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MoM antenna model verified against measurements

Abstract. *This paper discusses numerical simulation of the E-Field generating antenna for susceptibility testing according to military EMC standard. The authors compare results of antenna simulation with Method of Moments with measurements of the near field in a non-echoic chamber. The difficulties arising when comparing numerical models with measured circuital parameters of generator-antenna system are discussed in detail.*

Streszczenie. *Artykuł przedstawia weryfikację numerycznego modelu anteny generującej pole elektryczne do militarnych testów odporności urządzeń elektronicznych przez pomiary wykonywane w komorze bezodbiciowej. Praca wskazuje na trudności przy porównaniu pomiarów pola w strefie bliskiej i wyników symulacji komputerowych wykonanych z wykorzystaniem Metody Momentów.* ***(Porównanie numerycznych modeli anteny z pomiarami)***

Keywords: EMC, E-Field, susceptibility, numerical model, experimental verification
Słowa kluczowe: kompatybilność elektromagnetyczna, pole elektryczne, testy narażaniowe, model numeryczny, weryfikacja

The problem

Susceptibility testing according to the military standards includes exposure to E-Field of large intensity (10 V/m, by 20 V/m and 50 V/m up to 200 V/m) and broad frequency range (10 kHz to 40 GHz) [1].

In this tests, the generating antenna is located 100 cm from the tested object (EUT = Equipment Under Test) placed on a long table (equipment table) with conductive top level (Fig. 1). All equipment should be placed in a shielded room, minimal size of which can be estimated as 7×5×3 meters.

Fig. 1. Antenna and near field sensor in the testing site

Due the size of the antenna, the EUT is placed in a near-field zone in which to achieve the desired field intensity one must apply a high-power antenna and a power amplifier. One of the useful antennas on the market is EFG-3B model [2]. This is the 2 kW antenna with frequency range 10 kHz to 220 MHz. The authors' goal is to improve the radiation characteristic of the antenna to reduce the cost of feeding amplifiers and/or to increase the field intensity generated by the given hardware. This task can be achieved with numerical simulation of the antenna [7], but the results need to be validated against the measurements done with a real system. It is not a straightforward task and the problems faced during it's solution are briefly presented in this paper.

The practical test environment of one of Polish EMC laboratories is shown in Fig. 1. During system calibration the antenna is placed in front of an E-Field sensor located atop of a dummy EUT. Generated field is measured on-line and according to this measurement the generator is tuned to keep the desired (50 V/m) value of the exposure.

MoM simulation

The numerical model of the antenna was implemented in the classical tool – NEC-2 code [3]. NEC-2 was originally written in 1981 at Lawrence Livermore Laboratories under contract to US Navy and then released to public domain, becoming the most popular tool for antenna simulation.

NEC-2 uses Method of Moments in which the antenna is represented as paths of wires and surface patches [6]. The code implements an integral equation for smooth surfaces with one specialized to wires.

In our research we have evaluated six NEC-2 models. Three of them turned out to be incorrect, giving very inaccurate results. Correct models have been presented in Fig. 2. From now on they will be referenced in the text as a, b and c. We have investigated how accurately EFG-3B antenna can be modeled using only 4 wires (model a) or 26 wires (model b and c).

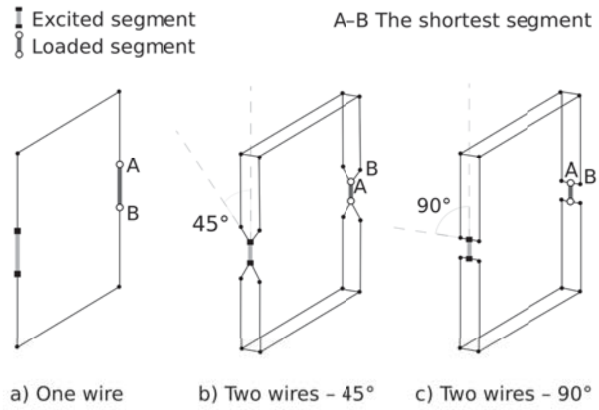


Fig. 2. Models designed for NEC-2 simulation software

The main difficulty in Method of Moments was satisfying all the constraints of maximal and minimal segment length. According to [8] to achieve proper solution accuracy geometrical model must follow set of rules (λ is the wavelength for frequencies within considered frequency range):

– maximum wire radius: $r < \frac{\lambda}{100}$,
– minimum segment's length: $l > \frac{\lambda}{1000}$, $l > 8\,r$,
– maximum segment's length: $l < \frac{\lambda}{18}$,
– relation of lengths of connected segments:
$l_1 < 5\,l_2, r_1 < 5\,r_2$, where $l_1 > l_2$ and $r_1 > r_2$.

It is obvious that if we want to simulate antenna in a wide range of frequencies, we are likely to not be able to use a single geometrical model due to the above constraints on segments dimensions. Moreover, we have encountered situation when we were unable at all to prepare a valid model for given frequencies, i.e. below 1 MHz.

For the lowest frequency of range declared by the antenna's producer – 10kHz, the wavelength is $\lambda = \frac{c}{f} \approx 30$ km what creates the length limit: $30\text{m} < l < 1670\text{m}$. The remaining rules were easy to satisfy, but, as we can see, there is no way to satisfy the constraint on minimum segment's length, because the antenna must have at least four wires each at least 1m long. It can be calculated that 0.3 MHz is the lowest frequency for which (according to Cebik's rules) we can satisfy the minimum segment's length criterion. At this frequency the lengths of all segments length should be $56\text{m} > l > 1\text{m}$, so we can consider 0.3 MHz being a minimum frequency yielding correct results. For the other side, the segments lengths for the frequency 100 MHz must satisfy the following condition: $0.003\text{m} < l < 0.167\text{m}$ which stands in contradiction to the constraint for 0.3 MHz.

We wanted to compare the simplest model of the antenna with more complex models (b and c). The shortest segment of model b and c (marked as $A - B$ in Fig. 2) is shorter than in the model a, because we have also taken into account depth of the considered frame antenna (10 cm). This again narrows the frequency range. Finally we decided to limit it to 10 MHz÷100 MHz what allows all model to comply with Cebik's rules. All simulations were conducted using wires of radius 1mm in a free space. The excited segment have been fed with 10V input voltage. Antenna was loaded with 200Ω resistance (the real antenna matches the 50Ω feeding cable and both input and output antenna's ports were connected through balun transformers with 4:1 impedance ratio).

Fig. 3 depicts the plot of power budget calculated using NEC-2 software for model a using 7 segments per wire. It seems that valid results start at approximately 10 MHz, not at 2.1 MHz as we could expected. It can be caused by a very low radiation in low frequencies: in fact, this construction acts like an antenna above the frequency of 40 MHz (radiated power is higher than the numerical error).

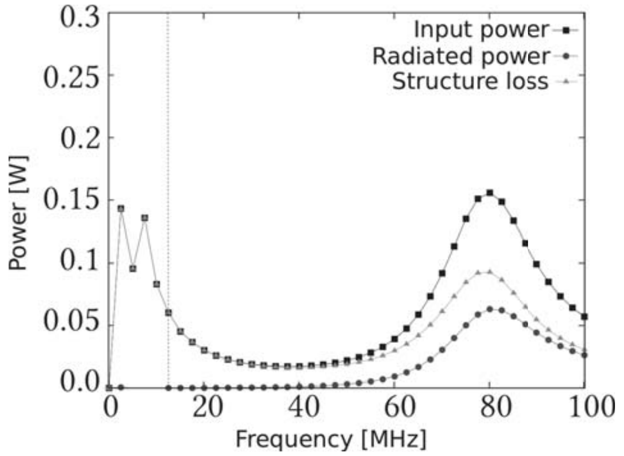


Fig. 3. Power budget plot for the a model in the full frequency range: 10 kHz÷100 MHz

For the purpose of our further analysis, we have picked the frequency range 10 MHz÷100 MHz.

Power budget comparison of NEC-2 models

In the first comparison of results we were focused on the power budget of the antenna. We were able to indirectly compare it with a plot of forward power measured by a directional coupler during antenna calibration. According to reasoning presented in the previous section we can reliably compare the results in the frequency range from 10 to 100 MHz (Fig. 5).

Forward power measured during calibration process cannot be directly compared to input power or radiated power calculations, because we were unable to simulate the power supply system with NEC-2. Thus we were trying to find some similarities between the forward power plot and power budget

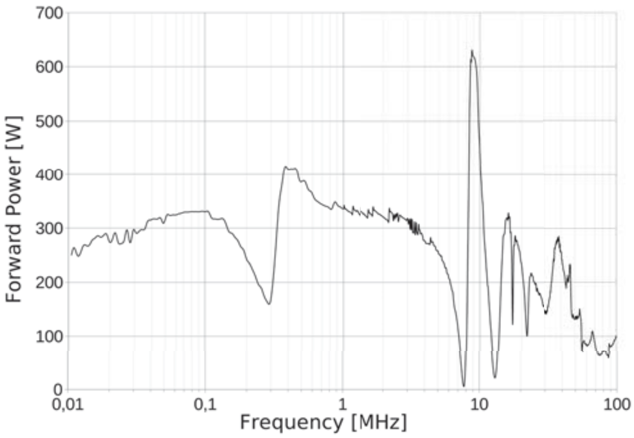


Fig. 4. Forward power measured in the range between 10 kHz and 100 MHz

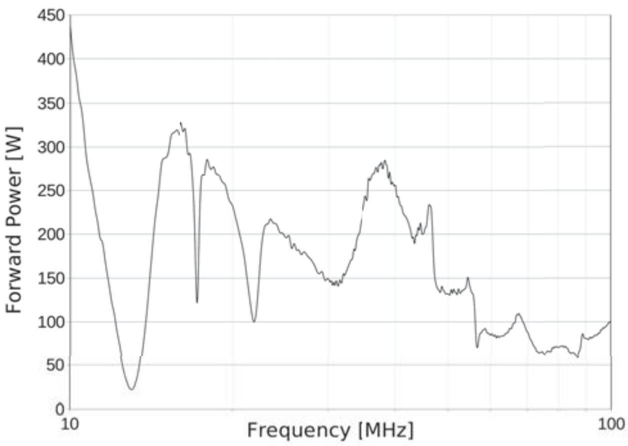


Fig. 5. Forward power measured in the range between 10 MHz and 100 MHz

obtained from NEC-2. We have expected to see a maximum value of radiated power for the frequency at which the forward power was minimal during antenna calibration. However, the plots shown in Fig. 5 and Fig. 6 seem to be unrelated to each other in that manner. There is no visible similarities in them. We can conclude, that power supply system, connecting cables and realistic material properties have very strong influence on simulation results. Because with NEC-2 we have very limited ability of power cables, material properties and power supply simulation, this kind of a model is clearly insufficient.

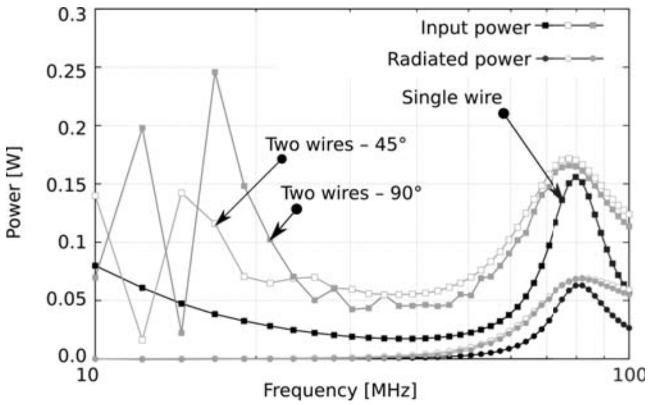
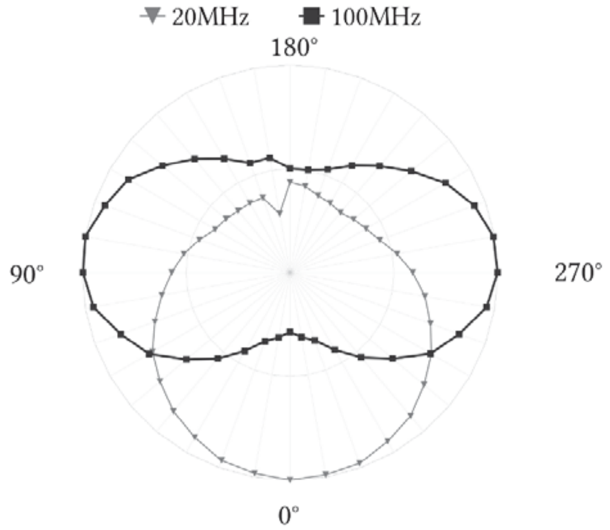


Fig. 6. Power budget plot for NEC-2 models for the frequency range – 10 MHz - 100 MHz

Near electric field patterns comparison

The susceptibility tests require achieving the desired intensity of E-field 1 m away from an antenna. For our frequency range this location is inside the near field zone (below 2-3 wavelengths) the antenna radiation pattern is not necessarily valid as the directional characteristic of the antenna. However, we were able to measure the intensity of E-field in a near zone with an E-field sensor located 3 m from the center of the antenna rotated around its vertical axis. The obtained polar plot have been presented in Fig. 7a.

a) measured



b) computed

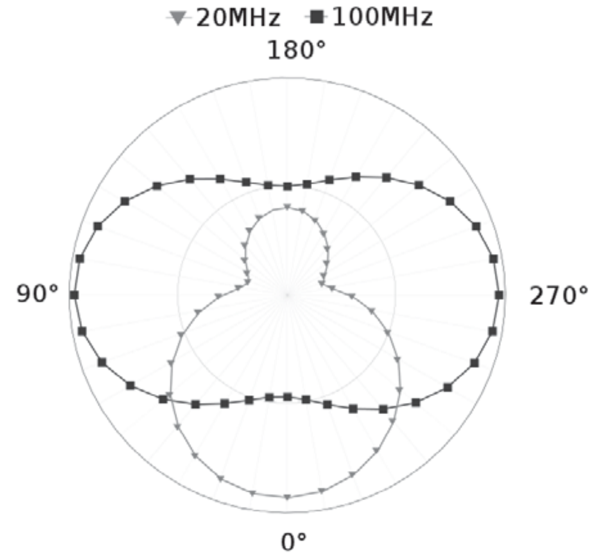


Fig. 7. Near electric field pattern measured 3m from the center of the antenna for 20 MHz and 100 MHz

This experiment has been simulated using Method of Moments implemented in NEC-2. Results from NEC-2 (Fig. 7b) are very similar to the measurements. Missing null points at $110°$ and $250°$ can be explained by misaligned antenna plane with the plane of E-field sensor. If the sensor is above or below the antenna's plane, the null points are less visible due to cardioid shape of its characteristic. Conclusion from this is clear, that influence of power supply system has very small impact on the shape of the near E-field characteristic of the antenna. Also, near field pattern resembles far field radiation pattern according to producer's manual [5].

Hybrid FEM-MOM model

In the previous sections we have examined three MoM models, however in order to confirm its accuracy, a hybrid model of the antenna have been created using FEKO software bundle [4]. This model uses Finite Element Method (FEM) in lower frequencies and MoM in higher frequencies. Fig. 8 presents the power budget plot obtained from this hybrid simulation. If we compare this with Fig. 6, we can see some similarities, yet none of presented numerical models was able to yield results matching closely the measurements (Fig. 5).

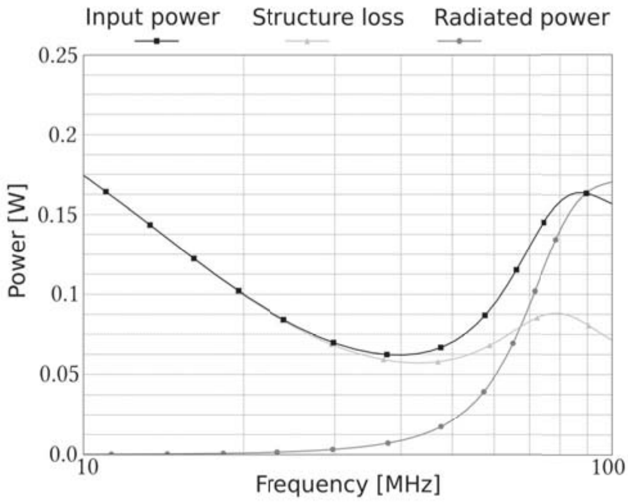


Fig. 8. Power budget calculated using the hybrid FEM/MoM model in FEKO

Conclusion

To sum up, we have created three numerical models using Method of Moments implemented in NEC-2 application. Based on our results we can state that without a careful modeling of the power supply system and the cables it is impossible to simulate or predict the frequency characteristic of the forward power. On the other hand, the power supply system model is not crucial for the near field pattern. In this part our numerical model was compliant with the data from the measurement of the real antenna. To validate our MoM models, the hybrid FEM/MoM model was created using FEKO Suite. Its power budget results seem to match our MoM model, although hybrid model gives us better accuracy in lower frequencies, where pure MoM simulation is limited by the method itself.

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