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Review of the doctoral thesis titled
"Perforated dielectrics and higher-order mode dielectric resonator antennas"
submitted Ing. Michal Mrnka

Ing. Michal Mrnka is a doctoral candidate in the doctoral study program Electrical Engineering and Communication – specialization Electronics and Communications at the Brno University of Technology, Faculty of Electrical Engineering and Communication. He performed his research and written his thesis under the supervision of Prof. Dr. Ing. Zbynek Raida (FEEC BUT).

The doctoral thesis "Perforated dielectrics and higher-order mode dielectric resonator antennas" submitted for review by Ing. Michal Mrnka contains 171 pages, 133 figures, 5 tables, list of references, list of figures and tables, list of abbreviations and symbols, abstract and keywords (both in Czech and English), author's CV and a list of author's selected publications.

Although known more than 30 years, dielectric resonator antennas are recently gaining interest of many researchers because of their small size and weight and excellent performances and efficiency at millimeter wave frequencies. This make them suitable for many applications from mobile sensor networks and broadband communications up to the imminent Internet of things. Therefore, **the topic of the doctoral thesis proposed by Ing. Michal Mrnka is up-to-date and appropriate for the area of Electronics and Communications.**

The thesis is divided in five chapters. The first chapter presents the state of the art for each of the topics concerned in the thesis with comprehensive overview of the previous work by other authors. The second chapter brings the three research objectives where the original contributions are expected, namely:

1) Proposing an original directive DRA element based on the excitation of the higher-order modes.
2) Research of mutual coupling between the higher-order mode DRA elements.
3) Research and description of the anisotropic behavior of the perforated dielectric substrates. The excitation of surface waves on such substrates and evaluation of possible DRA performance deterioration.

The chapters 3, 4 and 5 are the core part of the thesis and are dedicated to the three research objectives. Each of these chapters has a theoretical part and/or part with the results of numerical modelling and parametric studies and it is concluded with the description of antenna prototype manufacturing and measurement results. Such a detailed approach to each of the research objectives gives an additional value to the presented thesis.

Chapter 3 deals with the rectangular and cylindrical dielectric resonator antennas operating with higher order modes. The author has performed detailed parametric sweeps in order to determine the optimal resonator dimensions, their input impedance and radiation properties. Also the influence of the ground plane size and of the air gap between the resonator and the ground plane have been studied. The applicability of dielectric resonator antennas at 5.8, 10.25 and 25.8 GHz has been experimentally demonstrated.

As also other authors proposed the operation of dielectric resonator in higher order modes to increase the antenna gain, the author should clearly emphasize what is new and original in his approach. This should be discussed at the defense.

Furthermore, the excitation of the dielectric resonators is addressed very scarcely. The dimensions of the coupling aperture, microstrip line width and stub length are sometimes missing in the text describing the antenna, in figure captions and tables (e.g. Table 3.1). This should be corrected in the thesis, as without these data the presented simulation and measurement results can't be repeated and verified by other researchers. The three design equations (3.11 – 3.13) are given without any credit to the source and are barely explained. It is a pity that the excitation of the dielectric resonator antennas was not considered in more detail in the thesis as it influences all the antenna characteristics and gives to the antenna designer additional degrees of freedom for antenna optimization.

In Table 3.1 are missing the units in which the frequency is expressed.

Chapter 4 addresses the coupling between dielectric resonator antennas operating in higher modes. The coupling for rectangular dielectric resonator antennas excited in TE_{113}, TE_{115} and TE_{133} modes has been investigated both numerically and experimentally. Similar analysis has not yet been presented in the available literature it is a novel contribution by the author.

Here again the dimensions of the coupling aperture used in experimental verification are missing. Furthermore, expressing the inter-element distance s in terms of the wavelength, when the frequency to which the wavelength is associated is not specified and fixed, is misleading. This is especially true e.g. in Figs 4.14, 4.17., 4.20, 4.21, 4.28, 4.29 where the parameter s is given in terms of wavelength while the frequency is swept from 8 to 10 GHz.

At the end of section 4.2.3 the radiation patterns are mentioned, but no figures are given.

Figure 4.29 is not mentioned in the text.

In Tables 4.1 – 4.4 the magnitudes of the parameter S_{21} are listed as unitless, yet they are obviously in dB.

Chapter 5 introduces the perforated dielectrics. It starts with a theoretical part, which resembles a textbook, but it is nevertheless useful for the completeness of the presented material, for defining the nomenclature, introducing the theory of homogenization and anisotropic materials. It is accompanied with comparison between the results of theoretical model based on Maxwell-Garnett mixing rules and numerical simulations for different periodicities and perforation diameters. Surface waves in the perforated substrates are studied and the effective relative permittivity for TM and TE waves is determined. A single element dielectric resonator antenna manufactured on perforated dielectric as well as two-element arrays of these antennas have been studied. It has been found that the coupling for inter-element distances smaller than half wavelength is smaller in comparison to conventional dielectric resonator antennas. The presented results fulfill the third research objective.

In the captions of figures 5.2 – 5.6 it would be good to remind the reader which are the cases a) to e) to improve the readability.

The Figs 5.7 – 5.10 introduce the periodicities p_1 and p_2 , while in the text the same values are referred to as p_y and p_x , which is confusing. Same quantities should be marked with same symbols or their relationship should be explained in the text.

In Fig 5.9 the values beside the dimension lines describing the waveguide do not correspond to the coordinate system plotted in the same figure. The same oversight is copied in the subsection "Phase delay".

A general comment for all the chapters is that some figures are rather distant from the text referring to them, and sometimes are even in other sections, which affects the readability of the thesis. Figures sometimes split sentences which is not a good practice.

The list of references contains 138 entries. It is comprehensive and cites most relevant papers and books concerning antenna theory, electromagnetism and especially dielectric resonator antennas which are the main topic of the thesis. The previous work of other authors is properly credited.

From the before mentioned it can be concluded that the thesis is based on extensive study of the literature, good theoretical knowledge, comprehensive numerical simulations, parametric studies and experimental work. The three research objectives, addressed in three separate chapters, are fulfilled in a satisfactory manner. **The presented results have enough novelty and originality to accept the work proposed by Ing. Michal Mrnka as doctoral thesis.**

The list of selected publications provided by Ing. Michal Mrnka contains eight (8) papers. Three (3) papers are published in recognized international journals and the other five (5) at outstanding international conferences. All the papers have been published in the period 2015-2016. Such **scientific production is satisfactory for a doctoral candidate and it established Mr. Mrnka as a recognized researcher.**

Part of the thesis core has been published in one journal paper and at four international conferences. Although it would be better to have more core results from the thesis published in outstanding international journals, also **this publishing record confirms the value of the results presented in the thesis and qualifies the candidate for obtaining the doctoral degree.**

From the CV submitted by Mr. Mrnka, it can be seen that the candidate is highly motivated for scientific research and improving his knowledge and skills. He participated at several courses, summer schools and internships. He has acquired valuable experience as visiting researchers in foreign laboratories as well as at his present job as R&D engineer in industry.

For the defense, I propose the following questions:

1) Explain what is new and original in your approach in proposing an original directive DRA element based on the excitation of the higher-order modes (Objective 1) in comparison to the previous work of other authors (e.g. refs [58] and [59] in the thesis)?
2) The coupling aperture size, shape and relative position to the dielectric resonator influence the input impedance bandwidth, radiation properties as well as excitation of higher resonant modes in the dielectric resonator. Why have you not considered any of these parameters in your parametric studies? Which are the guidelines in determining the dimensions of the coupling aperture?
3) In your thesis you have considered only linearly polarized dielectric resonator antennas. How can you use dielectric resonator antennas to produce circular polarization?
4) In dielectric resonator antennas using higher modes for gain enhancement you have observed that maximum gain and the best impedance matching sometimes do not coincide in frequency (e.g. Fig. 4.6). From the viewpoint of overall system performance, is it better to operate at the frequency of smallest reflection or at the frequency where the maximum gain is obtained?
5) Have you measured the radiation efficiency of any of the antenna prototypes you manufactured? Which methods can be used for measuring the antenna radiation efficiency?
6) Have you considered a combination of perforated dielectric for obtaining an array of dielectric resonator antennas and EBG structure made of perforations for surface wave suppression in such DRA array?

Based on the results presented in the doctoral thesis submitted by Ing. Michal Mrnka, I conclude that he has shown the ability for independent scientific work. He addressed a contemporary topic, presented original results and fulfilled the proposed objectives in satisfactory way.

I recommend the doctoral thesis submitted by Ing. Michal Mrnka for defense.

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