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DC and AC Bias Dependence of Capacitors

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DesignCon 2011 13-TH2, February 3, 2011

Outline

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- Unit-to-unit variations

- Comparing X5R and X7R parts

- ESR and ESL variations

- Beware of details

- AC bias dependence

- Dependence of timing and sweep type

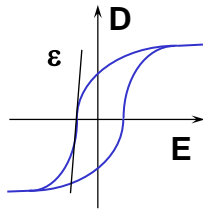
How all this may impact our design

- Paralleled capacitors

- LC filters

Conclusions

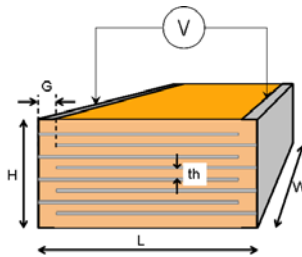
Introduction and Background



Class II and higher ceramic materials are ferroelectric

Ferroelectric materials have saturated hysteretic D-E curves

Layer count
 $N = H/th$



$$D = \epsilon E$$

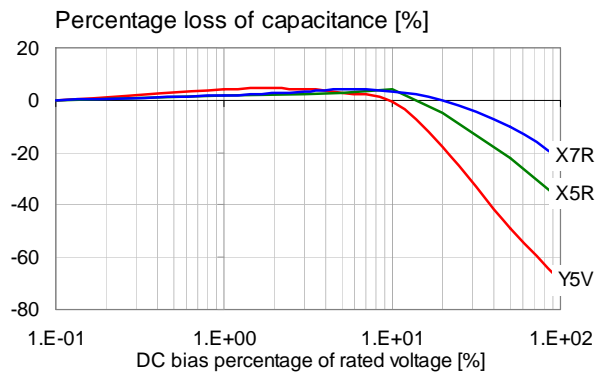
$$C = \epsilon_0 \epsilon_r N \frac{W(L-2G)}{th}$$

$$E = \frac{V}{th}$$

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Introduction and Background



For some time, it was a common assumption that X7R MLCCs had less DC bias sensitivity than X5R parts.

But lately...

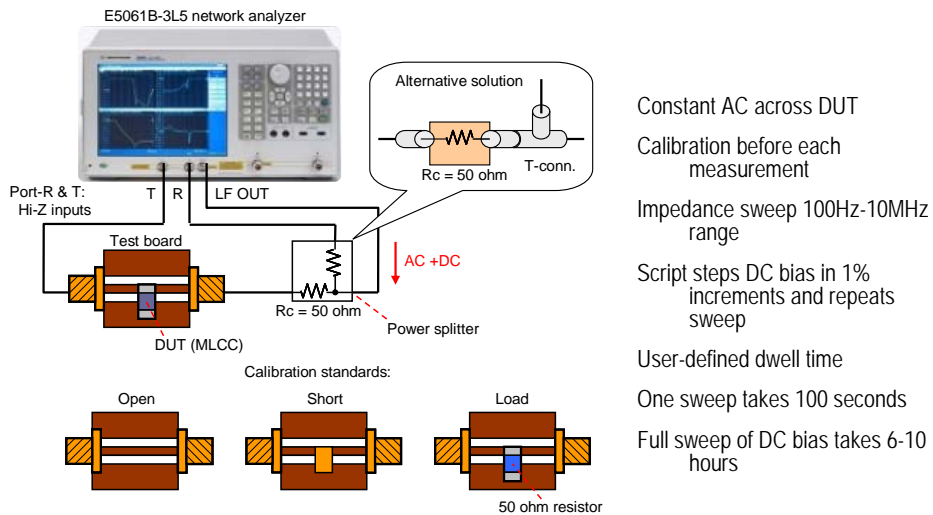
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Scope of Work

- Class II X5R and X7R parts
- 0402, 0603, 0805, 1206 and 1210 body sizes
- 4-16VDC nominal voltage rating
- Six different MLCC vendors
- 25 different part numbers
- Multiple pieces of each part number
- Room temperature testing only

Instrumentation Setup

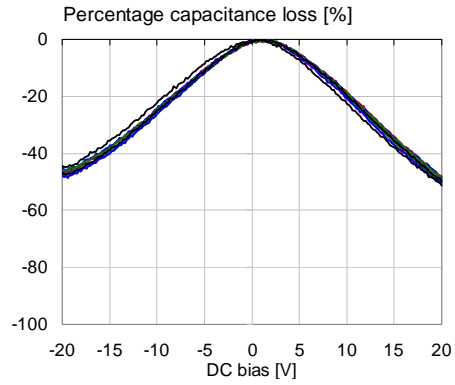
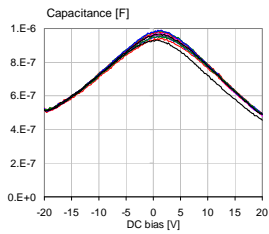


- Constant AC across DUT
- Calibration before each measurement
- Impedance sweep 100Hz-10MHz range
- Script steps DC bias in 1% increments and repeats sweep
- User-defined dwell time
- One sweep takes 100 seconds
- Full sweep of DC bias takes 6-10 hours

For details, see: Novak-Mori-Resso, "Accuracy Improvements of PDN Impedance Measurements in the Low to Middle Frequency Range," Proceedings of DesignCon 2010, Santa Clara, CA, February 1-4, 2010

Unit-to-Unit Variations

1uF 0603 16V
X5R



Ten samples from same vendor
Capacitance measured at 100 Hz

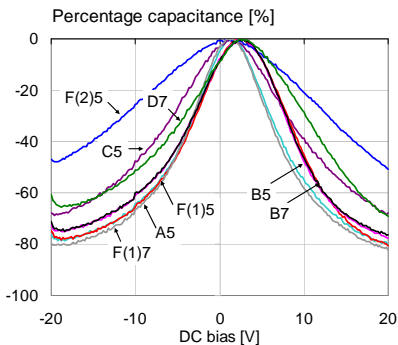
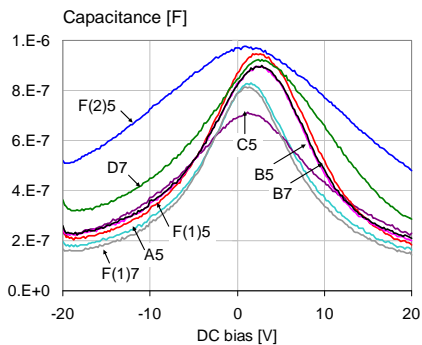
X5R vs X7R

Vendor allocation for measuring X5R and X7R 1uF 0603 16V MLCC parts

	X5R	X7R
Vendor-A	√	X
Vendor-B	√	√
Vendor-C	√	X
Vendor-D	X	√
Vendor-F (1)	√	√
Vendor-F (2)	√	X

X5R vs X7R at 10mV AC

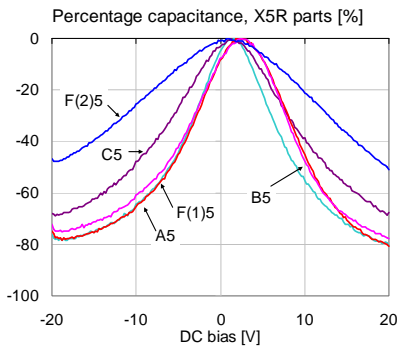
1uF 0603 16V X5R and X7R



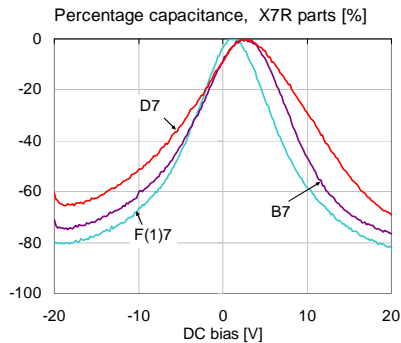
Samples from Vendors
A,B,C,D,F

X5R vs X7R at 10mV AC

1uF 0603 16V X5R
parts only

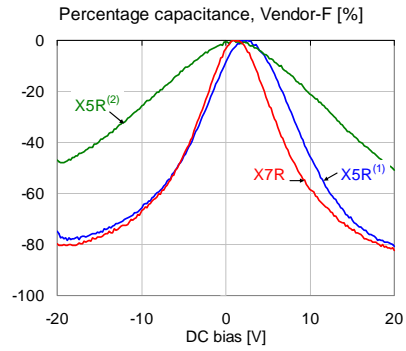
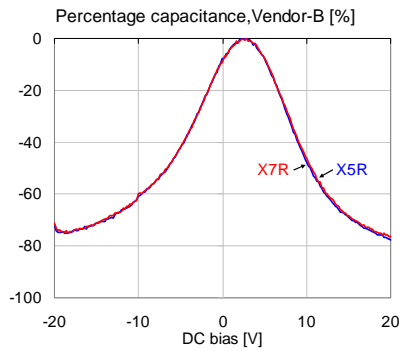


1uF 0603 16V X7R
parts only



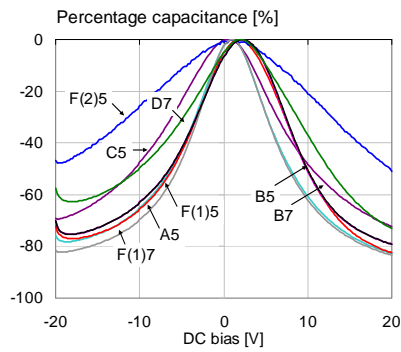
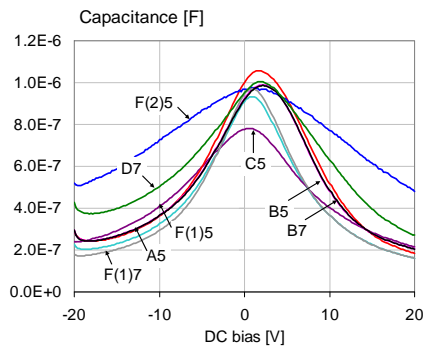
X5R vs X7R at 10mV AC

X5R vs X7R from the same vendor



X5R vs X7R at 500mV AC

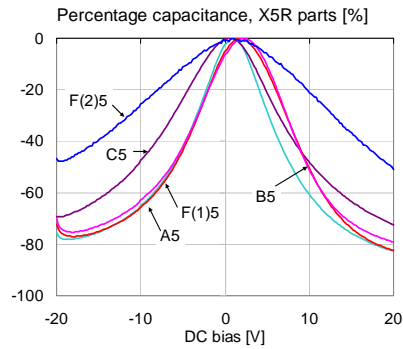
1uF 0603 16V X5R and X7R



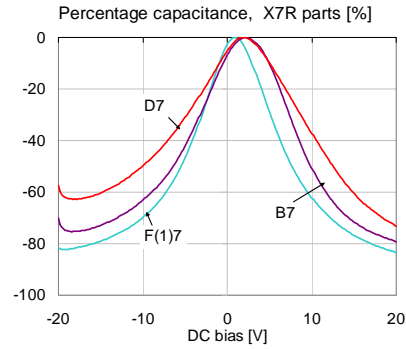
Samples from Vendors
A,B,C,D,F

X5R vs X7R at 500mV AC

1uF 0603 16V X5R
parts only



1uF 0603 16V X7R
parts only

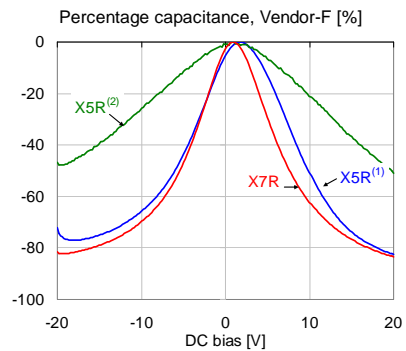
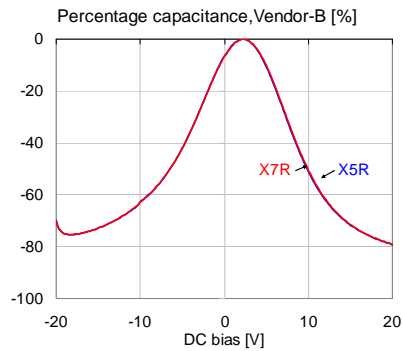


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X5R vs X7R at 500mV AC

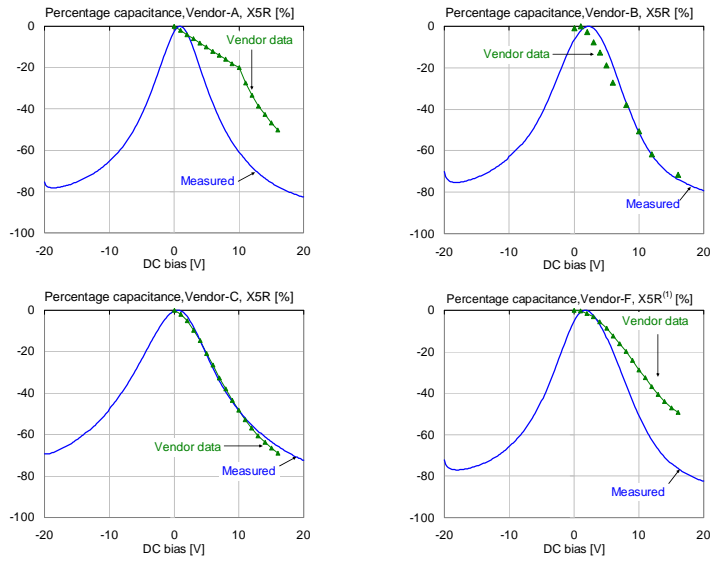
X5R vs X7R from the same vendor



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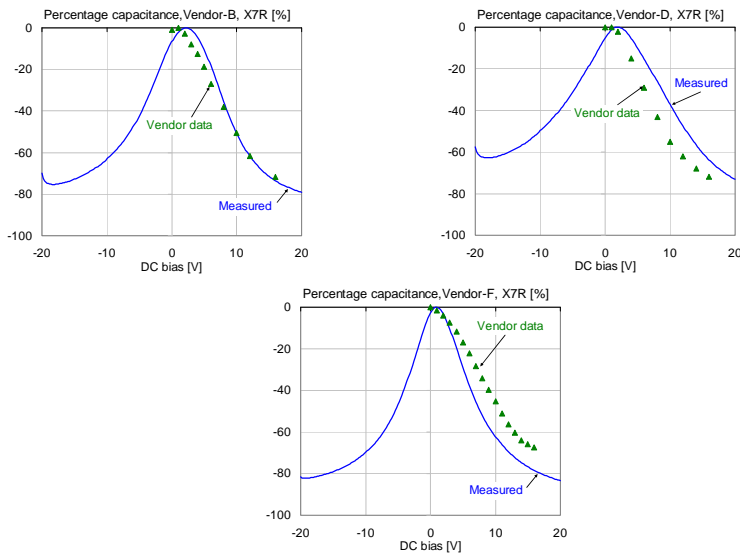
X5R Correlation at 500mV AC



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X7R Correlation at 500mV AC

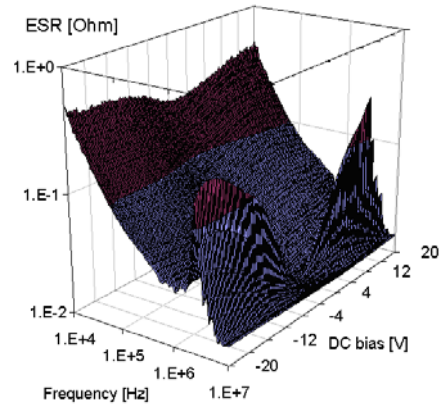
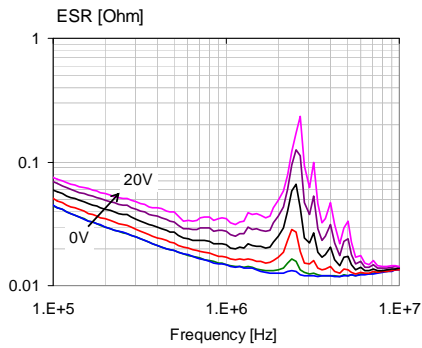


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ESR and ESL vs. Bias

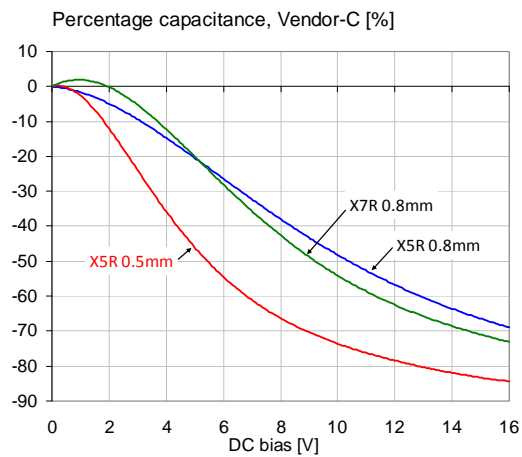
- ESR does not change above SRF
- ESR increases below SRF as C drops
- Piezo effect shows up with increasing bias
- ESL shows no measurable difference



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Beware of Details



Sensitivity vs. body height

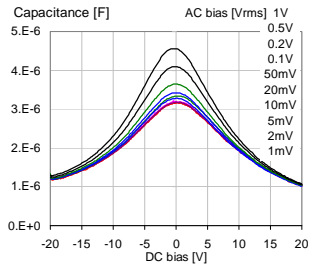
Data from vendor

Lower body height comes with higher sensitivity

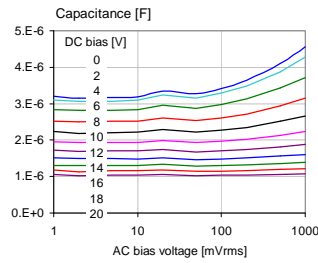
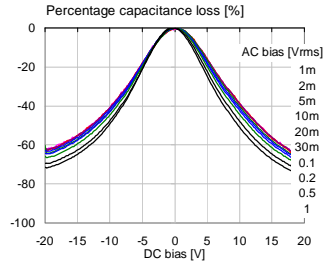
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AC bias dependence



4.7uF 0805-size
16V X5R parts
from Vendor F



High AC bias increases
capacitance at low DC bias.

High AC bias lowers
capacitance at high DC bias.

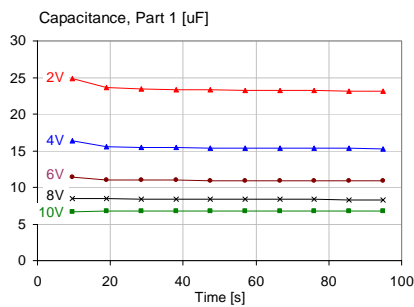
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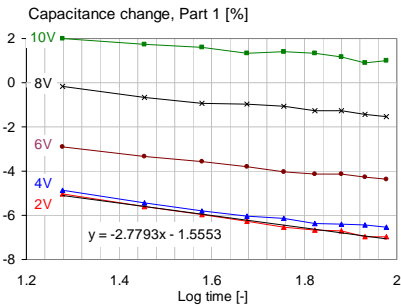
Relaxation of Part 1

Part 1: Vendor-A, 47uF 1206-size 6.3V X5R part.
100Hz, 10mVrms AC bias.

Absolute capacitance change.



Relative capacitance change.



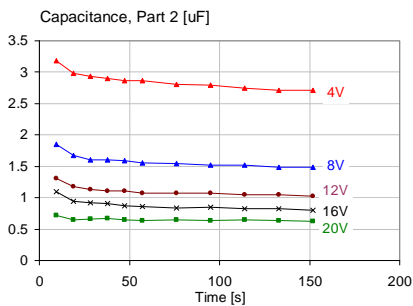
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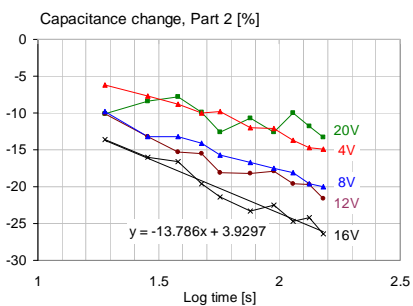
Relaxation of Part 2

Part 2: Vendor-D, 4.7uF 0805-size 16V X7R part.
100Hz, 10mVrms AC bias.

Absolute capacitance change.

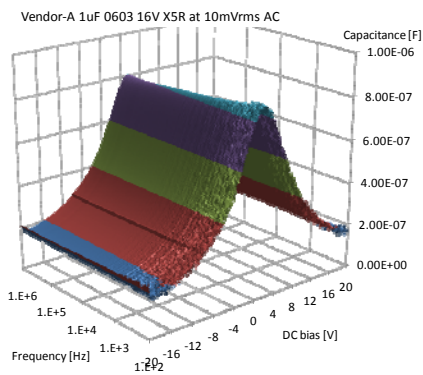


Relative capacitance change.

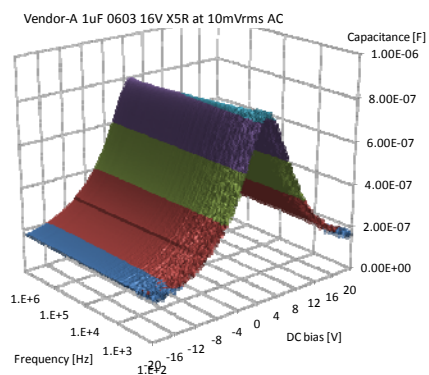


Quick Relaxation Part

Readings 10 sec after changing bias



Readings 100 sec after changing bias

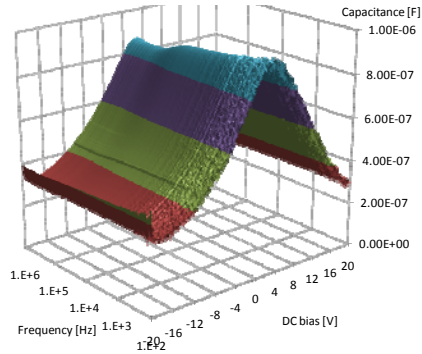


Slow Relaxation Part

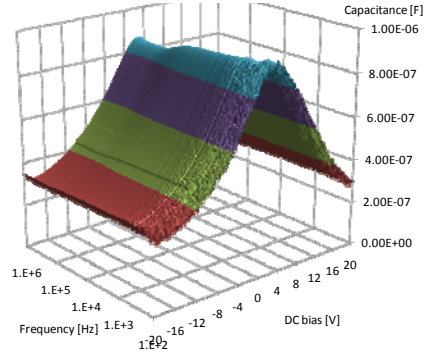
Readings 10 sec
after changing bias

Readings 100 sec
after changing bias

Vendor-D 1uF 0603 16V X7R at 10mVrms AC bias

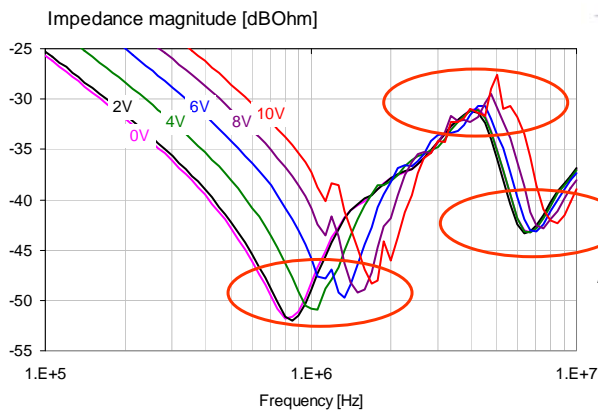


Vendor-D 1uF 0603 16V X7R at 10mVrms AC bias



Paralleled Capacitors

1uF 0603-size 16V X7R part from Vendor-D and
47uF 1206-size 6.3V X5R part from Vendor-E

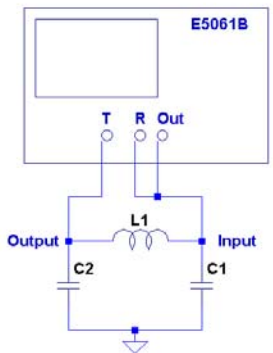


All three resonances shift.

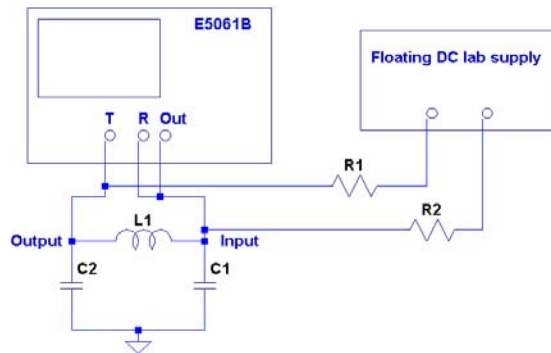
Capacitors in Filters, Test Setup

C1: 390uF 16V OSCON, DUT: 47uF 6.3V X5R 1206-size MLCC from Vendor-E, L1: 2A ferrite bead

No DC current through L1



With DC current through L1



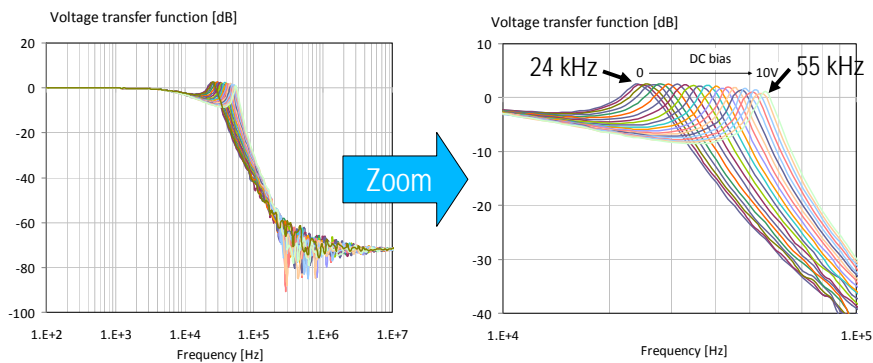
Filter Response vs. DC Bias Voltage

No DC current bias through L1

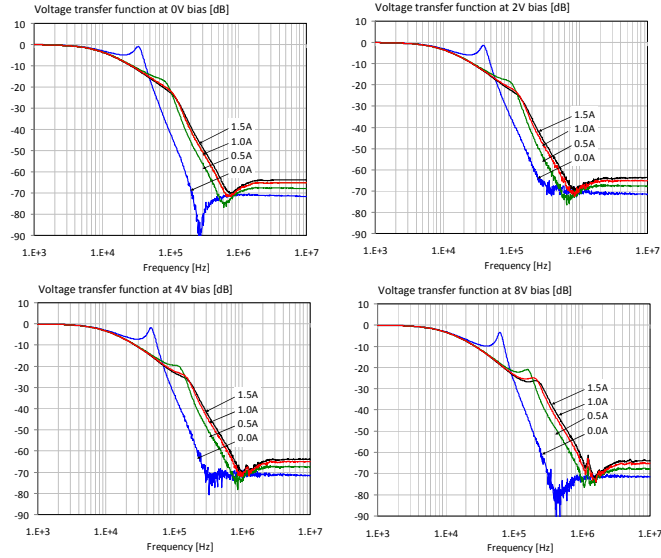
No change below 10 kHz and above 1 MHz

No change in peaking

Peak frequency and cut-off frequency increases with increasing bias

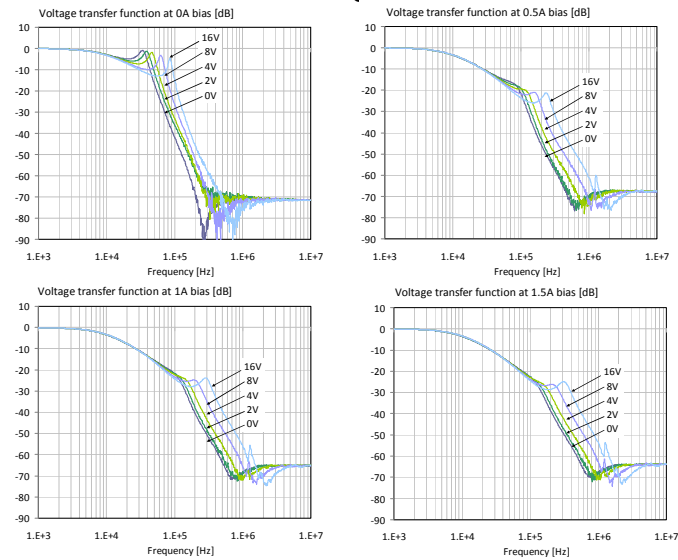


Filter Response vs. DC Bias Voltage and Current



Parameter: DC current through L1

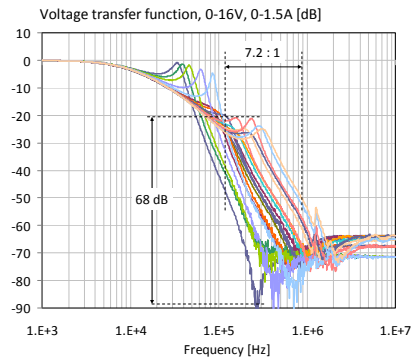
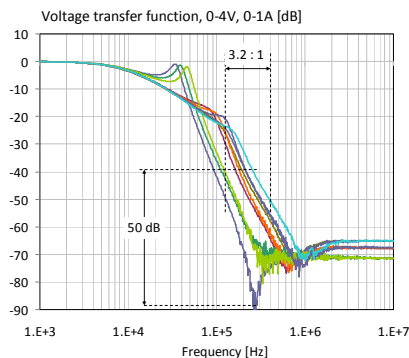
Filter Response vs. DC Bias Voltage and Current



Parameter: DC voltage across C2

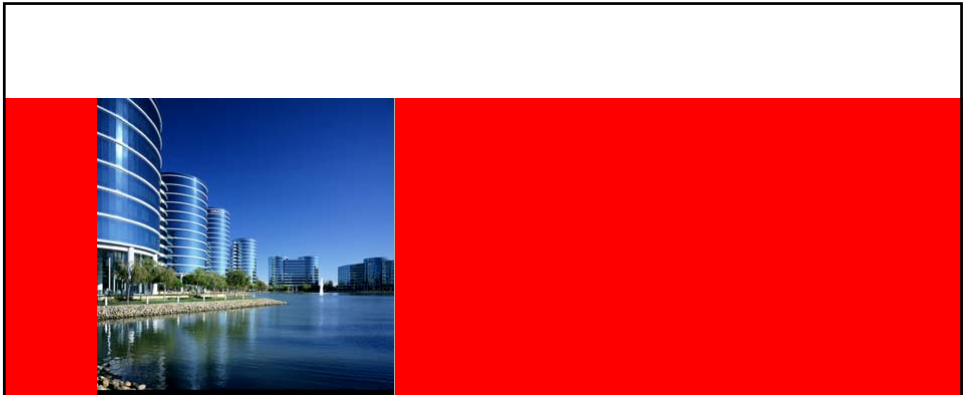
Overall Change in Filter Response

Current bias through L1 eliminates peaking



Conclusions

- High volumetric density creates big capacitance drop in Class II MLCCs with DC bias
- X7R parts are not necessarily less sensitive to DC bias than X5R parts
- Slow relaxation may result in an additional 20-30% capacitance drop over time (not on the spec sheet!)
- Major vendors provide models for DC and AC bias sensitivity
- DC and AC bias sensitivity is very different across vendors
- >> DC and AC bias sensitivity must be taken into account in alternate source selection



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THANK YOU

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