June 25th, 2025

Taking the Mystery Out of RF Ceramic Capacitors

Introduction

RF or Radio Frequency refers to the oscillation rate of an AC voltage, current, or electromagnetic wave in an electronic device. Design engineers use RF to define frequencies above 3kHz but can range from a few MHz up to 100s of GHz. RF Capacitors are devices specifically designed for applications in this frequency range.

What is RF?

The radio frequency (RF) spectrum is a segment of the electromagnetic spectrum. Electromagnetic radiation, such as radio waves, travels in waves, with varying frequencies and wavelengths. Frequency is measured in Hertz (Hz), where 1 Hertz equals one cycle per second. Microwaves operate in a band from 300MHz to 300GHz, while the mm wave band is from 27GHz to 300GHz. Wavelength refers to the physical distance between two peaks of the AC wave and decreases as the frequency increases as shown in figure 1 below.

Figure 1 - RV Waveform

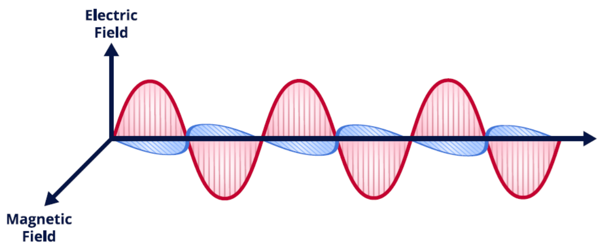
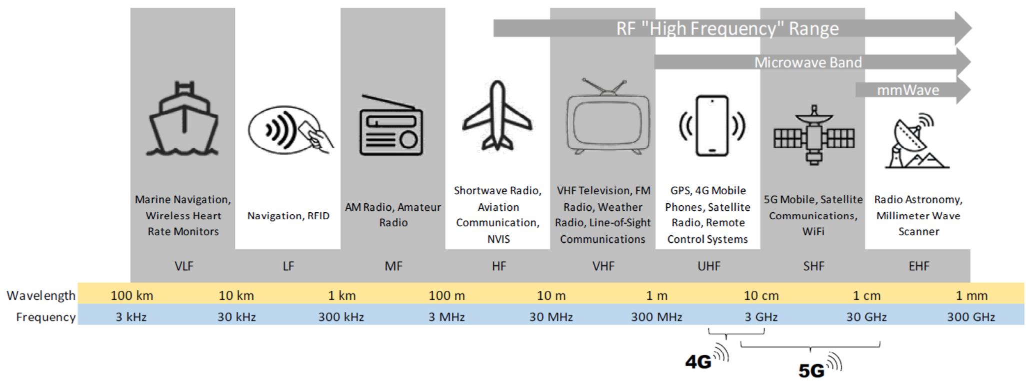


Figure 2 - RF Frequency Spectrum



June 25th, 2025

What is RF?

The RF spectrum is fundamental to modern communication and technology. It's the pathway through which a vast array of information is transmitted wirelessly. Figure 2 above shows the typical applications for a given frequency band. A few examples are:

- Cellular communications: Mobile phone networks (2G, 3G, 4G, and 5G) rely heavily on RF waves to transmit voice and data.
- Wireless networking: Wi-Fi uses RF signals to connect devices to networks.
- Satellite communications: Communication with satellites for television, internet, and navigation (GPS) depends on RF transmission.

As consumers demand faster device connectivity, RF development and implementation continues to shift toward higher frequency technologies. Moving to higher frequencies poses significant advantages and disadvantages.

Advantages of moving to higher frequencies:

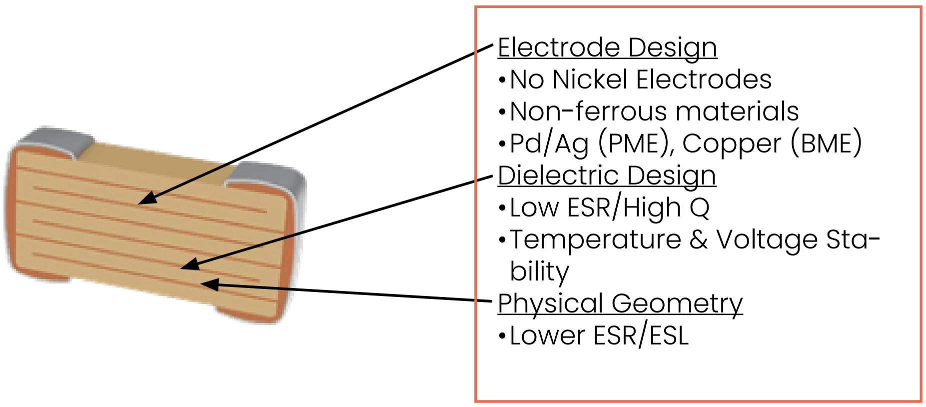
1. More use of the frequency spectrum
2. High capacity (bandwidth) – This is the ability to send more data in less time. When thinking of 5G, the first thing to come to mind is a higher transmission of data.

Disadvantages of moving to higher frequencies:

1. Signals can be blocked by more objects
2. Weather conditions can be an impact
3. Higher frequencies travel shorter distances before attenuating, requiring more 5G base stations to cover the same area.

What are RF Capacitors?

YAGEO Group's Nanomet was created through rapid quenching, resulting in a smooth, spherical powder. After precise annealing, the alloy exhibits a fine nanocrystalline structure with remarkable magnetic properties, including a coercivity as low as 23 A/m and a saturation magnetic flux density of 1.55T through hot molding (as shown in Figure 1). These figures are impressive compared to conventional magnetic powders, making this alloy an excellent material for creating efficient, high-performance inductors.



June 25th, 2025

What are RF Capacitors?

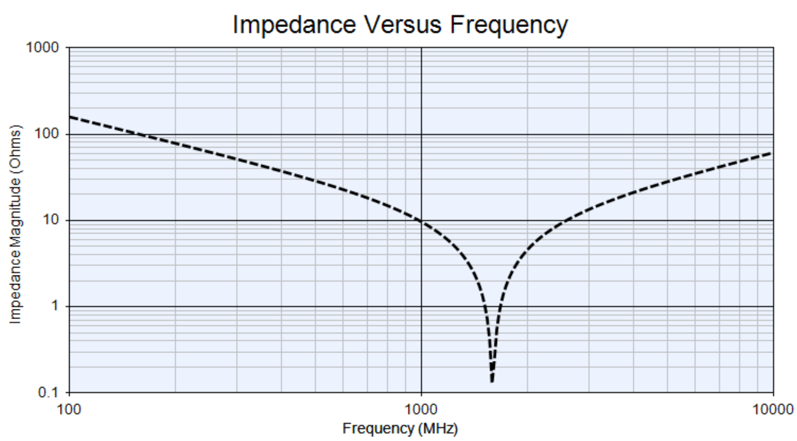
Some Key Characteristics of RF capacitors:

1. ESR at High Frequencies – ESR is a measure of the resistance in a capacitor, which can be translated into power lost as heat. For high frequency applications low ESR is desired for efficiency.
2. Q at High Frequencies – This is a measure of the efficiency of the capacitor. Q is inversely related to ESR. The higher the Q value, the lower the ESR, and the more efficient the capacitor. RF capacitors' combination of low ESR & low capacitance pair to make a high Q value.
3. S-Parameters - S-Parameters (scattering parameters) are often used when analyzing RF circuits. They demonstrate electrical reflective behavior at high frequencies and are crucial when comparing RF circuits.
4. TCC – This determines the value in which the capacitance will shift at different temperatures. RF capacitors require extreme stability over a broad temperature range.
5. SRF – The Series Resonant Frequency in RF capacitors is higher than those of a traditional MLCC. The SRF is the frequency at which the total impedance is no longer capacitive and begins an upward trend to becoming inductive. The higher the SRF value, the better suited the capacitor is for RF applications, as RF engineers need to stay well below the SRF value.

Understanding SRF

Series Resonant Frequency (SRF) is the frequency where the capacitive and inductive reactances are equal in magnitude but cancel each other out leaving only ESR remaining in the impedance equation. The magnitude of the impedance for frequencies below the SRF is dominated by the capacitive reactance. Frequencies above SRF are dominated by inductive reactance. An example of these functions are shown in Figure 3 below. When designing in the RF frequency spectrum, this value becomes vitally important. For increasingly higher operating frequencies, the SRF of a RF capacitor needs to be above the operating frequency of the application in order to remain in the capacitive reactance region.

Figure 3 - Impedance & ESR vs. Frequency for 10pF MLCC

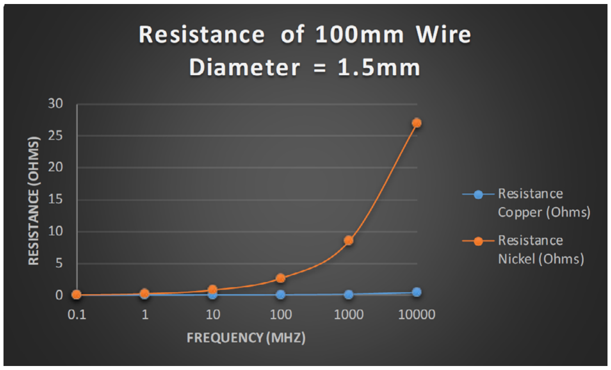


June 25th, 2025

Copper Electrodes

Copper electrodes are important in RF capacitors primarily due to their contribution to achieving low Equivalent Series Resistance (ESR) and high Quality (Q) factor, both of which are critical for optimal performance at radio frequencies. When comparing copper electrodes to traditional nickel electrodes used in most MLCCs, copper electrodes have a more stable resistance value as the operational frequency increases. Nickel is a ferrous material, so as the frequency is increased the resistance drastically increases in the material. Figure 4 below shows the resistances of copper compared to nickel over a given frequency. In RF applications, this is not ideal as low-loss materials become important at these higher frequencies.

Figure 4 - Resistance of Copper & Nickle Wire



S-Paremeters

S-parameters, or scattering parameters, are a fundamental concept in RF and microwave engineering used to describe the electrical behavior of linear electrical networks when undergoing various steady-state stimuli by electrical signals. When applied to capacitors, S-parameters help characterize how the capacitor behaves at high frequencies. S-parameters describe how RF signals behave in a network:

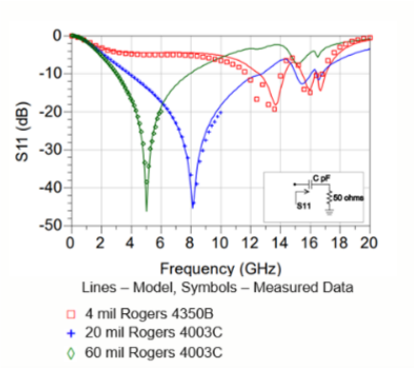
- S11: Input reflection coefficient (how much of the signal is reflected back from the input).
- S21: Forward transmission coefficient (how much of the signal passes through from input to output).

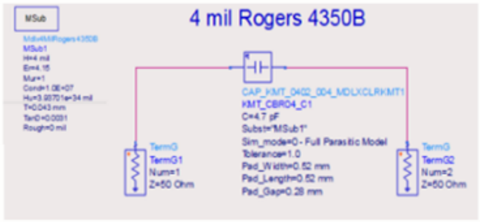
Advanced Modelithic Models

Characterizing RF capacitors requires different approaches compared to standard capacitors. While low-frequency designs often use impedance/ESR methods, high-frequency RF designs utilize S-parameters. S-parameters describe how RF energy propagates through a network. They are used to quantify reflection and transmission of waves, crucial for RF design and simulation. For accurate simulations, advanced models like Modelithics models are used to represent real-world parasitics, including capacitance tolerance, PCB properties, and pad dimensions. These models can be found on the YAGEO Group website here: https://www.yageogroup.com/SalesResources/ResourceLibrary/asset/10739. Figure 5 below shows how S-parameters look in practice.

June 25th, 2025

Figure 5 - Example of data given from a Modelithic Model





KEMET HiQ-CBR Series

The KEMET HiQ-CBR series exemplifies RF capacitors designed for high-frequency applications. These capacitors utilize copper electrodes for low ESR, high Q, and high SRF, and employ high Q BME Class 1 dielectrics for low ESR, high Q, and low TCC.

Want to find out more?

For more information about HiQ RF Capacitors and the RF spectrum please visit:
https://yageogroup.com/SalesResources/ResourceLibrary