International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

Influence of Variable Plate Separation on Fringing Electric Fields in Parallel-Plate Capacitors

Tejveer Singh Dhingra

Abstract: ***The influence of variable plate separation on fringing electric fields in parallel plate capacitors was investigated. The experiment to deduce a conclusion with given controlled and dependent variables was completed at The Doon School, Dehradun under normal conditions.***

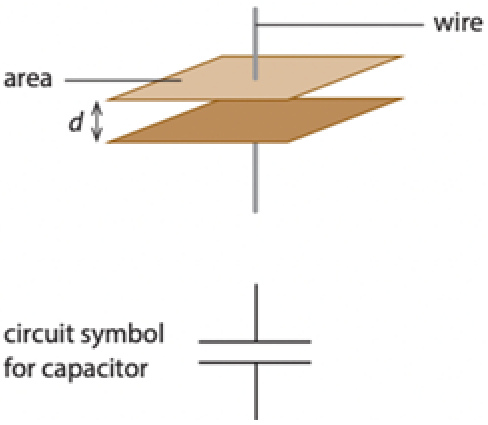
1. Introduction

Any arrangement of two conductors separated from each other by insulating material (or a vacuum) is called a **capacitor**. The capacitor is capable of storing electric charge and, as we will see, electrical energy. Electric field lines are formed between the two plates from the positive to the negative charges. The polarisation of the dielectric material of the plates by the applied electric field increases the capacitor's surface charge proportionally to the electric field strength in which it is placed. When a voltage is applied between the two conductive plates, a uniform electric field between the plates is created.

Capacitance depends on the geometry of the capacitor. For the parallel plate capacitor:

$$C = \varepsilon_0 \frac{A}{d}$$

where A is the area of one of the plates, d the separation of the plates and ε the permittivity of the medium between the plates. If the plates are in a vacuum, then $\varepsilon_0=8.85\times10^{-12}\mathrm{Fm}^{-1}$.



Discussing an ideal parallel-plate capacitor, σ usually denotes the area charge density of the plate as a whole - that is, the total charge on the plate divided by the area of the plate. There is not one σ for the inside surface and a separate σ for the outside surface. Or rather, there is, but the σ used in textbooks takes into account all the charge on both these surfaces, so it is the sum of the two charge densities.

$$\sigma = Q/A = \sigma(\text{inside}) + \sigma(\text{outside})$$

With this definition, the equation we get from Gauss's law is

$$E\ (\text{inside}) + E\ \text{outside} = \frac{\sigma}{\varepsilon_0}$$

where "inside" and "outside" designate the regions on opposite sides of the plate. For an isolated plate, Einside=Eoutside and thus the electric field is everywhere $\frac{\sigma}{2\varepsilon_0}$

If another oppositely charge plate is brought nearby to form a parallel plate capacitor, the electric field in the outside region (A in the images below) will fall to essentially zero, and that means

$$E\ \text{inside} = \frac{\sigma}{\varepsilon_0}$$

However, at the edges of the two parallel plates, instead of being parallel and uniform, the electric field lines are slightly bent upwards due to the geometry of the plates. This is known as the fringing or edge effect. The electrodes of a mechanical capacitor are considered to be parallel and the dimensions of the electrodes are much larger than the distance between them. In practical situations for microsensors and actuators, the dimensions of the mechanical electrodes are often comparable with the distance between them. Therefore, the capacitance between two parallel electrodes cannot be approximated with high accuracy. The capacitance caused by the side edges and even the back sides may play a significant role. The effect is often referred to as fringe effects. Due to fringe effects, the capacitance of a mechanical structure is larger than that calculated. Consider a structure of two parallel bars with its cross section, where the top plate is movable in the *z*-direction. The capacitance calculated by parallel-plate approximation is:

$$C = \frac{2al\varepsilon_0}{z}$$

where l is the length of the bars that is much larger than a, h and z. Due to the fringe effect, the capacitance between the bars, C, is always larger than C. Generally speaking, the exact value of the capacitance of a micromechanical capacitor cannot be found in a closed form and can only be calculated by numerical methods based on the Poisson equation (i.e., $\nabla^2 V = 4\pi\rho$, where ρ is the charge density) and appropriate boundary conditions.

2. Uses and Circuit

The dielectric does not allow the flow of electric current through it due to its non-conductive property. However, the atoms of the dielectric material get polarised under the effect of electric field of the applied voltage source, and thus there are dipoles formed due to polarisation due to which, a negative and positive charge get deposited on the plates of a parallel plate capacitor**.**

The accumulation of charges on the plates takes place due to which, a charging current flows through the capacitor until the potential difference between the plates equalises the source potential. A parallel plate capacitor can be defined as a device which is capable of storing electrostatic energy in the form of charge in the dielectric medium between the plates, and thus it can be visualised as equivalent to a rechargeable DC battery.

It behaves as open circuited when we connect a DC source across it, while it acts as a short circuit when we connect an AC source to it. The said property of a parallel plate capacitor makes it suitable for filtering of harmonics from AC supply. A parallel plate capacitor can be used for tuning purpose in electronic circuits for various applications. It is also used in various transducers applications. A capacitor can act as a source of capacitive reactive power, and thus it serves as an essential element in power system auxiliaries for improving the power factor of the system thereby, enhancing the stability of a system. The energy storing capacity of a magnetic field is higher as compared with an electric field and therefore not used for energy storage.

Relationship between separation and electric field

To derive a relationship between the distance between plates of a capacitor and the electric field and understand the influence of variable plate separation on fringing electric fields in parallel-plate capacitors I used the initially discussed formula.

$$C = \varepsilon_o \frac{A}{d}.$$

Using the equation of electric field where A = area and ε_o = the permittivity of free space or absolute permittivity or electric constant, represented by the Greek alphabet ε0. The Epsilon Naught value is constant at any part of the universe.

$$E = \frac{\sigma}{\varepsilon_o}$$

Then, using the formula $\sigma = \frac{q}{A}$

We substitute A from this formula into the electric field formula above, getting:

$$E = \frac{q}{A\varepsilon_o}$$

Changing the subject to ε_o, we get:

$$\varepsilon_o = \frac{q}{EA}$$

Therefore to get a relation between Distance (d) and Electric field (E) we substitute the derived equation for εo into the initial formula for distance - $d = \varepsilon_o \frac{A}{C}$.

Getting the equation for distance between plates in terms of charge, electric field and capacitance.

$$d = \frac{Q}{EC}$$

Where d = Distance between the plates of a parallel plate capacitor, Q = Charge, E = Electric field, and C = Capacitance.

The same formula can be derived by substituting the below formula of area in the initial formula.

$$A = \frac{q}{E\varepsilon_0}$$

This derived equation denotes that d and E are **inversely proportional.**

$$d \propto \frac{1}{E}$$

To prove the relationship between the distance between the plates and electric field, using a basic parallel plate capacitor setup without a dielectric, I varied the distance between the plates to measure the electric field while keeping the capacitance, charge and temperature constant. To understand - ***How does varying the distance between two plates affect the electric field?***

<u>Controlled Variables</u>
Capacitance (Farad), Charge of the capacitor (coulomb) and surrounding temperature (Kelvin)

<u>Independent Variables</u>
Distance between plates (cm)

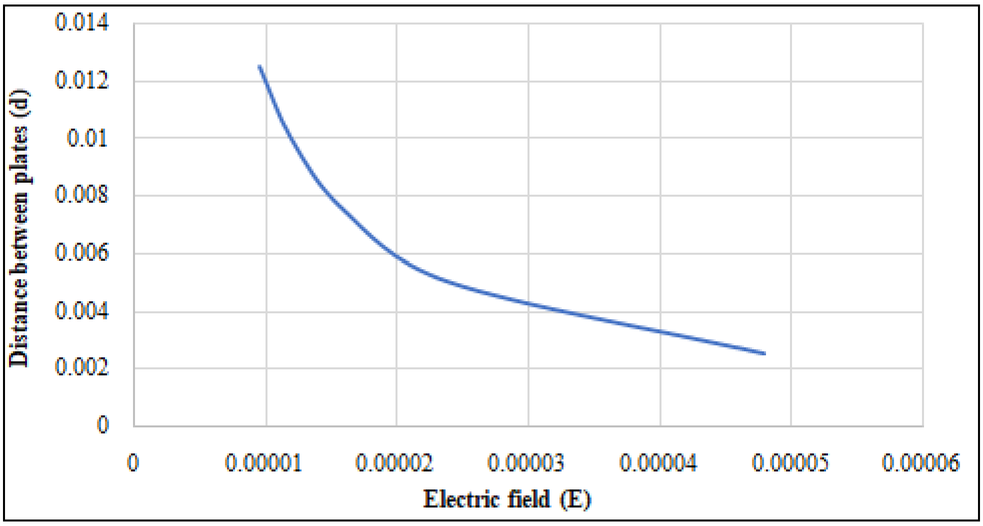
<u>Dependent Variables</u>
Electric Field between plates (V/m)

C = 500µF,
Q = 600nC

Raw data

Reading	Distance (d) (cm)	Electric field (E) (V/cm)
1.	0.25 cm	0.0048
2.	0.5 cm	0.0024
3.	0.75 cm	0.0016
4.	1 cm	0.0012
5.	1.25 cm	0.00096

Presenting data



3. Conclusion

As seen in the graph, the negative gradient shows an inverse relationship between the electric field in a parallel plate capacitor and distance between two plates of a plate capacitor.

References

[1] https://www.sciencedirect.com/topics/engineering/fringe-effect
[2] https://www.electrical4u.com/parallel-plate-capacitor/
[3] http://xn--webducation-dbb.com/wp-content/uploads/2019/11/K.-A.-Tsokos-Peter-Hoeben-Mark-Headlee-Physics-for-the-IB-Diploma-Coursebook-Cambridge-University-Press-2014.pdf
[4] https://phys.libretexts.org/Bookshelves/Electricity_and_Magnetism/Electricity_and_Magnetism_(Tatum)/05%3A_Capacitors/5.15%3A__Changing_the_Distance_Between_the_Plates_of_a_Capacitor
[5] http://www.fisica.uns.edu.ar/albert/archivos/124/368/3821191769_grove_ajp73_52_(2005).pdf