EM Modelling of Microstrip T-Junction with an Open Stub Printed over a Dielectric Cylinder

Tomislav Milošević and Dušan Nešić

Abstract — **This paper presents EM modelling of microstrip T-junction with open stub printed over a dielectric cylinder. Software tool used for modelling and simulations is a full 3D EM Method-of-Moments, Surface Integral Equation solver applied to quadrilateral mesh elements. The paper investigates the stability of simulation results with respect to various parameters. This includes settings of the numerical kernel, quality of cylindrical surface approximation using segments of bilinear surfaces, different modelling of microstrip edge effects, and comparison between various excitation configurations with and without de-embedding. The purpose of this comprehensive investigation was to establish the optimum calculation parameters for the case of the particular resonator structure. The investigation was concluded with simulations of several EM models with numerical kernel parameters and geometrical model parameter set to optimal values. Relative dielectric constant of the dielectric cylinder has been varied and the additional dielectric layer modeling an impurity in form of the precipitate has been included. High numerical efficiency of the calculations has been achieved and the results obtained follow the theoretical expectations.**

Keywords — **EM modelling, Geometrical modelling, Microstrip T-junction, Open stub, Simulation.**

I. Introduction

In the last couple of decades, electromagnetic (EM) modelling has become a standard process in research and development of various microwave devices. The analytical methods for analysis of such structures are limited to several simple cases. For realistic, complex devices only numerical solutions are adequate. Tremendous efforts have been made to develop efficient tools for versatile, yet intuitive geometrical modelling and efficient numerical analysis of various classes of real-world EM devices. The structures of interest include antennas, scatterers, passive microwave circuits etc. The main requirement for a numerical method suitable for the analysis of such structures is to accurately determine the distribution of the electromagnetic field, currents and charges. Such an analysis is often referred to as the electromagnetic modeling.

Within electromagnetic modeling, various structures can be treated following similar guidelines. For example, passive microwave circuits, such as microstrip transmission lines, usually represent structures consisting of metallic and dielectric parts collectively referred to as composite metallic and dielectric structures. If all the parts are made of linear materials, analysis can be facilitated in the frequency domain [1]. In this paper, we exploited WIPL-D Pro, a full wave, 3D EM frequency-domain Method-of-Moments (MoM) based code for geometrical modelling and simulation which applies higher order basis functions (HOBFs) on quadrilateral mesh elements using Surface Integral Equations (SIE) [4].

The stability of output results is usually checked by manually varying numerical kernel parameters. In addition, the influence of some other parameters of interest for EM modelling can be investigated for optimum numerical efficiency.

The geometrical modeling in WIPL-D Pro assumes drawing a composite metallic and dielectric structure combining available building elements, bilinear surfaces – plate entities, and wire entities. The modeling can in general be exact or approximate. In the particular case of geometry modeling considered here, the modeling of curved\cylindrical structures is approximate and a search for an acceptable approximation basically involves finding a minimum number of straight segments to approximate curved\cylindrical geometry [1].

The microstrip structures are widely used in microwave engineering. The operating frequencies of modern microstrip structures available on the market becomes higher and higher due to the lowering cost of microwave components. The same stands, for example, for microstrip components used in microwave sensors.

Standard microstrip devices are planar and easily modeled. However, in some applications, the basic microstrip structure can be modified and the properties of a modified structure exploited for a particular advantage, as a structure described in [3]. This paper focuses on EM modelling of a modified, not strictly planar microstrip structure which represents fluid sensors and can be used in measurements of a fluid characteristics [2,3].

The model considered here is a non-strictly planar microstrip structure operating between 0.4 GHz and 4.0 GHz. It is a T-junction structure which is suitable to be used as fluid sensor. The results of various simulations are presented and explained.

II. Geometrical Model

The particular T-junction structure with an open stub over the dielectric cylinder is shown in Fig. 1. The dimensions of the parts are indicated in the same figure. The structure has been modeled using one symmetry plane named (A)Symmetry, also presented in Fig. 1. (A)Symmetry

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represents a software feature where a symmetry of the structure is exploited to reduce an original number of unknowns. The original number of unknowns is approximately halved. With the feature made active, the numerical kernel is automatically invoked two times and the results are automatically combined.

In order to efficiently control meshing of cylindrical areas, software built-in objects Body-of-Revolution (BoR) were used (Fig. 2). Furthermore, to optimize numerical accuracy, the resonator structure was modeled by introducing ‘imaging’ where necessary (Fig. 2). This means that closely located ‘upper’ and ‘lower’ surfaces from the model of the structure are meshed in the same way. This modification improves the stability of MoM matrix.

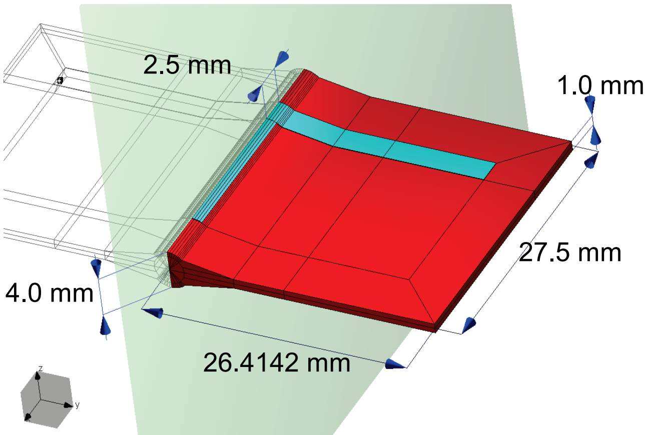

Fig. 1. Simulated structure with overall dimensions and one symmetry plane

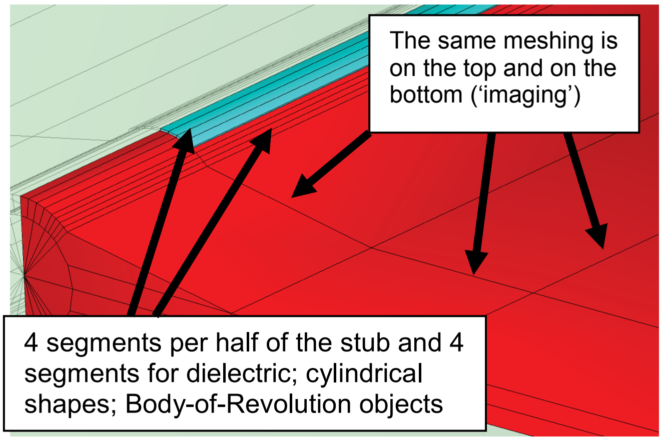

Fig. 2. Simulated structure-the detail. Body-of-Revolution objects modelling curved cylindrical surfaces and meshing lines on the ‘upper’ surface can be recognized

Finite metallization thickness (Fig. 3) was added using a built-in software manipulation. The metallization thickness was added to all metallic surfaces located on the top of the structure. For example, planar surfaces and the surfaces modelling curvature both have finite metallization thickness.

Dimensions of the resonator structure are parametrized through the symbolic variables and can be changed easily.

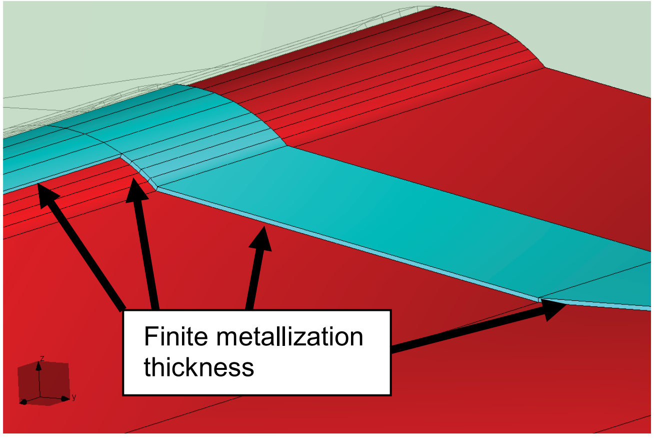

Fig. 3. Finite metallization thickness added to metallic surfaces located on the top of the structure

The dielectric substrate is with the following parameters: relative dielectric constant is 3, while loss tangent is set to 0.01. Relative dielectric constant of a lossless cylinder is 10. The cylindrical dielectric located in the interior of the structure, the neighboring conductors, and the infinitesimally thin metallic ground are shown in the Fig. 4.

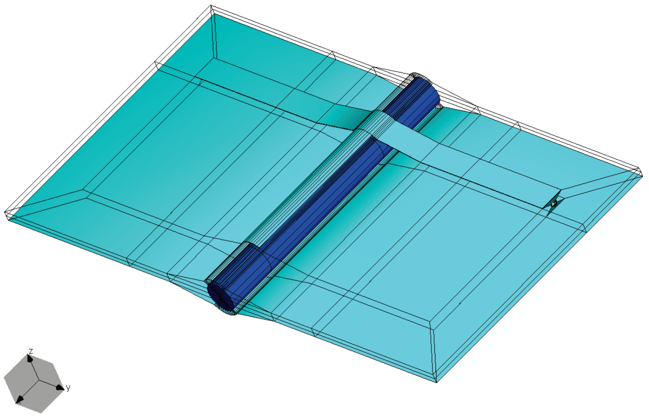

Fig. 4. The cylindrical dielectric and neighboring conductors in the full model without the symmetry applied

Improved handling of edge effects in particular MoM SIE based software was achieved by automatic subdividion of the plates having a common edge which in fact separates areas belonging to different materials. The automatic subdivision follows after applying, so called, Edge-ing manipulation. Details of modified structure are in Fig. 5.

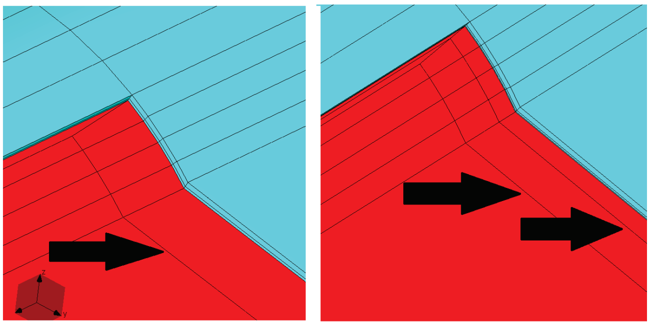

Fig. 5. Handling of edge effects – the pre-simulated structure modification after application of single Edge-ing and double Edge-ing manipulations

The location of the reference plane required for the de-embedding and position of generator used for feeding are shown in Fig. 6.

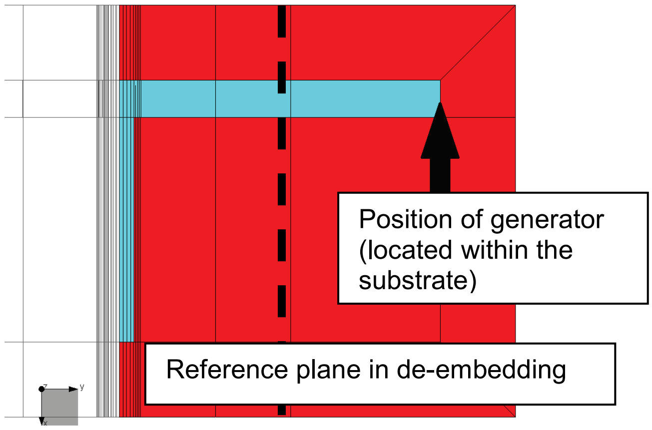

Fig. 6. Reference plane defined in the de-embedding process and position of the generator used for feeding

III. Simulation Results

In order to demonstrate EM modelling of the structure, to highlight the most important steps in the investigation of this, to discuss some actions required in usual EM modeling, and to investigate the model of the microstrip open stub with optimum simulation parameters above the dielectric cylinder with varied relative dielectric constant, we present here S-parameters from several simulation scenarios. At first instance, we investigate the convergence of the simulations by varying standard calculation parameters. Then, we investigated influence of a number of bilinear surface segments used in cylindrical objects modelling. The quality of edge effects modelling was investigated followed by comparing the results obtained with and without the de-embedding. Finally, the EM model of the microstrip structure with optimum simulation parameters was used to investigate the influence of the dielectric cylinder parameters to microstrip open stub resonant frequency and the influence of an additional dielectric modeling the impurity.

All of the models have been simulated at 21 frequency points. The smooth curves are resulting from excellent graphical fitter used. All of the models were simulated on standard Intel® Core™ i7-7700 CPU @ 3.60 GHz with 64 GB RAM. The most time-consuming simulation is the one where a model of the structure includes Edge-ing manipulation applied two times (total simulation time is 900 seconds). The most of the other simulations finish after 500 seconds - 850 seconds.

A. Obtaining Optimally Stable Results

Convergence check was performed by manually varying numerical kernel parameters. The first step was increasing parameter Integral Accuracy (IA) from *normal* to *Enhanced 1* and graphically comparing the responses obtained (Fig. 7). Parameter IA influences evaluation of integrals related with accurate calculation of MoM matrix elements. In general, higher IA enables more accurate results exploiting longer simulation time. Results obtained after IA set to *normal* and set to *Enhanced 1* are denoted in Fig. 7 as IA = 0 and IA = 1, respectively.

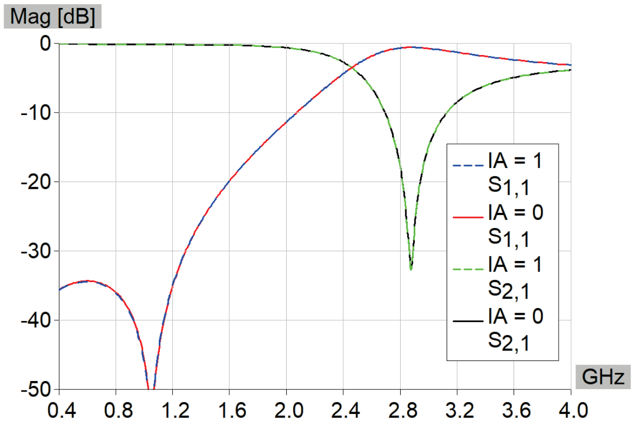

Fig. 7. S-parameters with Integral Accuracy parameter varied

The effect of increasing a number of unknowns has been investigated next. The number of unknowns represents the number of unknown coefficients used for current distribution approximation. Comparison of the results is shown in Fig. 8 and Fig. 9.

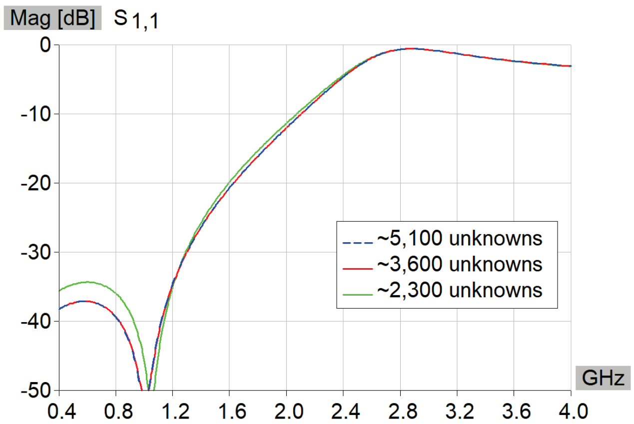

Fig. 8. S_{11}-parameters obtained for varied number of unknowns

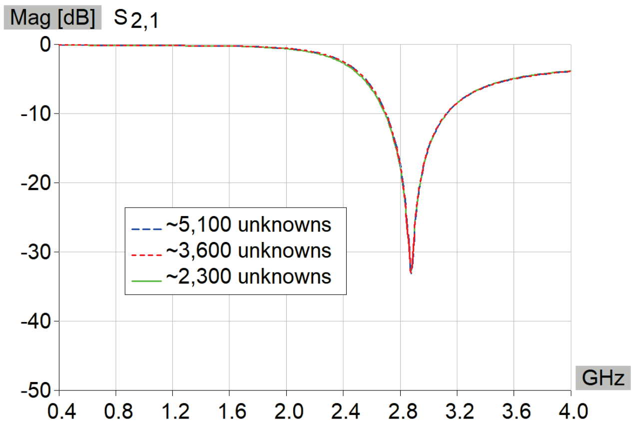

Fig. 9. S_{21}-parameters obtained for varied number of unknowns

A tradeoff between sufficient accuracy and minimum computer resources required suggests that a value for the Integral Accuracy should be set to *normal* with a number of unknowns set to approximately 3,600.

B. Bilinear Segments Used in Cylindrical Surfaces Modelling

Cylindrical objects are approximated using planar bilinear surfaces, as in Body-of-Revolution objects shown in Fig. 2. As a next step towards establishing the optimum calculation parameters, a number of segments is varied and the influence of changing number of segments to the results investigated. Results with various numbers of segments determining stub curvature and dielectric curvature are shown in the Fig. 10 and Fig. 11, respectively. A quality of approximation using a total of 12 and 8 segments was investigated for the case of a stub curvature. Since one symmetry plane was applied, this means that 6 and 4 segments are used in simulated model. A total of 6 and 4 segments were used for modelling the dielectric near the stub curvature.

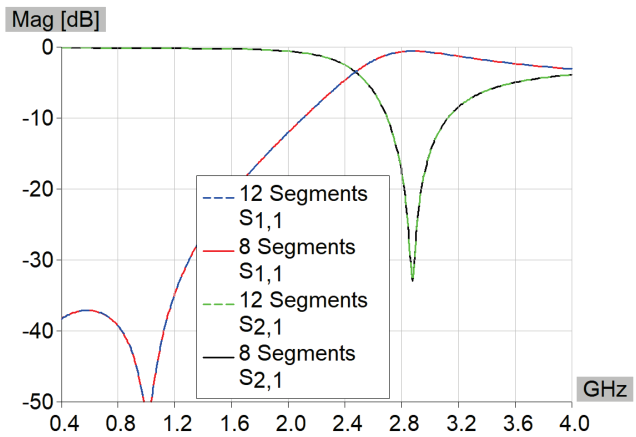

Fig. 10. S-parameters for varied number of segments of the Body-of-Revolution object modelling stub curvature

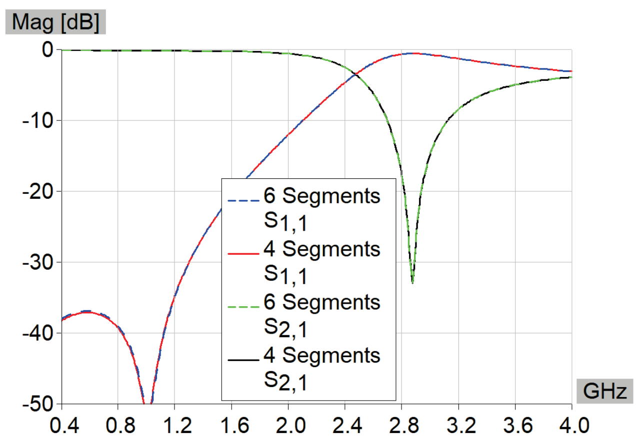

Fig. 11. S-parameters for varied number of segments of the Body-of-Revolution object modelling dielectric curvature near stub

C. Investigating Edge Effects

According to the recommendations for the particular software used for the simulations, at least one Edge-ing manipulation (Fig. 5) should be used for microstrip and microstrip-like structures. Following the recommendations, in the analysis of the model of the structure with IA set to *normal* requiring about 3,600 unknowns, which S-parameters are shown in Fig. 8 and Fig. 9, one Edge-ing manipulation has been used already. However, the influence of Edge-ing manipulation to the accuracy of the simulations is investigated as follows. The S-parameters obtained without Edge-ing are compared with results with one Edge-ing manipulation applied and with two Edge-ing manipulations applied. The S-parameters are presented in Fig. 12.

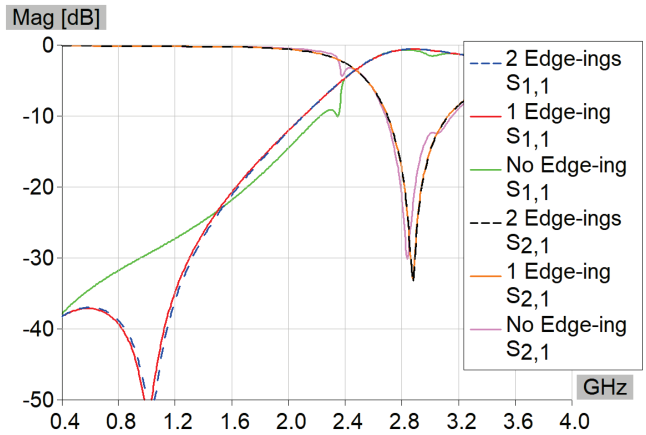

Fig. 12. S-parameters for models where Edge-ing manipulation is not applied with models where one and two manipulations Edge-ing are applied

D. The Influence of De-Embedding Procedure

In the simulations presented so far, S-parameters are calculated with respect to the reference planes coinciding with the location of the generators. These generators represent delta-function generators. In the other words, these are a point-like, ideal voltage generators.

In order to calculate S-parameters in reference planes shown in Fig. 6, the de-embedding technique is applied. The comparison between S-parameters obtained with and without de-embedding is shown in Fig. 13.

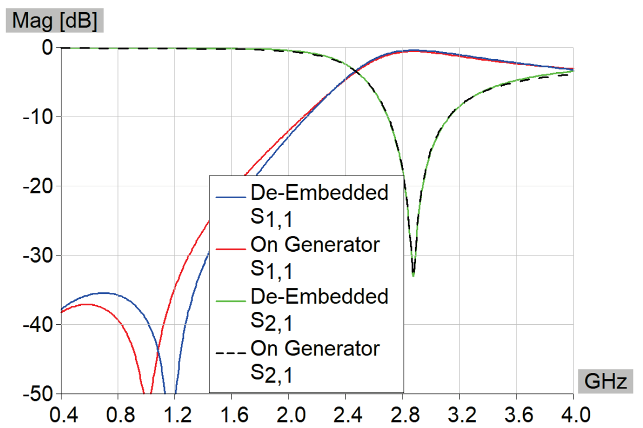

Fig. 13. De-embedded S-parameters and S-parameters calculated on the generators, without de-embedding

E. Varying Relative Dielectric Constant of the Dielectric Cylinder

In order to fully exploit EM model with optimally selected simulation parameters of the investigated microstrip T-junction, variations of relative dielectric constant of the cylinder were investigated. Five models of the T-junction were simulated. The geometry of the models and the simulation parameters are the same in all of the models, but the relative dielectric constant of the cylinder varies and takes values from the following set {1, 5, 10, 20, 40}. Both, S_{11} and S_{21} parameters were compared as relative dielectric constant changes values. S_{11}-parameters are displayed in Fig. 14, while S_{21} parameters are displayed in Fig. 15. In the figures a corresponding value of the relative dielectric constant is specified through the legend entries.

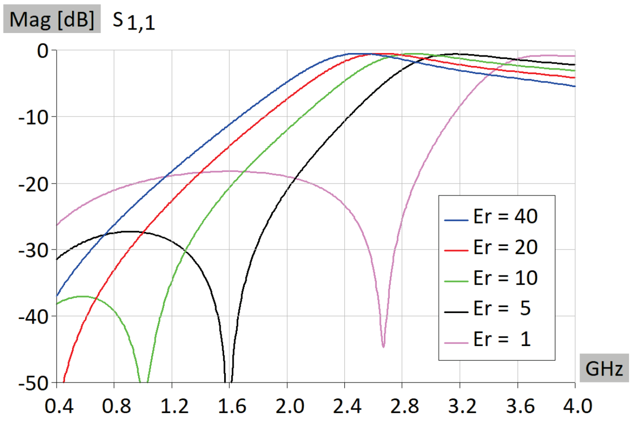

Fig. 14. S_{11}-parameter calculated for various values of relative dielectric constant

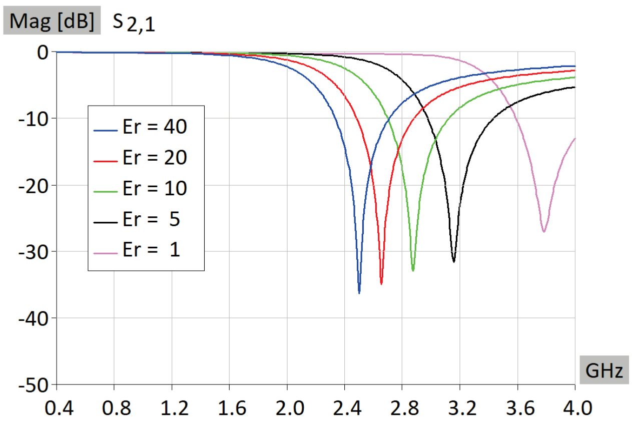

Fig. 15. S_{21}-parameters calculated for various values of relative dielectric constant

By inspection it can be concluded that resonance of the microstrip stub moves with as dielectric constant value changes. More specifically, the resonant frequency decreases as the value of the relative dielectric constant of the dielectric cylinder increases. This change is easier to track from S_{21}-parameter graphs (Fig. 15) as the transmission minima are more distinct than reflection maxima.

F. The Influence of the Impurities

Another interesting modeling assumes that the cylindrical space below the stub is filled with two dielectrics – the fluid with relative dielectric constant equal to 10 and additional dielectric modeling impurities that may occur during the operation of a real sensor. The impurities actually model the precipitate resting 'below' a fluid. It was assumed that relative dielectric constant of an impurity was 80, while the loss tangent was 0.005. The height of the precipitate takes values of 0.93 mm, 0.44 mm, and 0.18 mm. The sensor with the height of the impurities set to 0.93 mm is shown in Fig. 16.

The EM model was slightly changed comparing to the previously simulated models, so the meshing of the structure has been modified at the bases of the cylinder (Fig. 2 and Fig. 16). It is reasonable to assume that the modification has the minor effect on other previously optimized parameters.

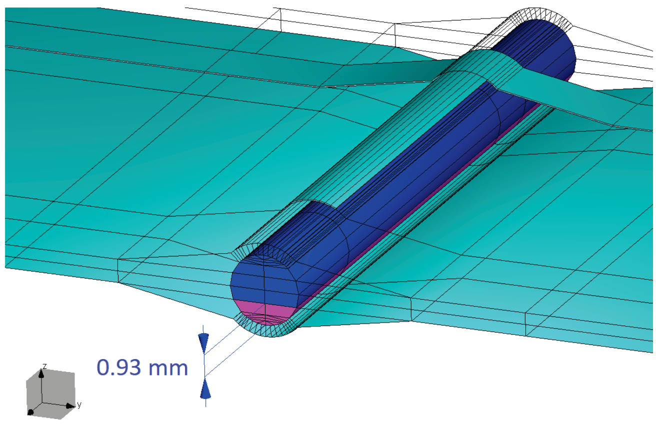

Fig. 16. The dielectric and an impurity in a form of a precipitate. The height of the precipitate is 0.93 mm

The S_{21}-parameter graphs of the resonator with varying precipitation height and without the precipitation are shown in the Fig. 17.

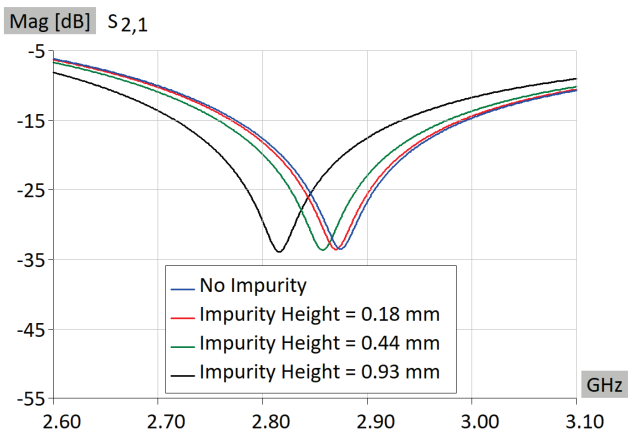

Fig. 17. S_{21}-parameter calculated for various heights of the precipitation and without the precipitation

IV. Conclusion

This paper presented EM modelling of microstrip T-junction with open stub printed over a dielectric cylinder. Software tool used for modelling and simulations was a full 3D EM Method-of-Moments, Surface Integral Equation solver applied to quadrilateral mesh elements.

The paper investigates the stability of EM simulation results with respect to various parameters: settings of the numerical kernel through changing parameters of a numerical integration and a number of unknowns required, quality of approximation of cylindrical surfaces, different modelling of microstrip edge effects, and comparison between various excitation configurations with and without de-embedding. At the end, the EM model of the microstrip structure with optimum simulation settings was exploited for investigating the influence of relative dielectric constant of the cylinder below the microstrip stub to the resonant frequency.

The investigation of EM modeling of the structure was established in order to reveal the optimum simulation parameters for the case of the particular resonator structure which modification can act as a real-life sensor for fluid measurement. With the optimum parameter settings, the high numerical efficiency of the calculations has been confirmed. It has been shown that, with proper EM model, even with the standard settings applied to control the operation of the numerical kernel, the utilized software produced very stable S-parameters. The stability has been confirmed as changes in several numerical kernel parameters haven't introduced noticeable changes in S-parameter values. It was shown that quality of approximation of cylindrical structures and stability of S-parameters is high even with relatively small number of linear segments utilized. Also, it has been shown that edge effect has to be properly taken into the account if a non-strictly planar microstrip-like structure is simulated. The edge effect has been conveniently modeled with application of a single Edge-ing manipulation. Finally, we showed that De-embedding procedure is not mandatory if the proper feeding structure is used for excitation of the EM model.

With simulation parameters considered as optimum for relative dielectric constant set to 10, additional simulations of varying relative dielectric constant of the dielectric cylinder below the microstrip stub were performed and the S-parameters calculated. It has been confirmed that the resonant frequency of the stub changed in theoretically expected manner – it became lower as the relative dielectric constant increased.

The influence of the impurities appearing in the form of precipitate was also investigated. The results are conforming with the theoretical expectations that the impurity with high dielectric constant shifts the resonance of the S_{21}-parameter toward lower frequencies.

The high efficiency of all the simulations can be confirmed in a different sense - through the simulation times as they are all relatively short.

From a practical side this is very significant result as the simulations were carried out on a standard desktop platform.

Final investigation of the operation of this structure was motivated with a possible practical implementation of the resonator structure in a fluid identification sensor. The investigation has shown that a quantitative relation between the dielectric constant and a resonant frequency can be easily established, either by calculation or by measurements. Therefore, knowing a resonant frequency of the stub and the established quantitative relation, the value of relative dielectric constant of the fluid can be easily estimated and a fluid identified accordingly.

The further investigation of this structure will include test sample fabrication and utilization in measurement of various fluid characteristics.

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