Simulation of a Broadband Antenna with the Method of Moments

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Abstract. *In the paper selected problems of computer simulations of a broadband antenna containing large metallic surfaces with the Method of Moments have been discussed. A novel broadband combined spiral-discone antenna, built of a complementary spiral and a cone has been analyzed. Since the antenna contains large metallic surfaces wire-grid models had to be developed in order to simulate the antenna with the thin-wire kernel method of moments. Several wire-grid models of the antenna have been proposed and analyzed. The simulation results for input impedance have been compared to those obtained from measurements and the best model of the antenna has been identified.*

Keywords

Broadband antenna, Method of Moments, wire-grid modeling.

1. Introduction

The method of moments (MoM) is a very popular algorithm of computer electromagnetic calculations. It is widely used for antenna simulations and electromagnetic wave scattering analysis. The popular version of MoM applied in NEC code uses thin wires to simulate the antenna structure, so the base functions applied for this are derived for thin, straight-line wires. This originally used version is also called thin wire kernel. The first applications of MoM were antennas build with wires, but good results of simulation that were obtained for those antennas inspired antenna designers to use NEC also for other structures.

The wire-grid modeling is the way of applying the method of moments derived for thin wires into surface modeling. Numerous papers describe the rules of constructing the models in this particular approach [1, 2, 3] however they focus only on the cases of electromagnetic wave scattering. In scattering analysis only the distribution of electromagnetic field is computed and there is no need to precisely determine the input impedance of the radiator. Moreover the analyzed structure has usually only one side of the surface that is radiating (e.g. sphere or cylinder). The simulation of a broadband antenna has different assumptions. It requires the possibility of calculating input impedance (or VSWR) and radiation pattern. For broadband antenna the stable value of S_{11} or VSWR is required across the operating frequencies and it is used for bandwidth qualification.

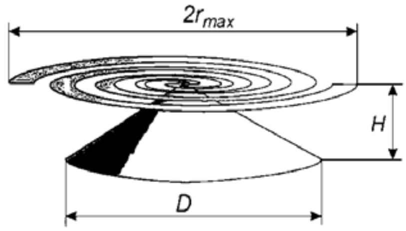

Fig. 1. Combined spiral-discone antenna.

The input impedance is very important parameter that can be used also for model verification, giving simple, quantitative criterion (e.g. by rejection of negative resistance). The most popular thin wire kernel MoM can give accurate calculations of input impedance for wire antennas and is very difficult to obtain good results in the case of surface antennas. Thus applying the wire-grid modeling derived for scattering to broadband antenna is not obvious. A broadband combined spiral-discone antenna is the object that contains large, conducting surfaces with both sides radiating. The way of applying wire grid modeling for such a case is not trivial and needs careful consideration. In the case of modeling the combined spiral-discone broadband antenna the calculation of input impedance is critical from the design and optimization point of view. Thus this parameter has been carefully analyzed in presented paper; the radiation pattern is only presented for final evaluation of the selected model.

The MoM approach has been applied to the modeling of the input impedance of broadband combined spiral-discone antenna [4]. This is a new construction for which no design rules exist and therefore computer simulations are necessary for the design and optimization of such antenna.

2. The Antenna Structure

The antenna that has been simulated with the method of moments is a broadband radiating structure. It is a combined spiral-discone antenna [4]. The structure of the spiral-discone antenna is shown in Fig. 1. It consists of flat spiral top part and the conical bottom part. The antenna is fed by a coaxial line with the center conductor connected to the spiral and the shield connected to the cone (see Fig. 2). The excitation point of the spiral is surrounded by metallic circle. The radius r_0 of this circle should be as small as possible. Due to technological limitations this radius has been selected to 10 mm.

The two-arm, self–complementary equiangular spiral part is flat, conducting element of the same shape that complementary part of the plane. It is described in the spherical coordinates by the following equation (1)

$$\begin{cases} r_1 = r_0 \cdot e^{a\varphi} \\ r_2 = r_0 \cdot e^{a(\varphi-\varphi')} \\ r_3 = r_0 \cdot e^{a(\varphi-\pi)} \\ r_4 = r_0 \cdot e^{a(\varphi-\pi-\varphi')} \end{cases} \tag{1}$$

where $r_1(\varphi)$, $r_2(\varphi)$, $r_3(\varphi)$, $r_4(\varphi)$ represent the edges of each arm of the spiral, $\varphi' = \pi/2$ is the axial width of the spiral arms, r_0 = 10 mm is the spiral minimum radius, a = 0.25 is the spiral expansion ratio.

The maximum radius of the spiral is $r_{\max}$ = 250 mm. The height of the antenna equals to H = 110 mm while the diameter of the base of the cone is D = 380 mm. The ratio of the maximum radius of the spiral to the wavelength corresponding to the low end of the frequency band (measured at VSWR = 2) is about 0.54.

The antenna can operate within the frequency band of 650 ÷ 3000 MHz with VSWR < 2.

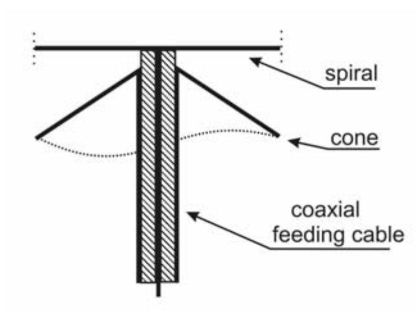

Fig. 2. The feeding of combined spiral-discone antenna.

3. The NEC Model of the Antenna

Several models of the antenna have been developed for the simulation of antenna input impedance. Firstly the model, in which the wire-grid is constructed according to principles presented in [2] has been examined. This rule is derived for scattering on the large metallic surfaces and is the starting point for model development. The main condition that has to be satisfied requires the equivalence of two surfaces. The first surface is the lateral surface of the wires that form the grid and it is proportional to wire radius and length. The second surface is the surface of the modeled element.

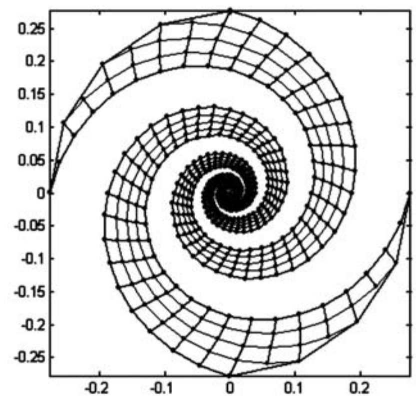

Fig. 3. The wire-grid model of the spiral component of the antenna.

The model of the spiral component (top part) is made of 5 sets of wires (for each arm of the spiral) evolving from the center of the spiral towards the ends. Those sets are subdivided into short wires interconnected to form a skeleton as shown in Fig. 3. The area near to the excitation point is modeled with several wires approximating its circular shape as shown in Fig. 4.

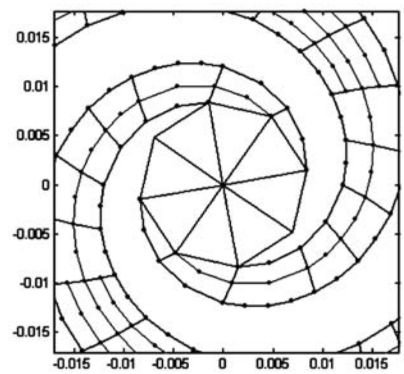

Fig. 4. The layout of wires at the excitation point of the spiral.

The number of wires in this part of the model is equal 1238 and the total number of segments in the first model is 1499. The cone component (bottom part) is made of several rings with the number of wires increasing towards the base of the cone. The topmost ring contains 6 wires of the length equal to 5 mm – that is 1/20 of the length of the shortest wave radiated by the antenna. According to [1] this is the optimal length for the upper frequency 3 GHz. The nodes of each ring are connected to the corresponding nodes in the lower ring and the distance between the rings is proportional to the average length of wires in the upper and the lower ring. The radii of wires in each ring are selected according to the guidelines concerning the surface equivalence formulated in [1, 2, 3]. When this condition is satisfied the radii of wires do not grow monotonically towards the base of the cone.

The cone part wire-grid structure is shown in Fig. 5 and the overall view of antenna model is presented in Fig. 6. The figures do not show the real wire radii.

The feeding of the structure is modeled as a single segment that contains a point voltage source in its center. It is connected to the middle point of the top spiral part and to the cone topmost ring. It is presented in Fig. 7. The radius of the source segment is the same as the radius of the segments that it is connected to.

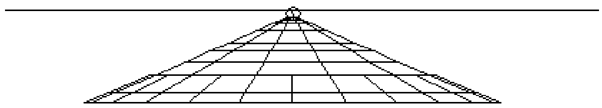

Fig. 5. The side view of model.

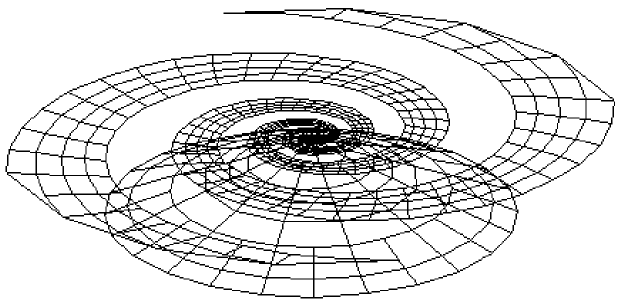

Fig. 6. The top-side view of model.

The second model examined has the same structure of the spiral component. The discone is also made of interconnected rings but the radii of the wires in subsequent rings and connections grow monotonically towards the base of the cone. The starting radius is equal 0.42 mm and the end radius is equal 14.4 mm. The rings are uniformly separated. The total number of segments in this model is equal 1443.

In antenna optimization procedure the number of simulations needs to be run so the computational time of the model needs to be relatively short. To significantly reduce the computational cost the reduced model has been proposed. In the third model the complicated structure of the spiral has been replaced with a simple one consisting only of the outline of the spiral and the circular excitation point (Fig. 8). The cone component is constructed in the same way as in the model 2. The total number of segments in model 3 is equal 549. This significantly decreases the computational time of simulation.

4. Simulation Results

The three models presented in the previous sections have been used for simulations in *SuperNec* [5]. The selected software uses the thin wire MoM version. The results obtained with *SuperNec* have been compared to the results obtained from measurement. For the comparison VSWR vs. frequency has been chosen since this parameter is very important for a broadband antenna. It defines the bandwidth of the antenna and is the essential condition that can be used to recognize if the given model may be used for simulations. Thus it has to be calculated before the radiation pattern is examined.

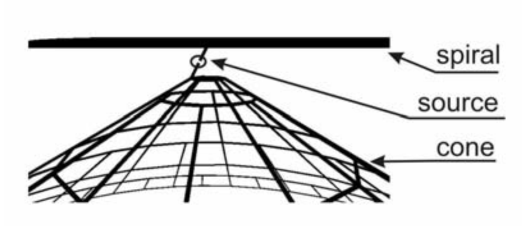

Fig. 7. The feeding of model.

The VSWR seems to depend strongly on the model structure so the most of the efforts has been focused on the development of a model giving satisfactory input impedance of the antenna in a wide frequency range 600 – 3000 MHz.

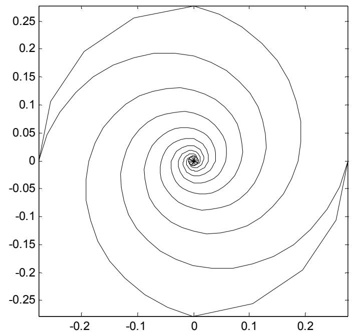

Fig. 8. The spiral component in model 3.

For each model several variants have been examined. It has been found that the selection of wire radii is the key parameter of the model. The slight variations of wire radii result in major differences in calculated VSWR.

The simulation results of VSWR obtained with model 1 are presented in Fig. 9 and the Smith chart is presented in Fig. 10. Those figures show the results for the best variant of the model (in terms of mean square error) compared to the measured values. It may be noticed that the general distribution of VSWR vs. frequency is well reflected in the simulations although the absolute values are not the same and differ by more than 1. The computation time on a 2 GHz processor is 19 minutes.

The values of the input impedance of the antenna are overestimated by a mean factor of 2. This may be observed in Fig. 10.

It may be shown also that the model is best matched to measurements if wire radii are not less than calculated according to equivalent surface principle [2]. This has been shown in Fig. 11.

The results obtained with model 2 (Fig. 12) do not conform to the measurements so well as in the case of model 1. The variability of VSWR is much greater than for the previous model and grows towards higher frequencies. It has been observed that the best results are obtained for wire radius scaling factor in the range 0.9 – 1. The input impedance in Fig. 13 also shows high variability, but the mean factor by which it is overestimated is close to 2 as in the case of model 1. The computation time is equal to 17 minutes.

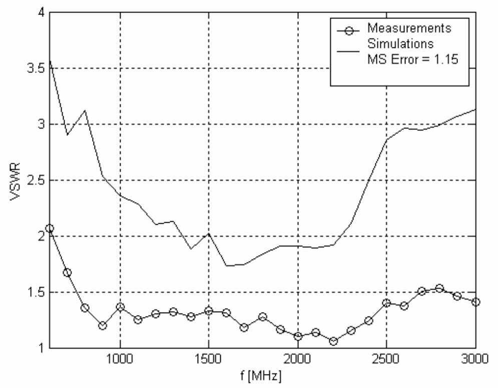

Fig. 9. The comparison of VSWR obtained from simulations and measurements for model 1.

The results obtained with model 3 are similar to those obtained with model 2. Model 3 uses the simplest approximation of the spiral component and therefore it also requires the smallest computation time (less than 2 minutes). The results in Fig. 14 show the dependence of VSWR vs. frequency for the best variant of the model. For this model a slightly lower value of mean square error has been obtained than for the model 2 while the description of the spiral part is much simpler. The behavior of the model at lower frequencies is worse than of the model 2.

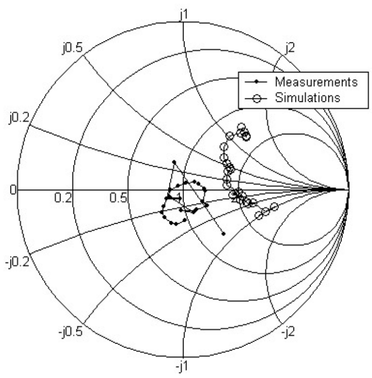

Fig. 10. The Smith chart of the input impedance – model 1.

In all cases the input impedance of the antenna has been overestimated. This may due to the fact that NEC code does not take into account the currents flowing on both surfaces of radiating metallic structure of the antenna.

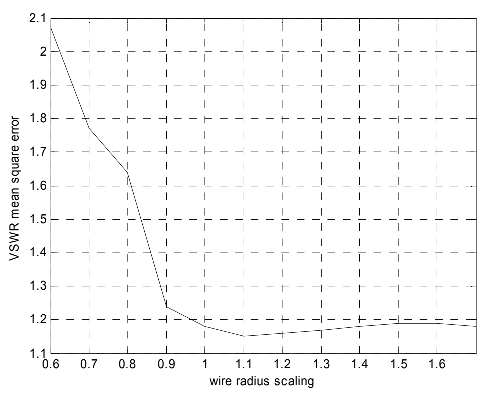

Fig. 11. VSWR error vs. wire radius scaling factor in model 1.

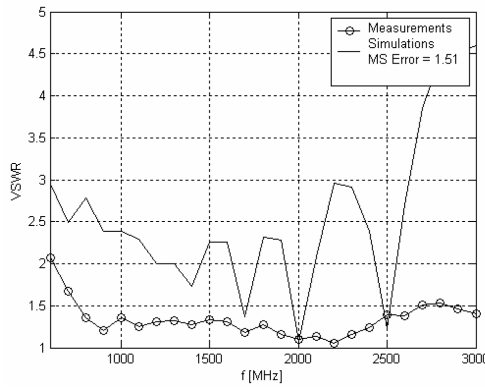

Fig. 12. The comparison of VSWR obtained from simulations and measurements for model 2.

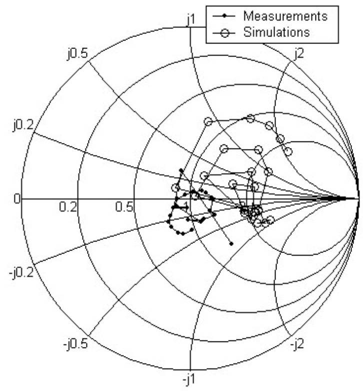

Fig. 13. The Smith chart of the input impedance – model 2.

For the first model, that shows the best input impedance performance, the radiation pattern has been calculated and compared with the results of measurements. The figures 15 and 16 show the elevation cut of radiation pattern calculated and measured for 1000 and 2100 MHz. The average difference between the results of calculations and measurements is 5 dB and the distribution for minima and maxima is convergent.

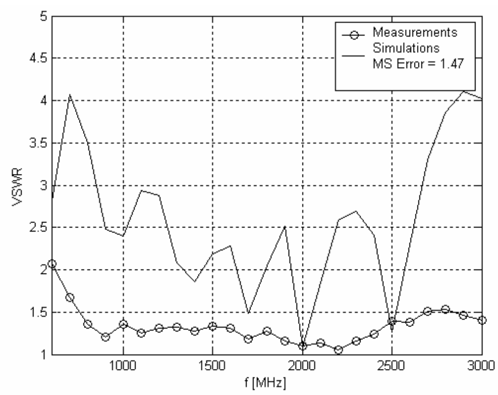

Fig. 14. The comparison of VSWR obtained from simulations and measurements for model 3.

5. Conclusions

The results of simulations have shown that calculations of the input impedance of the broadband antennas containing large metallic surfaces with both sides radiating can be made with thin wire kernel Method of Moments. This approach gives the quantitative error of VSWR that is almost equal to 90 %. Still the distribution of minima and maxima is close to the results of measurements and the simulation results may be used to estimate the bandwidth of the antenna. While the value of the error is high the results of input impedance simulation can not be authoritative, but the stability of VSWR across the bandwidth is good enough to determine the frequency operation range for the antenna.

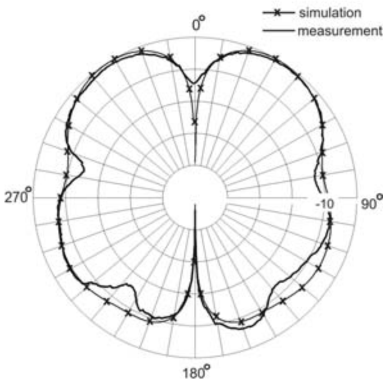

Fig. 15. The elevation cut of radiation pattern @ 1000MHz.

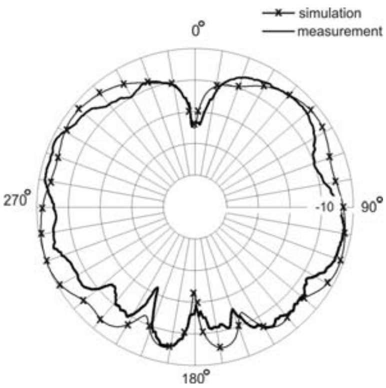

Fig. 16. The elevation cut of radiation pattern @ 2100MHz.

Several wire-grid models of combined spiral-discone antenna have been developed. The most accurate results have been obtained with the model designed using the principle of equivalent surfaces of the wire-grid and the real structure. That shows that the principle derived for scattering analysis can be applied for antenna simulations with the limitations mentioned above. The best model obtained in this way will be further used in the optimization of antenna geometry aiming towards maximum bandwidth. The presented results of radiation pattern simulations for this model show good convergence with the results of measurements.

The main drawback of the model is the overestimated input impedance of the antenna. The most possible reason for this phenomenon is that the both-sided current flow in a real antenna cannot be simply modeled with the wire-grid approach. The method of moments that uses different base functions is the subject of further research.

Also the significant limitation of the number of segments tested in the third model show that if the inner segments of conducting surface are neglected unacceptable errors in VSWR calculations occur. Thus such a simple model cannot be used in antenna optimization process despite a very low computational time. For further optimization the first model has been selected.

Acknowledgements

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