around the slot edges gives rise to additional Return Loss Peaks in different frequency bands. The slot edges, when appropriately placed, act as pseudo patch edges from which electromagnetic energy can radiate. A slot can therefore effectively create one or more further resonant states for the patch and so increase the versatility of the antenna.

[0046] The provision of a slot on the patch can also affect the effective impedance of the patch with respect to the feed point. The slot can therefore affect the magnitude of the Return Loss Peak in one or more resonant frequency bands.

[0047] Thus, with appropriate design and arrangement of slots in accordance with the invention, the natural resonance frequency bands of a planar antenna can be adjusted, further resonance frequency bands, i.e. operational frequencies, can be created and the return loss value (i.e. patch efficiency) in resonance frequency bands can be improved. However, removal of material from a patch to form a slot can be detrimental to the efficiency of the antenna and this must be taken into account during slot design.

[0048] Figure 7 shows in plan view a slotted patch 318 arranged in accordance with a preferred embodiment of the invention. The patch 318 is suitable for use in the antenna 112 of Figure 2. The patch 318 has a first pair of opposing edges 338, 342, a second pair of opposing edges 336, 340 and a feed point 326. The patch 318 further includes a first and a second slot 330, 332 for manipulating the performance of the antenna 112. The slots 330, 332 are formed by removing portions of the metal conductive layer that forms the patch itself. In the preferred embodiment, the slots 330, 332 each comprise a respective elongate body portion 331, 333 and two respective feet portions 335, 337, one foot 335, 337 at either end of the respective body portions 331, 333. Preferably, the slots 330, 332 are generally I-shaped.

[0049] The slots 330, 332 are arranged so that the respective elongate body portions 331, 333 are substantially parallel with respect to one pair of oppositely disposed edges of the patch 318. The slots 330, 332 are dimensioned so that, in this position, the respective feet 335, 337 are located in close proximity with the other pair of opposing edges of the patch 318. In the preferred embodiment, the body portions 331, 333 are substantially parallelly disposed with the shorter edges 342, 338 of the patch 318 and the feet 335, 337 are therefore located adjacent the longer edges 336, 340. It is noted from Figure 5b that the edges 342, 338 are key radiation areas of the patch 318 in the second resonant state i.e. the 1971 MHz frequency band (which in the present example is the frequency band in respect of which the patch 318 was primarily designed to operate using equations [1] to [4] of Figure 10). The longer edges 336,

340 are key radiation areas in the first and third resonant states (1389 MHz and 2476 MHz frequency bands respectively - see Figures 5a and 5c). The slots 330, 332 are arranged one on either side of the feed point 326. The slots 330, 332 are located relatively near to the respective edges 342, 338.

[0050] The patch 318 preferably includes a third slot 334 located between and substantially perpendicularly with the first and second slots 330, 332. Advantageously, the third slot 334 is substantially centrally located in the patch 318. The third slot may be similarly shaped to the first and second slots 330, 332 but, in the illustrate embodiment, the third slot 334 does not comprise feet.

[0051] The patch 318 of Figure 7 is designed particularly for operation in the GSM and DCS commercial frequency bands GSM, GPS, DCS and Bluetooth. The function of the slots 330, 332 is to manipulate the natural resonant states of the unslotted patch 218 to provide a patch that resonates at least in said two commercial frequency bands with efficiency that is satisfactory for use in an antenna for a telecommunications product, particularly a mobile telephone.

[0052] Figures 8a to 8e show plots of the current density across the slotted patch 318 at different feed frequencies where resonance occurs. Figures 8a to 8e thus show the current density of patch 318 in five different resonant states.

Figure 8a shows the current density in a resonant state when patch 318 is fed with an excitation signal of approximately 948 MHz. This frequency band falls in the GSM frequency band. The main area of high current density in this frequency band is indicated approximately by dashed line 801. This area corresponds to the area of most significant electromagnetic radiation from the patch 318 in this resonant state (and therefore in the frequency band centred at around 948 MHz). As can be seen from Figure 8a, in this frequency band the key areas of high current density occur at and around the opposing longer edges 336, 340, and across the patch 318 between the two edges 336, 340. There are further areas of high current density around the feet 335, 337 of the slots 330, 332. Consequently, the main radiation of electromagnetic energy in this frequency band (around 948 MHz) occurs at and around the mid-sections of the edges 236, 240, from the patch surface between the edges 236, 240 and from around the feet 335, 337 of the slots 330, 332.

[0053] The resonant state shown in Figure 8a for the slotted patch 318 corresponds with the resonant state shown in Figure 5a for the unslotted patch 218. This can be appreciated by comparison of the respective key radiation areas shown in Figures 5a and 8a. Because the feet 335, 337 and part of the body portions 331, 333 are located in key radiation areas in this resonant state, the current density increases around the feet 335, 337 and said parts of the body portions 331, 333 as shown in Figure 8a. This increase in current density causes the patch 318 to become electrically larger which in turn low-

ers the frequency at which radiation occurs in this resonant state. Thus, for the corresponding resonant states shown in Figures 5a and 8a, the slotted patch 318 radiates electromagnetic energy from the key areas shown in Figure 8a in a frequency band (around 948 MHz) that is lower than the frequency band (around 1389 MHz) in which the unslotted patch 218 resonates.

[0054] In arranging the slots 330, 332 to cause the patch 318 produce radiation in a particular frequency band (in this case at around 948 MHz), it may be required to make adjustments to the size and/or position of one or both of the slots 330, 332 in order to change the natural resonant frequency of the unslotted patch (around 1389 MHz) by the desired amount. For example, the effect of moving the -slot 330 away from the edge 342 of the patch 318 (preferably without changing the orientation of the slot 330) is to lower the radiation frequency. This is because the feet 335 and part of the body 337 are being moved further into the area of high current density (as shown in Figure 5a) such that the increased current density caused by the slot 330 itself is increased which in turn increases the effect of the slot i.e. lowering the frequency. A similar effect is obtained by moving the second slot 332 relative to the edge 338. Also, increasing the length of the feet 335 of the slot 337 has the effect of lowering the radiation frequency in this resonant state. This is because the increased length of the feet 335 increases the areas of increased current density caused by the feet 335. A similar effect is obtained by adjusting the length of the feet 337 of the second slot 332. Moving the slots 330, 332 in the opposite direction, or reducing the length of the feet 335, 337, has an opposite effect. Further, reducing the length of the body 331, 333 of one or both of the slots 330, 332 (and thereby moving the feet 335, 337 away from the edges 340, 336 of the patch 318) decreases the current density around the feet 335, 337, and in particular between the feet 335, 337 and the slot edges 340, 336, which has the effect of increasing the resonant frequency value, and vice versa. However, as the feet 335, 337 are moved away from the edges 340, 336 the return loss value becomes poorer.

[0055] Figure 8c shows the current density in a resonant state when patch 318 is fed with an excitation signal of approximately 1805 MHz. This frequency band falls in the DCS frequency band - the frequency band for which the -dimensions of the patch 318 were originally calculated. The main area of high current density in this frequency band is indicated approximately by dashed line 805. This area corresponds to the area of most significant electromagnetic radiation from the patch 318 in this resonant state (and therefore in the frequency band centred at around 1805 MHz). As can be seen from Figure 8c, in this frequency band the key areas of high current density occur at and around the mid-sections of the two opposing edges 338, 342 and generally across the patch 318 between the two edges 338, 342. In particular, there are areas of high current density around the ends

338, 339 of the third slot 334, between the third slot 334 and the respective body portions 331, 333 of the first and second slots 330, 332, and between the mid-portions of the first and second slots 330, 332 and the respective edges 342, 338 of the patch 318. Consequently, the main radiation of electromagnetic energy in this frequency band (around 1805 MHz) occurs at and around these areas. There is a small but not significant increase in current density around the feet 335, 337.

[0056] The resonant state shown in Figure 8c for the slotted patch 318 corresponds with the resonant state shown in Figure 5b for the unslotted patch 218. This can be appreciated by comparison of the respective key radiation areas shown in Figures 5b and 8c. In general, the feet 335, 337 of the slots 330, 332 do not significantly affect the radiation in this frequency band. This is because the feet 335, 337 are not located in areas of high current density in this resonant state. However, the third slot 334, and the mid-portions of the slot bodies 331, 333 are located in an area of high current density for this -resonant state and therefore cause a significant increase in current density leading to a reduction in the frequency at which radiation occurs in this state. Thus, for the corresponding resonant states shown in Figures 5b and 8c, the slotted patch 318 radiates electromagnetic energy from the key areas shown in Figure 8c in a frequency band (around 1805 MHz) that is lower than the frequency band (around 1971 MHz) in which the unslotted patch 218 resonates.

[0057] As before, the extent to which the frequency is altered in this resonant state depends on the size and position of the slots 330, 332, 334. For example, shortening the length of the third slot 334 reduces the increase in current density caused by the slot 334 in conjunction with the first and second slots 330, 332, and this reduces the extent to which the slot 334 reduces the resonant frequency of the patch 318 in this resonant state.

[0058] Figure 8b shows the current density in a resonant state when patch 318 is fed with an excitation signal of approximately 1344 MHz. The main areas of high current density in this frequency band are indicated approximately by dashed lines 803. These areas correspond to the areas of most significant electromagnetic radiation from the patch 318 in this resonant state (and therefore in the frequency band centred at around 1344 MHz). As can be seen from Figure 8b, in this frequency band the key areas of high current density occur at and around the feet 335, 337 of the first and second slots 330, 332 and along respective parts of the slot bodies 331, 333 adjacent the feet 335, 337. It can be seen from Figure 8b that the third slot 334 does not cause an appreciable area of high current density around itself and so the third slot does not play a significant role in this resonant state.

[0059] The resonant state at 1344 MHz does not correspond with any of the resonant states shown in Figures 5a to 5c for the unslotted patch 218. Rather, the

presence of the slots 330, 332 gives rise to the 1344 MHz resonant state. The slots 330, 332, and in particular the feet 335, 337, serve as pseudo patch edges which radiate electromagnetic energy in a resonant state (and therefore a frequency band) other than those observed for the unslotted patch 218. The resonant frequency in this state depends on the proximity of the feet 335, 337 to the patch edges 340, 336. The closer the feet 335, 337 are to the edges 340, 336, the higher the current density caused by the slots 330, 332 and consequently the lower the resonant frequency. However, as the feet 335, 337 are moved away from the edges 340, 336, (i. e. the length of the body 331, 333 is shortened) not only is there an increase in resonant frequency but the Return Loss becomes poorer. Thus, if the feet 335, 337 are remote from the edges 340, 336, then the effect of the slots 330, 332, and therefore the 1344 MHz resonant state, may become negligible.

[0060] Figure 8d shows the current density in a resonant state when patch 318 is fed with an excitation signal of approximately 2390 MHz. The main areas of high current density in this resonant state are indicated approximately by dashed lines 807. These areas correspond to the areas of most significant electromagnetic radiation from the patch 318 in this resonant state (and therefore in the frequency band centred at around 2390 MHz). As can be seen from Figure 8d, in this frequency band the key areas of high current density occur at and around the feet 335, 337 of the first and second slots 330, 332, along and around the patch edges 336, 340 between the feet 335, 337, and between the mid-portions of the slots 330, 332 and the respective edges 342, 338. The third slot 334 does not play a significant role in this resonant state.

[0061] The resonant state shown in Figure 8d for the slotted patch 318 corresponds with the resonant state shown in Figure 5c for the unslotted patch 218. This can be appreciated by comparison of the respective key radiation areas shown in Figures 5c and 8d. In Figure 8d, the feet 335, 337 are located in areas of significant current density and therefore give rise to an increase in current density around themselves. Similarly, the respective bodies 331, 333 of the slots 330, 332 are located in areas of significant current density and give rise to areas of increased current density particularly between the mid-portions of the slot bodies 331, 333 and the respective patch edges 342, 338. As before, the increase in current density in key radiation areas has the effect of lowering the resonance frequency. Thus, for the corresponding resonant states shown in Figures 5c and 8d, the slotted patch 318 radiates electromagnetic energy from the key areas shown in Figure 8d in a frequency band (around 2390 MHz) that is lower than the frequency band (around 2476 MHz) in which the unslotted patch 218 resonates.

[0062] As before, the location and size of the slots 330, 332, 334 can be used to adjust the resonance frequency by determining by how much the corresponding

natural resonance frequency of the unslotted patch 218 is raised or lowered. For example, in this resonant state, increasing the length of the feet 335, 337 of one or both of the slots 330, 332 tends to decrease the resonant frequency value by increasing current density in key areas of the patch 318, and vice versa. Shortening the length of the slot bodies 331, 333 tends to decrease the current density in key radiation areas which in turn tends to increase the resonant frequency.

[0063] Figure 8e shows the current density in a resonant state when patch 318 is fed with an excitation signal of approximately 2445 MHz. This frequency band also corresponds to the Bluetooth frequency band. The main areas of high current density in this resonant state are indicated approximately by dashed lines 809. These areas correspond to the areas of most significant electromagnetic radiation from the patch 318 in this resonant state (and therefore in the frequency band centred at around 2445 MHz). As can be seen from Figure 8e, in this frequency band the key areas of high current density occur at and around the feet 335, 337 of the first and second slots 330, 332 (including along part of the slot bodies 331, 333), along and around the patch edges 336, 340 between the feet 335, 337, and between the mid-portions of the edges 336, 340 across the centre of the patch 318 (including around the edges of the third slot 334).

[0064] The resonant state shown in Figure 8e for the slotted patch 318 does not correspond with any of the natural resonant states shown in Figure 5 for the unslotted patch 218. Rather, the resonant state shown in Figure 8e corresponds to a further natural resonance state of the unslotted patch 218 that is not shown in Figure 5 but which is now evident because its resonance frequency is lowered by the presence of the slots so that it lies in the illustrated frequency range.

[0065] As before, the location and size of the slots 330, 332, 334 can be used to adjust the resonance frequency. For example, in this resonant state, increasing the length of the feet 335, 337 of one or both of the slots 330, 332 tends to decrease the resonant frequency value by increasing current density in key areas of the patch 318, and vice versa. Shortening the length of the slot bodies 331, 333 tends to decrease the current density in key radiation areas which in turn tends to increase the resonant frequency. Moving one or both of the slots 330, 332 away from the respective edges 342, 338 tends to decrease the operational frequency value (and vice versa) since the slots 330, 332, and particularly the feet 335, 337, are moved into areas of higher current density which in turn increases the current density around the slot 330, 332 edges in this resonant state. Similarly, increasing the length of the third slot 334 tends to decrease the operational frequency in this resonant state because the increase in the length of the slot edges causes a corresponding increase in current density around the slot 334 (and vice versa).

[0066] The dimensions and locations of the slots 330,

332, 334 also have an effect on the return loss value (which relates to the efficiency of the patch 318) in at least some of the resonant frequency bands. This is a result of a change in the effective impedance of the patch 318 with respect to the feed point 326 caused by the presence of the slots 330, 332, 334. Thus, alterations to one or more of the slots 330, 332, 334 can provide a better impedance match between the patch 318 and the feed mechanism 324 which improves the efficiency, and therefore the return loss value, of the antenna. With respect to the preferred embodiment of the patch 318 shown in Figure 7, it is noted in particular that movement of the first slot 330 away from the edge 342 of the patch 318 improves the return loss value in the DCS frequency band (Figure 8c). The second slot 332 may be moved to provide a similar effect. Also, increasing the length of the feet 337 of the second slot 332 tends to give a poorer return loss value in the second frequency band (Figure 8b) and so it is preferred to keep the length of the feet 337 relatively small. Further, shortening the respective body lengths 331, 333 of the slots 330, 332 tends to give a poorer return loss value in both the GSM (Figure 8a) and second (Figure 8b) frequency bands and so it is preferred to arrange the slots 330, 332 so that the feet 335, 337 are relatively close to the edges 340, 336 of the patch 318.

[0067] It will be appreciated from the foregoing that in order to design a patch for operation in a number of different frequency bands, it is necessary to carefully select an arrangement of slots so that the patch resonates in the desired frequency bands and with a satisfactory efficiency (i.e. a satisfactory return loss value). Figure 7 shows a preferred slot arrangement in patch 318 (based on the unslotted patch 218 of Figure 4) for an antenna intended for operation primarily in the two frequency bands GSM and DCS. The feed point 326 is located approximately 10.01 mm from a corner 380 of the patch 318 along the longer edge 336, and approximately 8.53 mm from the corner 380 along the shorter edge 338. The width of both the first slot 330 and the second slot 332 is approximately 0.57 mm (width of the body portions 331, 333 and of the feet portions 335, 337), and the length of the body portions 331, 333 is approximately 21.09 mm. The feet 335, 337 are spaced from the respective edges 340, 336 by a distance approximately the same as the width of the slots 330, 332 (i.e. 0.57 mm). The length of the feet 335 of the first slot 330 is approximately 4.20 mm, while the length of the feet 337 of the second slot 332 is approximately 1.71 mm. The body 331 of the first slot 330 is substantially parallel with the patch edge 342 with the feet 335 are spaced approximately 3.89 mm from the edge 342. The body 333 of the second slot 332 is substantially parallel with the patch edge 338 with the feet 337 are spaced approximately 5.13 mm from the edge 338. The third slot 334 is approximately 0.57 mm in width and approximately 12.00 mm in length. The third slot 334 is substantially centrally located with respect to the edges 336, 340 (ap-

proximately 11.4 mm from each edge 336, 340), and is spaced approximately 11.37 mm from the edge 342.

[0068] It will be seen therefore that in the preferred embodiment, the slots 330, 332 (including feet 335, 337) are approximately 95% of the width of the patch 318, the feet 335 are approximately 12.3% of the length of the patch 318, the feet 337 are approximately 5% of the length of the patch, and the third slot 334 is approximately 35% of the length of the patch. In total, the slots 330, 332, 334 account for approximately 5% of the total area of the patch 318 surface.

[0069] -It will be understood that the feed point does not necessarily have to be positioned exactly on, or exactly in-line with, said notional straight line (or diagonal in the case of a generally rectangular patch) in order to achieve the effects described herein. For example, in the embodiment of Figure 7, the feed point 326 may be positioned within an area that extends approximately 2 mm perpendicularly from the diagonal from corner 380 to the centre of the patch 318, and from both sides of the diagonal. In general, the required proximity of the feed point to the diagonal will depend on the dimensions of the patch and on the arrangement of any slots provided therein.

[0070] Figure 9 shows plots of return loss (dB) against frequency (GHz) for the patch 318. It will be seen that the patch 318 exhibits return loss peaks 901, 903 falling respectively in the GSM and DCS frequency bands (corresponding to the resonance states shown in Figures 8a and 8c respectively). The value and position of each return loss peak 901, 903 are each considered to be more than adequate to allow an antenna comprising the patch 318 to operate, both for transmitting and/or receiving signals, in the GSM and DCS frequency bands. The Figure 9 plot also shows further return loss peaks 902, 904, 905 corresponding to the resonance states shown in Figures 8b, 8d and 8e respectively. The respective values of the return loss peaks 902, 904, 905 are poorer than for the peaks 901, 903 but this is expected as the patch 318 is not designed specifically to operate in the corresponding frequency bands. It will be appreciated, however, that the peaks 902, 904, 905 are nonetheless significant and represent possible further operational frequency bands for the patch 318. To arrange the patch 318 for commercial operation in the frequency bands corresponding to peaks 902, 904, 905, it would be desirable to improve the value of the respective return losses by adjustment of the shape size and/or position of the slots in accordance with the teaching described above. It is also noted that the resonance peak 902 is close to the GPS frequency band and if it is desired for the patch 318 to operate in the GPS band, then this too can be achieved by manipulation of the slots in accordance with the teaching described above. Similar comments apply with respect to the resonance peaks 904, 905, which lie very close to the Bluetooth frequency band.

[0071] It will be understood that the effects described

above may be obtained using one or more slots, not necessarily three slots as used in the preferred embodiment. For example, one slot may be used on its own, particularly in cases where it is only desired to provide a patch for operation in only two frequencies. More than one slot is preferred as it facilitates the adjustment of a larger number of frequency bands - for example, one slot can be used to adjust the frequency value and/or return loss value primarily in one resonant frequency state, while another slot can be used to adjust the frequency value and/or return loss value primarily in another resonant frequency state.

[0072] For example, in the design of the patch 318 of Figure 7, the first slot 330 was used primarily to adjust the value of the resonance frequency in the resonant state shown in Figure 8a (corresponding to the GSM frequency band) but also to adjust the return loss value in the resonant state corresponding to the DCS frequency band (Figure 8c). The second slot 332 was also used primarily to adjust the frequency value in the resonant state corresponding to GSM. The third slot 334 was used primarily to adjust the value of the frequency in the resonant state corresponding to DCS.

[0073] In general, for determining the arrangement of one or more slots in order to adjust one or more resonant frequencies, it is found that placing a slot (or part of a slot) in, or adjacent, an area of significant electromagnetic radiation in a particular resonant state increases the current density in said area thereby lowering the frequency of radiation in that state. Increasing the length of the slot (or part-slot) in said area also increases the current density and decreases the radiation frequency (and vice versa). Moving the slot (or part-slot) closer to a patch edge that radiates in said resonant state also increases the current density around the slot (or-part slot) thereby lowering the radiation frequency (and vice versa). Similarly, moving a slot (or part-slot) into or towards an area of higher radiation density further increases current density and lowers frequency. Further, the slot(s) can give rise to additional resonant states that are not appreciable in an unslotted patch. This is particularly the case when the slot(s) (or part-slot(s)) are located in close proximity with, and substantially in parallel with, a patch edge.

[0074] In this connection, with respect to the patch 318, it is found that the addition of the first slot 330, and its movement away from patch edge 342 decreases the value of the lowest operational frequency (Figure 8a - corresponding to GSM). The addition of the second slot 332, and its movement away from patch edge 336 also decreases the value of the lowest operational frequency (Figure 8a - corresponding to GSM) and that moving the slot 332 beyond the feed point 326 causes said lowest operational feed point 326 to be effectively lost.

[0075] Increasing the length of the feet 337 of the slot 332 causes the resonant frequencies shown in Figures 8a, 8b, 8d and 8e to be lowered but also results in a poorer return loss value in the band corresponding to

Figure 8b. Increasing the length of the feet 335 of slot 330 acts to shift the operational frequencies shown in Figures 8a, 8b, 8d and 8e lower (and vice versa). Shortening the length of the body portions 331, 333 serves to increase the operational frequency values in the resonant states of Figures 8a, 8b, 8d and 8e, but gives a poorer return loss value in the frequency bands of Figures 8a and 8b. It is noted that increasing the width of the slots 330, 332 does not have a significant affect on the performance of the patch 318.

[0076] It will be understood that for a patch of different dimensions, the resonance states of both a slotted or unslotted patch may occur in different frequency bands to those described above and so the slots may have effect in different frequency bands.

[0077] It will be understood that the slot design techniques described herein may be applied to patches that are not necessarily fed from a point on a diagonal.

[0078] Having more than one slot in the patch is preferred as this facilitates manipulation of more than one operational frequency. It will be appreciated, however, that an operable patch may also be achieved using only one slot.

[0079] It will also be understood that the or each slot does not necessarily have to be I-shaped. It is preferred, however, that at least one slot includes a first and a second non-parallel slot portions. This increases the length of slot edges in a given area (for example around the feet) which increases the effect that the slot has on the operational frequencies. More preferably, the first and second slot portions are substantially perpendicular with each other. This is particularly useful for generally rectangular patches as it allows the slot to be positioned with a respective portion substantially parallel with a respective patch edge. For a non-rectangular patch, the relative angle between the first and second slot portions can be set accordingly. A skilled person will appreciate that there are many different slot shapes that may be used to take advantage of the teaching of the invention. For example, the feet portions of the slot need not necessarily be located at the very end of the body portion.

[0080] The second non-parallel slot portion need not necessarily be integral with the first slot portion. For example, for an I-shaped slot, the feet portions may be detached from the body portion. This results in a decrease in current density particularly in the area between the feet portions and the body portion. The reduction in current density leads to an increase in operational frequency in the resonant states where the key radiation areas include the area around the feet portions, namely the resonant states shown in Figures 8a, 8b, 8d and 8e. It is also found that separating the feet from the body improves the return loss value in the DCS frequency band (Fig. 8c).

[0081] It is also possible to omit the second slot portion. For example, the feet portions of an I-shaped slot may be omitted. This leads to a decrease in current density in the areas where the feet would have been which

in turn leads to an increase in operational frequency in the resonant states where the key radiation areas include the area around the feet portions, namely the resonant states shown in Figures 8a, 8b, 8d and 8e. It is also found that omitting the feet gives a poorer return loss value in the frequency bands shown in Figures 8a and 8b.

[0082] A further alternative is to omit at least part of the body portion of the slot. For example, for an I-shaped slot as shown in Figure 7, the mid-portion of the slot body may be removed to leave two spaced apart T-shaped slots. This arrangement is suitable in cases where the patch is intended for operation in frequency bands where the mid-portions of the slots do not play a significant role. For example, for a patch intended to operate in the frequency bands shown in Figures 8a and 8b only, the mid-portions of slots 330, 332 do not play a significant role (see Figures 8a and 8b) and may be omitted.

[0083] It is generally desirable for an antenna to produce as symmetrical a radiation pattern as possible, and so it is preferred if the slots are generally symmetrical in shape and generally symmetrical in arrangement in the patch.

[0084] It will be understood that the patch need not necessarily be rectangular, or generally rectangular, in shape. For example, the patch may be shaped to conform with the shape of the apparatus, e.g. mobile telephone handset, into which it is to be incorporated.

[0085] It will also be understood that the invention is not limited to use with antennas in which the patch is fed directly with an excitation signal. Other conventional feed arrangements, such as coupling, coplanar waveguide or microstrip feedline, can also be used. In each case, the feed point is arranged, in accordance with the invention, to be substantially on, or in-line with, a notional line from a corner of the patch to the centre of the patch.

[0086] It will be understood that the patch 118, 218, 318 is capable of both transmitting and receiving signals in multiple frequency bands. Preferably, the patch 218, 318 of the invention is mounted on a front end module (FEM) that is arranged for both transmitting and receiving signals in the appropriate frequency bands. However, the patch 218, 318 may alternatively be used with an FEM that is receive-only or transmit-only.

[0087] It is also noted that the patches 118, 218, 318 may resonate in further frequency bands than described herein. For example, in Figure 6 a small Return Loss Peak 604 is present at approximately 2750 MHz. However, such additional Return Loss Peaks are not utilised by the preferred embodiment of the invention.

[0088] The invention is not limited to the embodiments described herein which may be modified or varied without departing from the scope of the invention.

Claims

1. An antenna comprising a multi-sided conductive patch arranged to resonate when excited by an electromagnetic signal; and a feed mechanism arranged to provide electromagnetic signals to said conductive patch, wherein said feed mechanism is arranged to feed electromagnetic signals to a point substantially on, or in-line with, a notional line through a corner and the centre of the conductive patch.
2. An antenna as claimed in claim 1, wherein the feed mechanism is arranged to provide a direct feed to the conductive patch.
3. An antenna as claimed in claim 1 or 2, wherein the conductive patch is generally rectangular in shape and the feed point is substantially on, or in-line with, a diagonal of the patch.
4. An antenna as claimed in any preceding claim, wherein the antenna further comprises a dielectric substrate having first and second oppositely disposed surfaces, said patch being provided on said first surface, and a conductive layer provided on said second surface and arranged to act as a ground plane.
5. An antenna as claimed in claim 4, wherein the antenna is formed from microstrip.
6. An antenna as claimed in any preceding claim, wherein one or more slots are formed in the conductive patch, at least one of said slots being arranged to increase the current density in one or more areas of the patch during resonance in one or more frequency bands thereby lowering said one or more frequency bands.
7. An antenna as claimed in claim 6, wherein at least one of said slots is arranged to adjust the effective impedance of the conductive patch in one or more resonant frequency bands in order to improve the Return Loss value of the patch in said one or more frequency bands.
8. An antenna as claimed in claim 6, wherein at least part of at least one of said slots is positioned in close proximity with an edge of the patch so that said at least one slot part radiates electromagnetic energy in a frequency band other than the natural resonant frequency bands of the patch.
9. An antenna as claimed in claim 6, wherein at least one slot includes a first and a second non-parallel slot portions.
10. An antenna as claimed in claim 9, wherein said first and second slot portions are substantially perpendicular with each other.
11. An antenna as claimed in claim 9, wherein said at least one slot is substantially "I"- shaped.
12. An antenna as claimed in any of claims 6 to 11, wherein the antenna includes a first and a second slot, one on either side of the feed point, each slot having an elongate body portion with a respective foot portion at, or adjacent, either end of the body portion, the slots being arranged so that the respective elongate body portions are substantially parallelly disposed with respect to one pair of opposing edges of the patch and that the respective foot portions are located in close proximity with the other pair of opposing patch edges.
13. An antenna as claimed in claim 12, wherein said one pair of opposing patch edges are the patch edges that radiate electromagnetic energy during resonance in a frequency band in respect of which the conductive patch is designed primarily to resonate.
14. An antenna as claimed in claim 12 or 13, wherein said first and second slots are substantially "I"-shaped and said respective foot portions are arranged to be substantially parallelly disposed to said other opposing patch edges.
15. An antenna as claimed in any of claimed 12 to 14, wherein the patch includes a third slot located between, and substantially perpendicularly with, said first and second slots.
16. A method of designing a multi-band antenna comprising a multi-sided conductive patch arranged to resonate when excited by an electromagnetic signal; and a feed mechanism arranged to provide electromagnetic signals to said conductive patch, the method including providing a feed point substantially on, or in-line with, a notional line through a corner and the centre of the conductive patch so that the conductive patch is capable of resonance in more than one frequency band; and providing one or more slots in the patch to manipulate the frequency bands in which resonance occurs.

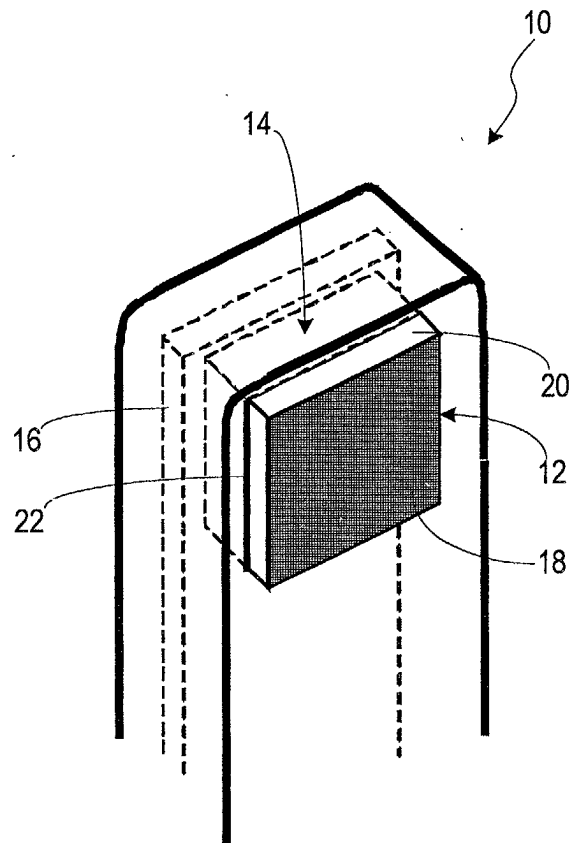


FIG. 1

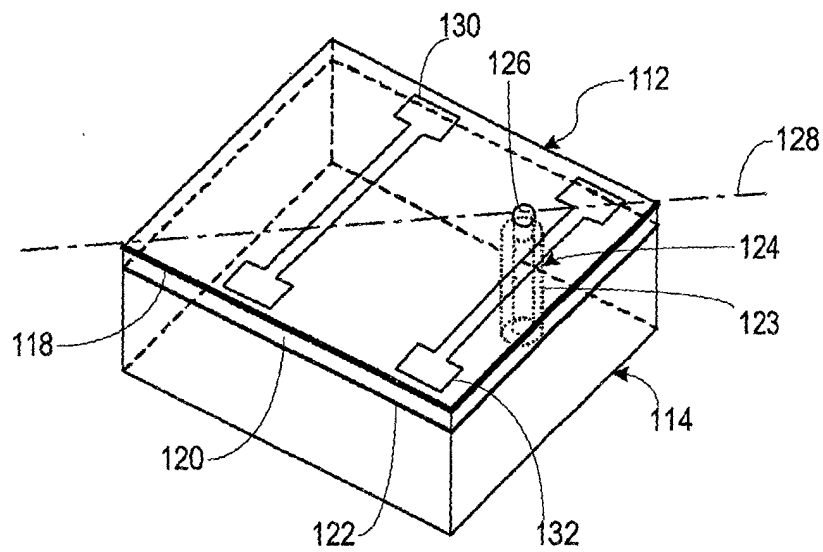


FIG. 2

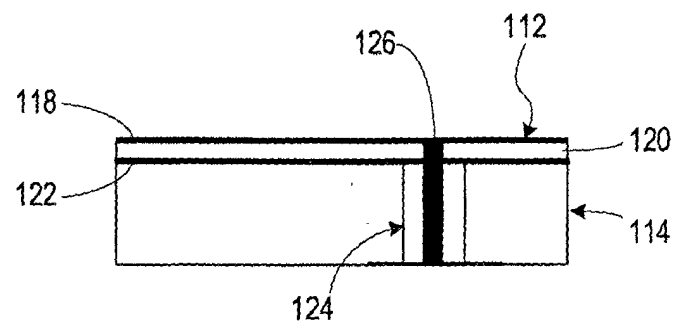


FIG. 3

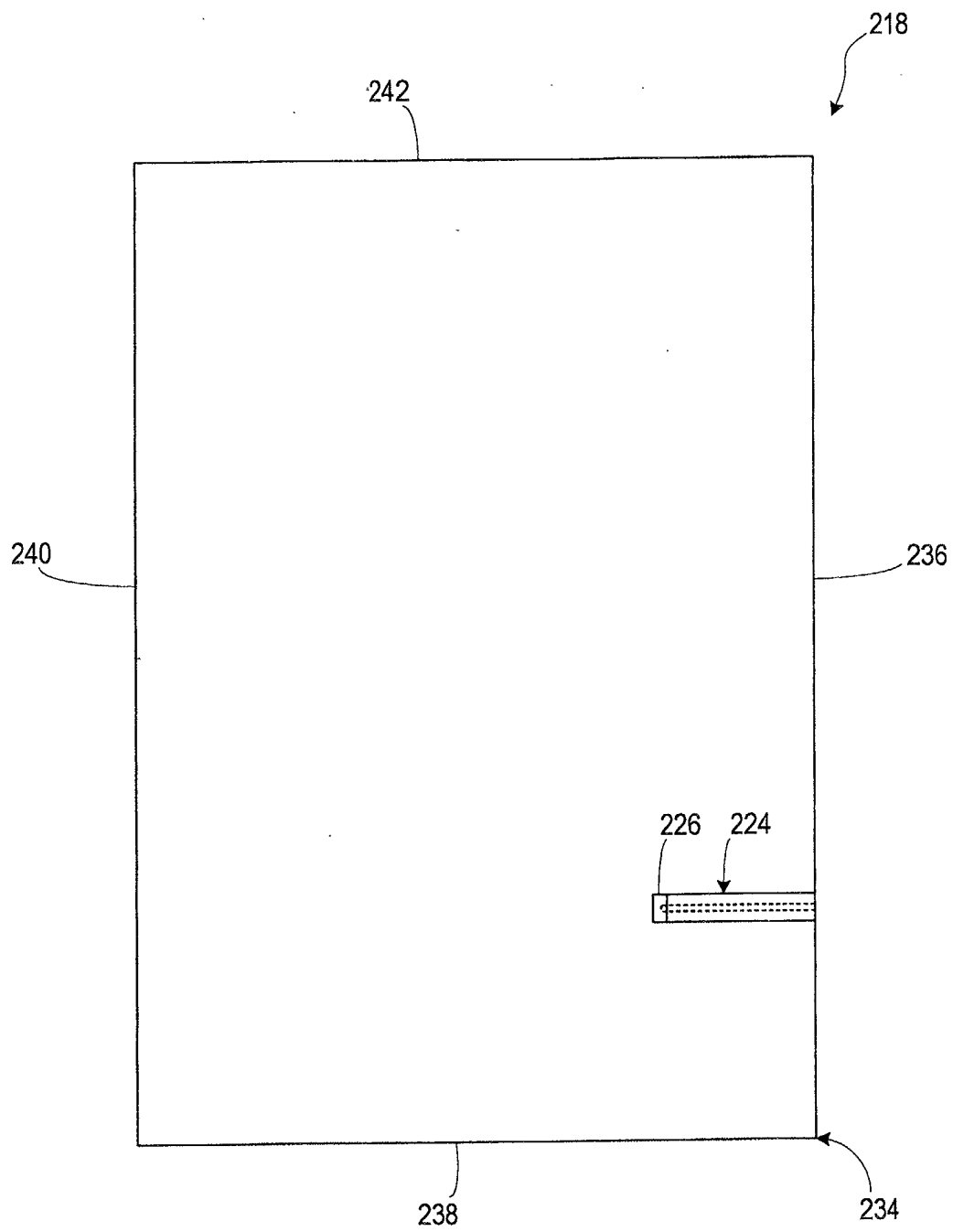


FIG. 4

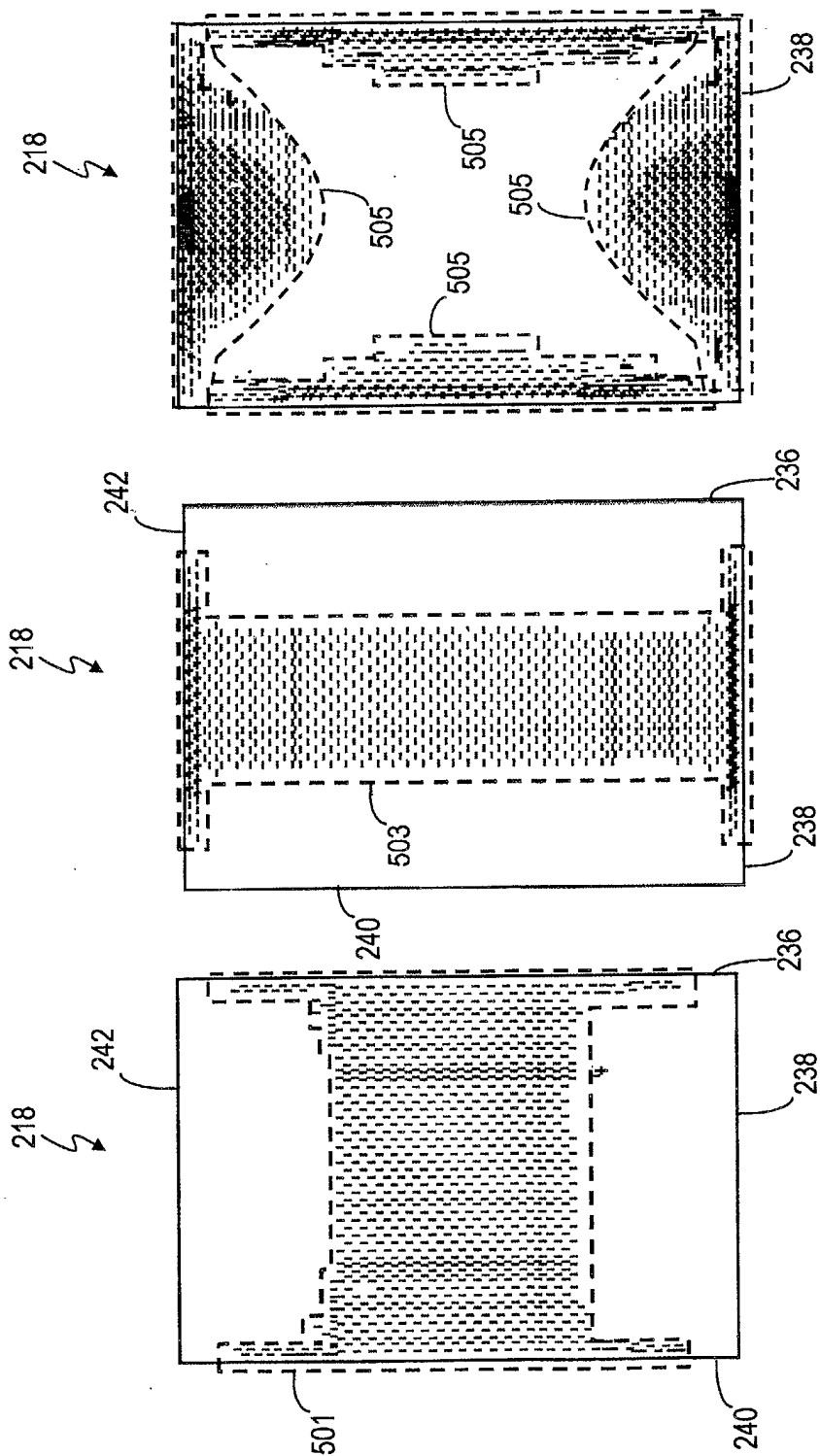


FIG. 5c

FIG. 5b

FIG. 5a

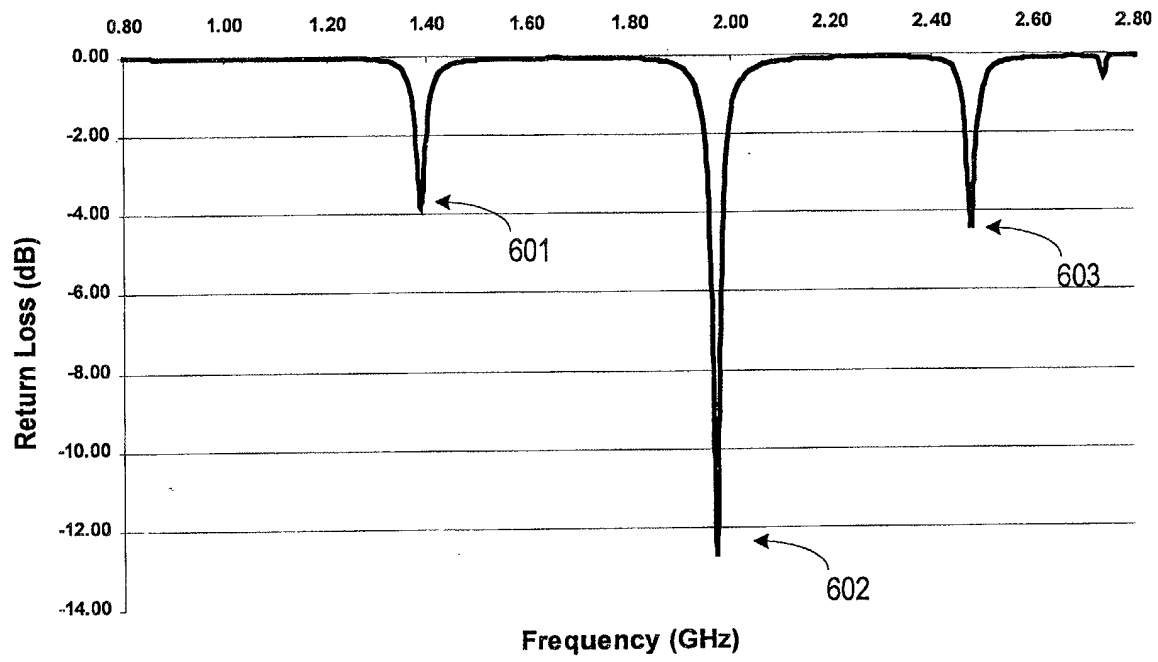


FIG. 6

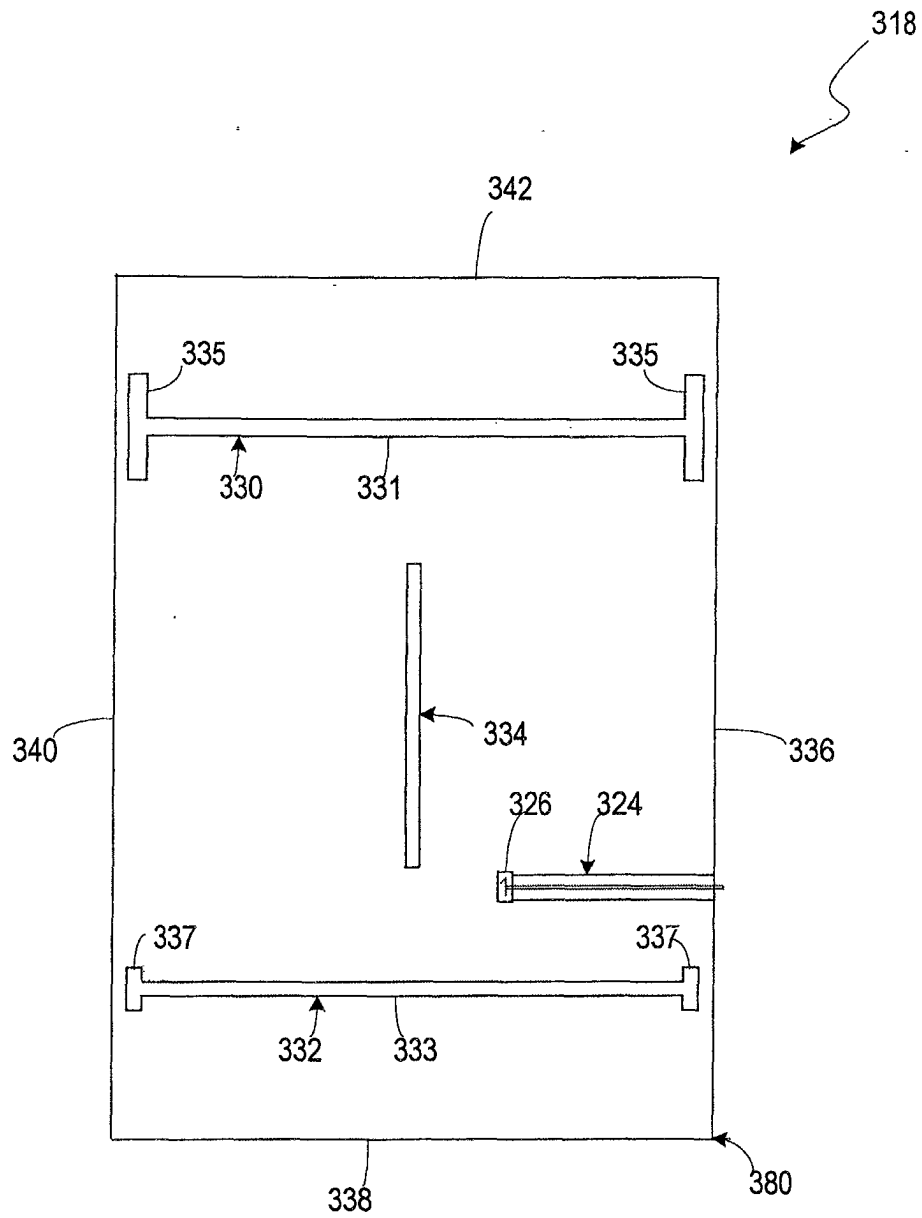


FIG. 7

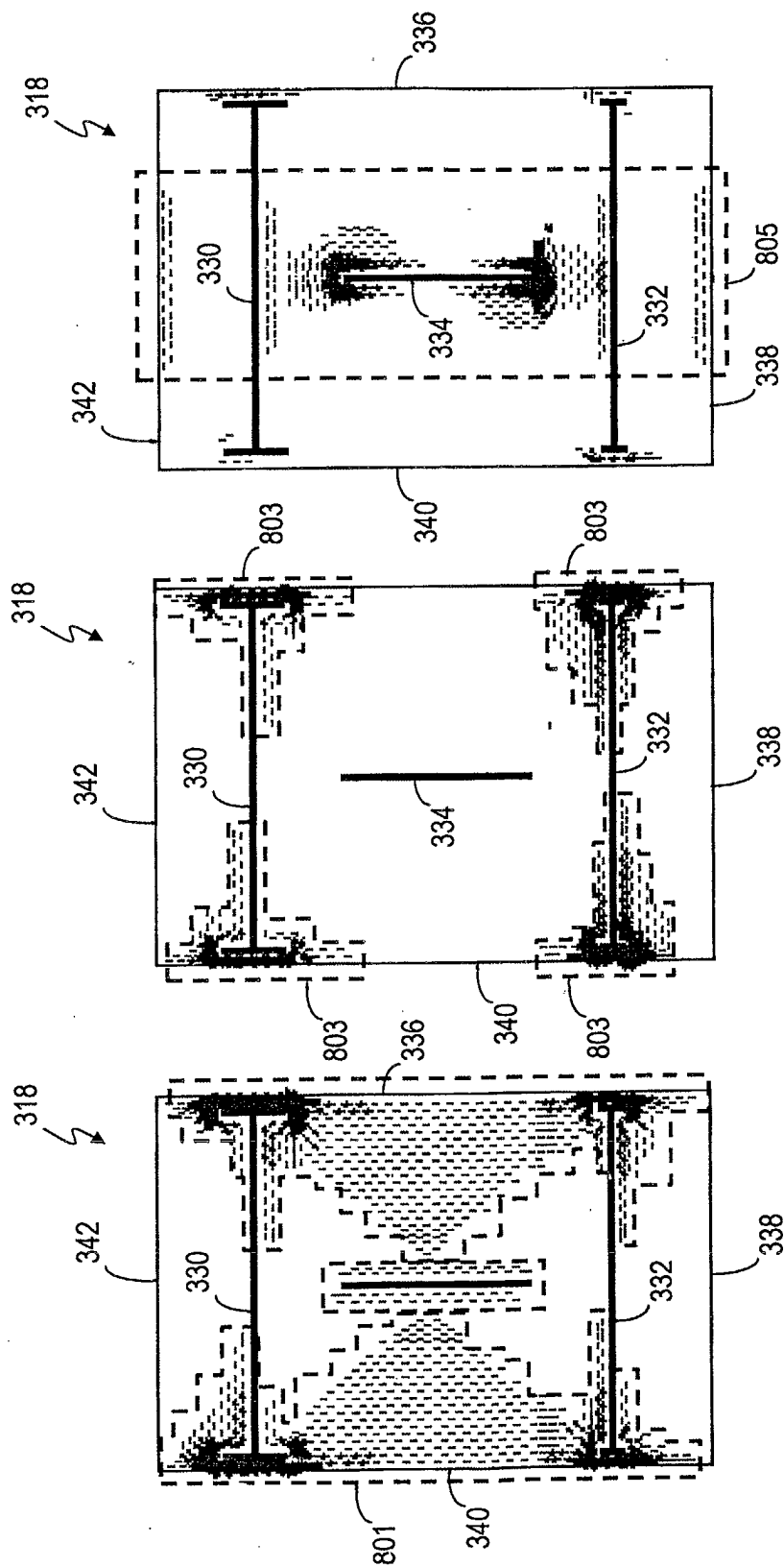


FIG. 8a

FIG. 8b

FIG. 8c

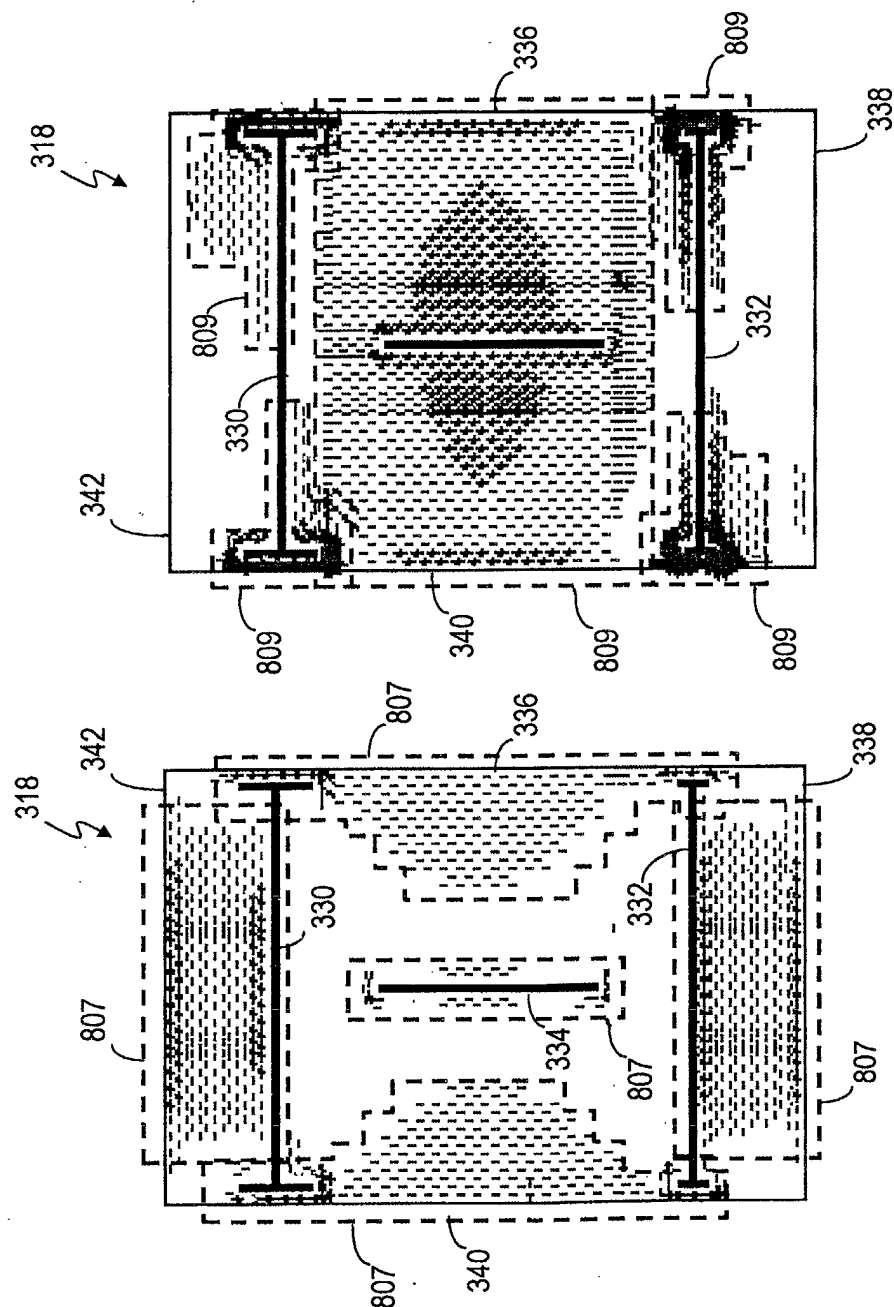


FIG. 8e

FIG. 8d

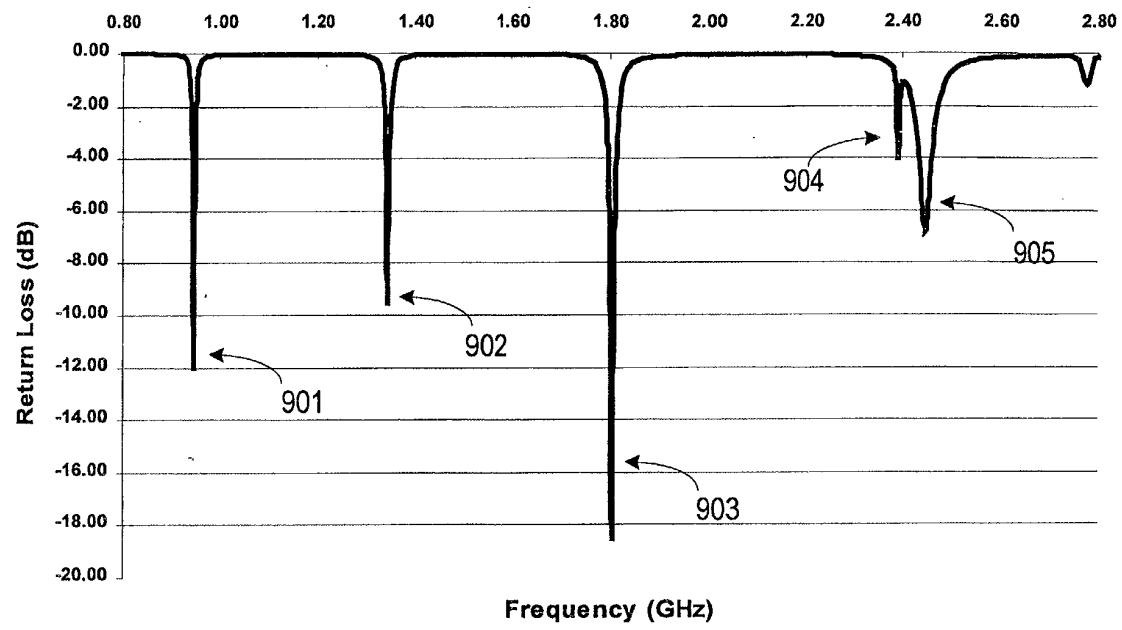


FIG. 9

Dielectric Constant	$\epsilon_r := 10$		
Substrate Thickness	$t := 1.2$		
Design Frequency	$f_r := 1.8 \cdot 10^9$		
Speed of Light	$c := 3 \cdot 10^{11}$		
Loss Tangent	$\tan \delta := 0.0175$		
Free Space Wavelength	$\lambda_0 := \frac{c}{f_r}$		
	$\lambda_0 = 166.667$		
Feed Point Impedance	$Z_0 := 50$		
	$\pi := \frac{22}{7}$		
Patch Antenna Width	$w := \left(\frac{c}{2 \cdot f_r} \right) \cdot \left(\frac{\epsilon_r + 1}{2} \right)^{-\frac{1}{2}}$	$\Rightarrow w = 35.533$	[1]
Effective Dielectric Constant	$\epsilon_{eff} := \left(\frac{\epsilon_r + 1}{2} \right) + \left[\frac{\epsilon_r - 1}{2 \cdot \left[1 + 10 \cdot \left(\frac{t}{w} \right) \right]^{0.5}} \right]$	$\Rightarrow \epsilon_{eff} = 9.391$	[2]
Patch Antenna Length uncertainty	$\Delta L := 0.412 \cdot t \cdot \left[\frac{(\epsilon_{eff} + 0.3) \cdot \left(\frac{w}{t} + 0.262 \right)}{(\epsilon_{eff} - 0.258) \cdot \left(\frac{w}{t} + 0.813 \right)} \right]$	$\Rightarrow \Delta L = 0.515$	[3]
Patch Antenna Length	$L := \left(\frac{c}{2 \cdot f_r \cdot \sqrt{\epsilon_{eff}}} \right) - (2 \cdot \Delta L)$	$\Rightarrow L = 26.164$	[4]
	$\frac{w}{L} = 1.358$		

FIG. 10



European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 01 20 2677

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.7)
X	SZE JIA-YI ET AL: "Broadband rectangular microstrip antenna with pair of toothbrush-shaped slots" ELECTRONICS LETTERS, IEE STEVENAGE, GB, vol. 34, no. 23, 12 November 1998 (1998-11-12), pages 2186-2187, XP006010604 ISSN: 0013-5194 * the whole document *	1-14,16	H01Q1/36 H01Q1/38 H01Q9/04 H01Q5/00
A	ZÜRCHER J-F AND GARDIOL F.E.: "Broadband Patch Antennas" 1995, ARTECH HOUSE, BOSTON, USA XP002184167 * section 2.5 Broadbanding * * page 37 - page 40 *	10,11,14,15	
X	LU J-H AND WONG K-L: "Slot loaded, meandered rectangular microstrip antenna with compact dual-frequency operation" ELECTRONICS LETTERS, IEE STEVENAGE, GB, vol. 34, no. 11, 28 May 1998 (1998-05-28), XP000846178 ISSN: 0013-5194 * the whole document *	1-8,12,13,16	TECHNICAL FIELDS SEARCHED (Int.Cl.7) H01Q
A		15	
X	FANG SHYH-TIRNG ET AL: "Bandwidth enhancement of inset-microstrip-line-fed equilateral-triangular microstrip antenna" ELECTRONICS LETTERS, IEE STEVENAGE, GB, vol. 34, no. 23, 12 November 1998 (1998-11-12), pages 2184-2186, XP006010612 ISSN: 0013-5194 * the whole document *	1-7,9,12,13,16	
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 30 November 2001	Examiner Van Dooren, G
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

EPO FORM 1503 03.82 (PC4C01)



European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 01 20 2677

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.7)
X	WONG K-L ET AL: "BROADBAND TRIANGULAR MICROSTRIP ANTENNA WITH U-SHAPED SLOT" ELECTRONICS LETTERS, IEE STEVENAGE, GB, vol. 33, no. 25, 4 December 1997 (1997-12-04), pages 2085-2087, XP000773551 ISSN: 0013-5194 * the whole document *	1-7,9,10,16	
X	US 6 181 281 B1 (MADIHAN MOHAMMAD ET AL) 30 January 2001 (2001-01-30) * figure 5 *	1-8,16	
			TECHNICAL FIELDS SEARCHED (Int.Cl.7)
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 30 November 2001	Examiner Van Dooren, G
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

EPO FORM 1503 03.02 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 01 20 2677

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

30-11-2001

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 6181281 B1	30-01-2001	JP 3177967 B2	18-06-2001
		JP 2000165134 A	16-06-2000
		JP 2000165135 A	16-06-2000

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82