Determination of Optimal Values of the Substrate Parameters in Microstrip Antennas

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Abstract –**This paper presents results of research into the resonant properties of the printed antennas. The research has been carried out by means of varying relative dielectric permittivity and the thickness of the substrate. A field of unsuitable values of dielectric permittivity and substrate thicknesses have been noted. The values of the impedance bandwidth were examined as a function of substrate parameters.**

Keywords – **bandwidth, radiation Q, substrate thickness, microstrip antenna.**

I. Introduction

Microstrip antenna arrays are widely used in modern telecommunication systems. Along with their advantages – ease of manufacturing, functionality, low cost they have some significant disadvantages. The main shortcoming is their narrow working frequency band. This property is determined by the resonant character of this type of antennas. There are several electrical models that describe the resonant behavior of the microstrip resonator. Most commonly used are the transmission line model (TLM) and the cavity model. The working bandwidth (BW) of the antenna mainly depends on the total quality factor (Q_{tot}) of the resonant system, and on VSWR. Their relationship is defined by Eq. 1:

$$BW = \frac{VSWR - 1}{Q_{tot}\sqrt{VSWR}} \qquad (1)$$

When the microstrip antenna is properly matched, the working impedance bandwidth depends entirely on the feeding type and the total quality factor of the resonant system. The present paper investigates the behavior of the Q_{tot} in conditions of different substrate parameters.

II. Empirical and Theoretical Models

The Q_{tot} is a function of several components. From the microstrip antenna theory there are well known formula (Eq2):

$$\frac{1}{Q_{tot}} = \frac{1}{Q_{rad}} + \frac{1}{Q_{sw}} + \frac{1}{Q_{di}} + \frac{1}{Q_c} \qquad (2)$$

Where Q_{sw} is surface waves related quality factor component, $Q_{di}=1/\tan(\delta)$ – dielectric losses quality factor component, Q_c is the component associated with the Ohmic loses in the resistance of the metal plate and Q_r is radiation quality factor, defined as fraction of energy stored at resonance and the associated power loss [1]. These components have a different contribution to the total quality factor. The data presented on Fig. 1 makes it clear that the radiation quality factor Q_{rad} has the most important role.

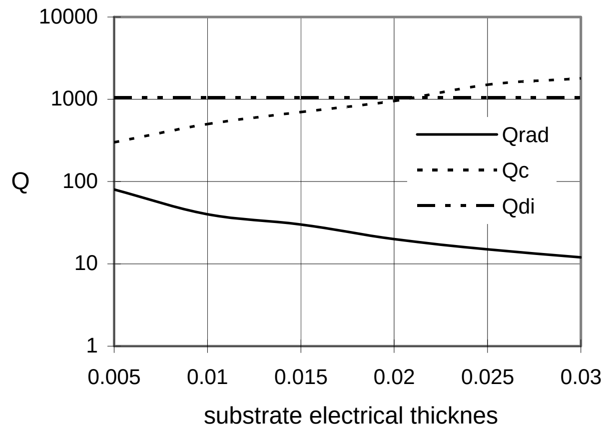

Fig. 1. Variation of Q_{rad}, Q_c and Q_{di} versus relative substrate thickness (h/λ), after K. R. Carver, [2]

There is theoretical low limit of the Q_{rad} and it can be determined by Eq. 3:

$$Q_{rad} = \frac{1}{k^3 a^3} + \frac{2}{ka} \qquad (3)$$

Where k is $2\pi/\lambda$ and **a** is the radius of a sphere enclosing the maximum dimension of the antenna. It has been calculated that typical value of that factor is between 0.5 and 100. The first value is for relatively electrical large antennas, and second value - for electrical small antennas (with dimensions smaller than $\lambda/2\pi$). These limits cannot be reached because of the resonant character of the radiating edges. Hence the typical values for the relative impedance bandwidth of the microstrip antenna are between 0.7 ÷ 1.5%, depending on dielectric permittivity

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III. RESULTS

The analysis has been performed at frequency of 5.7 GHz, with electromagnetic simulator using the method of moments. It can be seen that there is an area where Q_{rad} has definite extreme value (Fig.2). At that area of dielectric permittivity the expected reduction in impedance bandwidth is about 20 to 500 times and the related BW values range between 0.01 and 0.001%. This sharp resonant character is extremely undesirable. It not only leads to reduction of the working bandwidth, but also to instability of the central frequency of the antenna, caused by the coefficient of thermal expansion of the substrate.

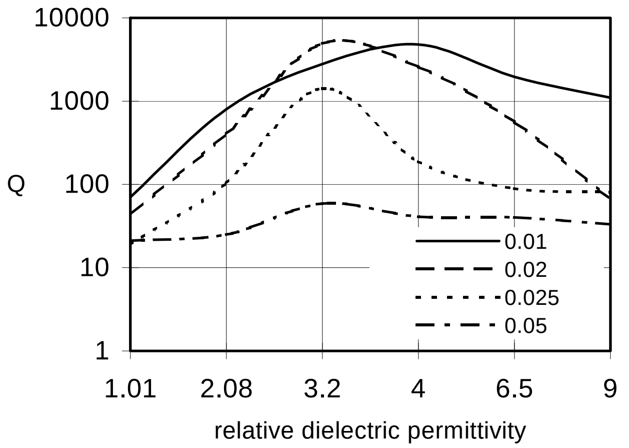

Fig. 2. Q_{rad} as function of ε_r for different substrate thicknesses (in h/λ).

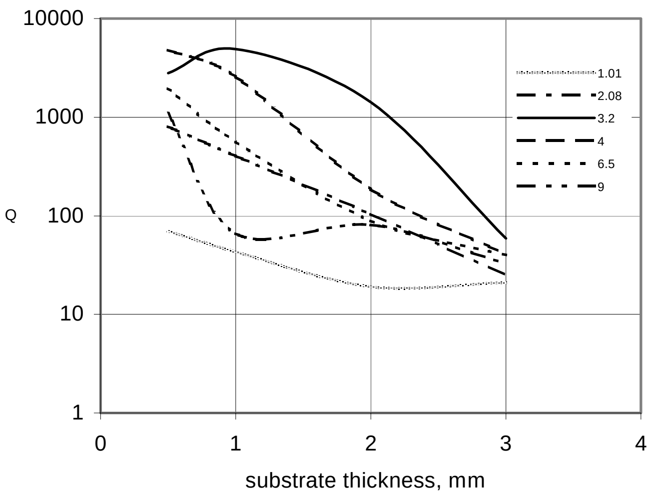

Fig. 3. Q_{rad} as function of substrate thickness (h) for different dielectric permittivity

Since these extremes depend on the relative dielectric permittivity, but not on the substrate thickness - h (Fig. 3), it can be concluded that in rectangular microstrip antenna there are types of substrate that should be avoided. Undesirable areas exist in all types of substrates (in terms of thickness) and should be carefully defined and avoided. Similar results are achieved with circular patches. Another effect that limits the choice of substrate is the lost of radiation efficiency. On Fig 4 we can see that in substrates with dielectric permittivity above 2 there is significant lost of efficiency. On the other hand, additional loss of efficiency can be expected in cases of substrates with higher thickness and permittivity because of excitation of the surface waves.

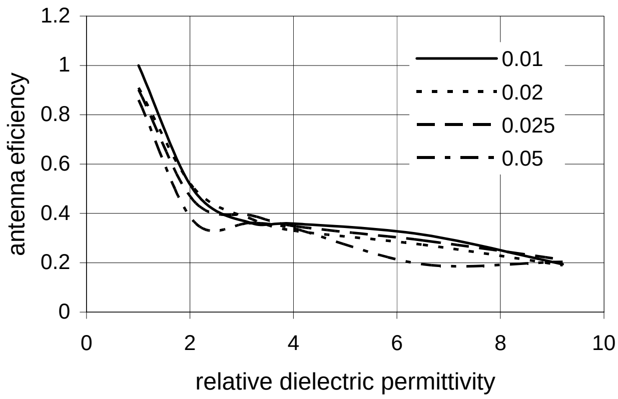

Fig. 4. Radiation efficiency as function of dielectric permittivity for different substrate thicknesses (in h/λ).

That effect is very well examined and explained in previous publications and also by other authors [3], [4]. A recommended method of suppression of the surface waves is the use of PBG (Photonic Bandgap Structures). Yet another unwanted effect of broadbanding achieved by increased substrate thickness is the complex impedance of the feeding probe that makes the matching complicated and narrowband. In conclusion, as a general rule of thumb in cases when precise analysis cannot be performed, we recommend substrates with permittivity below 2. The choice of substrate thickness should be made taking into account the degree of complexity of the feeding system.

IV. CONCLUSION

This paper examines the problems of broad banding in printed microstrip antennas. The study defines empirically an area of undesirable substrate dielectric permittivity and thicknesses. In this area energy stored in the resonating element is much higher than radiated; hence this area should be avoided. It also emphasizes the theoretical limit in broadband abilities which is determined by the physical size of the radiating element and it resonant abilities. Increasing further the frequency band over these limits is possible through changing the shape of the radiating element (fractalization) or by using parasitic elements.

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