Ceramic Capacitors for RF Applications:
PSMA (Virtual) Capacitor Workshop 2020

April 2020

Outline

What is RF?

Capacitor Basics

RF Capacitors

Properties and Characterization

KEMET CBR Series

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RF Overview

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- Low MHz to 300GHz.
- Higher frequency ranges allow for:
  - More use of the frequency spectrum
  - Efficiency in propagating signals from one point to another
  - Reduction in size of components such as antennas.
- Markets
  - Telecom
  - Medical
  - IoT
  - Autonomous Driving
  - Military, Space and Aeronautics, etc

Table of IEEE bands[4]

Band	Frequency range	Origin of name [citation needed]
HF band	3 to 30 MHz	High Frequency
VHF band	30 to 300 MHz	Very High Frequency
UHF band	300 to 1000 MHz	Ultra High Frequency
L band	1 to 2 GHz	Long wave
S band	2 to 4 GHz	Short wave
C band	4 to 8 GHz	Compromise between S and X
X band	8 to 12 GHz	Used in WW II for fire control, X for cross (as in crosshair)
K_u band	12 to 18 GHz	Kurz-under
K band	18 to 27 GHz	German Kurz (short)
K_a band	27 to 40 GHz	Kurz-above
V band	40 to 75 GHz	
W band	75 to 110 GHz	W follows V in the alphabet
G band	110 to 300 GHz	

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What is RF?
Capacitor Applications

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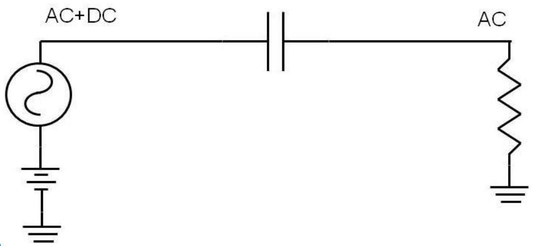
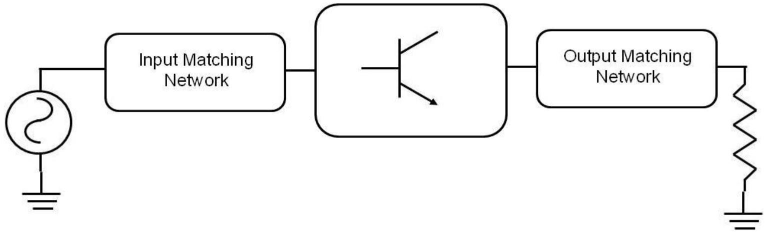
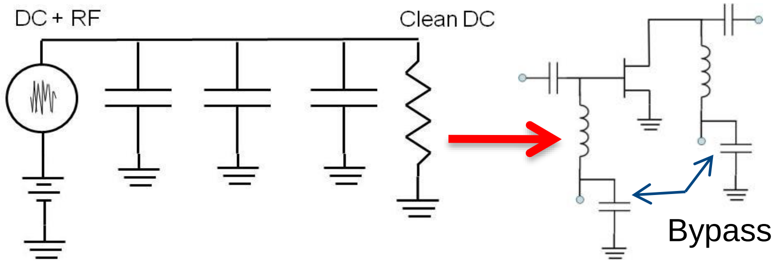
DC BLOCKING



MATCHING



BYPASS



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Capacitor Basics

A Refresher

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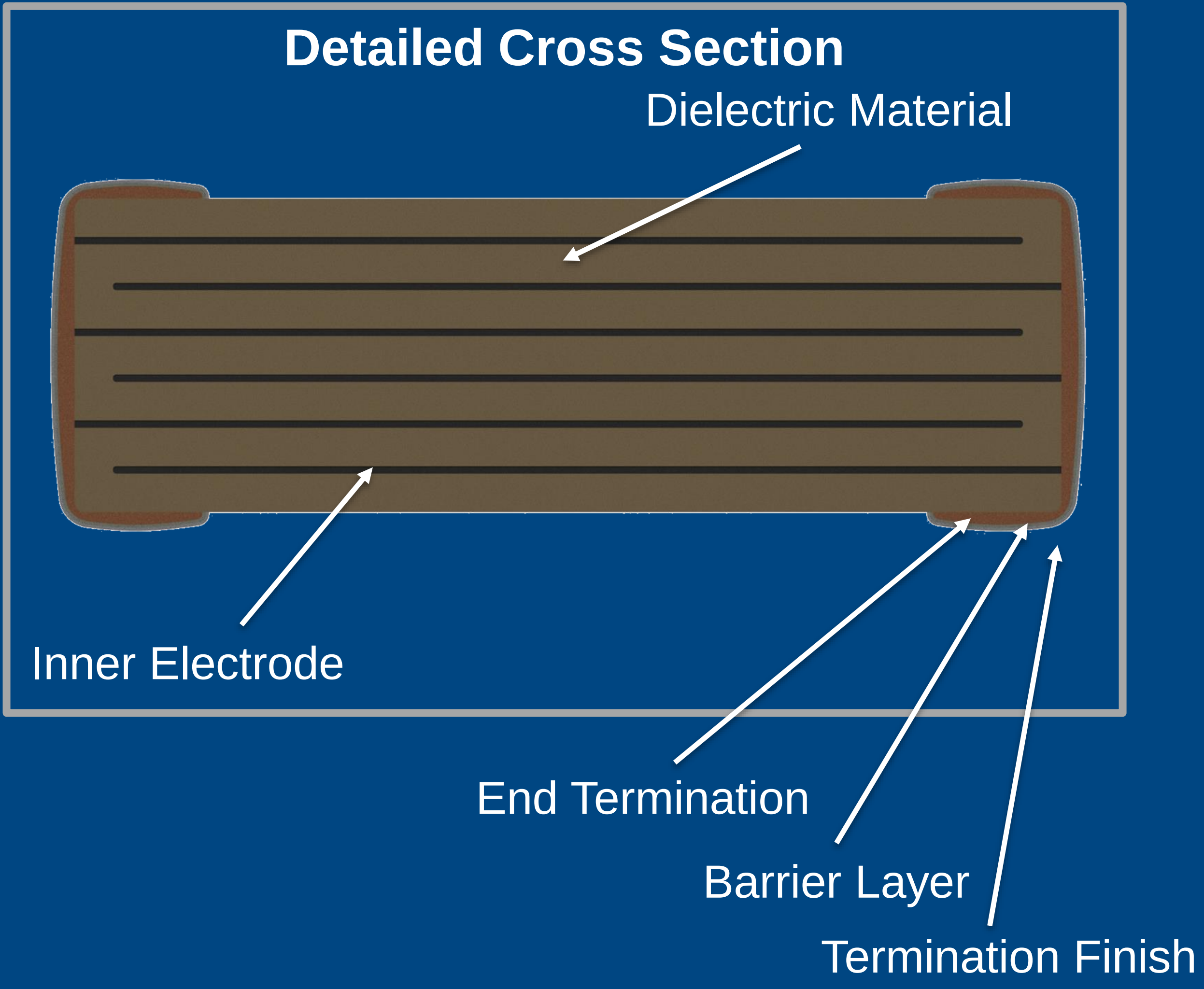
Capacitor Basics



C = Design Capacitance

K = Dielectric Constant

A = Overlap Area

d = Ceramic Thickness

n = Number of Electrodes

$$C = \frac{\varepsilon_0 K A (n-1)}{d}$$

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Capacitor Basics
The Ideal Capacitor

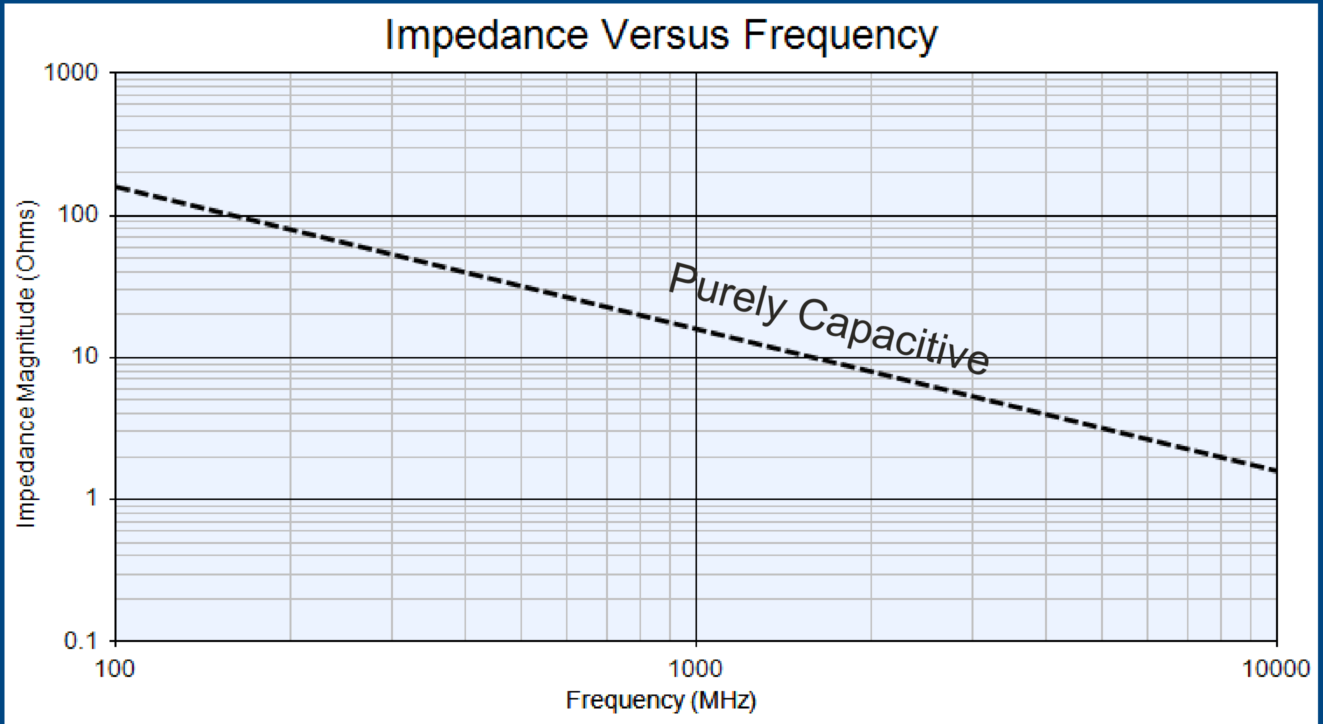
Ideal Capacitor
- Pure Capacitance
- No resistance (ESR)
- No Inductance (ESL)

Z=Capacitive Impedance or Reactance

$$Z = \frac{1}{2*\pi*Frequency*Capacitance}$$

Ideal Model

10pF example



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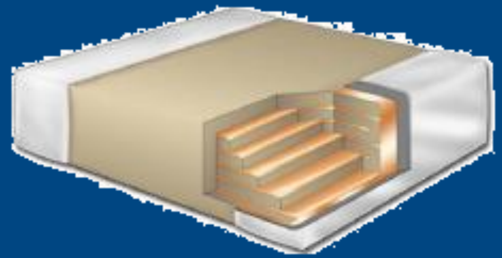
Capacitor Basics

Real Capacitor

Real Capacitor

- **C -** Nominal capacitance
- **ESR -** Series resistance (terminations, dielectric, and electrodes)
- **ESL -** Series inductance

Simplified Real Model



$$Z = \sqrt{ESR^2 + (X_L - X_C)^2}$$

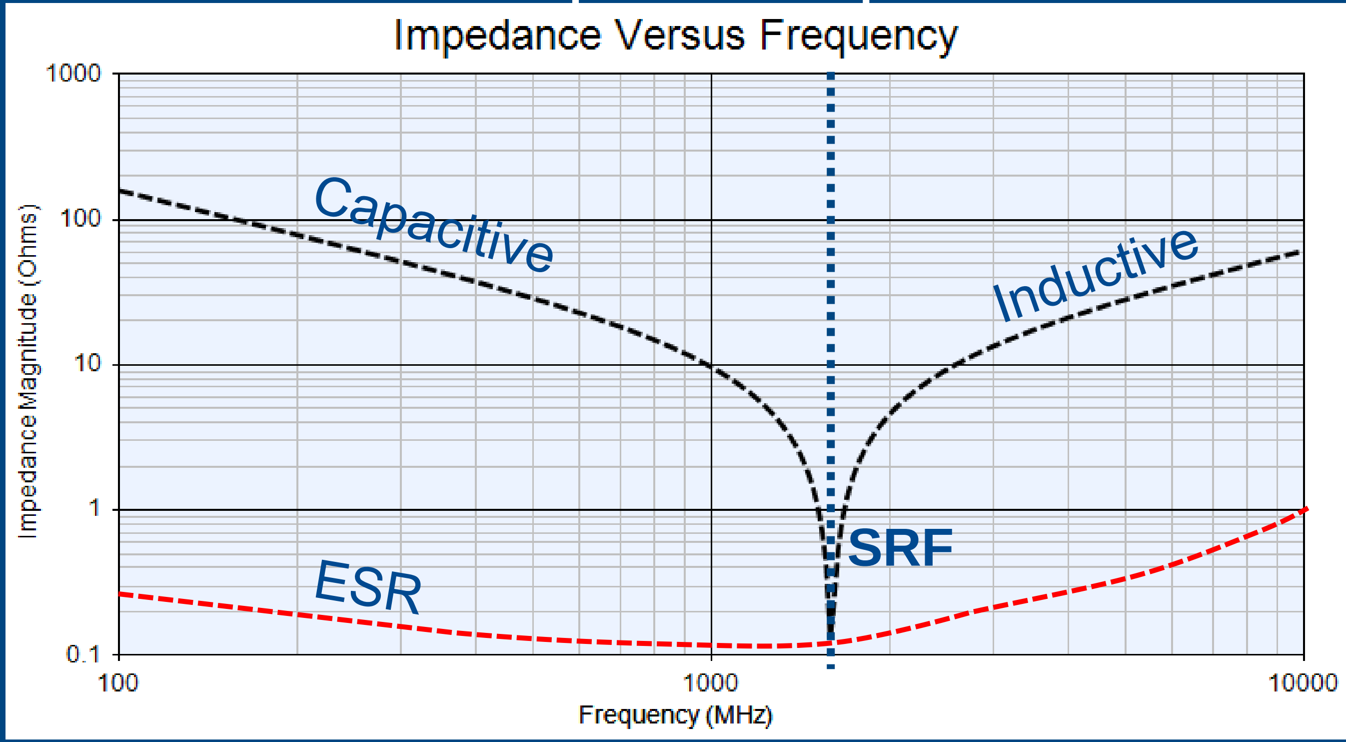
Where : Z = Total Impedance

ESR = Equivalent Series Resistance

X_C = Capacitive Reactance $= 1/(2\pi f C)$

X_L = Inductive Reactance $= (2\pi f)(ESL)$

10pF example



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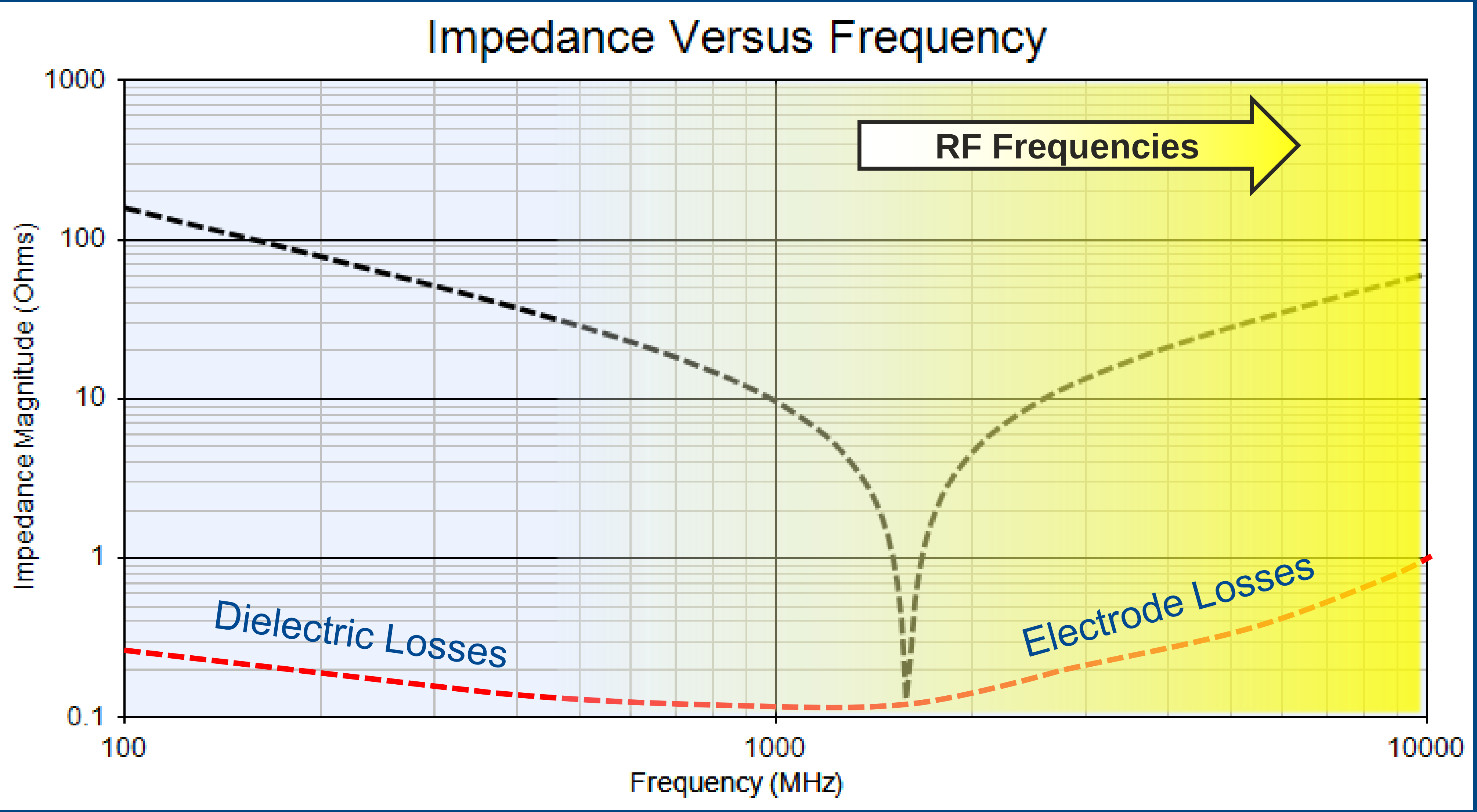
Capacitor Basics
Closer Look at ESR



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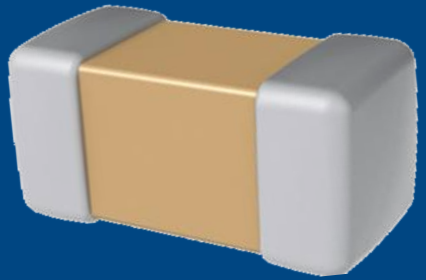
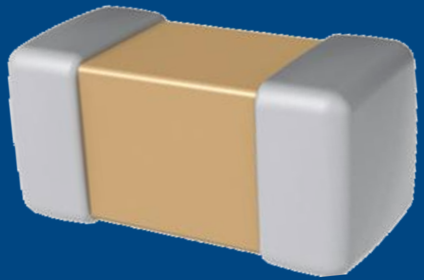
RF Capacitors

What's the Difference?

"Regular" Capacitor



RF Capacitor



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RF Capacitor Basics
Some Key Parameters

ESR
The resistance of the capacitor which includes resistance due to the dielectric as well as electrodes.

Q
Quantifies the amount of energy stored versus how much is dissipated as heat. It represents the efficiency of the capacitors. Higher Q's are needed for RF capacitors to limit power dissipation.

SRF
Shows where the total impedance is no longer capacitive and begins an upward trend (becomes inductive). Higher SRF = better RF capacitor, since some applications require the designer to stay well below the SRF.

TCC
Determines how much the capacitance values will shift at different temperatures. RF capacitors need to be very stable over a broad temperature range.

$$Q = \frac{Xc}{ESR} = \frac{1}{DF}$$

$$SRF = \frac{1}{2 * \pi * \sqrt{C * L}}$$

C0G → ppm/ ºC level
X7R → % level

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So, What is an RF Capacitors

An RF capacitor is a capacitor whose "characteristics" are favorable at RF frequencies

Characteristic	RF Capacitor Requirements
ESR (Effective Series Resistance)	RF Capacitors are designed to have the lowest possible ESR. This allows for minimal power loss at RF frequencies.
Q (Quality Factor)	RF Capacitors are designed to have a high Q.
SRF (Series Resonant Frequencies)	RF Capacitors are designed to have high SRF allowing for a higher operating frequency range.
TCC (Temperature Coefficient of Capacitance)	Dielectric chosen to have minimal capacitance shift across entire operating temperature range.

So, for RF capacitors, materials are chosen and the design is optimized so that the capacitors' characteristics are well suited at the higher frequencies.

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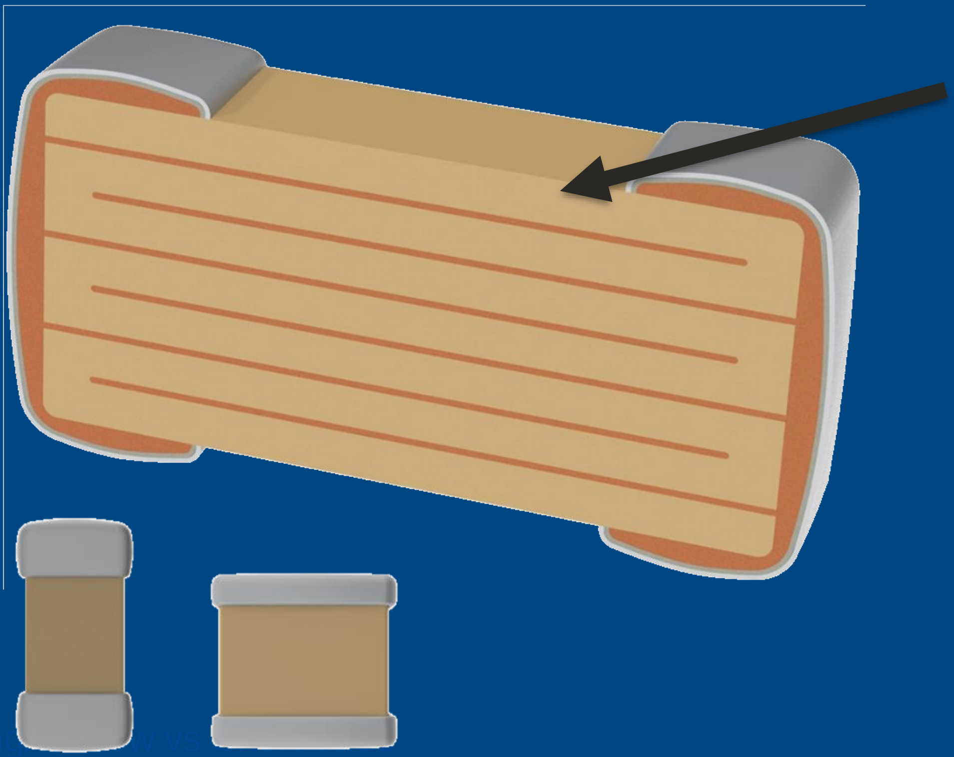
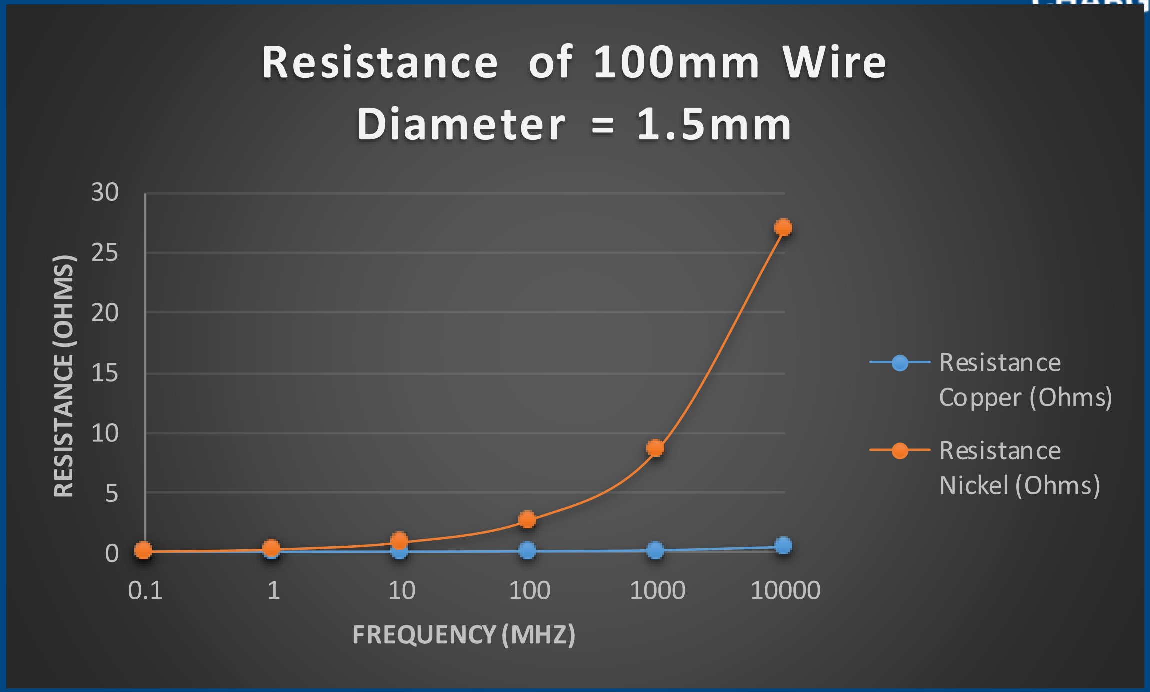
Optimizing for RF





Design	Design Goal	How?
Dielectric	• Low Loss • Temperature and Voltage Stability	High Q class 1 dielectrics such as C0G or NPO
Electrodes	• Low Loss • Low Inductance	Non-ferrous electrode materials
Construction / Physical Geometry	• Low Loss • Low Inductance	Consider square case size

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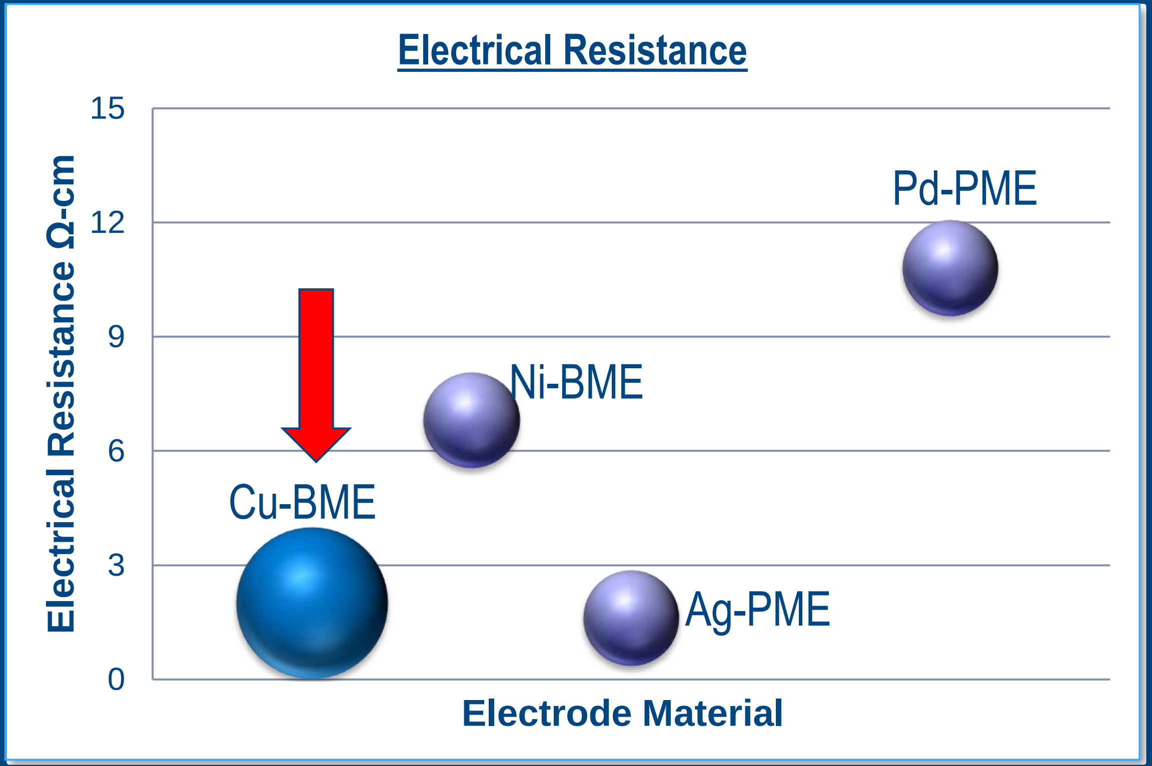
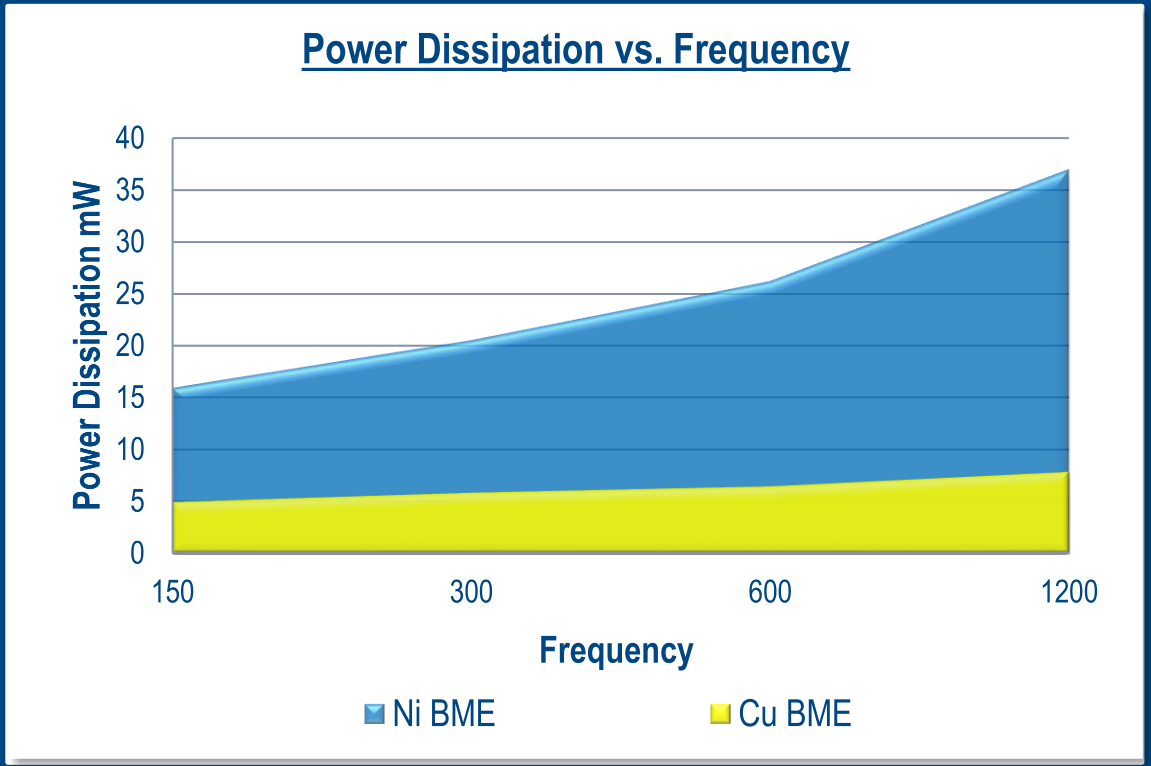
RF Capacitors
Why Copper BME





Copper BME = Lower ESR = Better power dissipation = Ideal for High Frequency applications

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RF Capacitor Properties and Characterization

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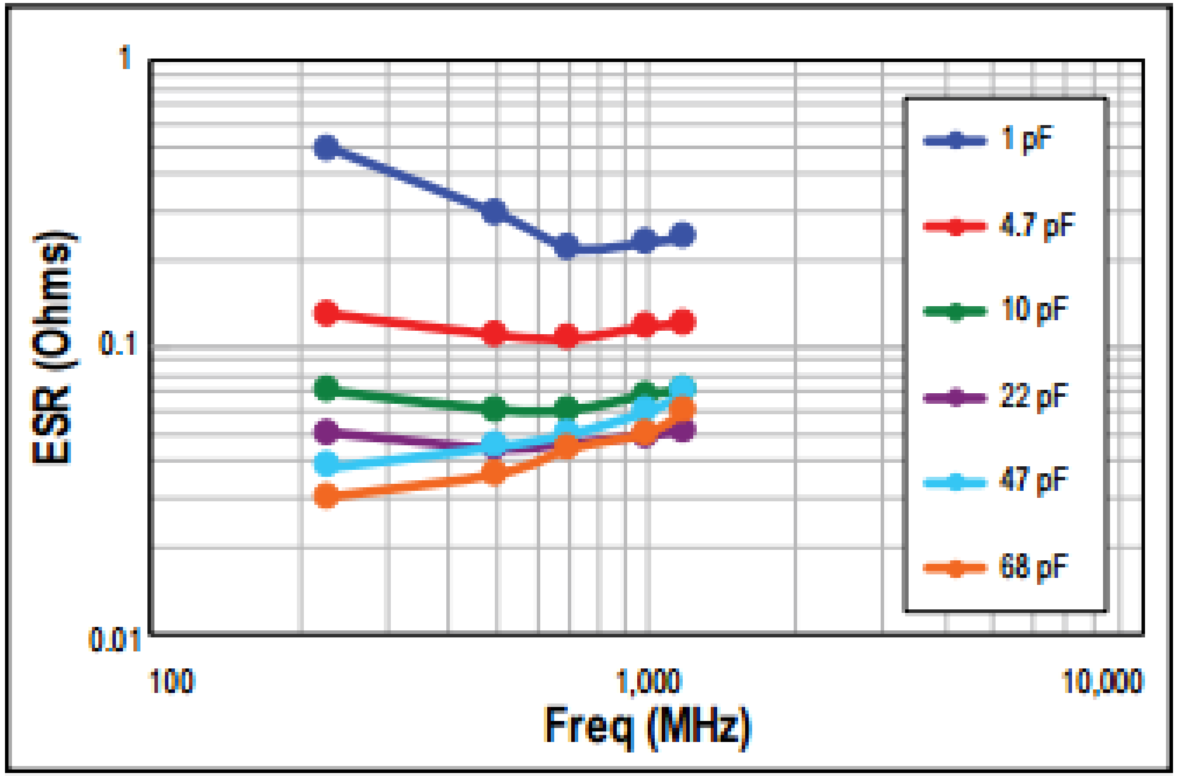
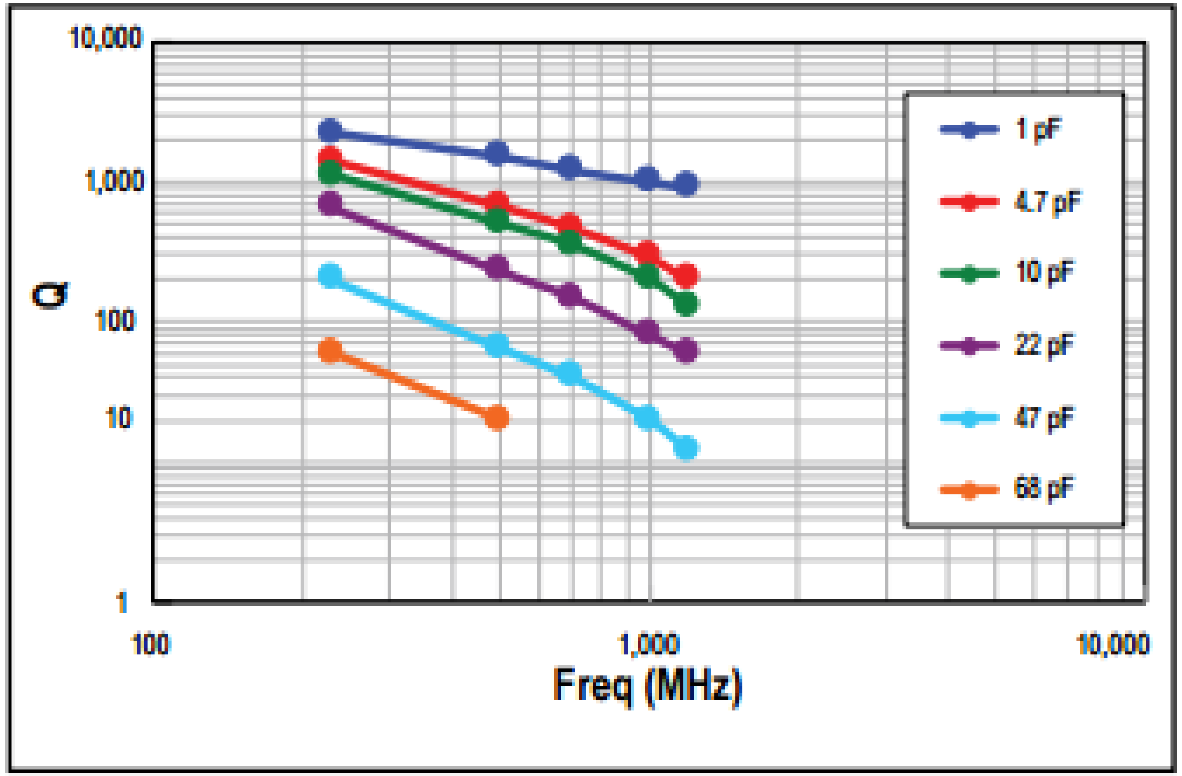
ESR and Q





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Low Frequency Design vs RF Design

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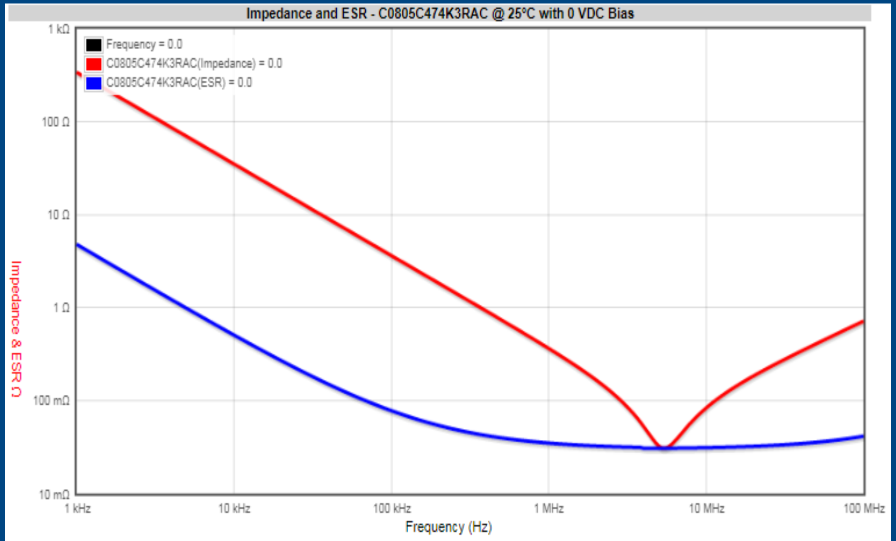
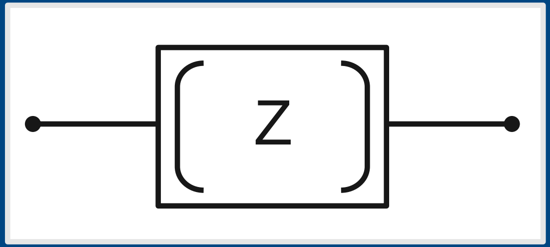
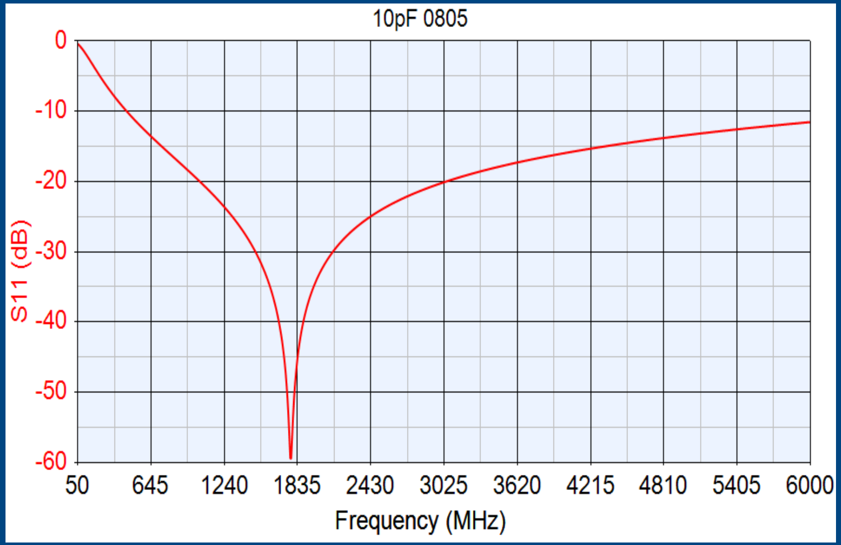
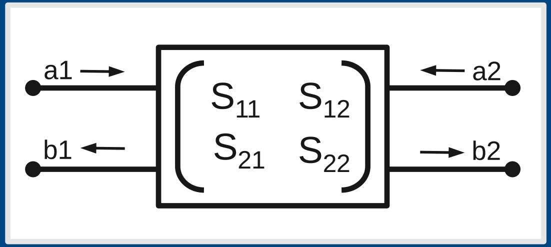
Impedance / ESR Approach





S-Parameter Network Approach





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S-Parameters

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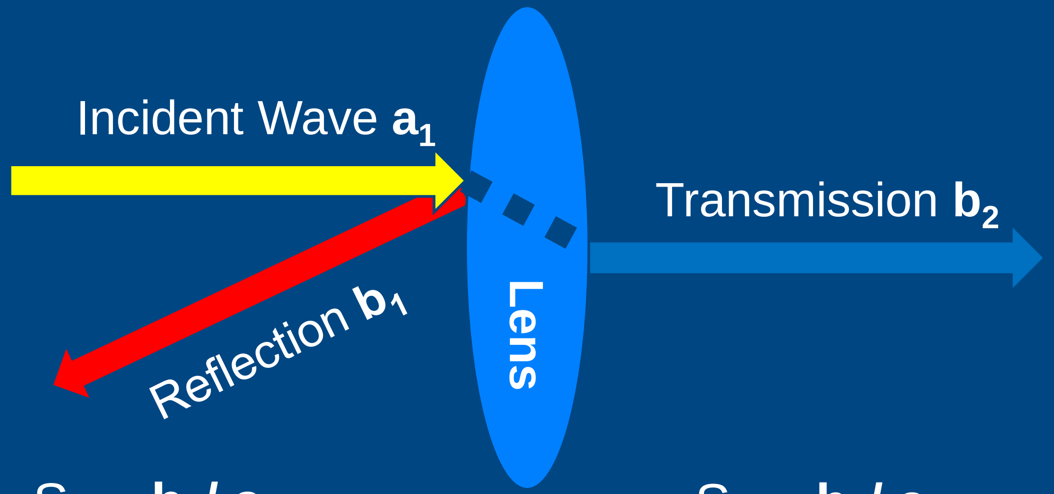

$S_{11} = \mathbf{b_1} / \mathbf{a_1}$

$S_{21} = \mathbf{b_2} / \mathbf{a_1}$

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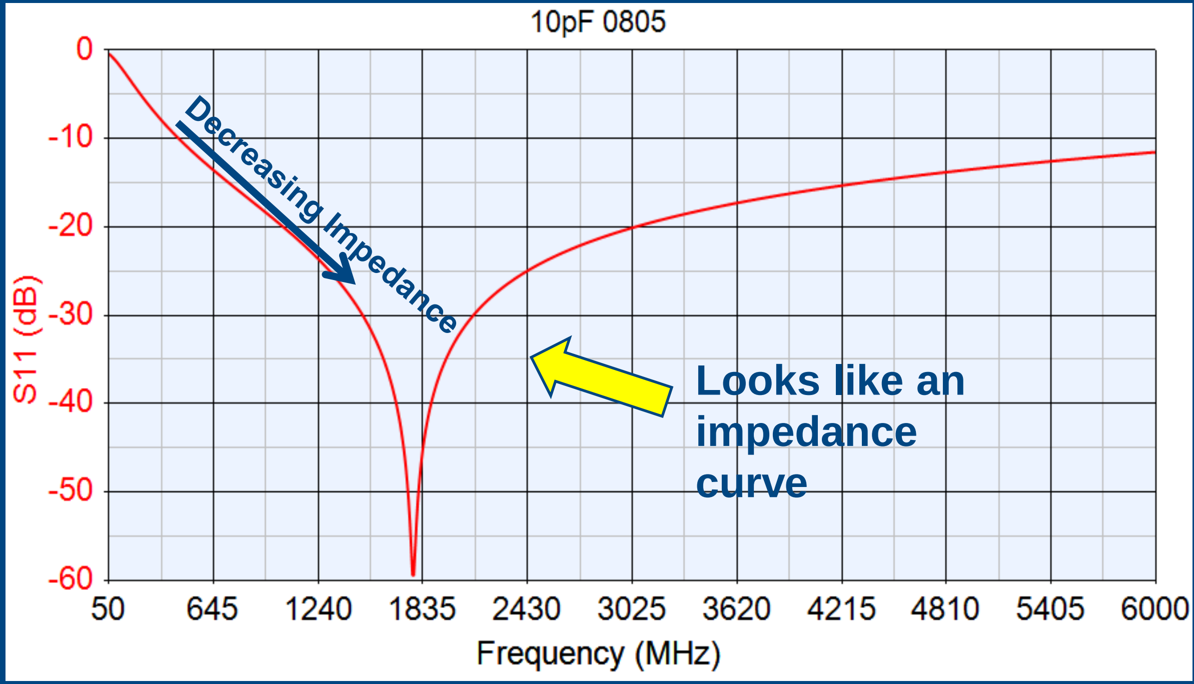
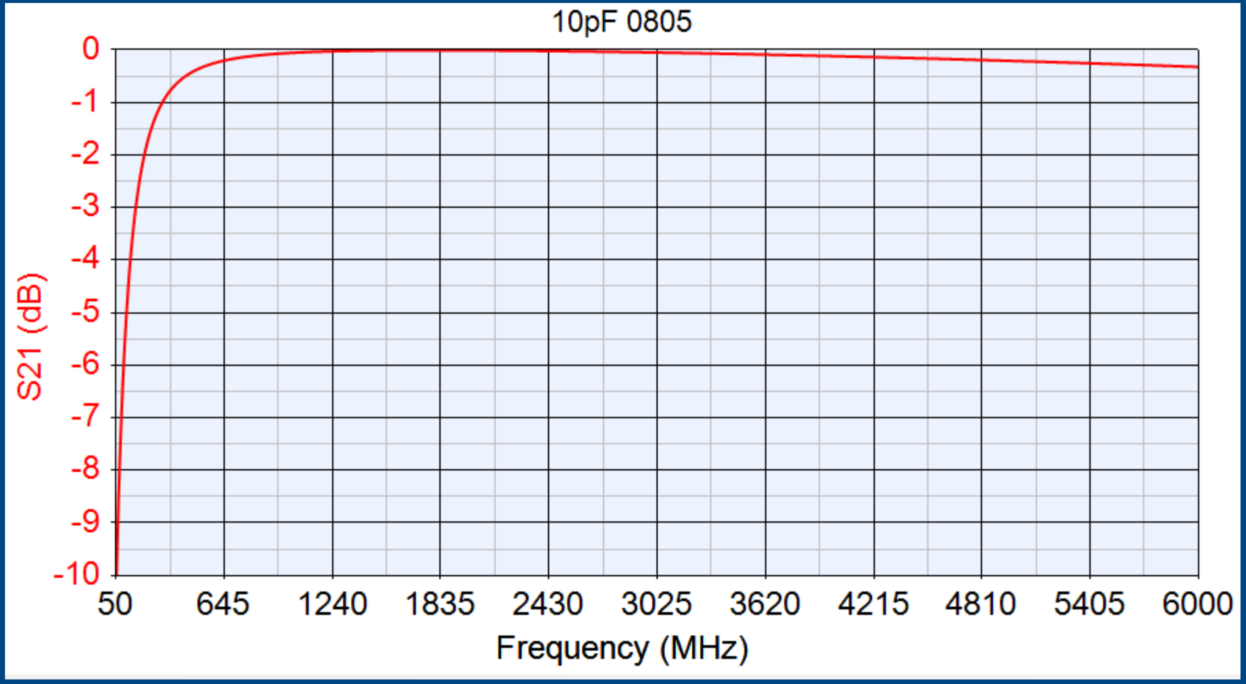
S-Parameters

S11



Reflected

S21



Transmitted

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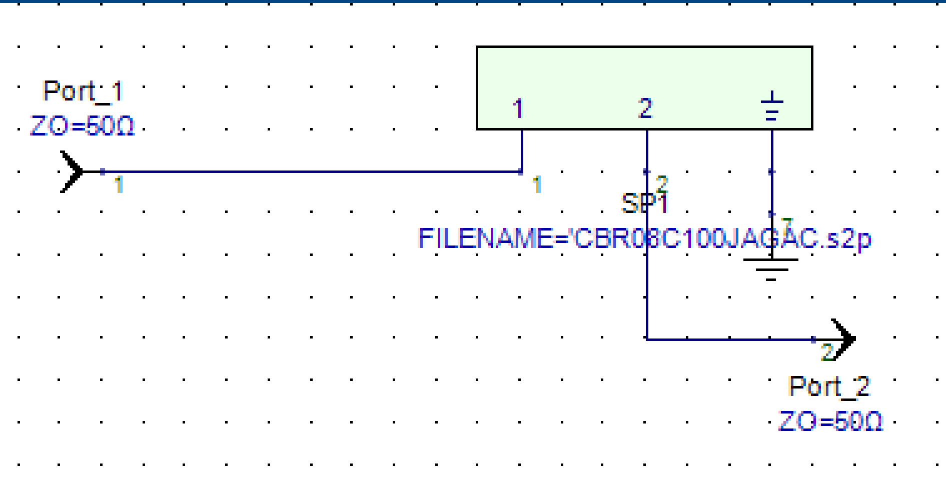
S-Parameters
How Designers Use Them?

- RF designers use simulation tools to run analysis on circuits similar to P-Spice.
  - Keysight's Advanced Design Systems (ADS)
  - Keysight's Eagleware Genesys
  - AWR's Microwave Office



Schematic of circuit to simulate S-Parameter file in Eagleware Genesys

```
!Agilent Technologies,E5071C,MY46109480,A.09.54
!Date: Tue Oct 11 20:23:29 2011
!Data & Calibration Information:
!Freq    S11:SOLT2(ON)    S21:SOLT2(ON)    S12:SOLT2(ON)    S22:SOLT2(ON)
# Hz S dB R 50
50000000        -3.760025e-001  -1.745230e+001  -1.070520e+001  7.279950e+001   -1.070309e+001  7.281087e+001   -3.737441e
74937500        -8.168459e-001  -2.525207e+001  -7.644260e+000  6.481506e+001   -7.641570e+000  6.482366e+001   -8.142310e
99875000        -1.360752e+000  -3.223251e+001  -5.704231e+000  5.780029e+001   -5.702769e+000  5.781035e+001   -1.357891e
124812500       -1.973216e+000  -3.834190e+001  -4.391318e+000  5.161158e+001   -4.389353e+000  5.162188e+001   -1.970618e
149750000       -2.616565e+000  -4.365442e+001  -3.463572e+000  4.626452e+001   -3.460819e+000  4.627317e+001   -2.613514e
```

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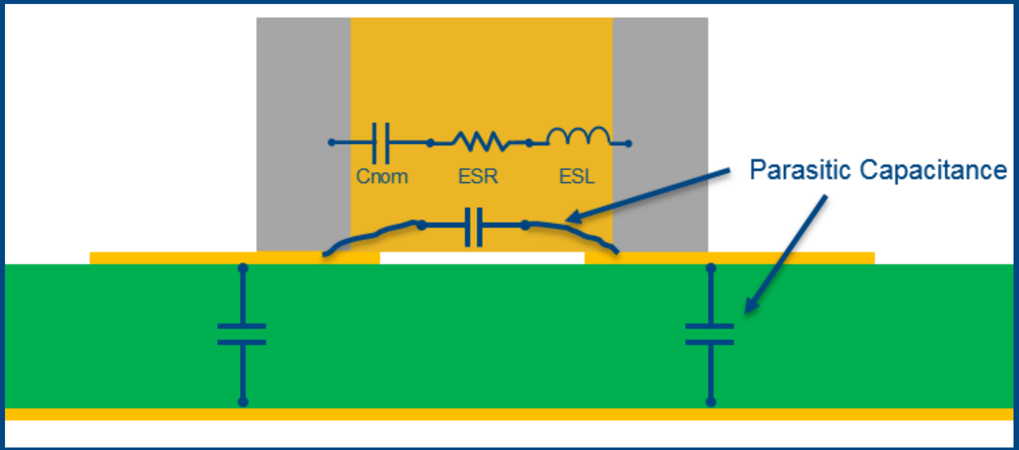
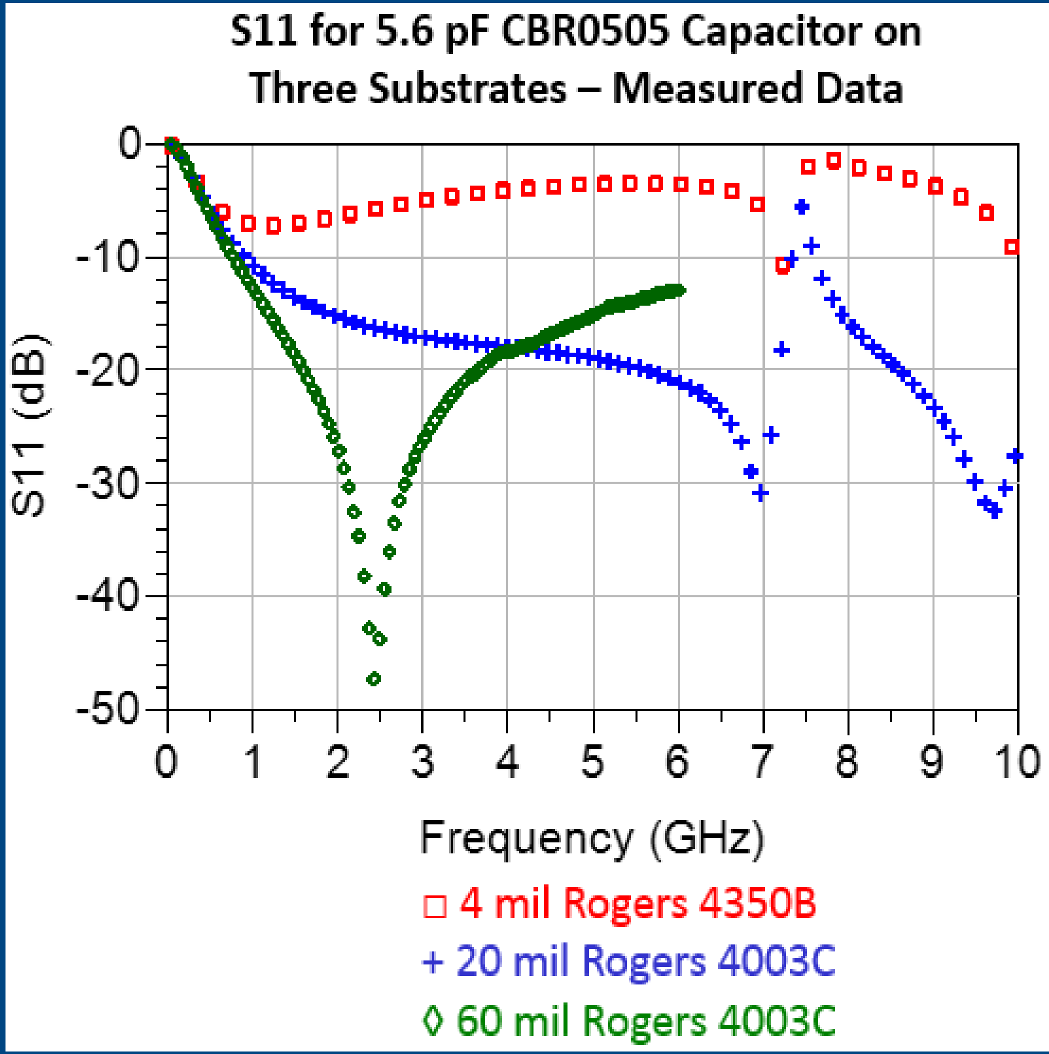
What about the substrate?

High Frequency (RF Capacitors)

- Parasitic capacitances and ESL dependent on
  - Substrate properties
    - Height
    - Er
    - Loss Tangent
    - Metal Thickness
  - Pad Dimensions
    - Length
    - Width
    - Spacing





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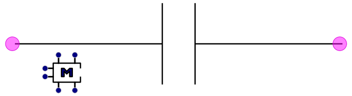
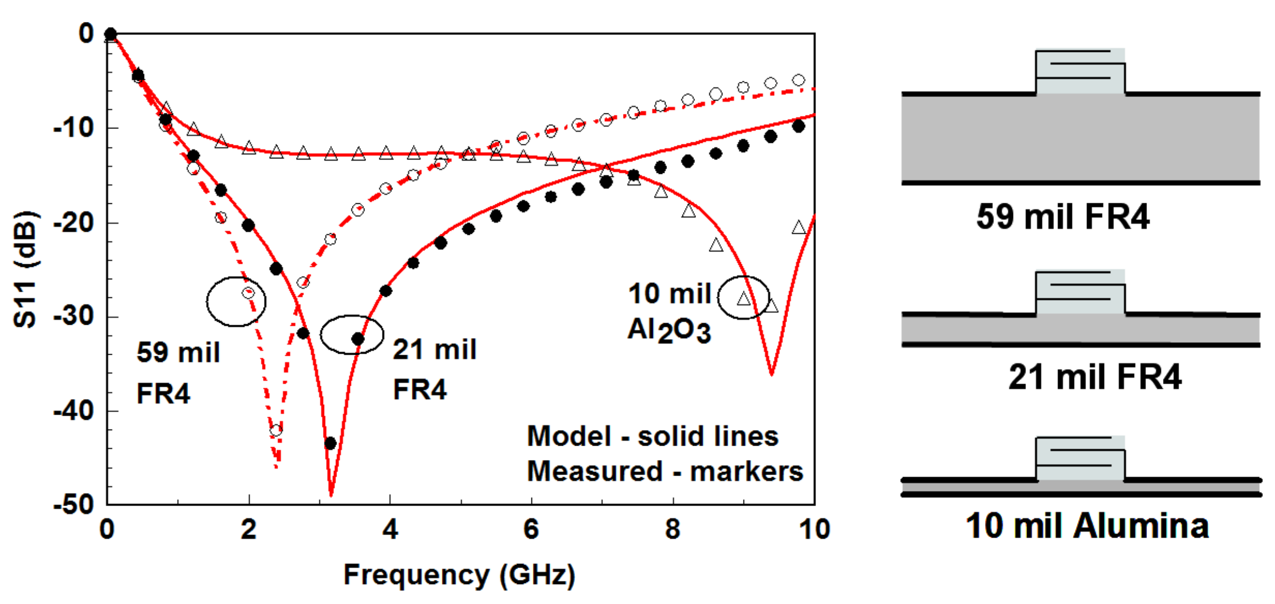
What about the substrate?

Modelithics Global Model™



CAP_KMT_0805_107_4
Part=KEMET CBR08
C=47 pF
Sim_mode=0 - Full Parasitic Model
Tolerance=1
PADW=1.45 mm
PADL=1 mm
PADG=0.6 mm
SUBST=5mil FR4



- Measurement Based
- Part Value Scalable
- Substrate Scalable
- Pad Scalable

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What about the substrate?

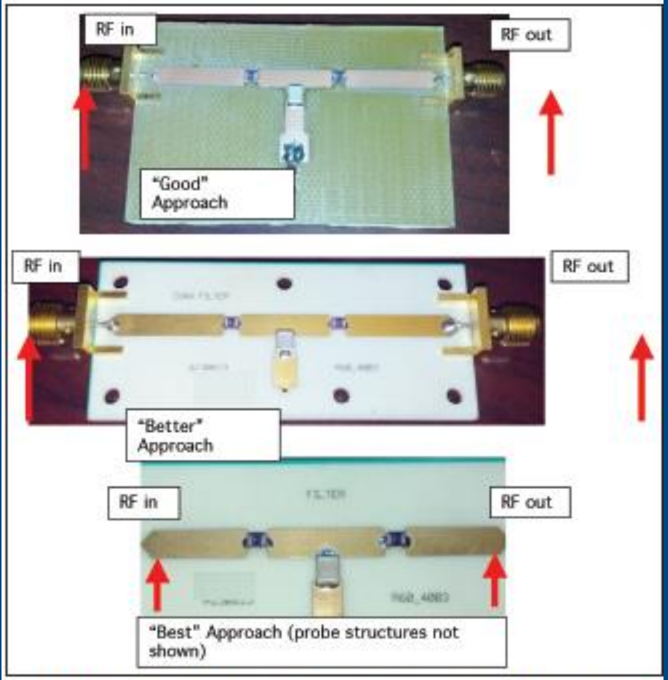

Figure 1 • Fabricated 250 MHz LPFs. "Good" approach (top image), "Better" approach (middle image), "Best" approach (bottom image); measurement reference planes indicated by the red arrows.

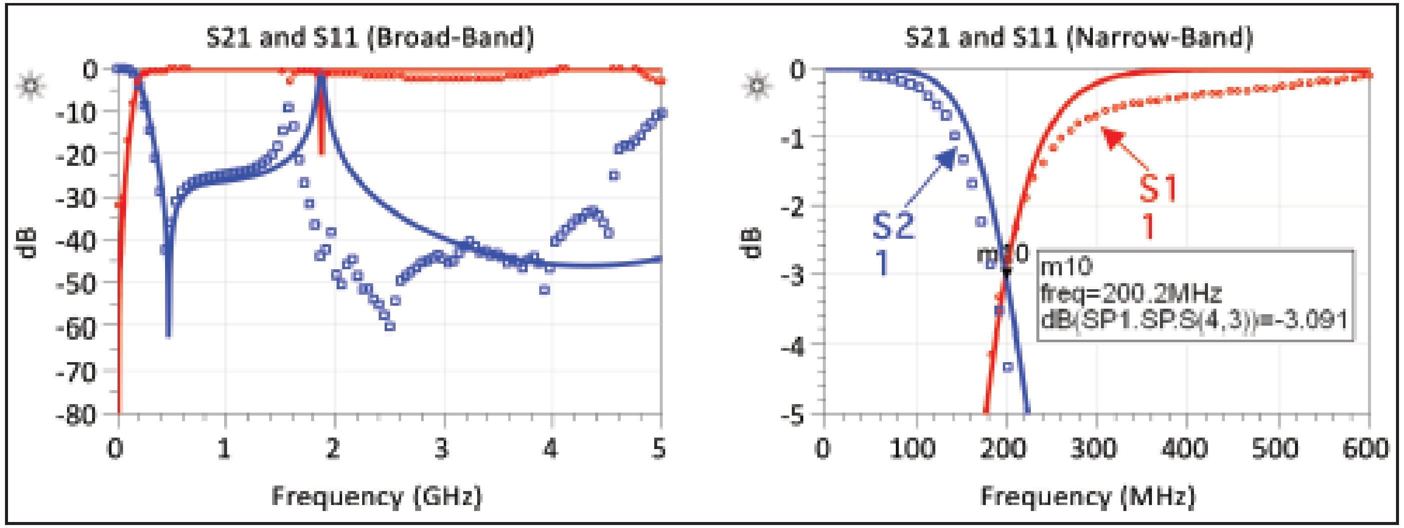

Figure 6 • Ideal "good" LPF with TL elements; measured data (symbols) vs model performance (solid line). S21 (blue) and S11 (red); broad-band (left) and narrow-band (right).

Poor Fit

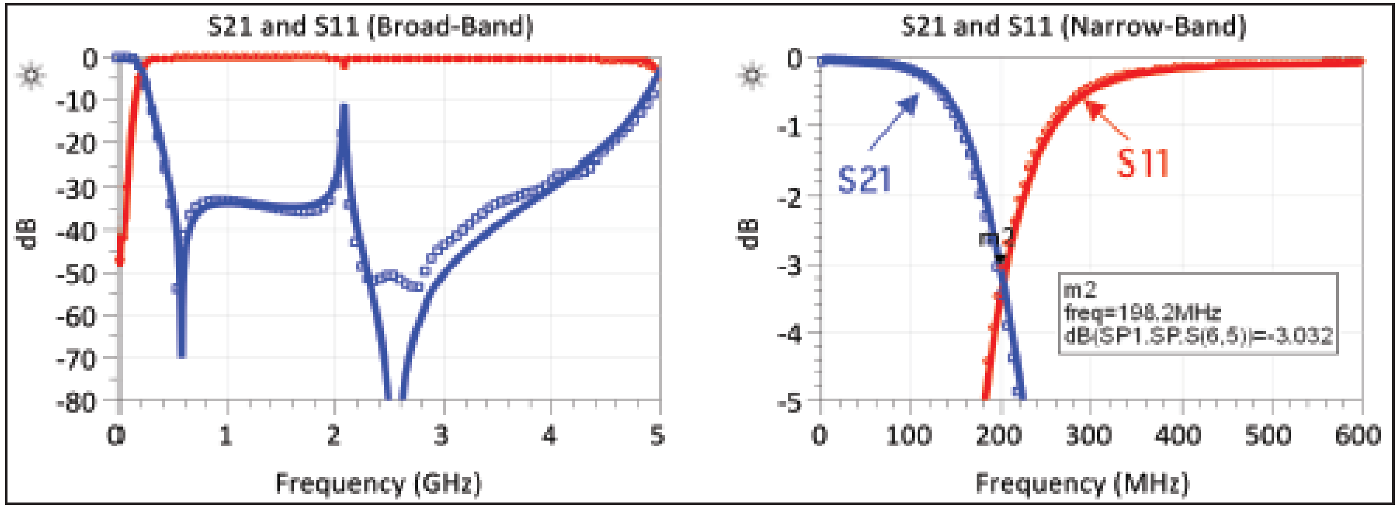

Figure 7 • Full parasitic "good" LPF; measured data (symbols) vs model performance (solid line). S21 (blue) and S11 (red); broad-band (left) and narrow-band (right).

Excellent Fit

KEMET CBR Series

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KEMET CBR Series

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Ultra High Q-CBR Squared Series Offering

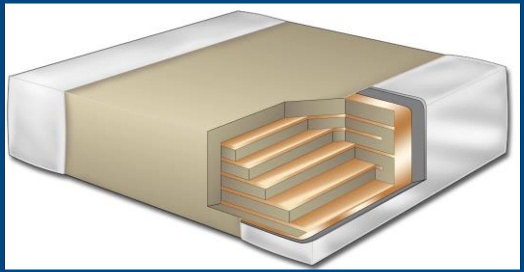
Case Size	Typical ESR (10pF @ 1 GHz)	Dielectric	Operating Frequency Range	Operating Temperature Range	Temp Coef. (TCC)	Capacitance Range	Max Voltage
0505 (NEW!)	< 0.068	C0G	1MHz - 50GHz	–55ºC to +125ºC	0 ±30 ppm/ºC	0.4pF - 100pF	250

High Q-CBR Series Offering (EIA Case Sizes)

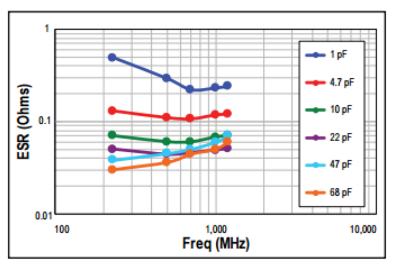
Case Size	Typical ESR Ohms (10pF @ 1 GHz)	Dielectric	Operating Frequency Range	Operating Temperature Range	Temp Coef. (TCC)	Capacitance Range	Max Voltage
0201	-	C0G	1MHz - 50GHz	–55ºC to +125ºC	0 ±30 ppm/ºC (0 ±60 ppm/ºC for 0201 case size ≥ 22 pF)	0.1pF - 33pF	50
0402	< 0.095					0.1pF - 100pF	200
0603	< 0.100					0.3pF - 100pF	250
0805	< 0.085					0.3pF - 100pF	500

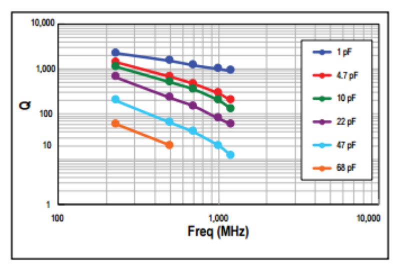
HiQ-CBR
RF & MICROWAVE

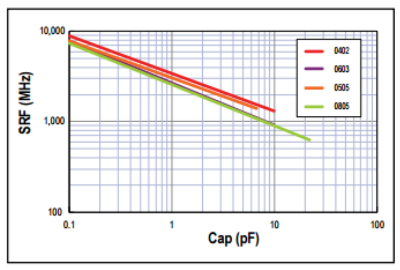
RoHS



Copper Electrodes







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Summary

KEMET CHARGED.®

- RF adoptions continues to grow
- RF capacitors are designed and optimized to
  operate at higher frequencies
- High frequencies bring unique design challenges
- Design tools are readily available

HiQ-CBR
RF & MICROWAVE

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Thank You!!!

Submit your questions to the Q&A window

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