

**Conclusions:** The presented circuit can be used to realise three different functions depending on the selected input-output ports and through the adequate choice of its component values. Experimental and simulation results have validated the theoretical analysis presented. The novel V-I converter developed enables floating loads to be excited differentially.

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## High directivity fractal boundary microstrip patch antenna

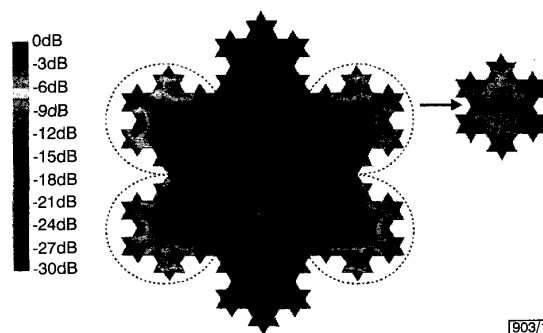
C. Borja, G. Font, S. Blanch and J. Romeu

A novel patch antenna with a fractal boundary condition is proposed. Experimental and numerical results corroborate the fact that the fractal characteristic of the perimeter produces localised modes. This property is utilised in the design of a microstrip patch antenna with a measured directivity of 12.7dB.

**Introduction:** The emergence of antennas with fractal geometries has been a very valuable tool for solving two of the major limitations of classical antennas: the single band performance and the dependence of the operating wavelength on size. The self-similar properties of certain fractals result in antenna with fractal properties having multiband behaviour [1]. On the other hand, the highly convoluted shape of these fractals makes possible the reduction in size of certain antennas [2].

In addition, the use of fractal geometries has been investigated by physicists and mathematicians. In particular, Sapoval and collaborators have studied the acoustical properties of irregular cavities described by fractal shapes. Their theoretical and experimental work into what is known as the 'fractal drum' shows that certain high order fractinos (vibrational modes) of a membrane with a fractal boundary condition exhibit a localisation property [3, 4]. Such fractinos are confined or localised at the boundary. The effect of localisation is to enhance locally the amplitude of the vibration. The spatial localisation of confined fractinos is linked to a Neumann boundary condition for which the boundary region is free to vibrate.

Cavity models for microstrip patch antennas are analogous in their physical behaviour to a 'fractal drum'. Therefore, high order modes with high current density localisation should be expected. As will be shown, under these conditions the microstrip patch antenna behaves as an extended source with dimensions of the order of a wavelength. The result is a microstrip patch antenna with high directivity.



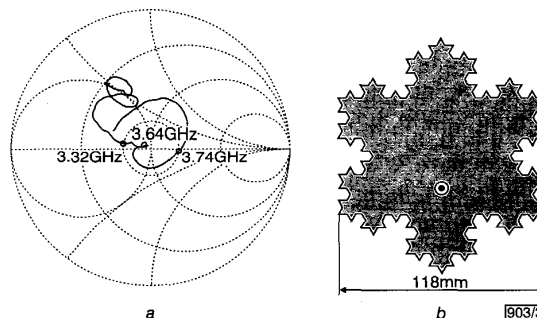
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**Fig. 1** Electric current density magnitude for localised mode of Koch3 patch at 3.5GHz

Circled areas show localised currents; in these areas the current distribution resembles that of a smaller Koch2 patch antenna at the fundamental mode, which is shown on the right

**Antenna description:** The Koch3 patch antenna geometry is shown in Fig. 2b. A three iteration version of the Koch island or 'snowflake' fractal has been built. The fractal patch was etched on a 0.8mm substrate with  $\epsilon_r = 3.38$ . An additional airgap of 7mm between the substrate and the ground plane was introduced. The patch was fed through a coaxial probe.

This antenna presents multiple resonant modes. Fig. 1 displays the computed electric current density magnitude for the sixth resonant mode of the Koch3 patch which occurs at 3.5GHz. Some interesting observations can be made from the current density plot. First, the current density is essentially localised in four regions (dotted circles) of the patch boundary. The current density in these regions is similar to the current density distribution of the fundamental mode of a smaller Koch2 patch antenna, which is also shown in Fig. 1. Therefore, the behaviour of the Koch3 microstrip patch antenna at this high order mode can be interpreted as that of a  $2 \times 2$  array of smaller Koch2 microstrip patch antennas resonating at the fundamental mode.



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**Fig. 2** Input impedance of Koch3 patch antenna at localised mode frequency and Koch3 geometry with annular gap probe compensation

a Input impedance of Koch3 patch antenna at localised mode frequency

Markers show frequency range with return losses smaller than -14dB  
 b Koch3 geometry with annular gap probe compensation  
 Size of patch at 3.5GHz is 1.38 $\lambda$

**Results:** The inductive effect of the feeding probe is considerable since the separation between the patch surface and the ground plane is high in terms of wavelength ( $h_g/\lambda \approx 0.09$ ). A capacitive gap is used to properly compensate the probe inductance. The gap is etched on the patch surface and takes the form of an annular gap around the probe. The feed point is placed at 19.2mm from the centre of the patch and the annular ring has an internal ratio of 4mm and external one of 8mm (Fig. 2).

The measured input impedance is displayed in Fig. 2a. The fractal patch is matched at 50 $\Omega$ , the central marker is placed at the minimum input return loss, and the other two markers correspond to the frequencies for which the input return loss level is -14dB. Therefore, a 12% impedance bandwidth is obtained for an input return loss level of -14dB.

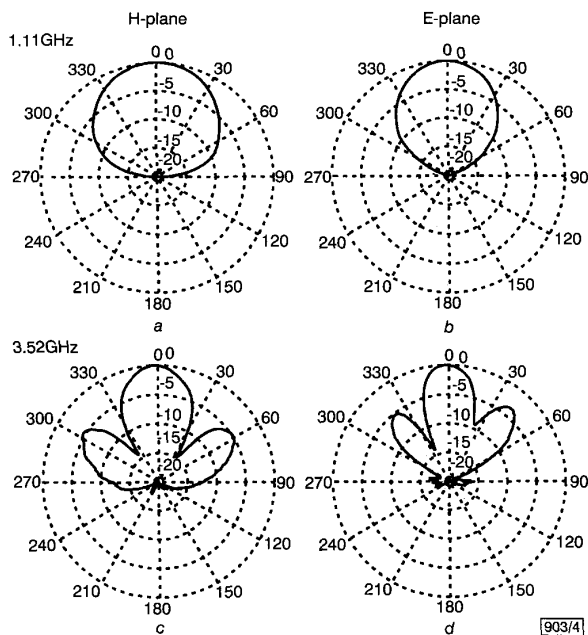


Fig. 3 Koch3 patch radiation pattern main cuts

a, b At frequency of 1.11 GHz corresponding to frequency of fundamental mode  
 Pattern is broad with 9dB directivity  
 c, d Patterns at 3.52 GHz  
 A narrow pattern with 12.7dB directivity is obtained

The main cuts of the measured radiation pattern are displayed in Fig. 3c and d. The cuts are measured at the central frequency of the operating band, 3.52GHz. The pattern is broadside for both planes and the beamwidth is  $36.9^\circ$  in the H-plane and  $27.4^\circ$  in the E-plane; the directivity is  $\sim 12.7$ dB. For comparison in Fig. 3a and b the pattern of the same antenna at the fundamental mode, which occurs at a frequency of 1.11GHz, is shown. At this frequency the patch antenna has a broader pattern with a directivity of 9dB. Therefore, an increase of almost 4dB is achieved.

It must be noted that at a frequency of 3.5GHz the size of the patch is  $1.38\lambda$ , which explains the higher directivity. This also explains the high sidelobe levels of the radiation pattern, as the antenna can be interpreted as being an array with elements spaced more than one wavelength apart.

**Conclusion:** It has been shown that a patch antenna with a fractal boundary exhibits localised modes. The localisation effect produces an electric current density that is mainly concentrated in certain regions at the boundary. The result is that the microstrip fractal boundary antenna behaves as an array of antennas. When the localised modes are properly in phase, a broadside pattern is obtained and the directivity increases in comparison with the directivity of the antenna at the fundamental mode frequency.

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## Low profile spiral antenna with PBG substrate

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A novel spiral antenna backed on photonic bandgap (PBG) material is presented. It consists of a spiral radiator, a PBG substrate and a feed network; and exhibits a wider frequency bandwidth, larger ratio of front-to-back radiation level, and higher gain than a traditional spiral antenna with  $\lambda/4$  spaced ground plate.

**Introduction:** A traditional spiral antenna with a unidirectional beam is performed by appropriately backing a cavity or conducting plate, or loading an electromagnetic wave absorber [1]. The former method restricts the bandwidth of a wide band spiral radiator, and the latter results in low efficiency due to the power dissipation. Besides, a spiral antenna fed by a coaxial line requires a broadband balun that will lead to the increment of antenna volume and loss of the advantage of a low profile. By means of the characteristics of photonic bandgap (PBG) material in which the electromagnetic wave propagation is prohibited for a certain frequency band [2], a PBG substrate can be used as a reflector for a spiral antenna to enhance the directive gain and to suppress the surface wave mode [3, 4]. In this Letter, a really low profile, broadband spiral antenna backed with PBG substrate and fed by a coplanar strip (CPS)-coplanar waveguide (CPW)-coaxial line is proposed. Compared to a traditional spiral antenna with a  $\lambda/4$  spaced ground plate,  $\sim 1.15$  times band coverage, 1.3 times gain enhancement and 8.9dB F/B level improvement are obtained.

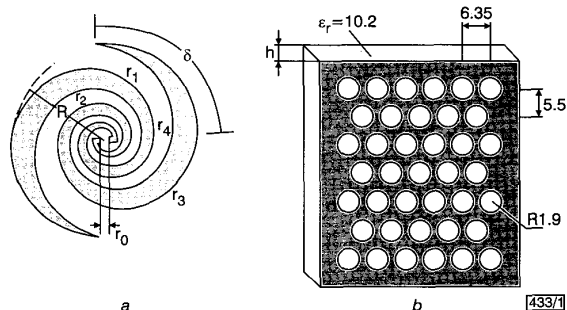


Fig. 1 Equiangular spiral radiator and PBG structure

a Spiral radiator

b PBG structure (dimensions in millimetres)

**Antenna structure:** The novel low profile spiral antenna consists of an equiangular spiral radiator, a PBG substrate and a feed network. The spiral radiator printed on a 1mm thin superstructure with low relative permittivity of 2.65 is placed on the top of the PBG substrate and backed on a ground plate; the feed network is placed under the PBG substrate. The total thickness is  $\sim 3.27$ mm. The designed frequency bandwidth is (2-16) GHz for a spiral radiator with two symmetric arms, which are composed of four equiangular spiral wires. The maximum radius of the spiral radiator is  $\lambda_{max}/4$ , the cut-off minimum radius is  $\lambda_{min}/4$ , and the spiral rate is 0.221. The compensation angle  $\delta = 90^\circ$  is employed (Fig. 1a) to form a self-compensatory structure with frequency-independent