Quality Factor Q of a Miniaturized Meander Microstrip Patch Antenna

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Introduction

Microstrip antennas are widely used due to their low profile, light weight and conformal nature. They are utilized in many applications abound from HF through 5.8 GHz ISM band frequencies. Moreover, the advance in the electronic technology leads to an extensive decrease in the overall size of the electronic parts leading to miniature communication systems that are required to function at RF wavelengths much larger that their own physical dimensions. Based on this fact, there is a demand in modern communication systems for smaller antennas, with size significantly less than the usual half wavelength. However, the antenna size with respect to the wavelength, is the parameter that will have the preponderant influence on the radiation characteristics, thus making the miniaturization process a challenging field. Antennas can be made smaller and one of the most commonly used methods to miniaturize a microstrip antenna is by increasing its electrical length. Nevertheless, this procedure has a negative impact in the antenna's bandwidth, gain and efficiency.

In this work the area miniaturization of a rectangular microstrip patch antenna by inserting a number of slits parallel to the radiating edges, is investigated in relation to the quality factor. The slits force the surface currents to meander, thus artificially increasing the antenna's electrical length without modifying the patch's global dimensions. A significant decrease in the resonant frequency is observed, depending on the slit's length and width. The resultant antennas can be characterized as small antennas in accordance to the relevant fundamental limitations.

Fundamental Limits and Computation of Q

The fundamental limitations of small antennas were first addressed by Wheeler [1] and Chu [2]. It has been shown that when an antenna becomes electrically small its bandwidth decreases. Chu derived an expression relating the antenna's radiation quality factor Q with the space the antenna fills, called the radiansphere where the radius of this radiansphere is the largest linear antenna

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dimension. Chu established a fundamental Q limitatation, which later re-examined by McLean [3], and is given by:

$$Q = \frac{1}{k^3 a^3} + \frac{1}{ka} \tag{1}$$

Where $k=2\pi/\lambda$, λ is the operating wavelength and α is the radius of the radiansphere.

The above expression establishes a fundamental limit which means that no antenna can ever exceed this threshold. If the antenna presents losses, meaning the radiation efficiency is lower than unity, then: $Q_{lb}=\eta_r Q$. The more efficiently an antenna occupies its radianshpere, the closer its Q would be to the Chu limit. An antenna is said to be a miniature if the radius $a<\lambda/2\pi$ or alternatively if $k\alpha<1$.

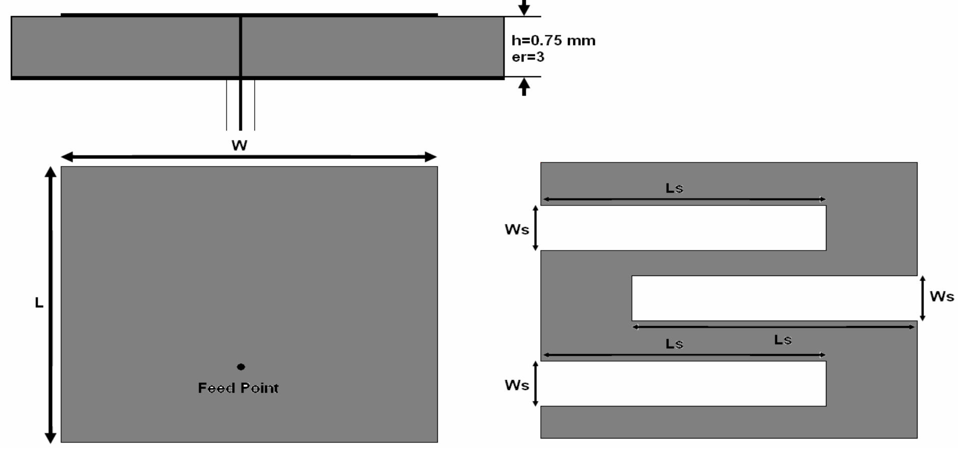
An approximate expression for the computation of the quality factor of an antenna is presented by Yaghjian and Best in [4], and it is given by:

$$Q_z(\omega_0) = \frac{\omega_0}{2R(\omega_0)}\sqrt{\left[R'(\omega_0)\right]^2 + \left[X'(\omega_0) + \frac{\left|X(\omega_0)\right|}{\omega_0}\right]^2} \tag{2}$$

Where $R(\omega)$ and $X(\omega)$ are the resistance and reactance of the antenna. This expression is used to calculate the quality factor of the presented antenna configurations and it is compared with the Chu limitation and the miniature antenna limit.

Area Miniaturization Method and Results

The original patch that was used is a rectangular microstrip patch antenna of resonant length L=36 mm and width W=44 mm, and it is designed on the Rogers RO3003 laminate substrate with h=0.75 mm, ε_r=3.00 and tanδ=0.0013, as shown in Fig. 1a. The layout of the slitted configuration is depicted in Fig. 2b. The slits are placed in parallel with the radiating edges.



(a) (b)

Fig. 1 (a) The original patch antenna utilized and (b) the layout of the resultant small antenna.

The area miniaturization is achieved due to the presence of the slits. The current on the surface of the patch is forced to follow a meander route. Thus, the electrical length is increased; the antenna's electrical size is decreasing while its overall dimensions stay constant. The slit width (W_S), after a number of simulations, was set equal to 6 mm. The slit length (L_S) is mainly responsible for the decrease of the antenna's resonant frequency. By increasing this length, the resonant frequency can be significantly shifted downwards. Multiple slit lengths were chosen, which are: 22, 25, 28, 31, 33, 36 and 39 mm.

The proposed configurations were simulated and the results are presented in Fig. 2. The resonant frequency is shifted from 2.38 GHz, which is the resonant frequency of the original rectangular patch, to 0.435 GHz for the L_S=39 mm case. All the above design cases are shown in Fig. 2.

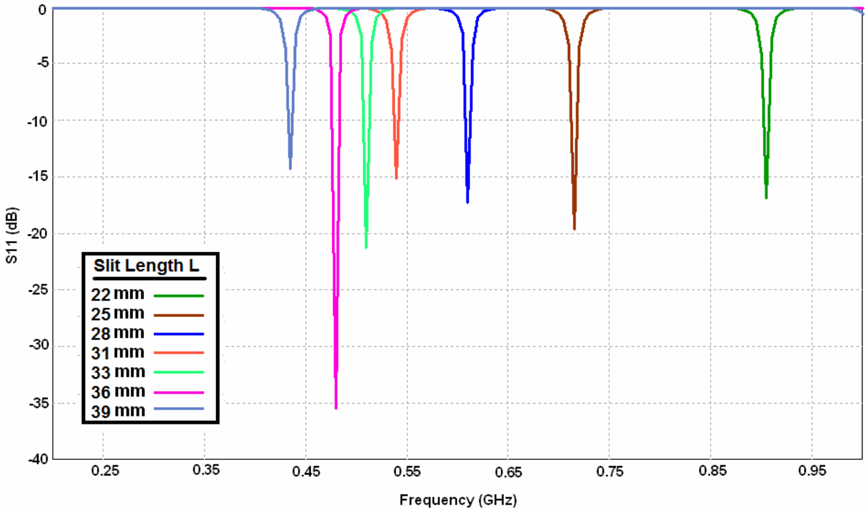


Fig. 2 Simulated Return Loss (in dB) for the slitted antenna as a function of the slit length L_S.

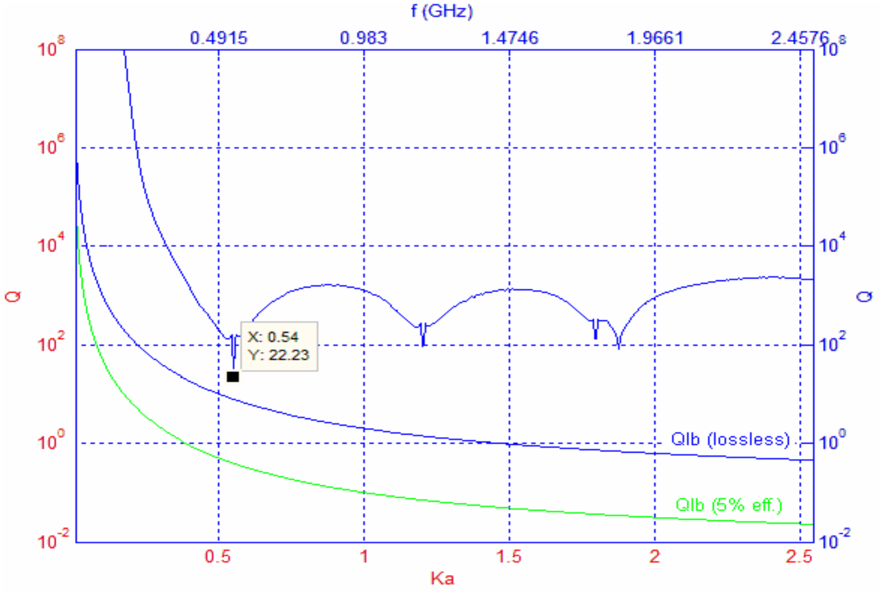


Fig. 3 The simulated Q curve for the 31 mm slit length case.

The radiation quality factor Q for each one of the fore mentioned slitted configurations was calculated using expression (2), and is given in Table 1. In Fig. 3 the typical simulated Q curve for a specific slit length is depicted in comparison to the Q Chu limit for the lossless case and the 5% efficiency case. The marker corresponds to the resonant frequency and the relevant Q value. As can be seen for all the demonstrated cases, the ratio of the antenna maximum dimension to the resonant wavelength is such that the product kα is below the Chu limit concerning the small antenna definition (kα<1). Thus, the designed antennas can be labeled as "small antennas". Of course, the large value of Q denotes deterioration in the bandwidth, an inherent characteristic of small antennas. The primary reason for the low radiation efficiency of 5% is the very low profile (small effective height) of the meander antenna discussed above.

Table 1. The performance of the slitted configured antenna

L_s (mm)	f_0 (GHz)	Q	Q_{lb} (lossless)	Q_{lb} (5% efficiency)	kα
22	0.905	60.03	2.37	0.12	0.92
25	0.715	29.02	3.97	0.20	0.72
28	0.61	45.58	5.79	0.29	0.62
31	0.54	22.23	7.85	0.39	0.55
33	0.51	26.45	9.09	0.46	0.52
36	0.48	24.09	10.64	0.53	0.49
39	0.435	18.57	13.8	0.69	0.44

Conclusions

A basic rectangular microstrip patch antenna can be miniaturized by inserting a number of slits parallel to the radiating edges. A frequency reduction of up to 80% and an area reduction up to 97% can be observed, depending on the length of the slit. For all the above cases, the resultant antennas can be characterized as "small antennas" since the Chu and Wheeler limit is satisfied. Nevertheless, there is deterioration in the bandwidth and the radiation efficiency of the antenna, but these can be compensated by investigating a stacked configuration of the proposed antenna which can fill more efficiently the radiansphere.

References:

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