CAPACITOR SELECTION FOR DC/DC CONVERTERS:

WHAT YOU NEED TO KNOW TO PREVENT EARLY FAILURES, AND REDUCE SWITCHING NOISE

TI – Silicon Valley Analog in Santa Clara, California, USA
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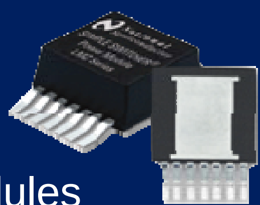
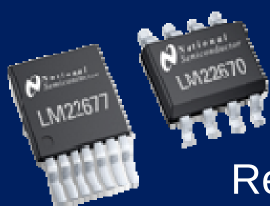
Additional material provided by Chuck Tinsley of capacitor manufacturer KEMET

The SIMPLE SWITCHER® Experience

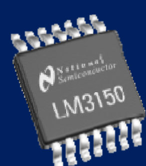
Easy-to-Use ICs



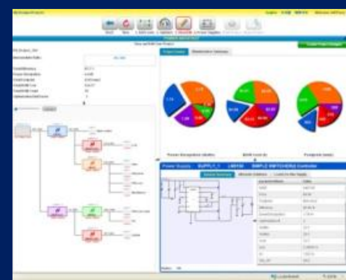
Power Modules



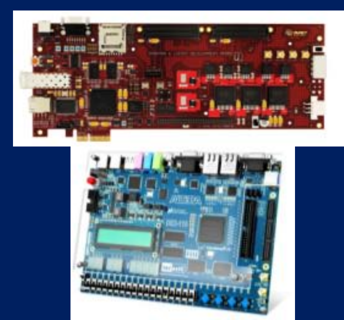
Regulators



Controllers



WEBENCH® Power Designer



Reference Designs

Design Tools

SIMPLE SWITCHER
Easy-to-use tools. Simple solutions.

- Enables designers at any level to create a power supply easily and quickly
- Reduces overall design time with proven solutions
- Delivers faster time to market

TEXAS INSTRUMENTS

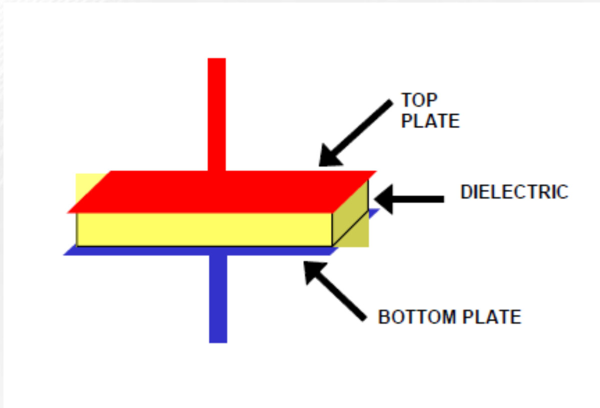
2012 POWER FORUM
AN AVNET VIRTUAL CONFERENCE

AVNET electronics marketing

Table of Contents

CAPACITOR TYPES

What is a Capacitor?



» Capacitance = The ability to store charge in an electric field.

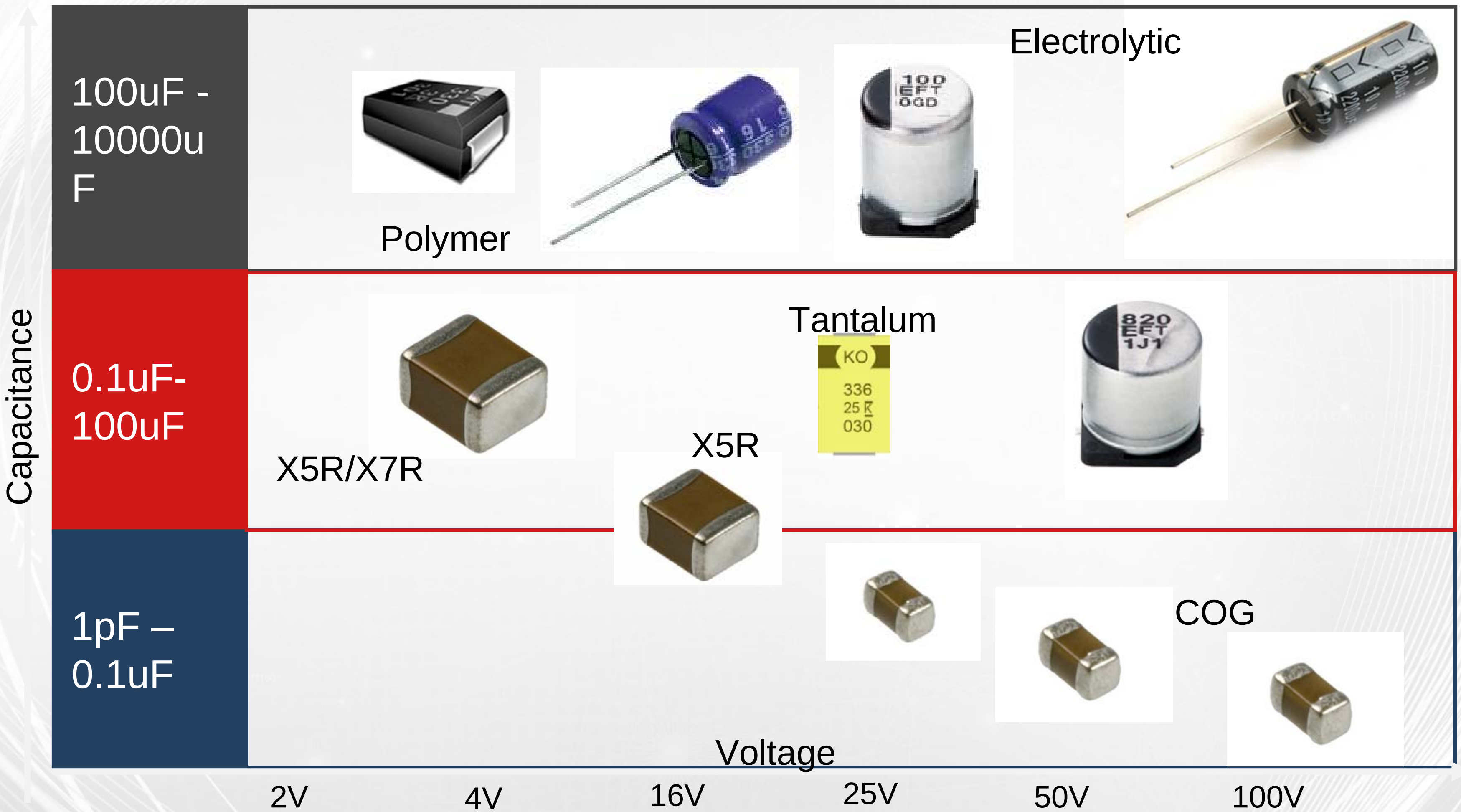
$$c\ (farads) = \frac{\varepsilon\ (dielectric\ constant) * A\ (area)}{d\ (distance\ between\ the\ plates)}$$

$$c\ (capacitance\ in\ farads) = \frac{q\ (charge)}{V\ (voltage)}$$

$$i\ (current) = c(capacitance) * \frac{dV\ (change\ in\ voltage)}{dT\ (change\ in\ time)}$$

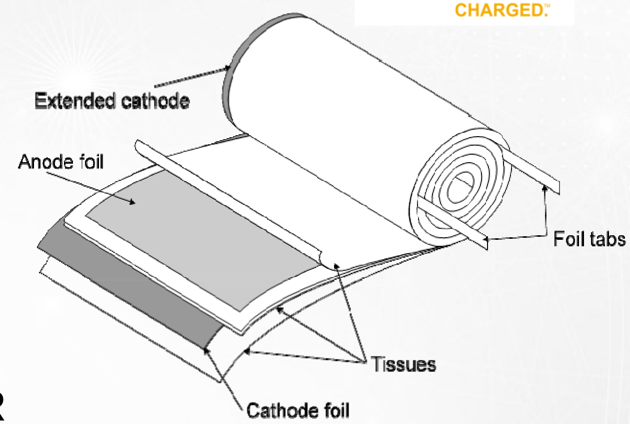
DIELECTRIC CONSTANT OF MATERIALS	
Air	1.00
Alsimag 196	5.70
Bakelite	4.90
Cellulose	3.70
Fiber	6.00
Formica	1.75
Glass	7.75
Mica	5.10
Mycalex	7.10
Mycalex	7.10
Paper	3.00
Plexiglass	2.80
Polyethylene	2.30
Polystyrene	2.60
Porcelain	5.57
Pyrex	4.00
Quartz	3.80
Steatite	5.80
Teflon	2.10

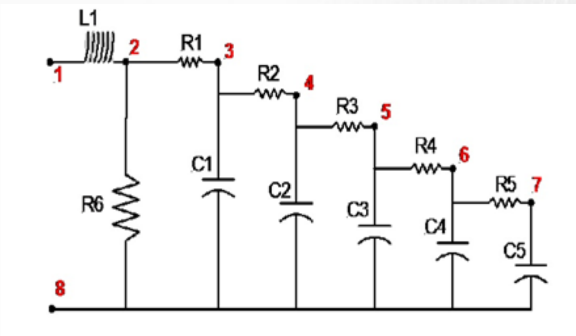
Capacitor Chemistry - Value and Voltage Rating



Aluminum Electrolytics - Overview

- **Least expensive** capacitors for bulk capacitance
  - Multiple vendors
  - Small size, surface mountable
- How is it made?
  - Etched foil with liquid electrolyte
  - Placed in a can with a seal/vent
- **Highest ESR**
- Low Frequency Cap roll off due to higher ESR
- Wear Out Mechanisms lead to **– limited lifetime**
  - Liquid electrolyte – with a vent
  - Cap changes over time with voltage and temp
  - ESR changes over time
- Mounting
  - High shock and vibration can cause failure





Aluminum Electrolytics - Packaging

KEMET CHARGED.

- Through hole versions, usually in a **round can**.
  - Large ones have screw terminals or solder lugs
  - Radial or axial leads
  - Non SMT may have higher inductance because of long leads
- Surface mountable versions, are modified from radial leaded versions.
  - SMT versions usually have the capacitor value visibly printed on can.
  - SMT versions may use letter codes instead of numeric rating.

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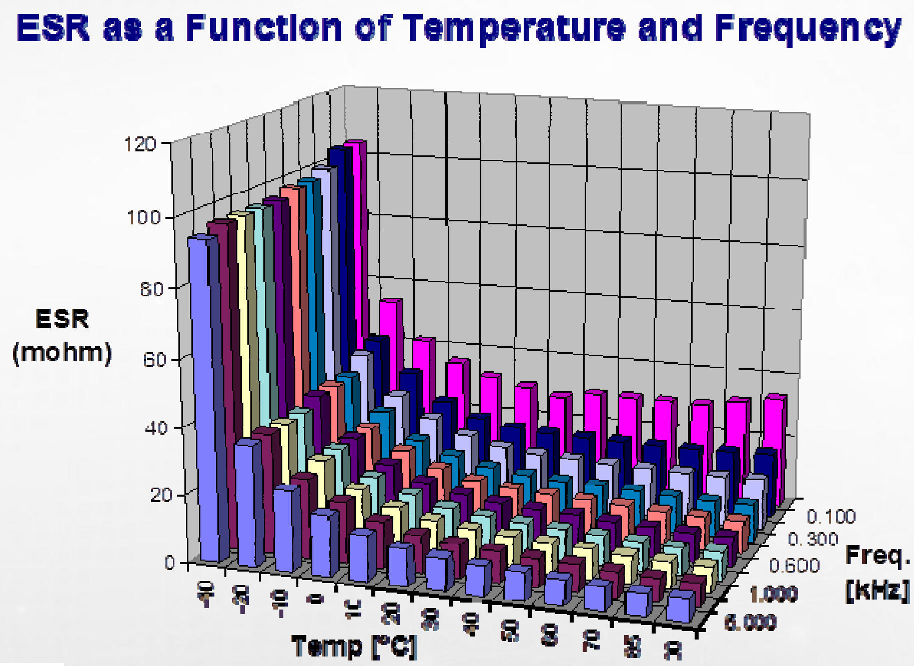
Aluminum Electrolytics - Advantages

- Low cost
  - Mature technology with low cost materials
- Long history
  - Industry started in the 1930s
- Many manufacturers to choose from
- High capacitance values available
- Only choice for SMPS that need high voltage and high capacitance

Aluminum Electrolytics - Disadvantages

» Large swings in ESR vs temperature

» Cold temps have 4 - 8x higher ESR than room temps



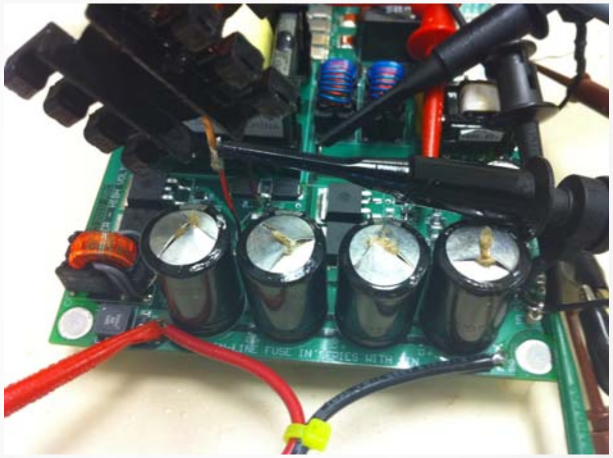
Aluminum Electrolytics - Disadvantages

KEMET CHARGED.

- **Large Parasitics**
  - High ESR (Effective Series Resistance)
  - High ESL – (Effective Series Inductance).
- Electrolytic capacitors eventually **degrade over the life of the product**.
  - The electrolyte eventually dries out.
  - Long term storage may cause the Aluminum oxide barrier layer to de-form.
    - Capacitance drops
    - ESR increases.
      - Higher ESR causes more internal heat causing the electrolyte to dry out even faster
      - This effect is worse at high temperatures
  - **Lesson: don't use "old stock"** aluminum capacitors in your product
- **Needs a ceramic in parallel** for most switch mode applications
  - High ESR and ESL can cause SMPS malfunction
- Have measurable DC leakage current
  - Probably not an issue in power circuits
    - Leakage current can be a problem in timing circuits

Aluminum Electrolytics – Venting Failure

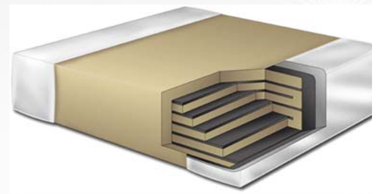
- Fails open or shorted
- Catastrophic explosive venting
  - From over-voltage of the capacitor
  - From exceeding the ripple current rating of a capacitor
    - – May have the same effect as overvoltage, but it takes longer for the capacitor to overheat and vent

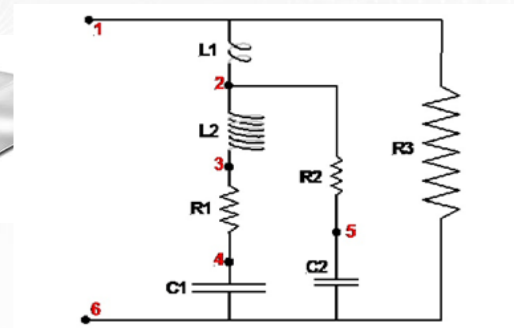


450V rated capacitors after accidental application of 600V

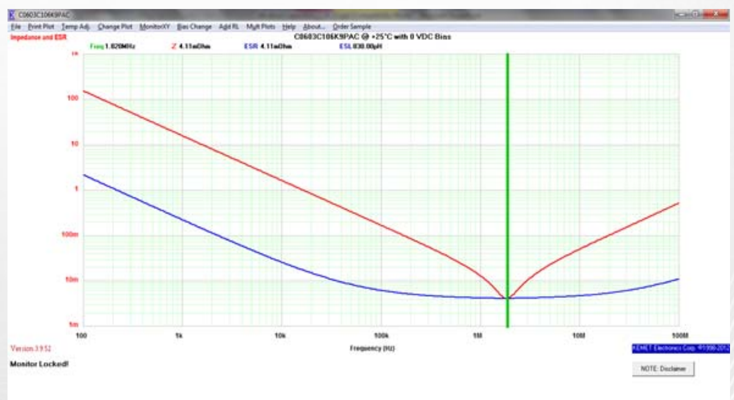
Ceramics - Overview

- **Lowest Cost** devices
  - Primarily for **decoupling** and bypass applications
  - Multiple vendors, sizes
  - Surface mountable
- How is it made?
  - Alternating layers of electrodes and ceramic dielectric materials





- **Things to watch out for** with Class 2 Dielectrics i.e. X5R, X7R …
  - Voltage bias effect
  - Temperature effects
  - Ageing
    - 2%/decade hour for X7R
    - 5%/decade hour for X5R
    - Starts decay after soldering
  - High Q
    - Frequency selective



Ceramic Dielectric – 3 Character Codes

Class 1: (Best Performance)

- Temperature Coefficient Decoder

ppm/°C	
C	0.0
B	0.3
L	0.8
A	0.9
M	1.0
P	1.5
R	2.2
S	3.3
T	4.7
V	5.6
U	7.5

Multiplier	
0	-1
1	-10
2	-100
3	-1000
4	+1
6	+10
7	+100
8	+1000

Tolerance in ppm/°C (25-85 °C)	
G	±30
H	±60
J	±120
K	±250
L	±500
M	±1000
N	±2500

Typical Values:

- NP0, C0G, values up to 100,000 pF

Class 2: (Higher Capacitance)

- Temperature & Capacitance Tolerance Decoder

Minimum temperature	
X	-55 °C
Y	-30 °C
Z	+10 °C

Maximum temperature	
4	+65 °C
5	+85 °C
6	+105 °C
7	+125 °C
8	+150 °C
9	+200 °C

Capacitance change permitted	
A	±1.0%
B	±1.5%
C	±2.2%
D	±3.3%
E	±4.7%
F	±7.5%
L	+15% / -40%
P	±10%
R	±15%
S	±22%
T	+22% / -33%
U	+22% / -56%
V	+22% / -82% [1]

Typical Values:

- X5R, X7R, values up to 150 uF

Ceramic Capacitors - Advantages

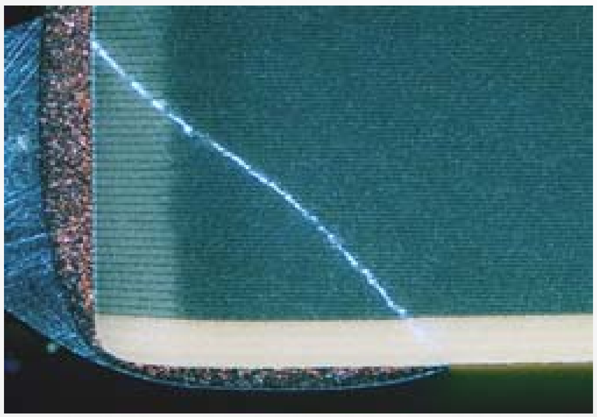
- Low Cost
  - Mature technology with low cost materials
- Many Manufacturers to choose from.
- Reliable and rugged
  - Extremely tolerant of over voltage surges
- Best Choice for local bypassing
- Not Polarized
- Lowest effective series resistance (Low ESR)
  - several milliohms
  - Leads to high RMS current rating
- Low effective series inductance (Low ESL)
  - < 2nH

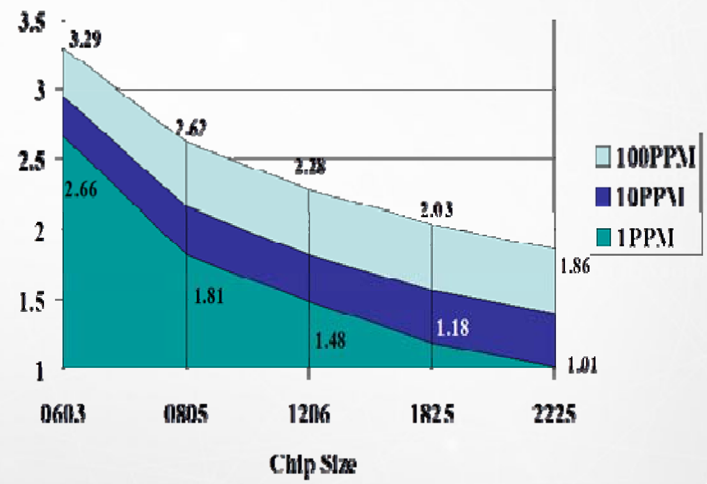
Ceramic Capacitors - Disadvantages

- **Capacitance limited** to around 150 uF / 6.3V
- Large body sizes prone to **cracking** with PCB flexing
  Several small units in parallel may be a better choice
- Have both a **voltage and temperature coefficient** that reduces capacitance value
- Some large package size units exhibit piezo-electric audible **"singing"**
  - Difficult to control. (Ceramic speaker effect.)
  - More noticeable with Class 2 dielectrics
- Incomplete data sheets!
  - ESR, ESL, SRF and Ripple Current rating often missing from data sheets
  - Contact the manufacturer for ripple current
- Capacitance value not printed on SMT device package.
  - Impossible to visually inspect for value once mounted on the PCB
- Some power supply circuits are not stable with ceramic output capacitors
  - Usually LDOs and parts using COT control

Ceramics - Cracking

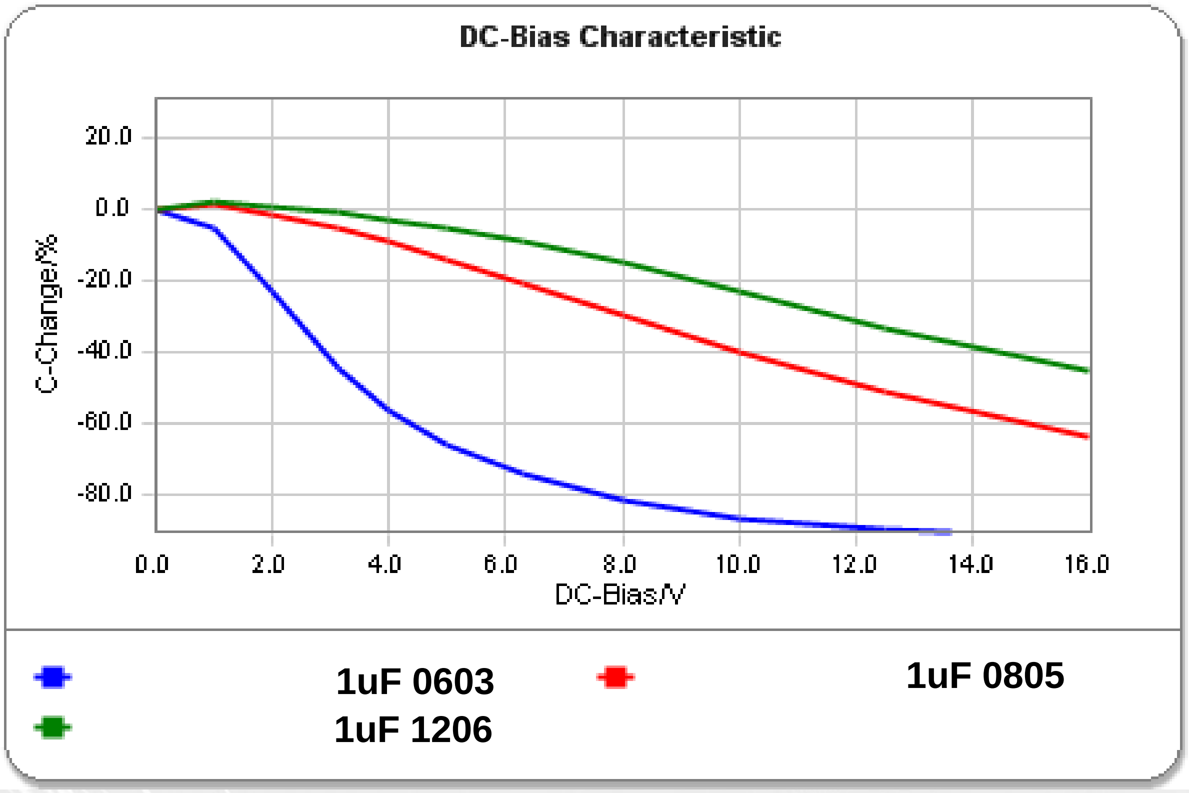
- Flex cracking – Number 1 failure mode!
  - Cracks formed after mounting to PCB
    - Mechanically stressed after assembly
    - Larger parts generate cracks more easily





Voltage Bias Effect Including Case Size

X5R, 16V Rated Capacitors



Capacitance decreases more quickly with smaller case sizes

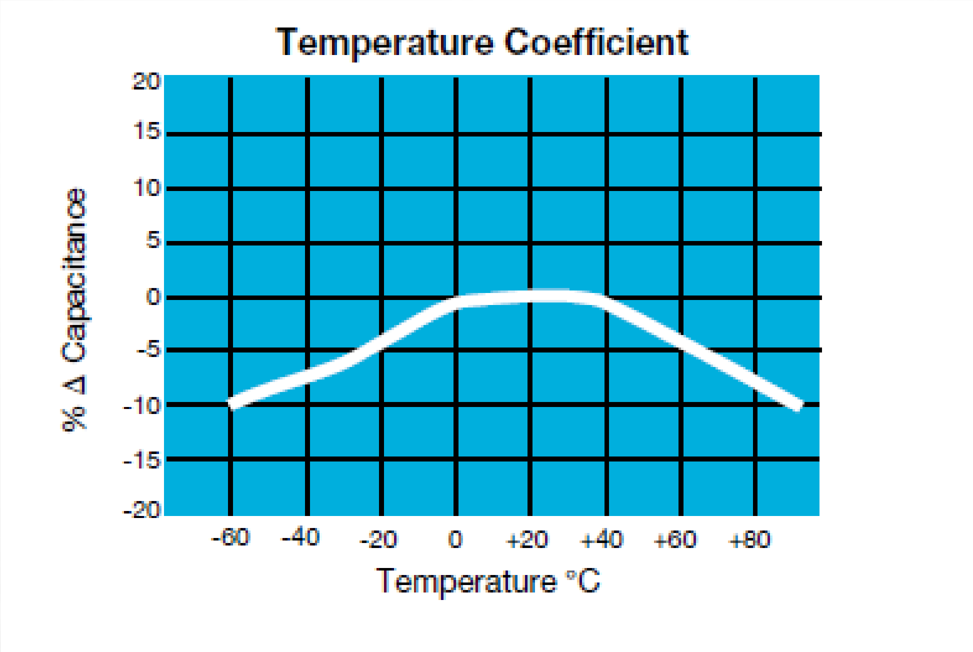
Voltage de-rating

- Class 1 Dielectrics COG etc do not require voltage derating.
- Class 2 Dielectrics such as X7R and X5R, lose significant capacitance as you approach the rated voltage.

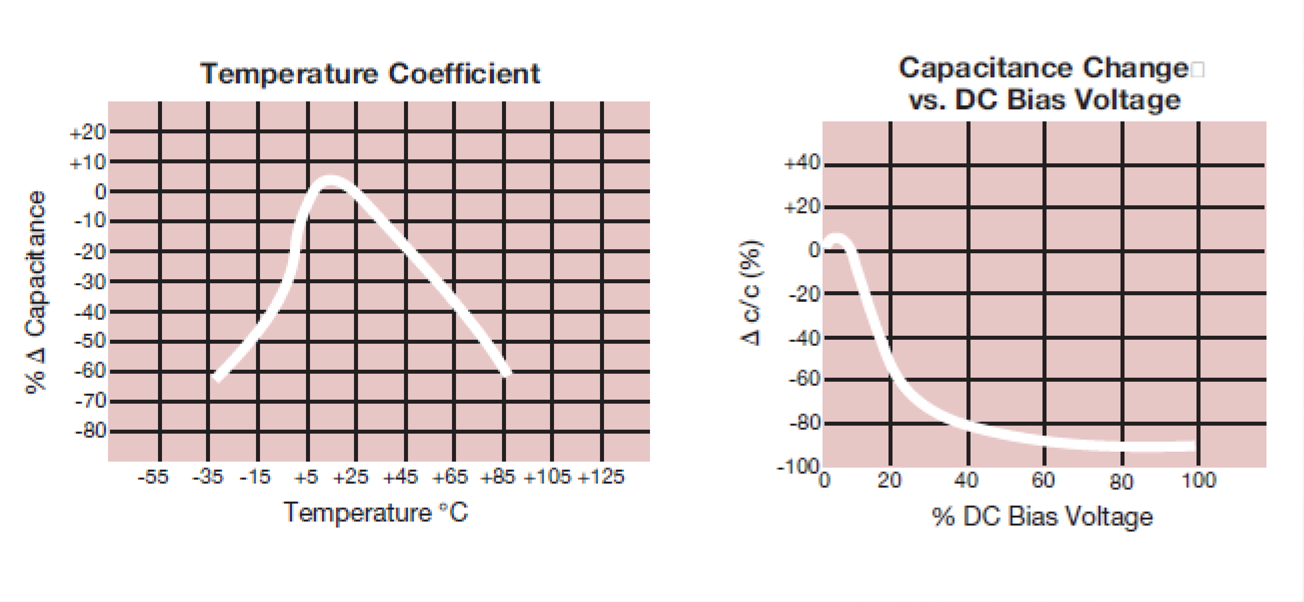
Ceramic Capacitance Change Due To Temperature

» AVX Capacitor X5R dielectric – typical of any brand

» You lose another 10% over temperature



Y5V Dielectric Characteristics

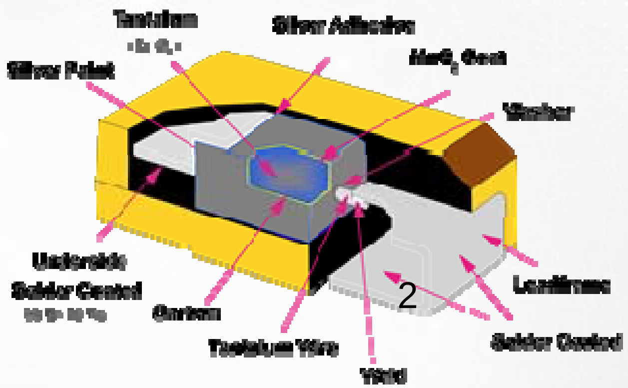


<u>DO NOT USE</u> Y5V and Z5U ceramic dielectrics for power supply designs

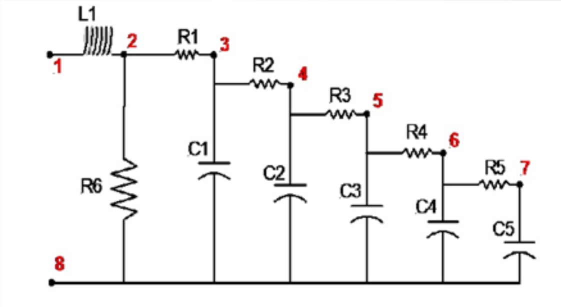
Tantalum – Overview (MnO_2 based)

KEMET CHARGED.

- High capacitance per unit volume technology
  - Small package sizes available
    - Thin devices are available
- How is it made?
  - Tantalum anode pressed around a tantalum wire
  - Oxide grown on surface
  - Cathode formed by dipping and heat conversion Mn→MnO
  - Epoxy encapsulated



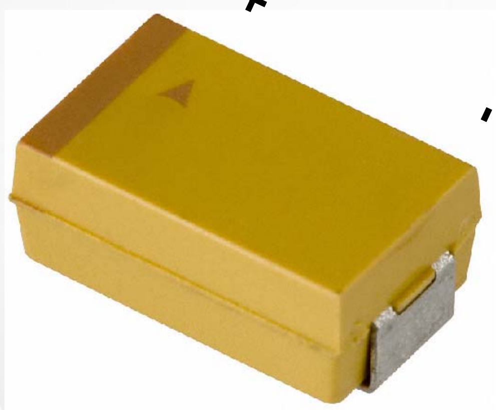
- Old technology
  - Requires 50% Voltage de-rating
    - PPM failure rates increase exponentially above 50% voltage de-rating
  - Can fail **explosively**
  - High ESR compared to polymer types
  - Fairly low cap roll off vs. frequency



Tantalum Model

Solid Tantalum Capacitors - Packaging

- Usually rectangular surface mount technology – SMT machine mountable
- Capacitance ratings for 1 uF to 1,000 uF



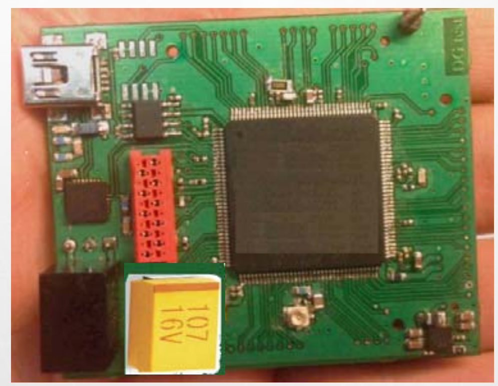
Solid Tantalum Capacitors - Advantages

- Lots of capacitance in a **small** package.
  - 1uF to 1000uF max
- Medium-high effective series resistance (Low ESR)
  - 10 to 500 milliohms
  - Medium level of RMS current
- Low effective series inductance (Low ESL)
  - < 3nH
- Numerous manufacturers
- Good datasheet vs. electrolytic

Solid Tantalum Capacitors - Disadvantages

- » Limited voltage range of 50V rating (max)
  - » Therefore, only reliable for operating voltages less than 25 to 35VDC
- » Fairly high in cost
  - » Historically tantalum has had supply shortages
- » Limited in-rush surge current capability
  - » Do not use tantalum for hot pluggable input capacitors!

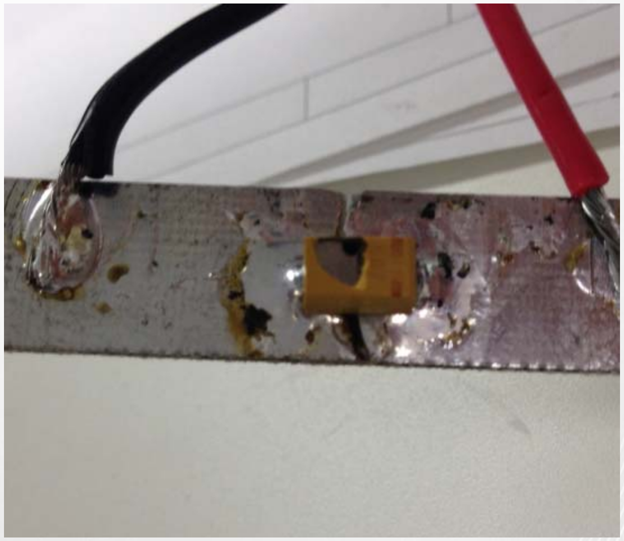
Don’t use tantalum to hot plug!



Solid Tantalum Capacitors – Application Safety

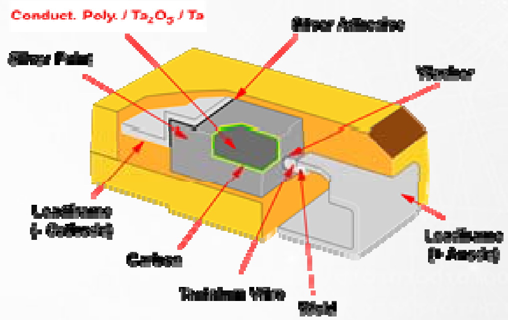
KEMET CHARGED.

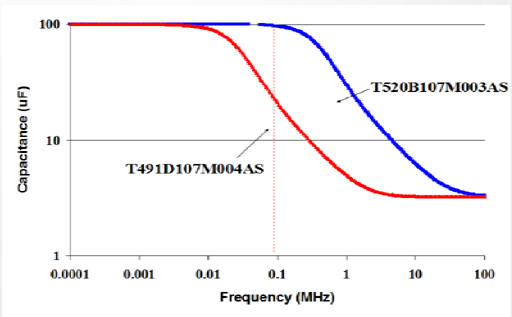
» ALWAYS observe voltage polarity
» DO NOT exceed voltage rating
» DO NOT exceed inrush surge rating
» Can fail catastrophically if misapplied
» Can fail open or short



Polymer - Overview

- Highest capacitance per unit volume technology
  - Small package sizes available
- How is tantalum polymer made?
  - Tantalum anode pressed around a tantalum wire
  - Oxide grown on surface
  - Cathode formed by dipping into Monomer and cured at room temperature
  - Epoxy encapsulated
- **Lower ESR vs. MnO2-based tantalums**
  - Higher frequency operation – over a MHz it still looks like a cap!
  - Lower power dissipation
    - Higher ripple current capability
    - May need less capacitance

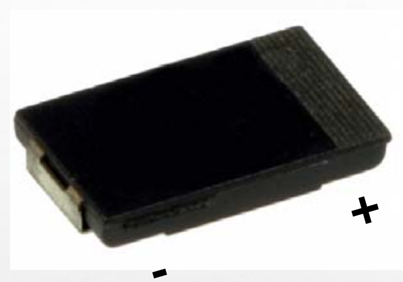




Polymer & Organic Capacitors - Packaging

- » SMT Block style similar to tantalum
- » Round / Radial versions in SMT and through-hole
- » Types: Tantalum polymer / Aluminum polymer / Organic semiconductor

Kemet Tantalum Polymer



PosCap

OSCON

Polymer & Organic Capacitors - Advantages

- Low ESR, but not as low as equivalent ceramic
- Low ESL depending on construction method
- New technology designed for SMPS
- Can be very **low profile**
- High capacitance per unit volume
  - Much better performance than aluminum electrolytic and much smaller in size
- No voltage coefficient
- Viable alternative to solid tantalum

Polymer - Reliability

» Voltage de-rating is 10 - 20% depending on rated voltage

  » PPM failure rates significantly reduced

	$Ta\text{-}MnO_2$	Ta-Poly KO V_R>10VDC	Ta-Poly KO V_R<=10VDC	Alum-Poly AO
@50% V_{Rated} FR(PPM)	9	0	0	0
@80% V_{Rated} FR(PPM)	458	4	1	0
@90% V_{Rated} FR(PPM)	1,700	12	2	0
@100% V_{Rated} FR(PPM)	6,310	35	8	0

» Can withstand higher transient voltages

	$Ta\text{-}MnO_2$	Ta-Poly KO V_R>10VDC	Ta-Poly KO V_R<=10VDC	Alum-Poly AO
100 PPM FR % V_{Rated}	68%	126%	197%	235%

Polymer & Organic Capacitors - Disadvantages

- High cost
- Voltage surges capability depends on chemistry
  - OSCON very intolerant of voltage surges
- Tend to be from a single supplier
  - May have availability issues

Polymer & Organic Capacitors – Failure Mode

- Tantalum polymer
  - Less prone to catastrophic failure than solid tantalum, but will still vent and emit smoke
- Organic (OSCON)
  - Emits noxious smoke

Capacitor Chemistry – General Parameters

Characteristic	PET (MKT)	PEN (MKN)	PPS (MKI)	PP MKP/KP	COG (NPO)	X7R	X8R	Tantalum MnO2	Tantalum Polymer	Aluminum Polymer	Aluminum Electrolytic
Operating Temperature Range (°C)	-55° to 125°	-55° to 125°	-55° to 140°	-55° to 105°	-55° to 125°	-55° to 125°	-55° to 150°	-55° to 125°	-55° to 105° -55° to 125°	-55° to 105° -55° to 125°	-55° to 105°
Temperature characteristic (C/C)	±5%	±5%	±1.5%	±1.5%	0±30ppm	±15%	±10%	±10%	±10%	±10%	25 to -30%
DC Voltage Coefficient (%) at Vr	Negligible	Negligible	Negligible	Negligible	Negligible	-20%	±15%	Negligible	Negligible	Negligible	10 to -15%
Aging Rate (%hr/Decade)	Negligible	Negligible	Negligible	Negligible	Negligible	2%	1%	N.A.	N.A.	N.A.	N.A.
Dissipation Factor (%) 1 KHz 10 KHz 100 KHz	 1.5 3.0	0.8 1.5 3.0	0.2 0.25 0.5	0.05 0.5 1	0.1 0.1	2.5	3.5	8	8	8	5 20
ESR	low	low	very low	very low	low	Moderate to high	Moderate to high	high	Low to Moderate	Low to Moderate	high
Insulation Resistance (MΩxμF) 25°C 85°C	10,000 1,000	10,000 1,000	10,000 1,000	10,000 1,000	10,000 1,000	1,000 500	1,000 200	100 10	10 1	17 1.7	500 5
Dielectric absorption (DA) (%)	0.5	1	0.2	0.05	0.6	2.5	1	0.5	0.5	0.5	N.A.
Capacitance Range	1000pF to 10μF	1000pF to 6.8μF	100pF to 1μF	100pF to 10μF	0.5pF to 1μF	100pF to 4.7μF	100pF to 1μF	0.1μF to 1500μF	10μF to 1500μF	6.8μF to 470μF	0.1μF to 100μF
Capacitance Tolerances (±%)	5; 10	5; 10	2.5; 5	5; 10; 20	5; 10	10; 20	5; 10; 20	5;10; 20	20	20	-20 +50
Failure Mode Self Healing	Open Yes	Open Yes	Open Limited	Open Yes	Short No	Short No	Short No	Short Limited	Short Limited	Short Limited	Short Limited
Reliability	High	High	High	High	High	Moderate	Moderate	High	High	High	Low
Piezoelectric effect	No	No	No	No	No	Yes	Yes	No	No	No	
Resistance to thermal and mechanical shock	High	High	High	High	Low	Moderate to Low	Low	High	High	High	
Non-Linear distortion (3rd harmonic)	Very Low	Very Low	Very Low	Very Low	Low	High	High	N.A.	N.A.	N.A	High
Polar	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
260°C Pb-Free Capable	Not Yet	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No

DC/DC CONVERTER TOPOLOGIES

Capacitor Selection for DC/DC Converters

- Design factors that are known before selecting capacitors:
  - Switching frequency: Fsw ; from 50 KHz (high power) to 6 MHz (low power)
  - Input voltage range: V_{IN}
  - Output voltage: V_{OUT}
  - Switch duty factor: Duty Cycle (D) ~ V_{OUT}/V_{IN} (for Buck/Step Down)
  - Output current: I_{OUT}
  - Inductance: L is usually designed such that the ripple current is ~30% of I_{OUT} at the switching frequency
  - Topology: chosen in architectural stage

Capacitor Selection for DC/DC Converters

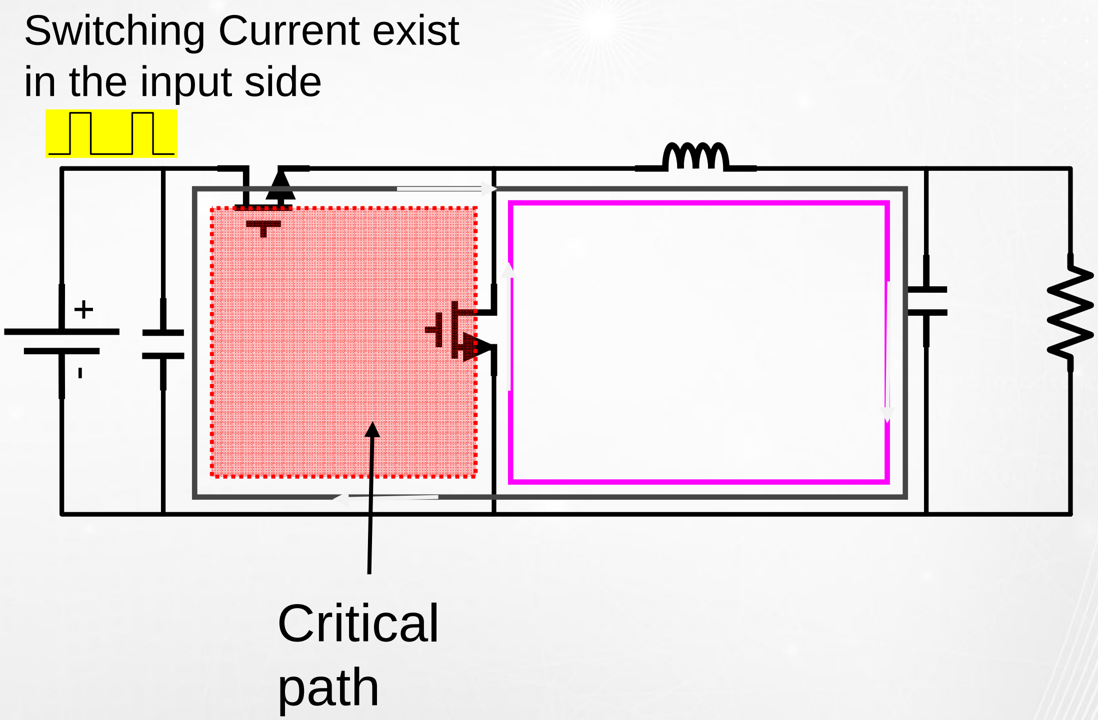
- RMS current of a capacitor is one of the most important specifications for capacitor reliability
- It also affects the converter’s performance and varies by topology
- Self-heating: proportional to RMS current and internal losses
- Voltage ripple: higher RMS current leads to larger voltage ripple
- Let’s calculate RMS current for different topologies

Common Topologies - BUCK

Buck Converter

Boost Converter

Buck-Boost Converter

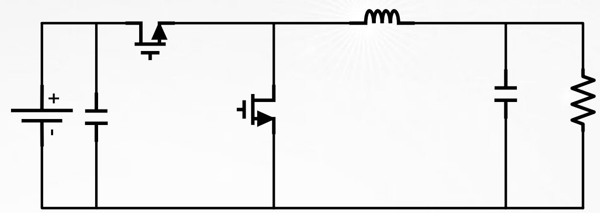


Common Topologies - BUCK

Buck Converter

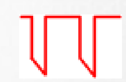
Boost Converter

Buck-Boost Converter



Input Capacitor RMS Current

$$I_{CIN\_RMS} \approx \sqrt{\left[I_{OUT} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right) \times \sqrt{\frac{V_{OUT}}{V_{IN}}}\right]^2 + \left[I_{OUT} \times \left(\frac{V_{OUT}}{V_{IN}}\right)^{\frac{3}{2}}\right]^2}$$



Output Capacitor RMS Current

$$I_{COUT\_RMS} = \frac{(V_{IN} - V_{OUT}) \times \frac{V_{OUT}}{V_{IN}}}{2 \times L \times F_{SW} \times \sqrt{3}}$$

Texas Instruments

2012 POWER FORUM AN AVNET VIRTUAL CONFERENCE

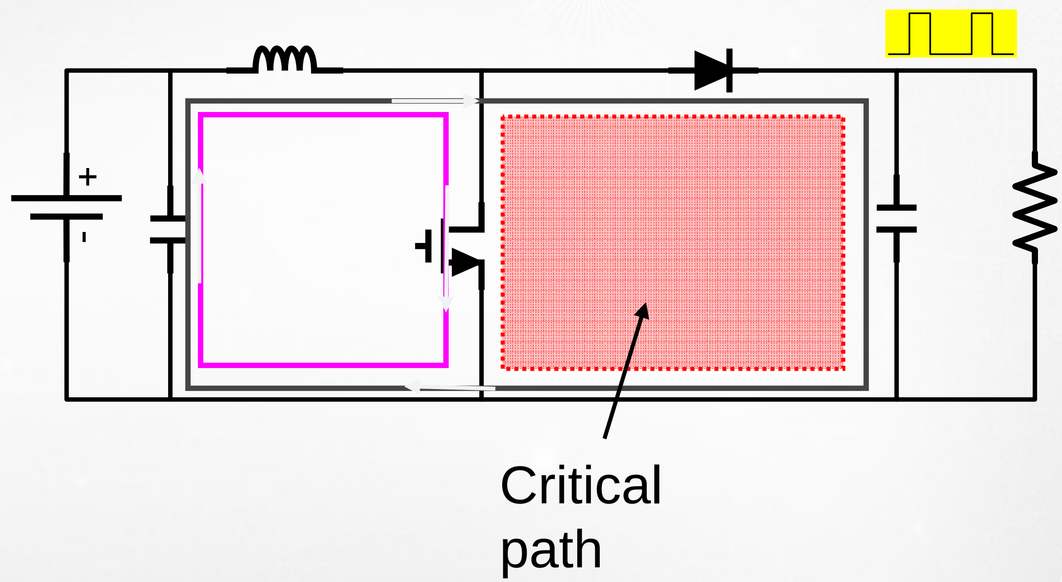
AVNET electronics marketing

Common Topologies - BOOST

Buck Converter

Boost Converter

Buck-Boost Converter

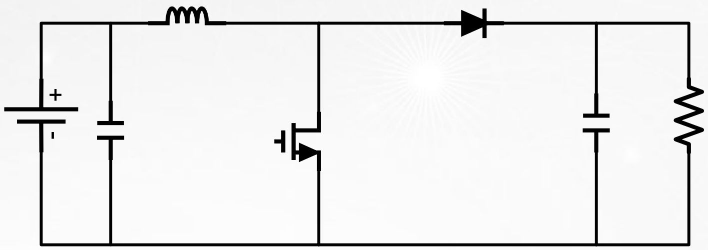


Common Topologies - BOOST

Buck Converter

Boost Converter

Buck-Boost Converter



Input Capacitor RMS Current

$$I_{CIN\_RMS} = \frac{(V_{OUT} - V_{IN}) \times \frac{V_{IN}}{V_{OUT}}}{2 \times L \times F_{SW} \times \sqrt{3}}$$

Output Capacitor RMS Current

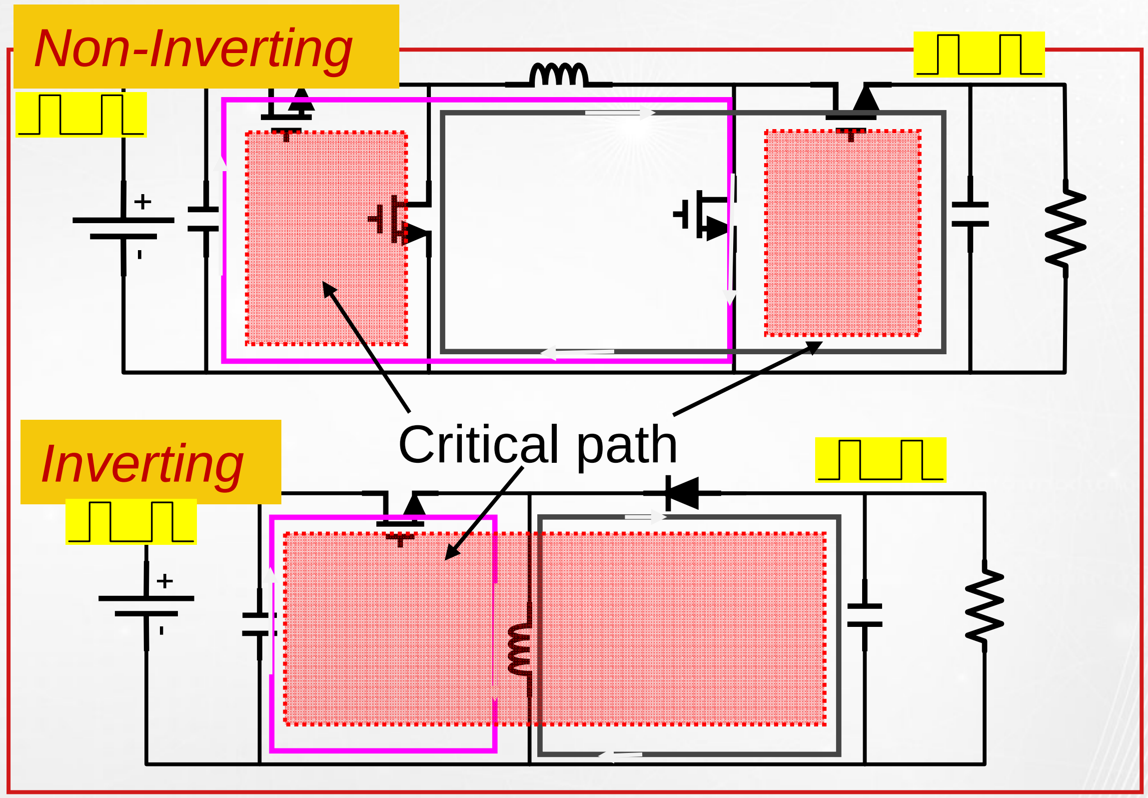
$$I_{COUT\_RMS} \approx \sqrt{\left[I_{OUT} \times \left(1 - \frac{V_{IN}}{V_{OUT}}\right) \times \sqrt{\frac{V_{OUT}}{V_{IN}}}\right]^2 + \left[I_{OUT} \times \sqrt{\frac{V_{IN}}{V_{OUT}}}\right]^2}$$

Common Topologies – BUCK BOOST

Buck Converter

Boost Converter

Buck-Boost Converter



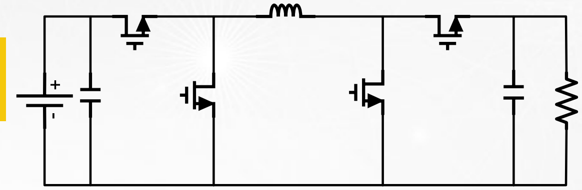
Common Topologies – BUCK BOOST

Buck Converter

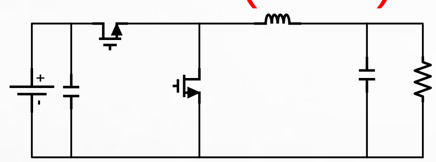
Boost Converter

Buck-Boost Converter

Non-Inverting



Mode 1 (Buck)



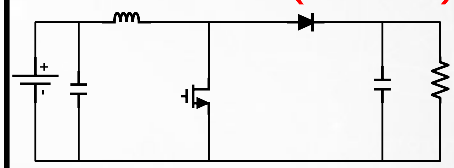
Input Cap RMS Current

$$I_{CIN\_RMS} \approx \sqrt{\left[I_{OUT} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right) \times \sqrt{\frac{V_{OUT}}{V_{IN}}}\right]^2 + \left[I_{OUT} \times \left(\frac{V_{OUT}}{V_{IN}}\right)^{\frac{3}{2}}\right]^2}$$

Output Cap RMS Current

$$I_{COUT\_RMS} = \frac{(V_{IN} - V_{OUT}) \times \frac{V_{OUT}}{V_{IN}}}{2 \times L \times F_{SW} \times \sqrt{3}}$$

Mode 2 (Boost)



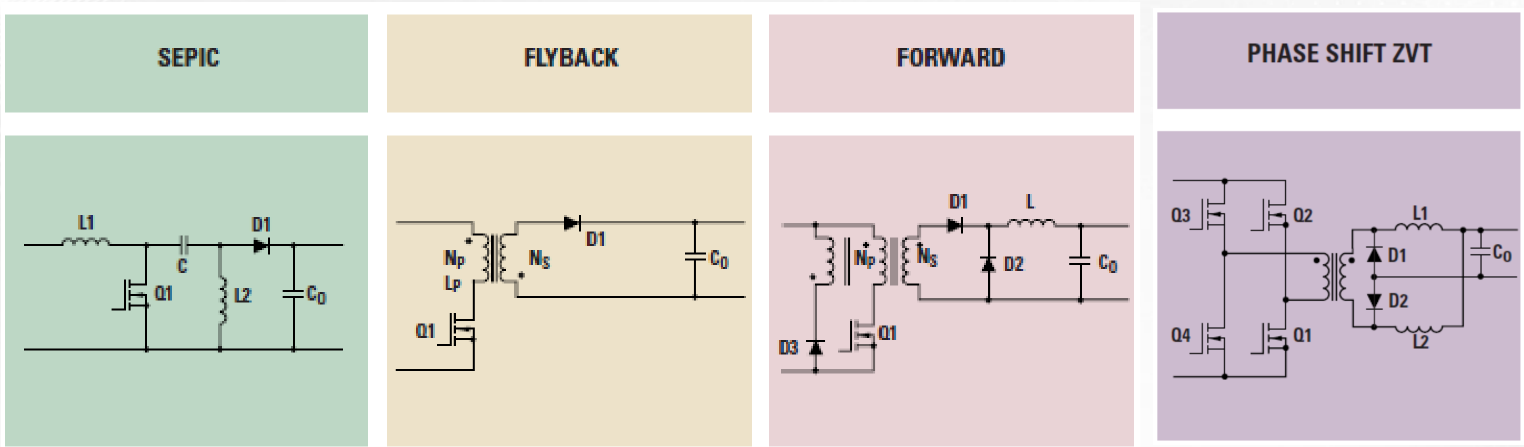
Input Cap RMS Current

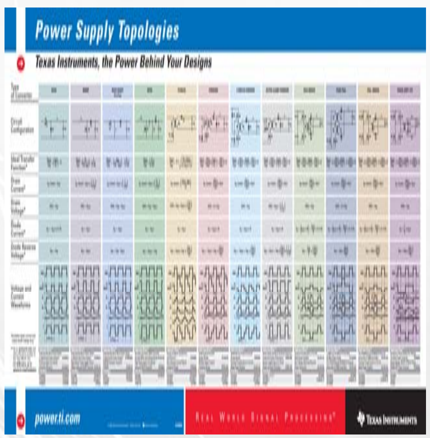
$$I_{CIN\_RMS} = \frac{(V_{OUT} - V_{IN}) \times \frac{V_{IN}}{V_{OUT}}}{2 \times L \times F_{SW} \times \sqrt{3}}$$

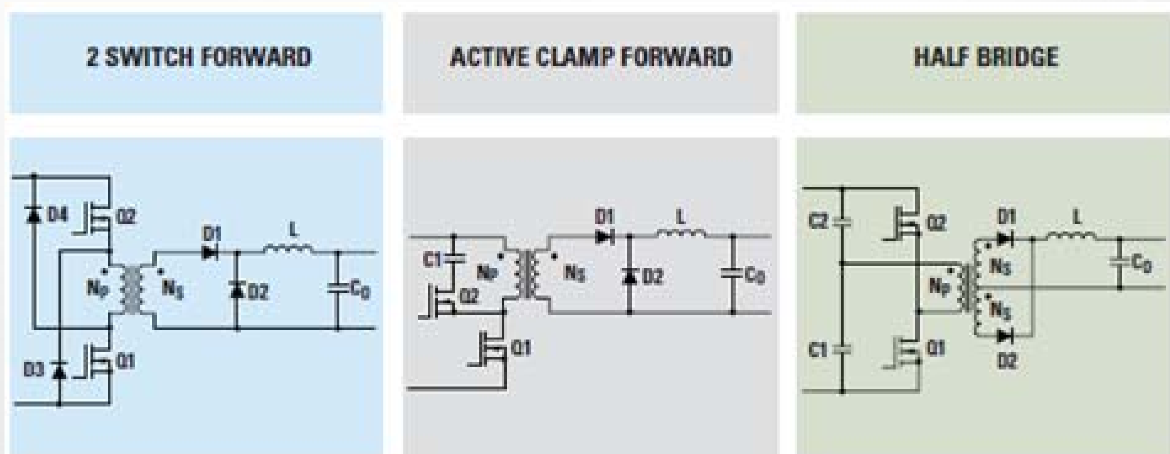
Output Cap RMS Current

$$I_{COUT\_RMS} \approx \sqrt{\left[I_{OUT} \times \left(1 - \frac{V_{IN}}{V_{OUT}}\right) \times \sqrt{\frac{V_{OUT}}{V_{IN}}}\right]^2 + \left[I_{OUT} \times \sqrt{\frac{V_{IN}}{V_{OUT}}}\right]^2}$$

Additional Topologies





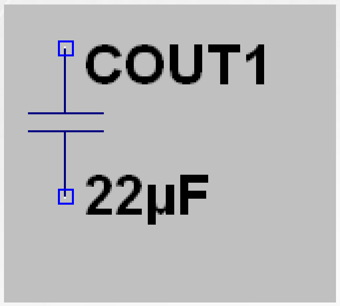


SLUW001A

CAPACITOR PARASITICS

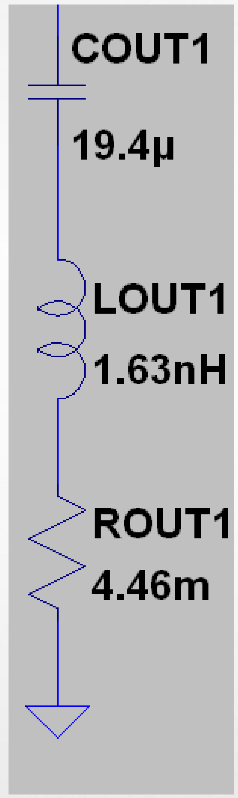
Ideal Capacitor Compared to Actual Capacitor

You buy this



22uF 4V X5R 0603 Ceramic

You get this



Voltage and Temperature De-rated Capacitance

(ESL)

Effective Series Inductance

- Parasitic inductance term

(ESR)

Effective Series Resistance

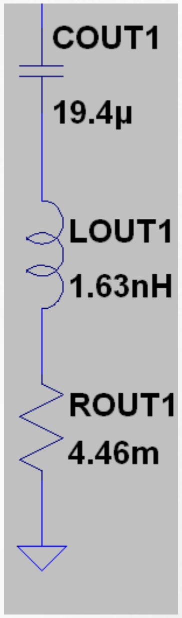
- Parasitic resistance term

Get three parts for the price of one!

Important to Know Your Parasitics

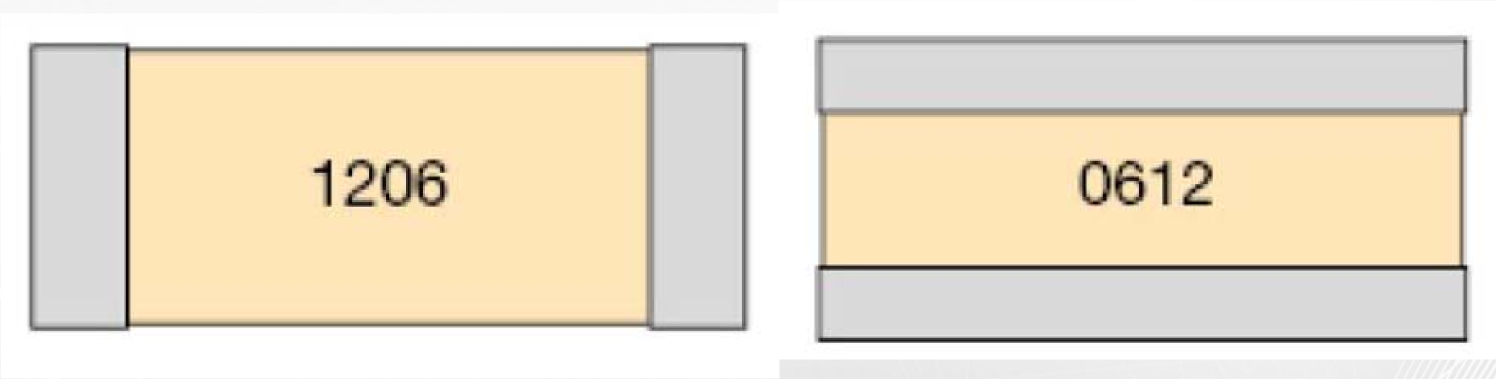
- Equipment to use to measure capacitor parasitic elements
- **RLC Analyzer**
  - Some can apply DC bias
- **RF Network Analyzer**
  - DC bias can easily damage analyzer source and receiver inputs
  - AC performance measurement very accurate
  - Agilent (aka Hewlett Packard) i.e. HP3755A goes to 200MHz
  - Many other brands
- **Frequency Response Analyzer**
  - Allows DC bias so voltage coefficient can be measured, RLC results are less accurate, frequency range is lower than network analyzer
  - 30 MHz max - usually just 1 or 2 MHz range; may allow plotting on reactance paper with line of constant capacitance and constant inductance; **FRA is also used for loop stability analysis**
  - Brands : Venable Industries, Ridley (A/P) and several others

→ Measure the parasitic terms and include them in the design ←



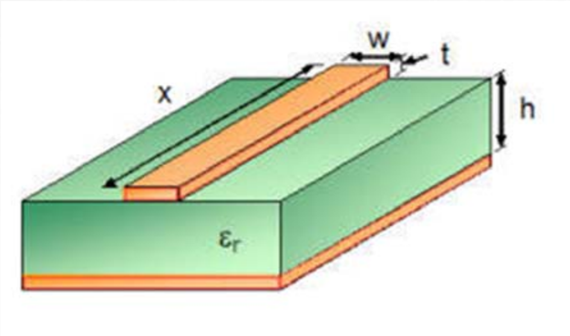
First Pass Parasitic Inductance for Ceramics

PACKAGE	ESL (pH)
0201	400
0402	550
0603	700
0805	800
1206	1250
0612	63



First Pass Trace Inductance for FR-4, Microstrip

Typical Inductance for a 2500um (60mil) wide 1oz Trace
19.5 nH / inch, 19.5pH / mil , **767pH / mm**
Typical Inductance for a 250um wide 1oz Trace
26.4 nH / inch, 26.4pH / mil , **1.039nH / mm**



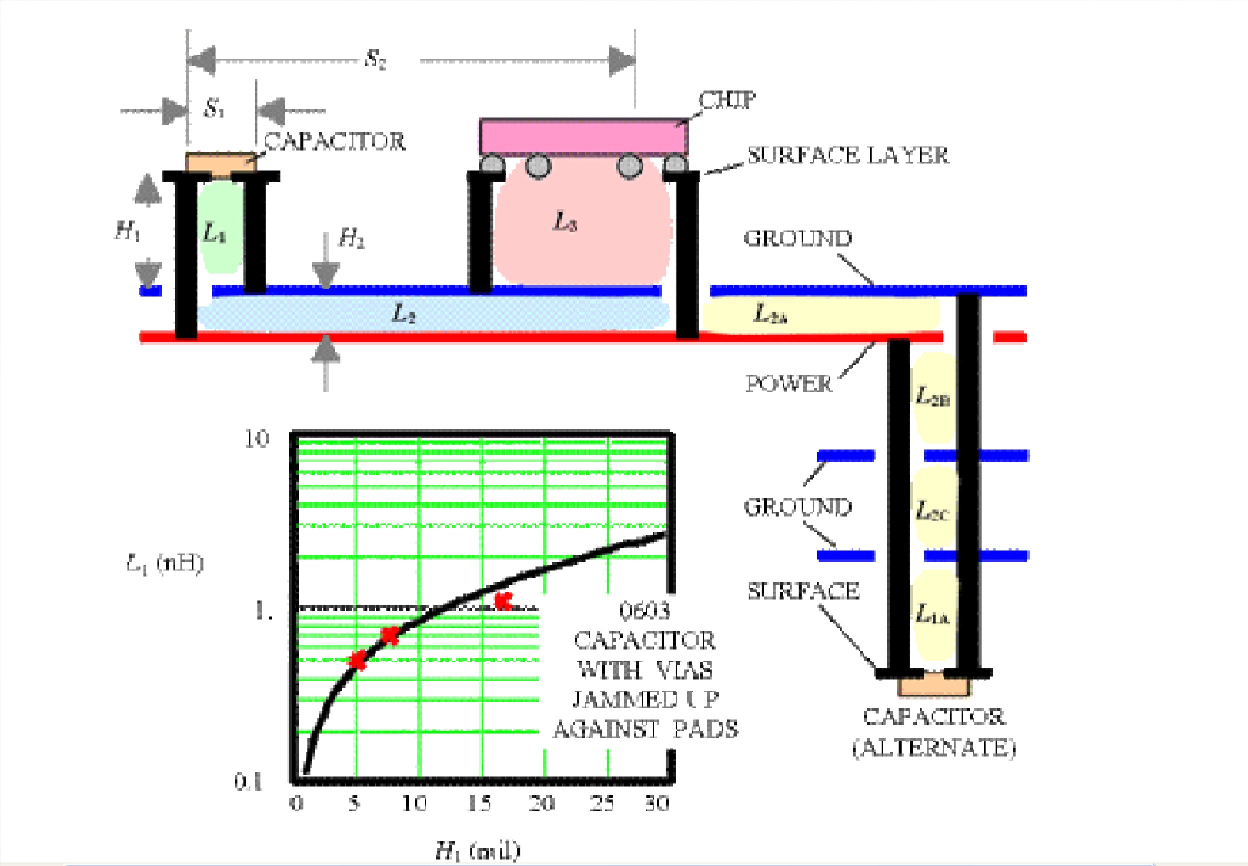
L= 0.00508*b*(ln(2*b/(w+h))+.5+0.2235*(w+h)/b)

where:

w is width of the strip in inches,
b is the length in inches,
h is the distance between the strip and the ground plane, and
L is inductance in uH.

From ARRL Handbook

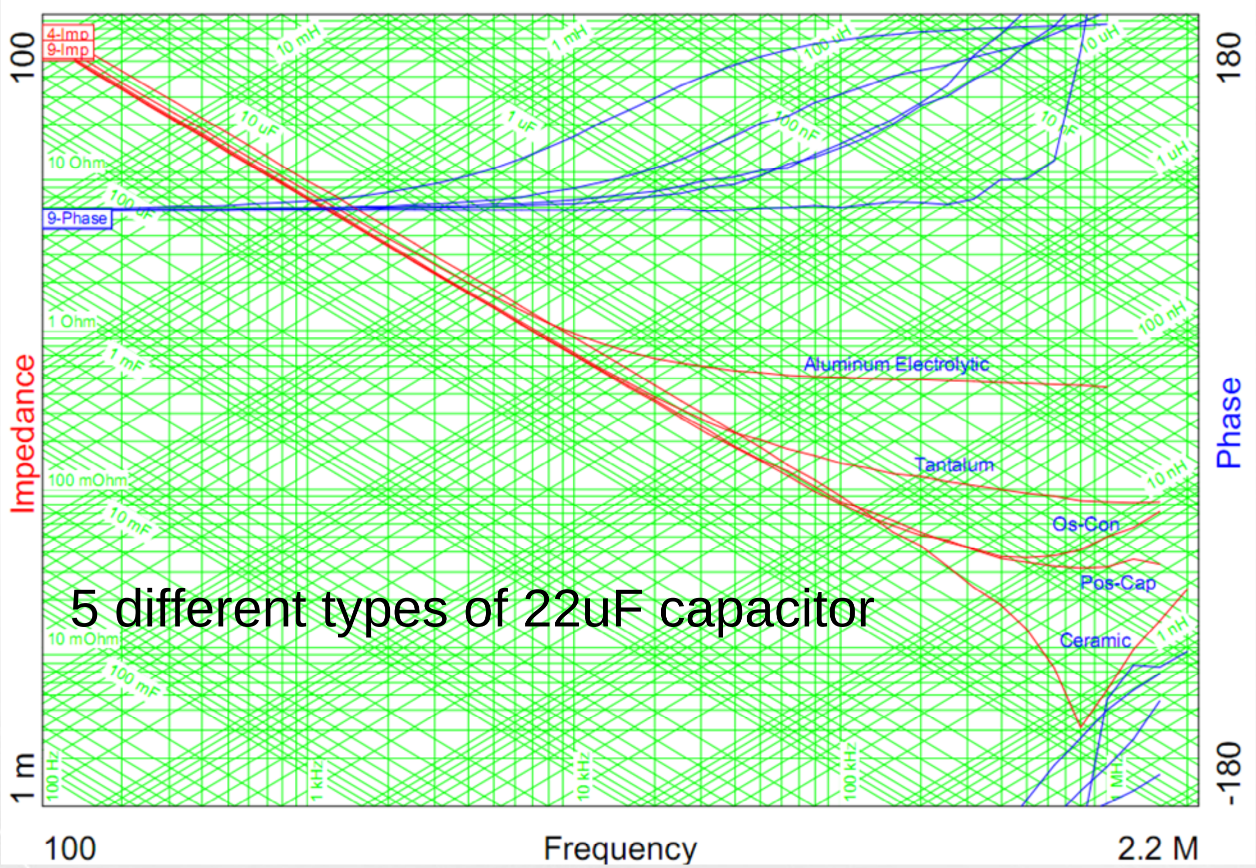
First Pass Trace Inductance for Via



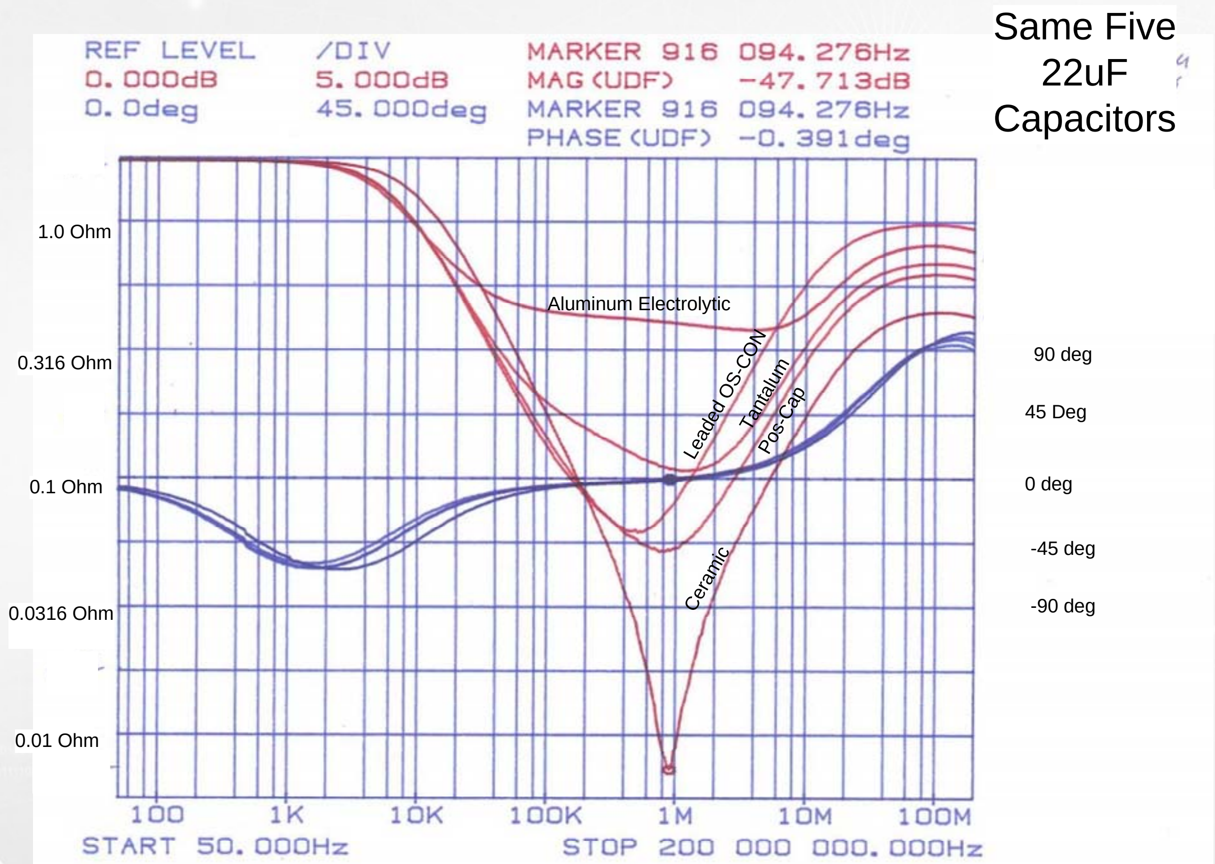
From Dr. Howard Johnson - http://www.signalintegrity.com/Pubs/edn/ParasiticInductance.htm.

Comparison of Capacitor Types Using Frequency Response Analyzer

(Shown in reactance coordinate system)



Comparative Performance of Different Capacitor Types Using RF Network Analyzer



Output Voltage Ripple by Chemistry

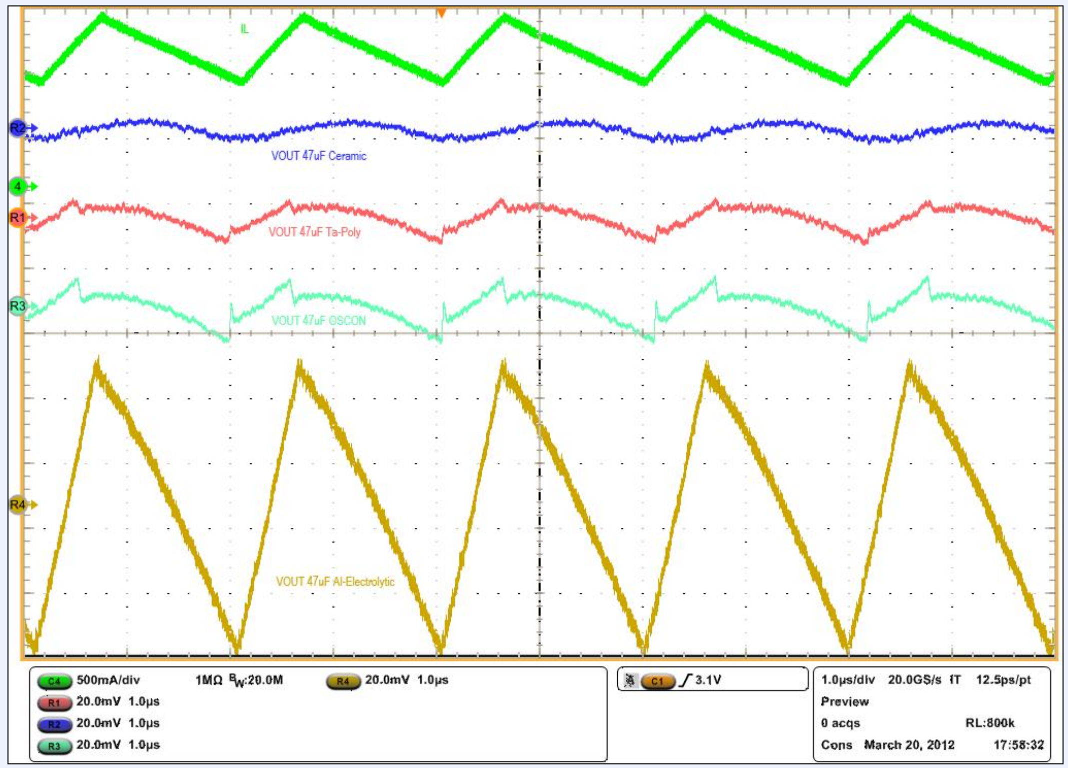
Inductor Current

Ceramic

Tantalum Polymer

OSCON

Electrolytic



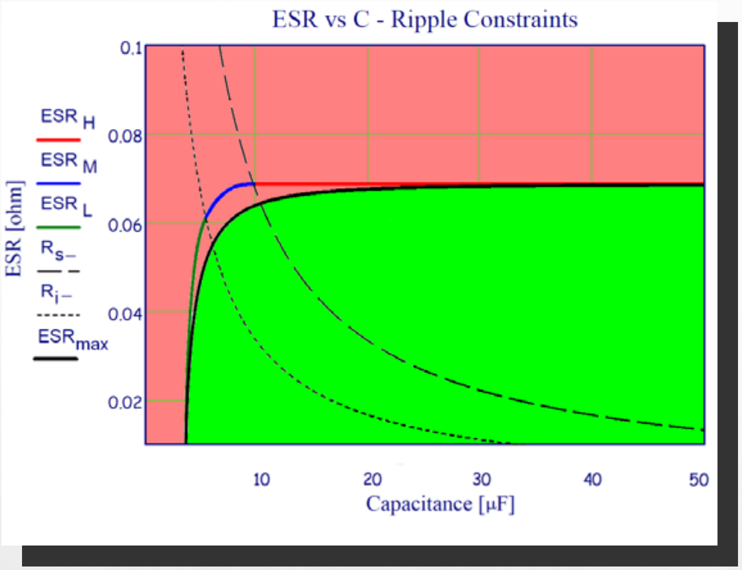
This plot shows a comparison of the output voltage ripple of a buck converter using 4 different capacitor chemistries

All caps = 47uF; Scale = 20mV/div

Output Caps Selection – Output Ripple Analysis (Simplified Formula)

» A simplified equation can be derived by calculating the fundamental component of the output ripple voltage as:

$$\Delta V_{opp} = \Delta i_{Lpp} \cdot \sqrt{ESR^2 + \left(\frac{1}{8 \cdot f_S \cdot C_O}\right)^2} \quad \Rightarrow \quad ESR_{max} = \sqrt{\left(\frac{\Delta V_{opp}}{\Delta i_{Lpp}}\right)^2 - \left(\frac{1}{8 \cdot f_S \cdot C_O}\right)^2}$$



There is an overestimation of the needed output cap nearby the MID ESR area

Capacitor - Selection Process Summary

Electrical specifications:

» Electrical performance

- » RMS Current in the capacitor
  - – Look for RMS current equation in the chosen DC/DC topology
- » Applied voltage at the capacitor
  - – De-rate the capacitor based on the chemistry Remember to de-rate voltage by at least 20% for all chemistries
  - – 50% for tantalum to improve reliability
  - – 50% for class 2 ceramics to decrease capacitance lost to DC biasing
  - – Note: Capacitor data sheet MUST include 100kHz data if the capacitor is to be applied in a switch mode power supply (SMPS). 120 Hz only versions are not suitable for SMPS
  - – Consider NP0 (C0G), X7R, X5R and X7S ceramic dielectrics* - in this order
  - – **DO NOT USE Y5V**

» Capacitor impedance

- » Does this capacitor chemistry look inductive at the frequency of interest?

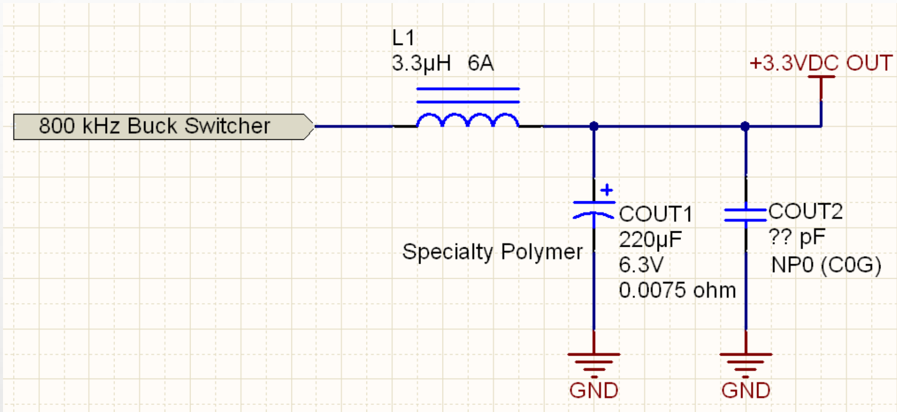
Capacitor - Selection Process Summary

- Transient and stability requirements
  - Size bulk capacitance based upon voltage deviation requirements
  - Check that the selected capacitor meets stability requirements for the part
- Most designs use a combinations of technologies
  - Tantalums or Aluminum Electrolytics for bulk Capacitance
  - Ceramics for decoupling and bypass
- Selection might also depend on mechanical challenges
  - Vibration, Temperature,Cooling
- Lifetime comes into play
  - Ceramics and polymer have improved lifetime over electrolytic and tantalum
- Costs - Tradeoffs
  - Component cost vs. total cost of ownership

PARALLELING CAPACITORS TO REDUCE HIGH FREQUENCY OUTPUT VOLTAGE RIPPLE

A Technique for Reducing High Frequency Output Noise

» If the output capacitor(s) *is not* ceramic; then adding a small ceramic(s) in parallel with the output will reduce high frequency ripple
» Choose a ceramic capacitor that has an impedance null (self resonance) that is the same as the frequency to be attenuated
» One, two or three small ceramics can give 10X improvement (-20 dB)



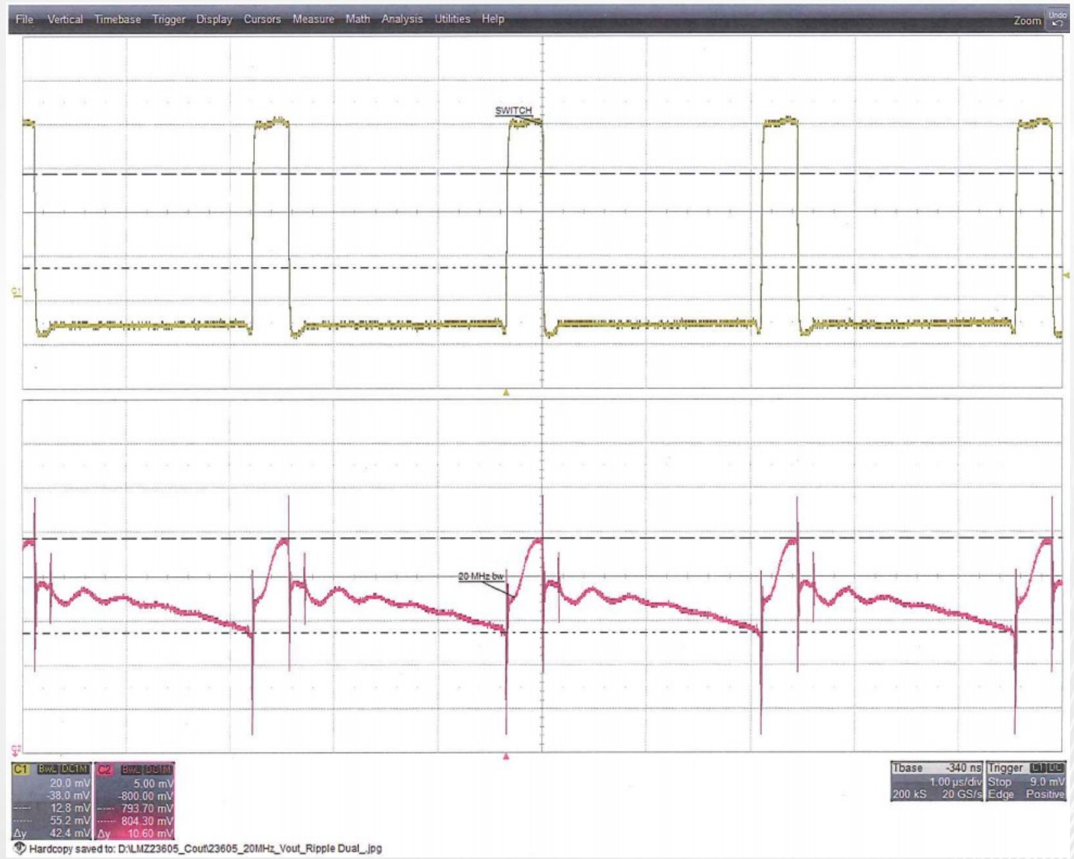
High Frequency Ripple

Switch
waveform
(scope trigger)

Vout ripple w/ 20
MHz bandwidth (bw)

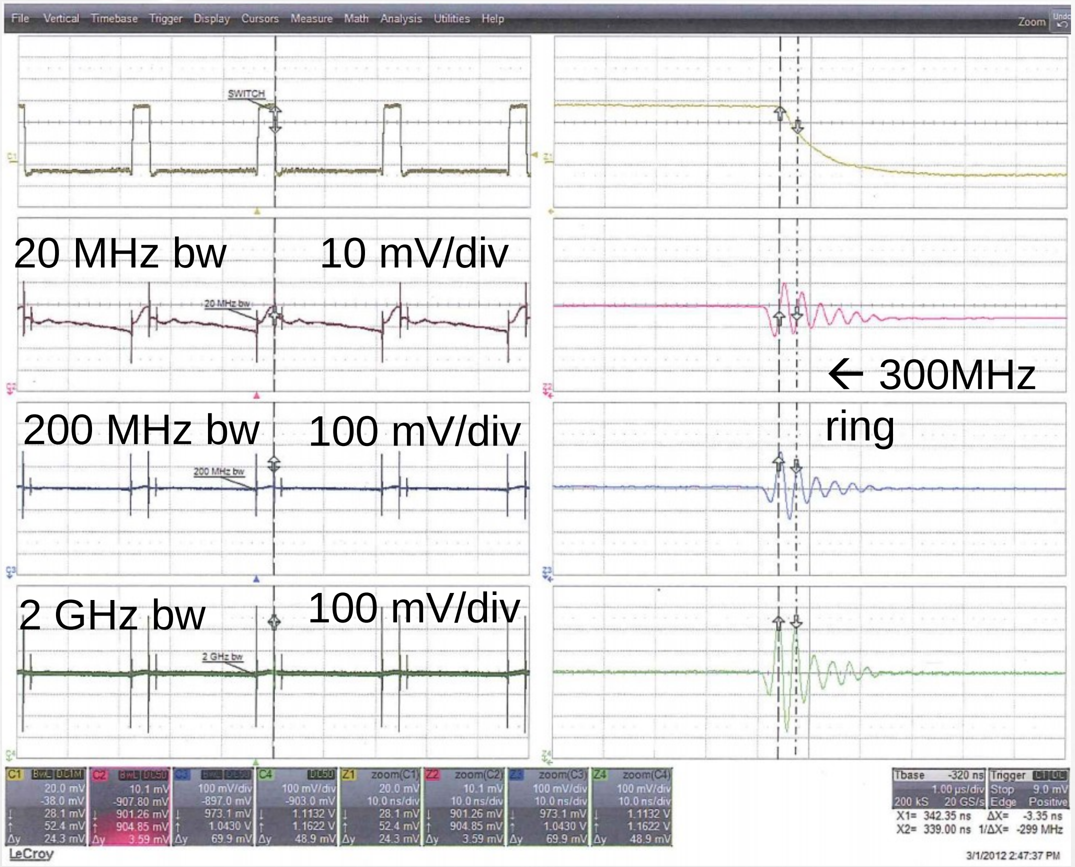
5 mV /div →
10 mv p-p

HF spikes ignored !



Use Zoom Function to Measure Ring Frequency

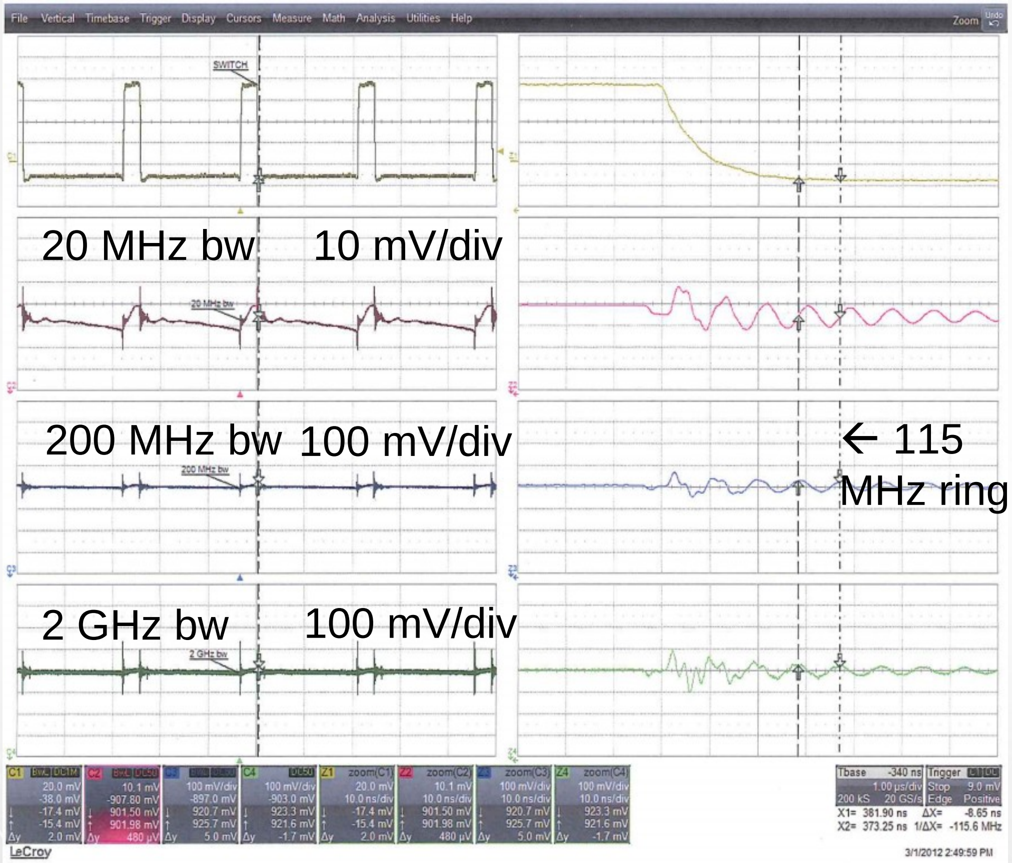
Timebase Zoomed traces



Need to add 470 pF 0603 bypass SRF ~ 300 MHz

Continue the Method

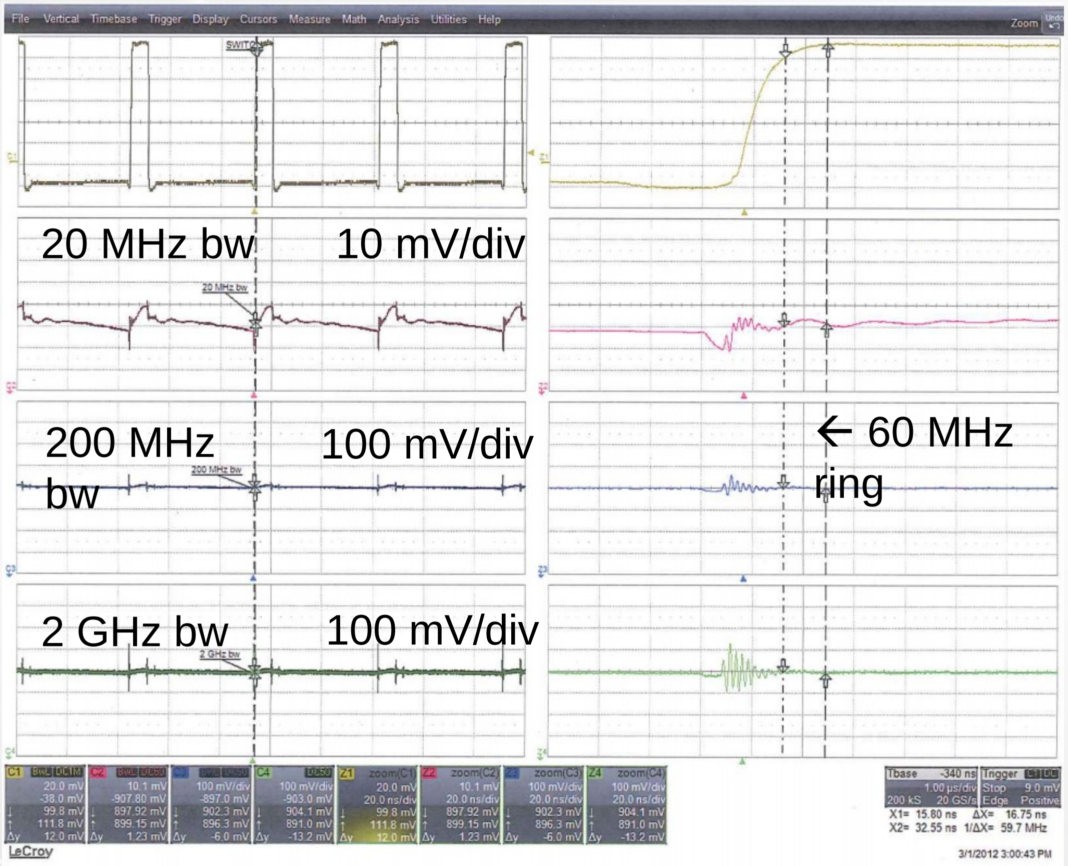
Timebase Zoomed traces



Measured after adding a 470 pF 0603 but before adding 2200pF 0603

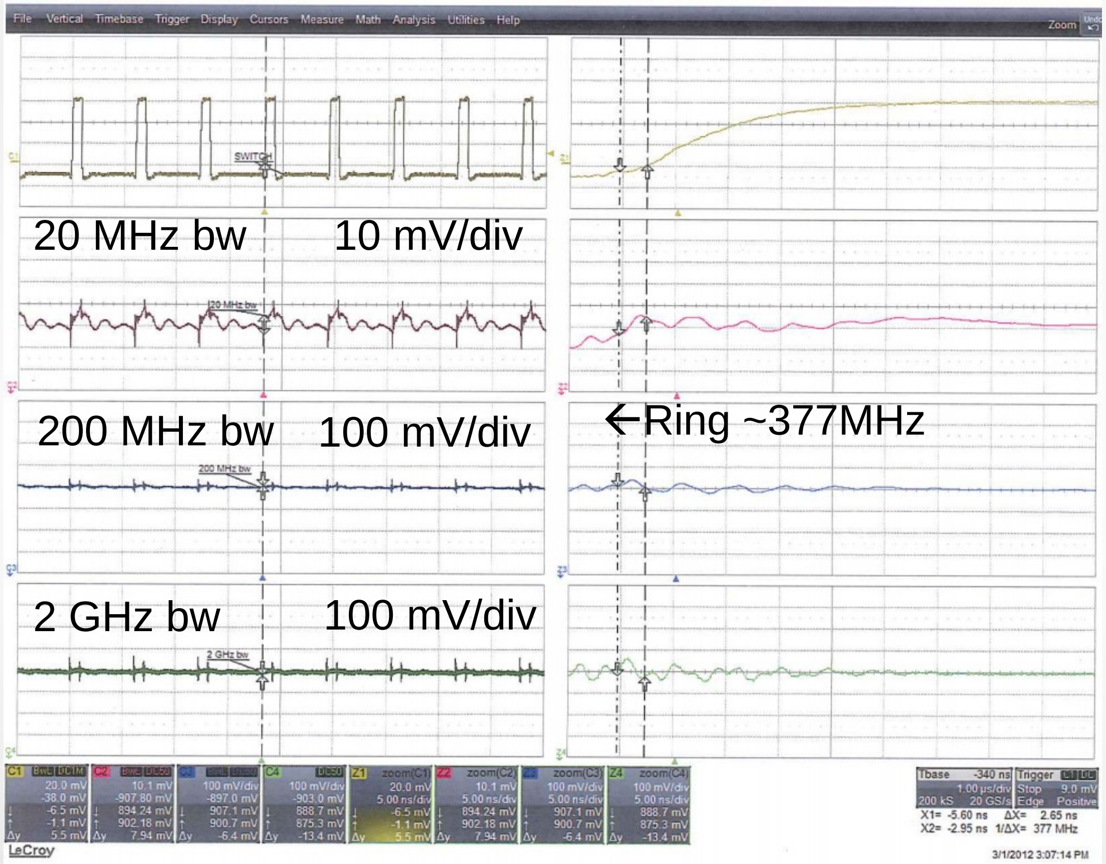
Continue the Method

Timebase Zoomed traces



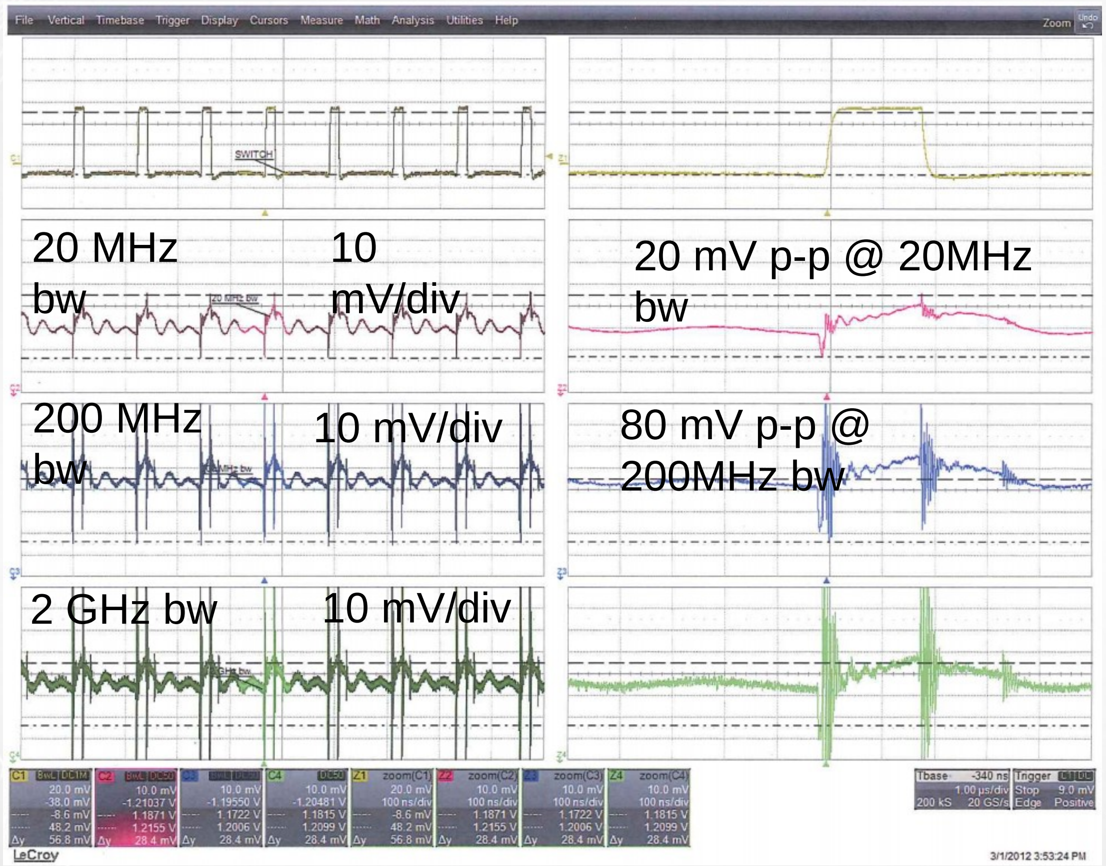
Measured after adding a 470pF 0603 and a 2200pF 0603 but before 4700pF 0805

Results After 3rd Added Small Capacitor



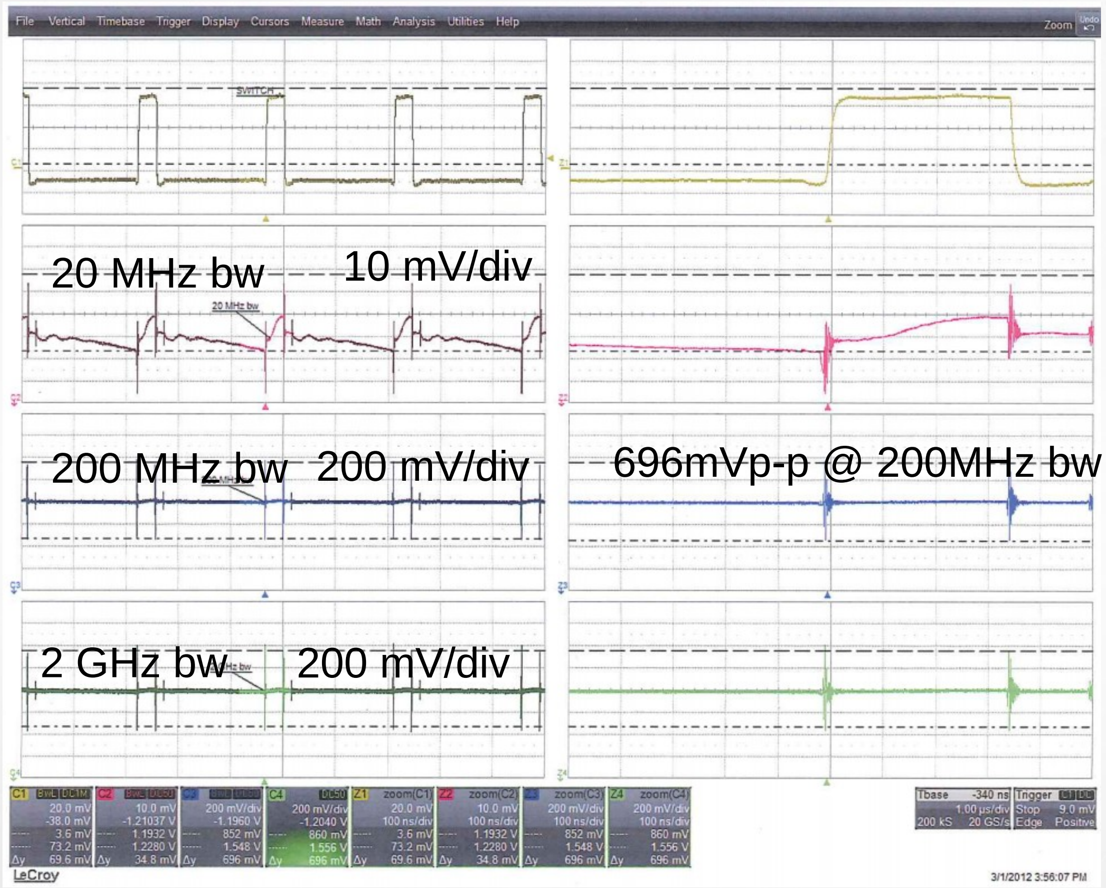
Measured after adding a 470pF 0603, 2200pF 0603, and 4700pF 0805

Final Amplitude Improvement Results

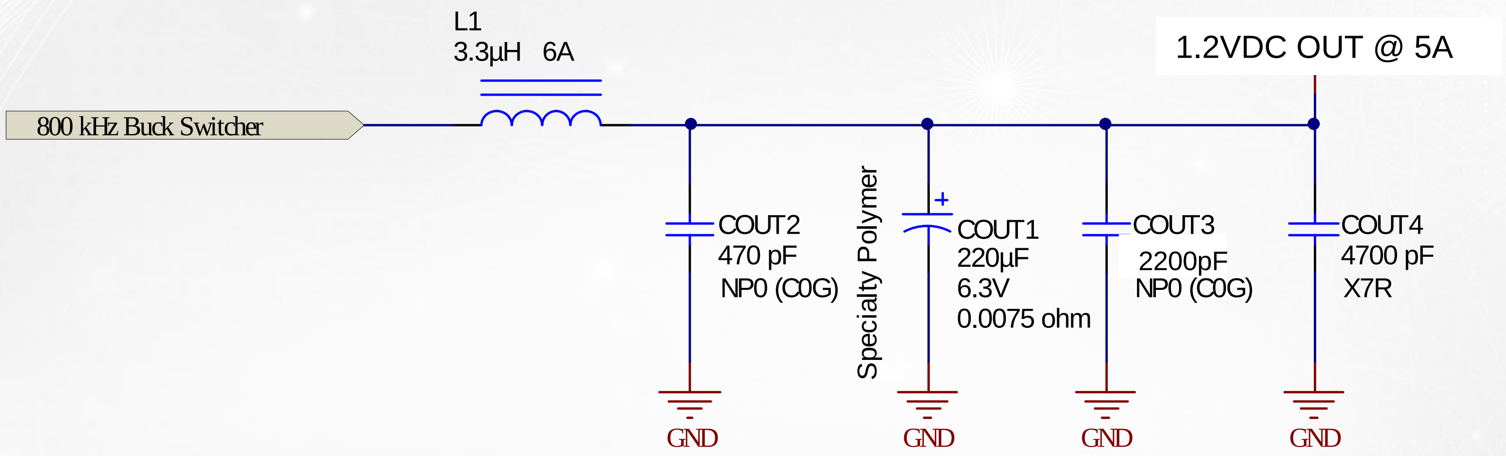


After 470pF
2200pF
4700pF

Starting Point for Comparison - 3 caps Removed



Final Schematic and BOM: 15 mins. Later



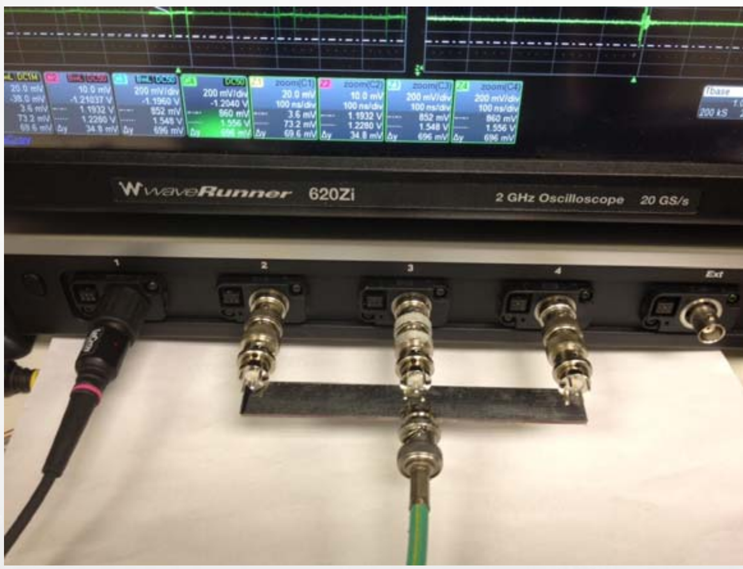
» Remember to reserve locations on the schematic and PCB for these parts

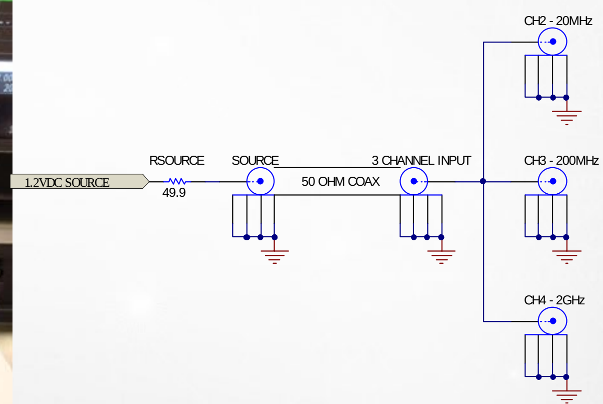
» You won't know the capacitor values until after you test the running power supply for ringing noise

» Plan ahead

Bench Requirements

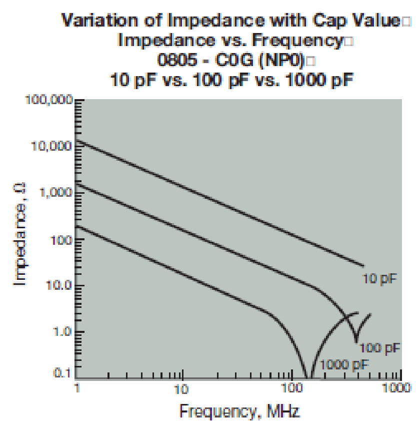
- 2GHz bw / 20Gsps Digital oscilloscope with zoom feature and adjustable channel bandwidth
- Selection of small capacitors pre-characterized by self-resonant frequency
- High quality interconnections with controlled impedances

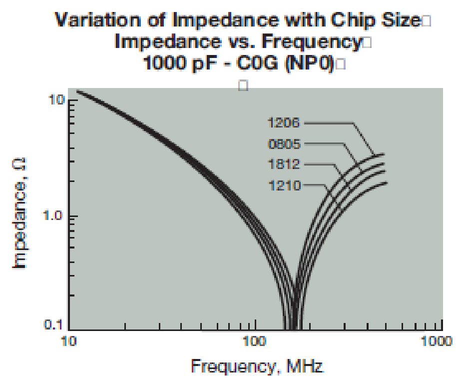


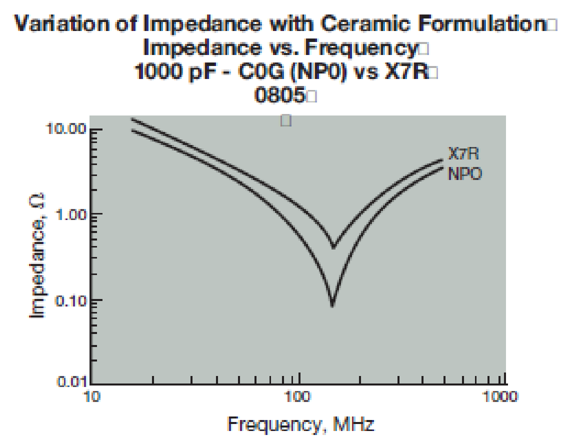


Example of 3 channel input adapters built for this tutorial (net 4x passive probe)

Use C0G (NP0) Dielectric for High Frequency Shunt Filter Capacitors







Start with manufacturer data sheets, then measure SRF on bench to confirm

THANK YOU

Questions?