# Report of Electromagnetics Lab:
# MIM Capacitor and Magnetic Buzzer Using *ElectNet* and *MagNet*

**Course:** Electromagnetism (EEC 261)

Team Data

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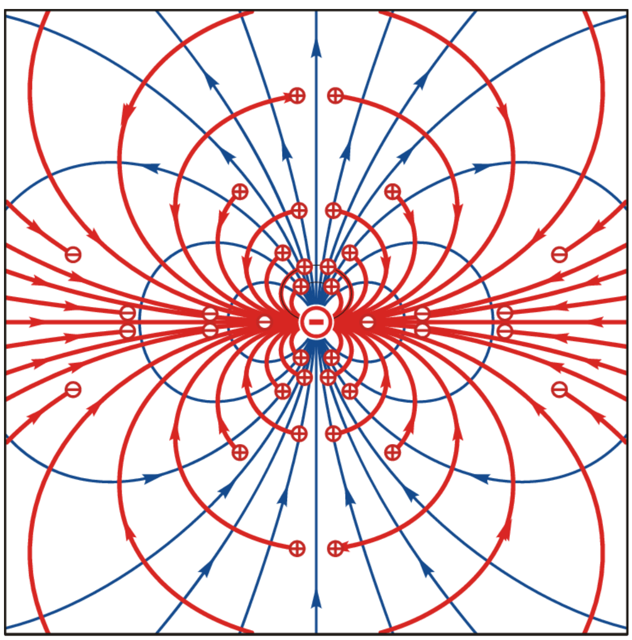


# Contents

# 1 Experiment 1: MIM capacitor

## 1.1 Introduction

ElecNet v7 is a 2D/3D electric field simulation software, based on the Finite Element Method (FEM). It is developed by the Canadian company Infolytica. ElecNet solves static, AC (time-harmonic) and transient electric field and current flow problems. Using ElecNet, the designers can model complicated devices and accurately predict their behavior.

Metal-Insulator-Metal (MIM) capacitors are fundamental components widely used in microelectronics and integrated circuits due to their ability to store and regulate electrical energy efficiently. These capacitors consist of two metal layers separated by an insulating material, forming a simple yet essential structure with diverse applications in various electronic systems.

Understanding the characteristics and behavior of MIM capacitors is crucial for optimizing their performance in different technological domains. The dielectric properties of the insulating layer, the choice of metals, and fabrication techniques significantly impact the capacitor's capacitance, voltage handling capacity

## 1.2 Capacitor types in RF citcuits

1. Metal-Oxide-Semiconductor (MOS) Capacitors: MOS capacitors are based on the MOS structure commonly used in CMOS technology. These capacitors consist of a metal electrode, an insulating layer (typically silicon dioxide), and a semiconductor substrate. MOS capacitors can be easily integrated into ICs and offer high capacitance density. They are widely used in RF circuits for applications such as impedance matching, tunable filters, and voltage-controlled oscillators. MOS capacitors can be adjusted by applying a voltage to the gate electrode, allowing for variable capacitance values.

2. Metal-Insulator-Metal (MIM) Capacitors: MIM capacitors are fabricated using a metal-insulator-metal structure. These capacitors offer excellent high-frequency performance, low parasitic resistance, and low leakage current. MIM capacitors are commonly used in RF integrated circuits (ICs) due to their small size and compatibility with standard CMOS (Complementary Metal-Oxide-Semiconductor) processes. They provide stable capacitance values over a wide frequency range and are suitable for applications such as RF filters, matching networks, and voltage-controlled oscillators.

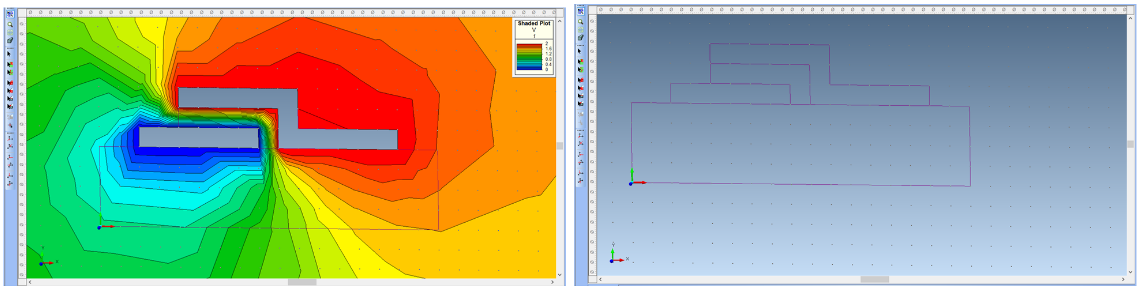
3. Variable Capacitors: Variable capacitors, also known as trimmer capacitors, are used in RF circuits that require adjustable capacitance values. These capacitors consist of two or more plates that can be mechanically adjusted to vary the effective capacitance. Variable capacitors are commonly used in tuning circuits, oscillators, and antenna systems.

4. Tantalum Capacitors: Tantalum capacitors are known for their high volumetric efficiency and stable capacitance over a wide temperature range. They are commonly used in RF circuits where space is limited, and stable performance is essential. Tantalum capacitors also exhibit low ESR and high reliability. However, they are sensitive to overvoltage conditions and can be prone to catastrophic failure if operated beyond their specified limits.

5. Ceramic Capacitors: Ceramic capacitors are widely used in RF circuits due to their small size, low cost, and high capacitance values. They exhibit excellent stability, low parasitic inductance, and low equivalent series resistance (ESR). However, they may have limited capacitance tolerance and voltage ratings.

6. Film Capacitors: Film capacitors are popular in RF applications that require high capacitance values and good stability. They are available in different dielectric materials such as polyester (Mylar), polypropylene, and polystyrene. Film capacitors offer low ESR, low dielectric loss, and high voltage ratings. They are suitable for applications involving high-frequency signals and high-power RF amplifiers

## 1.3 Results



(a) MIM Capacitor Plot

(b) MIM Capacitor Diagram

Figure 1: *ElectNet* Simulations

## 1.4 Discussion

| Relative Permittivity $\epsilon_r$ | 2 | 2.5 | 3 | 3.5 | 4 | 4.5 |
|---|---|---|---|---|---|---|
| Capacitance $fF$ | 1.28 | 1.525 | 1.79 | 2.04 | 2.29 | 2.54 |

Table 1: Relative Permittivity with Capacitance Outputs

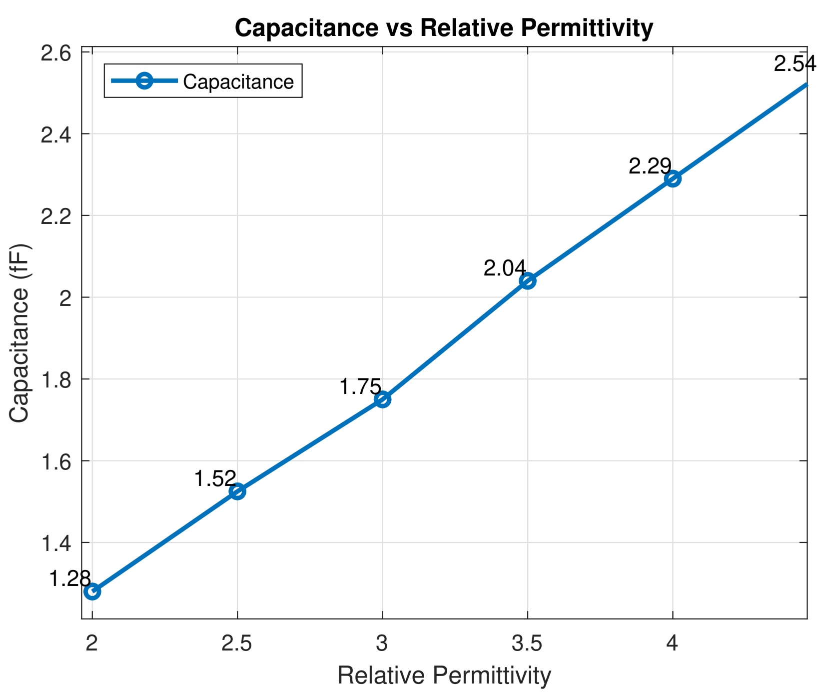



Figure 2: Relative Permittivity with Capacitance Plot

By observing the graph, we can notice that the relation between the relative permittivity and capacitance is linear, and this also can be deduced from this equation:

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

$C$: The capacitance of the capacitor.
$\epsilon$: Permittivity of dielectric.
$A$: The area of the plates.
$d$: The space between the plates.

Hence, materials differ greatly in their permittivity values because some provide less resistance to field flux for a given field force. The more relative permittivity you increase, the more capacitance you obtain.

For a given amount of field force (applied voltage), materials with a higher permittivity allow for more field flux (provide less opposition), and consequently a bigger collected charge.

| Voltage $V$ | 0.8 | 1.2 | 1.6 | 2 | 2.4 |
|---|---|---|---|---|---|
| Capacitance $fF$ | 1.28 | 1.28 | 1.28 | 1.28 | 1.28 |

Table 2: Relative Permittivity with Voltage Outputs

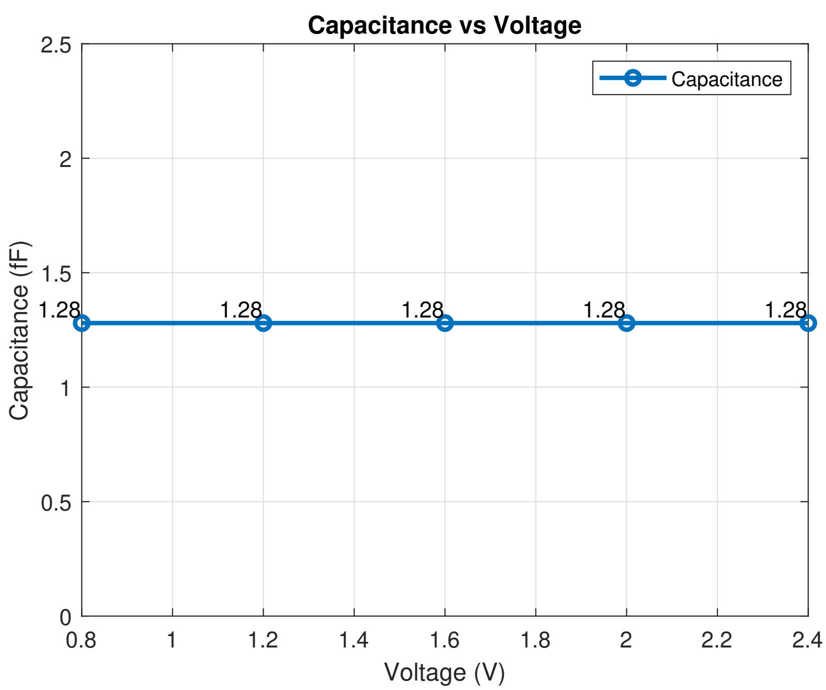


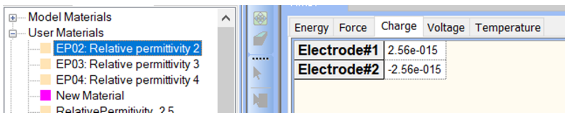

Figure 3: Relative Permittivity with Voltage Plot

We can see by observing the graph, that the capacitance remains constant even after increasing the voltage because from the previous equation:

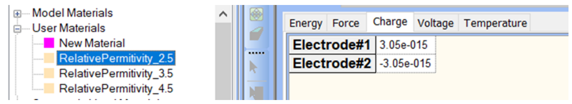
$$C = \frac{\epsilon A}{d}$$

We can clearly see that the capacitance doesn't depend on the voltage and all its parameters are related to the capacitor itself not the voltage applied.

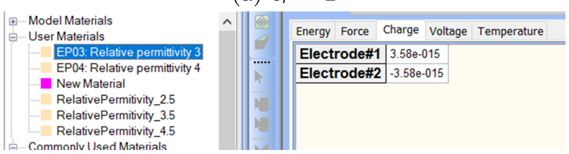
## 1.5 *ElectNet* Outputs



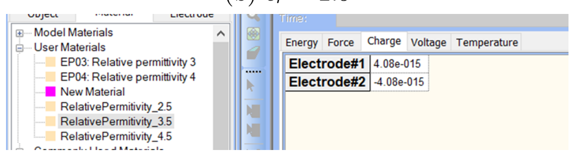

(a) $\epsilon_r = 2$



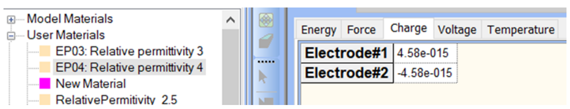

(b) $\epsilon_r = 2.5$



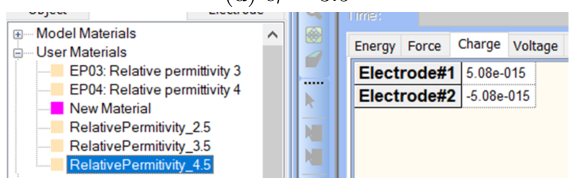

(c) $\epsilon_r = 3$




(d) $\epsilon_r = 3.5$



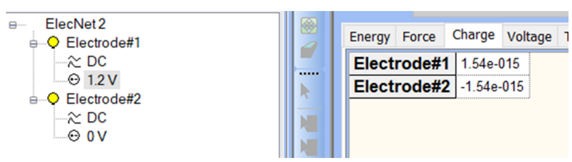

(e) $\epsilon_r = 4$




(f) $\epsilon_r = 4.5$

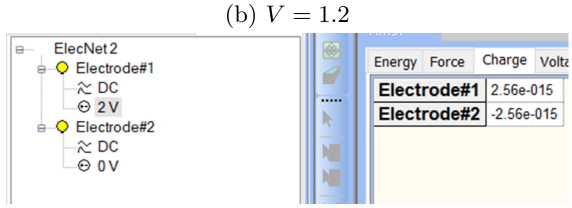
Figure 4: *ElectNet* Software Outputs for $\epsilon_r$


(a) $V = 0.8$

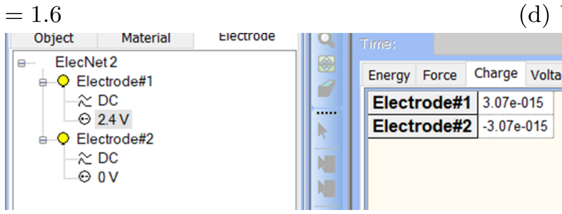



(b) $V = 1.2$


(c) $V = 1.6$




(d) $V = 2$




(e) $V = 2.4$

Figure 5: *ElectNet* Software Outputs for Voltage

# 2 Experiment 2: Magnetic buzzer

## 2.1 Introduction

MAGNET is a powerful electromagnetic field simulation solution for performance prediction of motors, generators, sensors, transformers, actuators, solenoids or any component with permanent magnets or coils.

Model the physics of electromagnetic devices Simcenter MAGNET includes capabilities to accurately model the physics of electromagnetic devices. This includes the ability to model manufacturing processes, temperature dependent material properties, magnetization and de-magnetization modeling, and vector hysteresis models among others.

## 2.2 Magnetic buzzer theory of operation

In a magnetic buzzer, current flowing through a wire coil produces a magnetic field that attracts a flexible ferromagnetic disk. When the coil's current is switched off, the disk oscillates back and forth and then returns to its initial position, producing sound waves. Magnetic buzzers operate at higher currents and lower voltages and have a lower sound pressure level capability than piezo buzzers. Magnetic buzzers are more common than piezo buzzers and are often found in house alarms, watches, keyboards, and clocks.

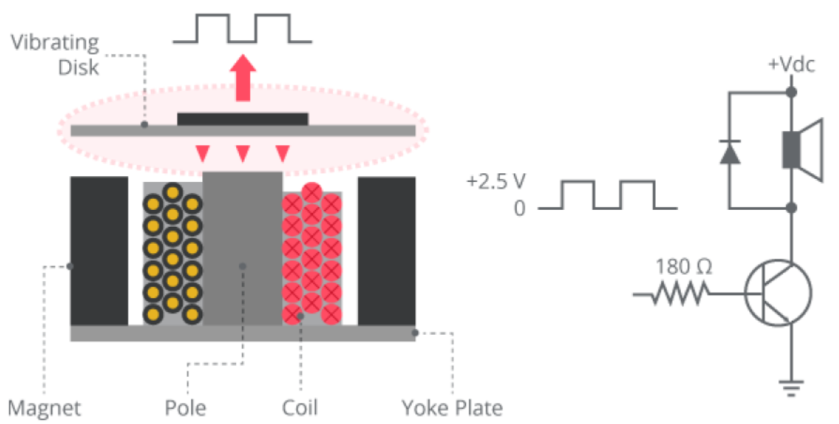



Figure 6: Magnetic buzzer diagram

## 2.3 Results

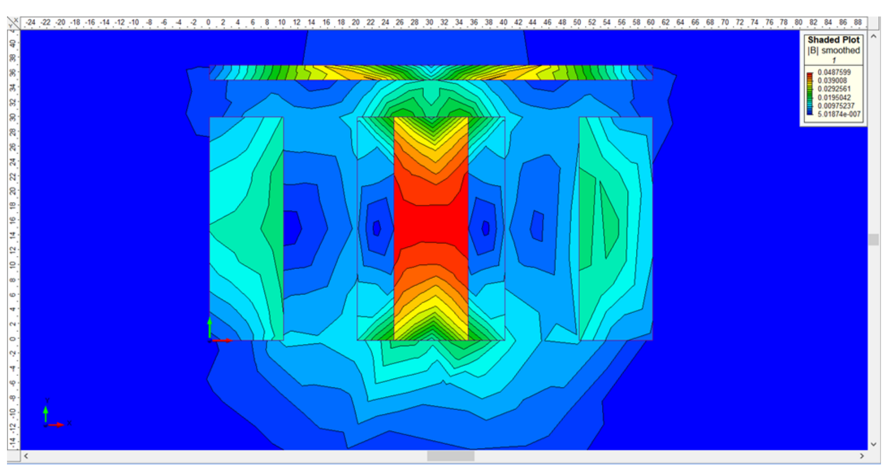



Figure 7: Magnetic buzzer contour plot using MagNet

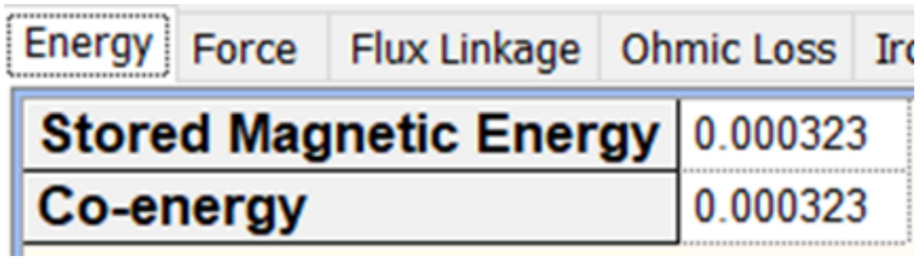



Figure 8: Magnetic Stored Energy

## 2.4 Buzzer types

1. Magnetic Buzzers:
   Advantages:
   - Simple design and construction.
   - Can produce a loud sound output.
   - Low power consumption.

   Disadvantages:
   - Limited frequency range.
   - Difficulty in producing complex or multi-tone sounds.
   - Relatively larger in size compared to other types.

2. Piezoelectric Buzzers:
   Advantages:
   - Compact and lightweight design.
   - Wide frequency range.
   - Can produce a variety of tones and patterns.
   - Response time is generally faster.

   Disadvantages:
   - Higher power consumption compared to magnetic buzzers.
   - Sound output may not be as loud as magnetic buzzers.
   - More sensitive to voltage variations.

3. Electrostatic Buzzers:
   Advantages:
   - Can produce high-quality sound with good clarity.
   - Wide frequency range.
   - Lower power consumption compared to magnetic buzzers.

   Disadvantages:
   - More complex design and construction.

# 3 Conclusion

In conclusion, the implementation of **ElecNet** and **Magnet** simulations has offered invaluable insights into the behavior and characteristics of MIM capacitors and magnetic buzzers. Through meticulous analysis and experimentation, we've observed the intricate interplay between electric fields in capacitors and magnetic fields in buzzers, elucidating their fundamental principles and performance parameters.

The simulations enabled a comprehensive exploration of various design configurations, shedding light on how different geometries, materials, and electrical/magnetic properties impact the overall functionality and efficiency of these devices. This deeper understanding of their behaviors not only enhances our theoretical knowledge but also holds significant practical implications for optimizing and innovating future capacitor and buzzer designs.

Furthermore, the utilization of simulation software like ElecNet and Magnet underscores their indispensable role in modern engineering. Their ability to model complex electrical and magnetic phenomena with accuracy and detail provides a cost-effective and time-efficient means for prototyping and fine-tuning device designs.

As we conclude this study, it becomes evident that these simulations serve as powerful tools, offering a bridge between theory and application, and empowering engineers to develop more efficient, reliable, and innovative MIM capacitors and magnetic buzzers for diverse technological applications.

# 4 References


1. Kemet Corporation. "What is an RF Capacitor?" URL: kemet.com/en/us/technical-resources/what-is-an-rf-capacitor.html. This resource from Kemet Corporation provides insights into the function and applications of RF capacitors.

2. American Piezo. "Piezo Buzzers vs. Magnetic Buzzers." URL: americanpiezo.com/blog/piezo-buzzers-vs-magnetic-buzzers/. This article compares piezo buzzers and magnetic buzzers, offering valuable information for individuals seeking to understand the differences between these two types of buzzers.

3. OpenStax. "Capacitors and Capacitance." In University Physics II - Thermodynamics, Electricity, and Magnetism. URL: phys.libretexts.org/Bookshelves/University$_Physics/Book$