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EVALUATION OF CAPACITANCE OF CONDUCTING BODIES FOR ELECTROMAGNETIC MODELING

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ABSTRACT

This paper represents the evaluation of capacitance of different conducting bodies are calculated using finite element method (FEM). There are different numerical methods like Finite Difference method, Method of Moment and Monte Carlo methods. But the finite element method has more advantages. The surfaces are discretized using triangular subsections. Finite element method is a suitable method for computation of capacitance in metallic surface. The accurate estimation of electrical parameters is essential for Electromagnetic modeling and Antenna design. In this paper, capacitance of the square plate, rectangular plate, elliptical plate and circular plate are computed using finite element method. For simulation COMSOL multiphysics software was used. FEM is suitable and efficient method for computation of electrical parameters. We evaluate some of our simulation results with other available results in the literature and good matching the results.

Keywords: capacitance, antenna design, circular plate, finite element method, metallic surface, rectangular plate, square plate.

INTRODUCTION

Computational electromagnetics (CEM) well-defined as the branch of electromagnetics that involves the usage of computers to simulate electric and magnetic fields produce in definite environments. In this work we address the CEM problem of calculating, as accurately as possible, the electromagnetic behavior of a two-dimensional conducting structure. Such models can be applied to a large variety of industrial uses. Design and placement of transmitting or receiving antennas and aircraft technologies, are a few examples. Computational electromagnetics simulations are conducted to assist the analysis of the radar signature of an aircraft, either during the design or at manufacturing stages. Ultimately they aim to replace very expensive and time consuming measurements.

The Electromagnetic modeling and design of antenna systems has been the subject of extensive research in the last three decades. While in the past, antenna design may have been considered a secondary issue in overall system design, today it plays a critical role in spacecraft. Today, space expansion and manufacture have rapidly increased. This has led to significant interest in the evaluation of the electrical parameters such as capacitance of different conducting structures located in free space due to their use in spacecraft. For example, the capacitance has been used in determination of spacecraft equivalent circuit models for the predication electrostatic discharge. Therefore, the improvement of accurate and efficient computational method to analyze the modeling of various forms such as rectangular, cylindrical, and triangular becomes an important area of interest in spacecraft technology.

In fact, many system successes rely on the design of the antenna. Antennas involved in modern spacecraft are often composed of metallic parts of arbitrary – shaped and with arbitrary curvature. The high operating frequency causes electromagnetic interactions within integrated circuits. The accurate evaluation of charge distribution and capacitance of metallic structures is an important step in design of these high frequency integrated circuits. In this paper, it has been chosen the triangular shape of the subdomains because of its ability to conform easily to any geometrical surface or shape and at the same time to maintain simplicity of approach compared to the another shaped modeling. The determination of square plate and rectangular plates are has already been performed (Sadiku M. N. O., 2007). The capacitances of square plate, rectangular plate, elliptical plate and circular plate are compared with other available data in literature (Balsami Karthikeyan *et al.* 2013).

FINITE ELEMENT METHOD

The finite element method is simpler and easier method compare to other methods like the finite difference method (FDM) and the method of moments (MOM). Finite element method is a more powerful and versatile numerical technique for handling electromagnetic problems involving complex geometries and inhomogeneous media. The systematic generality of the method makes it possible to construct general-purpose computer programs for solving a wide range of problems.
The finite element method is nowadays widely used in industrial applications, including aeronautical, aerospace, automobile, naval and nuclear construction. A number of general-purpose computer codes are available for industrial users of the finite element method (Jin 2002).

The accurate valuation of charge distribution and capacitance of metallic constructions is an important step in design of Antenna design. In this paper, the subdomains

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of any geometrical surface or shape and at the same time to maintain simplicity of approach compared to another shaped modeling. The finite element method is based on the transformation of partial differential equation, into a matrix equation by employing expansion of the unknown basis functions with unknown coefficients such as charge distribution and the capacitance computed. A computer programs based on the preceding designs has been established to determine the charge distributions hence capacitance of the conducting structures.

There are remarkable attentions in the approximation of capacitance of different conducting bodies such as cylinder, cube, cone, elliptical, sphere, pyramid and tetrahedron. The finite element method is one of the widely used numerical techniques in use for the solution a variety of difficulties formulated in the form of partial differential equations.

The estimation of the capacitance of several structures like three-dimensional spherical, cone and cylindrical surfaces and in two-dimensional square, rectangular and circular metallic plate has been considered using the finite element method. The capacitance of the different geometrical frames was obtained by subdividing the structure into uniform triangular subsections and calculating the effect of the charge on each subsection on the potential of the others. The use of triangular subsection in a curved boundary needs a very fine meshing in order to obtain convergence for the data of the capacitance and charge distribution.

The aim of this paper is to compute the capacitance of simple geometries like rectangular plate, square plate, elliptical plate and circular plate by using finite element method. The first geometry to study is a rectangular plate with that there is validated the mesh and the loop of calculation. The second geometry is square plate with a length of the edge is 1m formed and the capacitance calculated. In the third geometry circular plate with a radius of 1m is validated the mesh and the capacitance computed.

We use COMSOL multiphysics software for designing square plate, rectangular plate and circular plate for simulation. COMSOL multiphysics is a software package used in modeling and simulation of electrostatic problems. The models are designed in two-dimensional modelling using electrostatic condition in order to compare our results with some of other available results. Many industrial applications depend on electromagnetic modeling and simulation. Simulation of metallic plates is very useful for Electromagnetic Analysis and Antenna Design. COMSOL has high speed computation and also high speed accuracy. The capacitance values are computed for several cases such as with respect to variation in number of segments and variation in objects.

SIMULATION MODELS

Rectangular plate

In this section, we demonstrate the modelling of rectangular plate by finding capacitance of the unit length. The geometry is 4 x 1 m^2 rectangular plates and the top of the plate has a specified voltage of 1V and the bottom of the plate is specified as ground with a voltage of 0V. It is assumed that the rectangular plates are made of highly conductive material, that total effective resistive value much lower. The input voltage of V=1V is applied for simulation. When the unit voltage is applied to the object that stores electrical energy when a voltage difference is applied voltage squared and is computed by the capacitance of the object. The model presents a model of simple capacitor resolved for under electrostatic condition. Under the hypothesis of electrostatic condition, the entire surface of each conductor must be at the same potential, otherwise current would flow through these conductors.

From the model, we generate more number of subsection like the finite element mesh with 156 domain elements and 38 boundary elements as shown in Figure-1. Figure-2 shows 2D surface potential distribution. The potential distribution models allow the better understanding of potential distribution of metallic object.

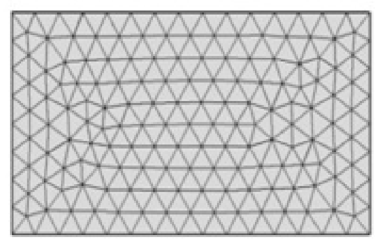

Figure-1. Rectangular plate divided into subsection.

Figure-2 shows the potential distributions of inhomogeneous media of metallic rectangular plate. The potential distribution is uniform between the plates, but differences are seen at the ends of the plates. The potential distribution shows that top edge of the rectangular plate having more current flow compare to bottom of the rectangular plate.

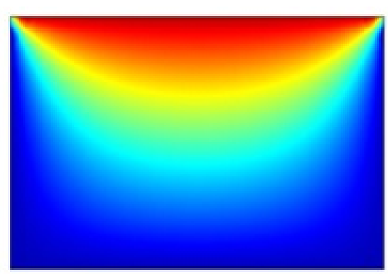

Figure-2. Potential distribution of rectangular plate.

The capacitance values are computed for several cases such as with respect to variation in number of domain elements and boundary elements. The results are tabulated in Table-1. The capacitance value 54.18pF is

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obtained for the total number of 156 triangular subsections is compared with the value obtained from the previous result. As obvious with the increase in number of segments, the results tend to converge and the deviation in analytical and numerical results reduces.

Table-1. Capacitance of a rectangular plate.

Number of domain elements	Number of boundary elements	Capacitance (pF)
30	16	48.23
54	20	50.51
68	26	52.81
156	38	54.18

In this simulation we consider four different subsections are analyzed. In this analysis the values of capacitance are good matching with the published results (Ghosh, 2008).

Square plate

To validate the methodology, square plate was consider for the analysis. Figure-3 shows a square plate of 1 m^2 with triangular subsection and the top of the plate has a specified voltage of 1V and the bottom of the plate is specified as ground with a voltage of 0V. The modelling realization of the perfectly insulating surface in the zero charge boundary condition. This boundary condition implies that the electric field are tangential to the boundary.

The plate is divided into equal subdivisions on both axes. The total number of triangle subsection is 928 elements. We generate the finite elements mesh with 928 elements as shown in Figure-3. Figure-4 shows the 2D surface distribution of the model.

The capacitance values are computed for several cases such as with respect to variation in number of domain elements and boundary elements for 1 x1 m^2 square plate. The results are tabulated in Table-2. The capacitance values are compared with the value obtained from other published papers for variation in number of segments.

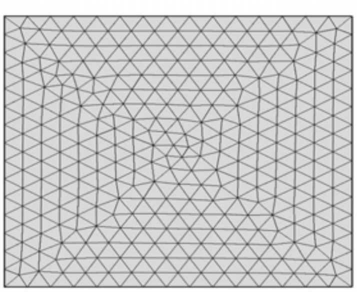

Figure-3. Square plate divided into subsection.

Figure-4 shows the potential distributions of inhomogeneous media of metallic square plate. The potential distribution is uniform between the plates, but differences are seen at the ends of the plates. The potential distribution shows that top edge of the square plate having more current flow compare to bottom of the square plate.

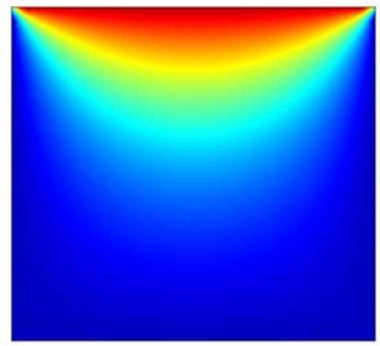

Figure-4. Surface potential distribution of square plate.

The capacitance values are computed for several cases such as with respect to variation in number of domain elements and boundary elements. The results are tabulated in Table-2. The capacitance value 40.31pF is obtained for total number of 928 triangular subsections and compared with the value obtained from analytical formula for variation in number of segments. As obvious with the increase in number of segments, the results tend to converge and the deviation in analytical and numerical results reduces.

Table-2. Capacitance of a square plate.

Number of domain elements	Number of boundary elements	Capacitance (pF)
166	32	36.56
268	40	39.08
578	60	40.65
928	76	40.31

In this paper we consider four different subsections are analyzed. In this analysis the values are good matching with the published results (Karthikeyan, 2013).

Circular plate

In this section, we demonstrate the modelling of circular plate by finding capacitance of the unit length. The capacitance values are computed for several cases such as with respect to variation in number of domain elements and boundary elements in circular plates. The results are tabulated in Table-3.

Figure-5 shows metallic circular plate of radius1m with triangular subsection and the top of the plate has a specified voltage of 1V and the bottom of the plate is specified as ground with a voltage of 0V. It is assumed that the circular plates are made of highly conductive material, that total effective resistive value

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much lower. The input voltage of V=1V is applied for simulation. When the unit voltage is applied to the object that stores electrical energy when a voltage difference is applied voltage squared and is computed by the capacitance of the object. Under the hypothesis of electrostatic condition, the entire surface of each conductor must be at the same potential, otherwise current would flow through these conductors. We generate the finite elements mesh with 926 elements as shown in Figure-5.

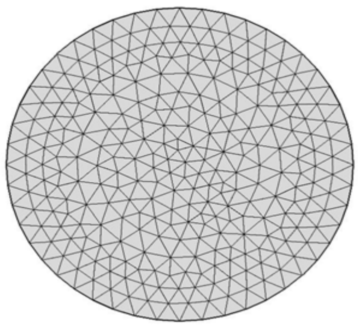

Figure-5. Circular plate divided into subsection.

Figure-6 shows the potential distributions of inhomogeneous media of metallic circular plate. The potential distribution is uniform between the plates, but some differences are seen at the ends of the plates. The potential distribution shows that top edge of the circular plate having more current flow compare to bottom of the circular plate.

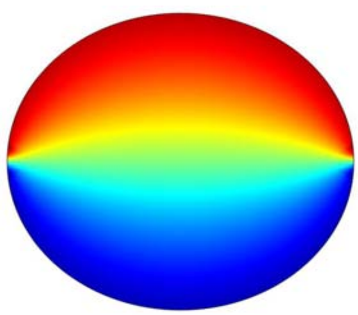

Figure-6. Surface potential distribution of circular plate.

The capacitance values are computed for several cases such as with respect to variation in number of domain elements and boundary elements. The results are tabulated in Table-3. The capacitance value 70.71pF is obtained for total number of 926 triangular subsections and compared with the value obtained from analytical formula for variation in number of segments. As obvious with the increase in number of segments, the results tend to converge and the deviation in analytical and numerical results reduces.

Table-3 shows the finite element method results for the capacitance per unit length of circular plate compare with the previous work. The results are good agreement with previous results.

Table-3. Capacitance of a circular plate.

Number of domain elements	Number of boundary elements	Capacitance (pF)
250	32	68.81
546	48	69.45
926	60	70.71

In this paper we consider three different subsections are analyzed. In this analysis the values are good matching with the published results (Ghosh, 2008).

Elliptical plate

In this section, we demonstrate the modeling of elliptical plate by finding capacitance of the unit length. The capacitance values are computed for several cases such as with respect to variation in number of domain elements and boundary elements in elliptical plate. The results are tabulated in Table-4.

Figure-7 shows metallic elliptical plate of radius 1m with triangular subsection and the top of the plate has a specified voltage of 1V and the bottom of the plate is specified as ground with a voltage of 0V. It is assumed that the elliptical plates are made of highly conductive material, that total effective resistive value much lower. The input voltage of V=1V is applied for simulation. When the unit voltage is applied to the object that stores electrical energy when a voltage difference is applied voltage squared and is computed by the capacitance of the object. Under the hypothesis of electrostatic condition, the entire surface of each conductor must be at the same potential, otherwise current would flow through these conductors. We generate the finite elements mesh with 266 elements as shown in Figure-7.

The capacitance values are computed for several cases such as with respect to variation in number of domain elements and boundary elements. The results are tabulated in Table 4. The capacitance value 65.82pF is obtained for total number of 266 triangular subsections and compared with the value obtained from analytical formula for variation in number of segments. As obvious with the increase in number of segments, the results tend to converge and the deviation in analytical and numerical results reduces.

Table-4. Capacitance of an elliptical plate.

Number of domain elements	Number of boundary elements	Capacitance (pF)
164	24	64.84
214	48	65.06
266	52	65.82

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In this paper we consider three different subsections are analyzed. In this analysis the values are good matching with the published results (Rizwan, 2012).

RESULTS

In the present study, the rectangular, square, elliptical and circular plate models are designed in two-dimensional (2D) modeling using electrostatic environment in order to compare our results with some of the other available methods. The results of various geometry are summarized in Table-5 and compare with the previous results. Using finite element method most accurate value obtained. The procedure outlined using triangular subsection most accurate value obtained.

Table-5. Comparison of capacitance.

Geometry	C in pF (Present Method)	C in pF (Previous results)
Rectangular plate	54.18	54.73(Ghosh,2008)
Square plate	40.31	40.34(Karthikeyan,2013)
Circular plate	70.71	70.73(Ghosh,2008)
Elliptical plate	65.82	66.02(Rizwan, 2012)

CONCLUSIONS

In this paper, a simple and efficient numerical technique based on Finite Element Method is presented for the estimation of capacitance of different conducting plates analyzed. The conducting bodies are divided into triangular subsections. We calculated the capacitance per unit length of square plate, rectangular plate and circular plate for simulation. Some of the results obtained efficiently using finite element method with COMSOL multiphysics software. The result found from COMSOL multiphysics simulation software good matching with earlier results. So this method is more appropriate for Electrostatic modeling and Antenna design.

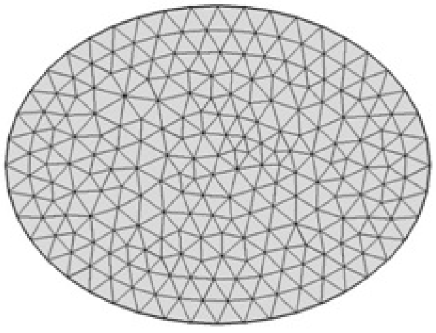

Figure-7. Elliptical plate divided into subsection.

Figure-8 shows the potential distributions of inhomogeneous media of metallic elliptical plate. The potential distribution is uniform between the plates, but some differences are seen at the boundaries of the plates. The potential distribution shows that top edge of the elliptical plate having more current flow compare to bottom of the elliptical plate.

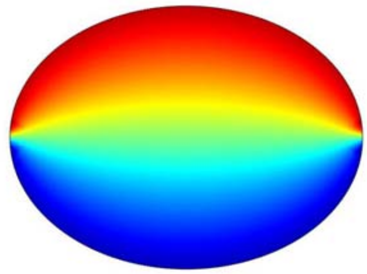

Figure-8. Surface potential distribution of elliptical plate.

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