Compact Shorted Rectangular Microstrip Antennas

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Abstract

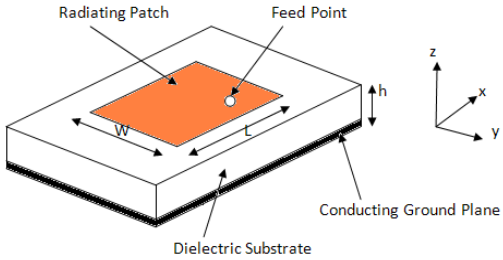
A compact microstrip patch antenna is presented in this paper in order to reduce the surface area of the normal rectangular microstrip patch .The reduction in size were made by meaning of shorting the normal rectangular patch at the middle of its length using shorting posts .A comparison between the normal and shorted patches antenna shows that the shorted microstrip patch has similar properties such that return loss, input impedance, bandwidth and radiation pattern as the normal microstrip patch antenna. The investigation made at resonance frequency 1.691GHz using an evaluation version of Sonnet 12.53 Software .

I-Introduction

The concept of Microstrip Antenna (MSA) was first proposed by Deschamps in 1953 [1]. However, practical antennas were developed by Munson [2], [3] and Howell [4] in the 1970s. The numerous advantages of MSA, such as its low weight, small volume, and ease of fabrication using printed-circuit technology, led to the design of several configurations for various applications [5–9]. With increasing requirements for personal and mobile communications, the demand for smaller and low-profile antennas has brought the MSA to the forefront.

A MSA in its simplest form consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other side as shown in Figure 1. The dielectric constant of the substrate ranges from 1.07 to about 13, with the loss tangent ranging from 0.0001 to 0.017 [10].

The most popular models for the analysis of microstrip patch antennas are the transmission line model, cavity model, and full wave model



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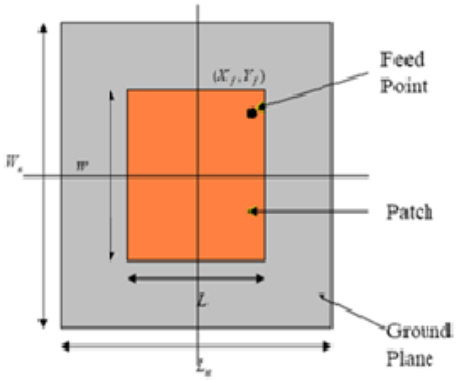


(b)

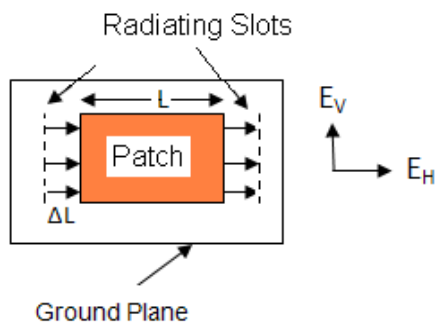
Figure 1. (a) Microstrip Patch Antenna Structure. (b) Top view.

[11] which include primarily integral equations (Moment Method) [12].The transmission line model is the simplest of all and it gives good physical insight but it is less accurate. The cavity model is more accurate and gives good physical insight but is complex in nature. The full wave models are extremely accurate, versatile and can treat single elements, finite and infinite arrays, stacked elements, arbitrary shaped elements and coupling. These give less insight as compared to the two models mentioned above and are far more complex in nature.

However, the patch can assume any shape, be it rectangular, circular, triangular, elliptical, helical, circular ring, etc. The variety in design that is possible with microstrip antennas probably exceeds that of any other type of antenna element. Microstrip antennas are used where size, weight, cost, better performance, compatibility with microwave and MIllimeter Wave Integrated Circuits (MMICs), robustness, ability to conform to planar and non-planar surfaces, etc. are required [2],[5].

Bandwidth and efficiency of a microstrip antenna depends upon patch size, shape, substrate thickness, dielectric constant of substrate, feed point type and its location, etc..

Radiation from the microstrip antennas can occur from the fringing fields between the periphery of the patch and the ground plane as shown in Figure 2. The length *L* of the rectangular patch for the fundamental TM_{10} mode excitation is slightly smaller than $\lambda/2$, where λ is the wavelength in the dielectric medium, which in terms of free-space wavelength λo is given as $\lambda o / \sqrt{\varepsilon_{reff}}$, where ε_{reff} is the effective dielectric constant of a microstrip line of width *W*. The value of ε_{reff} is slightly less than the dielectric constant ε_r of the substrate because the fringing fields from the patch to the ground plane are not confined in the dielectric only, but are also spread in the air.



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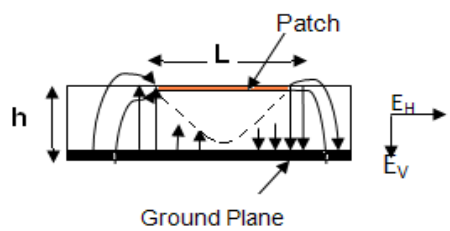


(b)

Figure 2. Microstrip electric field pattern
(a) Top view (b) Side view

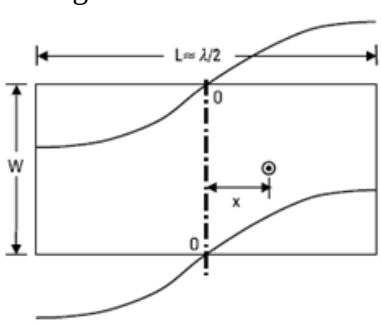
Personal mobile communication and other miniaturized communication systems need a small-sized microstrip antennas. The size of the regularly shaped of a half-wavelength ($\lambda/2$) microstrip antennas operating in the UHF band is quite large because its resonant length is inversely proportional to frequency. To design a smaller antenna at these frequencies, conventional microstrip antennas configurations, such as rectangular and circular configurations, need to be modified.

Compact microstrip antennas can be designed with substrate having a higher dielectric constant ε_r . In this case, the size of the regularly shaped microstrip antennas will be much smaller than that of the low dielectric constant substrate at a given resonance frequency, but the bandwidth is small [10]. The compact antennas have also been realized by cutting slots in regularly shaped antennas. The requirements of these compact broadband microstrip antennas will increase in the future

due to the ever-growing miniaturization of communication systems. The bandwidth of the compact microstrip antennas has been increased in both planar as well as multilayer configurations [13],[14].

A compact shorted λ/4 rectangular microstrip antenna has the same resonance frequency as that of a λ/2 rectangular microstrip antenna, with half the area [15]. The resonance frequency reduces further as the width of the shorting plate decreases [15], [16].

A rectangular microstrip antenna operating in the fundamental TM_{10} mode has a resonant length of λ/2; the voltage distribution along its length is shown in Figure 3(a). The zero potential field is along the line OO, which is in the middle of the resonant length. By shorting the patch along the line OO to the ground plane, and by using only half of the patch, a compact shorted rectangular microstrip antenna is realized with λ/4 length as shown in Figure 3(b) [14]. This antenna has nearly the same resonance frequency as that of a λ/2 rectangular microstrip antenna, but the size is reduced by one-half (here the resonant length is λ/4). The shorting can be realized either by using a shorting plate or by shorting posts [10]. In this paper a rectangular microstrip patch shorted at the middle of its length by placing number of shorting posts will be investigated .



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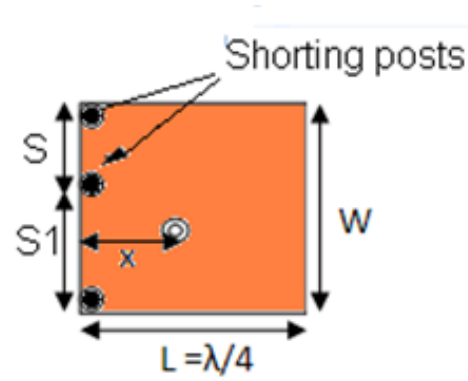

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Figure 3.(a) Field distribution of fundamental TM10 mode of RMSA. (b) Shorted λ/4 RSMA .

II-Design Specifications

A normal rectangular microstrip patch will firstly designed and its properties investigated to be considered as a reference to compare the shorted patch properties with. The three essential parameters for the design of a rectangular microstrip patch antenna are:

• *Frequency of operation* f_o *:*

The resonant frequency of the antenna selected to operate for reception of Meteosat WEEFAX at 1.691GHz [17].

• *Dielectric constant of the substrate* ε_r :

The dielectric material selected is Rogers RT5880 which has a dielectric constant of 2.2 and loss tangent .0009.

• *Height of dielectric substrate h*:

For microstrip patch antenna to be used in cellular phones or in any other applications, it is essential that the antenna is not bulky. Hence, the height of the dielectric substrate is usually $0.003\lambda o \leq h \leq 0.05\lambda o$ .The height was selected to be $.0179\lambda o$ which equals to 3.175 mm.

Hence, the essential parameters for the design are:

• f_o = 1.691 GHz

• ε_r = 2.2

• h = 3.175 mm

III-Design Procedure

The transmission line model will be used to design the antenna [11].

1- *Patch Width (W)*

For efficient radiation, the width of the patch is given by *Bahland Bhartia* [5], as

$$W = \frac{c}{2f_0\sqrt{\frac{(\varepsilon_r+1)}{2}}} \quad (1)$$

Where

f_0 = Resonant Frequency

ε_r = Relative dielectric constant

c =Speed of light

Substituting c = 3e8 m/s, ε_r = 2.2 and f_o = 1.691GHz, the patch width W = 70.127 mm **.**

2-*Effective dielectric constant* ε_{reff} **:**

The expression for ε_{reff} is given by Balanis [18] as

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-\frac{1}{2}} \quad (2)$$

Substituting ε_r = 2.2, W = 70.127 mm and h = 3.175 mm, the effective dielectric constant ε_{reff} = 2.0829 **.**

3-*Patch Effective Length* L_{eff} **:**

The patch effective length calculated as [9],

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \quad (3)$$

Substituting ε_{reff} = 2.0829, c = 3e8 m/s and f_o = 1.691 GHz, the patch effective length L_{eff} = 61.462 mm .

4- *Length extension* ΔL**:**

Given empirically by Hammerstad [19] as:

$$\Delta L = .412h\frac{(\varepsilon_{reff}+.3)\left(\frac{W}{h}+.264\right)}{(\varepsilon_{reff}-.258)\left(\frac{W}{h}+.8\right)} \quad (4)$$

Substituting ε_{reff} = 2.0829, W = 70.127 mm and h = 3.175 mm, the *length extension* ΔL =1.6681 mm **.**

5- *Actual length of patch* L**:**

The actual length is obtained as

$$L = L_{eff} - 2\,\Delta L \quad (5)$$

Substituting L_{eff} = 61.462 mm and ΔL = 1.6681 mm, the *actual length of patch* L = 58.126 mm **.**

6*: Calculation of the ground plane dimensions* L_g *and* W_g **:**

The transmission line model is applicable to infinite ground planes only. However, for practical considerations, it is essential to have a finite ground plane. It has been shown by [10] that similar results for finite and infinite ground plane can be obtained if the size of the ground plane is greater than the patch dimensions by approximately six times the substrate thickness all around the periphery. The width of the patch was optimized using Microstrip Antenna Calculator [20] and reduced to 39 mm to resonate the full sized patch at 1.691 GHz.

Hence, for this design, the ground plane dimensions would be given as:

$L_g = 6h + L$= 77.176 mm

$W_g = 6h + W$ = 58.1mm

7-*Determination of feed point location* **(**X_f ,Y_f **):**

A coaxial probe type feed is to be used in this design. As shown in Figure 1(b) the center of the patch is taken as the origin and the feed point location is given by the co-ordinates **(**X_f , Y_f **)** from the leading edge of the patch. The feed point must be located at that point on the patch, where the input impedance is 50 Ω for the resonant frequency. Hence, a trial and error method is used to locate the feed point. For different locations of the feed point, the return loss RL is compared and that feed point is selected where the RL is most negative. According to [11] there exists a point along the length of the patch where the RL is minimum. Hence in this design, Y_f will be zero and only X_f will be varied to locate the optimum feed point.

IV-Results and discussion

The main goal in using a compact rectangular microstrip antenna structure is to reduce the surface area required to construct the antenna while not sacrificing any loss in bandwidth or efficiency .

The software used to model and simulate the microstrip patch antenna is an evaluation version of Sonnet 12.53 software [21]. Sonnet is a full-wave electromagnetic simulator based on the method of moments. It analyzes 3D and multilayer structures of general shapes. It has been widely used in the design of MICs, RFICs, patch antennas, wire antennas, and other RF/wireless antennas. It can be used to calculate and plot the return loss RL parameters, standing wave ratio SWR, current distributions as well as the radiation patterns.

Return Loss and Antenna bandwidth calculation:

The results tabulated below are obtained after varying the feed point location along the length of the patch from the leading edge of the full sized patch and from the shorted edge of the shorted patch to their right most edge. The coaxial probe feed used is designed to have a radius of 0.25mm. A frequency range of 1.6-1.8 GHz is selected.

Table 1 shows the calculated results for different feed locations for both full sized and

Table 1. Effect of feed location on center frequency, return loss and bandwidth .

No.	Patch type	Feed location $(X_f, Y_f)_{mm}$	f GHz	Return loss (RL) dB	Bandwidth (RL>-9.5dB) MHz
1	Normal	(2.6563,0)	1.695	-5.81996	-
2	Normal	(5.5626,0)	1.689	-6.38216	-
3	Normal	(8.4689,0)	1.687	-7.45897	-
4	Normal	(11.3752,0)	1.689	-9.42306	-
5	Normal	(14.2815,0)	1.689	-13.495	86
6	Normal	(17.1878,0)	1.691	-30.533	89
7	Normal	(20.0941,0)	1.693	-13.0796	56
8	Normal	(23.0004,0)	1.694	-5.42061	-
9	Normal	(25.9067,0)	1.696	-1.3967	-
10	shorted	(2.6563,0)	1.67	-7.54369	-
11	shorted	(5.5626,0)	1.679	-22.4345	72
12	shorted	(8.4689,0)	1.683	-13.1067	78
13	shorted	(11.3752,0)	1.69	-7.64516	-
14	shorted	(14.2815,0)	1.697	-5.34203	-

shorted patches .The center frequency is selected as the one at which the return loss is minimum.The full sized rectangular microstrip patch structure has a relatively high resonance seen at 1.691GHz in Figure 4. When the full sized patch is modified with the introduction of shorting posts, the antenna behaves in much the same way as shown in Figure 5. The shorting posts and their relative position enables the operation of the modified patch in much the same way as the full sized patch dose.

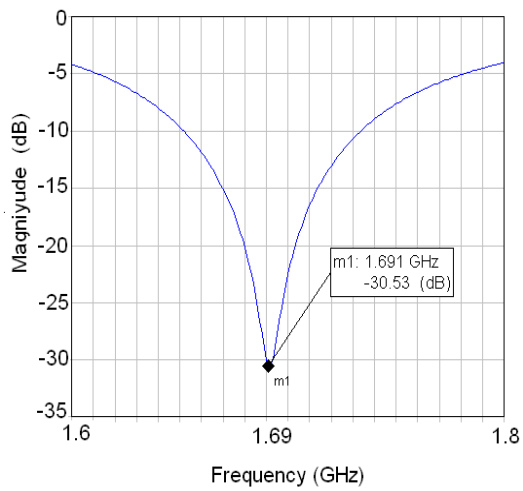


Figure 4. Normal patch input return loss S11 .

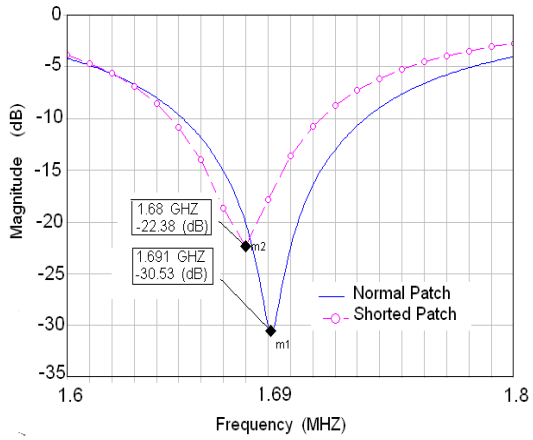


Figure 5. Normal and shorted patch's input return loss comparison .

This sample antenna has a reduction of 50% of its length when its shorted by using closely spaced shorting posts along its width as shown in Figure 3(b).The length of the shorted patch L= 29.063 mm ,the width W= 39 mm, the height h= 3.175 mm, the posts have a diameter of 0.5mm located at distances S=11.7mm,S1=27.3mm .

From table 1, the optimum feed point is found to be at f_x = 17.188mm where a RL of -30.58 dB for the full sized patch and at f_x =5.563mm where RL of –22.435 dB for the shorted patch are obtained respectively .

The bandwidth of the antenna can be calculated from the return loss RL plot which is usually specified as frequency range over which VSWR is less than 2 (which corresponds to a return loss of -9.5 dB or 11% reflected power) [10]. The bandwidth of the antenna for this feed point location for both full sized and shorted patches is calculated to be 89 MHz at a center frequency of 1.691 GHz for full sized patch, and 72MHz at resonant frequency of 1.68 GHz for shorted patch which is very close to the desired design frequency . It is observed from table 1 that, as the feed point location is moved away from the center of the patch, the center frequency starts to decrease slightly. The resonance frequency of the shorted patch is slightly smaller than the corresponding λ/2 full sized patch due to the inductance of the shorting posts; the bandwidth is also smaller.

Input impedance:

Impedance analysis as shown in Figure 6 shows that at resonance frequency the full sized patch operates at 53.05Ω while the shorted compact patch operates at 43.29Ω which provides a good match for a feed system. Changing the physical parameters of the antenna can have a multiple effect on the operation of the antenna i.e adjusting height and length of the patch would change the operating frequency , the return loss and the input impedance.

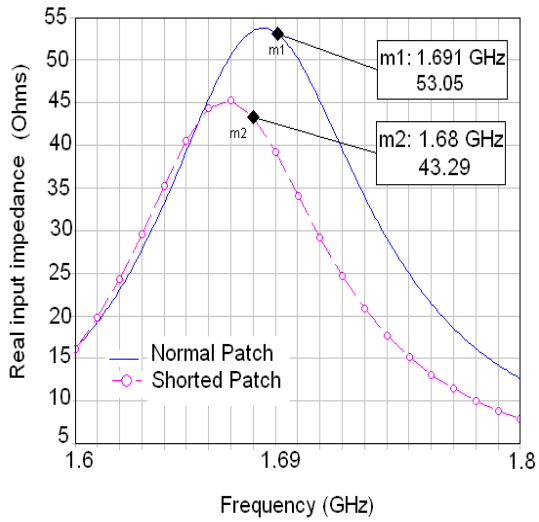
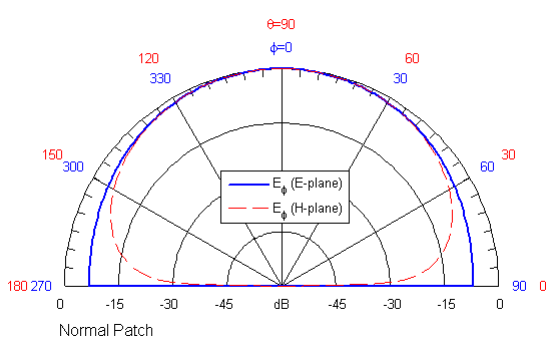


Figure 6 . Normal and shorted patch's impedance comparison.

Radiation Pattern:

Since a microstrip patch antenna radiates normal to its patch surface, the elevation pattern for ϕ = 0° and θ = 90° would be important. The predicted radiation pattern of both normal and shorted MSA at the resonance frequencies are shown in Figure 7 .The maximum gain is obtained in the broadside direction and is found to be 1.87 dBi for both, normal and shorted patches. The back lobe radiation is sufficiently small and is found to be -5.3 dBi. This low back lobe radiation is an added advantage for using this antenna in a cellular phone, since it reduces the amount of electromagnetic radiation which travels towards the users head.



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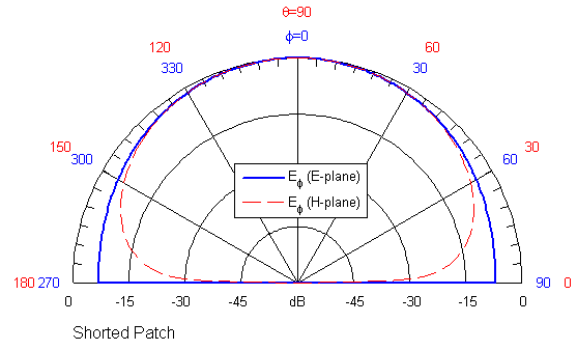

(b)

Figure 7. Radiation patterns (a) for the normal patch and (b) for the shorted patch .

IV- Conclusions

A compact shorted microstrip patch antenna resulting from shorting a normal rectangular patch by means of shorting posts were presented .The obtained results showed that reduction in size of the normal rectangular patch can be achieved while retain its properties if the shorting to the ground made along the line at the middle of its length at the zero field point. The feed point location along patches length and the shorting posts for the shorted patch have pronounce effect on the properties of the antenna. Table 1 and return loss plots illustrates the similarity in behavior of both normal and shorted patches.

هوائي الرقعة الشريطي المضغوط

محمد مسعود ابوالعوينات

قسم الفيزياءِ- كليّة العُلُومِ

جامعة سبها

الملخّص

تم في هذه الورقةِ دراسة إمكانية تقليص المساحةَ السطحيّةَ لهوائي الرقعة الشريطي الدقيقِ المستطيل الشكل (rectangular microstrip patch antenna)، حيث تم ذلك بقسر الرقعة في منتصف طولها و ذلك بوضع عدد من المناصب (shorting posts) مكونا ما يسمى بهوائي الرقعة الشريطي المضغوط (compact microstrip patch antenna).

وقد اظهرت النتائج المتحصل عليها إن لهذا الهوائي خصائص مماثلةُ لهوائي الرقعة العادي من هذه الخصائص: فقد العودة (return loss)، معاوقة الدخولَ ، النمط الإشعاعي وعرض النطاق الترددي. تمت الدراسة عند ترددِ رنينِ 1.691GHz باستخدام برنامج Sonnet 12.53.

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VI-References

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