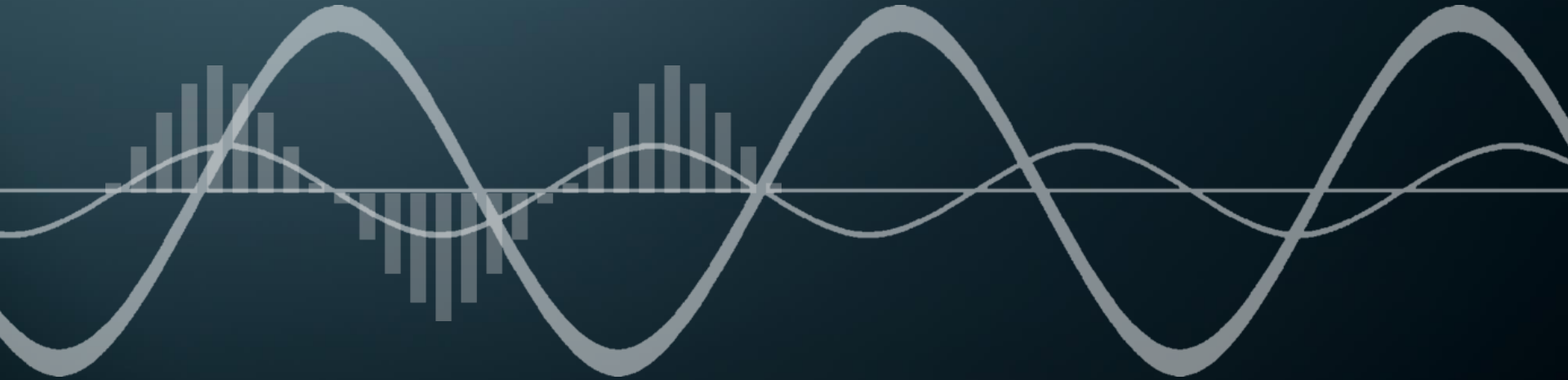
RF Engineering

Parasitic Effects on passive Components for Frequencies between 1 kHz and 10 GHz

Holzkirchen, Germany | 09.07.2024



Lukas Lischke

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2011-2017:	Master in Electrical Engineering TU Munich with focus on high frequency technologies
Since 2019:	WORK Microwave: Hardware Engineer for satellite base station equipment
2021:	WORK Microwave: Systems- & Sales-Engineer Sensors
2022:	WORK Microwave: Product Manager for Sensors & Measurement Department
Since 2024:	WORK Microwave: Leader of the Sensors & Measurement Product Group

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Microwave & Signal Processing KnowHow

SATELLITE COMMUNICATION 65%

Modems | Modulators | Demodulators, Satellite Frequency Converters, Test Loop Translators, Redundancy Systems 1:1 / N:1 Digital Optical Ground Station, Virtual Ground Station

DEFENCE ELECTRONICS 15%

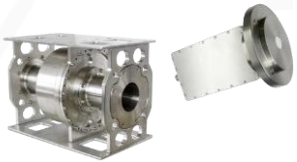
Radar Synthesizers and front-ends, radar transponders, ECM equipment, RF selectors, medium-power amplifiers and drivers up to 200 watts, application-specific RF, and Microwave solutions

NAVIGATION SIMULATORS 10%

WORK Microwave's Xidus supports all existing and planned navigation systems such as GPS, Galileo, GLONASS, QZSS, BeiDou or SBAS, providing leading GNSS signal capability

SENSORS& MEASUREMENT 10%

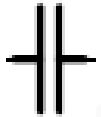
Microwave-based instant inline sensors for measuring mass, moisture, density to optimize product properties on fast running large scale production lines



Companies supporting this talk / referenced in this talk

Manufacturer of RF and digital signal processing products
https://work-microwave.com/
The presenters workplace

Distributor for electrical components incl. RF Passives – we focus on Capacitors
https://www.we-online.com/de/components/products/pbs/capacitors
https://redexpert.we-online.com/we-redexpert/en/#/home



RF Choke Manufacturer
https://www.coilcraft.com/en-us/products/rf/
https://www.coilcraft.com/en-us/tools/rf-inductor-and-choke-finder/#/results
https://www.coilcraft.com/en-us/other/coilcraft-lc-filter-designer-software/

RF Resistor Manufacturer
https://www.vishay.com/en/resistors-fixed/high-frequency/
https://www.vishay.com/docs/53077/microwavethinfilmres.pdf

RF Connector Manufacturer with good understanding on passive intermodulation
https://www.rosenberger.com/markets/mobile-communication/passive-intermodulation-testing/

Radio Frequency Band Overview

Radio Frequency Band	Frequency	Wavelength
extremely low frequency (ELF)	3 - 30 Hz	100 - 10,000 km
super low frequency (SLF)	30 - 300 Hz	10 - 1,000 km
ultra low frequency (ULF)	300 - 3000 Hz	1000 - 100 km
very low frequency (VLF)	3 - 30 kHz	100 - 10 km
low frequency (LF)	30 - 300 kHz	10 - 1 km
medium frequency (MF)	300 - 3000 kHz	1000 - 100 m
high frequency (HF)	3 - 30 MHz	100 - 10 m
very high frequency (VHF)	30 - 300 MHz	10 - 1 m
ultra high frequency (UHF)	300 - 3000 MHz	1000 - 100 mm
super high frequency (SHF)	3 - 30 GHz	100 - 10 mm
extremely high frequency (EHF)	30 - 300 GHz	10 - 1 mm
tremendously high frequency (THF)	0.3 - 3 THz	1 - 0.1 mm

WE „High Frequency“

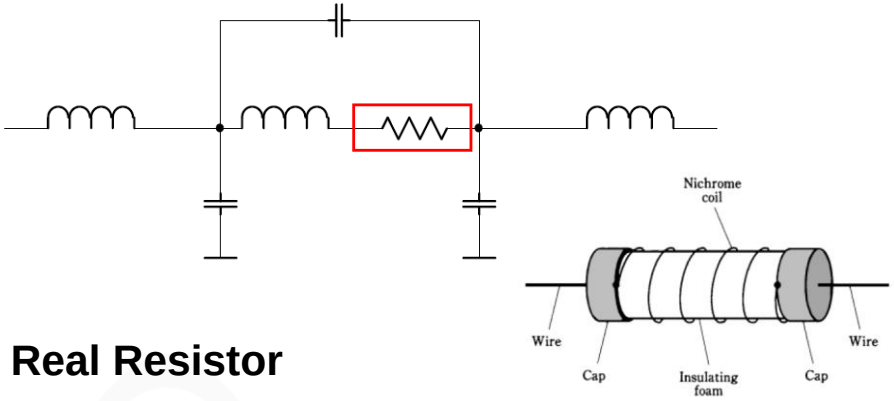
Radio Frequency (RF)

Microwave

Parasitic Effects on Resistors

Ideal Resistance

- $U = R \cdot I$
- Constant relationship for all
  - Frequencies
  - Temperatures
  - Tensile stress levels



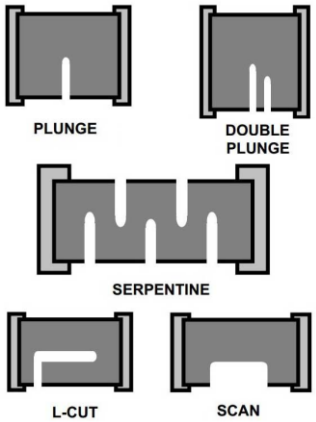
Real Resistor

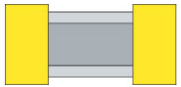
- Construction dependent (Metal film, wire wound, thick film, thin film, trimming method, …)
- Housing dependent (THT, SMD 0805, 0603, 0402, …)
- PCB Footprint dependent (Pad size & Shape)
- Frequency dependent
- Temperature dependent
- https://www.vishay.com/en/resistors-fixed/

Technology
Carbon film
Copper strip
MELF
Metal film
Metal foil
Metal glaze
Metal oxide
Metal plate / grid
Power Metal Plate™ current sense
Power Metal Strip®
Thick film
Thin film
Wirewound

Parasitic Effects on Resistors

Laser Trimming (Film Resistors)





https://laserod.com/capabilities/laser-resistor-trimming/
https://www.thinfilm.com/trimming.html

Skin Effect in Resistive Film

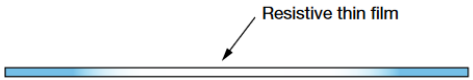
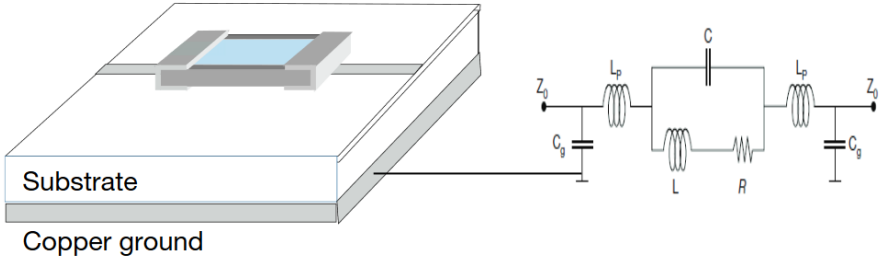


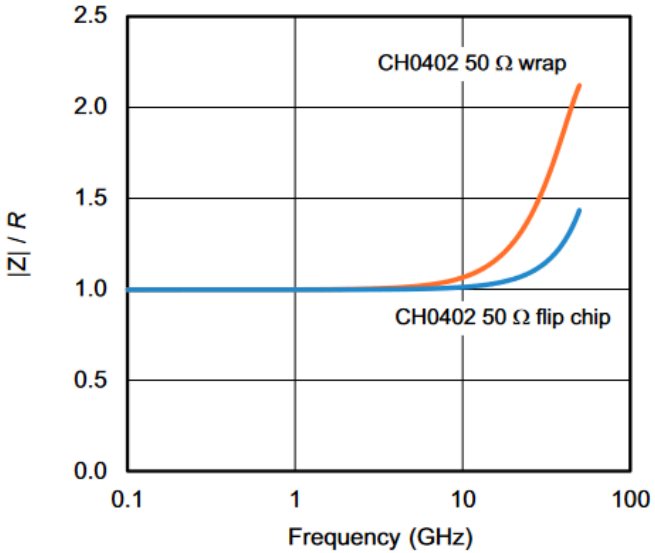
Fig. 9 - A non-linear current distribution in the layer. Current is more concentrated in the lateral sides (dark areas)

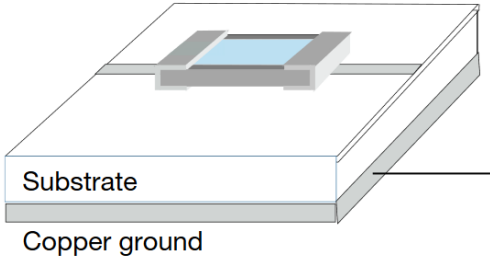


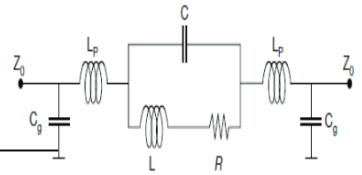
Resistor Frequency Test & S-Parameter Model:

- R is the nominal resistance value
- L is the inductance relevant to the resistor
- C is the capacitance relevant to the resistor
- LP is the parasitic inductance due to the mounting of the resistor on the circuit
- Cg is the parasitic capacitance due to the mounting of the resistor on the circuit
- Z0 is the characteristic impedance of the line

Parasitic Effects on Resistors







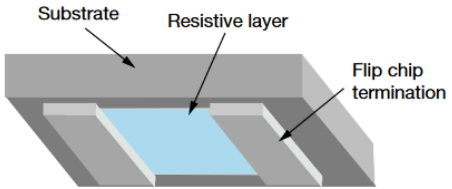
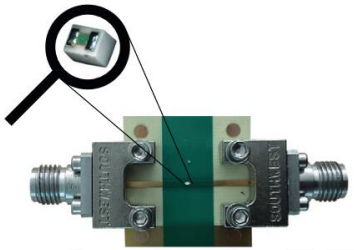


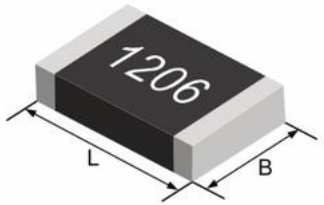
Fig. 7 - Flip chip design



https://www.vishay.com/docs/53077/microwavethinfilmres.pdf

Parasitic Effects on Resistors – Housing Size

Imperial Code	Länge mm	Breite mm	3D
2512	6,35	3,2	
2010	5,08	2,54	
1812	4,6	3,2	
1806	4,6	1,6	
1210	3,2	2,5	
★ 1206	3,2	1,6	
1008	2,5	2,0	
★ 0805	2,0	1,25	
★ 0603	1,6	0,8	
0402	1,02	0,5	



https://edistechlab.com/lerne-einfach-die-passiven-smd-bauteile-kennen

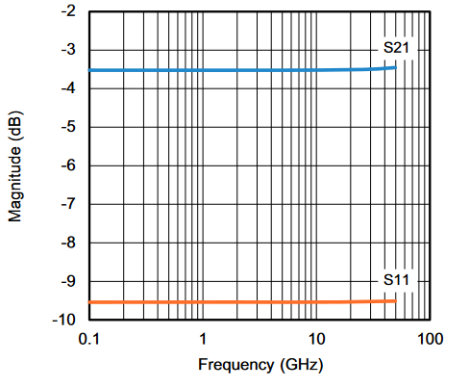


Fig. 10 - CH02016 flip chip ($Z_0 = Z_g = R = 50\ \Omega$)

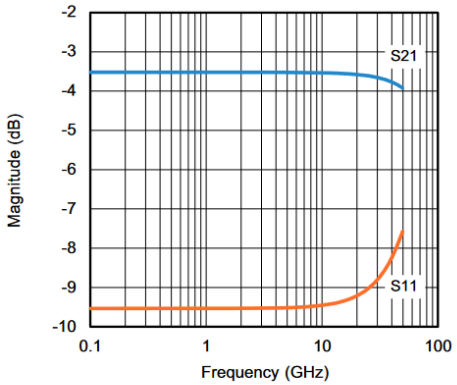
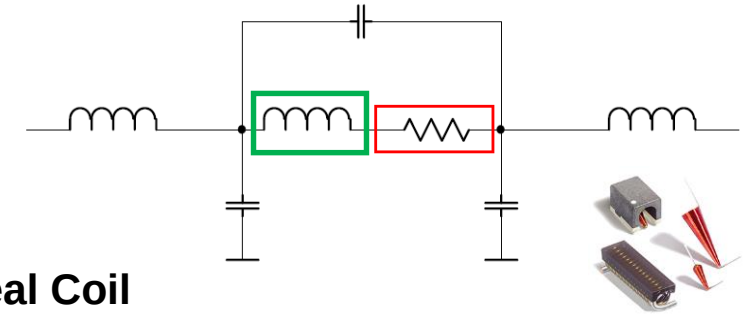


Fig. 12 - CH0402 flip chip ($Z_0 = Z_g = R = 50\ \Omega$)

Parasitic Effects on Chokes / Coils

Ideal Inductance

- $L = \mu_0 K N^2 \frac{A}{l}$
- $Q = \frac{\omega L}{R}$
- $W = \frac{1}{2} L {I_0}^2$
- https://en.wikipedia.org/wiki/Inductor
- Constant relationship for all
  - Frequencies
  - Temperatures
  - Tensile stress levels

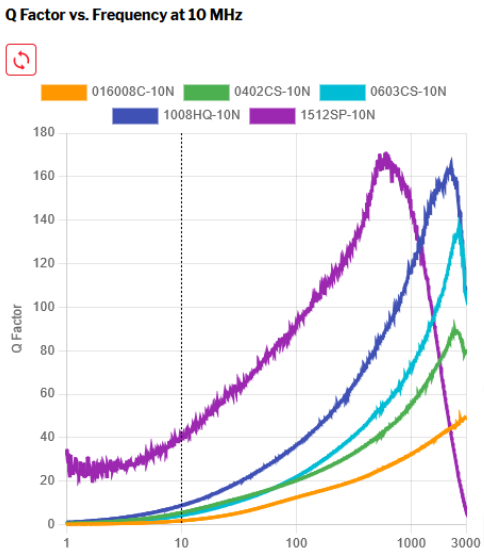


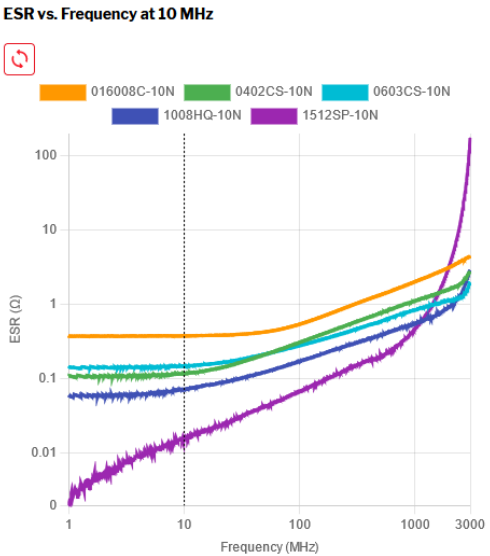
Real Coil

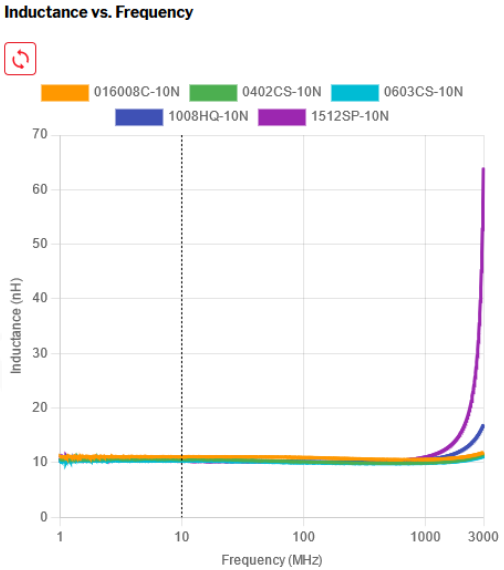
- Construction dependent (Ceramic Core, Ferrite Core, Air Core, Conical, Tunable …)
- Housing dependent (THT, SMD)
- PCB Footprint dependent (Pad size & Shape)
- Frequency dependent
- Temperature dependent
- Current dependent
- https://www.coilcraft.com/en-us/products/rf/

Parasitic Effects on Chokes / Coils

All coils have 10nH Inductance nominal in different package

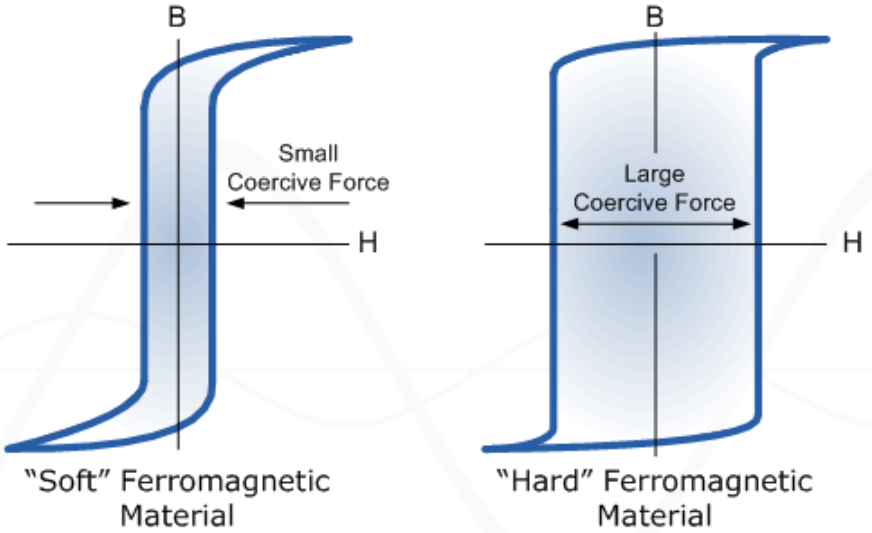






Parasitic Effects on Chokes / Coils

Current dependency on chokes with ferrite core due to hysteresis



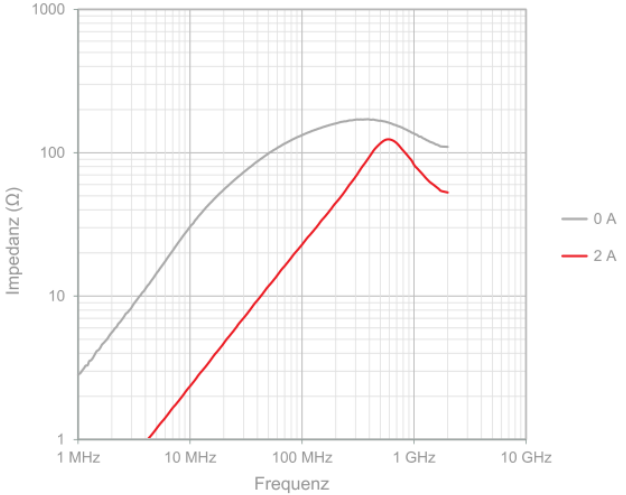
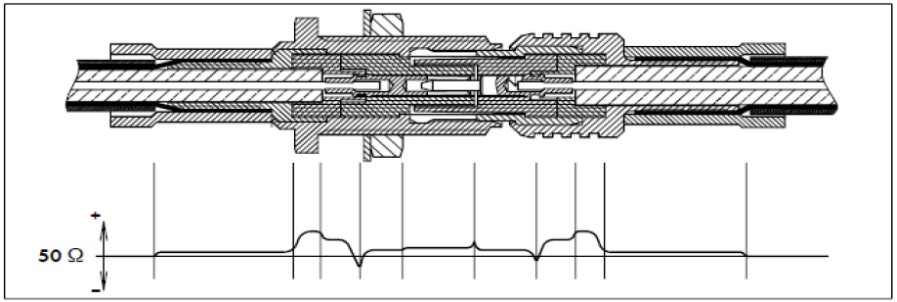


Abbildung 7: Änderung der Impedanz eines SMD-Ferrits durch den Strom (0 A grau, 2 A rot)

Parasitic Effects on Connectors / Cables

Ideal Connector

- Constant relationship for all
  - Frequencies
  - Temperatures
  - Tensile stress levels



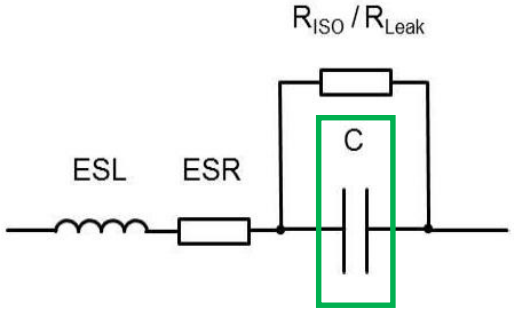
Real Connector

- Construction dependent (SMA, BNC, N, 2.92mm, …)
- Contact material dependent (Nickel, Silver, Gold, Brass, …)
- Dielectric dependent (Air, Teflon, …)
- Cable shield construction dependent
- Frequency dependent
- Temperature dependent
- https://www.rosenberger.com/products/connectors-adaptors/rf-connectors/
- https://www.rosenberger.com/markets/mobile-communication/passive-intermodulation-testing/
- https://en.wikipedia.org/wiki/Intermodulation#Passive_intermodulation_(PIM)

Parasitic Effects on Capacitors

Ideal Capacitance

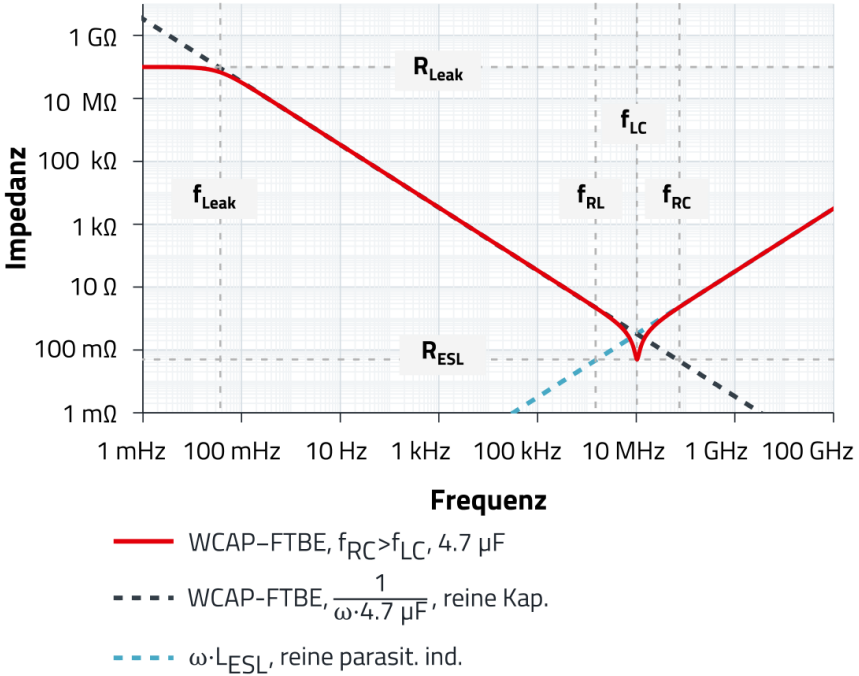
- $C = \frac{\varepsilon A}{d}$
- $Q = C \cdot U$
- https://en.wikipedia.org/wiki/Capacitor
- Constant relationship for all
  - Frequencies
  - Temperatures
  - Tensile stress levels

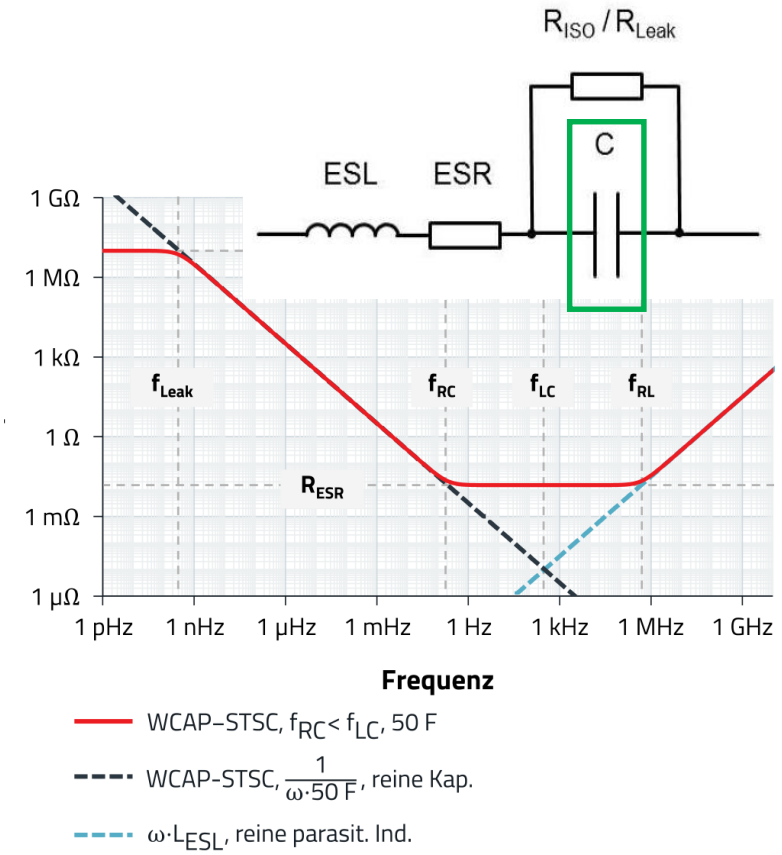


Real Capacitor

- Construction dependent (MLCC, Foil, Supercap, Electrolyte, Al-Polymer, Al-Electrolyte, Al-Hybrid, …)
- Housing dependent (THT, SMD)
- PCB Footprint dependent (Pad size & Shape)
- Frequency dependent
- Temperature dependent
- Voltage Dependent
- https://www.we-online.com/de/components/products/pbs/capacitors

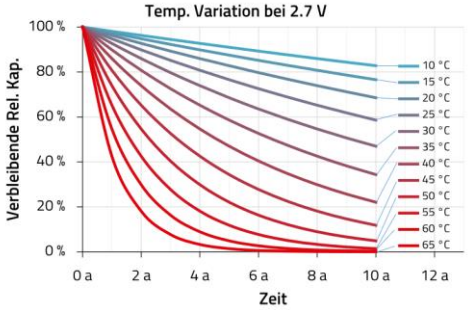
Parasitic Effects on Capacitors

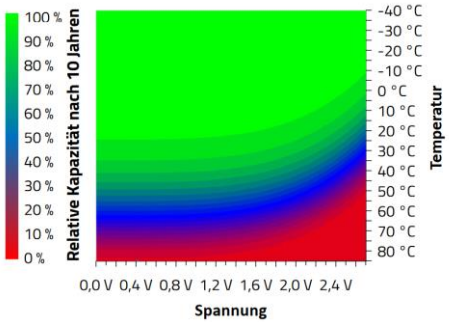




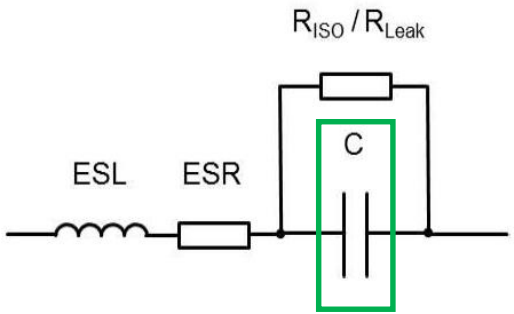
Parasitic Effects on Capacitors

Aging Supercaps (& Elkos)





https://www.we-online.com/components/media/o707130v410%20SN012a%20DE.pdf



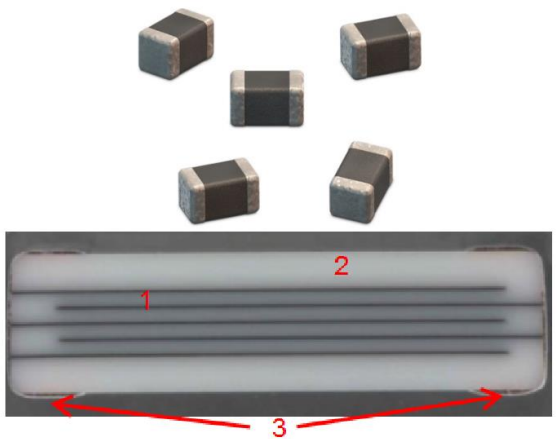
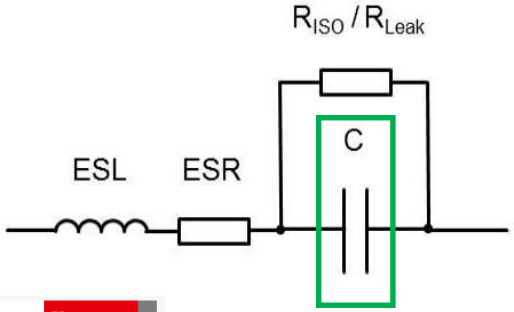
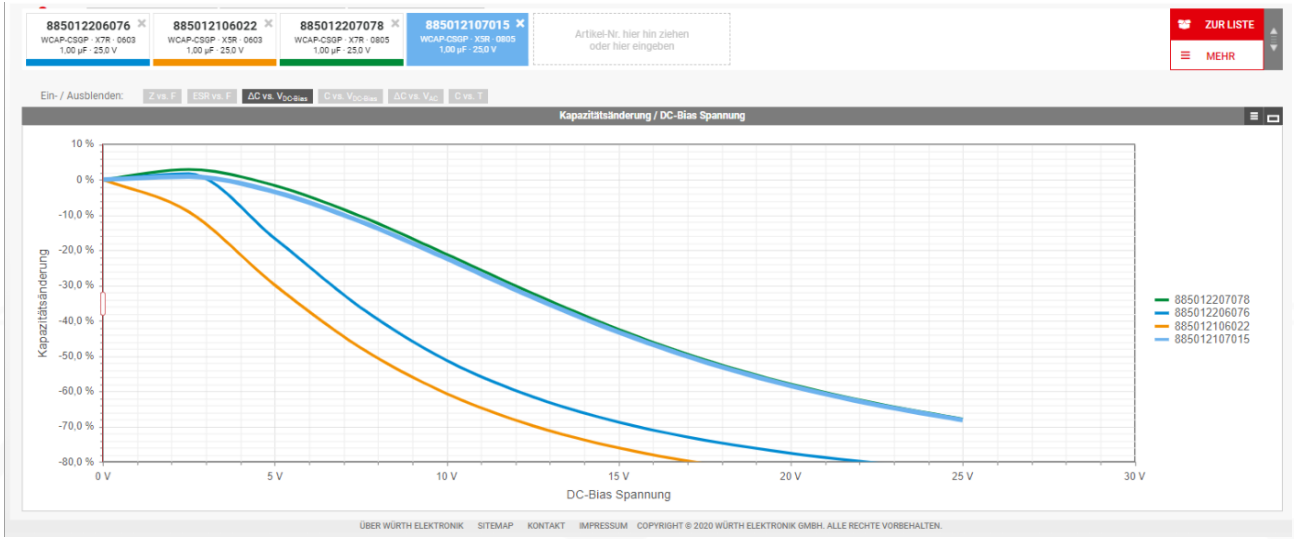


Abbildung 1: Aufbau von einem MLCC: 1 = leitende Elektroden, 2 = Keramikmaterial, 3 = Kontaktflächen

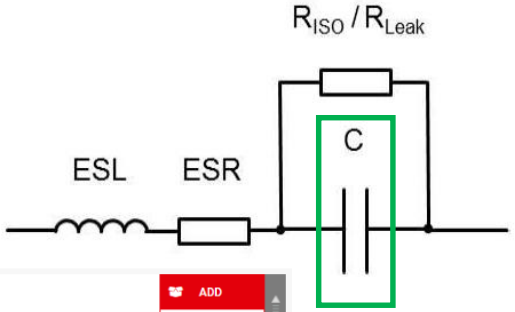
Parasitic Effects on Capacitors



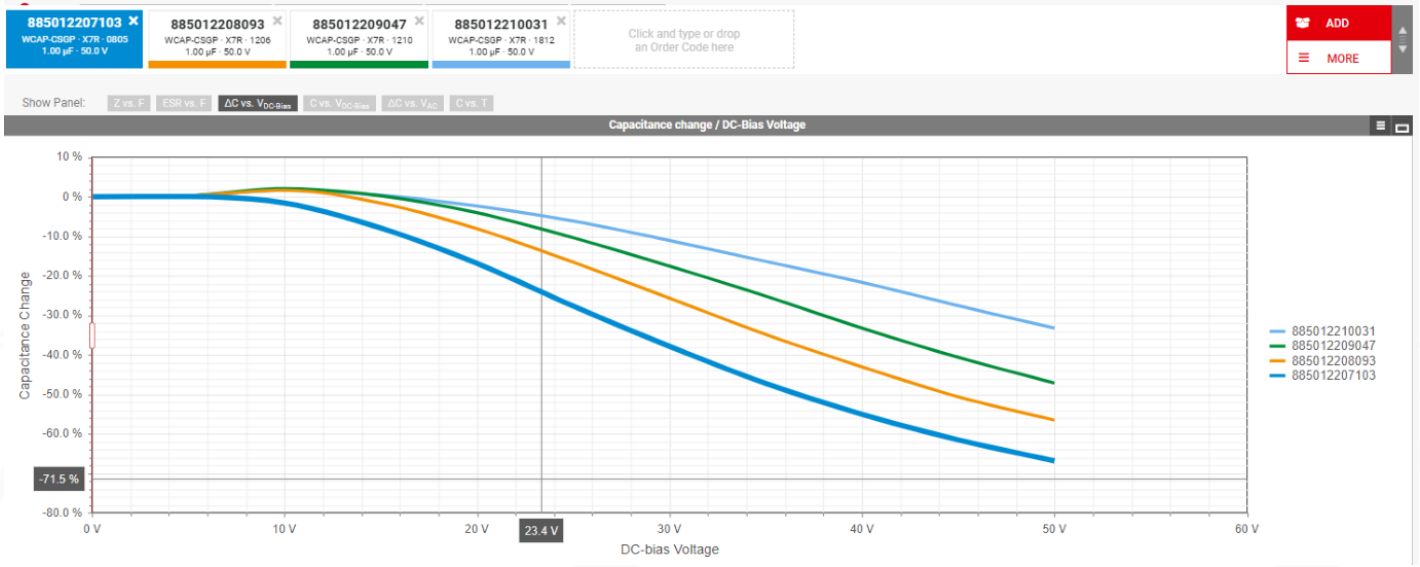
MLCC DC-Bias on different dielectrics



Parasitic Effects on Capacitors



MLCC DC-Bias on different package sizes



Parasitic Effects on LC Filters

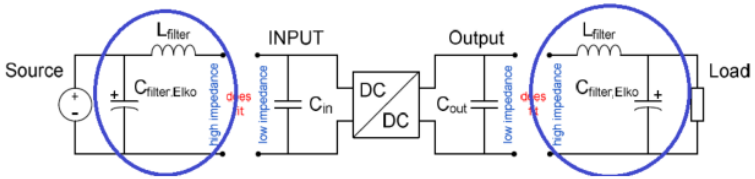


Abbildung 6: LC-Filter am Ein- und Ausgang von Spannungswandler

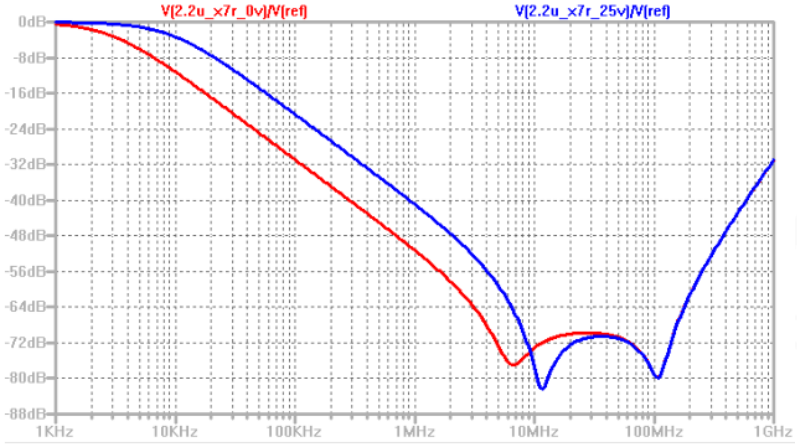
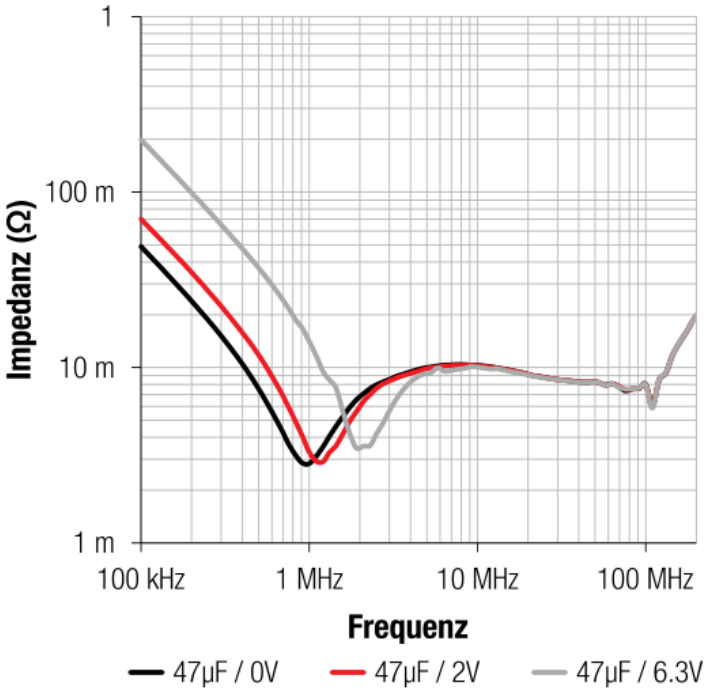


Abbildung 24: Simulationsergebnis des LC-Filters bezogen auf eine 50Ω-Referenz



Summary

- Component Values can vary by more than 100 % in different conditions
- Construction and mounting of electrical components is critical in RF
- Temperature, Current and Voltage during RF circuitry operation must be taken into account

Further References:

- https://www.fritz.dellsperger.net/smith.html
- https://www.analog.com/en/design-center/design-tools-and-calculators/ltspice-simulator.html
- https://youtu.be/O5Cyg6k5i-o