Electromagnetic Design of
flexIble SensOrs

Report 1. Planar Antennas Design and Mesh Projection onto Arbitrary Surface

Maciej Jasiński
September 28, 2018

The „EDISOn - Electromagnetic Design of flexIbleSensOrs"project, agreement no TEAM TECH/2016-1/6, is carried out within the TEAM-TECH programme of the Foundation for Polish Science co-financed by the European Union under the European Regional Development Fund.

Revision	**Date**	**Author(s)**	**Description**
1.0	28.09.2018	M. Jasiński	created

1 Introduction

The matter of this report is about the first steps of work, which final puprose is to design quasi planar antenna. It has been divided into two main sections, which the former is about validating simulation software results and the latter concerns the method of projecting antenna topology onto surface of arbitrary shape.

2 Planar antennas designs

Because of possible usage of these antennas in cloth wearable applications, the back lobe of radiation have to be low. Therefore, only the antennas on grounded substrate were chosen to design. The purpose of these simulations was to get acquainted with InventSim software and to investigate how simulation parameters affect analysis results accuracy . In order to check corectness of simulation results further, two antenna designs have been made in three different softwares: InventSim, HFSS and ADS Momentum. It should be noted that the final test confirmating propriety of design procedure is a measure of physical device, but this will be performed at a later stage of work.

2.1 Simulation software

InventSim is the main software used in design process, because it allows mesh deformation into arbitrary shape. The simulation of microwave structure is based on Finite Element Method. HFSS and ADS Momentum are used as source of reference results. HFSS is based on the same method as InventSim and ADS Momentum uses method of moments.

2.2 Material

At this stage three substrate materials have been used in simulations.

FR4
This substrate was used in simulations of the antennas to indicate influence of analysis settings on simulation results. Material parameters are presented in table 1:

substrate thickness	1.6 mm
relative permitivity	4.4
dissipation factor	0.02
conductor thickness	18 µm
relative permeability	0.999991
conductivity	5.8e7 S/m

Table 1: FR4 parameters

Isola

This is the substrate material utilized in project of two planar antennas, which are going to be fabricated. Material parameters are presented in table 2:

substrate thickness	0.762 mm
relative permitivity	3.45
dissipation factor	0.0035
conductor thickness	18 µm
relative permeability	0.999991
conductivity	5.8e7 S/m

Table 2: Isola parameters

Kapton

In order to fabricate antenna on curved surface, the substrate should be able to bend into arbitrary shape. Because of its flexibility, Kapton film meets this requirement. Parameters of this material are presented in table 3:

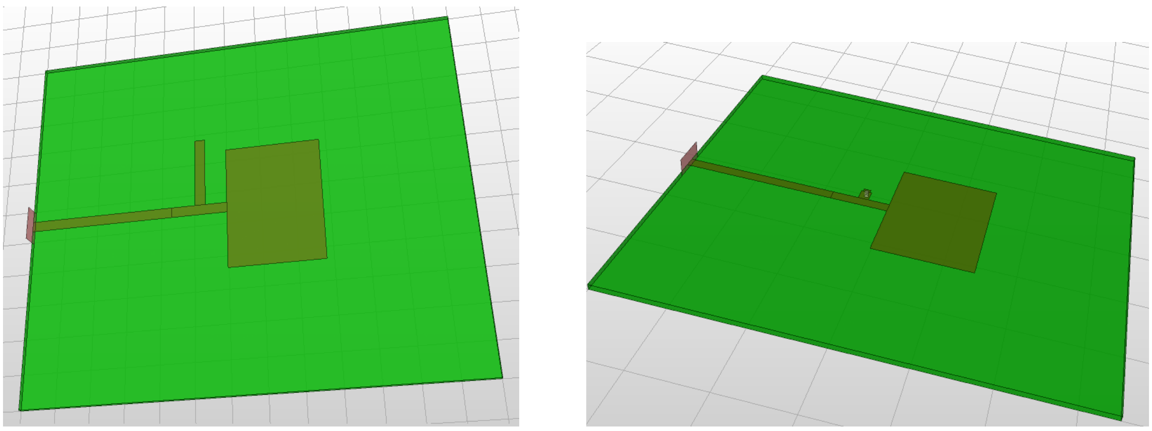
substrate thickness	0.075 mm
relative permitivity	3.5
dissipation factor	0.002

Table 3: Kapton parameters

Very low thickness of substrate makes 50 Ω impedance line width equal to 0.15 mm, which is difficult to manufacture. Moreover, the thin substrate narrows the bandwidth of the antenna.

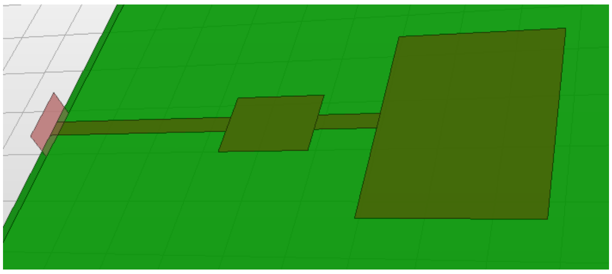
2.3 Patch antenna with various impedance matching circuits

Four patch antennas were designed on FR4 substrate, which differed only in type of matching circuit. Design procedure consists of two stages and is based on [1]. First part is about finding patch dimensions based on resonant frequency and material parameters of the substrate. The second stage is impedance matching of the antenna. Following matching circuits were simulated: circuit with open stub, circuit with shorted stub, quarter-wave transformer and inset feed. Models of these antennas are shown in figures 1 and 2.

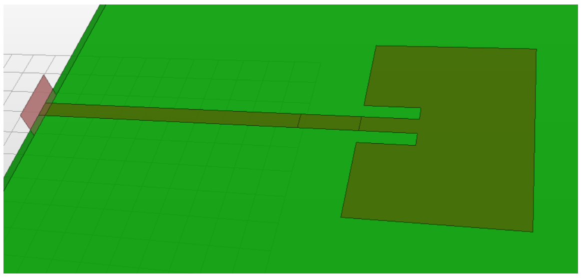


(a) (b)

Figure 1: Antenna with short stub circuit (a) and antenna with short stub circuit (b)



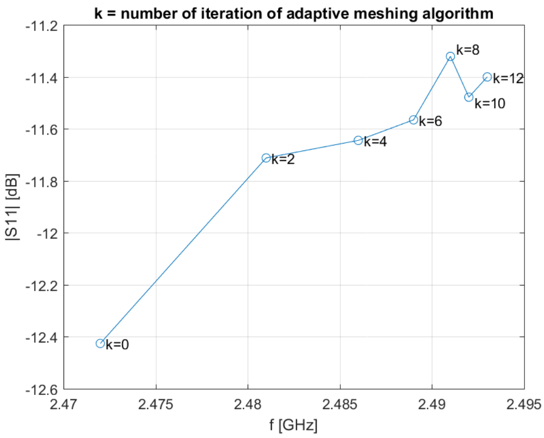
(a)



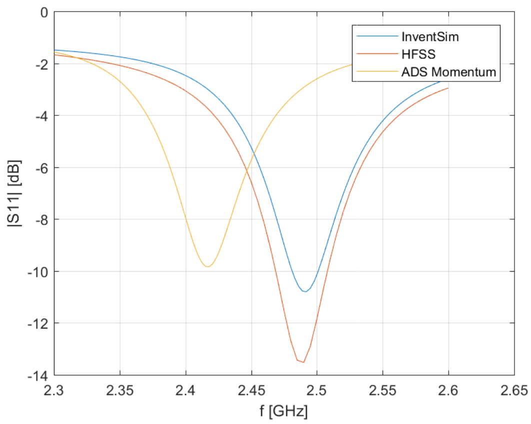
(b)

Figure 2: Antenna with quarter-wave transformer (a) and antenna with inset feed (b)

A strong relationship between the results and mesh density has been found. The results should converge with increasing number of mesh nodes, but the resonant frequency shift was still significant, even for maximum mesh dense allowed by hardware resources. After obtaining access to calculation server and performing simulation with denser mesh, the convergence has been achieved. The points of resonance frequency in function of adaptive meshing algorithm iteration are shown in fig 3a and characteristics of antenna for convergence mesh are presented in fig 3b.



(a)



(b)

Figure 3: Resonance frequency point dependency on mesh density (a) and comparison of antenna characteristics from different software (b) of antenna with open stub circuit

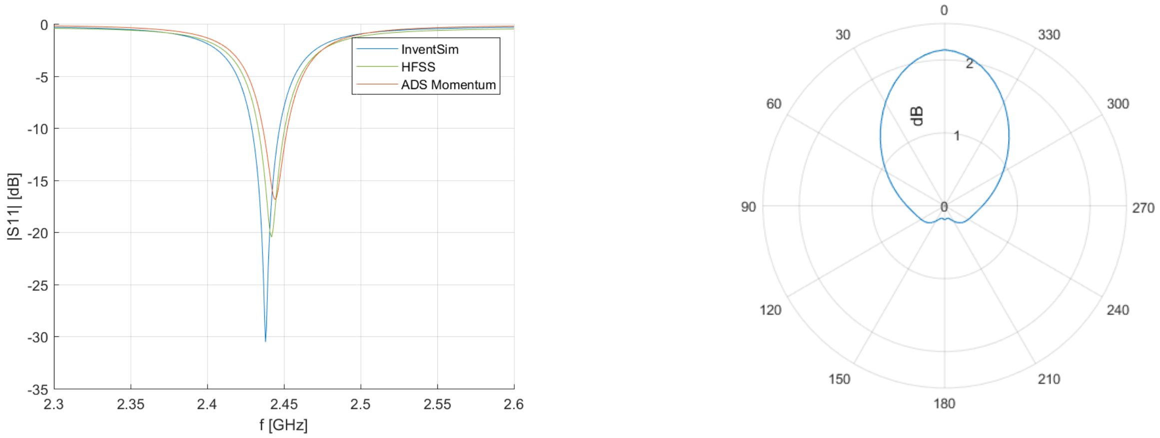
The characteristics from InventSim and HFSS are close to each other, while result from ADS Momentum is shifted to lower frequencies. It could be caused by usage of another analysis method in ADS Momentum than InventSim and HFSS.

2.4 Design antennas for fabricating

To find out which software result is correct, the measurement of physical device have to be performed. Two antenna types are chosen to be fabricated: an antenna with inset feed and coplanar feed antenna, both on Isola substrate.

Inset feed antenna

The $|S_{11}|$ characteristic and radiation pattern of designed antenna are shown in figure 4. The results from different software differs only slightly. Radiation pattern have desired shape - the back lobe is low.

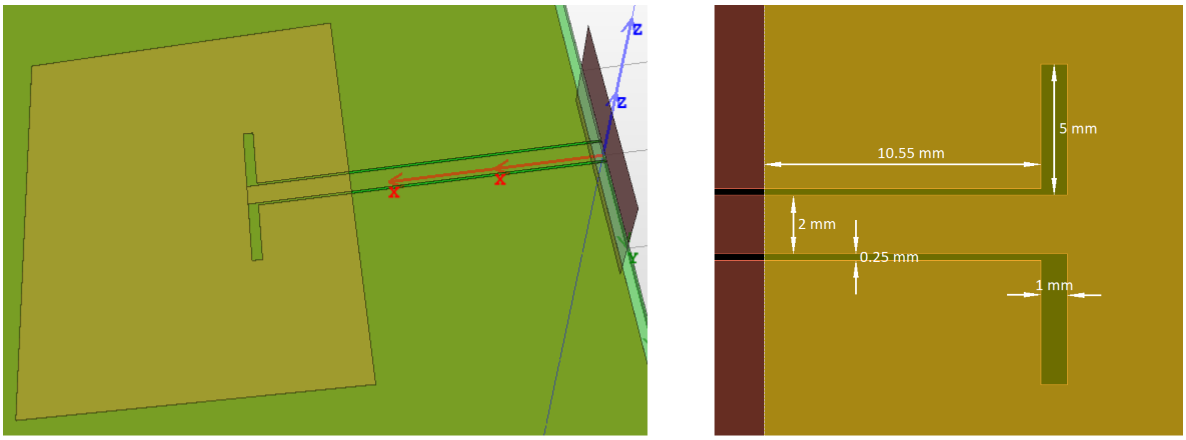


(a) (b)

Figure 4: $|S_{11}|$ characteristic (a) and radiation pattern (b) of the inset feed antenna

Coplanar feed antenna

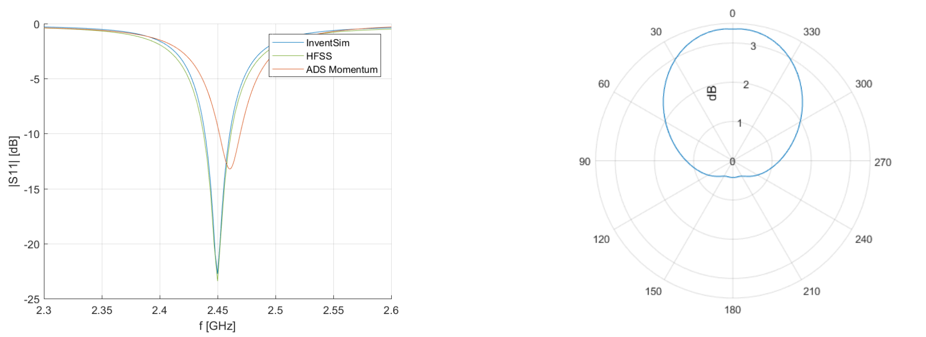
The project of this antenna is based on the article [2]. All dimensions have been determined by simulation experiments. The structure of the antenna and dimensions are presented in figure 5 below.



(a) (b)

Figure 5: Structure (a) and dimensions (b) of the coplanar feed antenna

Figure 6 shows that the results from InventSim and HFSS are nearly identical, but characteristic from ADS Momentum differs noticeably. Similar to the previous antenna, the backward radiation is low.



(a) (b)

Figure 6: Structure (a) and dimensions (b) of the coplanar feed antenna

2.5 Bow Tie Antenna

Being aware of narrowing the bandwidth by thin substrate, some wideband antennas were considered. Bow Tie Antenna on grounded substrate, described in [3], was chosen to design and simulate. During simulation $|S_{11}|$ = -16 dB at desired frequency has been achieved, but it corresponds to length of the structure equal to 11.8 cm. This results in significantly increased dimensions comparing to patch antenna. Due to this disadvantage, the project of this antenna was suspended.

3 Mesh projection onto arbitrary surface

The main purpose of antenna shape deformation is to obtain different radiation patterns while resonant frequency remains constant. The idea of design steps proceeds as follow:

1. design planar antenna with fixed resonant frequency
2. make antenna model in InventSim
3. project the mesh of model onto given surface
4. perform simulation based on deformed mesh.

In order to left resonant frequency unchanged, the projection have to preserve phase relation in each point of the circuit. It means that the distance between each point of initial mesh, and between points of the new one has to be equal.

The function describing projection surface is represented by set of radial basis functions . The radial basis function used in algorithm has a form:

$$\Phi(r) = e^{-(\beta r)^2} \tag{1}$$

where r is a distance from the center of radial basis function and β is arbitrary coefficient. Then, the surface function is represented as a series of functions described in equation 1, multiplied by set of unknown coefficients. To determine these coefficients, a matrix equation have to be solved. The accuracy of mesh deformation depends on number of radial basis function. Mesh projection effects are shown in figures 7, 8 and 9. The planar patch antenna was projected onto side of cylinder.

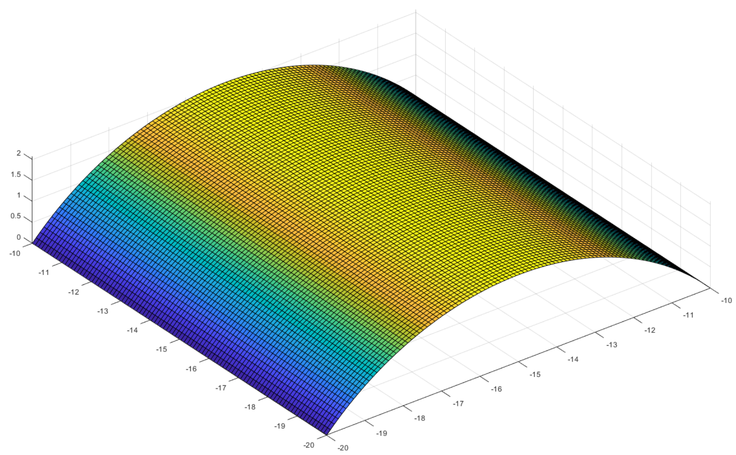
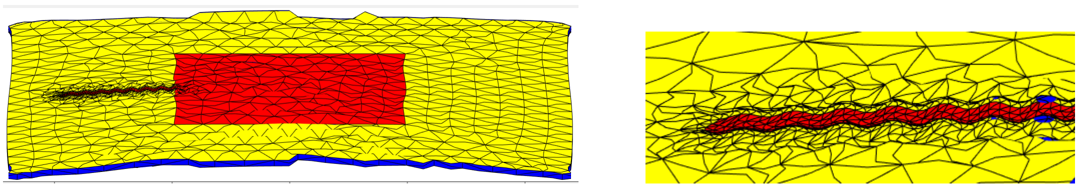
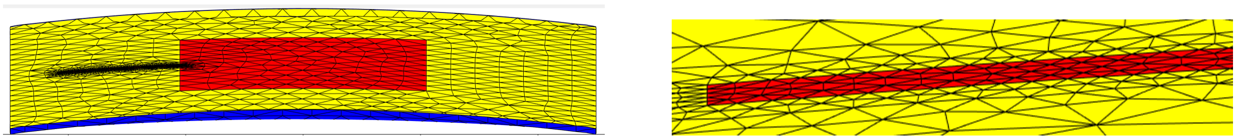


Figure 7: Projection surface



(a) (b)

Figure 8: Deformed structure (a) and close-up view on microstrip (b) with 1600 radial basis functions



(a) (b)

Figure 9: Deformed structure (a) and close-up view on microstrip (b) with 3600 radial basis functions

4 Further work

The projects of two antennas were ordered to fabricate and when they will be ready, the measurements will be performed. The attempts to bond multiple layers of Kapton film will be performed, in order to improve its thickness. To reduce the number of radial basis functions in mesh deformation procedure some additional polynomials will be involved in the function representation.

References

[1] Balanis C. A. "Antenna Theory: Analysis and Design." 3rd ed. Hoboken, NJ: John Wiley, 2005: 811-826.

[2] Menzel W. and W. Grabherr. "A Microstrip Patch Antenna with Coplanar Feed Line" IEEE MICROWAVE AND GUIDED WAVE LETTERS, VOL. 1, NO. 11, NOVEMBER 1991.

[3] Fraga-Rosales H., M. Reyes-Ayala, G. Hernandez-Valdez, E. A. Andrade-Gonzalez, J. R. Miranda-Tello, F. A. Cruz-Perez and S. L. Castellanos-Lopez. "Triangular Patch Antennas for Mobile Radio-Communicaions Systems" WSEAS TRANSACTIONS on COMMUNICATIONS E-ISSN: 2224-2864 2017.