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ANNULAR-RING MICROSTRIP PATCH ANTENNAS

BY

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Abstract. This paper reviews the annular-ring microstrip antennas, as proposed in the literature. Aiming to offer useful design insights about frequency performances, typical design parameters and constraints, technology, implementation and measurement, this study covers the annular-ring architectures reported so far in the scientific literature and making use of a single ring.

Key words: antenna; microstrip; patch; ring.

1. Introduction

The annular-ring microstrip (patch) antenna (ARMSA) represents a good alternative to simple rectangular or circular geometry when addressing more sophisticated applications. Demonstrating wider bandwidth and smaller radius compared with the circular disk microstrip antenna when both operated in the lowest mode (TM_{11}, TM_{12}), this particular structure can be used in conjunction with other geometric elements to develop either wideband or multi-band capability. An interesting feature of ARMSA is that the separation of resonant modes can be simply controlled by setting the ratio of outer to inner radius. In the meantime, it offers the great advantage of insensitivity to large variation of incident angle (making them useful for GPS applications) and simplicity of fabrication.

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Another advantage is that such antenna can be integrated with active microwaves devices, such as MESFETs, Gunn diode (Kanaujia & Vishvakarma, 2004) or IMPATT diode (Kanaujia *et al*., 2008a, 2008b) to implement an active antenna, by simply mounting the active device between the ring patch and ground plane. The possibility of integrating the ring antenna with MOS capacitor was investigated as well (Kanaujia *et al.*, 2008c).

Based on the previous work reported so far in the literature, any implementation of ring antenna falls into one of the following categories:

a) basic annular-ring structure (substrate + patch), firstly investigated by (Mink, 1980);

b) concentric annular ring antenna array, to implement multi-band antennas, usually two rings being used (Kanaujia & Vishvakarma, 2003);

c) microstrip disc antenna with annular-ring (Prior & Hall, 1985);

d) stacked annular-ring microstrip antenna (Dahele *et al*., 1987), i.e. two ring antennas are actually implemented, triple annular ring antennas being also reported (Pathak & Shrivastava, 1994);

e) annular-ring slot microstrip antenna (Sze & Chen, 2011).

This study focuses on the basic structure of annular-ring shape, different design aspects being reviewed by the following sections, other advanced structures, corresponding to categories mentioned above, being subject to future research.

2. Annular-Ring Microstrip Antenna – Basic Shape, Modelling and Topics

The geometry of ARMSA is shown in Fig. 1, where R_1 and R_2 represent the inner and outer radius, also referred as a and b in the literature. According to this figure, the substrate is completely characterized by ε_r and thickness h (not represented).

The annular-ring geometry is not a novel concept, one of the first articles focused on this particular microstrip antenna dating about 4 decades ago (Mink, 1980). This particular geometry gained constant attention from researchers who improved the basic geometry in such way that multi-band or wideband performances could be achieved.

Based on the microstrip resonator's theory, *i.e.* the annular ring without the feed, when the mean circumference of the ring is a multiple of half a guided wavelength, *i.e.* $l = 2\pi r = n\lambda_g/2$, the ring will resonate at $f_0 = nc/(4\pi r \cdot \varepsilon_{\text{eff}}^{1/2})$, where c is the light speed, λ_g is the guided wavelength, ε_{eff} is the effective dielectric constant, λ_0 is the wavelength in free space and n = 1, 2, 3… Choosing the correct connectivity point for the feed and its shape represents the second step in antenna design procedure. An interesting use of ring resonators for practical implementation of a 4-band selective surface with an array of ring resonators and addressing application within *X* and *Ku* bands has been reported in (Liang *et al*., 2012).

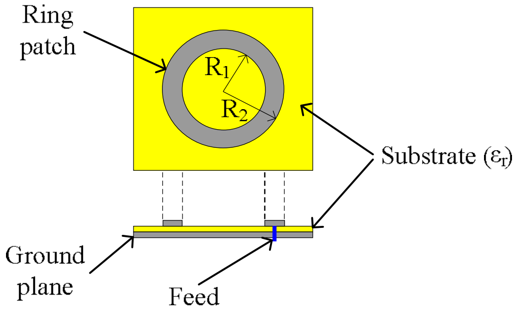


Fig. 1 – ARMSA - geometry (top and side view).

The analysis (modelling) of annular-ring microstrip antenna (ARMSA) is not easy mainly due to the presence of fringing field and more complicated boundary shape (compared with rectangular patch). In this regard, many efforts have been dedicated to develop accurate analysing techniques, as simple as possible. Thus, all articles addressing ARMA published for the first time in literature, this meaning several decades ago, dealt with antenna modelling as some recent articles do as well:

a) research focused on pure mathematical modelling of the ARMSA (Mink, 1980; Lin & Shafai, 1990; Krasyuk & Rigikov, 2004; Barkat, 2012a; Huang, 2015);

b) applying the vector Hankel transform (VHT) to ARMSA modelling (Ali *et al.*, 1982), a well cited reference in the literature for its great contribution;

c) research work applying the cavity model to ARMSA modelling, theoretical results being compared with practical measurements (Lee & Dahele, 1985), a modified Cavity model being proposed two decades later (Mahajan *et al.*, 2008);

d) studying the input impedance of an ARMSA with basic shape (Dahele & Le, 1982), using thick substrate (Liu & Fu, 1996), superstrate layer (Zhibo & Jingxi, 1997) or of a probe-fed cylindrical ARMSA (Huang & Chen, 1997);

e) modelling microstrip elements of arbitrary shape in multi-layered media (Tsai & Alexopoulos, 1985);

f) experimental validation (Dahele & Lee, 1982) of theoretical predictions discussed in (Ali *et al.*, 1982), in case of TM_{11} and TM_{12} modes;

g) accurate modelling of the field distribution for ARMSA by applying Mittag-Leffler expansion and Galerkin's method (Alanen, 1991);

h) study of the electroacoustic effect on the radiation efficiency in case of an ARMSA immersed in plasma medium, with application in space communication (Singh & Gupta, 1991; Pattnaik & Devi, 1996);

i) modelling of an ARMSA by means of artificial neural networks (Akdagli & Kayabasi, 2014);

j) theoretical analysis of superconducting ARMSA with several dielectric layers (Barkat, 2012b), a similar approach with that proposed in (Barkat & Benghalia, 2009) where the resonant frequency was also determined, other studies focusing on ARMSA with two dielectric layers, such as (Gürel & Yazgan, 2014; Vasconcelos *et al*., 2011; Lee & Dahele, 1986);

k) studying the rejection of undesired modes for ARMSA, as researched in (Nurie & Langley, 1989; Tanaka & Takahashi, 2002);

l) studying the effect of cylindrical enclosure on the resonant frequency (Singh *et al*., 2013), with the design of a particular cavity backed ARMSA for Personal Wireless Communications (Singh *et al*., 2015a);

m) studying shorting-pin loaded ARMSA (Zhou, 1998; Mahajan *et al*., 2011);

n) studying new feeding mechanism for ARMSA, such as capacitive coupling to a rectangular strip (Ridgers *et al*., 2000), with the advantage of overcoming the matching problem for TM_{11} mode while increasing the bandwidth;

o) studying new ways to decrease the antenna size, either by replacing the substrate inside the patch cavity with another material offering optimum relative permittivity (Mehrotra *et al*., 1999) or adding some improvements to the geometry (Moernaut & Vandenbosch, 2004; Abdelaal & Ghouz, 2014).

3. Equivalent Passive Model for ARMSA

It is interesting to notice that an equivalent passive model has been developed and associated to ARMSA, the antenna being assimilated with a resonant cavity. The main advantage of such model is that it can be further developed for more complicated structures, developed by starting from annular-ring shape, in most cases including other geometries (circular disc, rectangular, slots, etc.) or even semiconductor devices (such as diodes, capacitors, transistors, etc.) to implement active antennas.

The equivalent model for ARMSA is shown in Fig. 2, being an RLC parallel tank, where:

1º L and C represent the magnetic and electric energies stored in the fields below the patch metallization and in the fringing fields around the radiation apertures;

2º $Y = 1/R$ represents the power loss through the radiating apertures;

3º R_p and X_p are added to model the effects of coaxial probe feed.

Based on this model, any extra component implemented within the antenna is simply inserted in parallel. This is the case of implementing an ARMSA with Gunn diode, where $-R_d||C_d$ are inserted in parallel after X_p, as already shown.

This model has been reported in several articles, such as (Kanaujia & Vishvakarma, 2004; Kanaujia *et al*., 2008a, 2008b, 2008c; Kanaujia & Vishvakarma, 2002; Singh *et al*., 2016; Singh *et al*., 2015; Singh *et al*., 2013), with different changes depending on the supplementary geometry inserted into the antenna.

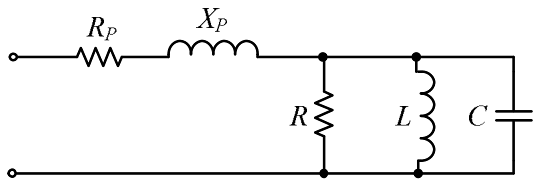


Fig. 2 – Equivalent circuit of the annular-ring microstrip patch antenna.

For TM_{12} mode the *R*, *L* and *C* values have the following values (Kanaujia *et al*., 2008a), where J_1 and Y_1 are Bessel and Neumann function of order *n*, *f* is the patch resonance frequency, *T* is the feed location and ` indicates the derivative with respect to argument:

$$C = \frac{\pi \varepsilon_r \varepsilon_0}{\varepsilon_1^2 h} \cdot \frac{b^2\left(1-\frac{n^2}{k_{12}^2 b^2}\right)F_{12}^2(b) - a^2\left(1-\frac{n^2}{k_{12}^2 a^2}\right)F_{12}^2(a)}{F_{12}^2(T)}, \quad (1)$$

$$L = \frac{\varepsilon_1^2 \mu_0 h}{\pi k_{12}^2} \cdot \frac{F_{12}^2(T)}{b^2\left(1-\frac{1}{k_{12}^2 b^2}\right)F_{12}^2(b) - a^2\left(1-\frac{1}{k_{12}^2 a^2}\right)F_{12}^2(a)}, \quad (2)$$

$$R = \frac{Q_0}{\pi f C}, \quad (3)$$

where: $F_{12}(b) = J_1(k_{12}b)Y_1^{'}(k_{12}a) - J_1^{'}(k_{12}a)Y_1(k_{12}b)$, $F_{12}(a)$ and $F_{12}(T)$ being similarly computed.

4. Design solutions for multiband capability

Even though the ARMSA outperforms the frequency performances of rectangular or circular patch, its bandwidth is still too narrow to address real applications requiring larger bandwidth, such as wireless or broadband communications (UWB, future 5G communications, etc). In this regard, many efforts have been dedicated to improve the ARMSA bandwidth at higher frequencies (GHz range). This section reviews the wideband architectures based on ARMSA only (single ring patch), other performant prototypes mixing the annular-ring with other geometries (topic left as future work).

Such review would be of high interest at least to understand the significance of the word “wideband” with respect to annular-ring antenna. On the other side, how wideband capability can be developed is another issue as well.

First of all, based on the articles reported so far in the literature for wideband ARMSA, any ring antenna with wideband capability falls into one of the three distinct categories shown in Fig. 3. The first two are detailed below.

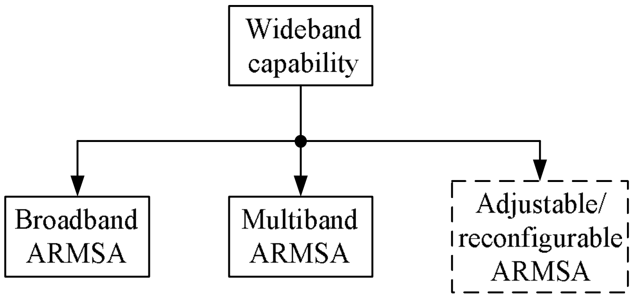


Fig. 3 – Wideband perspectives for ARMSA.

a) Designing broadband ARMSA is not a new problem, this topic emerging several decades ago with a research work (Chew, 1982) proving, for the first time, that in the ARMSA case:

– the lowest TM_{11} mode has poor bandwidth performances, yet with the advantage of lower size compared with rectangular/circular patch;

– TM_{12} mode favours wideband applications, its bandwidth increasing with decreasing b/a ratio, much larger compared to circular disk.

However, this result is based on theoretical calculus only so practical implementation and real performances were not reported.

Several notable wideband implementations have been proposed in literature, all these making use of distinct design solutions, such as:

– narrowing the ground plane (Rawat & Sharma, 2015), shown in Fig. 4, a first in the literature since the ground plane should normally be infinite for microstrip antennas (BW = 2.36 GHz, f_0 = 4.54 GHz or 52%);

– using a broadband 90^0 hybrid feed (BW = 0.7 GHz, f_0 = 1.85 GHz or 38%), as reported in Guo *et al*., (2009) and shown in Fig. 5;

– using defected ground plane with 4 circular ring sectors (BW = 1.33 GHz, f_0 = 11.29 GHz or 11.78%), as reported in Sharma *et al*., (2013) and shown in Fig. 6;

– orthogonally slit loaded ARMSA or slit cut ARMSA (SC-ARMSA), with extra *L*-probe for improved coupling (BW = 1.55 GHz, f_0 = 3.36 GHz or 36%) as proposed in Singh et al., (2013), where 4 slits are cut at outer periphery (Fig. 7);

– orthogonally slot loaded ARMSA, with extra *L*-probe for improved coupling (BW = 1.18 GHz, f_0 = 3.15 GHz or 37%) as proposed in Singh *et al*., (2015), where 4 slots are cut at inner periphery, as shown in Fig. 8;

– using a supplementary arc shape stub and defected ground (rectangular slot) for improving the impedance bandwidth (BW = 29 GHz/3 GHz ÷ 32 GHz), as proposed in Yan *et al*., (2011), as shown in Fig. 9*a*;

– using a ring resonator excited by annular-shaped microstrip feed (BW

= 3.71 GHz, f_0 = 5.35 GHz or 66%), as reported in Chaudhary *et al*., (2013) and shown in Fig. 9*b*.

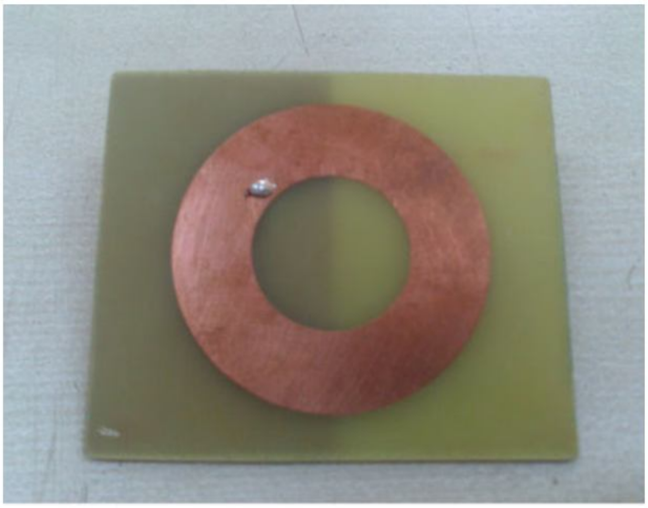


Fig. 4 – Wideband ARMSA with finite ground.

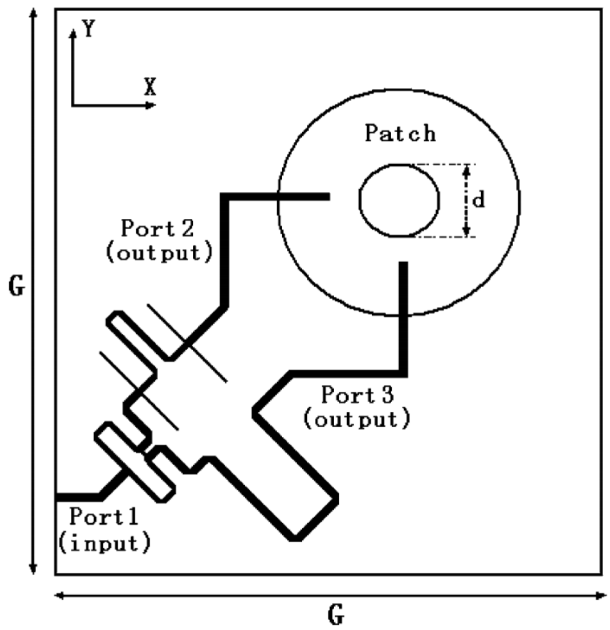


Fig. 5 – Wideband ARMSA with broadband 90^0 hybrid feed.

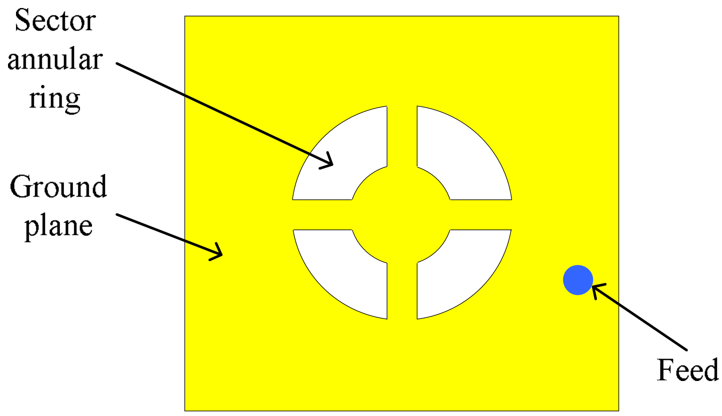


Fig. 6 – Wideband ARMSA with DGS (circular ring sectors).

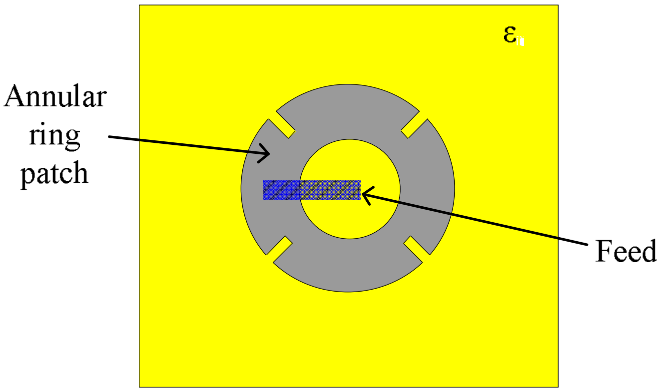


Fig. 7 – Wideband ARMSA with DGS (slits cut at outer periphery).

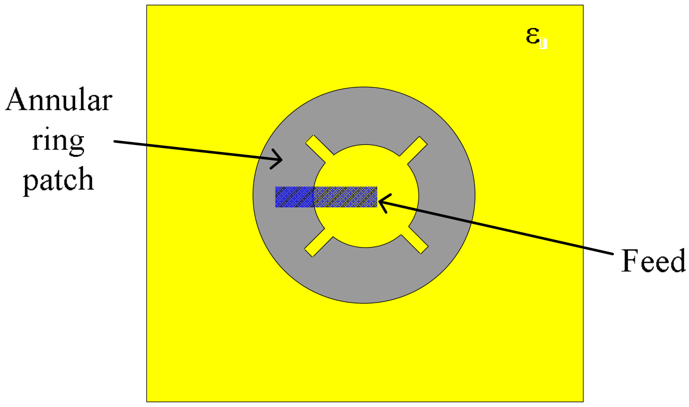
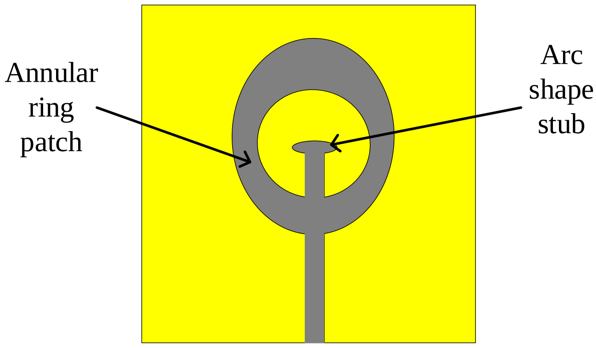
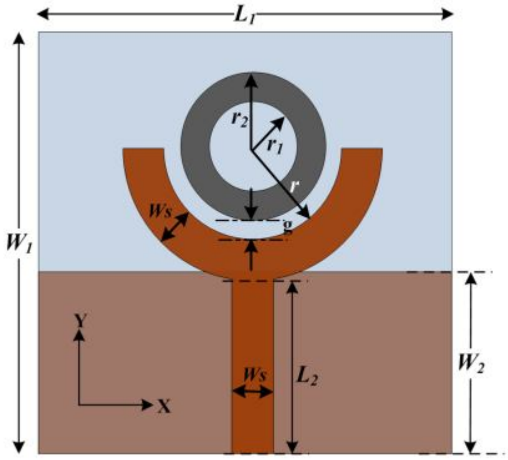


Fig. 8 – Wideband ARMSA with DGS (slits cut at inner periphery).



a



b

Fig. 9 – Wideband ARMSA with arc shape stub (*a*) or resonator excited by annular-shaped microstrip feed (*b*).

b) Multiband capability is critical in applications associated to multiband standards, such as mobile communications, navigation (GPS), ISM implementations, etc. In such case, multiband antennas might represent the best solution to cover frequency bands situated too far from each other, a practical context that makes wideband antennas innappropriate (and hard to design).

Even though many solutions of multiband ARMSA have been proposed in the literature, either making use of several ring patches on the same substrate, two or more substrates or even mixing annular-ring geometry with other shapes (disc patch, slots), due to length constraints imposed to this article, the ARMSA based on a single ring topology is reviewed. In other words, it might be interesting to see how an ARMSA with a single ring only could cover multiple bands, the answer being offered in this section. Using a single ring patch to cover multiple bands means not only smaller size but also cheaper antenna, no matter what design artifice is made. In this regard, several interesting solutions have been reported in the literature, as follows:

– implementation of a dual-frequency ARMSA (f_1=1.24 GHz – TM_{11} mode, f_2 = 3.9 GHz – TM_{12} mode) by means of a supplementary strip inserted inside the ring and connected to the feed (Row, 2004), solution that could be of help to implement circular polarisation as well (as proposed in the same reference), shown in Fig. 10;

– implementation of a quad-band ARMSA (1.85, 3.5, 4.55 and 5.6 GHz) by means of a segmented dual-aperture coupled annular antenna with two substrate layers and annular ring slot cut in the ground plane (Rayno *et al.*, 2013), as shown in Fig. 11;

– implementing dual-band antenna by means of a gap loaded ARMSA (f_1 = 2.45 GHz and f_2 = 3.5 GHz), the frequency of interest being tuned with a single or two grooves, therefore improving the multiband behaviour of the antenna, such as the triband case (f_1 = 2.45 GHz, f_2 = 3.5 GHz, f_3 = 5.5 GHz), as reported in (Jhamb & Rambabu, 2011), shown in Fig. 12.

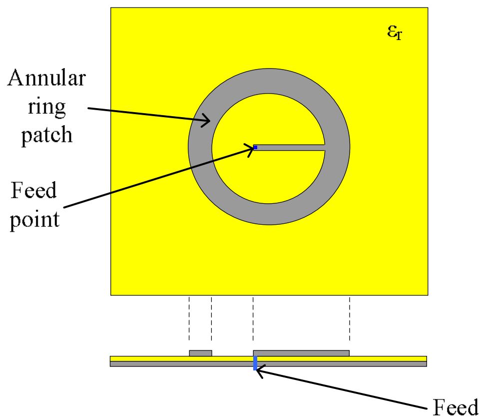


Fig. 10 – Dual-frequency ARMSA.

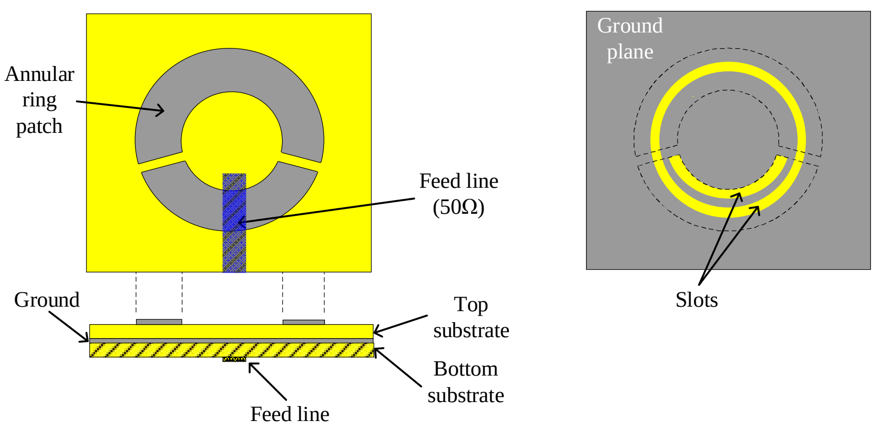


Fig. 11– Quad-band ARMSA.

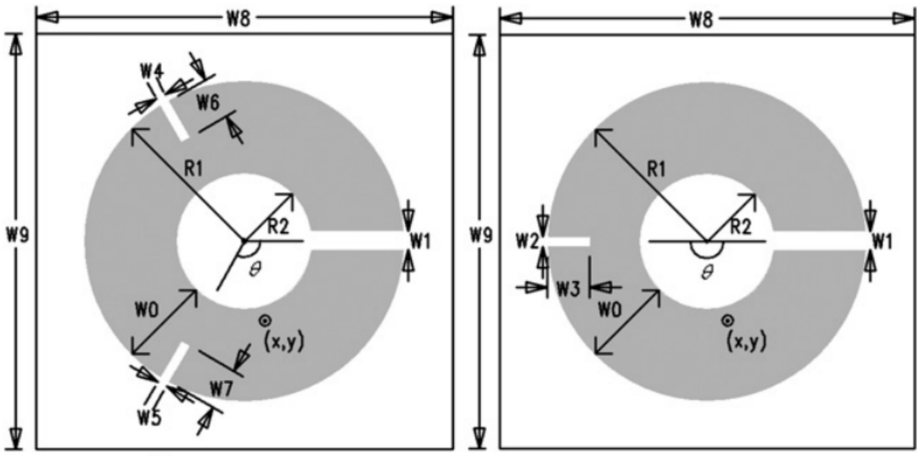


Fig. 12 – Dual-band ARMSA.

Even though not falling into one of these categories, it is worth mentioning the solution of etching a lattice of 4x4 circular slots in the ground plane, fact that increases the resonant frequency by 15% and the bandwidth from 0.91% to 4.1% (Lin & Wong, 2001), as shown in Fig. 13. Usually the slot geometry, implemented either on top or in the ground, greatly improves the bandwidth capability of the microstrip antenna.

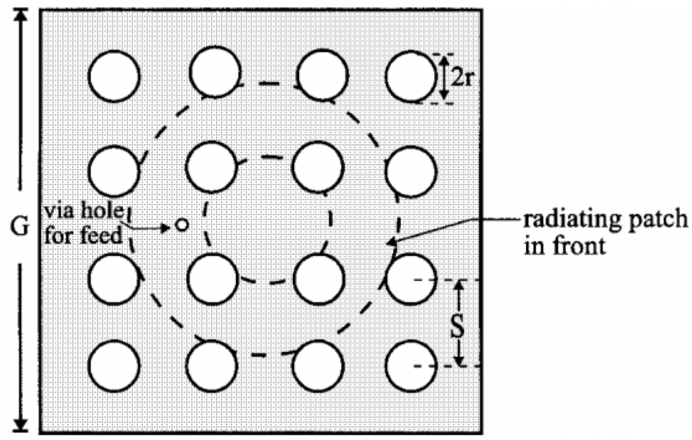


Fig. 13 – Bandwidth increase for an ARMSA with defected ground.

5. Antenna Polarization and Design Challenges

Circular polarisation (CP) is mandatory for GPS applications and mobile satellite communications. In this regard, while most papers focused on ring patch antennas address wireless or ultra-wide band communications where circular polarisation is not mandatory, several articles are particularly focused on designing circularly polarised ARMSA. Implementing this polarisation for ARMSA is entirely different of the rectangular case where cutting the patch edges would be sufficient to induce CP. The solutions proposed for ARMSA in the literature are as follows, CP being implemented by means of:

– using a broadband 90^0 hybrid feed, with two L-probe feeds orientated to have phases of 0º and 90º, solution already shown in Fig. 5 (Guo *et al*., 2009) and reiterated in Fig. 14;

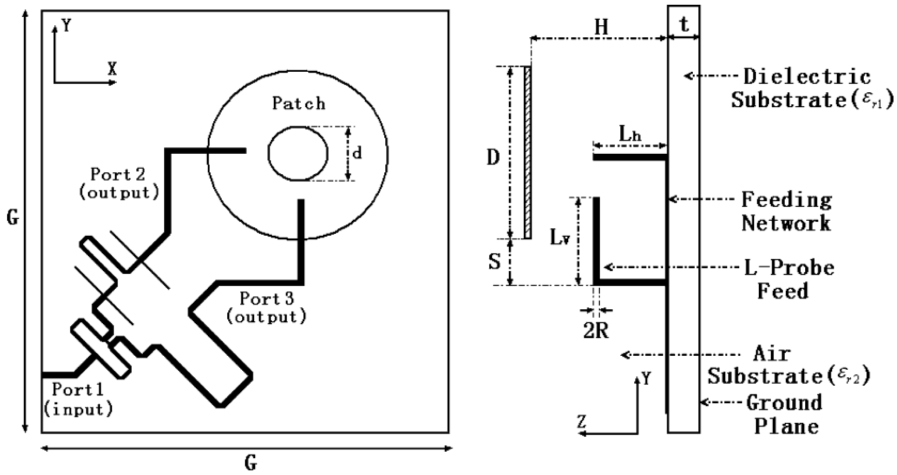


Fig. 14 – CP-ARMSA implemented with 2 *L*-probe feeds.

– inserting and connecting an L-shaped strip to the inner ring, originally proposed in (Row, 2004) and reiterated in (Row & Lin, 2004; Sim *et al*., 2004), as shown in Fig. 15, solution that avoids any additional phase shifter or impedance-transformer;

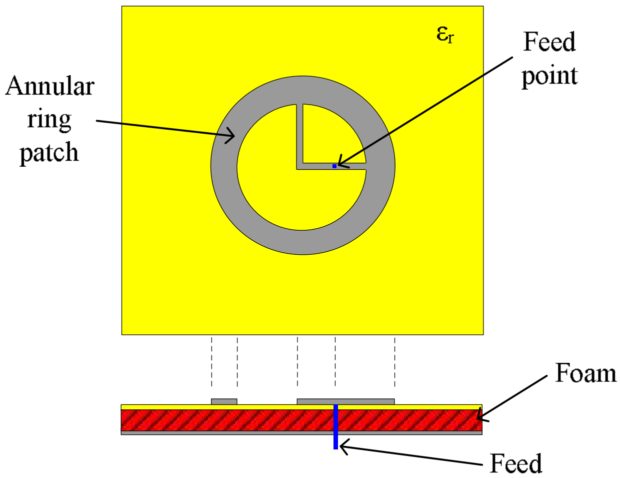


Fig. 15 – CP implemented with L-shape strip.

– designing ARMSA with two slits (Fig. 16) for RHCP or tuning stubs (Fig. 17) for LHCP, as reported in (Chen, 1998);

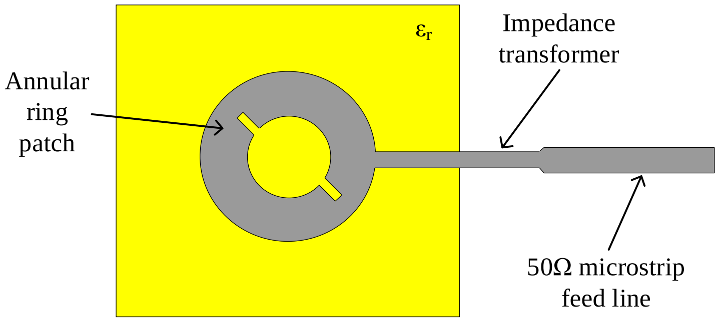


Fig. 16 – RHCP implemented with two slits.

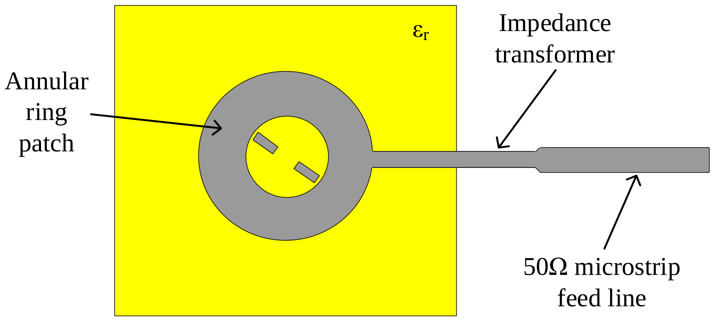


Fig. 17 – LHCP implemented with two stubs.

– simultaneous use of a pair of symmetrical slots inserted into the inner boundary together with L-shaped strip with the two ends at 90º apart so that RHCP and LHCP are created simultaneously (Singh *et al.*, 2016), as shown in Fig. 18;

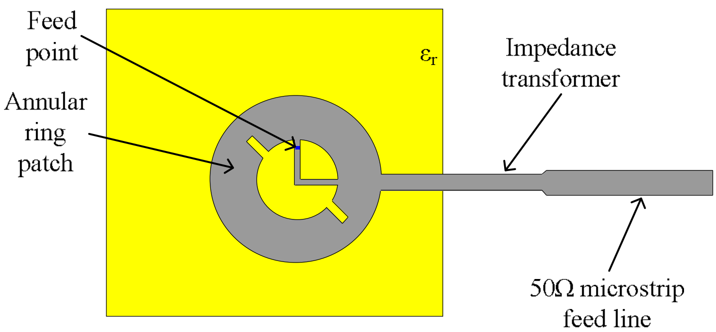


Fig. 18 – CP implemented with 2 slots and *L*-shaped strip.

– adding a tab for RHCP or a trimmed slot for LHCP (Fig. 19), as originally proposed in (Pyo *et al*., 2014);

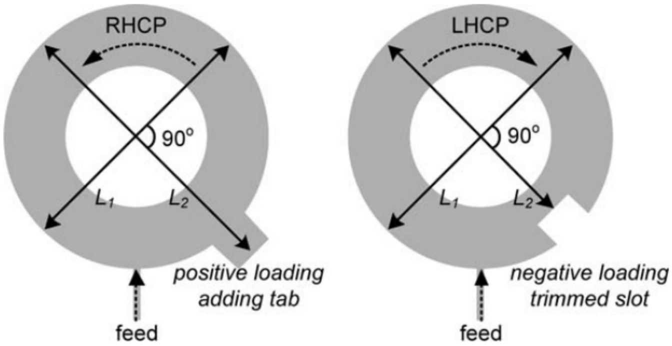


Fig. 19 – Methods to implement circular polarisation for ARMSA.

– adding a ring-shaped feeding line inside the ring (Fig. 20) to implement impedance matching and CP (mainly RHCP), with the main benefit of saving space, as proposed in (Chen *et al*., 2011).

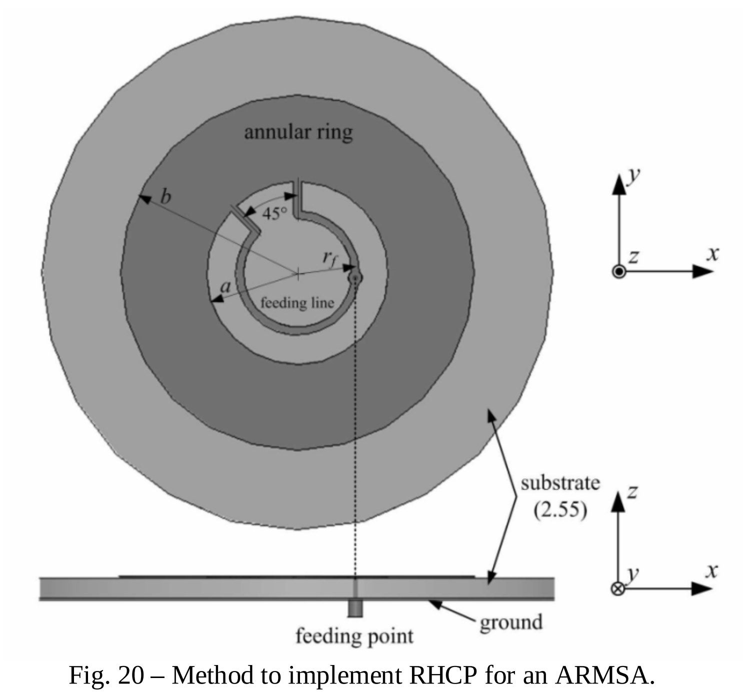


Fig. 20 – Method to implement RHCP for an ARMSA.

A last method proposed in the literature consists of loading degenerate separation elements (rectangular trim slots), as shown in Fig. 21, the antenna working at 10.2 GHz (Tanaka & Takahashi, 2002).

Fig. 21 – Method to implement CP for an X-band ARMSA.

6. Substrate for Annular-Ring Antennas, Number of Layers

Choosing a particular substrate for ARMSA depends on different factors that should be considered (including targeted application): frequency performances (center frequency and bandwidth), efficiency, cost and (system) integration. According to the results reported so far in literature, the following materials have been used for ARMSA (Table 1), ranked after the number of references reporting the same substrate (or ε_r).

Table 1
Substrate Used for ARMSA

ε_r	Substrate name (if mentioned)	No. of references	References/no. of RMSA layers if >1 & name of the other layer(s)
4.4	FR4	11	Rawat & Sharma, 2015; Pyo *et al.*, 2014; Abdelaal & Ghouz, 2014; Sharma *et al.*, 2013; Chaudhary *et al.*, 2013; Yan *et al.*, 2011; Sim *et al.*, 2004 – 2 & foam layer, (Row & Lin, 2004) – 2 & foam layer, (Row, 2004; Lin & Wong, 2001), (Chen, 1998)
2.2	Rogers RT/ duroid 5880	8	Singh *et al.*, 2015 – & air, Akdagli & Kayabasi, 2014; Singh *et al.*, 2013 – 2 & air, Mahajan *et al.*, 2011; Mahajan *et al.*, 2008; Kanaujia & Vishvakarma, 2002; Ridgers *et al.*, 2000 – 2 & air, Tsai & Alexopoulos, 1995 – 3 & 2.2 (all layers)
2.32	Rogers RT/ duroid 5870	8	Barkat, 2012 – 2 & YBCO film, Kanaujia *et al.*, 2008a 2008b, 2008c; Kanaujia & Vishvakarma, 2004; Lee & Dahele, 1986; Lee & Dahele, 1985; Lee & Dahele, 1982
2.65	–	5	Barkat, 2012; Barkat & Benghalia, 2009; Liu & Hu, 1996; Chew, 1982; Ali *et al.*, 1982
2.55	–	3	Chen *et al.*, 2011; Zhibo & Jingxi, 1997 – 2 & 10.2, (Mink, 1980)
1.07	Foam layer	3	Singh *et al.*, 2016; Singh *et al.*, 2015 ; Singh *et al.*, 2013

Table 1
Continuation

ε_r	Substrate name (if mentioned)	No. of references	References/no. of RMSA layers if >1 & name of the other layer(s)
2.5	PTFE	2	Rayno *et al.*, 2013 – 2 & 2.5 similar substrate, (Rambabu, 2011)
2	–	2	Zhou, 1998; Alanen, 1991 – 3 & (4, 5.5)
3.55	–	1	Singh & Fiete, 1991
3.35	Bendflex	1	Nurie & Langley, 1989
3	–	1	Huang & Chen, 1997
2.52	–	1	Lin & Shafai, 1990
2.33	–	1	Mehrotra *et al.*, 1999
2.3	–	1	Krasyuk & Rigikov, 2004
2.17	–	1	Tanaka & Takahashi, 2002
1.55	–	1	Huang, 2015 – 2 & –2
1.44	Polyester (body-worn applications)	1	Sankaralingam, 2010
3.38	RO4003	1	Guo *et al.*, 2009
1	Air substrate	1	Moernaut & Vandenbosch, 2004
–	Ferrite (ferromagnetic layer)	2	Vasconcelos *et al.*, 2011; Pattnaik & Devi, 1996

As could be noticed, some references don't report any substrate name which is the case of theoretical studies focused on comparing the antenna performances as function of the substrate type. In the same time, there are other studies reporting stacked substrates (and a single ring patch) to achieve wideband performances. Such cases are mentioned with a number in the table above and '&' symbol to specify the permittivity of the additional substrate(s).

7. Antenna Dimension

The size of ring antenna represents an important indicator that helps us compare different antennas and eventually correlate with frequency performances. In this regard, similar to the rectangular patch microstrip antenna that is completely characterized by its patch parameters (*W*, *L*), the annular-ring antenna is completely characterized by its inner and outer radius. Both radius influence directly the frequency performances but from antenna size perspective the outer radius is the most important when evaluating the antenna dimension. In this regard, based on the results reported in the literature, the smallest ring patch size (outer radius), *i.e.* less than 1 cm, are reported as follows:

– 2 mm (Vasconcelos *et al.*, 2011), theoretical results only;
– 2.64 mm (Barkat, 2012a), theoretical results only;
– 6.2 mm (Chaudary *et al.*, 2013), implemented and measured;
– 6.9 mm (Kanaujia *et al.*, 2008b), theoretical results only;

– 7 mm (Krasyuk & Rigikov, 2004), theoretical results only;

– 7.5 mm (Tsai & Alexopoulos, 1995), theoretical results only;

– 8 mm (Tanaka & Takahashi, 2002), theoretical results only;

– 8.5 mm (Singh *et al*., 2013) with theoretical results only, (Yan *et al*., 2011) with implementation;

– 9 mm (Singh *et al*., 2016), implemented and measured;

– 1 cm (Sharma *et al*., 2013), implemented and measured.

Large patch size is reported as follows:

– 7 cm (Lee and Dahele, 1986), (Lee & Dahele, 1985);

– 8.16 cm (Kanaujia *et al*., 2008a).

Even though radii smaller than 1 cm have been reported, the final patch antenna is always larger, usually ranging up to 3×3 cm^2 and even 5×5 cm^2.

8. Simulation Tool

Since the use of a professional design tool is of utmost importance when it comes to model and manufacture a commercial antenna, a review of the software tools preferred for antenna design would be of great interest. In this regard, the following software modelling tools have been reported for annular-ring antennas:

1. *IE3D* (Mentor Graphics) was reported by 11 references, such as (Akdagli & Kayabasi, 2014; Mahajan *et al*., 2011; Sankaralingam *et al*., 2010; Guo *et al*., 2009; Kanaujia *et al*., 2008b, 2008c; Mahajan *et al*., 2008; Row, 2004a; Row & Lin, 2004b; Moernaut & Vandenbosch, 2004; Sim *et al*., 2004);

2. *Ansys High Frequency Structure Simulator* (HFSS) is clearly reported by 5 references, such as (Singh *et al*., 2015; Singh *et al*., 2013; Sharma *et al*., 2013; Vasconcelos *et al*., 2011; Lin & Wong, 2001);

3. *CST Microwave Studio* is reported by 2 references, such as (Abdelall *et al*., 2014; Yan *et al*., 2011);

4. HP-Momentum is clearly reported by 2 references, (Tanaka & Takahashi, 2002; Zhou, 1998);

5. Singh *et al*., 2015; Singh *et al*., 2013; Sharma *et al*., 2013; Vasconcelos *et al*., 2011; Lin and Wong, 2001;

6. C++ and FORTRAN are reported independently by Pattnaik & Devi, (1996) and Barkat, (2012a) respectively;

7. 2 references report two simulators (one for design and the second for validation), such as Matlab+HFSS (Singh *et al*., 2016) and CST+HFSS (Jhamb & Rambabu, 2011).

All other references do not report the modelling tool used for antenna design.

9. Issues Identified in the Scientific Literature

A first issue common to the most articles in the scientific literature focused on ring antennas is lacking information about the size, fact that complicates the review and reduces the attractiveness of a particular solution from practical perspective. In this regard, while some articles report the outer radius size but don’t mention the patch size of the antenna or inner radius, others don’t mention any size, usually when the article is focused on antenna modelling and theoretical aspects.

Another issue is that most articles report simulations only, some mention about measurements without saying anything about the experimental setup while very few references mention the VNA used to measure the antenna input impedance, such as:

– R&S VNA (Sharma *et al*., 2013);

– HP VNA (Liu & Hu, 1996; Lee & Dahele, 1985);

– Agilent VNA (Singh *et al*., 2016 ; Chaudhary *et al*., 2013; Yan *et al*., 2011 ; Sankaralingam *et al*., 2010).

Even though not mentioning anything about the experimental setup, three articles report measurements of the radiation pattern for the proposed ARMSA, probably in an anechoic chamber (not clearly specified), such as Pyo *et al*., (2014), Row, (2004) and Sim *et al*., (2004).

10. Conclusions

An original review of the annular-ring microstrip (patch) antennas was conducted in this paper. Different design perspectives were addressed to classify and compare the performances of the ARMSAs proposed so far in the literature. According to the references, the main proved benefit of this particular geometry consists in its low (ring) size, much lower compared to the rectangular or circular patch and designed at the same frequency.

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ANTENE MICROSTRIP DE TIP PATCH ÎN INEL

(Rezumat)

Acest articol sintetizează antenele microstrip de tip patch în inel, aşa cum au fost propuse în literatură. Cu intenția de a oferi indicații utile cu privire la performanțe în frecvență, parametrii tipici de proiectare şi constrângeri, tehnologie, implementare şi măsurători, acest studiu acoperă toate antenele de tip patch, cu un singur inel, raportate până acum în literatura ştiințifică.