Understanding Capacitance of Multi-Layer Capacitors

Physics

Capacitance is a fundamental concept in physics, defined as the ratio of the amount of charge stored in a capacitor to the potential difference between its electrodes. Let's consider an example of a parallel-plate capacitor, as shown in Figure 1. In this example, the capacitor is constructed by filling the space between two square plates with blocks of three different dielectric materials.
The capacitance of each dielectric block is determined by the equations (1), (2), and (3):

$$ C_1 = \frac{K_1 \epsilon_0 A_2}{d} $$ (eq.1)

$$ C_2 = \frac{K_2 \epsilon_0 \frac{A}{2}}{\frac{d}{2}} $$ (eq.2)

$$ C_3 = \frac{K_3 \epsilon_0 \frac{A}{2}}{\frac{d}{2}} $$ (eq.3)

K_1, K_2 and K_3 are the dielectric constants of individual dielectric materials, ϵ_0 is the permittivity of free space, A is the capacitor plate area and d is the distance between the plates. Figure 1 shows that the total capacitance is formed by connecting a capacitance of the dielectric block K_1 in parallel with a series connection of blocks K_2 and K_3. Therefore, the equivalent capacitance is given by equation (4) as:

$$ C = C_1 + \left(\frac{1}{C_2} + \frac{1}{C_3} \right)^{-1} = C_1 + \frac{C_2 C_3}{C_2 + C_3} = \frac{K_1 \epsilon_0 A}{2d} + \frac{\epsilon_0 A}{d} \left(\frac{K_2 K_3}{K_2 + K_3} \right) = \frac{\epsilon_0 A}{d} \left(\frac{K_1}{2} + \frac{K_2 K_3}{K_2 + K_3} \right) $$ (4)

***Figure1** - parallel plate capacitor with three dielectrics*

With the following parameters:
$d = 2 \, \text{mm}, \quad l = 100 \, \text{mm}$
$A = 100 \, \text{mm} \times 50 \, \text{mm} = 5000 \, \text{mm}^2$
$K_1 = 1.93, \quad K_2 = 3.25, \quad K_3 = 4$
The equivalent capacitance is: $C = 6.1050 \times 10^{-11} \, \text{F}$

Model

The following instructions show how to prescribe material to individual parts of your model and compute capacitance between two elements.
A model of the capacitor with multiple dielectrics has been created in Solidworks. The space between the parallel plates is filled by 3 different dielectric materials. The plate surface is $50 \times 100 \, \text{mm}^2$, while the thickness of each plate is 1mm. The thickness of the dielectric block K_1 is the same as the distance between the plates: 2mm; the thickness of the blocks K_2 and K_3 is

half of that:1mm (Figure 2).

The simulation is performed in the EMS **Electrostatic study** . Aluminum is used as a material for the electrode plates, Teflon, polyimide, and nylon are used for dielectric $$ K_1 $$,$$ K_2 $$and $$ K_3 $$, respectively. All these materials with their electromagnetic properties can be found in the EMS material library.

Assign material

To define the material for the Dielectric 1:

1. Under Materials in the EMS manager tree, right-click on Dielectric 1.
2. Select **Apply Material**
3. The **Material Browser** folder appears
4. Under “Cables” folder, choose Teflon
5. Click **Apply and Close** 

This procedure is repeated to assign Polyimide and Nylon to Dielectrics 2 and 3, as well as to assign Aluminum to the plates.

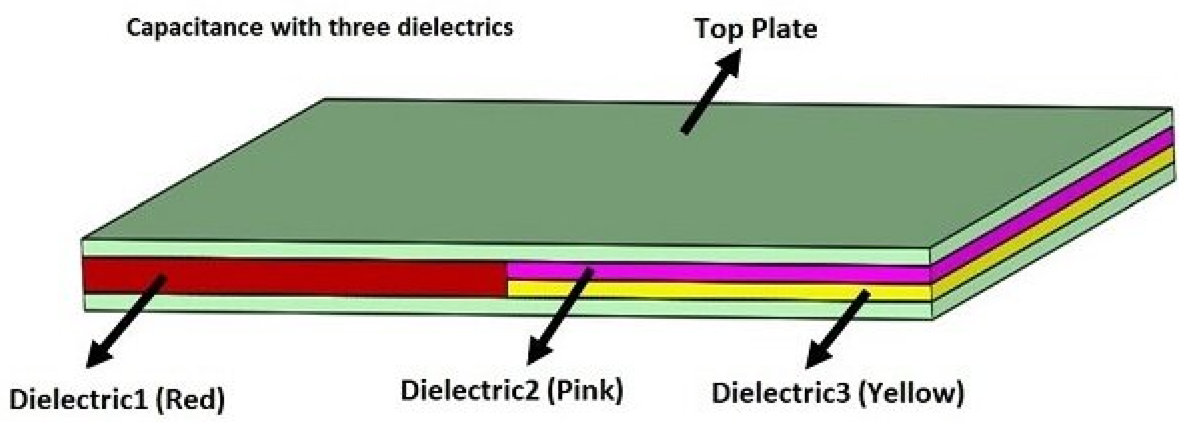

Figure 2 *- Solid works model of a capacitor with 3 dielectrics*

Compute capacitance

To obtain capacitance results from EMS:

1. In the EMS manger tree, Right-click on the **Electrostatic study** folder.

2. Select **Properties** 

3. Under **General Properties**, check **Compute Capacitance** box

4. Click OK  .

Boundary Conditions

To account for the capacitance, a Floating conductor boundary condition is assigned to both plates. To do so:

1. In the EMS manager tree, Right-click on the **Load/Restraint**  folder.

2. Select **Floating Conductor**  .

3. Click inside the **BodiesSelection**  box and then select the **Topplate**.

4. Click OK.

For the bottom plate:

1. In the EMS manger tree, Right-click on the **Load/Restraint** folder.

2. Select **Floating Conductor** .

3. Click inside the **BodiesSelection** box and then select the **Bottom plate**.

4. Click OK.

Results

In the EMS manager tree, under **Results** , open the **Results Table** to find the Capacitance matrix. EMS solution for total capacitance is 6.1056×10^{-11} F (Figure 3) and it matches the theoretical result very closely.

	Floating Conductor - 1	Floating Conductor - 2
Floating Conductor - 1	6.1056e-011	-6.1056e-011
Floating Conductor - 2	-6.1056e-011	6.1056e-011

Figure 3 - *EMS results for Capacitance*

Conclusion

This application note explores the concept of capacitance through the simulation of a parallel-plate capacitor filled with three different dielectric materials in EMS. By employing the superposition principle, the study calculates the capacitance contributed by each dielectric block and the total equivalent capacitance of the system, showcasing the impact of dielectric constants on the capacitor's overall capacitance. The simulation, created in SolidWorks and analyzed in an EMS Electrostatic study, utilizes materials like aluminum for electrodes and Teflon, polyimide, and nylon for the dielectrics. The process involves assigning materials, computing capacitance, and setting boundary conditions to accurately model the capacitor's behavior.
The findings from EMS closely align with theoretical calculations, demonstrating the software's effectiveness in predicting the capacitor's performance. The total capacitance obtained from the simulation is 6.1056×10^{-11} F, validating the theoretical approach. This study not only reinforces the fundamental principles of capacitance but also illustrates the practical application of simulation tools in understanding and analyzing complex electrical systems. Through detailed modeling and precise simulations, EMS proves to be a valuable tool in the design and analysis of capacitive systems, offering insights that bridge theoretical physics with practical engineering solutions.