a YAGEO company

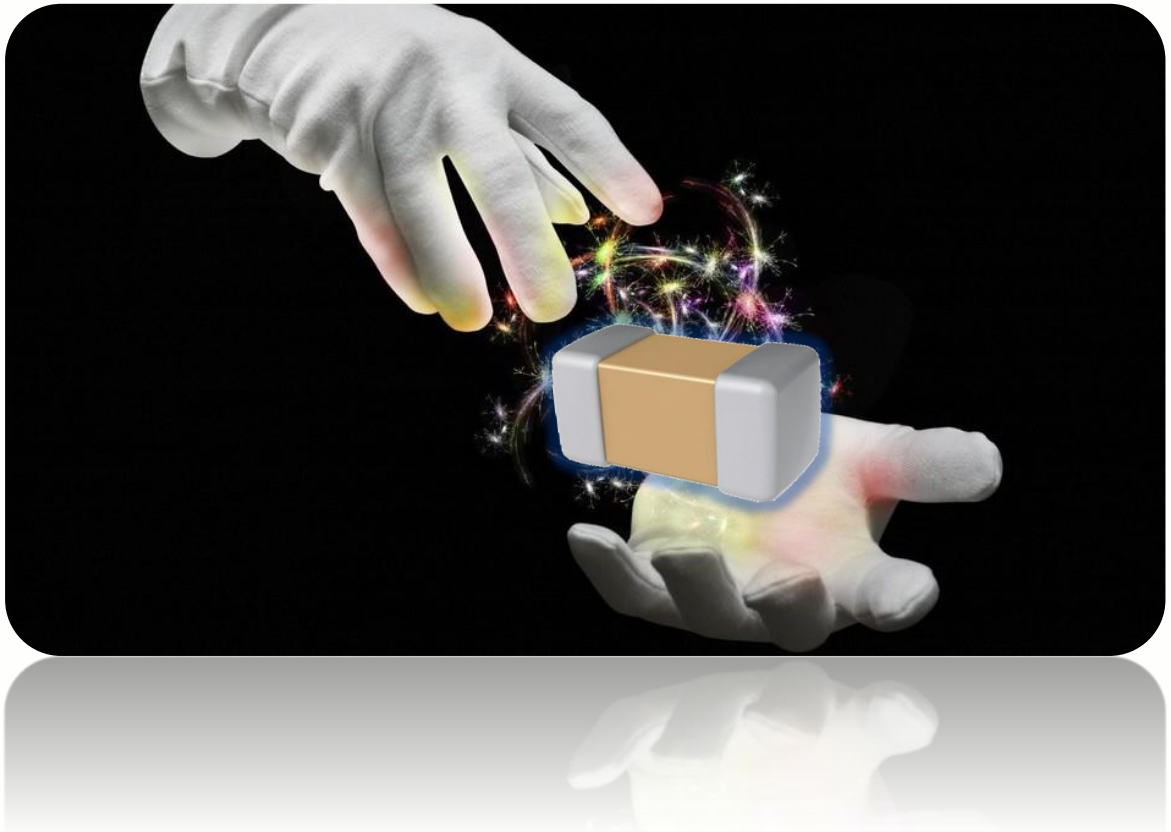
Taking the Mystery Out of RF Ceramic Capacitors

August 2021

Taking the Mystery Out of RF Ceramic Capacitors

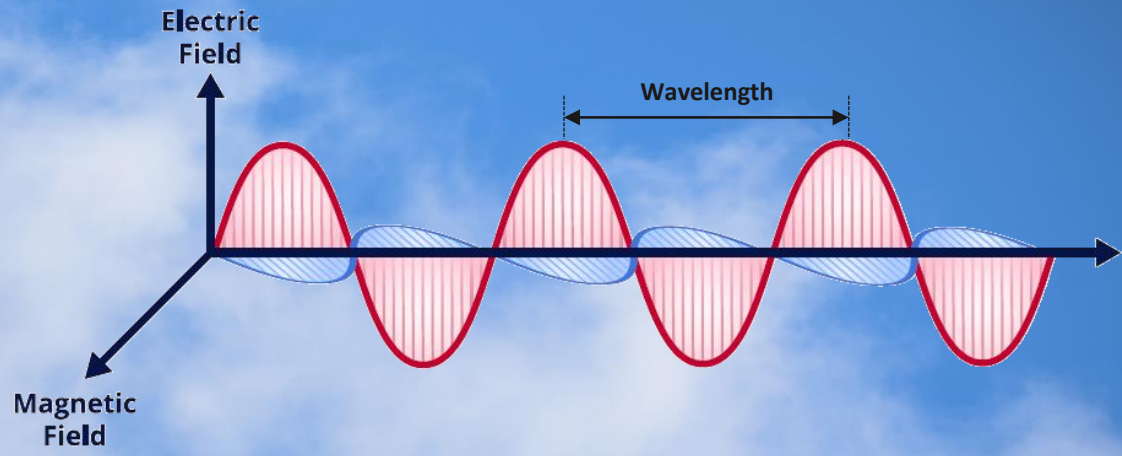
Agenda

- What is RF?
- RF Applications
- Ceramic Capacitor Basics
- What are RF Capacitors?
- KEMET HiQ-CBR Series
- Characterization and E2Di
- CBR Roadmap and Summary



What is RF?

Radio Frequency



$$frequency = \frac{C = Speed\ of\ Light}{\lambda = Wavelength}$$

10s MHz – 300GHz

“High Frequency”

RF Frequency Spectrum

RF "High Frequency" Range

Microwave Band

mmWave

Marine Navigation, Wireless Heart Rate Monitors

Navigation, RFID

AM Radio, Amateur Radio

Shortwave Radio, Aviation Communication, NVIS

VHF Television, FM Radio, Weather Radio, Line-of-Sight Communications

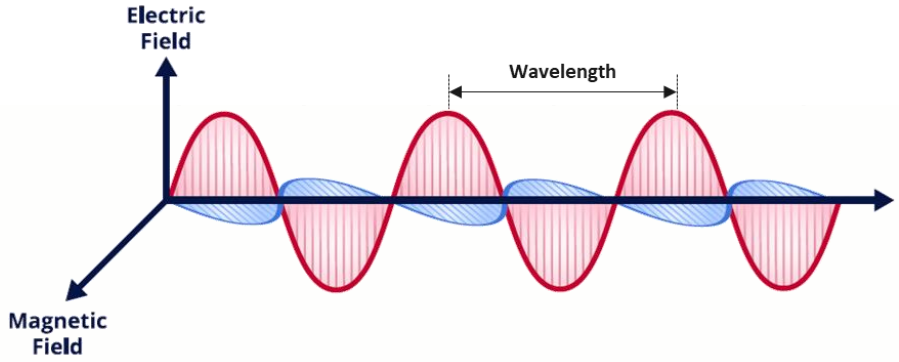
GPS, 4G Mobile Phones, Satellite Radio, Remote Control Systems

5G Mobile, Satellite Communications, WiFi

Radio Astronomy, Millimeter Wave Scanner

Designation	VLF	LF	MF	HF	VHF	UHF	SHF	EHF
Wavelength	100 km	10 km	1 km	100 m	10 m	1 m	10 cm	1 cm	1 mm
Frequency	3 kHz	30 kHz	300 kHz	3 MHz	30 MHz	300 MHz	3 GHz	30 GHz	300 GHz

4G 5G



Advantages of Higher Frequencies

- More use of the frequency spectrum
- High capacity (bandwidth) / sending more data in less time

Disadvantages of Higher Frequencies

- Shorter range
- Signals may be blocked by dense objects
- If outside, weather conditions have an impact

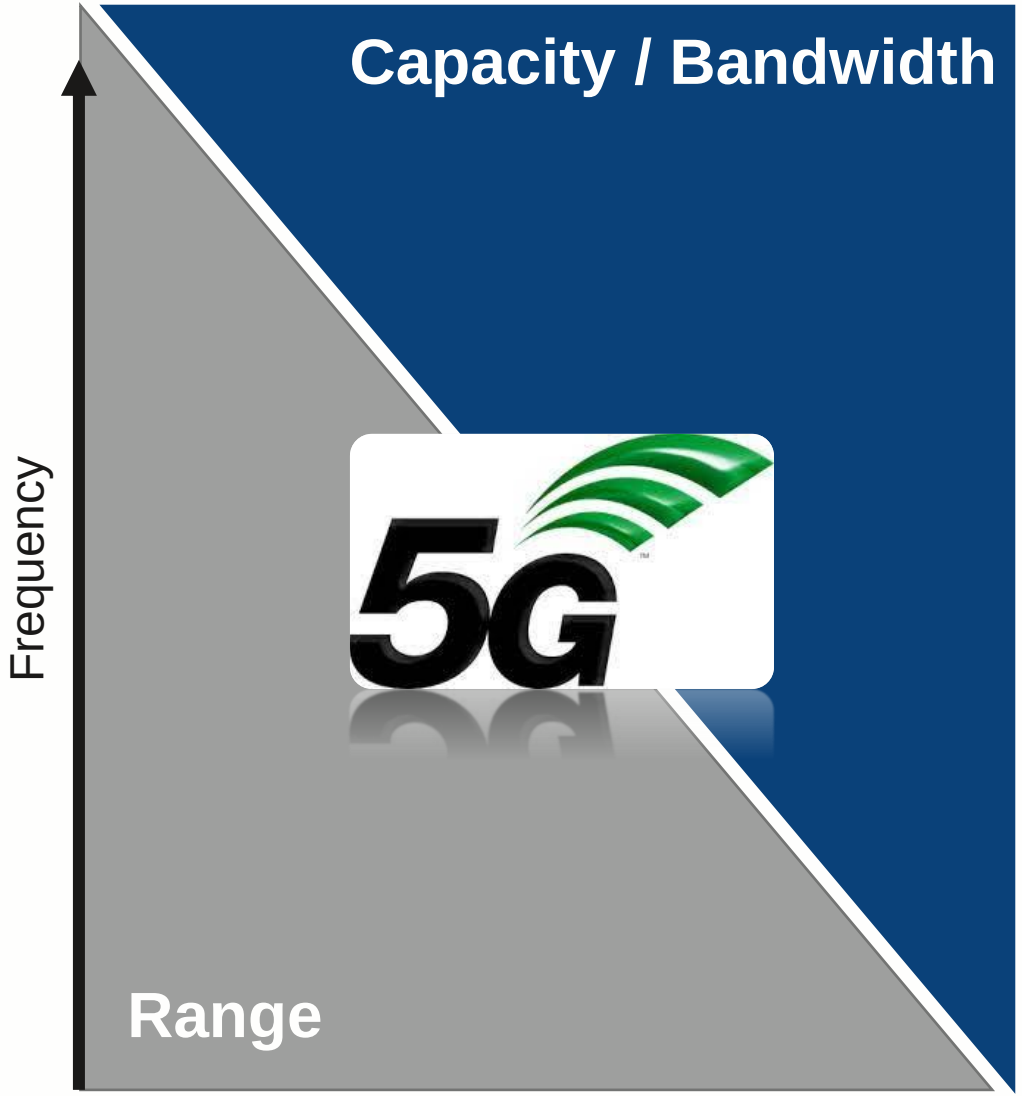
5G Technology

Capacity / Bandwidth vs Range

5G mmWave
- >24GHz

5G Mid Band
- 1GHz - 6GHz

5G Low Band
- <1GHz

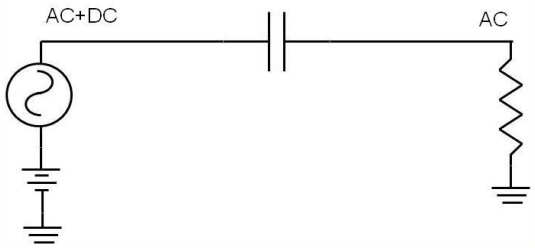


Urban Areas
Dense Population

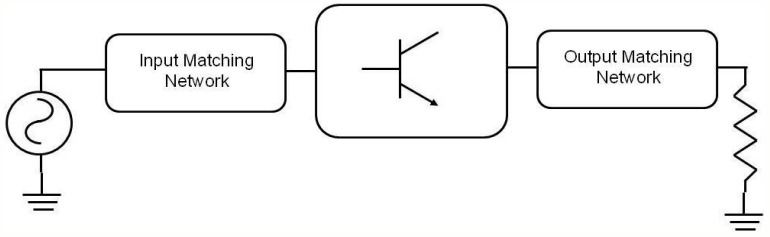
Rural Areas
Light Population

RF Capacitor Applications and Functions

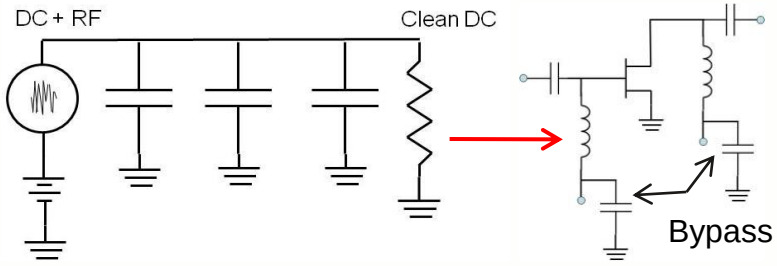
DC BLOCKING



MATCHING



BYPASS/FILTERING



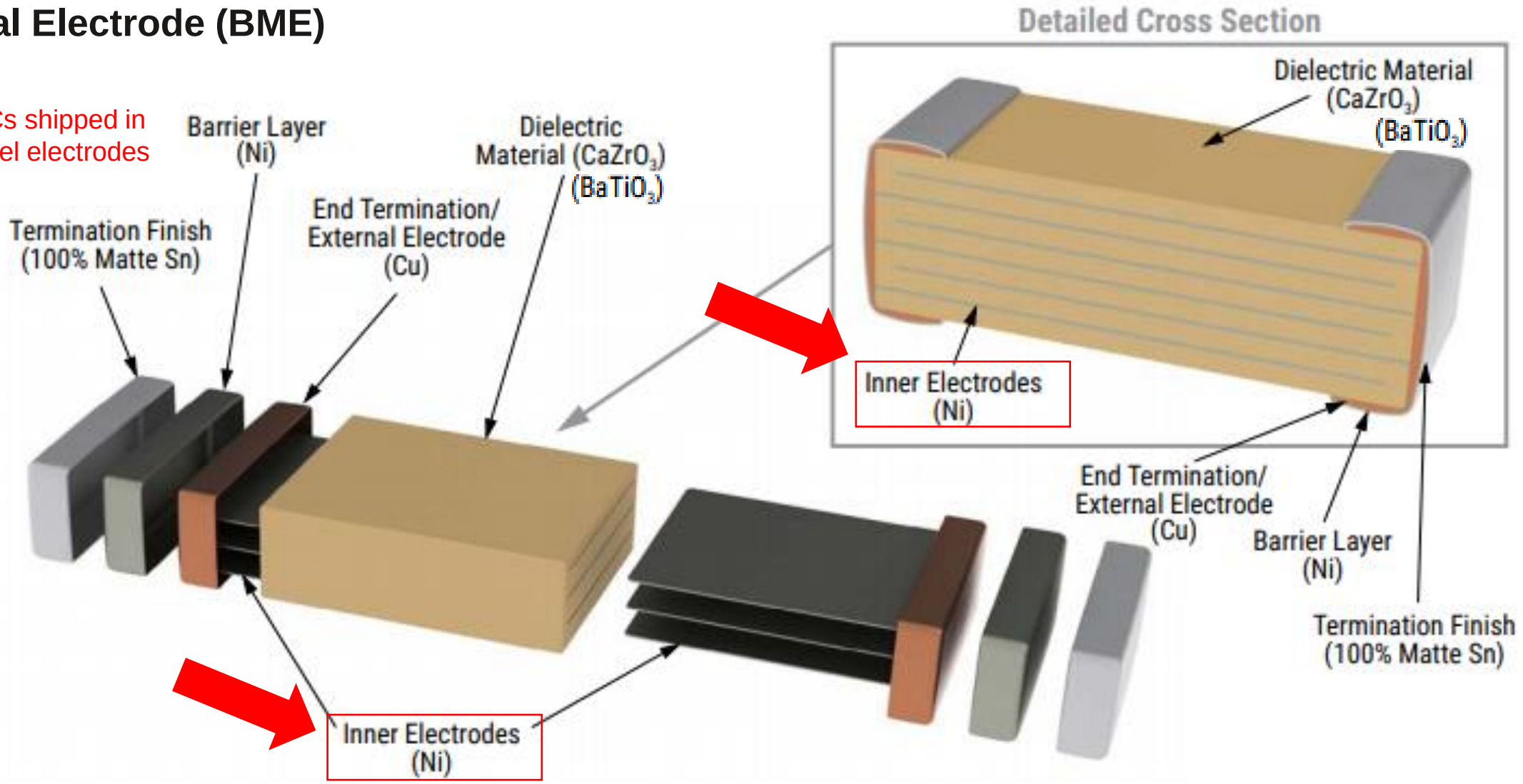
Ceramic Capacitor Basics

Ceramic Capacitor Basics

MLCC Construction

Base Metal Electrode (BME)

>99.9% of all MLCCs shipped in the world used Nickel electrodes



Ceramic Capacitor Basics

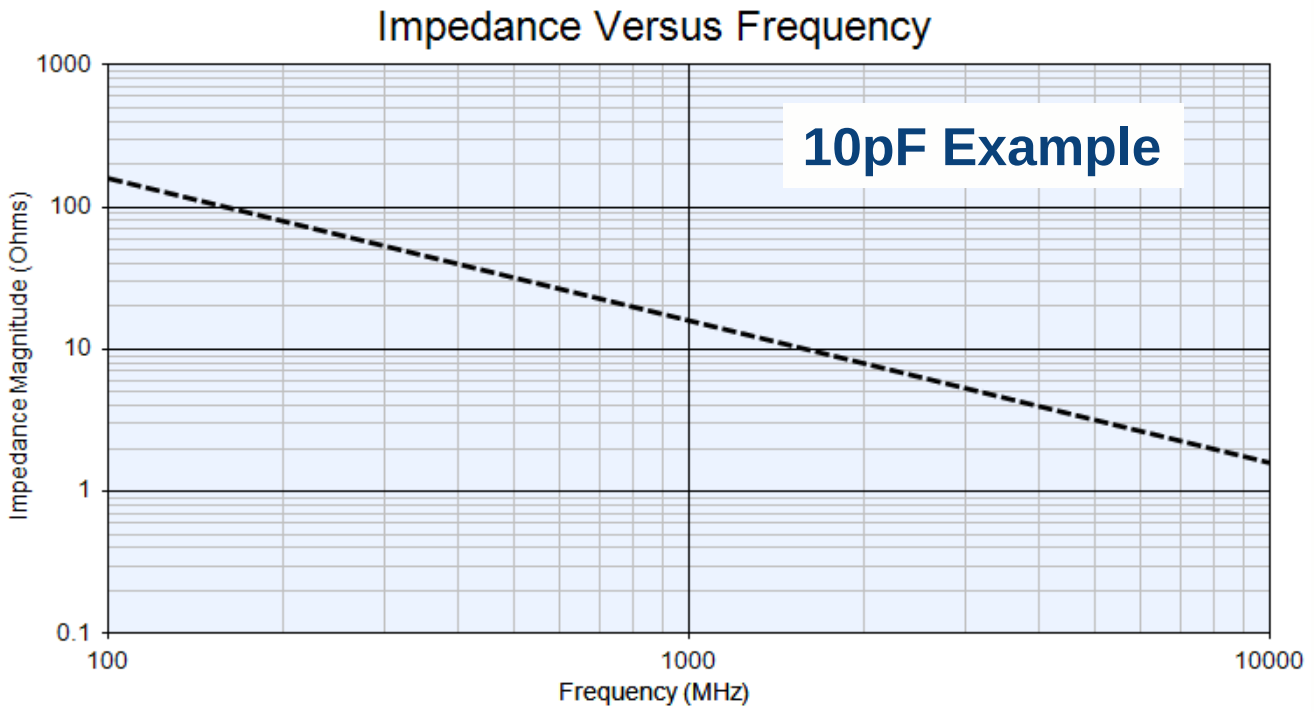
Ideal Capacitor

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

Ideal Model

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

$$Z = Total\ Impedance$$



Ceramic Capacitor Basics

Real Capacitor

- Real Capacitor
  - C - Nominal capacitance
  - ESR – Equivalent Series resistance
  - ESL - Equivalent Series inductance

Simplified Real Model

C ESR ESL

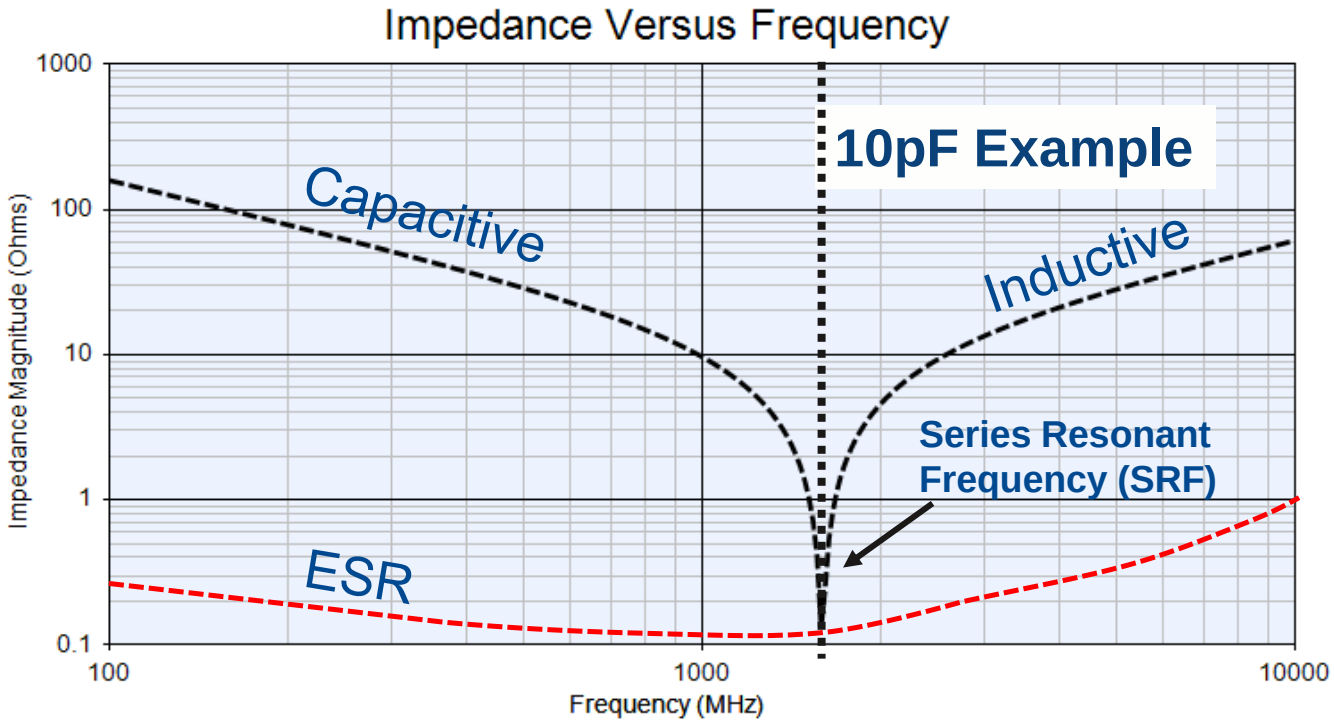
$$Z = \sqrt{ESR^2 + (X_L - X_C)^2}$$

$Z = Total\ Impedance$

$ESR = Equivalent\ Series\ Resistance$

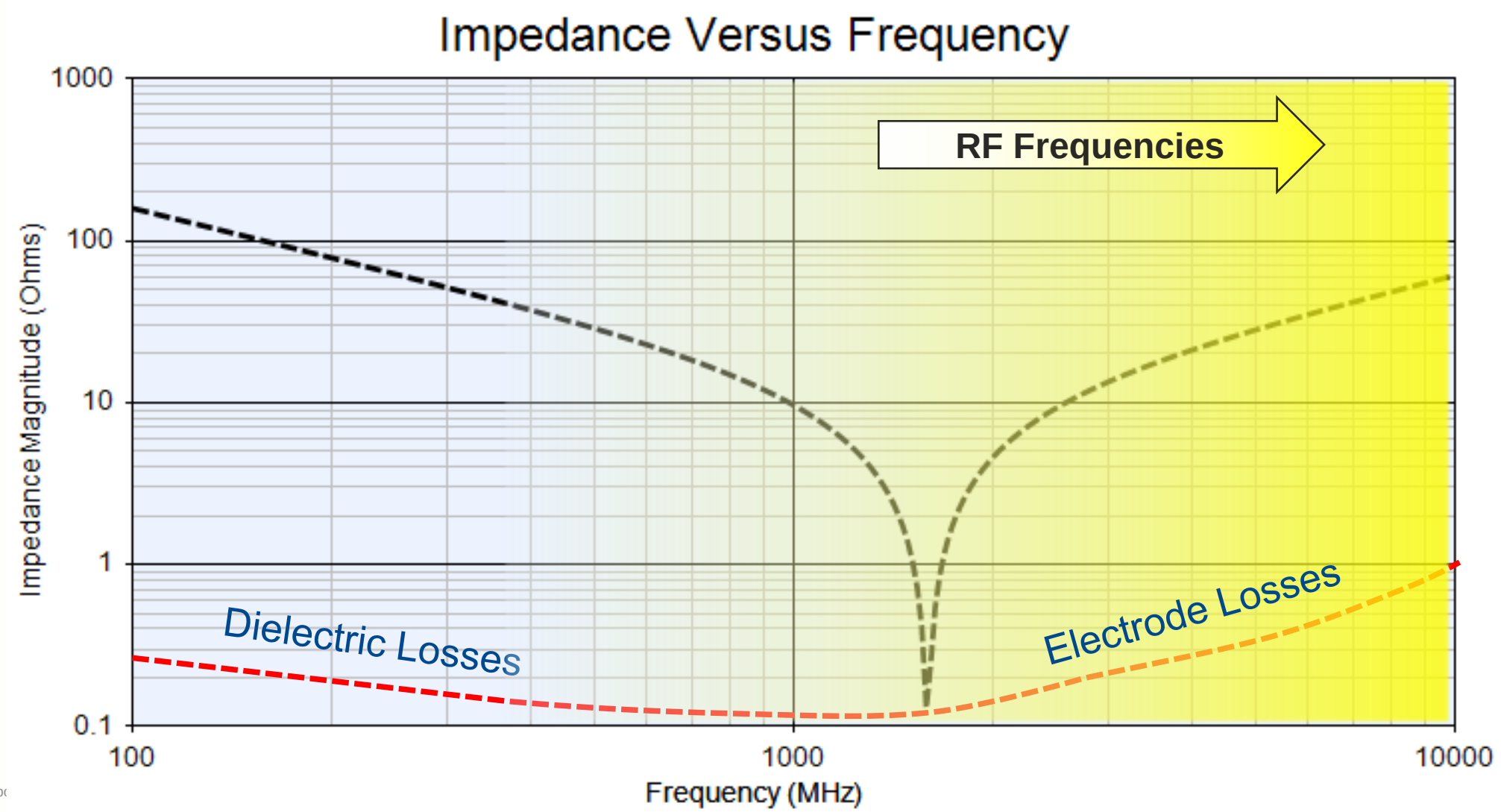
$X_C = Capacitive\ Reactance$

$X_L = Inductive\ Reactance$



Ceramic Capacitor Basics

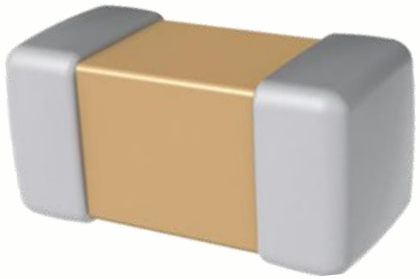
Closer Look at ESR



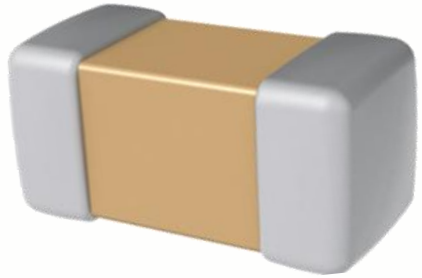
RF Capacitors

What's the Difference?

"Standard" Ceramic Capacitor



RF Ceramic Capacitor



Key Characteristics for Capacitors in RF Applications

What's Important for Design Engineers?

Most Important

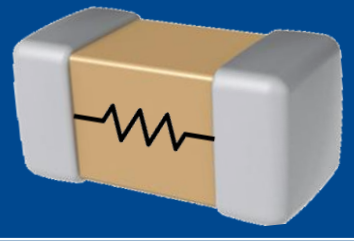
ESR @High Frequencies

Low

Equivalent Series Resistance

$$Power\ Dissipation = i^2 * ESR$$

$$ESR \rightarrow Waste\ as\ Heat$$



Q @High Frequencies

High

Quality Factor "Efficiency"

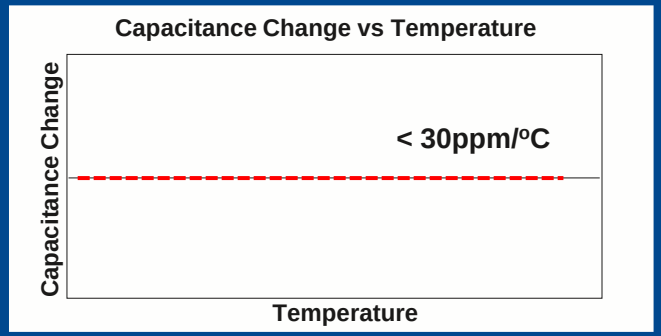
$$Q = \frac{X}{ESR}$$

$$\boldsymbol{Low\ ESR \rightarrow High\ Q}$$

TCC

Low

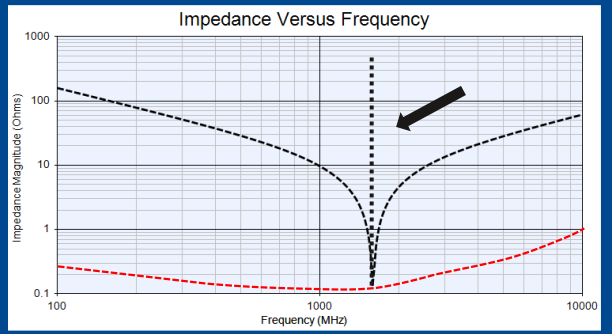
Capacitance Change with Temperature



SRF

High

Series Resonant Frequency



So, What is an RF Capacitor?

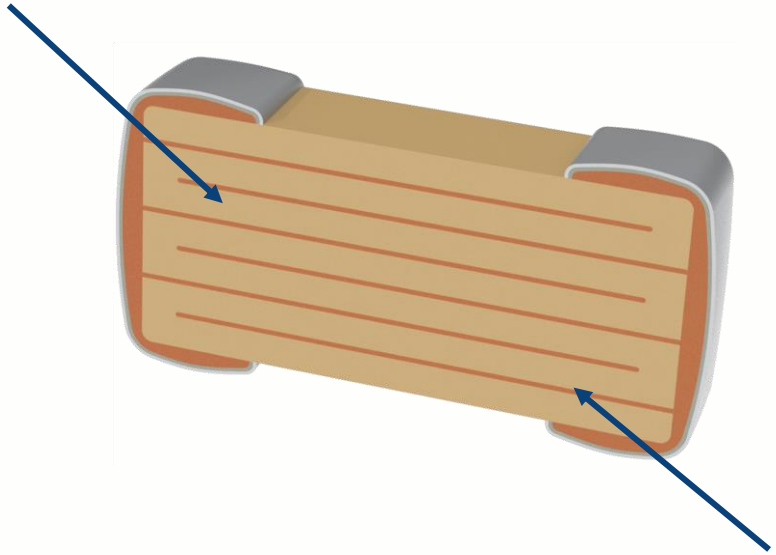
An RF capacitor is a capacitor whose "characteristics" are optimal at RF frequencies

Key Characteristic	RF Capacitor Requirements
ESR (Equivalent Series Resistance)	Lowest possible ESR at RF frequencies
Q (Quality Factor)	High Q at RF frequencies
SRF (Series Resonant Frequencies)	High SRF as high as possible
TCC (Temperature Coefficient of Capacitance)	Minimal capacitance shift across temperature

So, for RF capacitors, materials are chosen, and designs are optimized so that the capacitor's characteristics are optimal at the higher frequencies.

Optimizing MLCCs for RF Applications

Design	Design Goal	How?
Dielectric	• Low ESR / High Q • Temperature and Voltage Stability	Typically, High Q class 1 dielectrics such as C0G or NPO



Design	Design Goal	How?
Electrodes	• Low ESR / High Q • Low Inductance	• Non-ferrous materials • No Nickel electrodes • Copper (BME)

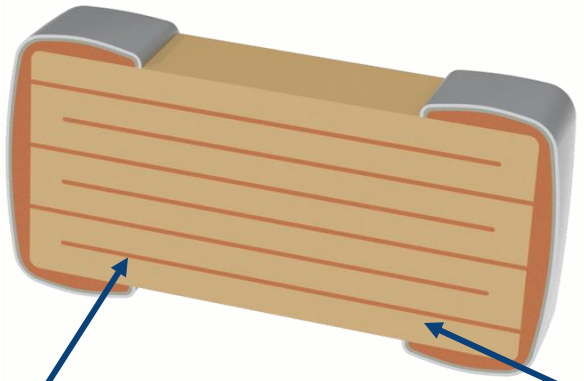
KEMET HiQ-CBR Series

KEMET HiQ-CBR Series RF & Microwave

Commercial and Automotive Grade

- RF Power Amplifiers, Base Stations, Radios, Wearables, etc.
  V2X, Automotive Communication Systems
- AEC-Q200 Qualified (Automotive Grade Only)
- RF, Microwave, mmWave Bands
  1 MHz to 50 GHz
- Ultra-Low ESR, High Q
- 0201 – 0805 EIA Case Sizes
- 0.1pF – 100pF
- 6.3 – 500 Vdc

RoHS | REACH COMPLIANT | Lead-free



Copper Electrodes

- Low ESR
- High Q
- High SRF

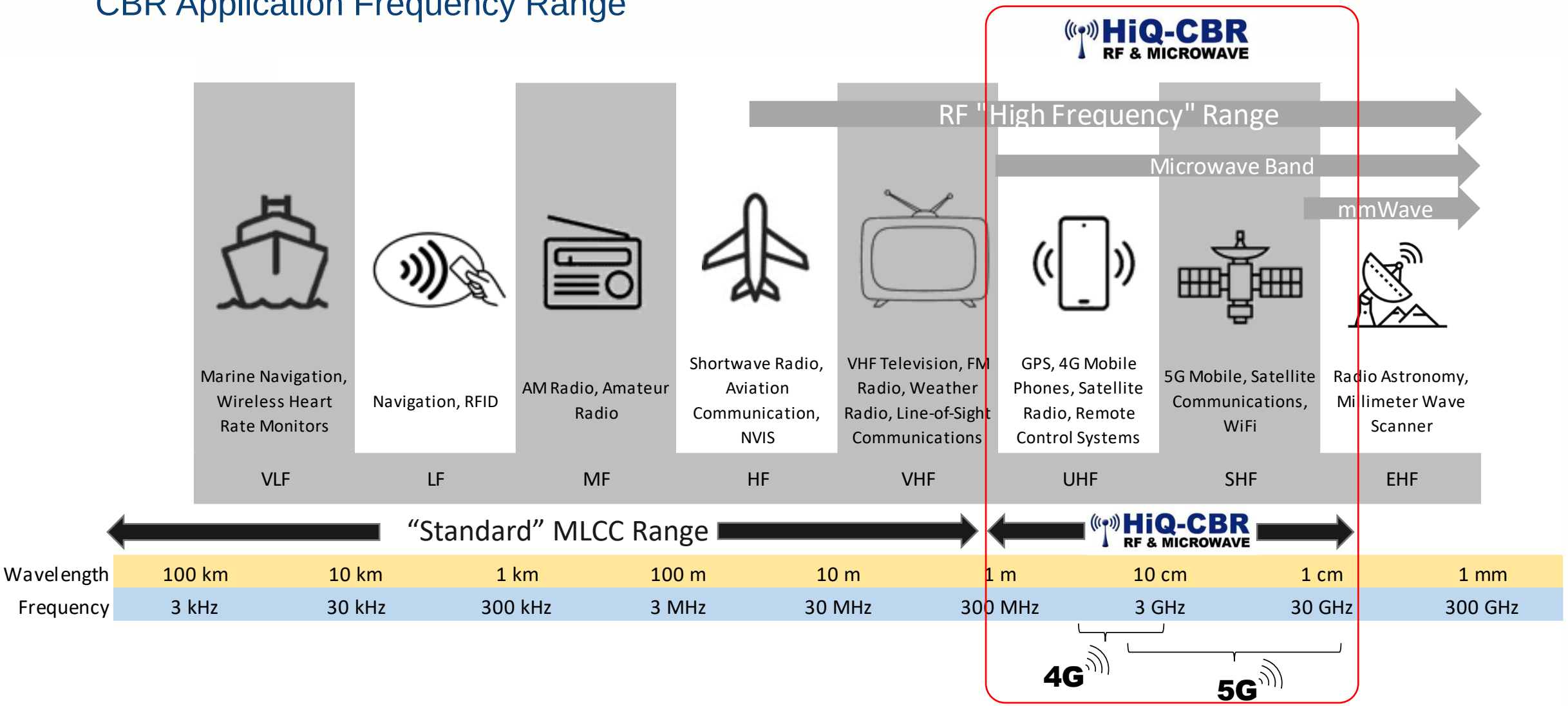
High Q BME Class 1 Dielectric

- Low ESR
- High Q
- Low TCC

Downloadable S-Parameters Available
Advanced Modelithics™ Models

KEMET HiQ-CBR Series

CBR Application Frequency Range



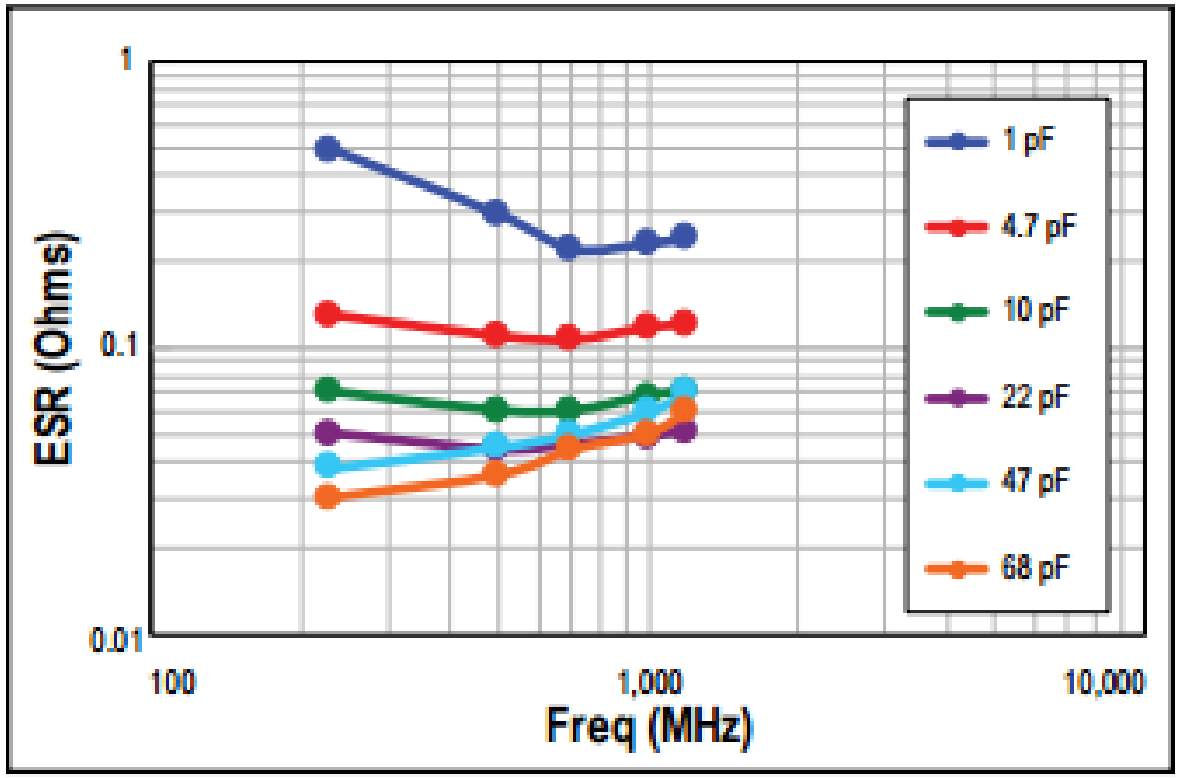
KEMET CBR Characterization and E2Di

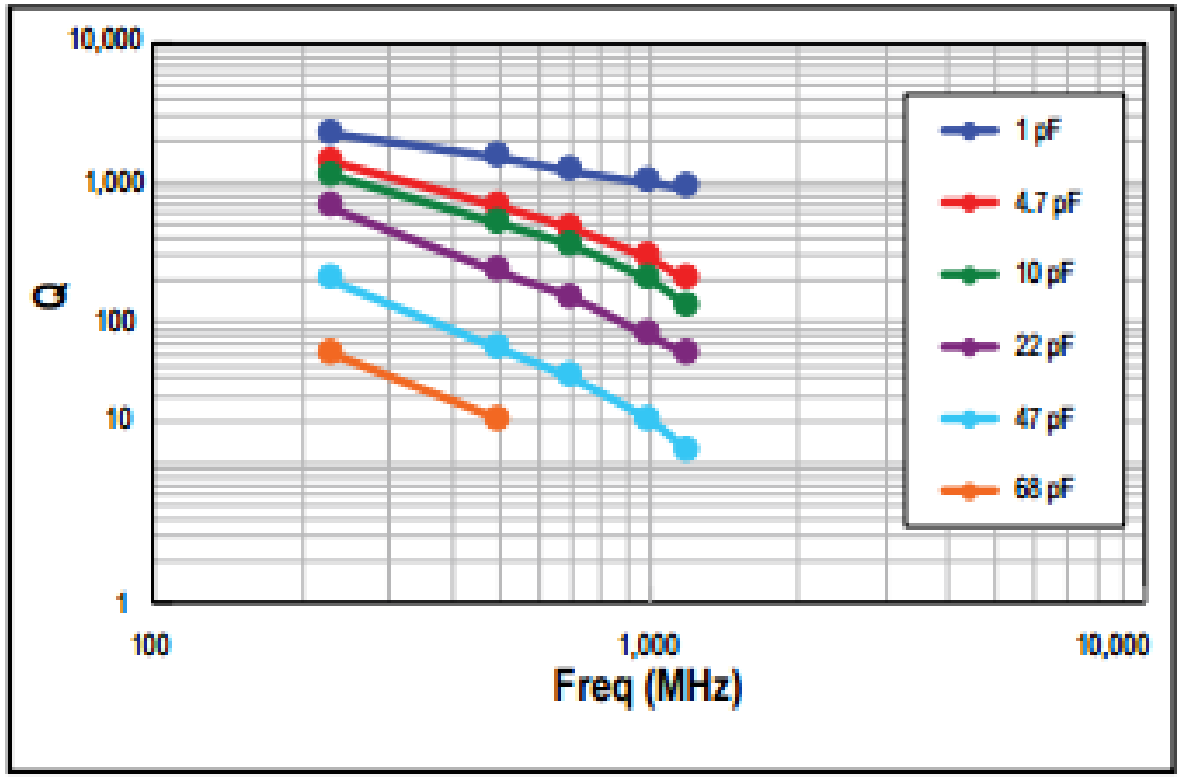
“Why is KEMET’s CBR Series not in the KSIM tool?”

ESR and Q

HiQ-CBR
RF & MICROWAVE

KEMET
a YAGEO company



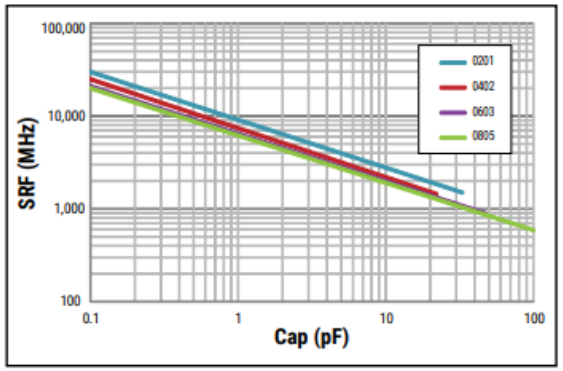


Boonton 34a – ESR and Q Measurements

ESR, Q, and SRF
Datasheet Availability

E2Di EASY TO DESIGN IN

SRF (MHz) vs. Cap (pF)



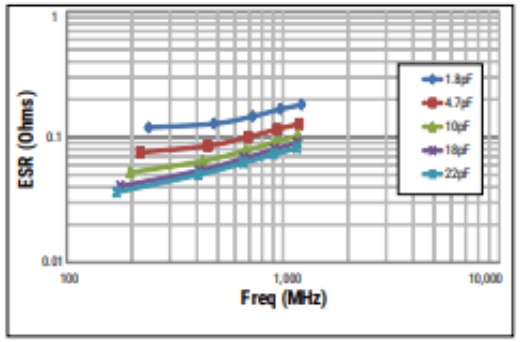
RF and Microwave

Ultra HiQ-CBR Squared, C0G Dielectric, 250 VDC
HiQ-CBR, C0G Dielectric, Low ESR, 6.3 - 500 VDC

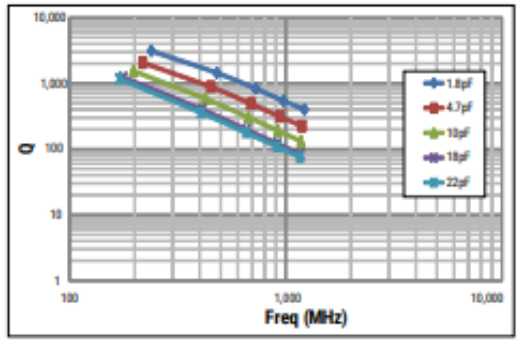
https://www.kemet.com/en/us/capacitors/ceramic.html#tab-datasheets

Electrical Characteristics cont.

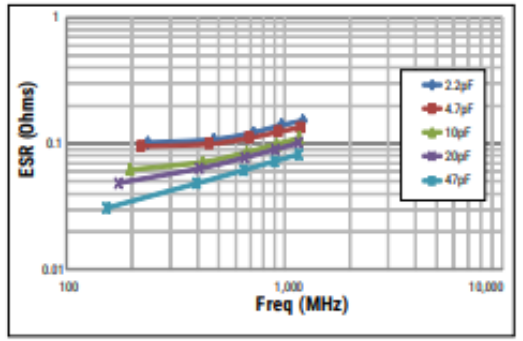
ESR vs. Frequency 0402



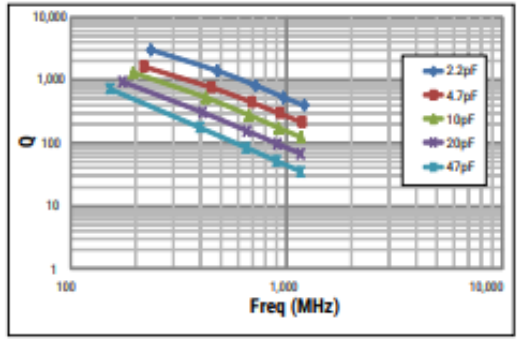
Q vs. Frequency 0402



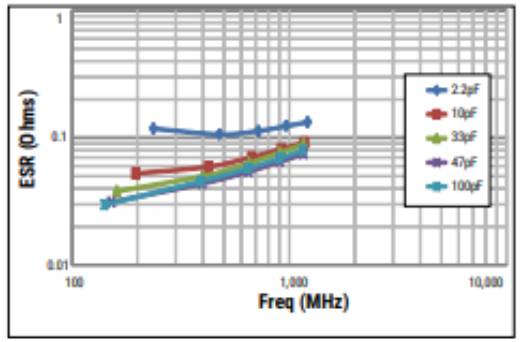
ESR vs. Frequency 0603



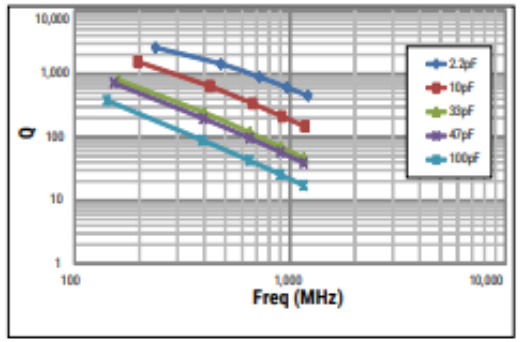
Q vs. Frequency 0603



ESR vs. Frequency 0805



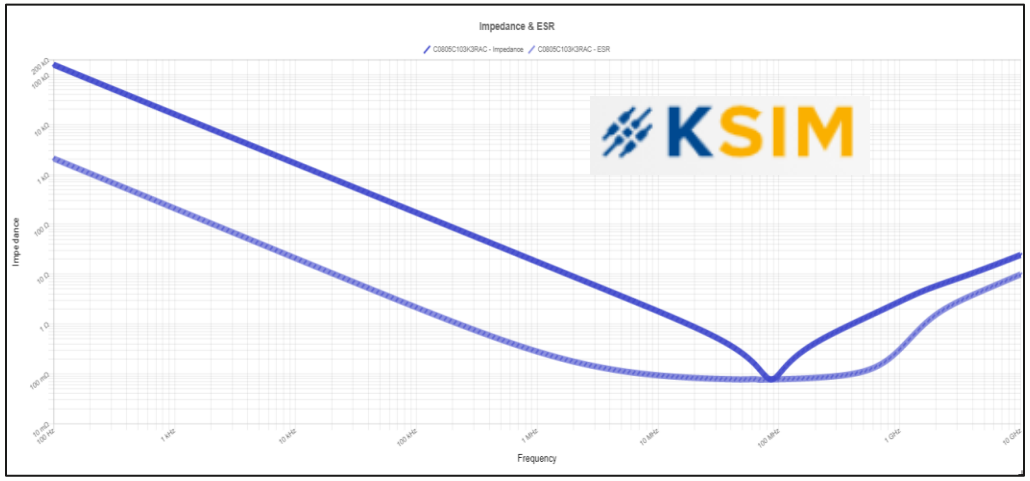
Q vs. Frequency 0805

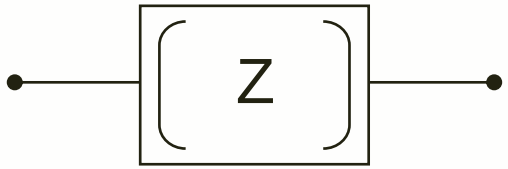


S-Parameters

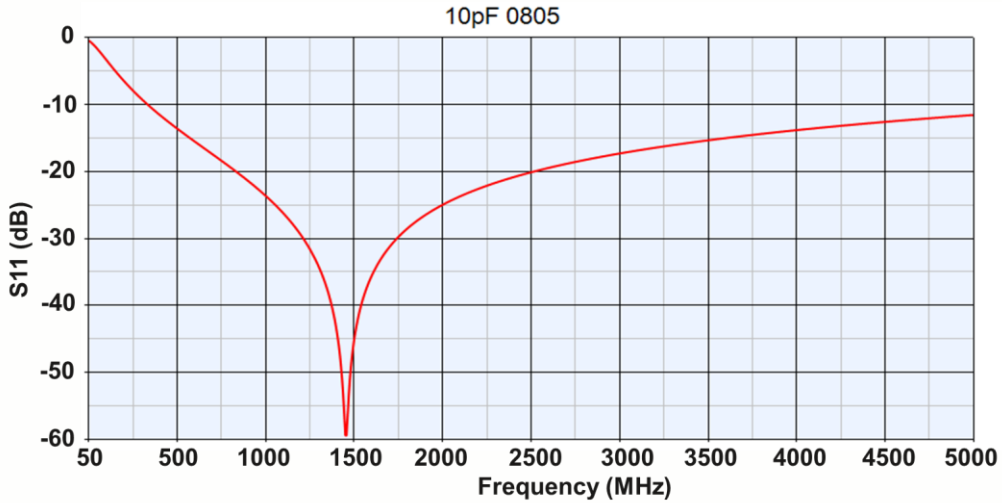
Low Frequency Design vs High Frequency “RF” Design

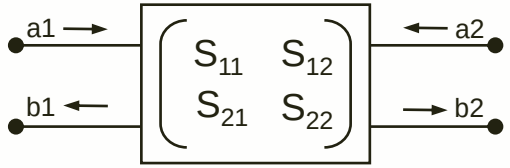
Impedance / ESR Approach





S-Parameter Network Approach

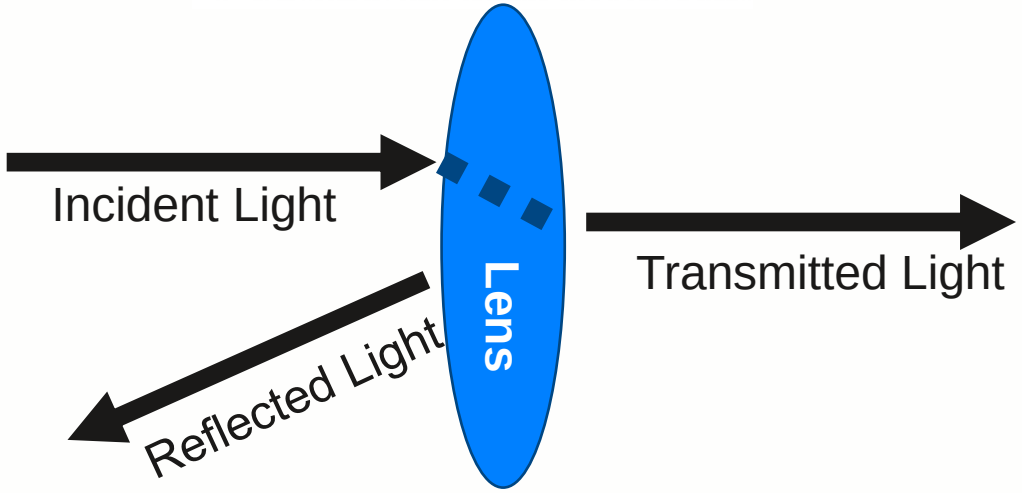




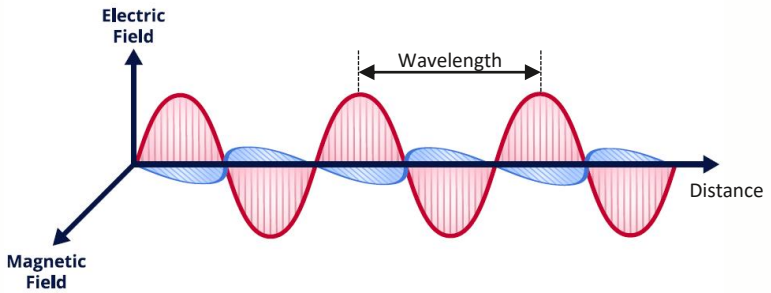
S-Parameters (Scattering Parameters)

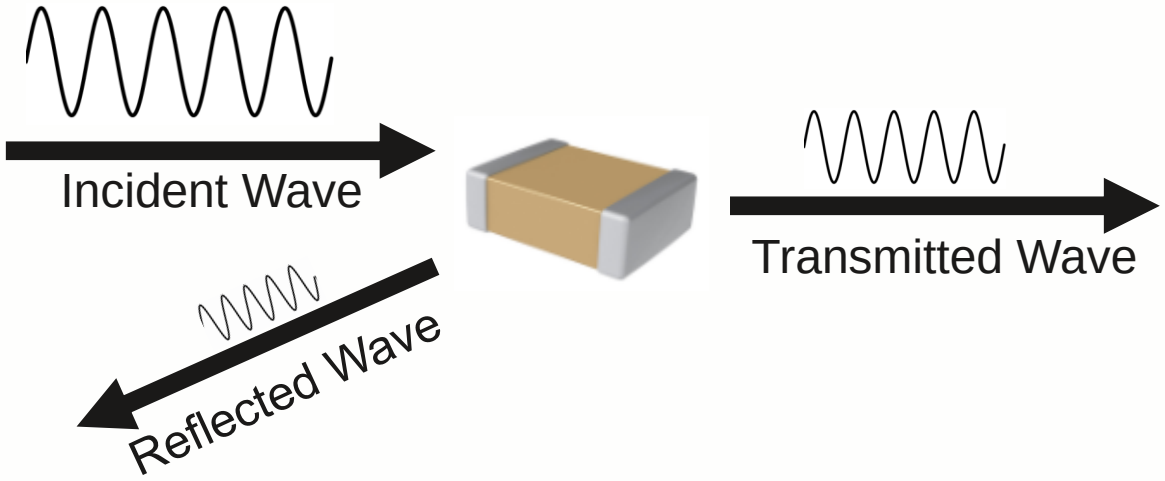
What are they?

Light Analogy



RF Voltage Wave

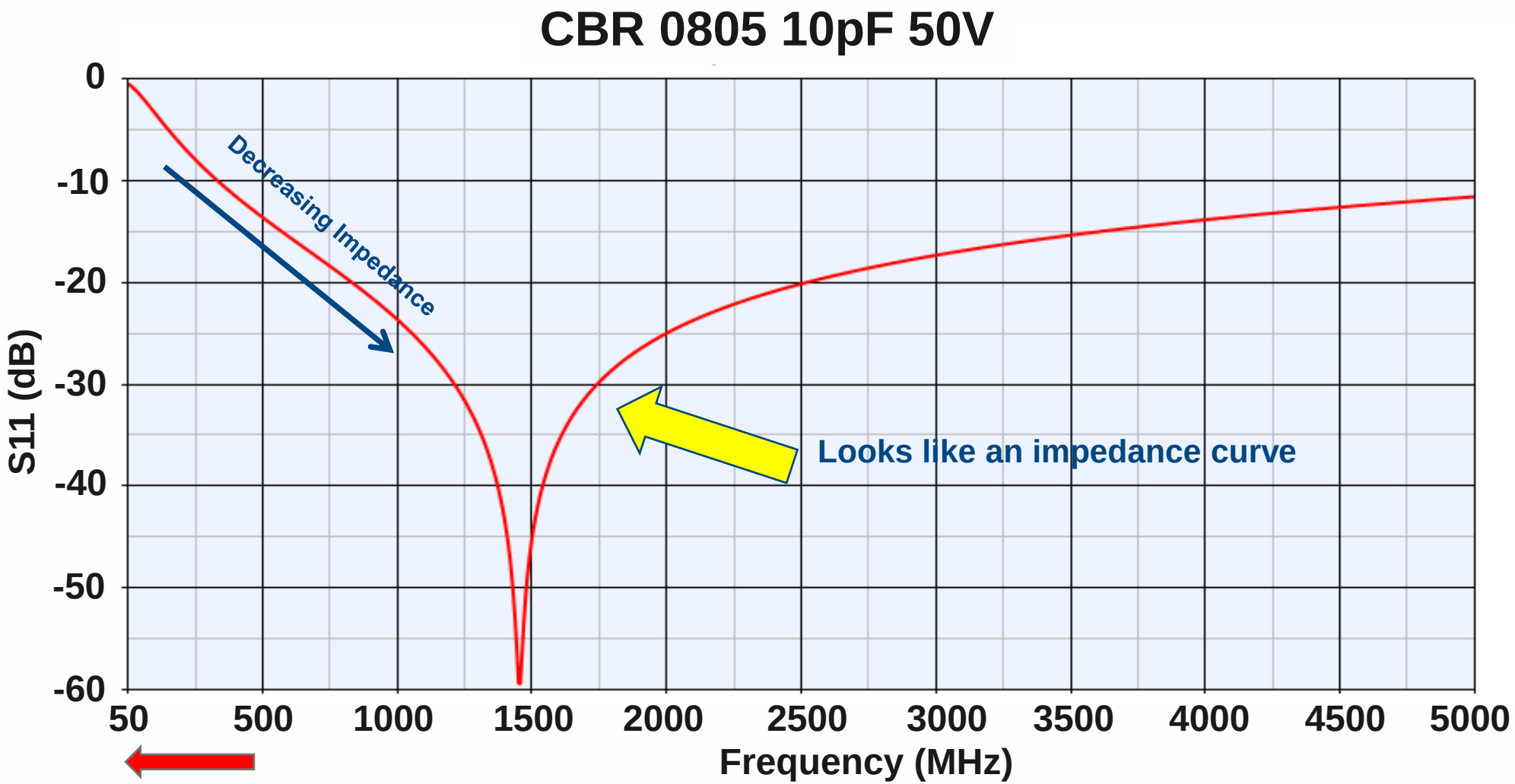




$$S_{11} = \frac{Reflected\ Wave}{Incident\ Wave} \qquad S_{21} = \frac{Transmitted\ Wave}{Incident\ Wave}$$

S-Parameters

Example of S11 Plot



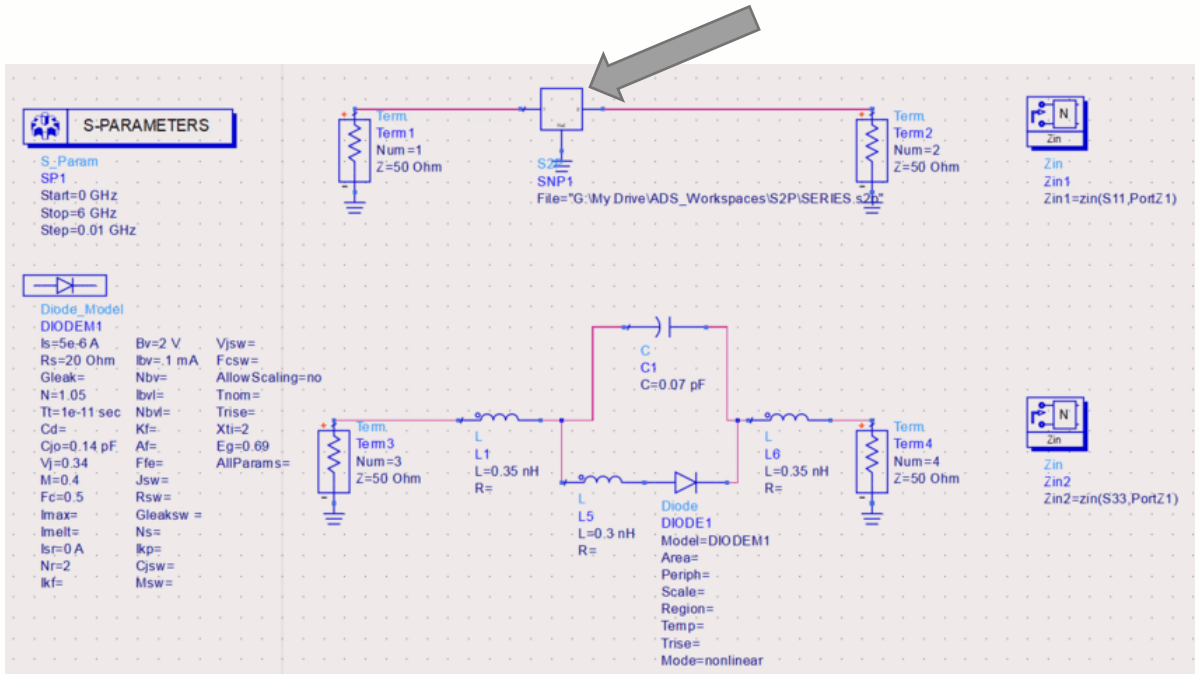
KSIM Frequency Range

S-Parameters

How Designers Use Them

RF Simulation Tools

- Keysight's Advanced Design Systems (ADS)
- Keysight's PathWave RF Synthesis (Genesys)
- Cadence AWR's Microwave Office
- Other tools available



ASCII text files - Touchtone Format

```
!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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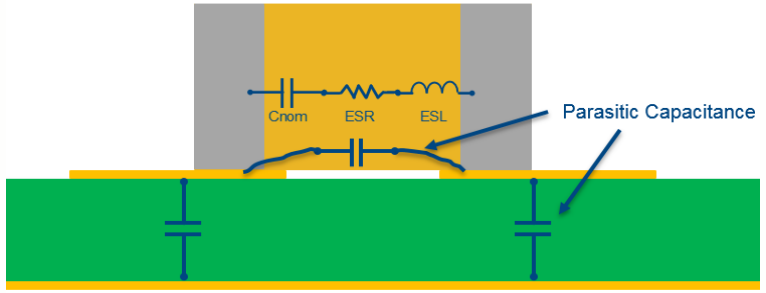
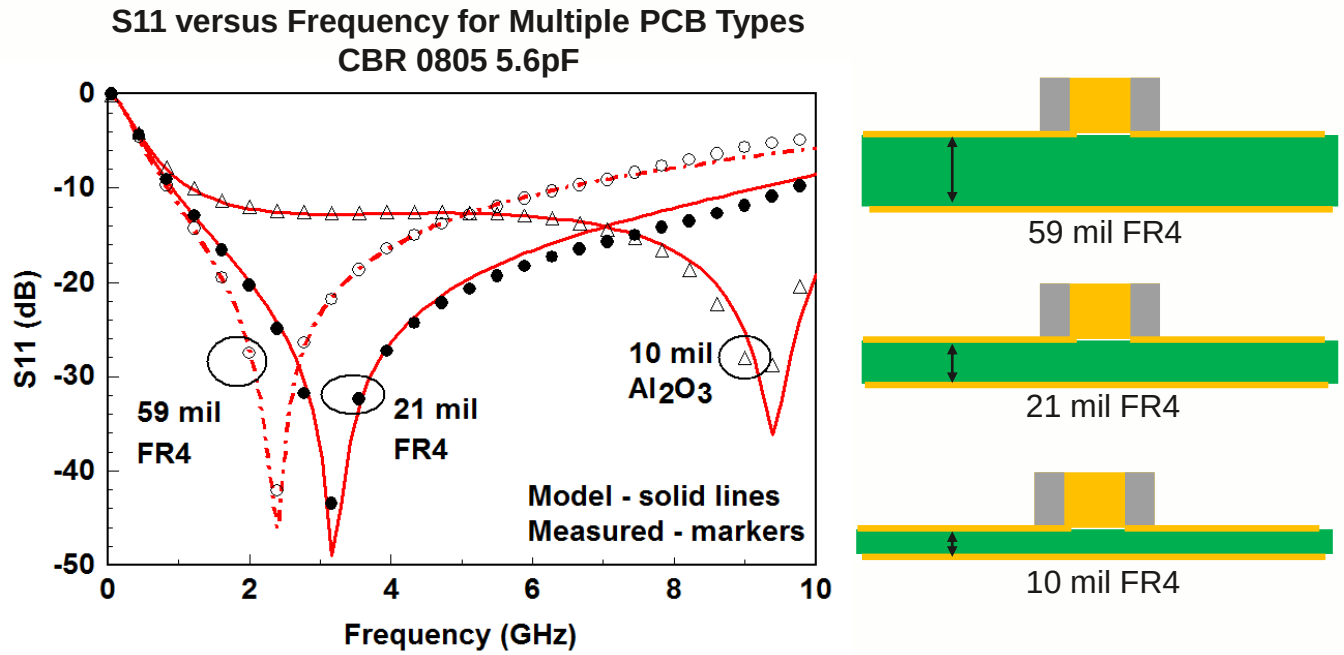
Considering Effects of the PCB and Pad Dimensions

PCB properties

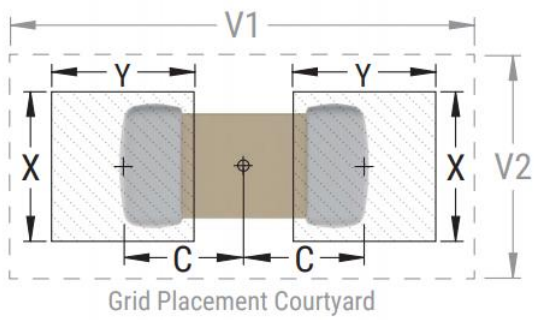
- Thickness
- Dielectric Constant
- Trace Thickness





Pad Dimensions

- Length
- Width
- Spacing



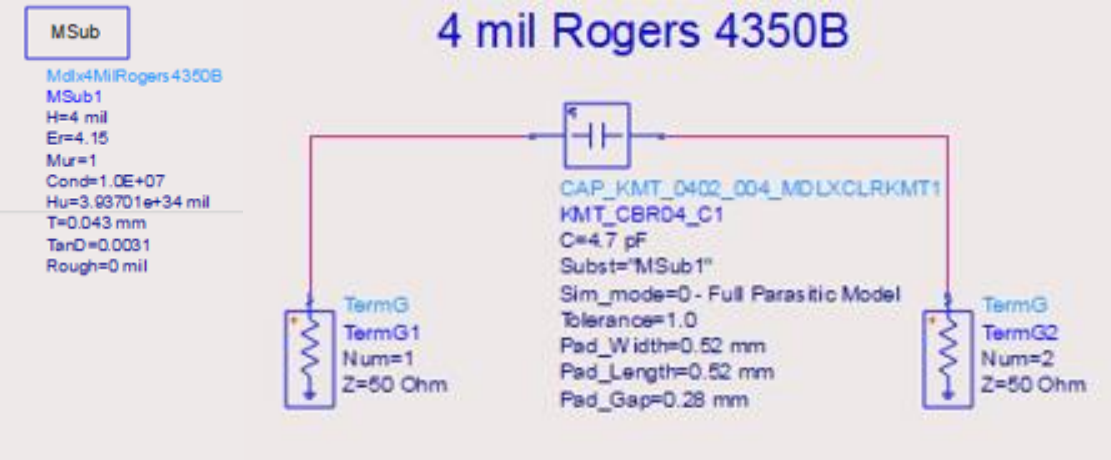
Advanced CBR Modelithics Models

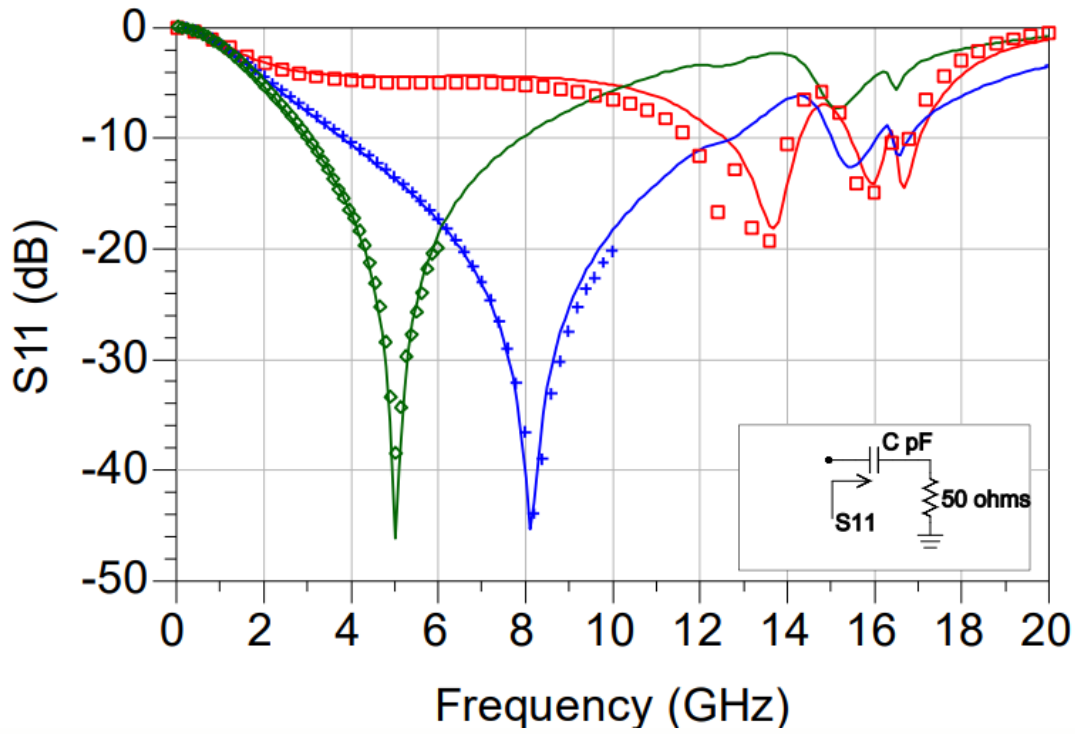
Full Parasitic Models

Modelithics®

Simulating Real World Parasitics

- Capacitance and Tolerance
- PCB Properties
- Pad Dimensions





Lines – Model, Symbols – Measured Data

- 4 mil Rogers 4350B
- 20 mil Rogers 4003C
- 60 mil Rogers 4003C

First Pass Design Success!!!

Advanced CBR Modelithics Models

How Designers Access Models

E2Di EASY TO DESIGN IN

KEMET a YAGEO company

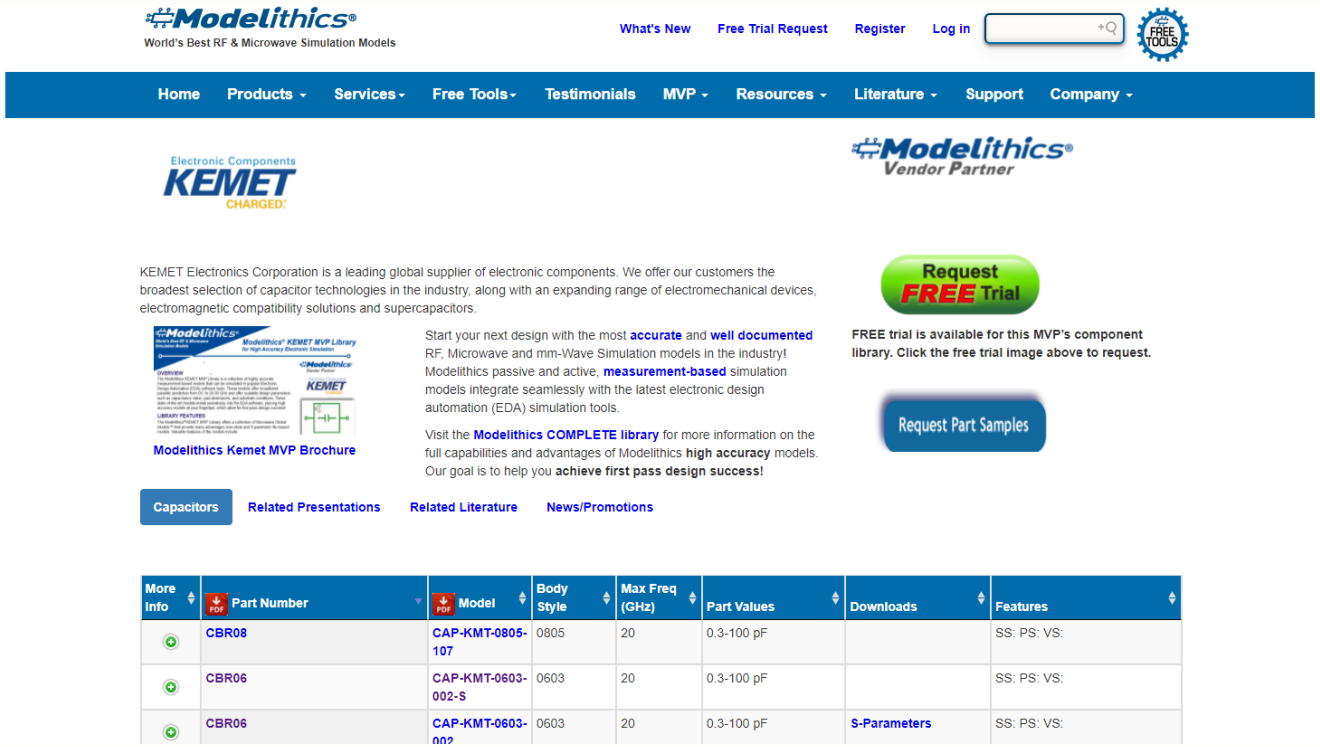
RF Simulation Tools

- Keysight's Advanced Design Systems (ADS)
- Keysight's PathWave RF Synthesis (Genesys)
- Cadence AWR's Microwave Office

Accessing Models

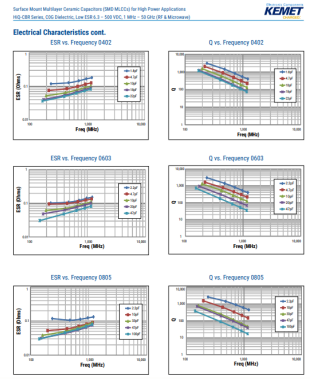
- Contact Product Management

https://www.modelithics.com/mvp/kemet

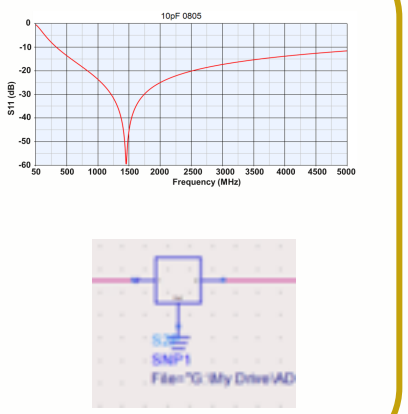


KEMET HiQ CBR

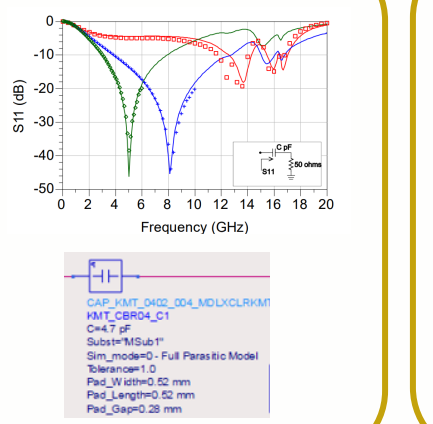
Full E2Di Support



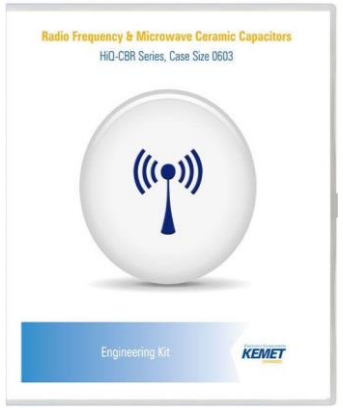
Datasheet Data
ESR / Q / SRF



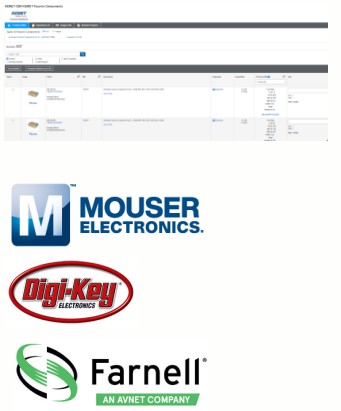
S-Parameters
Available



Advanced
Modelithics
Models



Engineering
Kits



Long Tail
Stocking
Package
0402/0603

HiQ-CBR RF & MICROWAVE

E2Di EASY TO DESIGN IN

“Standard” Capacitor

Low Frequencies <100MHz

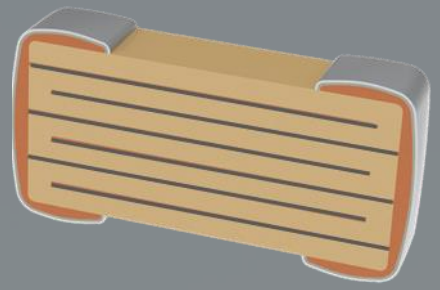
Nickel (BME)

Low ESR

Moderate Q-Factor

Class 1 or Class 2 Dielectrics

Standard E2Di Tools (KSIM)



CBR RF Capacitor

Higher frequencies >100MHz

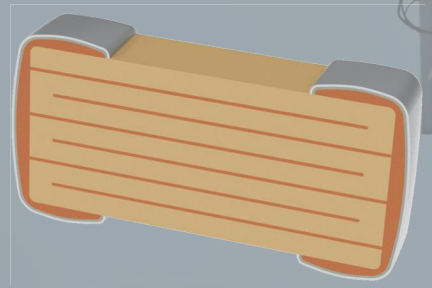
Copper (BME)

Very Low ESR

High Q-Factor

Class 1

Advanced Tools (S-Parameters, Modelithics Models)



Key Takeaways

- An RF capacitor is a capacitor whose “characteristics” are optimal at RF frequencies
- Applications including RF Power Amplifiers, Base Stations, 5G, wearables, autonomous and connected vehicles
- KEMET continues to expand the CBR Hi-Q RF Series
  - 01005 case size
  - CBR Automotive
- CBR E2Di Tools
  - Datasheet graphs
  - S-Parameters
  - Advanced Modelithics Models
  - Engineering Kits
  - Long Tail Stocking package