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Compact concentric annular-ring patch antenna for triple-frequency operation

X.L. Bao and M.J. Ammann

A novel single-layer, single-feed concentric annular-ring microstrip patch antenna providing triple-frequency operation is proposed and experimentally studied. This is achieved by embedding a small circular patch into a dual stub-loaded concentric annular-ring structure and by employing a cross-slot in the ground plane. The proposed technique can provide triple-band operation and reduce the antenna size by over 50% compared to the conventional annular-ring patch antenna for a given frequency. Experimental results show the proposed antenna to have impedance bandwidths of 6.38, 6.30 and 35% for the three bands, at 1.17, 1.428 and 1.9 GHz, respectively. The proposed structure is capable of realising a dramatically small frequency ratio. The measured radiation patterns for each band are presented.

Introduction: Both miniaturisation and multiband operation of antennas are essential for the emerging and rapidly developing communication systems. In the last decade, some single-layer single-feed dual-frequency patch antennas fed by a coaxial probe have been reported [1–6]. These structures using patches loaded by slots can excite dual resonant modes, and provide miniaturisation and narrowband operation with at least 3% impedance bandwidth. In this Letter, a compact multiple-frequency antenna fed by a 50 Ω coaxial probe for broadband operation is presented, which consists of a small circular patch embedded in concentric dual annular-rings. The structure is augmented by stub loading and a cross-slot is inserted into the ground plane. This new structure can excite three resonant frequencies by using the outer annular-ring, inner annular-ring, and the circular patch, which decreases the *Q*-factor and increases surface current path lengths, hence a compact broadband triple-frequency antenna is realised. The antenna size is reduced by 50% compared to conventional annular-ring patch antennas. A very small frequency ratio of the order of 1.25 is realisable.

Design of concentric dual annular-ring patch antenna: The single-layer antenna with two copper annular-rings concentrically located around a circular patch is shown in Fig. 1. It is printed on FR4 substrate of thickness 1.52 mm and relative permittivity 4.0, loss tangent $\tan \delta = 0.018$, and a 50 Ω coaxial probe feeds the top patch through a via hole in the bottom layer. The outer radii of the annular rings are given by *R*1 and *R*2 for the two concentric annular-rings. The radius of the circular patch embedded into the annular-rings is *R*3. To reduce the antenna size, a cross-slot of width *w* and *L*1, *L*2 lateral lengths is removed from the ground plane. To adjust the resonant frequency easily and obtain a good match, some stubs of width *N* and the lengths *M*1, *M*2, *M*3, *M*4, respectively, are added to the outer edges of both the annular-ring and the circular patch. For this new antenna structure, the lower operating frequency *f*1 is determined mainly by outer annular-ring dimension, the second frequency *f*2 is due to the inner annular-ring patch, and the higher frequency *f*3 is dependent on the circular patch dimension. Broad impedance bandwidths can be obtained by adjusting the dimensions of the concentric annular-rings (the individual annular-ring slots of width *W*1, *W*2) and the circular patch.

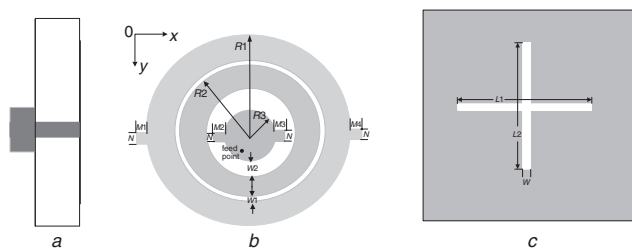


Fig. 1 Geometry of proposed triple-frequency annular-ring antennas

a Profile
b Patch on top
c With cross-slot ground plane

To determine the effects of the stubs with regard to bandwidth, the parameters of three different antennas are listed in Table 1. The ground plane size is 60 × 60 mm. The three proposed antennas have been fabricated and a full experimental evaluation made. By adjusting the length of the stubs and the radii of the annular-rings and circular patch, the *f*1/*f*2 frequency ratio can be tuned.

Table 1: Dimensional parameters of proposed antenna

Parameters (mm)	<i>R</i> 1	<i>R</i> 2	<i>R</i> 3	<i>W</i> 1	<i>W</i> 2	<i>L</i> 1	<i>L</i> 2	<i>M</i> 1	<i>M</i> 2	<i>M</i> 3	<i>M</i> 4	<i>N</i>	Feedpoint
Antenna 1	22.7	16.4	6.8	0.8	4.2	39.0	41.8	6.8	3.0	3.0	6.8	0.4	(−3.0, −3.0)
Antenna 2	22.2	15.8	6.5	0.8	4.8	39.0	42.0	2.4	0	4.8	0	4.0	(−3.0, −3.0)
Antenna 3	22.4	16.5	6.9	0.8	5.0	39	41.5	2.5	0	0	0	6.0	(−3.0, −3.0)

Experimental results: The three proposed annular-ring patch antennas were fabricated and tested. The optimised antenna dimensions are listed in Table 1. Using a Rohde&Schwarz ZVA24 network analyser, the input impedance was measured. Fig. 2 shows the measured *S*11 for the proposed antenna. From the experimental results for antenna 1 (which has four symmetrical stubs at the outer edge of the annular-ring and circular patch), it is seen that a broad impedance bandwidth of over 35 % with respect to 1.956 GHz exists for the third resonance frequency. The impedance bandwidth of the first and third bands are significantly broader than antenna 2 or antenna 3. For the antenna with one stub (antenna 3) and with two stubs (antenna 2), the measured impedance bandwidth for the third frequency was found to be about 6.75 and 17.9%, respectively. The proposed antenna 1 geometry yields suitably large impedance bandwidths for applications in wireless communication systems, and in particular in the third band. A very small frequency ratio *f*2/*f*1 is possible with this structure and in this case, it is listed in Table 2.

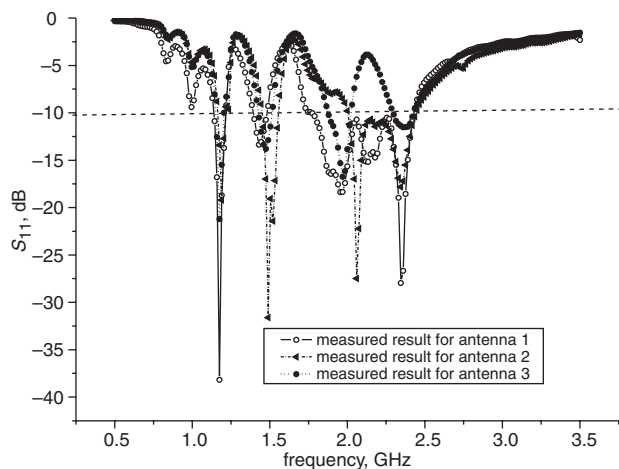


Fig. 2 Measured *S*11 for proposed antennas

Table 2: Measured results of proposed triple-band antennas 1, 2, 3

	<i>f</i> 1, BW (MHz, %)	<i>f</i> 2, BW (MHz, %)	<i>f</i> 3, BW (MHz, %)	<i>f</i> 2/ <i>f</i> 1
Antenna 1	1.175, 75, 6.38	1.428, 90, 6.31	1.956, 680, 35.0	1.22
Antenna 2	1.182, 73, 6.18	1.509, 102, 6.76	2.075, 372, 17.9	1.28
Antenna 3	1.182, 55, 4.66	1.484, 89, 6.00	1.969, 133, 6.75	1.25

The measured linear polarisation radiation patterns at the centre frequencies of the three bands for antenna 1 at 1.175, 1.428, 1.956 GHz in the *X*-*Z* plane and *Y*-*Z* plane are presented in Figs. 3–5, respectively. They illustrate a quasi-omnidirectional pattern for the first frequency, owing to the slotted small groundplane. The front-to-back ratio is increased slightly for the second band and the pattern becomes more directional for the third band, offering a front-to-back ratio of about 9 dB. The gain was found to be 0.5 dBi at 1.175 GHz, −0.5 dBi at 1.428 GHz, and 2.1 dBi at 1.956 GHz, respectively.

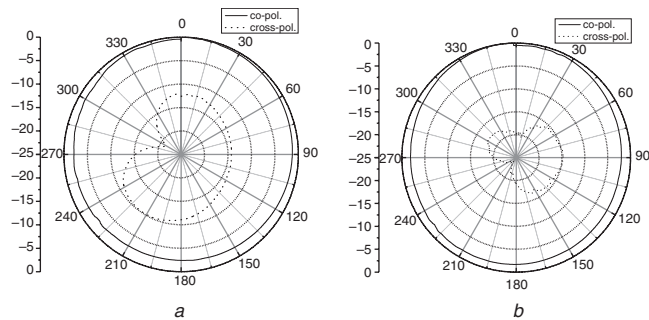


Fig. 3 Measured patterns of proposed antennas at 1.175 GHz
 a X-Z plane
 b Y-Z plane

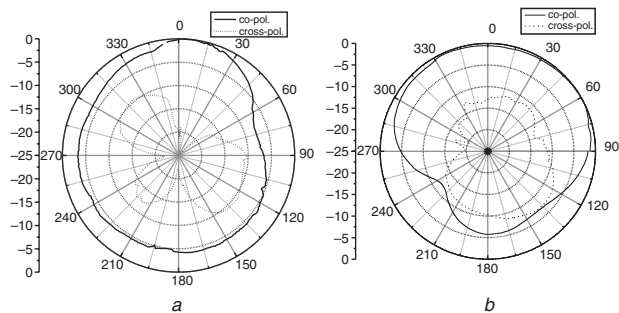


Fig. 4 Measured patterns of proposed antennas at 1.428 GHz
 a X-Z plane
 b Y-Z plane

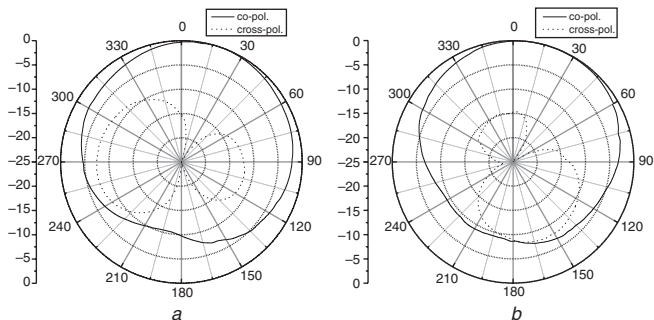


Fig. 5 Measured patterns of proposed antennas at 1.956 GHz
 a X-Z plane
 b Y-Z plane

Conclusions: A compact concentric dual annular-ring loaded circular patch antenna for triple-band operation has been introduced and experimentally verified. The proposed miniature antenna can provide broad impedance bandwidth over three frequency bands. The frequency ratio may be varied by adjusting the antenna dimensions. The new structure is arrayable and is proposed for multiband communication systems, where a small frequency ratio is required.

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