Research of the Substrate Characteristics' Influence on the Bandwidth of Rectangular Microstrip Resonator Antennas

Nicola Dodov[1]and Ralitsa Stoyanova[2]

Abstract – **In this paper it is made a research of the frequency bandwidth of a rectangular microstrip resonator antenna depending on relative dielectric constant (ε_r) and the height (h) of the used substrate. The results give the possibility to be taken definite engineer decisions when projecting microstrip antenna.**

Keywords – **Microtrip resonator antenna, Frequency bandwidth, Quality factor, Dielectric constant.**

I. Introduction

The idea for microstrip resonator antennas (patch antennas) originates from 1953 but they receive a significant development and application after 1973. That specific kind of antennas has an application in many different areas such as wireless and mobile radio communications and they can also be used for connecting spaceships, air crafts, for security systems, etc. The convenience of these antennas comes of their low cost, easy technological implementation, small weight and aerodynamic profile. Because of their small dimensions and narrow bandwidth, single elements often are projected in large scanning arrays and the number of the elements can reach some thousands. Also the antenna array can be an array with signal processing, which makes these antennas more attractive.

Microstrip resonator antennas as all the others have many advantages, but some disadvantages aren't absent. The main advantages, from technological point of view come from the fact that they obtain mechanical robust and they can be easy mounted over different surfaces. On another side, by varying with the resonators' dimensions and forms and with proper choice of the feeding method, it can be achieved appropriate working mode, optimal pattern and frequency bandwidth. This type of antennas are very flexible when choosing the resonant frequency, polarization, pattern, amplification coefficient and these characteristics can be corrected.

The microstrip antennas' disadvantages come from the fact that the frequency bandwidth is very narrow and limited (exert influence when the antenna is used for scanning), because of the high quality factor Q. Usually thin substrates are used, which makes impossible high power feeding. Also there is spurious radiation, coming from the feeder and low level of polarization purity. Because of the losses in the dielectric material, the efficiency is low. The problem with the narrow bandwidth is solved by different methods such as extension of the substrate height, which leads to efficiency increase, but it also leads to increase of the surface waves.

A basic part of the microstrip antenna is the dielectric substrate and it has to be chosen and measured off very carefully. To a higher extend by substrate choice depends the characteristics and the application of the antenna. In this aspect that papers has the aim to research the frequency bandwidth dependence when varying the substrate relative dielectric constant ε_r and thickness h. The results from this analysis can be considered when taking engineer decisions in microstrip antennas design.

II. Theory

It is well known that the frequency bandwidth B of one structure in higher extend depends on the quality factor Q of this structure. Higher the quality factor is, the frequency characteristic becomes thinner and the bandwidth decreases.

According to the model for defining these two basic characteristics of the microstrip resonator antennas given by [1] it is clearly shown that Q and B depend on a number of factors. The total quality factor Q_t represents the antenna losses and according to [1] the formula is:

$$\frac{1}{Q_t} = \frac{1}{Q_{rad}} + \frac{1}{Q_c} + \frac{1}{Q_d} + \frac{1}{Q_{SW}} \, , \qquad (1)$$

where Q_{rad} is a quality factor, due to radiation losses; Q_c – quality factor, due to conduction losses; Q_d – quality factor, due to dielectric losses; Q_{SW} – quality factor, due to surface waves.

For every single quality factor above there is a definite expression. The quality factor, which expresses the losses caused by radiation, according to [1], is written as:

$$Q_{rad} = \frac{2 \cdot \omega_0 \cdot \varepsilon_r}{h \cdot G_t / l} \cdot K \, , \qquad (2)$$

where ω_0 is the circus frequency, on which the resonator works; ε_r – substrate relative dielectric constant; h – substrate height (thickness); G_t/l – total conductance per unit length of the radiating aperture;

$$K = \frac{\displaystyle\iint_{area} |E|^2 dA}{\displaystyle\oint_{perimeter} |E|^2 dl} \, , \qquad (3)$$

[1]Nicola Dodov is with the Faculty of Communications and Communications Technologies, Technical University, Kliment Ohridski 8, 1000 Sofia, Bulgaria, E-mail: ndodov@vmei.acad.bg

[2]Ralitsa Stoyanova is with the Faculty of Communications and Communications Technologies, Technical University, Kliment Ohridski 8, 1000 Sofia, Bulgaria, E-mail: r_stojanova@softhome.net

where E is the electric field.

The quality factor Q_c, due to the conduction losses, according to [1], can be expressed as:

$$Q_c = h\cdot\sqrt{\pi\cdot f_0\cdot\mu\cdot\sigma}\ , \tag{4}$$

where f_0 is the resonant frequency of the resonator; μ – absolute magnetic constant of the dielectric material; σ – conductivity of the conductors assosiated with the patch and ground plane.

The quality factor Q_d due to the conductance losses, it is given by [1] as:

$$Q_d = \frac{1}{tg\delta}\ , \tag{5}$$

where $tg\delta$ is the loss tangent of the substrate material.

The frequency bandwidth B is inversely proportional to the total quality factor Q_t of the antenna and according to [1] it is expressed by:

$$\frac{B}{f_0} = \frac{1}{Q_t}\ . \tag{6}$$

With the account of the impedance matching at the input terminals of the antenna, according to [1], Eq. 6 modifies to:

$$\frac{B}{f_0} = \frac{VSWR-1}{Q_t\cdot\sqrt{VSWR}}\ , \tag{7}$$

where $VSWR$ is voltage standing wave ratio.

The exposition that was made shows that the method for defining the frequency bandwidth by quality factor Q_t is very complicated. That's why a simple expression is used – Stutzman formula, which according to [2], is given by:

$$B = 3.77\frac{\varepsilon_r - 1}{{\varepsilon_r}^2}\cdot\frac{W}{L}\cdot\frac{h}{\lambda_0}\ , \tag{8}$$

where W is the width of the patch; L – length of the patch; λ_0 – central wavelength of the resonator.

Fig. 1 shows the dimensions and the profile of the patch.

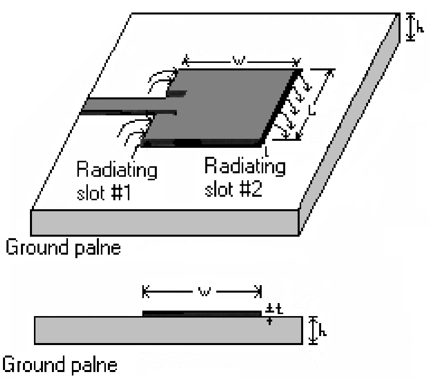


Fig. 1. Microstrip resonator.

According to the transmission line model, described in [1], the dimension W (width of the patch) is a function of the frequency and the dielectric constant. According to [1] and [3] the expression is:

$$W = \frac{C}{2\cdot f_0}\sqrt{\frac{2}{\varepsilon_r + 1}}\ , \tag{9}$$

where C is the light speed.

When the length L is determined, the influence of the "edge effect" is taken in account and according to [1] and [3], can be written as:

$$L = \frac{C}{2\cdot f_0\sqrt{\varepsilon_{reff}}} - 2\cdot\triangle L\ , \tag{10}$$

where ε_{reff} is the effective relative dielectric constant; L – extended incremental length as a result of the "edge effect".

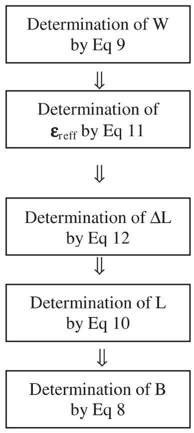
The effective relative dielectric constant reff, according to [1] and [3], it is given by:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{\sqrt{1 + 12\cdot h/W}}\ . \tag{11}$$

On the other hand the extended incremental length $\triangle L$, according [1] and [3], can be written as:

$$\triangle L = 0.412\cdot h\cdot\frac{(\varepsilon_{reff} + 0.3)\,(W/h + 0.264)}{(\varepsilon_{reff} - 0.258)\,(W/h + 0.8)}\ . \tag{12}$$

The aim of the results, received with the help of simulation analysis, is to show how the frequency bandwidth B changes when different kinds of substrates with various height h and relative dielectric constant ε_r are used. The initial parameters are: resonant frequency f_0=10GHz, ε_r and h that are varying in definite limits. The algorithm is as follows:



The results can be explained with the physical processes in the microstrip line and according to [4] they are as follows:

1. As the substrate height h increases, the quality factor Q becomes lower and therefore the frequency bandwidth becomes larger.

2. As the dielectric constant ε_r increases, the electric field concentrates deeper into the microstrip line. As the substrate height h increases, the quasitransverse electromagnetic wave concentration becomes weaker.

3. As the dielectric constant ε_r becomes larger, the influence of the height h decreases.

These fundamental conclusions can be used for an explanation of the results.

1) Fig. 2 shows that the frequency bandwidth decreases with the increase of ε_r and also that for higher values of ε_r the alteration rate decreases.

2) The increase of the bandwidth increases proportional to the increase of the substrate height h.

3) Fig. 3 shows that with the increase of the substrate height h, the bandwidth B increases linearly.

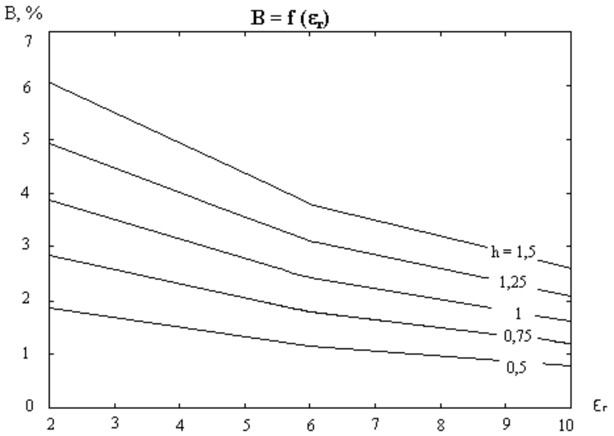


Fig. 2. Results from the research of the bandwidth (B,%) as a function of the substrate relative dielectric constant (ε_r) and a parameter – height (h,mm).

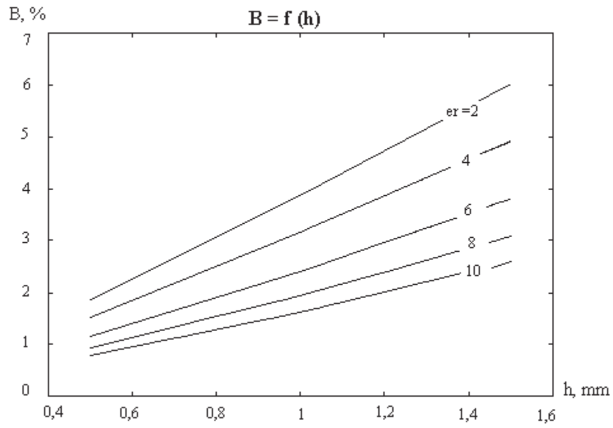


Fig. 3. Results from the research of the bandwidth (B,%) as a function of the height (h,mm) and a parameter – substrate relative dielectric constant (ε_r).

III. Recommendations

The following recommendations can be made on the base of Figs. 2 and 3:

1. When it is necessary to expand the resonator bandwidth, there has to be used substrates with lower values of ε_r and higher thickness.
2. When the frequency is resonant and a narrow frequency bandwidth is necessary and it is desirable to use thin substrates. The value of the ε_r depends on the frequency band and the technological requirements.
3. Microstrip resonator antennas are with narrow bandwidths. The standard width is around (1÷2)%.

References

[1] Balanis C. A. *Antenna Theory (Analysis and Design)*, John Wiley and Sons, Inc., New York, 1997

[2] Warren Stutzman, Gary Thiele, *Antenna Theory and design*, John Wiley and Sons, Inc., 1998

[3] Drabowitch S. A. Papiernik. *Modern Antennas*, Chapman and Hall, London, 1998

[4] Kai Fong, Wel Chen, *Advances in Microstrip and Printed Antennas*, John Wiley and Sons, Inc., New York, 1997

[5] Hansen R. C. *Phased Array Antennas*, John Wiley and Sons, Inc., New York, 1998

[6] Mailloux R. J. *Phased Array Antenna Handbook*, Artech House, Boston, London 1994

[7] Ramesh G. B. Prakash, *Microstrip Antenna Design Handbook*, Artech House, Boston, London, 2001