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Compact Omni-directional Broadband Monopole Antenna

Field of the invention

- 5 The present invention relates to a broadband circular monopole antenna, and to communication systems which employ the antenna.

Background of the invention

- UWB is one of the most popular wireless communication technologies. It has
10 features such as high transmission speed and low power consumption. An UWB antenna should ideally have good impedance matching and omni-directional radiation patterns.

- U.S. Patent Application. No. 2005/0243009 [1] discloses an omni-directional
15 broadband monopole antenna with a gain variation in its horizontal radiation pattern of less than 3 dB, but this antenna is a 3-D structure disposed on a broad ground plane, which is difficult to fabricate and hard to integrate into a portable transceiver.

- 20 Recently, planar monopole antennas have been more frequently used because they are easy to fabricate, low in cost and highly integrated. Printed monopole antennas provide wide bandwidths and satisfy radiation properties and therefore have been widely studied, for example in [2, 3]. Typically, a conductive patch, such as a circular patch, is printed onto a first side of a

substrate, and a conductive layer is provided on the other side of the substrate to act as a ground plane. The conductive patch is fed by a microstrip line or CPW (coplanar waveguide), which contacts one edge of the circular patch. Originally, the diameter of the patches was selected to be about half the wavelength corresponding to the centre frequency of the bandwidth of the antennas, but recently wider patches have been used to give better performance (though antennas of this kind are still sometimes referred to as "half-wavelength antennas").

In order to increase the impedance bandwidth or to realize frequency band rejection characteristics, it has been proposed to add narrow slits/slots to the conductive patches [4, 5]. [4] discloses an arrangement in which a rectangular conductive patch [5] includes an inverted U-slot and also a narrow slot to increase impedance bandwidth. The narrow slot is spaced from the axis of symmetry of the patch by 0.15λ , where λ is the wavelength of the radiation at its desired operating frequency (5.45GHz). [5] discloses an arrangement in which the antenna includes a circular region having two slots formed within it, on either side of the axis of symmetry of the antenna.

The direction perpendicular to the substrate is conventionally denoted as the z-direction, the direction on this surface transverse to the direction in which the microstrip line extends is denoted as the x-direction, and the direction in which the microstrip extends is denoted as the y-direction. θ represents the angle with

the z-axis, and φ represents the corresponding angle with the x-axis in the x-y plane.

Although the configurations of [4, 5] provide antennas with a wide band (from
5 3.1 GHz to 10.6 GHz) and with a good omni-directional pattern in the x-z plane
($\theta=90$, $\varphi=0$), they do not attempt to obtain a good radiation pattern in the y-z
plane ($\theta=90$, $\varphi=90$), which is also important for some applications. For example,
if the antenna is used in a portable device, then due to the pitches and yaw
movement of the portable device, it would be desirable to have a good radiation
10 pattern in the y-z plane to maintain an invariant gain which is important for
maintaining a constant link performance. By contrast, conventional designs of
omni-directional antennas focus on the x-z plane (elevation) and ignore the y-z
plane (elevation).

15 Summary of the invention

The present invention aims to provide a new and useful monopole antenna, and
a new and useful communication system employing the antenna.

20 In general terms, the present invention proposes an omni-directional monopole
antenna which comprises a substrate, a ground plane, a radiating element and
a microstrip line which is connected to the radiating element to feed the
antenna. The ground plane may be a piece of metal, and is provided on the

opposite side of the substrate from the radiating element and microstrip. The radiating element is a printed circular patch with a single slot on one side of the radiating element. The position of the slot is selected to provide a sufficiently wide impedance bandwidth and improved omni-directional radiation patterns in the elevation (y-z plane) direction in a desired range of operating frequencies.

In one expression of the invention, the slot is spaced from a centre line of symmetry of the antenna by a distance substantially equal to 0.25λ at the frequency corresponding to the centre of the desired bandwidth. (for example, in the range 0.20λ to 0.30λ , or more preferably 0.22λ to 0.28λ). Generally, this corresponds to the slot being spaced from the centre of the radiating element by about one quarter of the diameter of the radiating element.

In another expression of the invention, the antenna is circular or elliptical (having its major or minor axis in the x-direction), and the single slot is located to one side of an axis of symmetry of the antenna (extending in the y-direction). This scenario may achieve broader impedance bandwidth and better omni-directional property in the y-z elevation plane.

Typically, the microstrip line is a 50- Ω microstrip line. The width of the slot may be in the range from 0.5 to 1.0 times that of the microstrip. Preferably it is substantially 0.5 times that of the microstrip.

The slot, which is straight, extends, parallel to the microstrip, from an edge of the conductive patch. It preferably extends to about a line of symmetry of the patch transverse to the length direction of the slot (for example, if the slot is circular, it may extend as far as the diameter of the patch parallel to the x-direction). However, we have found experimentally that a shorter slot is also effective.

According to the present invention, the slot on one side of the radiating element monopole antenna may improve the y-z plane (elevation) omni-directional radiation pattern. Thus, in applications which benefit from reduced gain variation in this plane, the received or transmitted signals will have a better quality. For example, in a portable item of consumer electronics (such as a personal digital assistant (PDA)), the antenna may rotate with both pitches and yaw, so it is advantageous to have a uniform omni-directional radiation pattern in both the x-z plane and y-z plane to maintain a constant gain. Due to the inherently smaller gain of an omni-directional antenna than other forms of antenna, a system with a moving omni-directional antenna has stricter requirements on the omni-directional radiation patterns in both the x-z plane and the y-z plane. Otherwise, the signals received by the receiver may be quite weak, and the system may not be able to maintain constant performance.

Brief description of the drawings

A non-limiting embodiment of the invention will now be described for the sake of example only with reference to the following figures in which:

FIG. 1(a) is a front view of a circular disc monopole antenna which is a first embodiment of the invention;

FIG. 1(b) is a side view of the first embodiment of the invention;

FIG. 2(a) shows simulation results of the return loss of the first
5 embodiment of the invention;

FIG. 2(b) shows comparative results of return loss of a circular disc monopole antenna identical with the first embodiment except that it does not contain a slot;

FIG. 3(a) shows simulation results of the radiation pattern in the y-z
10 plane (elevation) of the first embodiment of the invention at a series of frequencies in an operating band;

FIG. 3(b) shows the radiation pattern in the y-z plane (elevation) of the circular disc monopole antenna of FIG. 2(b) at a series of frequencies in the operating band;

15 FIG. 4(a) a gain diagram obtained by simulation of the first embodiment of the invention;

FIG. 4(b) is a gain diagram of the circular disc monopole antenna of FIG. 2(b).

FIG. 5(a) is a front view of an elliptical monopole antenna which is a
20 second embodiment of the invention;

FIG. 5(b) is a side view of the second embodiment of the invention;

FIG. 6(a) shows simulation results of the return loss of the second embodiment of the invention;

FIG. 6(b) shows simulation results of the return loss of an elliptical monopole antenna which is identical to the second embodiment except that it does not include a slot;

FIG. 7(a) shows simulation results of the radiation pattern in the y-z plane (elevation) of the second embodiment of the invention at a series of frequencies in an operating band;

FIG. 7(b) shows simulation results of the radiation pattern in y-z plane (elevation) of the elliptical monopole antenna of FIG. 6(b);

FIG. 8(a) is a gain diagram obtained by simulation of a second embodiment of the invention; and

FIG. 8(b) is a gain diagram for the elliptical disc monopole antenna of FIG. 6(b).

Detailed description of the drawings

Referring firstly to FIGS. 1(a) and 1(b), an omni-directional circular monopole antenna is illustrated which is a first embodiment of the invention. The antenna comprises a cuboidal dielectric substrate 1. On a first major surface of the substrate 1 (i.e. a surface in the x-y plane) are formed a circular radiating element 3 of diameter d and a feed line 7. On the opposite major surface of the substrate 1 is formed a ground plane 5. FIG. 1(a) is drawn as if the substrate 1 were transparent (i.e. such that the ground plane 5 is visible when the substrate 1 is viewed looking, opposite to the z-direction, towards the surface on which the radiation element 3 and feed line 7 are formed). FIG. 1(b) is a view in the x-

direction. The radiating element 3 is a circular disc with a slot 9 on one side.

The ground plane 5 is a metal plate. The feed line 7 is a $50\text{-}\Omega$ microstrip line, which joins the radiation element 3 at a “feed point”. The ground plane extends in the y direction almost as far as the feedpoint, but (though this is not visible in FIGS. 1(a) and 1(b)) there is a small gap between the feed point and the upper edge of the ground plane 5 (as viewed in FIG. 1(a)). That is, the feed point is further in the y-direction than the upper edge of the ground plane 5.

We have found that, as confirmed by the simulation results presented below,

good omni-directional radiation (i.e. reduced gain variation in the elevation (y-z) plane radiation) and good omni-directional characteristics in the x-z plane, are obtained if the center of the slot on the radiating element is close to half way along the radius of the circular radiating element 3. That is, the distance e indicated on FIG. 1(a), between the diameter of the conductive patch 3 in the y-direction (which coincides with the centre line of the microstrip 7) and the centre of the slot 9, is one quarter of the diameter of the circular radiating element 3.

This corresponds to e being about one quarter of the wavelength λ in the substrate corresponding to the centre-frequency of the bandwidth of radiation emitted by the radiating element. The width of the slot 9 is chosen as about half the width of the $50\text{-}\Omega$ microstrip line 7.

FIG. 2(a) shows simulation results of the return loss of the antenna of FIG. 1(a), using a diameter d of 36.8mm. The dielectric constant of the substrate is 3.38.

For comparison, FIG. 2(b) shows simulation results for an antenna identical to that of FIG. 1(a) in the case that the slot 9 is not present (all the other parameters kept unchanged). In each of FIGS. 2(a) and (b) the vertical axis shows the return loss and horizontal axis the operating frequency.

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The center frequency is here preferably defined as half the sum of the lower VSWR 2:1 frequency (3.3 GHz in FIG. 2(a)) and higher VSWR 2:1 frequency (6.5 GHz in FIG. 2(a)), that is, $(3.3+6.5)/2=4.9$ GHz. Note that other definitions are known in this field. For example, it may be defined as the return loss (s_{11}) dip. For the antenna of the first embodiment, that is 4.5 GHz as shown in FIG. 2(a).

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The center operating frequency is such that the corresponding wavelength in the substrate is less than twice the diameter of the circular patch. As shown in FIG. 2(a), with a bandwidth definition of 9.6 dB return loss (2:1 VSWR), the impedance bandwidth is from 3.3 GHz to 6.5 GHz for the first embodiment. As shown in FIG. 2(a), the impedance bandwidth ranges from 3.5 GHz to 5.6 GHz for the antenna without the slot.

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FIG. 3(a) is the radiation pattern of the first embodiment in the y-z plane. FIG. 3(b) is the corresponding pattern for the antenna without the slot. In these figures, it will be seen that the gain variation is apparently improved by the adding of the slot. FIG. 4(a) shows the maximum total field gain of the first embodiment, against frequency within the operating frequency band. FIG. 4(b)

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shows the maximum total field gain against frequency of the antenna without the slot. As will be seen, the gain also is improved by the slot.

Turning to FIGS. 5(a) and (b), a second embodiment of the invention is shown.

5 Elements corresponding to those of FIGS. 1(a) and (b) are denoted by the same reference numerals. The only difference between the first and second embodiments is that in the second embodiment the radiating element 3 is elliptical, with its major axis in the x-direction and its minor axis in the y-direction. The ground plane 5 and the feeding microstrip line 7 in the second
10 embodiment are the same as the first embodiment. In the x direction, the primary axis diameter was 27.2mm, and in the y direction it was 24.3mm.

FIG. 6(a) shows simulation results of the return loss of the antenna of the second embodiment. FIG. 6(b) shows corresponding results for an elliptical
15 monopole antenna without the slot (all the other parameters kept unchanged). The centre operating frequency corresponds to a wavelength in the substrate which is less than twice the primary axis diameter. As shown in FIG. 6(a), the impedance bandwidth (2:1 VSWR) is from 3.4 GHz to 6.1 GHz for the second embodiment, while as shown in FIG. 6(b) the impedance bandwidth ranges
20 from 3.7 GHz to 5.6 GHz for the antenna without the slot.

FIG. 7(a) shows simulation results of the radiation pattern in the y-z plane of the second embodiment. FIG.7(b) is the corresponding pattern for the antenna without the slot. From these figures it can be seen that the gain variation is

improved by the adding of the slot 9. FIG. 8(a) shows the maximum total field gain of the second embodiment against frequency, for frequencies within the operating frequency band. FIG. 8(b) shows the maximum total field gain against frequency of the antenna without the slot 9. Again it can be seen that gain is improved by the slot 9.

Although the invention has been explained in detail with reference to the two embodiments above, the invention is not limited to these forms, and many variations are possible within the scope of the invention. For example, a further embodiment can be formed which is different from the first and second embodiments only in that the radiating element 3 is square or rectangular. Again, the slot 9 is parallel to the y-direction, and the position of the slot in the x-direction is substantially one quarter of the wavelength of the centre frequency of the bandwidth from the line of symmetry of the radiating element 3 which is parallel to the y-direction (and which coincides with the centre line of the microstrip line 7). Again, we have found by simulation that the slot improves the y-z gain pattern.

References

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Claims

1. A monopole antenna which comprises:
 - a substrate,
 - 5 a conductive ground plane formed on a first surface of the substrate,
 - a circular or elliptical radiating element formed on a second surface of the substrate opposite the first surface; and
 - an elongate microstrip formed on the second surface of the substrate and connected to the radiating element,
 - 10 a single slot being formed in the radiating element and extending from an edge of the radiating element parallel to the microstrip.

2. A monopole antenna which comprises:
 - a substrate,
 - 15 a conductive ground plane formed on a first surface of the substrate,
 - a radiating element formed on a second surface of the substrate opposite the first surface; and
 - an elongate microstrip formed on the second surface of the substrate and connected to the radiating element,
 - 20 a single slot being formed in the radiating element and extending from an edge of the radiating element parallel to the microstrip, the antenna having a bandwidth centred on a frequency corresponding to a wavelength λ in the substrate and the slot being spaced from an axis of symmetry of the monopole antenna by a distance which is substantially $\lambda/4$.

3 A monopole antenna which comprises:

a substrate,

a conductive ground plane formed on a first surface of the substrate,

5 a radiating element formed on a second surface of the substrate opposite the first surface; and

an elongate microstrip formed on the second surface of the substrate and connected to the radiating element,

a single slot being formed in the radiating element and extending from an
10 edge of the radiating element parallel to the microstrip, the antenna having a bandwidth centred on a frequency corresponding to a wavelength λ in the substrate and the slot being spaced from an axis of symmetry of the monopole antenna by a distance which is in the range 0.20λ to 0.30λ .

15 4. An antenna according to claim 3 in which the slot is spaced from the axis of symmetry by a distance which is in the range 0.22λ to 0.28λ .

5. An antenna according to any of claims 2 to 4 in which the radiating element is circular.

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6. An antenna according to any of claims 2 to 4 in which the radiating element is elliptical, with its axes respectively parallel to and transverse to the microstrip.

7. An antenna according to any of claims 2 to 4 in which the radiating element is square or rectangular, with its sides parallel to and transverse to the microstrip.
- 5 8. An antenna according to any preceding claim in which the microstrip is a 50- Ω microstrip line.
9. An antenna according to any preceding claim in which the slot is substantially half the width of the microstrip line.
- 10 10. An antenna according to any preceding claim in which the slot extends to a line of symmetry of the patch transverse to the length direction of the slot.
11. An item of consumer electronics including an antenna according to any
15 preceding claim and electronic circuitry for generating and/or decoding radio signals respectively transmitted or received using the antenna.