Construction of Equivalent Model of Patch Antenna Using Magnetic Dipole

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Happy Nkanta Monday
Oxford Brookes College of Chengdu University of Technology

Mordecai Raji
University of Electronic Science and Technology of China

Grace U. Nneji
Oxford Brookes College of Chengdu University of Technology

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Happy N. Monday
School of Computer Science and Technology
University of Electronic Science and Technology of China
Chengdu, China
mh.nkanta@gmail.com

Jian P. Li
School of Computer Science and Technology
University of Electronic Science and Technology of China
Chengdu, China
Jpli2222@uestc.edu.cn

Mordecai F. Raji
School of Computer Science and Technology
University of Electronic Science and Technology of China
Chengdu, China
mordecairaji@yahoo.com

Grace U. Nneji
School of Information and Software Engineering
University of Electronic Science and Technology of China
Chengdu, China
ugochinneji@gmail.com

Abel Ogungbile
Department of Geology
School of Mineral Sciences
Federal University of Technology, Akure
Ondo State, Lagos
rabelogun@gmail.com

Richard I. Nneji
Department of Chemical Engineering
School of Engineering
University of Lagos, Akoka
Lagos State, Lagos
richardnneji89@gmail.com

***Abstract*— This paper proposes a fast and efficient technique for constructing an equivalent model of patch antenna for predicting its radiation pattern. The equivalent model of the antenna is constructed based on its radiation properties. First, the initial model of the antenna is developed and then the arrangement of the initial model is optimized using FEKO optimization tool. The electric field of the magnetic dipole is determined based on numerical Green function derivation. The magnetic dipole is used to construct the equivalent model of patch antenna based on the radiation mechanism to predict its radiation pattern. Only two design parameters needed to be optimized making it more computational efficient. The derived radiation pattern from the equivalent model is validated with that of the original antenna model on FEKO to evaluate its efficiency. The simulation results show that the proposed equivalent model based on a magnetic dipole is fast and efficient and do not require the antenna's detailed material information.**

Keywords—*Magnetic dipole, patch antenna, optimization, equivalent model, radiation pattern, prediction*

I. Introduction

Fast techniques to perform accurate predictions of microwave devices are vital to develop modern telecommunication systems [1]-[3]. Patch antennas are widely used on aircrafts, spacecraft, satellites, and missiles because of their low profile. Patch antenna's radiation pattern changes obviously when mounted on different platforms. [4] - [5]. A simplified EM method can be termed a technique use to construct a problem equivalent to the actual Antenna Under Test (AUT). The model should correspond to the physical problem in the sense of producing similar EM fields when both the AUT and its equivalent model are communicating under the same influence [6]. In this regard, equivalent models based on elementary sources of infinitesimal dipoles have been successfully applied to predict both the far field and the near field in any direction [7]. Methods mentioned above assume that the geometry details of the antennas are known [8] Optimization method is employed to construct the equivalent model of the antenna based on a magnetic dipole in this paper. The magnetic dipole is used to construct the equivalent model. Simulation results show that the radiation pattern of the equivalent model agrees optimally with those of the patch antenna. This proposed model avoids detailed modeling of antennas.

II. Literature Review

Currently, patch antenna has become increasingly useful in several applications due to its characteristic advantages of low profile and radiation performance. Several methods have been proposed to construct an equivalent model of patch antenna based on its performance characteristics. Fast multipole technique was proposed in [3] which allow for the transformation of the antenna's far fields to its near fields to evaluate the radiation patterns. The equivalent dipole model method was proposed in [9] for reconstructing infinitesimal dipole models of an antenna based on its computed near field and far-field data. This generic method can handle all types of antenna but it is difficult to estimate the number of dipoles employed [10]. Multiple local minima is mostly associated with array synthesis problem due to cost functions are nonlinear and non-differential [11]. Global optimization such as genetic algorithm has been employed to avoid local minima [12]. Well known global optimization methods include genetic algorithm, simulated annealing, particle swarm optimization, and the DE method [8]. A thorough survey of the state-of-the-art DE algorithm was reported in [8] as a global optimization method.

III. Theory and Formulation

A. Numerical Green's Function

The mathematical expression was derived based on Green's Function using magnetic dipole to calculate the Electric field as stated below

$$\vec{E}(\vec{r}) = -\nabla \times \iint M(\vec{r}')G(\overrightarrow{\vec{r},\vec{r}'})\partial r' \quad (1)$$

The green's function is defined below

$$G\left(\overrightarrow{r,\vec{r}'}\right) = \nabla(e^{-jkr} / 4\pi r) \quad (2)$$

$M(\vec{r}')$ is the magnetic field, Hence, the E-field is given as;

$$G(\vec{r},\vec{r}') \times M(\vec{r}) = \begin{bmatrix} a_x & a_y & a_z \\ G_x & G_y & G_z \\ M_x & M_y & M_z \end{bmatrix} \quad (3)$$

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B. Far field and Near Field

The E-field radiation for both linear and planar arrays were obtained and validated. Using the Green's function based formulation. The results show good agreement when validated with FEKO solver. Figure 1-2 show validation result

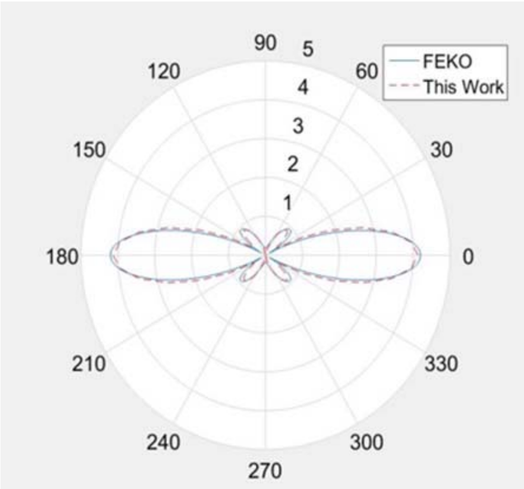

Fig. 1. Validation of the E-field polar plot of the 1x4 linear dipole array at ϕ = 45°, θ=0:360°

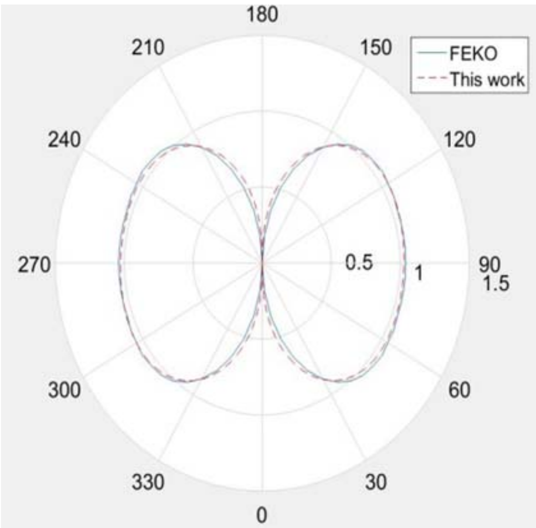

Fig. 2. Validation of the E-field polar plot of the 2x2 linear dipole array at ϕ = 45°, θ=0:360°

IV. Initial Model for the Patch Antenna

This paper considered a simple line fed patch antenna. Table I shows the geometry and material details of the patch antenna. The perfect electric contacting patch is given by $W_P \times L_P$. It was on a thin substrate, $W_s \times L_s$. Substrate thickness and relative permittivity are denoted by H_s and ε_r respectively. The antenna was fed with a probe at a point W/2 and F away from the left and lower end of the antenna. Figure 3 shows schematics of the patch antenna. However, the goal of this research is to construct a model that will generate similar radiation pattern when compared to the original antenna.

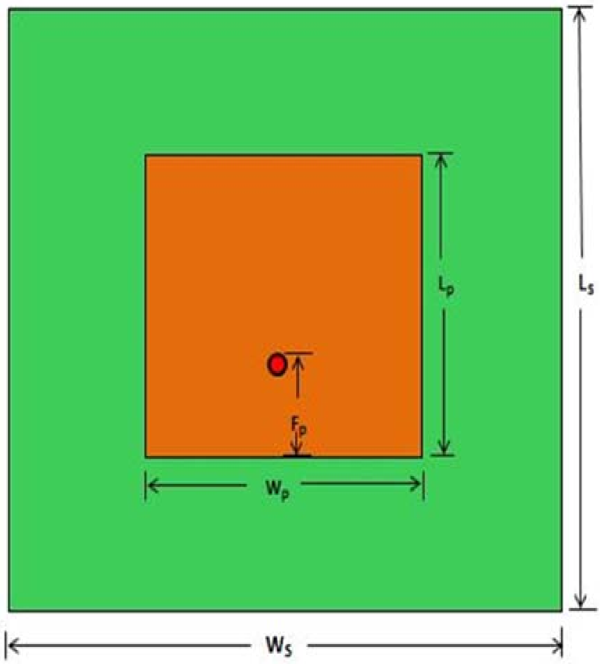

Fig. 3. Schematics of the Patch Antenna

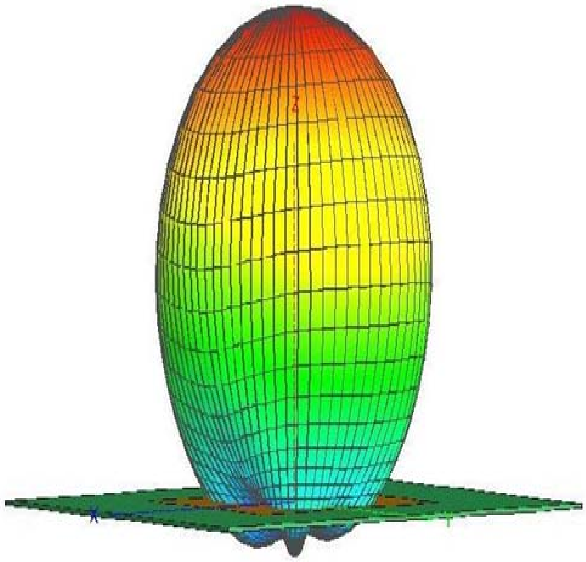

Fig. 4. Three-Dimensional plot of the Patch Antenna

V. Initial Model of the Patch Antenna

A magnetic dipole is implemented above the same ground plane to that of the patch antenna. A 2 ×2 dipole array was employed as shown in Figure 5.

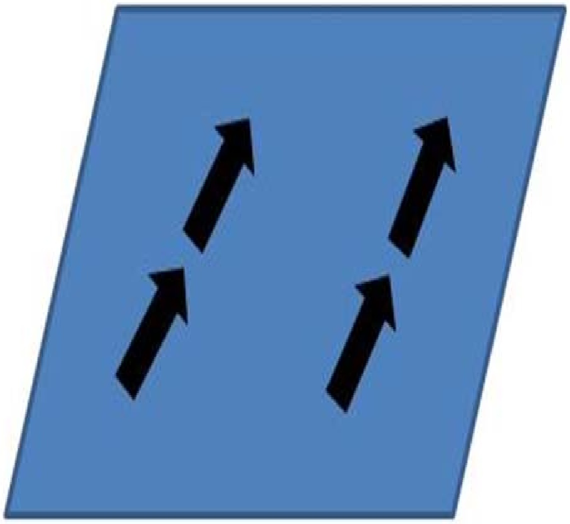

Fig. 5. 2X2 magnetic array dipole

VI. Optimization Method

FEKO is a computational electromagnetics (CEM) tool used widely in telecommunications, automobile, aerospace and defense industries. FEKO offers several frequency and time domain EM solvers under a single license. Hybridization of these methods enables the efficient analysis of a broad spectrum of EM problems, including RF components and biomedical systems, the placement of antennas on electrically large platforms as well as the investigation of electromagnetic compatibility (EMC). The FEKO solver is fully parallelized, and optimized to exploit multi-CPU distributed memory resources. FEKO is GPU-based solver acceleration. FEKO is an Optimized out-of-core solver to deliver solutions when RAM limits are reached. FEKO optimization tool has an advantage of fully automated optimization of multi-variable and multi-goal problems with several algorithms, including GA and particle swarm including a Real-time monitoring of the optimization process [9]. According to the proposed initial model, the positions (*x*- and *y*-directions) of the dipoles were the parameters needed to be optimized. The objective is to determine the optimal positions that will generate a radiation pattern that closely matches the pacth antenna's radiation pattern. To build an equivalent model with optimization technique, the FEKO optimization tool is employed. The optimization goal was defined by feeding the radiation details termed mask. The variables to be optimized were defined. The upper and lower values of the variables were chosen as well as the start value. The optimization process performs the optimization search to find the line of best fit by match the values of the equivalent model with the antenna at every angle in order to obtain an approximate fit. Thereafter, a plot was generated. The arrangement of the magnetic dipoles after optimization is shown in Figure 6

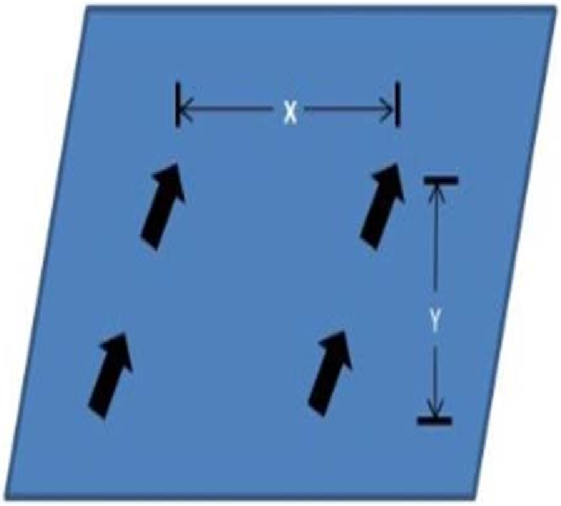

Fig. 6. Arrangement of magnetic dipoles afterv optimization

VII. Optimization Method

FEKO provides different optimization methods, each with specified characteristics. It is not a trivial task to select a suitable method for a given problem by specifying the function, range of the parameters, the required output of the optimization, the size of the model and the available resources. The methods available in FEKO are discussed below.

A. *Simplex Nelder-Mead*

The Simplex Nelder-Mead Optimization is a well-known local or hill-climbing search method. The final optimum relies mainly on the specified starting point. Simplex is a term that denotes the geometric figure of a set of N+ 1 point in an N-dimensional space. The aim of the Simplex method is to compare the values of the combined optimization goals at the N+1 points of a general simplex to wheel the movement of the simplex close to the optimum point during an iterative process. This movement is actualized by reflection, expansion and contraction operations [10].

B. *Particle Swarm Optimization (PSO)*

Particle Swarm Optimization is a stochastic evolutionary computation technique which is based on the operation and intelligence of swarms. A swarm of bees in a field is the best analogy by which the operation of the PSO method can be best understood. It aims at locating a segment with the highest density of flowers. The bees begin to look for flowers from random locations with random velocities without any prior knowledge of the field. Based on its own experience gained (local best) and the best position known (global best) found, each bee adjusts to fly to some point between the two points. At some point, the whole swarm would be attracted to that location together with the point of individual's personal best ascertainment. After all, the bees' flight directs them to the one same point in the field where the highest flower density is accumulated [10].

C. *Genetic Algorithm (GA)*

Genetic algorithm is a concept of natural selection and evolution. GA's are classified as global optimization algorithm. GA optimization conceptualizes from the natural world biological mutations. GA optimization is a set of generational selection, crossover and mutation. The GA process is model to fit the concept of the parent and children derivation. The fitness and goal function is synonymous to survival of the fittest type process [10].

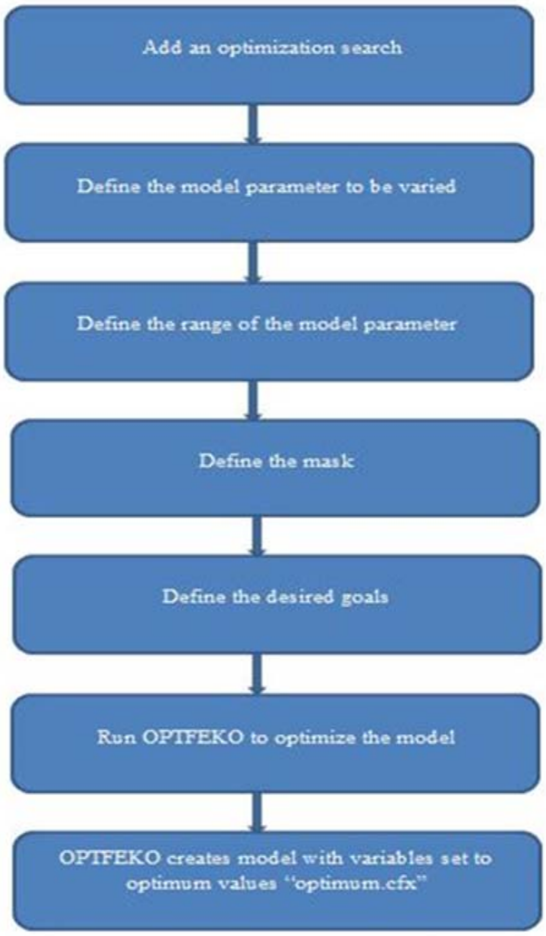

Fig. 7. Workflow in definding an optimization search in CADFEKO

For each optimization search, Far field Goals were defined to specify the desired state the optimization process should attempt to achieve. The Far field goal makes provision for optimization relating to all far field quantities computed as FEKO solution. The focus is identified based on Far field label request in CADFEKO. Below is the flow chart of FEKO optimization adopted in this paper as shown in figure 7.

VIII. SIMULATION RESULTS

The simulation results show the effectiveness and advantages of the proposed equivalent model based on a magnetic dipole. The antenna's radiation pattern is first generated by FEKO and was further used to construct the initial model of the antenna. The initial model was then optimized to construct the equivalent model of the antenna via FEKO optimization technique. The derived equivalent model was finally validated by matching its radiation pattern with that of the antenna. The parameters are described in Table II with the operating frequency of 1GHz. Good agreement could be observed between the E- and H-plane radiation pattern of the patch antenna and its equivalent model. It was observed that its radiating performance is close to that of the patch antenna in Figure 8 and figure 9. It was observed from the result that an optimum width of the backward radiation was obtained.

TABLE I. PARAMETERS OF FOR PATCH ANTENNA

Patch (cm)	**Substrate (cm)**	**Probe (cm)**	**HPBW (Deg)**	**Directivity**	**Permitivity**
Pl *Pw*	*Sl* *Sw* *Sh*	*F*	*E-* *H-*	*Dir(dBi)*	*Epsr (er)*
9.9 11.858	18 20 0.15	3.21	80.2 74.5	6.75	2.2

TABLE II. OPTIMIZATION PARAMETERS OF THE EQUIVALENT MODEL OF THE PATCH ANTENNA

Dipole (cm)	**GND Plane (cm)**	**Spacing (cm)**	**HPBW (Deg)**	**Directivity(dBi)**
L *H*	*Sl* *Sw*	*X* *Y*	*E-* *H-*	*Dir*
1.8 0.6	18 20	5 4.5	80.2 74.3	6.75

TABLE III. COMPARISON OF MEMORY AND CPU COST BY DIFFERENT MODELS

Antenna Model	**Number of Unknowns**	**CPU Time(S)**	**Memory Cost**
Original patch model	8,422	56.784	261.189 MB
Equivalent model	237	1.669	515.734 KB

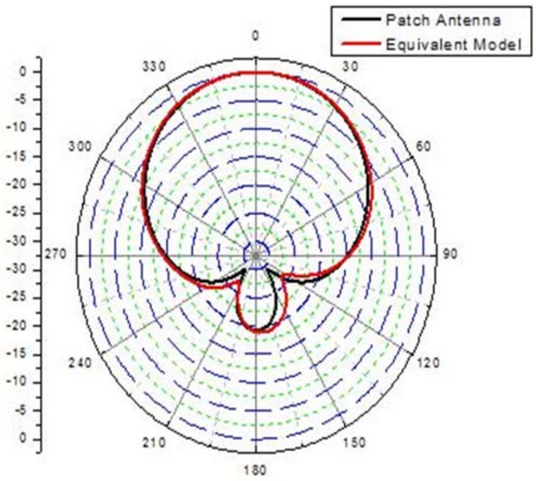

Fig. 8. Normalized radiation pattern of patch antenna and its equivalent model for E-plane

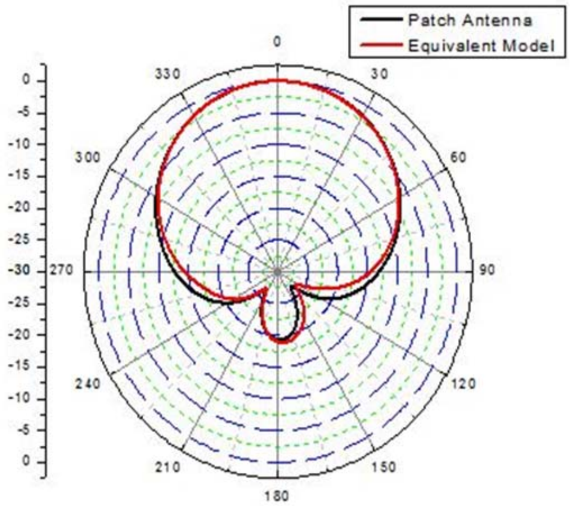

Fig. 9. Normalized radiation pattern of patch antenna and its equivalent model for H-plane

The simulation results show good agreement especially for the forward radiation on the upper direction. Although there is some difference in the backward radiation, the results are still satisfactory in view of the low radiation level. This proposed method is efficient for fast prediction of the antenna's radiation pattern.

IX. Comparison Efficiency

Summary of the CPU time and memory cost is presented in table III for the simulation of the original model and proposed model. It is observed that both the CPU time and memory cost is considerable reduced using the equivalent model. However, the complex geometry of the antenna may sometimes lead to ill-conditioned matrix during direct modeling. This ill-condition usually increases the memory cost. The equivalent model reduces memory cost and saves time due to its simplicity of geometry and PEC material details.

Conclusion

The proposed equivalent model of patch antenna based on a magnetic dipole is an efficient way of predicting radiation patterns of patch antennas. Two parameters of the equivalent model were optimized by the FEKO optimization tool to match the patch antenna's radiation pattern and the equivalent model which makes it more efficient than previous methods. The key feature of the proposed model is the magnetic dipole implementation for fast modeling of an equivalent model of the antenna. The spacing positions of the dipoles were the parameters optimized by the optimization technique to match the patch antenna‘s radiation pattern of the and the equivalent model.

Future Work

The above proposed model has huge benefits in biomedical, wearable devices etc. The derived equivalent model based on a magnetic dipole could be mounted on different platforms to compute and predict its installed radiation pattern which will be considered in future work. Multiple frequencies can be considered in future work

References

[1] T. S. Sijher and A. A. Kishk, "Antenna modeling by infinitesimal dipoles using genetic algorithms," Progr. Electromagn. Res., vol. PIER 52, pp. 225–254, 2005.

[2] S. M. Mikki and A. A. Kishk, "Theory and applications of infinitesimal dipole models for computational electromagnetics," IEEE Trans. Antennas Propag., vol. 55, no. 5, pp. 1325–1337, May 2007.

[3] C. D. Giovampaola, E. Martini, A. Toccafondi, and S. Maci, "A hybrid PO/ generalized-scattering-matrix approach for estimating the reflector induced mismatch," IEEE Trans. Antennas Propag., vol. 60, no. 9, pp. 4316–4325, Sept. 2012.

[4] X. Wang, Z. Peng, K.-H. Lim, and J.-F. Lee, "Multisolver domain decomposition method for modeling EMC effects of multiple antennas on a large air platform," IEEE Trans. Electromagn. Compat., vol. 54, no. 2, pp. 375–388, Apr. 2012.

[5] A. Barka and P. Caudrillier, "Domain decomposition method based on generalized scattering matrix for installed performance of antennas on aircraft," IEEE Trans. Antennas Propag., vol. 55, no. 6, pp. 1833–1842, June 2007.

[6] A. Barka, "Integration of antennas onboard vehicles and diffraction by large and complex structures with multipledomain–multiple-methods techniques," Proc. IEEE, vol. 101, no. 2, pp. 280–297, Feb. 2013.

[7] Z. Peng, K.-H. Lim, and J.-F. Lee, "Nonconformal domain decomposition methods for solving large multiscale electromagnetic scattering problems," Proc.IEEE, vol. 101, no. 2, pp. 298–319, Feb. 2013.

[8] S.P. Gao, B. Wang, H. Zhao, W.J. Zhao, C.E. Png " Installed radiation pattern of patch antenna: Predictive based on a novel equivalent model" IEEE Antenna and Propagation Magazine Vol. 57, pp. 81-94, 2015

[9] https://altairhyperworks.com/product/FEKO

[10] https://www.researchgate.net/publication/266462315_FEKO_Optimization_Capabilities_Simplex_Particle_SwarmGenetic_Algorithm

[11] Si-Ping Gao, Huapeng Zhao, Binfang Wang and Wei-Jiang Zhao, "Analysis of antennas on large platforms using equivalent model method," *2016 Progress in Electromagnetic Research Symposium (PIERS)*, Shanghai, 2016, pp. 128-128. doi: 10.1109/PIERS.2016.7734266

[12] A. V. Nerobeev, A. N. Yakimov, A. R. Bestugin and I. A. Kirshina, "Radiation investigation of the antenna array, taking into account vibration actions," *2018 Systems of Signals Generating and Processing in the Field of on Board Communications*, Moscow, 2018, pp. 1-4. doi: 10.1109/SOSG.2018.8350624