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SINGLE LAYER RECTANGULAR PATCH MICROSTRIP ANTENNAS WITH WIDEBAND FREQUENCY CAPABILITY

BY

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Abstract. This paper reviews the wideband rectangular patch microstrip antennas, as proposed in the literature. Aiming to offer some insights about frequency performances, design parameters, constraints, technology, implementation and measurement, this study covers the rectangular patch architectures reported so far in the scientific literature and implemented with single substrate layer.

Key words: antenna; microstrip; patch; rectangular; wideband.

1. Introduction

The microstrip antenna (or MSA) gained a distinct place in the field of microwave antenna thanks to many clear advantages, such as: small size, ease of fabrication and integration with other components, low cost and profile, etc. There are several classes of MSA geometries proposed and studied in the literature, among them, the patch MSA splitting into many distinct shapes: rectangular, circular, annular ring, annular slot, E-shaped, F-shaped, hexagonal, fractal, semicircular, split ring, etc. The simplest yet old geometry reported and studied for the first time in literature is the rectangular shape, hereinafter referred as RPMSA (rectangular patch microstrip antenna).

A significant drawback that affects all patch antennas is the effective

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antenna bandwidth, usually too narrow to satisfy the bandwidth requirements imposed by the current wireless standards. According to the literature, the bandwidth of a classic RPMSA could range from several MHz to tens of MHz. In this regard, an RPMSA existent in our Microwave Laboratory and theoretically designed at 4 GHz (according to its datasheet shown in Fig. 1), proved a bandwidth of maximum 50 MHz when tested, as illustrated in Table 1.

Fig. 1 – Datasheet for Amitec RPMSA.

Table 1
VSWR Measured for RPMSA

Frequency, [MHz]	$P_{max} - P_{min}$, [dB]	VSWR
3,800	12	3.98
3,810	11.3	3.63
3820	10.3	3.23
3,830	9.1	2.81
3,840	7.9	2.45
3,850	6.2	2.04
3,860	1.38	1.14
3,870	0.88	1.1
3,880	1.17	1.12
3,890	2.25	1.28
3,900	6.6	2.13
3,910	7.8	2.45
3,920	9.3	2.88
3,930	10.2	3.23
3,940	11.1	3.54
3,950	12	3.98
3,960	12.6	4.26
3,970	13.5	4.67
3,980	14.5	5.24
3,990	15.2	5.75
4,000	16.4	6.60
4,010	17.7	7.58

The antenna was characterized from VSWR perspective, a 4 GHz network analyzer and slotted line being used. Such antenna is currently used for educational activity, high precision not being mandatory.

To overcome the bandwidth limitations, different improvements have been applied to the classic RPMSA. This study aims to review all these RPMSAs with wideband frequency capability, hereinafter referred WRPMSA, as proposed in literature.

2. Frequency Performances

It should be mentioned that, in the case of microstrip antennas, the word "bandwidth" has 3 different meanings, fact that could create some sort of confusion: impedance bandwidth ($S_{11} < -10$ dB or VSWR < 2), gain bandwidth and AR (axial ratio) bandwidth. This study is primarily focused on impedance bandwidth, matching the antenna to 50 Ω reference impedance being of utmost importance for any microwave component.

To simplify the review of these frequency performances, the antennas are classified in several classes, distinct and representative from bandwidth perspective, as synthesized below.

1. Bandwidth of several hundred MHz (up to 450 MHz), *i.e.* less than 1 GHz, is reported by two references, (Murugan & Rajamani, 2012; Khaled & Saad, 2008), the second one reporting switched antenna covering the range 2 – 5 GHz but with narrow bandwidth for any of these three centre frequencies.

2. Most articles report a bandwidth of 1-2 GHz, as follows: 1 GHz (Yang *et al*., 2005), 1.3 GHz (Gupta *et al*., 2003), 1.34 GHz (Chen *et al*., 2001), 1.4 GHz (Kiran *et al*., 2007), 1.56 GHz (Qi *et al*., 2004), 1.56 GHz (Ansari & Ram, 2008a), 1.8 GHz (Ansari & Ram, 2008b).

3. Bandwidth ranging between 2 GHz and 10 GHz is reported by 5 references: 2.5 GHz (Kasabegoudar & Vinoy, 2009), 2.6 GHz (Nishamol *et al*., 2010), 3.3 GHz (Kasabegoudar & Vinoy, 2008), 4 GHz (Wang & Chan, 2016), 7.8 GHz (Azim *et al*., 2014), 8.5 GHz (Singh *et al*., 2009).

4. Bandwidth wider than 10 GHz is also reported: 12 GHz bandwidth (Naser-Moghadasi *et al*., 2009) and 17 GHz (Kibria *et al*., 2014).

According to the literature, different design strategies could be adopted to increase the bandwidth of single layer RPMSA from 2-3% to even more than 100% of the centre frequency, as reviewed below:

– using thicker substrates with smaller permittivity;

– using supplementary impedance matching networks (solution already adopted for commercial antennas by the companies);

– capacitive feeding (coupling);

– inserting larger slots into the antenna's patch;

– using multi-layer dielectric;
– inserting narrow slots into the ground plane;
– applying different feeding techniques and positions for the feed.

3. Feeding Strategy for WRPMSA

Similar to other geometries of patch antennas proposed in literature (circular, ring, slot etc.), the basic four feeding techniques are also reported for WRPMSA, as reviewed in Table 2, a supplementary feeding technique (PF-CC) being also reported and showing noticeable improvement of the RPMSA frequency performances.

In case of the probe feed, different feed radius and positions have been investigated in the literature. However, this technique is not so practical if real (commercial) applications are envisaged.

4. Substrate

Eleven substrate materials were reported in literature, as follows:

– FR-4 mentioned in 5 references, two with $\varepsilon_r = 4.6$ (Azim *et al*., 2014; Kibria *et al*., 2013), two with $\varepsilon_r = 4.4$ (Murugan & Rajamani, 2012; Nishamol *et al*., 2010) and another one using a substrate with $\varepsilon_r = 4.3$ (Ansari and Ram, 2008);

– a substrate with $\varepsilon_r = 4.4$, not clearly identified, reported by (Kiran *et al*., 2007; Chen *et al*., 2001);

– Duroid 5,880 ($\varepsilon_r = 2.2$) reported in two references (Wang & Chan, 2016; Khaled & Saad, 2008);

– two versions of foam substrate, one with $\varepsilon_r = 1.03$ (Ansari & Ram, 2008) and another with $\varepsilon_r = 1.07$ (Qi *et al*., 2004).

Five references mention other distinct substrates, with ε_r as follows: 4.2 (Singh *et al*., 2009), 3.05 (Gupta *et al*., 2003), 2.5 (Kasabegoudar & Vinoy, 2009), 2.33 (Naser-Moghadasi *et al*., 2009), 2.2 (Kasabegoudar & Vinoy, 2008).

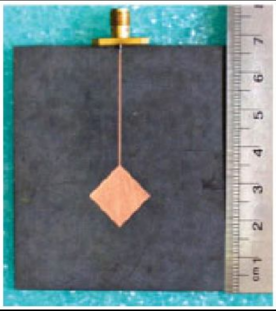
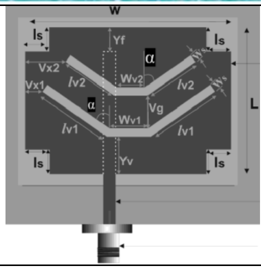
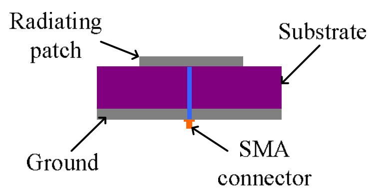
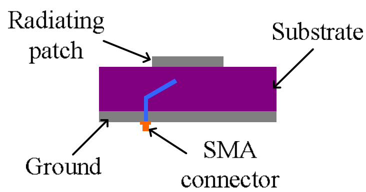
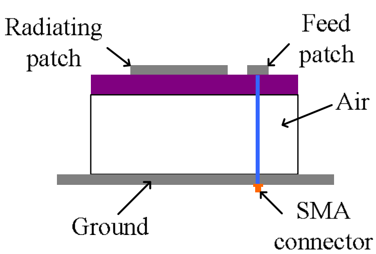
A single reference (Yang & Dougal, 2005) reports three RPMSAs implemented with different substrate materials: $\varepsilon_r = \{3.38; 2.2; 1.04\}$.

5. Antenna Polarization

Even though not mandatory for wideband applications, circular polarization (CP) was also reported by several references. There are four solutions to implement such polarization for WRPMSA, as follows:

a) by inserting a supplementary Wilkinson power divider (Chen *et al*., 2001) designed with a length difference of $\lambda/4$ between its output feedlines to produce a 90º phase shift, printed on the rear side of the antenna as shown in Fig. 2;

Table 2
Feeding Techniques for RPMSA

Feeding strategy	Picture	References
Microstrip line feed (MLF)		Azim *et al.*, 2014; Kibria *et al.*, 2014; Singh *et al.*, 2009; Naser-Moghadasi *et al.*, 2009; Kiran *et al.*, 2007; Gupta *et al.*, 2003
Microstrip line feed with capacitive coupling (MLF-CC)		Nishamol *et al.*, 2010; Chen *et al.*, 2001 – Wilkinson power divider
Probe Feed with direct coupling (PF-DC)		Wang & Chan, 2016; Khaled & Saad, 2008; Ansari & Ram, 2008a, 2008b; Yang *et al.*, 2005
Probe Feed with capacitive coupling (PF-CC)		Qi *et al.*, 2004 – tilted L-shaped probe
Probe Feed with stripline based capacitive coupling (PF-SLCC)		Murugan & Rajamani, 2012; Kasabegoudar & Vinoy, 2009; Kasabegoudar & Vinoy, 2008

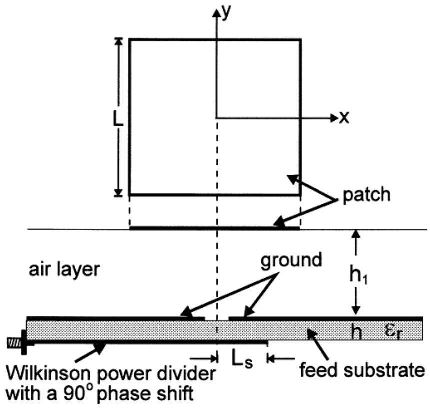


Fig. 2 – CP-WRPMSA implemented with Wilkinson power divider.

b) by truncating the square patch in two opposite corners with a square of particular size (25 mm), as reported in (Murugan & Rajamani, 2012) and shown in Fig. 3;

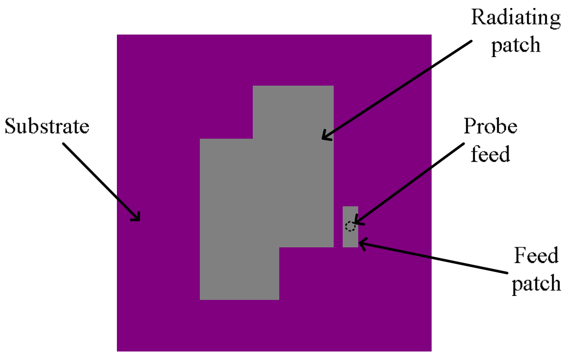


Fig. 3 – Truncated square patch with circular polarization.

c) by inserting a thin rectangular slot into the radiating patch (Kasabegoudar & Vinoy, 2009) with two possible orientations to implement either RHCP or LHCP, as shown in Fig. 4;

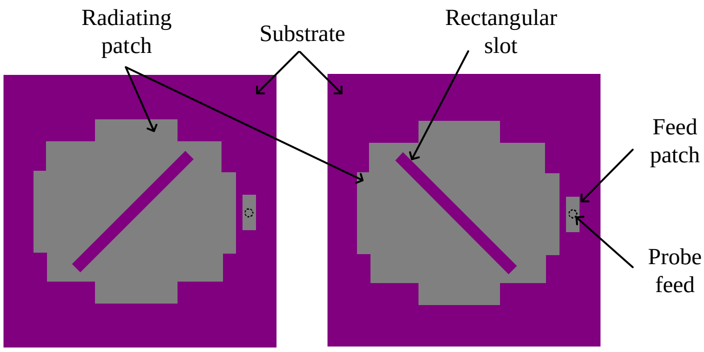


Fig. 4 – RHCP and LHCP achieved by means of a rectangular slot.

d) by inserting two square slots into the radiating patch (Yang *et al*., 2005), a technique that allows both RHCP and LHCP polarizations depending on the position of the larger square, as shown in Fig. 5.

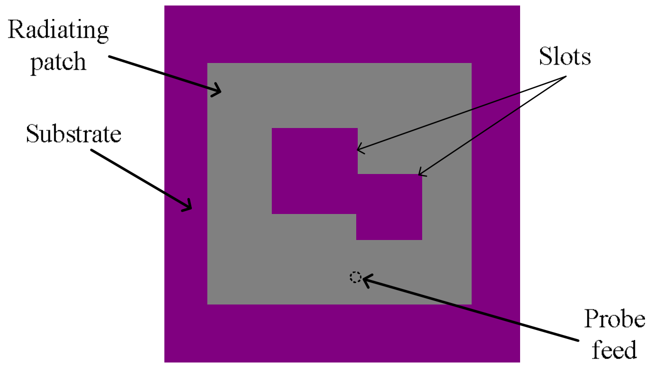


Fig. 5 – WRPMSA with LHCP geometry.

6. Gain and Measurements

A peak gain as high as about 8.5 dBi at 4 GHz is reported in (Qi *et al*., 2004) with an average gain of 7.93 dBi within the entire bandwidth (3.54 – 4.76 GHz). A lower gain value of 7 dBi was also reported in two references, (Nishamol *et al*., 2010) and (Kasabegoudar & Vinoy, 2008).

The last step of antenna design procedure consists of measuring the implemented antenna prototype. In this regard, it is interesting to notice that 3 references only report measurements conducted in anechoic chamber (up to 10 GHz):

– one reference (Kibria *et al*., 2014) mentioning the VNA as well (Agilent E8362C);

– one reference (Kasabegoudar & Vinoy, 2008) reports measurement conducted with an Agilent PNA (N5230A) in anechoic chamber;

– another reference reporting the radiation pattern measured within the UWB band without mentioning any detail about the VNA.

Other references report different VNAs used to characterize the antenna impedance match as follows:

– R&S VNA (Singh *et al*., 2009; Kiran *et al*., 2007);

– HP 8510C VNA (Nishamol *et al*., 2010);

– Agilent 8722ES VNA (Qi *et al*., 2004).

One reference mentions an Agilent VNA used to characterize the antenna up to 67 GHz without offering supplementary details about the VNA.

It is interesting to notice that other references mention experiments without specifying the VNA used for measurements (Kasabegoudar & Vinoy, 2009; Naser-Moghadasi *et al*., 2009; Yang *et al*., 2005; Gupta *et al*., 2003; Chen *et al.*, 2001), while others report simulation results only (Murugan & Rajamani, 2012; Khaled & Saad, 2008; Ansari & Ram, 2008a, 2008b).

7. Antenna Dimension

The patch size of RPMSA offers a useful insight when comparing different microstrip antennas. Normally the size should decrease with frequency and, from this perspective, it would be interesting to evaluate the interdependence between size and frequency for the RPMSAs reported in literature. In this regard, the smallest patch size and largest ones respectively are reported as follows:

– 0.76×0.76 cm^2 (Singh *et al.*, 2009);

– 1.31×0.58 cm^2 (Ansari & Ram, 2008b) ;

– 1.1×1 cm^2 (Gupta *et al.*, 2003) ;

– 4.13×4.94 cm^2 (Khaled & Saad, 2008) ;

– 7×7 cm^2 (Murugan & Rajamani, 2012).

Studying these solutions a conclusion that can be drawn is that two references only report the complete size (i.e. ground plane): 1.8×1.75 (Ansari & Ram, 2008b) and 5.1×5.9 (Khaled & Saad, 2008).

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. *Ansys High Frequency Structure Simulator* (HFSS) is clearly reported by 5 references, such as (Murugan & Rajamani, 2012; Nishamol *et al.*, 2010; Naser-Moghadasi *et al.*, 2009; G. Yang *et al.*, 2004; D. Qi *et al.*, 2005);

2. *IE3D* (Mentor Graphics) was reported by 3 references, such as (Kibria *et al.*, 2013; Kasabegoudar & Vinoy, 2009; Khaled & Saad, 2008);

3. *Empire Elecromagnetics* (based on FDTD) reported by one reference (Kasabegoudar & Vinoy, 2008).

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

9. Conclusion

An original review of the single layer based wideband rectangular patch microstrip antennas was conducted in this paper. Different design perspectives were addressed to classify and compare the performances of such antennas, as reported in the literature. According to these references, wide bandwidth can be achieved by single layer based MSAs, up to 17 GHz, circular polarization being implemented as well.

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ANTENE MICROSTRIP DE TIP PATCH DREPTUNGHIULAR CU UN SINGUR STRAT DE BANDĂ LARGĂ

(Rezumat)

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