Theoretical Investigation of Compact Microstrip Resonators With Stubs for Patch Antennas

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***Abstract*—The influence of the stubs on the resonance frequency and on the susceptance slope parameter of the disc resonator is investigated theoretically. It is shown that the stubs may significantly reduce the diameter of the resonator at the expense of bandwidth.**

***Index Terms*—Impedance boundary conditions, microstrip antennas, microstrip resonators with stubs.**

I. Introduction

MICROSTRIP antennas are characterized by small size, light weight, low production cost, conformal nature, and good aerodynamic characteristics [1]. One of the problems of microstrip antenna technology is reduction of the antenna sizes. Solution of this problem is important for many applications: in portable mobile communication equipment, in aircraft, spacecraft, satellite and missile antennas, and arrays. Several methods are used to achieve this aim: substrates with high dielectric constants, shorting posts [2], chip resistors or capacitors embedded in the substrate [3], [4], and narrow lines in the central segment of the rectangular patch resonator [5]. However, the use of substrates with high permittivity leads to lower radiation efficiency, chip resistors reduce the gain of the antenna due to the resistive load absorbing power. Deformation of the shape of a patch suggested in [5] allows one to obtain low antenna dimensions with better radiation performances in comparison with other methods. However, this method is not easily amenable to electrodynamic calculations because of the complex shape of the resonator.

In this paper, we suggest a new method of the microstrip antenna size reduction that consists of the use of microstrip stubs on the periphery of resonators (Figs. 1 and 2) and may be utilized in microstrip antennas of different shapes: circular, ring, rectangular, square, etc. Such structures have also an advantage of simple calculations simulating the comb of stubs by impedance boundary conditions. They are easy to manufacture. One can choose geometrical dimensions and shapes of the stubs (Fig. 3) in order to optimize characteristics of the antennas.

II. Theory

A. Geometrical Dimensions of the Disc Resonator

The equation that defines the resonance frequencies of the disc resonator with stubs on a dielectric substrate is [6]

$$J'_n(k_d R) - \alpha J_n(k_d R) = 0 \tag{1}$$

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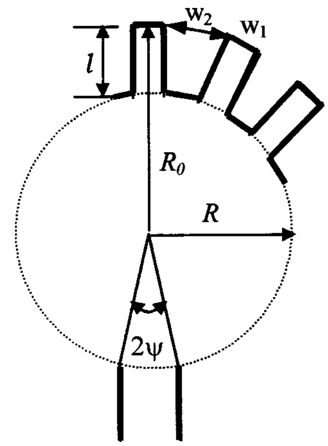

Fig. 1. Microstrip resonator with stubs on its periphery.

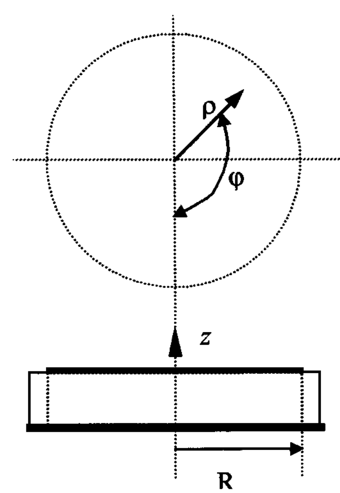

Fig. 2. Uniform part of the resonator with stubs (the impedance boundary conditions are at $\rho = R$).

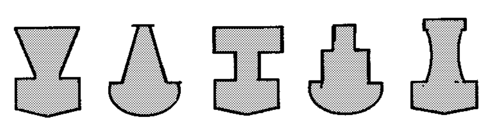

Fig. 3. Possible geometries of the stubs.

where $J_n(\bullet)$ and $J'_n(\bullet)$ are Bessel functions of the first kind, n-orders, and its derivatives, respectively, R is the radius of the resonator without stubs (Fig. 2), $K_d = \omega\sqrt{\varepsilon_0\varepsilon_d\mu_0}$, μ_o, and ε_o are permittivity and permeability of free space, ε_d is permittivity of the dielectric, α is the dimensionless parameter describing the comb of stubs, which is defined by the expression

$\alpha = -jZ_dY_s$, and $Z_d = \sqrt{\mu_0/(\varepsilon_d\varepsilon_0)}$ and $Z_s = 1/Y_s$ is the boundary impedance on the radius R of the resonator.

The boundary conditions on the cylindrical surface of the resonator at $\rho = R$ are written as follows:

$$H_\varphi = -Y_sE_z \quad E_z = -Z_sH_\varphi \tag{2}$$

where E_z and $H\varphi$ are the components of electromagnetic field in the resonator at $\rho = R$ (Fig. 2), Y_s and Z_s are the admittance and impedance of the disc cylindrical boundary, respectively. With $\alpha = 0$ (it corresponds to $Y_s = 0$), (1) reduces to the known one for the disc resonator with magnetic wall boundary conditions.

With this approach, the real discrete comb structure is replaced by a distributed smooth boundary with impedance properties. The averaged input admittance of the comb structure is defined as

$$Y_s = jY = jY_l\left(\frac{K}{1-l/R_0}\right)tg\left(\frac{2\pi l}{\lambda_g}\right) \tag{3}$$

where Y_l is the characteristic admittance of the stub, l is its length, λ_g is the wavelength in the microstrip line that forms the stub, and the coefficient K is defined at $\rho = R_0$ as follows:

$$K = \frac{w_1}{(w_1+w_2)}.$$

The dimensions of the comb w_1 and w_2 are shown in Fig. 1.

B. Approximate Evaluation of the Bandwidth of the Disc Antenna With Stubs

The influence of the stubs on the bandwidth of the antennas can be analyzed using a resonator model. It is well known that the bandwidth of the microstrip antennas is defined mainly by impedance matching. Considering the equivalent network of the resonator in the vicinity of the operating frequency, we may write down the input admittance of the resonator as follows:

$$Y_{\text{in}} = G_{\text{in}} + jB_{\text{in}} \tag{4}$$

where G_{in} is the shunt conductance and B_{in} is the shunt susceptance of the resonator. The input susceptance around the resonant frequency ω_0 at the reference terminals of such a resonator with a microstrip line feed (Fig. 1) can be written in the following form [7]:

$$B_{\text{in}} = 2B'\left(\frac{\omega-\omega_0}{\omega_0}\right) \tag{5}$$

where ω is the frequency and B' is the susceptance slope parameter of the resonator for the point $\omega = \omega_o$, which is defined as

$$B' = \frac{\omega_0}{2}\frac{\partial B_{\text{in}}}{\partial\omega}\bigg|_{\omega=\omega_0}. \tag{6}$$

The bandwidth of a microstrip antenna depends on the properties of the microstrip resonator and of external matching networks. The frequency properties of the antenna without matching networks are defined by the loaded Q-factor of the resonator

$$Q_l = \frac{B'}{G}. \tag{7}$$

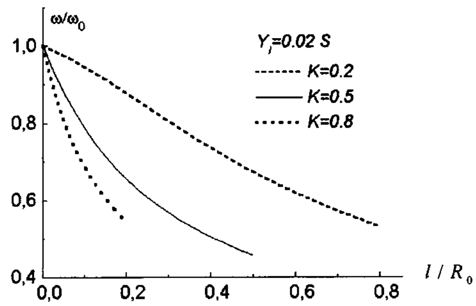

Fig. 4. Normalized frequency ω/ω_o as function of the normalized length of the stubs l/R_0 with K as a parameter.

Therefore, calculating the susceptance slope parameter B', we can approximately evaluate the bandwidth of the antenna. The susceptance slope parameter of our problem is [6]

$$B' = -\frac{\pi}{6Z_d\sin\psi} \times\left[k_dR\frac{J_1''(k_dR)J_1(k_dR)-[J_1'(k_dR)]^2}{[J_1(k_dR)]^2}-\gamma\right] \tag{8}$$

where $\gamma = \omega_0Z_d(\partial Y/\partial\omega)$, $Y = Y_s/j$, and 2ψ is the angle width of the feeding line (Fig. 1). For short stubs, the parameter γ may be expressed as follows:

$$\gamma \approx \omega_0\left(\frac{K}{1-l/R_0}\right)Z_dY_l\sqrt{\varepsilon_0\varepsilon_d\mu_0}\,l. \tag{9}$$

The frequency dependence of Z_d in (8) and (9) is neglected. Notice that the parameter B' defined above can be used for synthesis of external matching networks [7] to improve the bandwidth of the antenna.

III. Numerical Results

In order to compare electrical characteristics of the resonator with open-circuited stubs with those of the resonator with magnetic-wall boundary conditions, we will use the following method. Fixing the radius of the disc resonator R_0 without stubs, we calculate its parameters. For the new resonator, we fix the length of the stubs l preserving the sum $(R+l) = R_0 = \text{const}$, where R is the radius of the uniform part of the resonator with stubs (Fig. 1). Therefore, the whole area of the dielectric substrate occupying by the above two resonators is equal. Calculating parameters of the new resonator for different l, we can evaluate the influence of the stubs on the properties of the resonator.

Notice that, in this paper, we consider resonators with uniform stubs, therefore, the maximum length of the stubs for small w_1 can be limited. It is defined by the condition $1_{\max}/R_0 = 1-K$, which corresponds to joining adjacent stubs at $\rho = R$. The region of the possible values of l/R_0 in Figs. 4 and 5 is restricted according to this condition.

The following parameters have been used for numerical calculations: $w_1/(w_1+w_2) = 0.2, 0.5$, and 0.8; $\varepsilon_d = 2.2$; $Y_l = 0.0125, 0.02, 0.05$ S. The normalized frequency ω/ω_0 and the normalized susceptance slope parameter B'/B_0' as function of the normalized length of stubs l/R_0 with K as a parameter is shown in Figs. 4 and 5 and with Y_l as a parameter in Figs. 6 and 7. B_0' and ω_0 are the susceptance slope parameter and the

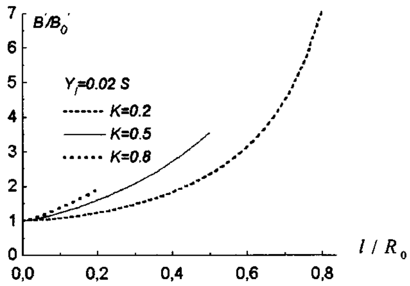

Fig. 5. Normalized function B'/B'_0 as function of the normalized length of the stubs l/R_0 with K as a parameter.

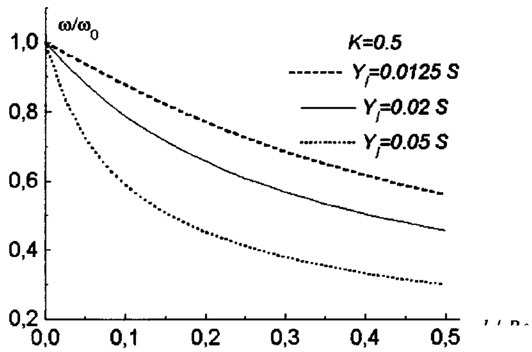

Fig. 6. Normalized frequency ω/ω_0 as function of the normalized length of the stubs l/R_0 with Y_l as a parameter.

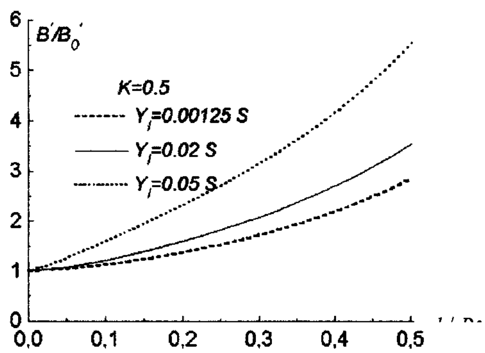

Fig. 7. Normalized function B'/B'_0 as function of the normalized length of the stubs l/R_0 with Y_l as a parameter.

resonant frequency, respectively, of the conventional disc resonator with the radius R_0. The behavior of the curves on Figs. 4 and 6 demonstrates explicitly that the resonant diameter of the resonator decreases when the length and the width of the stubs increase and the slots between the stubs are diminished. The diameter of the resonator can be reduced 2–3 times by this method. It gives a hope that using the new type of resonators, the dimensions of the corresponding microstrip antenna can be reduced. However, the susceptance slope parameter for the resonator with stubs increases (Figs. 5 and 7), which corresponds obviously to a narrower bandwidth of the antenna.

IV. Conclusions

Using the impedance boundary conditions, the disc microstrip resonator with stubs for application in patch antennas has been investigated theoretically. In order to calculate its parameters, we have used the combined electrodynamic and circuit theory method. The results of numerical calculations show that the dimensions of the resonator may be reduced at the expense of the bandwidth of the antenna.

The following steps in the analysis will consist of the evaluation of the radial dependence of the input resistance of the resonator with stubs in order to define the point of microstrip-line or coaxial-line feed and of the radiation pattern calculation. Further optimization of the shape of the stubs can perhaps provide larger bandwidth of the antennas.

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