Name: Dagmawi Abera  
Signal and Power Integrity

HFSS Project Report: Metal-Ceramic-Metal Capacitor on Rogers 4003C Substrate

# 1. Project Overview

This HFSS project models a metal-ceramic-metal capacitor on a Rogers 4003C substrate, simulating its performance across a wide frequency range. The goal is to investigate the impedance (Z-parameter) and reflection coefficient (S-parameter), with a focus on identifying the resonant frequency.

# 2. Model Components

## Materials:

**- Al2\_O3\_ceramic**: This is the ceramic dielectric layer in the capacitor. Ceramic materials, particularly alumina (Al2O3), are chosen for their high dielectric constant, contributing to the capacitance value.  
**- Copper**: Used for the conductive parts of the capacitor (the metal layers). Copper is a standard material for its excellent electrical conductivity.  
**- Solder Components (cap\_solder\_left, cap\_solder\_right):** These represent the soldering elements that connect the capacitor's terminals to other components on the PCB.

## Substrate and Region:

**- Rogers 4003C (Substrate):** The capacitor is placed on a Rogers 4003C PCB material. Rogers 4003C is a popular choice for high-frequency applications due to its stable dielectric properties.  
**- Vacuum (Region):** The surrounding environment is modeled as a vacuum to simulate free-space conditions without interference, typically necessary for high-frequency simulations.

## Excitations and Boundaries:

**- Lumped Port (Rectangular1)**: A lumped port is used for excitation, which simulates how the capacitor would be connected to a circuit. It defines how electrical signals enter and exit the system.  
**- Radiation Boundary (Rad1):** The radiation boundary ensures that the electromagnetic waves propagate in a free-space environment without reflecting back into the model.

## Mesh and Analysis Setup:

**- Mesh:** The mesh divides the model into smaller sections for accurate simulation. Denser meshing is applied to critical regions, like the ceramic-metal interface, to capture fine details.  
**- Sweep Frequency Setup:** The frequency sweep is configured to simulate the system’s response across a range from low GHz to above 10 GHz. This allows the identification of key operational points, such as resonant frequencies.

A screenshot of a computer

Description automatically generated

# 3. Variables and Design Parameters

|  |  |  |
| --- | --- | --- |
| Variable | Value | Description |
| sub\_L | 20 mm | Length of the substrate (Rogers 4003C), which forms the base of the capacitor and affects its electrical performance. |
| sub\_W | 20 mm | Width of the substrate, providing the dimensions of the PCB beneath the capacitor. |
| sub\_H | 1.524 mm | Height (thickness) of the substrate, which influences the capacitance and impedance due to the spacing from the ground plane. |
| strip\_W | 2 mm | Width of the conductor strips in the design, important for controlling the conductive paths and overall impedance. |
| strip\_L | 5 mm | Length of the conductor strips, affecting the distance between connections and impacting the impedance/resonance characteristics. |
| strip\_end\_L | 2 mm | The length of the end of the strip. This adds to the effective length and may contribute to the coupling effects or resonant frequency. |
| strip\_gap | 2 mm | The gap between conductor strips, an important factor for controlling coupling and preventing short circuits or high parasitic capacitances. |
| cap\_L | 3 mm | Length of the capacitor component (metal layer length), which directly impacts the overall capacitance value. |
| cap\_W | 3 mm | Width of the capacitor, defining its size and thus the capacitance, impacting the impedance. |
| via\_R | 0.5 mm | The radius of the via used to connect different layers, essential for maintaining proper electrical connectivity. |
| via\_offset | 1 mm | The offset of the via from the center, ensuring correct placement within the design. |
| copper\_t | 18 µm | The thickness of the copper conductive layer. Thicker copper helps lower the resistance and allows more current to flow through the capacitor. |
| cap\_H | 1 mm | The height of the capacitor, which corresponds to the distance between the two metal plates (top and bottom layers), defining the dielectric gap. |
|  |  |  |

# A screenshot of a computer Description automatically generated

A computer screen shot of a cube

Description automatically generated

# 4. Simulation Process

## a) Model Construction and Material Assignment:

The metal-ceramic-metal capacitor is built using copper for the conductive layers and alumina (Al2O3) as the dielectric layer. These materials are crucial for defining the electrical properties of the capacitor. The capacitor is positioned on a Rogers 4003C substrate, which provides a stable base with good electrical insulation properties, suitable for high-frequency designs.

## b) Ports and Excitations Setup:

A lumped port is defined to simulate the signal input into the capacitor, allowing for accurate calculation of the reflection coefficient (S11) and impedance (Z11). The radiation boundary ensures that the simulation mimics real-world conditions where electromagnetic waves can propagate freely, ensuring accurate impedance and reflection results.

## c) Frequency Sweep and Simulation Execution:

The frequency sweep was set up to cover a wide range, from 2 GHz to 15 GHz, allowing us to capture the behavior of the capacitor across a broad spectrum. The solver calculates the system’s impedance and reflection at each frequency step, providing detailed insight into how the capacitor performs, especially at resonant points.

# 5. Results: S-Parameter and Z-Parameter Analysis

## S-Parameter (Reflection Coefficient S11):

The S-parameter plot shows how much of the input signal is reflected back from the capacitor. At 11 GHz, the reflection coefficient reaches a minimum, indicating that the capacitor is resonating, with minimal signal reflection and maximum power transfer.

A graph on a screen

Description automatically generated

## Z-Parameter (Impedance Z11):

The Z-parameter plot provides the impedance of the capacitor as a function of frequency. At 5 GHz and 11 GHz, significant dips in impedance are observed, with 11 GHz being the resonant frequency. This low impedance at the resonant point confirms that the capacitor is functioning effectively in this range.

A screen shot of a graph

Description automatically generated

# 6. Conclusion

In this HFSS project I successfully modeled a metal-ceramic-metal capacitor and simulated its performance across a broad frequency range. The use of Rogers 4003C substrate and Al2O3 ceramic dielectric material provided excellent electrical insulation and high dielectric constant, enabling efficient operation at high frequencies. The results demonstrate that the capacitor resonates at **11 GHz**, as indicated by the S-parameter and Z-parameter plots. Further optimization of variables such as strip width and cap length could fine-tune the design for specific frequency applications.