International Journal of Engineering

Journal Homepage: www.ije.ir

Complementary Periodic Structures for Miniaturization of Planar Antennas

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PAPER INFO

Paper history:
Received 08 March 2015
Accepted in revised form 16 October 2015

Keywords:
Planar Antennas Miniaturization
Periodic Structures
Complementary Periodic Structures

ABSTRACT

In this paper various layered planar periodic structures which provide miniaturization of planar antennas are proposed and discussed. The proposed designs are based on two concepts, reactive impedance surfaces and complementary periodic structures. In the proposed structures, complementary periodic rings and slots are patterned on the intermediate boundaries of the dielectric layers. A patch antenna is patterned on top of the first layer and the whole structure is grounded. The dielectric layers can be either similar or may have different dielectric constants and thicknesses. The dielectric constants and thicknesses of the layers can be chosen in a wide range of values. Two distinct configurations are studied simultaneously, namely, complementary circular rings and complementary square rings. The proposed designs provide a miniaturization factor in the range of 2.1-4.5 for planar antennas working in the frequency range of 2-22GHz. Parametric studies are provided to demonstrate high flexibility of the structures.

***doi**: 10.5829/idosi.ije.2015.28.10a.09*

1. INTRODUCTION

Planar antennas are one of the common components of wireless communication systems. In comparison to other antenna configurations, they are light in weight, low profile and benefit from easy and cost effective fabrication process. Improving gain and bandwidth and reducing the dimensions are the main challenges in the area of microstrip antennas.

As examples of recent works on bandwidth improvement of planar antennas, we can refer to [1-4]. Size reduction of microstrip antennas is another consideration which is being extensively investigated in literature. A variety of methods have been proposed for designing compact antennas. From the structural view point, the miniaturized microstrip antennas can be categorized into two groups of planar and nonplanar designs. Albeit, the preference is to design miniaturized antennas which benefit from planarity advantages either.

Artificial magnetic conductors are nonplanar structures which provide high miniaturization for microstrip antennas [5-10]. From the group of nonplanar miniaturized microstrip antennas, we can also refer to literatures [11-13].

Several planar designs are investigated for size reduction of microstrip antennas. One of the most common designs are reactive impedance surfaces (RIS) [14, 15]. These structures cannot provide high miniaturization. They are proposed to provide improved bandwidth and compact antennas. From the group of planar techniques for antenna miniaturization, we can refer to [16-18]. To the best of our knowledge, the highest achieved miniaturization, using planar designs is 50% [16].

The authors have shown that complementary layered periodic structures, which are planar, provide considerable miniaturization. Numerical and experimental results showed that size of planar antennas can be reduced to 0.25 of the conventional patch antenna [19]. In this paper, two other complementary periodic configurations for size reduction of planar antennas are proposed and thoroughly discussed. Introduction of several structures for antenna miniaturization provides a high degree of flexibility and tuning range for design purposes.

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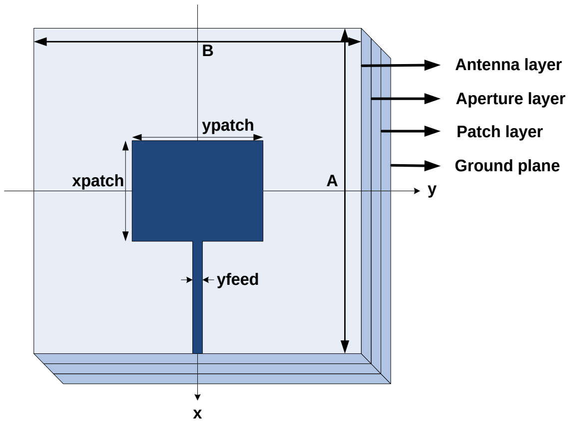


Figure 1. Geometry of the proposed antenna

2. ANTENNA GEOMETRY AND SIZE REDUCTION

2. 1. Antenna Geometry The proposed antenna is shown in Figure 1. The radiating element which is a rectangular patch is placed on a three layer grounded substrate. Complementary periodic patterns are etched on the intermediate boundaries of the dielectric layers. These patterns include complementary aperture and patch layers. The aperture layer is placed underneath the antenna layer and the patch layer is etched on the lower layer close to the ground plane. Lateral dimensions of the dielectric layers are chosen at most three times the width of the radiating element. For the periodic aperture layer, there are 4 unit cells in each coordinate direction resulting in a total of 16 unit cells. The number of unit cells of the periodic patch layer can be either equal to, or less than 16 unit cells, depending on the shape of the complementary pattern. The authors have designed and fabricated a miniaturized antenna on a complementary periodic structure [19]. In the present work, two other complementary periodic patterns are designed and investigated.

In order to have a measure of the miniaturization of the proposed structure, we define miniaturization factor as the ratio of the resonant frequency of the antenna on the layered substrate to the resonant frequency of the same antenna on the same dielectric layers loaded by the complementary periodic pattern. Resonant frequency reduction is an alternative description of size reduction of the antenna. All simulations are performed with HFSS software.

In order to define a default antenna, a conventional rectangular patch antenna on three layers of dielectrics all with relative dielectric constant of 2.2 and thickness of 31mils is considered. The antenna parameters are: x_{patch}=17mm, y_{patch}=20.6mm, y_{feed}=0.4mm, A=48.8mm and B=A. Resonant frequency and bandwidth of the antenna are 5.08GHz and 3.3%, respectively. Throughout the paper, whenever not mentioned, simulations are compared with this default antenna.

2. 2. Size Reduction A layered periodic structure to miniaturize planar antennas is designed and proposed. The designed structure is based on two concepts, namely reactive impedance surfaces (RIS) and complementary periodic patterns.

RISs are surfaces which represent reactive impedance to incident waves. They are investigated in [14]. It is shown that a dipole antenna over a RIS has enhanced performance compared to the same antenna over PEC and PMC surfaces.

Complementary periodic structures are discussed in [20]. It is shown that with applying complementary periodic patterns, resonant frequency of frequency selective surfaces decreases with a factor of 3.

In the proposed antenna configuration, we benefit from the advantages of RIS's and complementary periodic structures simultaneously. With placing complementary periodic structures on the intermediate boundaries of a grounded layered substrate a RIS is designed which provides high miniaturization for planar antennas, compared to conventional RIS's. Theory of the structure is extensively discussed in [19].

The proposed structure benefits from specific features which is briefly mentioned here and thoroughly discussed via simulations in the following sections. These features are:

- A considerable miniaturization is achieved for planar antennas with a planar design.
- The achieved miniaturization factor can be tuned in the range 2.6-4.2.
- Parameters of the complementary periodic pattern can be scaled easily to design miniaturized planar antennas in a broad range in microwave band.
- Dielectric constants and thicknesses of the dielectric layers of the structures can be chosen from a wide range of values.

3. ANTENNA DESIGN

3. 1. Complementary Circular Rings Complementary circular rings is discussed and examined in literature for frequency selective surface applications[20]. It is shown that in order to have maximum coupling, the circular apertures and circular patches should have a shift of half of a unit cell, in both coordinate directions.

In the propped antenna, complementary circular rings are patterned on the intermediate boundaries of dielectric layers. The circular ring aperture and patch layers and the corresponding parameters are shown in Figure. 2. There are 16 unit cells in the aperture layer. Because of a shift of half of a unit cell in circular patch layer, there are 9 unit cells in this layer. Unit cells' dimensions in x and y directions are a and b, respectively. Inner radius of the rings is Rin and the outer radius is Rout.

Width of the rings equals to SlotWidth=R_{out}-R_{in}, as shown in the figure. Unit cell dimensions and the inner and outer radii of the rings are the parameters which can be varied to achieve the desired resonant frequency and miniaturization factor for the antenna.

3. 2. Complementary Square Rings

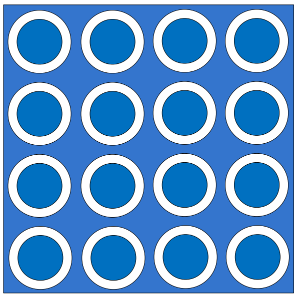
Complementary square rings is another configuration which is proposed to provide miniaturization for planar antennas. The geometry of the structure is analogous to complementary circular rings except the shape of the complementary pattern. Unit cell parameters are shown in Figure 3. Unit cells dimensions' in x and y directions are a and b, as in the case of complementary circular rings. Inner width of square rings is c, and the outer width is d. In this configuration we have width of the rings equals to SlotWidth=(d-c)/2. Unit cell dimensions and the square ring widths are the tuning parameters.

4. SIMULATION RESULTS

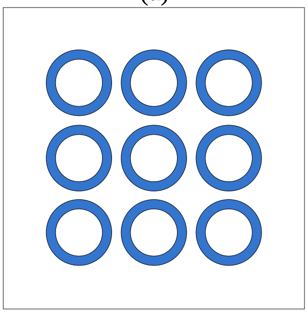
In this section the specific features of the designed structures mentioned briefly, is discussed via simulations. The substrate of the default conventional patch antenna is loaded with the proposed complementary periodic structures and it is shown that a high miniaturization factor is achieved for the antenna.

Complementary periodic circular rings with the parameters: a=b=12.2mm, R_{in}=5.4mm, SlotWidth=0.2mm are placed on the dielectrics of the default antenna. A miniaturization factor of 5.08/1.62=3.13 is achieved. For several values of R_{in}, the structure is simulated and return loss of the antenna is computed and shown in Figure 4. The figure illustrates that with varying the R_{in} parameter, resonant frequency of the antenna can be tuned for the desired value. Radiation pattern of the antenna with resonant frequency of 1.62GHz is simulated and plotted in Figure 5. Radiation pattern is similar to that of a conventional patch antenna, as expected.

Placing the complementary square ring structure with parameters equal to a=b=12.2mm, cc=9mm, SlotWidth=0.1mm on the dielectrics of the default antenna and with y_{feed}=0.4mm results to a miniaturized antenna with a resonant frequency of 1.645GHz. The achieved miniaturization factor is 5.08/1.645=3.09. For several values of the parameter c of the structure, the antenna is simulated and the results are shown in Figure 6. The figure shows that with varying the square ring's width, resonant frequency of the antenna can be changed and tuned for the desired value. Radiation pattern of the antenna with the resonant frequency of 1.645GHz is plotted and shown in Figure 7. The figure illustrates that radiation pattern is not affected by the complementary pattern, as expected.



(a)



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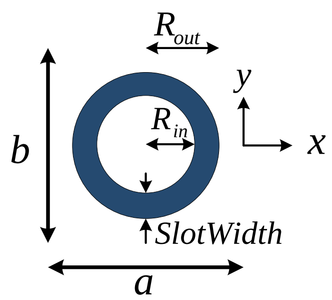


(c)

Figure 2. Circular rings and the parameters, (a) aperture layer, (b) circular ring patch layer, and (c) unit cell parameters.

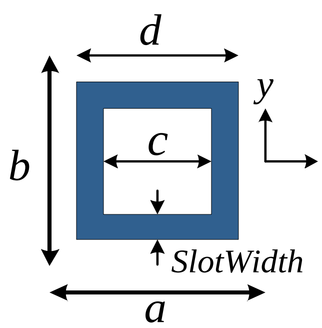


Figure 3. Unit cell and the parameters of square rings.

Miniaturization factors of the antenna, as well as the resonant frequencies, for various parameters of the complementary circular and square ring structures are simulated and illustrated in Tables 1 and 2, respectively. These Tables confirm that the structures are quite flexible and the miniaturization factor is tunable in the broad range of 2.2-4.2 for complementary circular ring structure, and 2.5-4.5 for complementary square ring structure.

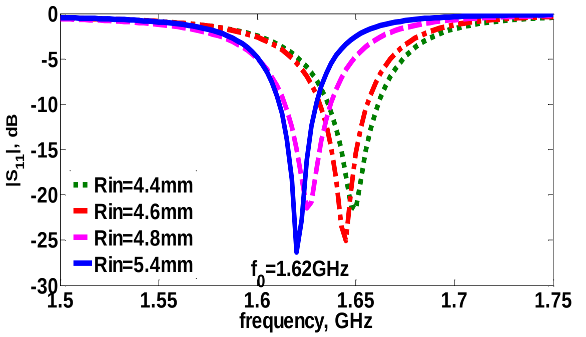


Figure 4. Return loss of the antenna on the complementary circular structure

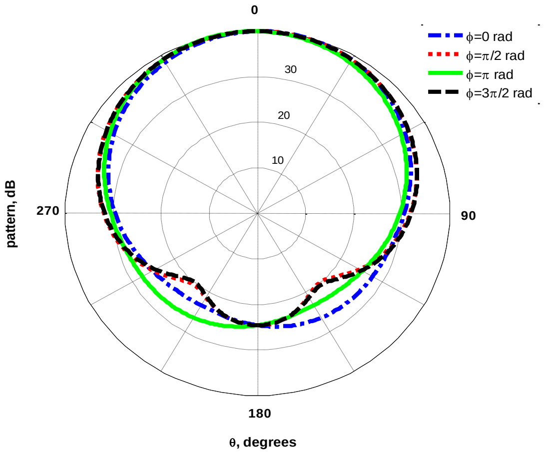


Figure 5. Radiation pattern of the antenna on the complementary circular ring structure

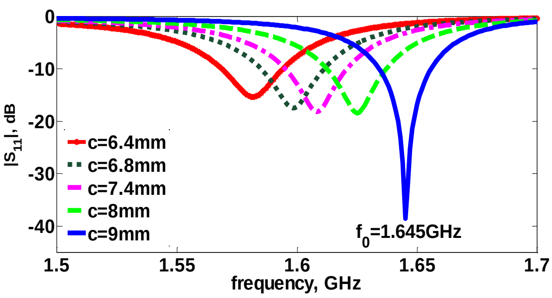


Figure 6. Return loss of the antenna on the complementary square ring structure.

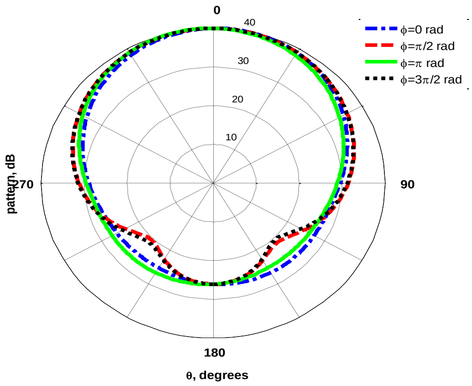
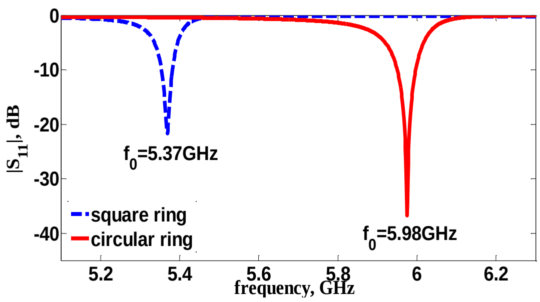
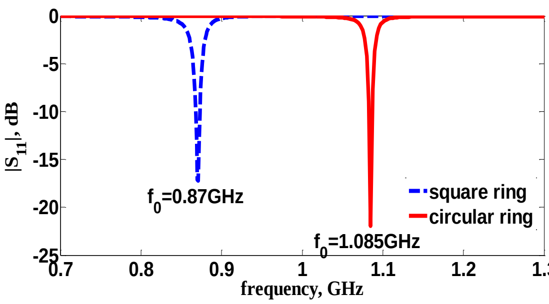


Figure 7. Radiation pattern of the antenna on the complementary square ring structure



(a)



(b)

Figure 8. Return loss of the complementary square ring and circular ring loaded antenna: (a) high frequency antenna, (b) the antenna on high dielectric constant layers.

TABLE 1. Resonant frequency (f_0) and miniaturization factor (MF) of the antenna on complementary circular ring structure. Dimensions are in mm.

a,b	R_{in}	R_{out}	y_{feed}	f_0(GHz)	MF
12.4	5.6	5.8	0.1	1.195	4.2510
12.2	5.1	5.4	0.2	1.485	3.4209
12.2	5.5	5.6	0.4	1.53	3.3203
12.2	5.4	5.6	0.4	1.62	3.1358
12.2	4.2	4.4	0.4	1.64	3.0976
12.2	4.4	4.6	0.4	1.65	3.0788
12.4	5.3	5.9	2.4	2.128	2.3872
12.2	5.5	5.8	2.6	2.243	2.2648
12.2	5.3	5.6	2.6	2.33	2.1803

TABLE 2. Resonant frequency (f_0) and miniaturization factor (MN) of the antenna on complementary square ring structure. Dimensions are in mm.

a, b	c	d	y_{feed}	f_0(GHz)	MF
12.1	11.3	12	0.2	1.137	4.4679
12.2	11.6	11.8	0.2	1.183	4.2942
12.2	11.8	12	0.2	1.21	4.1983
12.2	10.2	10.4	0.2	1.29	3.9380
12.2	9.6	9.8	0.2	1.384	3.6705
12.2	9.2	9.4	0.2	1.476	3.4417
12.2	7	7.2	0.2	1.612	3.1514
12.2	8.8	9	0.4	1.657	3.0658
12.2	11.6	12	2.8	1.98	2.5657

The proposed structures can be applied to miniaturize patch antennas over a wide range in microwave frequencies. To describe this feature a patch antenna with dimensions x_{patch}=4mm, y_{patch}=5mm, y_{feed}=0.5mm and A=B=12mm on three layers of dielectrics all with dielectric constants of 2.2 and thicknesses of 10mils is considered. The antenna resonant frequency is 21.26GHz. Loading the substrate with the proposed complementary circular rings with parameters equal to a=b=3mm, R_{in}=1.3mm, SlotWidth=0.1mm and y_{feed}=0.4mm results in a miniaturized antenna with a resonant frequency of 5.98GHz. A miniaturization factor of 21.26/5.98=3.55 is achieved.

Loading the substrate with the complementary square ring structure with the parameters of a=b=3mm, c=2.6mm, d=2.8mm and y_{feed}=0.4mm, the antenna resonant frequency decreases to 5.37GHz. A miniaturization factor of 21.26/5.37=3.95 is achieved. Return loss plots of the miniaturized antennas for both cases are shown in Figure 8(a). These examples confirm that the proposed structures can be applied for miniaturization of patch antennas over a wide range in microwave band.

Dielectric constants and thicknesses of the layers of the proposed structures can be chosen from a wide range of values. To confirm this flexibility, an antenna with the parameters x_{patch}=17mm, y_{patch}=20.6mm, y_{feed}=0.2mm on three layers of dielectrics with dielectric constants of 10.2 and thicknesses of 25mils is considered. The antenna resonant frequency on the layered substrate is 2.649GHz. Loading the substrate with the proposed complementary circular ring structure with parameters equal to a=b=12.2mm, R_{in}=4.8mm, R_{out}=5.8mm, y_{feed}=0.8mm results in a miniaturized antenna with a resonant frequency of 1.085GHz. A miniaturization factor of 2.649/1.085=2.44 is achieved.

Loading the substrate with the complementary square ring structure with parameters of a=b=12.2mm, cc=7.4mm, SlotWidth=0.1mm and with y_{feed}=0.2mm results in a miniaturized antenna with a resonant frequency of 0.87GHz. The achieved miniaturization factor is 2.649/0.87=3.04, in this case. The return loss of the miniaturized antennas on high dielectric constant substrate, are shown in Figure 8(b).

Complementary slots and dipoles is another configuration which provides high miniaturization using a planar design. The authors have thoroughly investigated such a structure [19]. The designed antenna was fabricated. A miniaturization factor of 2.67 with a gain of 3dB, for the fabricated antenna was achieved.

5. CONCLUDING REMARKS

Two planar layered periodic structures for planar antenna's miniaturization were proposed and investigated. Both of the proposed structures provide considerable miniaturization with a planar design. Because of the planar structure, manufacturing process is simple and the antenna can be fabricated with conventional techniques. Miniaturization of planar antennas for various parameters of the complementary structures were discussed. A tunable miniaturization factor in the range 2.1-4.5 was achieved. The proposed structures can be applied to miniaturize planar antennas over a broad range in microwave band. The proposed structures are quite flexible and can be designed with dielectric layers of desired dielectric constants and thicknesses.

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Complementary Periodic Structures for Miniaturization of Planar Antennas

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P A P E R I N F O

Paper history:
Received 08 March 2015
Accepted in revised form 16 October 2015

Keywords:
Planar Antennas Miniaturization
Periodic Structures
Complementary Periodic Structures

چکیده

در این مقاله چندین ساختار تناوبی مسطح چندلایه که کاهش ابعاد برای آنتن های مسطح ایجاد می‌کنند پیشنهاد و بررسی شده‌اند. طرح‌های پیشنهادی براساس دو مفهوم سطوح امپدانسی راکتیو و ساختارهای تناوبی مکمل هستند. در ساختارهای پیشنهاد شده، حلقه‌ها و شکاف‌های تناوبی مکمل بر روی مرزهای میانی لایه‌های دی‌الکتریک ایجاده شده‌اند. یک آنتن مسطح بر بالای لایه اول ایجاد شده است و کل ساختار زمین شده است. لایه‌های دی‌الکتریک می‌توانند مشابه باشند یا این که ثابت‌های دی‌الکتریک متفاوت و ضخامت‌های متفاوت دارا باشند. مقادیر ثابت دی‌الکتریک و ضخامت لایه‌ها می‌توانند در محدوده وسیعی انتخاب شوند. دو شکل مجزا به طور همزمان بررسی شده‌اند، حلقه‌های دایروی مکمل و حلقه‌های مربعی مکمل. طرح‌های پیشنهاد شده ضریب کاهش ابعاد در محدوده ۲/۱ تا ٤/۵ را برای آنتن‌های مسطح که در محدوده فرکانسی ۲گیگاهرتز تا ۲۲گیگاهرتز کار می‌کنند، ایجاد می‌کنند. مطالعات پارامتری انجام شده است تا انعطاف‌پذیری بالای ساختارها را نشان دهد.

doi*: 10.5829/idosi.ije.2015.28.10a.09*