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Medical Electronics Symposium

Applying Consumer RF Multi-Layer Ceramic Capacitor Technology to Portable Medical Devices

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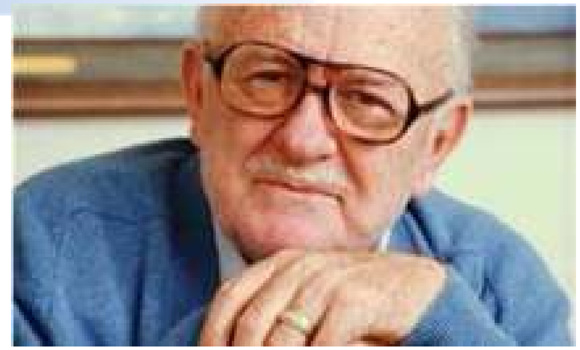
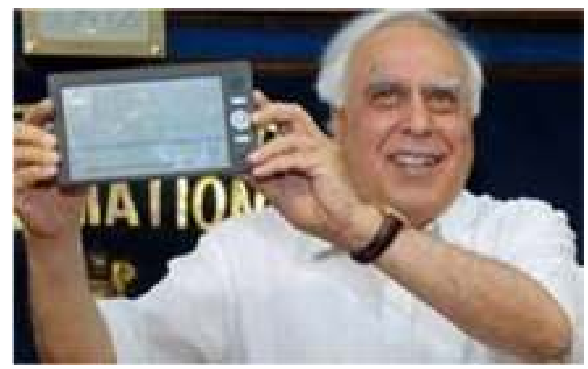
Outline

- *Portable medical industry background*
- *Capacitor Basics and RF Capacitors*
- *BME versus PME technologies*
- *Kemet CBR RF Capacitors*
- *Design Support*
- *Conclusion*

Evolving Medical Industry

- Mean population age is increasing
- Growing demand in low-cost regions is pushing medical technology to be more affordable
- Medical consumers are demanding portability and low cost solutions, similar to growth pattern in consumer electronics





Wireless Medical Potential

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- Manufacturers want to implement wireless into products to increase patient mobility and to provide real-time, constant monitoring
- Key OEM's are creating new products designed to wirelessly monitor patients in the hospital
- Early in 2012 the FCC allocated 40MHz of spectrum for the Medical Body Area Network (MBAN), allaying manufacturer's concerns about wireless spectrum for medical devices

Applications for RF in Medical

- Wireless medical technology utilizes RF frequencies operating between a few hundred MHz up to almost 3GHz.
- RF capacitors are an integral part of many RF circuit designs and their cost and performance characteristics cannot be ignored.

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Capacitor Basics

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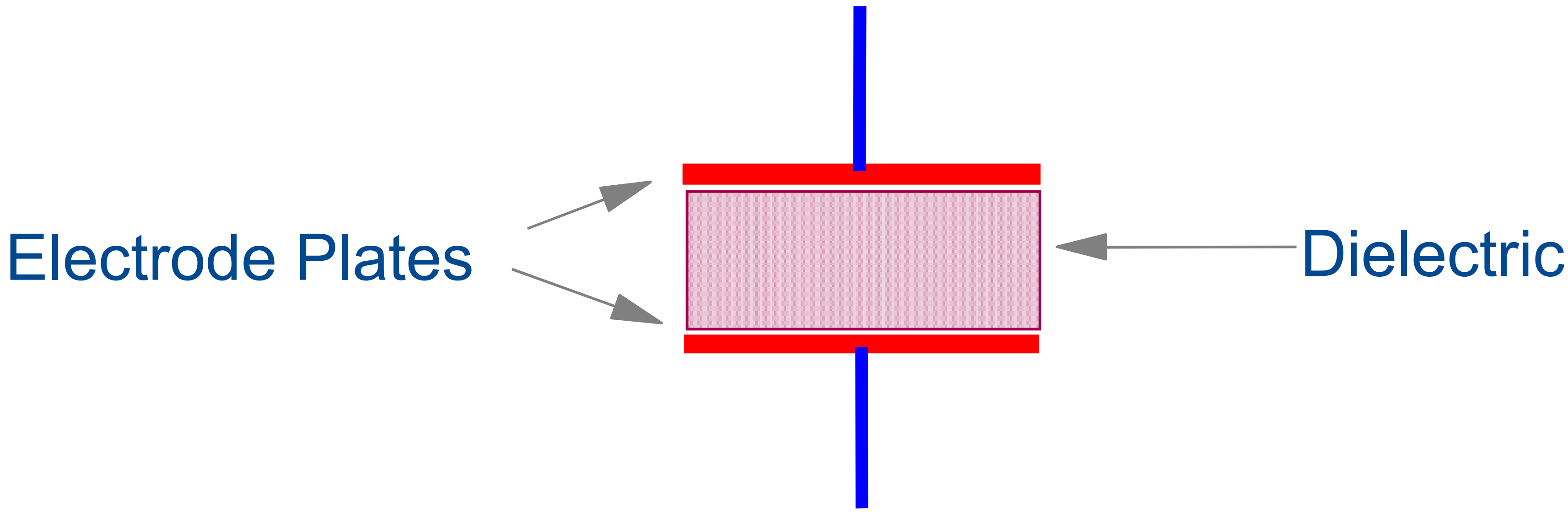
All capacitors utilize the same basic structure



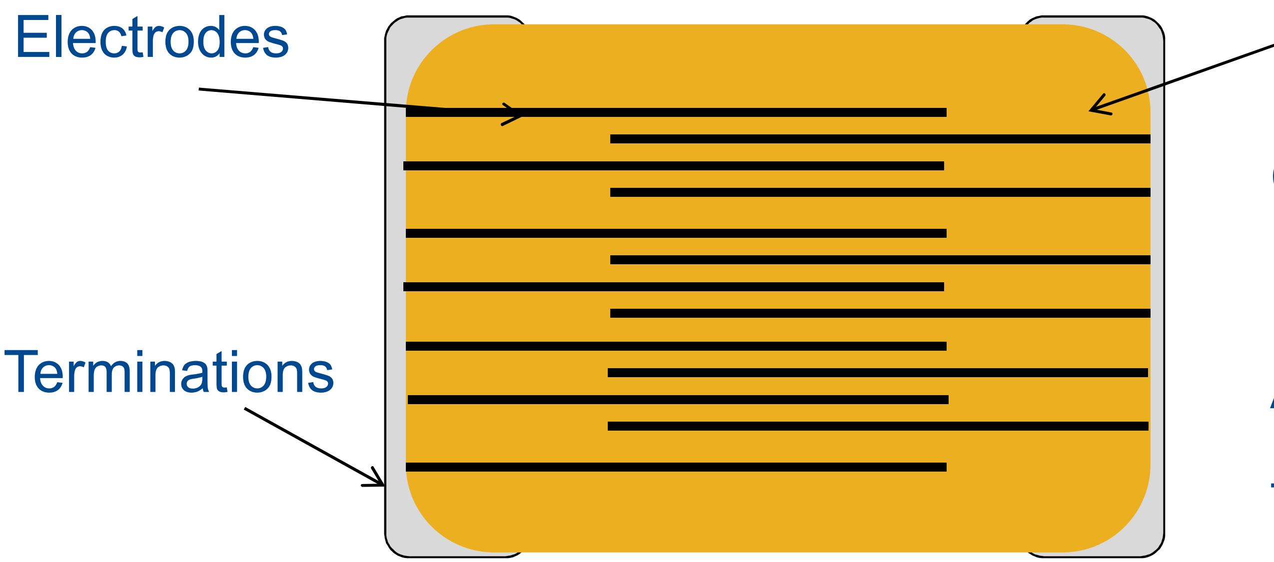
The value of a capacitor is measured in Farads. For 1 Farad of capacitance, 1 Coulomb of charge is stored on the plates, when 1 Volt of electric force is applied.

1 Farad = 1 Coulomb / 1 Volt

1 Coulomb represents ~ 6 x 10^{19} electrons

MLCC Construction

Multilayer Ceramic Chip Capacitor (MLCC) consists of parallel electrode plates separated by an insulating dielectric



C = Design Capacitance

K = Dielectric Constant

A = Overlap Area

t = Ceramic Thickness

n = Number of electrodes

ε_0 = permittivity of free space

Capacitance drivers:

- Dielectric constant
- Dielectric thickness
- Overlap area and number of active layers

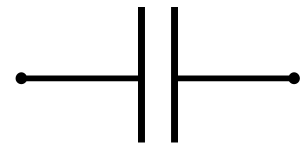
$$C = \frac{\varepsilon_0 KA(n-1)}{t}$$

Capacitor Basics
Ideal

Ideal Capacitor

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

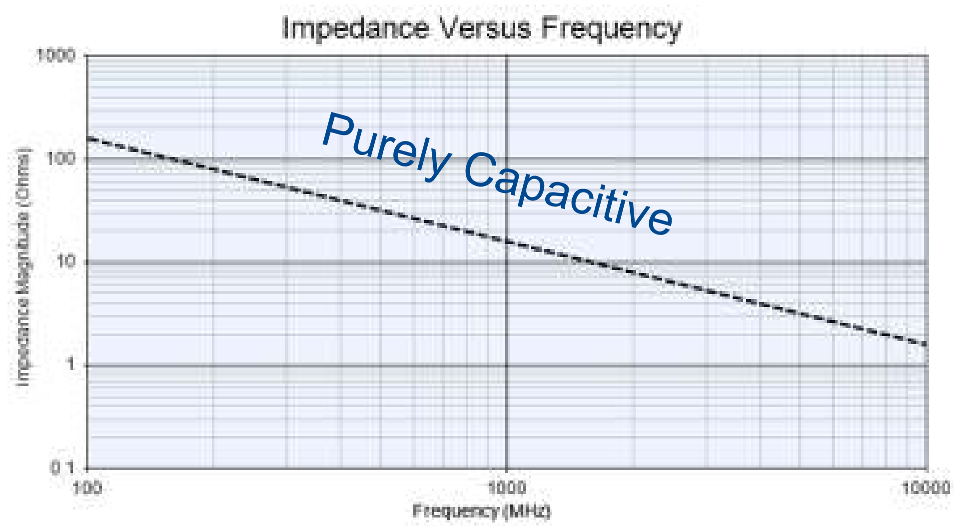
Ideal Model



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

Z=Capacitive Impedance or Reactance

10pF example

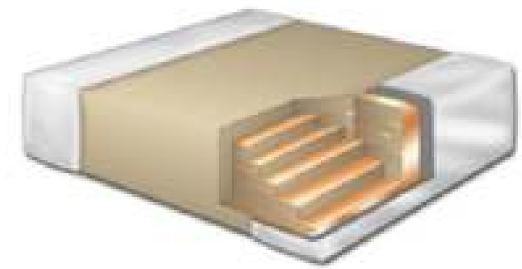


Multilayer Capacitor Basics
Real

Real Capacitor

- Nominal capacitance
- Series resistance (terminations, dielectric, and electrodes)
- Series inductance

Simplified Real Model



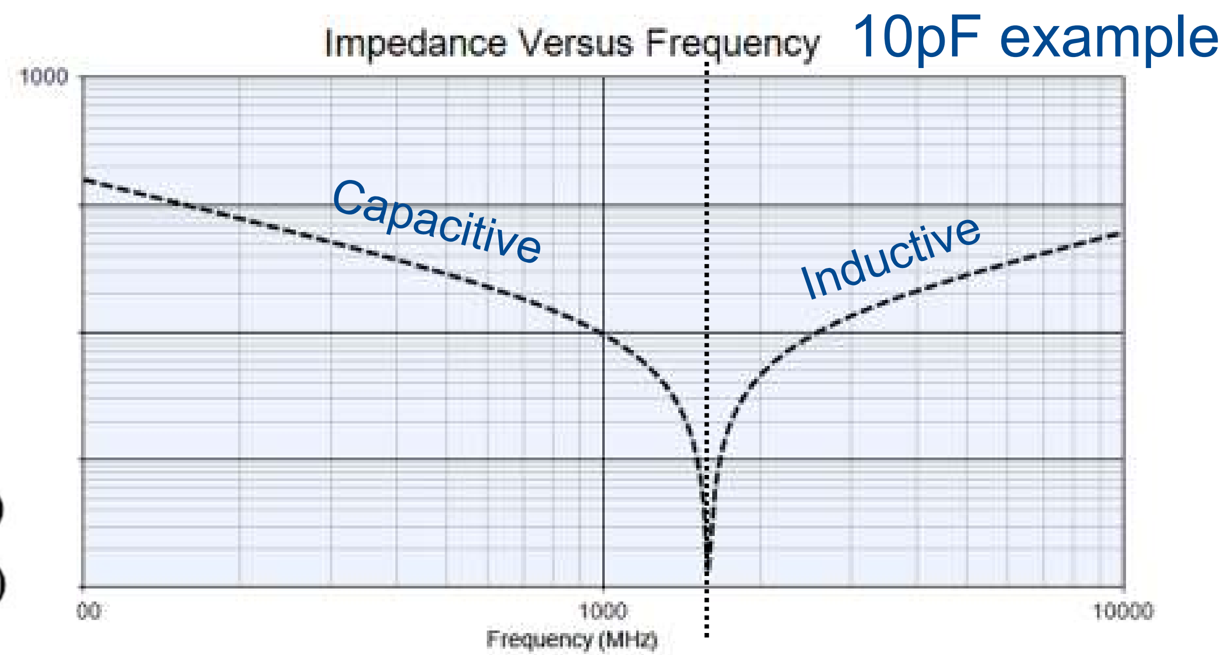
$$Z = \sqrt{ESR^2 + (X_L - X_C)^2}$$

Where : Z = Total Impedance

ESR = Equivalent Series Resistance

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

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



Series Resonance (SRF), where $X_C = X_L$

RF Capacitor Basics
Some Key Parameters

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Q (quality factor)

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

Quantifies the amount of energy stored versus how much is dissipated as heat. Higher Q (lower ESR) needed for RF capacitors to limit power dissipation and circuit noise.

SRF (Series Resonant Frequency)

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

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 (Temperature Coefficient of Capacitance)

$$\Delta C \Rightarrow C(25C) - C(T2)$$

C0G → ppm/ °C level
X7R → % level

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

S-Parameters… in layman's terms

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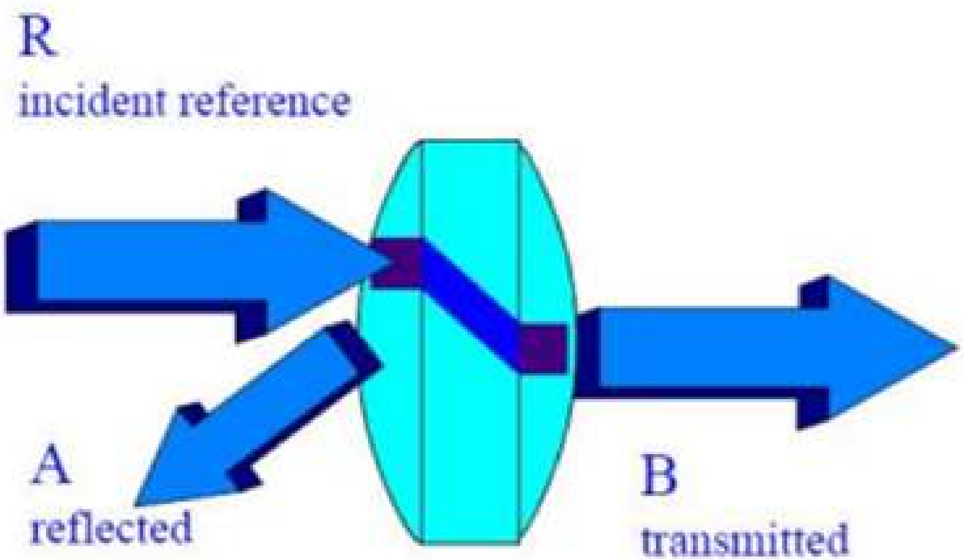
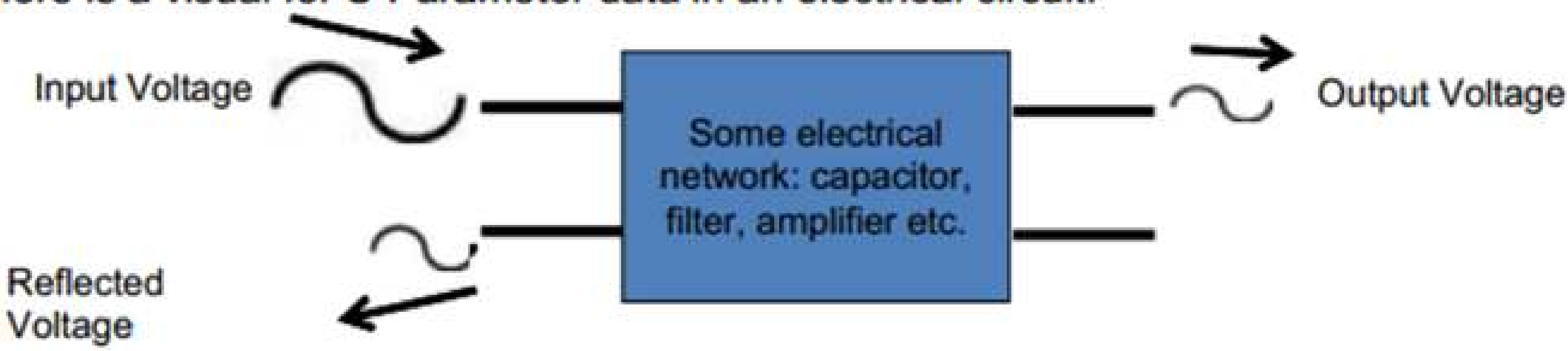
- S-Parameters are a mathematical tool that quantifies how RF energy propagates through a network.
- RF engineers use S-parameters to design RF circuits. The parameters describe how much energy is injected into the network versus:

1. How much actually gets through
2. How much gets absorbed
3. How much is reflected back to the source

S-Parameters… in layman's terms



Here is a visual for S-Parameter data in an electrical circuit:



RF Capacitor Basics

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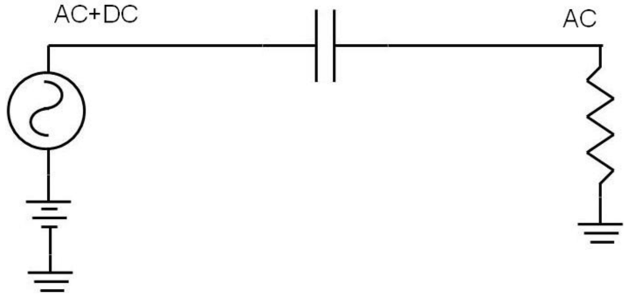
RF capacitors are made from low-loss dielectrics and non-inductive electrodes, enabling low ESR, high Q, and high SRF at RF frequencies.

	Standard MLCC	RF MLCC
Dielectric	C0G/X7R	C0G
Electrodes	Usually Ni	Pd, Ag, Cu
ESR	Low-high	Ultra Low
Q	Low	High
Frequency	Low (few hundred MHz)	High (GHz)
Power Dissipation	High	Low
SRF	Low	High

RF capacitors are ideal for RF medical devices

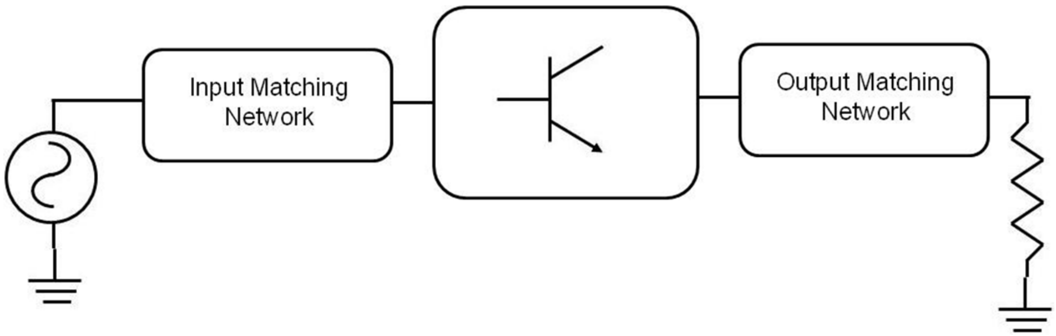
Common RF Capacitor Applications

AC Coupling
DC Blocking



Allows for the passage of RF signal while blocking DC. Example – Amplifier staging

Impedance Matching



Transform one impedance of the circuit to another allowing for maximum RF power transfer. Example – Amplifier input and output; antenna matching

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From PME to BME

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- PME – (Precious Metal Electrodes) refer to MLCC's manufactured with metals such as Palladium and Silver.
- BME – (Base Metal Electrodes) refer to MLCC's manufactured with metals such as Nickel.
- In the 1990's, the commercial capacitor industry began to transition away from PME to BME technologies
- BME (Nickel) offers several advantages over equivalent PME (Palladium-Silver) offerings, including:
  - Lower Cost
  - Higher voltage stress capability
  - Thinner dielectric layers
  - Higher capacitance values (better volumetric efficiency)

Copper BME

- For many years, RF capacitors were all made from PME technology.
- In early 2000's, RF Capacitor end-users began to demand a lower-cost solution to replace existing RF PME Designs
- Nickel met the cost requirement, but did not provide low enough power dissipation at high frequencies
- **Solution: Copper BME**

Example: 140mArms RF input current at various frequencies

Frequency	ESR (Ohms) Copper BME	Power Dissipation (mW) Copper BME	ESR (Ohms) Nickel BME	Power Dissipation (mW) Nickel BME
150	0.25	4.9	0.8	15.7
300	0.29	5.7	1.03	20.2
600	0.32	6.3	1.32	25.9
1200	0.39	7.6	1.86	36.5

BME = low-loss properties + lower cost

Element	Electrical Resistance (Ω-cm)	Cost
Silver (Ag, PME)	1.6	Medium
Palladium (Pd, PME)	10.8	High
Nickel (Ni, BME)	6.8	Low
Copper (Cu, BME)	1.7	Low

Higher electrode resistivity causes higher power dissipation.
This favors Copper BME over Nickel as a low cost solution.

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Kemet CBR RF Product Line

HiQ-CBR
RF & MICROWAVE

- Ultra High Q
- Low ESR
- High Thermal Stability
- RoHS Compliant & Lead-free
- Small case size selection for miniaturizing circuit design

Voltage	6.3 - 250V
Dielectric	C0G (NP0)
Cap Range	0.1pF – 100pF
Case Size	0201 - 0805
Tolerance	±0.05pF to ±0.5pF ±1% to ±10%

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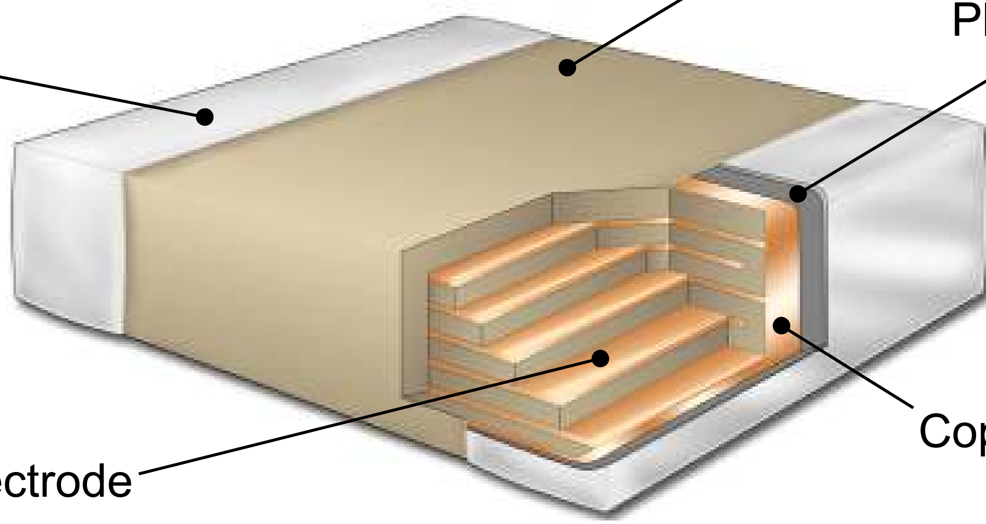

Base Metal, Copper Electrodes

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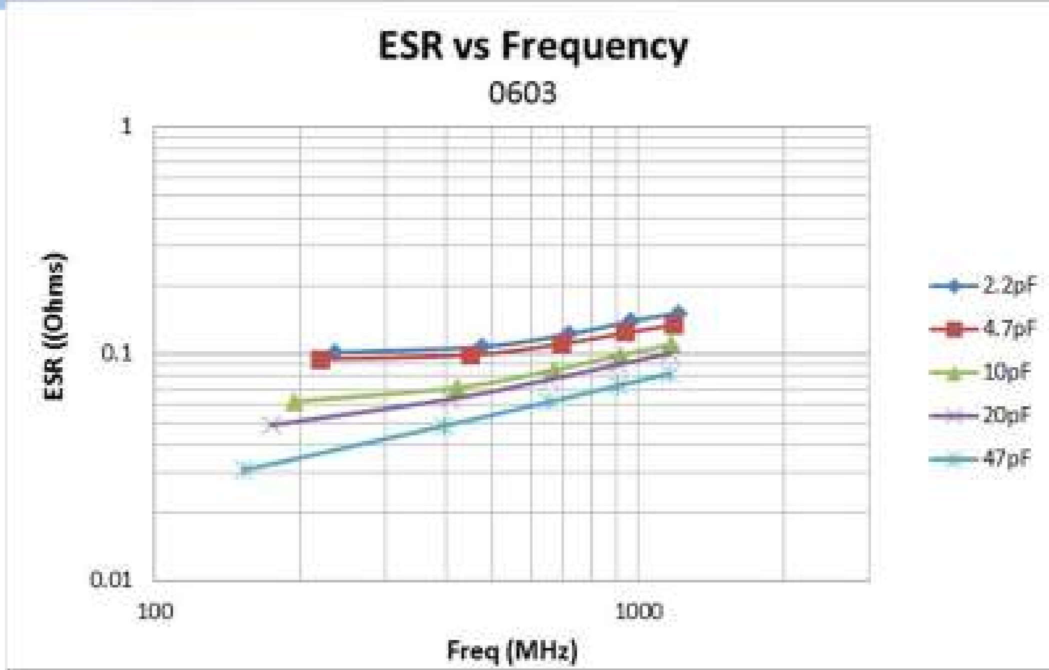
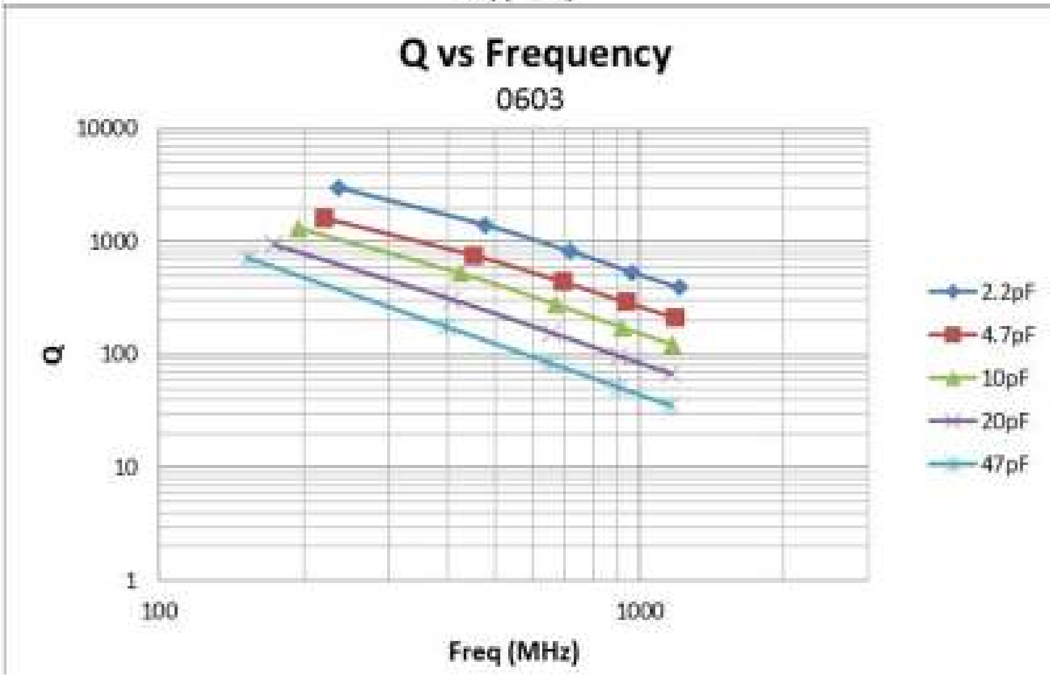
CBR RF performance

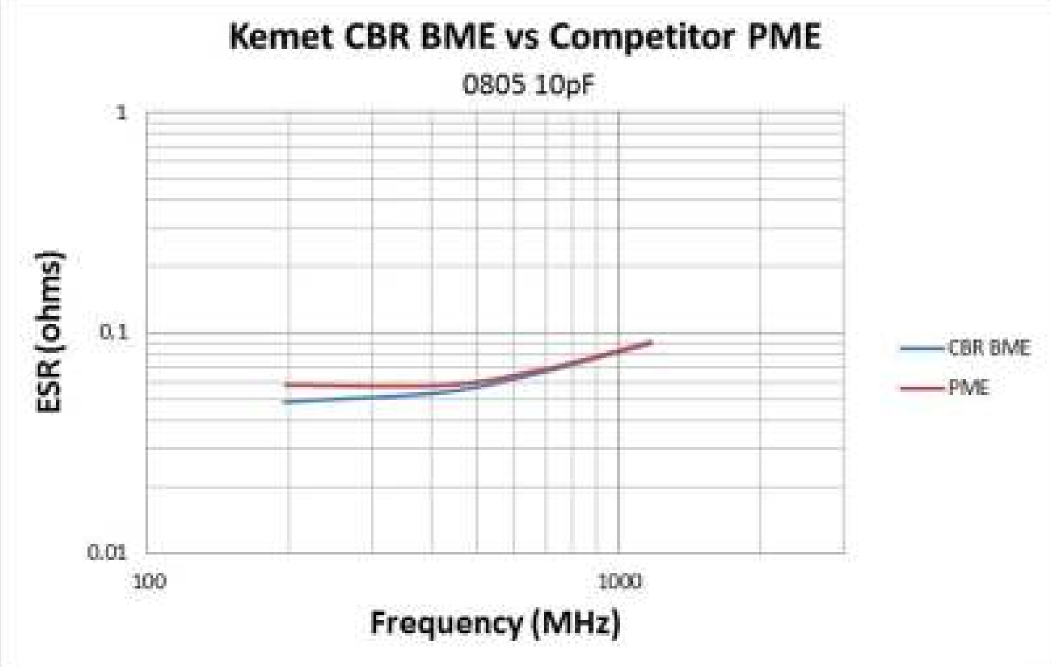
- ESR measurements of five 0603 capacitor values from the CBR BME family.
- Results show low ESR and high Q performance across the measured frequency range.

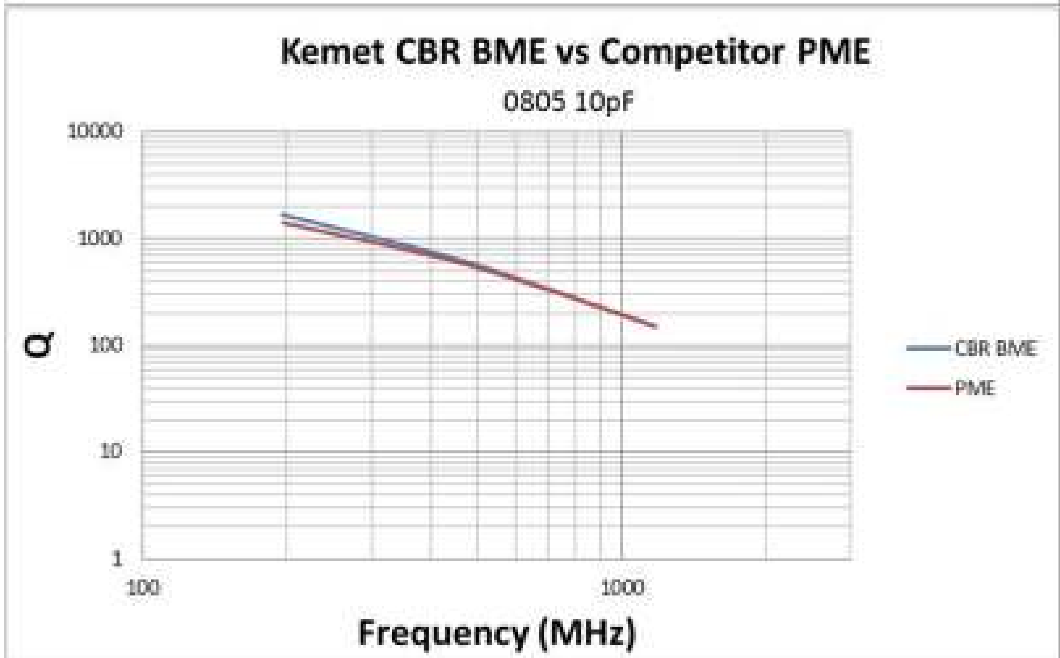




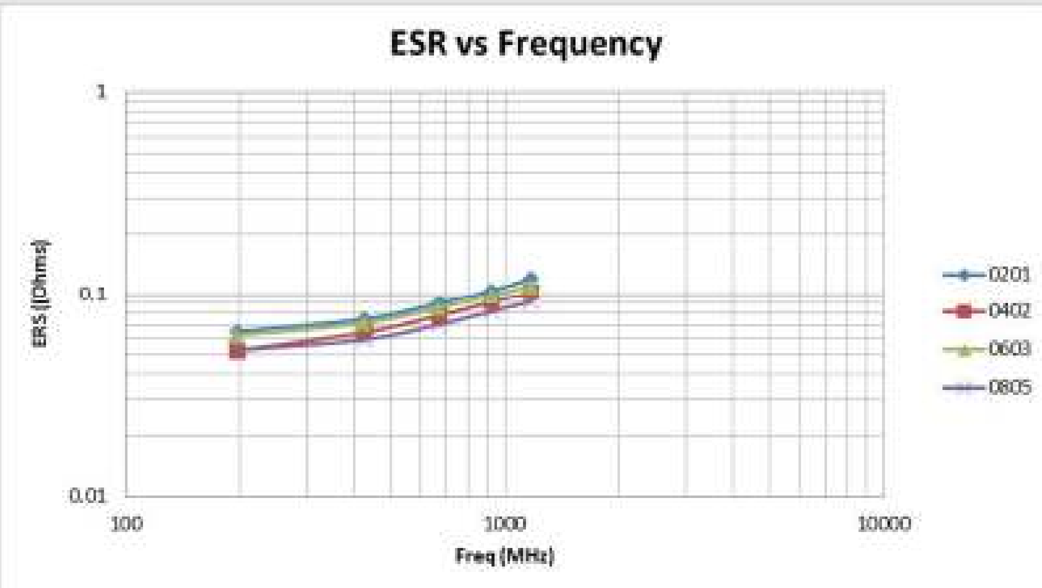
BME versus PME RF Performance

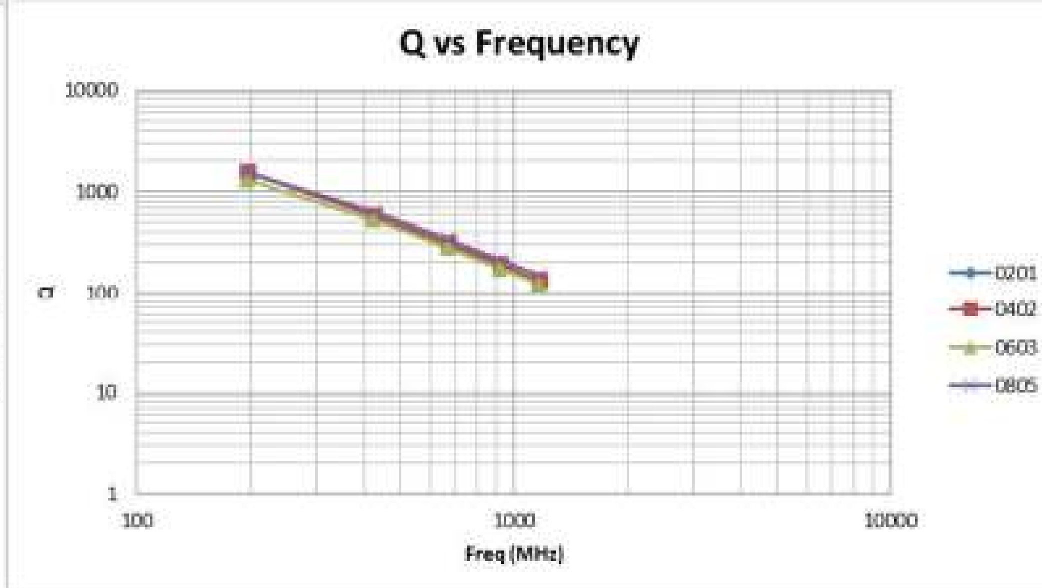
- Comparison between CBR BME and competitor PME capacitor.
- Measurements were made from same size, cap, and voltage rating capacitor.
- Results show good agreements between the two technologies.





Low ESR, High Q down to 0201 Case Size





CBR BME series provides low ESR and high Q down to 0201 case size for miniaturization.

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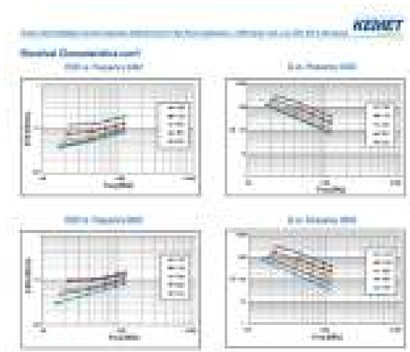
Designers Need Design Support

To design effective RF circuits, engineers need some key performance characteristics such as:

- ESR
- SRF
- S-Parameters
- Q data
- Temperature characteristics

To facilitate this design work, suppliers often provide

- Component datasheets
- Sample kits
- Measured component data

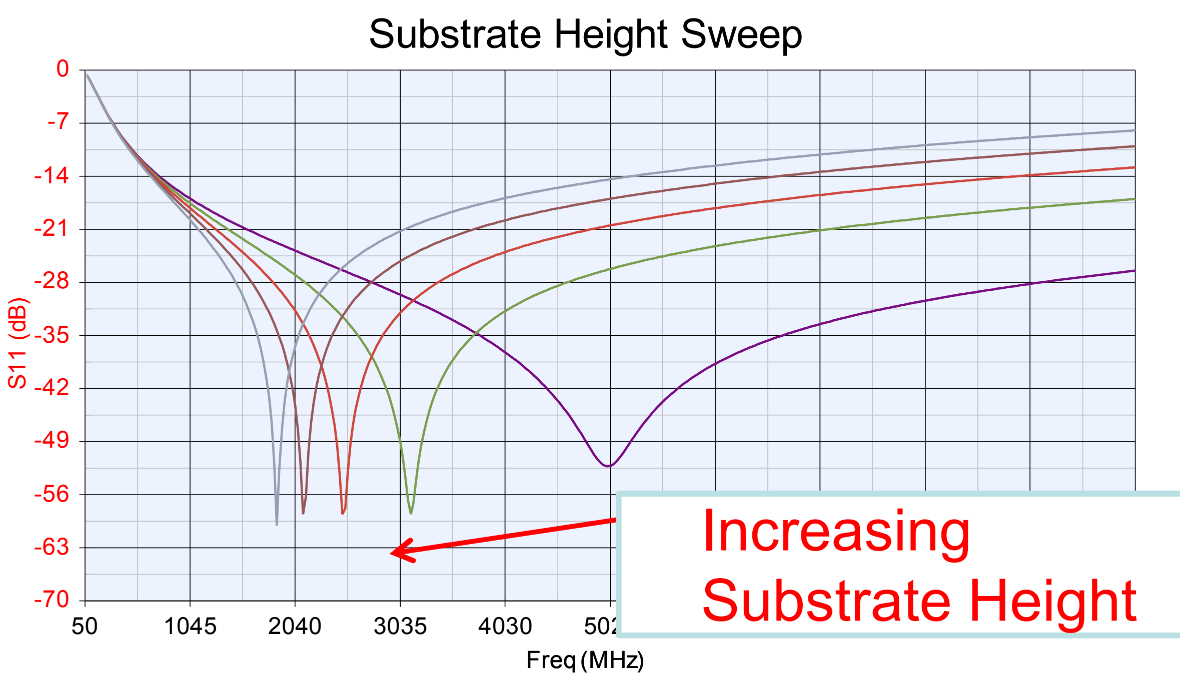


However, these do not always facilitate rapid design because they cannot always account for characteristics of in-circuit parasitic effects.

In-Circuit Effects on RF Capacitors

As frequency increases, the parasitics of the capacitors and substrates are more prominent. If the designer neglects to take these parasitics into considerations, circuit may not function as designed.

Below is an example of an 0402 capacitor mounted and measured on five different substrate thicknesses. You can see that the resonant frequency decreases dramatically as substrate height increases.



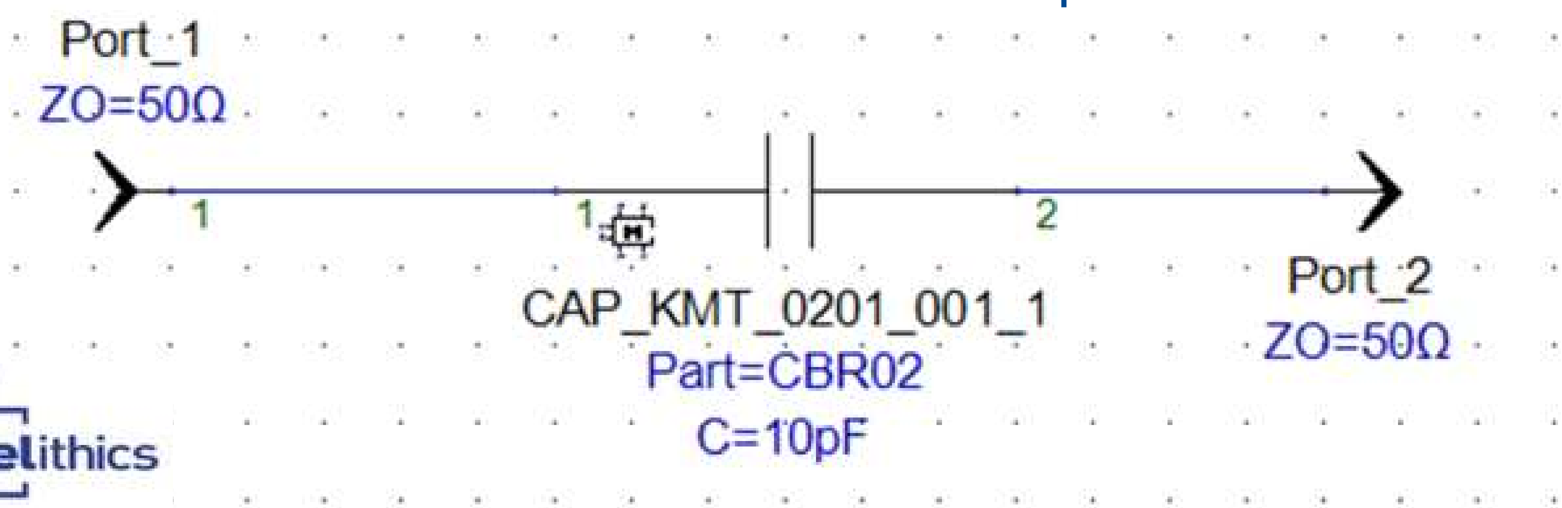
- Accurate RF performance prediction is needed by designers.
- Designers need measured S-Parameter files and/or RF models.

Design Support for CBR Series

KEMET has partnered with Modelithics, Inc to provide substrate and pad scalable models to assist engineers in speeding up the design process in EDA software

Benefits of Models

- Real-world, measurements-based
- Scalable parameters properties to simulate real world mounting conditions
- Scalable pad dimensions to simulate actual customer mounting configurations
- Statistical simulations to allow for effects of capacitor tolerance on design



Model Performance Data

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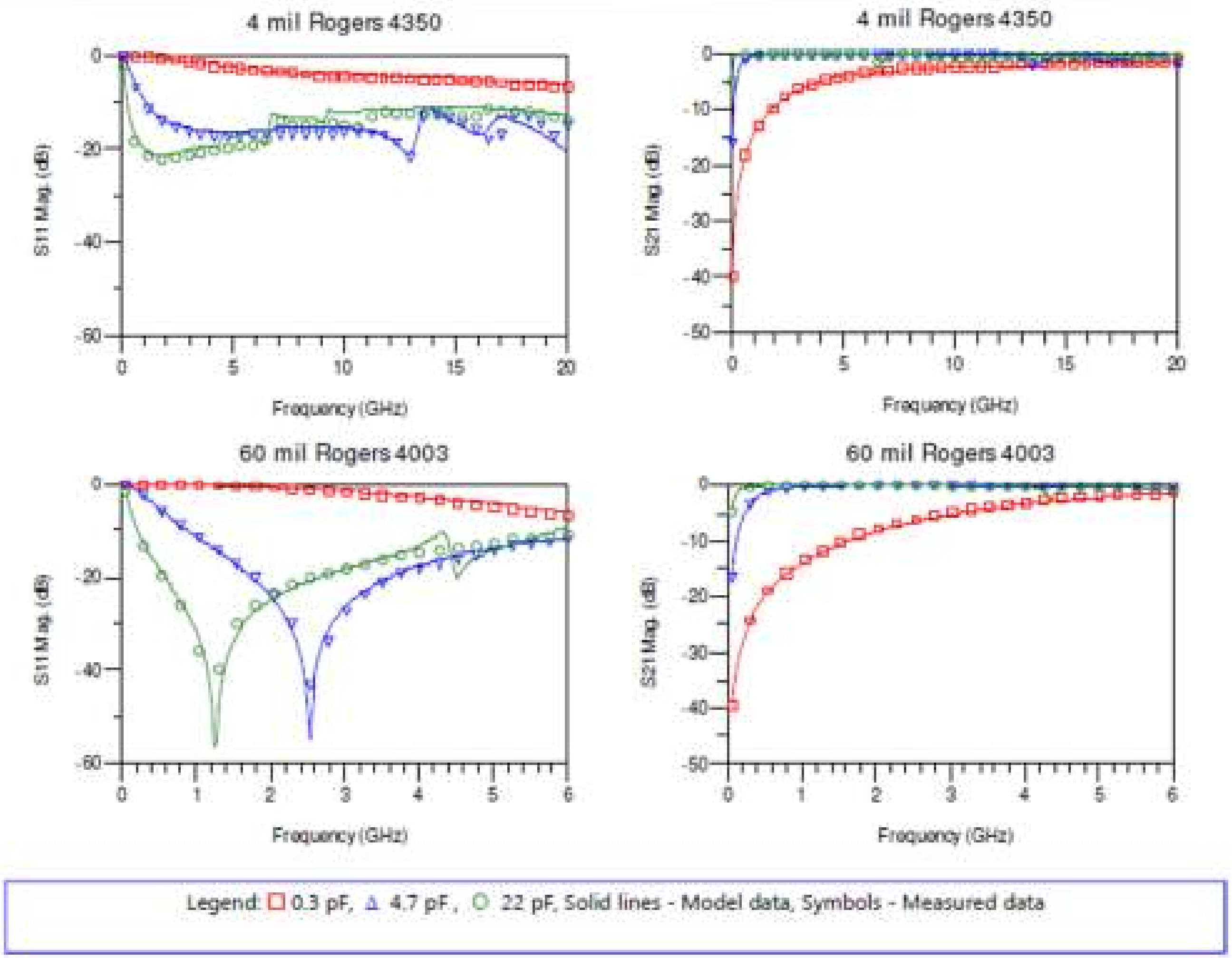

Models allow for designers to predict the capacitors behavior under various substrate conditions

What does this mean for designer?

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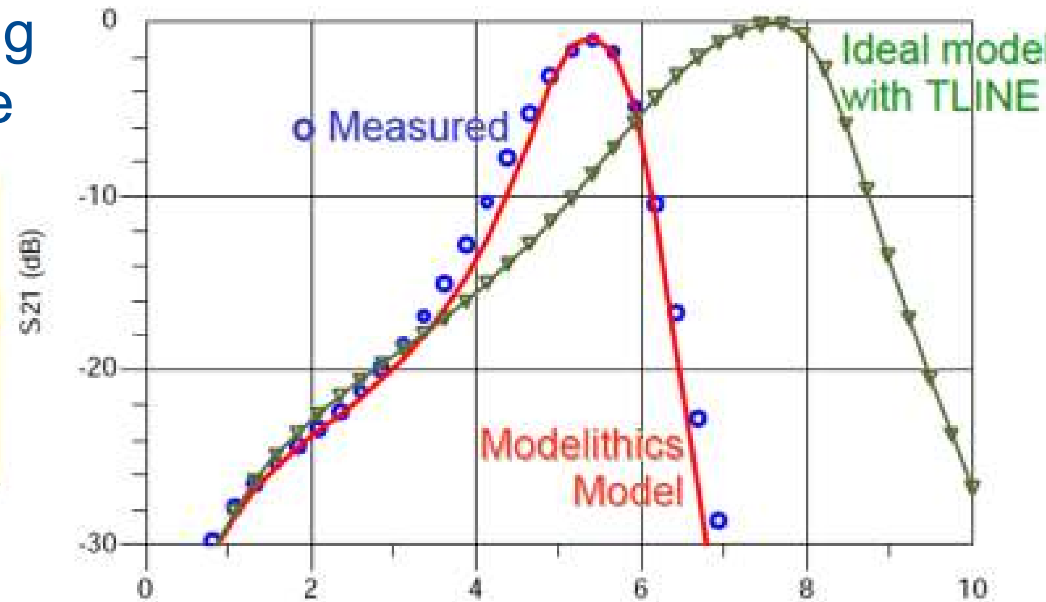
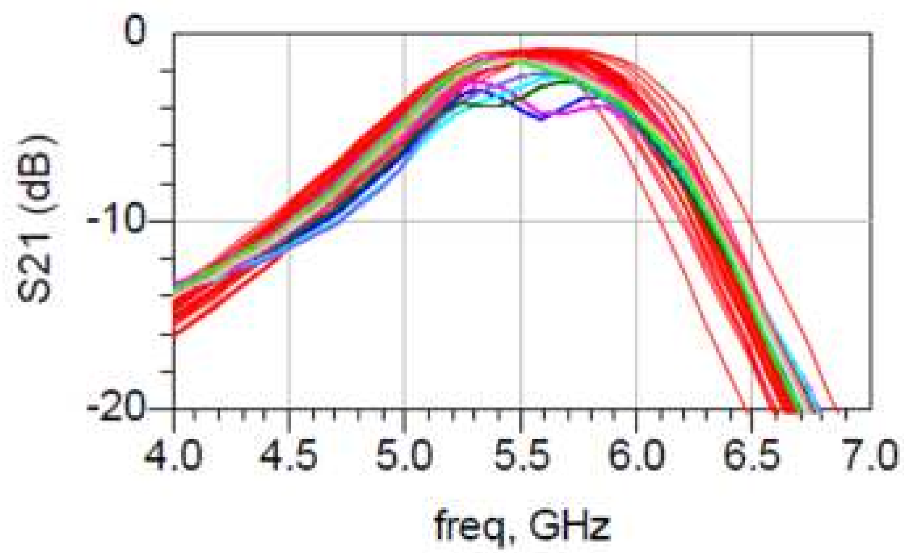
5.4GHz Bandpass Filter Design Using Modelithics' Models on 16mil substrate



- Accurate "first-pass" pass design success.
- Statistical simulations on capacitor tolerance



Modelithics

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Conclusion

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- Expansion of wireless in medical devices will create increased demands for low cost RF capacitor solutions
- Copper BME meets this market need for low cost RF capacitors
- Capacitors made with Copper BME are comparable with similar sized PME RF capacitors
- Copper BME is available in smaller cases sizes to facilitate miniaturization.
- Models are available to assist engineers in rapid RF circuit design