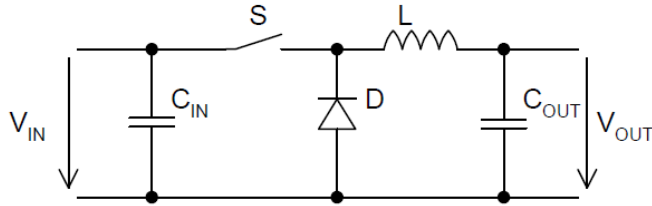


Optimizing EMI Behavior of Low-Power DCDC Converters

Juergen Neuhaeusler

Basic Considerations

Step-Down Converter

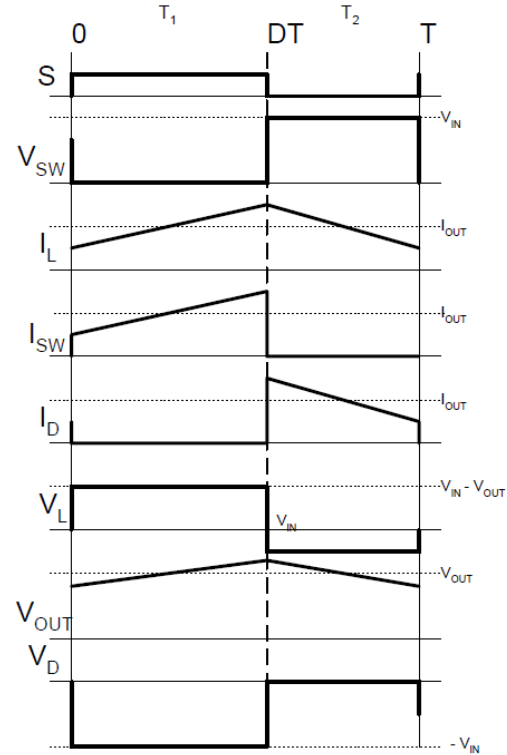


$$V_{L-T1} = V_{IN} - V_{OUT} \quad \Delta V_L = V_{IN}$$

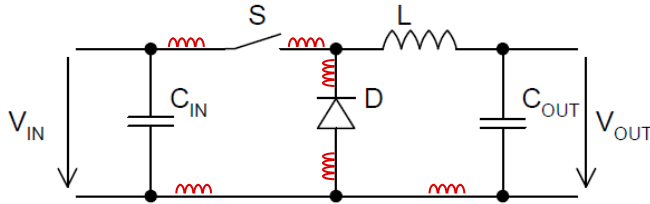
$$V_{L-T2} = -V_{OUT}$$

$$D = \frac{V_{OUT}}{V_{IN}}$$

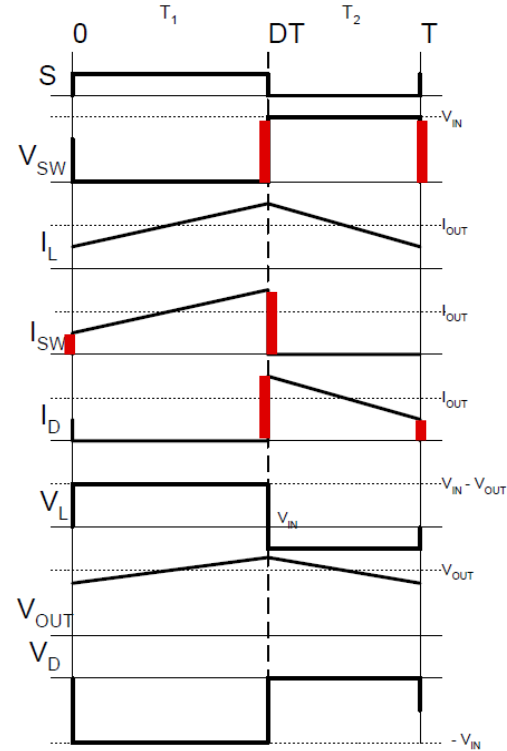
$$\frac{V_{OUT}}{V_{IN}} = D$$



Step-Down Converter - Parasitics

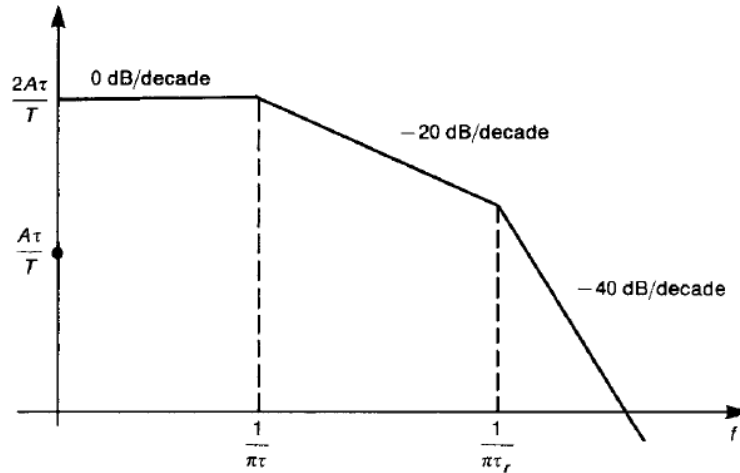


$$V_L = L \cdot \frac{di}{dt}$$



Spectrum

$$Envelope = 2A \frac{\tau}{T} \left| \frac{\sin \pi \tau f}{\pi \tau f} \right| \left| \frac{\sin \pi \tau_r f}{\pi \tau_r f} \right|$$

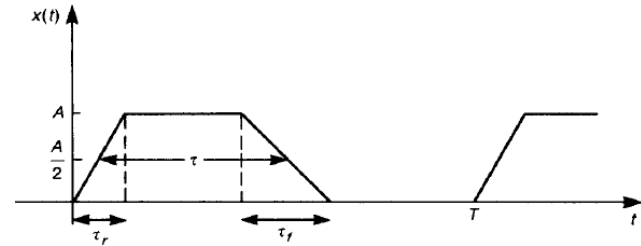


Example:

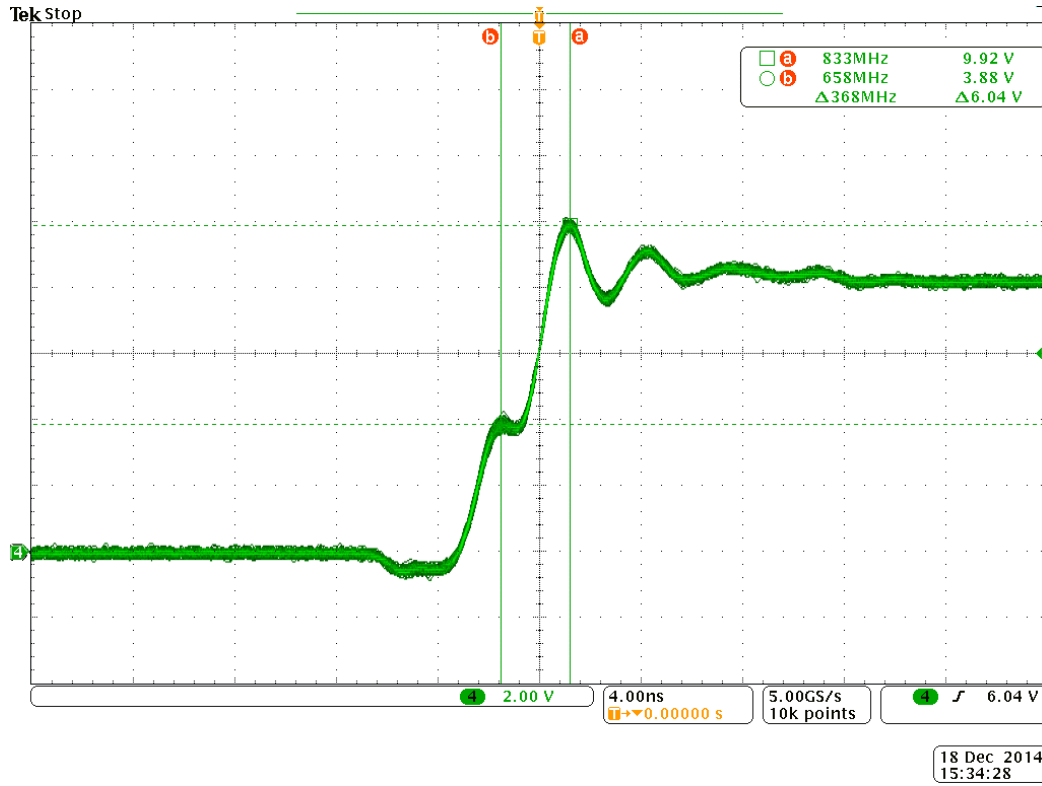
Switching frequency 2.5 MHz (400ns)

Duty cycle 30% (120ns)

Rise/fall time 2.. 4 ns



Example



Switching frequency 2.5 MHz (400ns)

Duty cycle 30% (120ns)

Rise/fall time 2.. 4 ns

Structures

Component Values

Capacitors	Inductance for resonance at					
	5	10	50	100	500	1000 MHz
0.01 uF	636.6	159.2	6.4	1.6	0.1	0.0 nH
0.1 uF	63.7	15.9	0.6	0.2	0.0	0.0 nH
1 uF	6.4	1.6	0.1	0.0	0.0	0.0 nH
5 uF	1.3	0.3	0.0	0.0	0.0	0.0 nH
10 uF	0.6	0.2	0.0	0.0	0.0	0.0 nH
100 uF	0.1	0.0	0.0	0.0	0.0	0.0 nH

Inductors	Capacitance for resonance at					
	5	10	50	100	500	1000 MHz
0.1 nH	63663.85	15915.96	636.64	159.16	6.37	1.59 nF
1 nH	6366.39	1591.60	63.66	15.92	0.64	0.16 nF
10 nH	636.64	159.16	6.37	1.59	0.06	0.02 nF
100 nH	63.66	15.92	0.64	0.16	0.01	0.00 nF

Mechanical structures

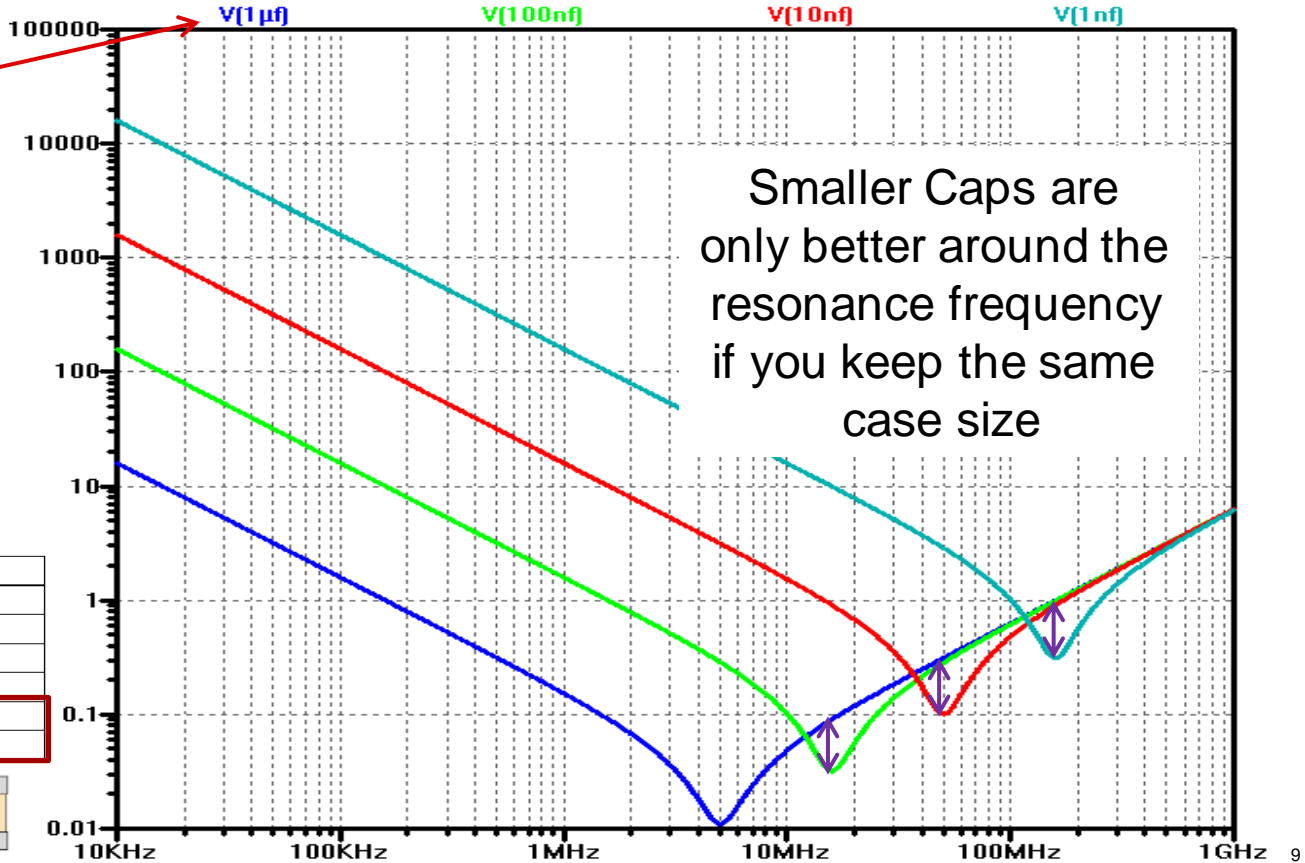
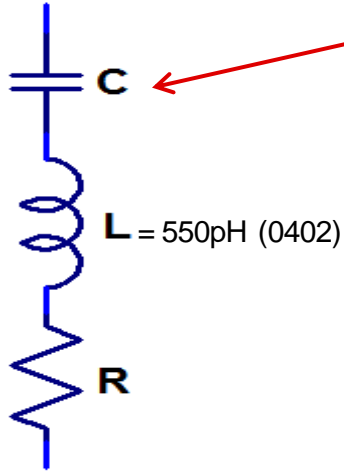
Structure size	related frequency			
	λ	$\lambda/2$	$\lambda/4$	$\lambda/8$
1 mm	300000	150000	75000	37500 MHz
5 mm	60000	30000	15000	7500 MHz
10 mm	30000	15000	7500	3750 MHz
50 mm	6000	3000	1500	750 MHz
100 mm	300	150	75	37.5 MHz
1000 mm	30	15	7.5	3.75 MHz

Frequency	related wavelength			
	λ	$\lambda/2$	$\lambda/4$	$\lambda/8$
10 MHz	30000	15000	7500	3750 mm
50 MHz	6000	3000	1500	750 mm
100 MHz	3000	1500	750	375 mm
500 MHz	600	300	150	75 mm
1000 MHz	300	150	75	37.5 mm

Components

Capacitor impedance vs. frequency

(same case size)



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



Input Capacitor selection

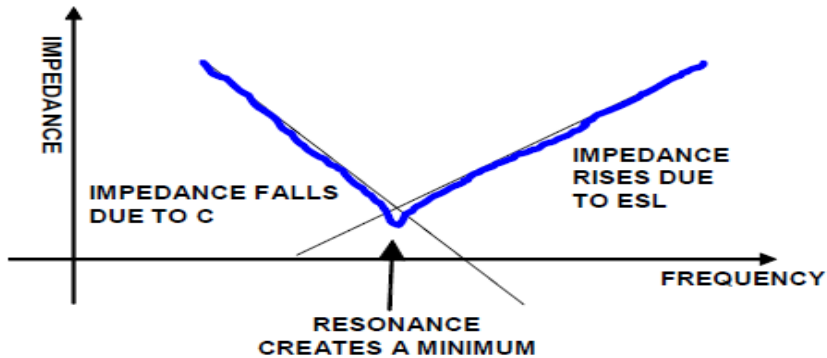


FIGURE 8. IMPEDANCE OF AN ACTUAL CAPACITOR (NON-IDEAL)

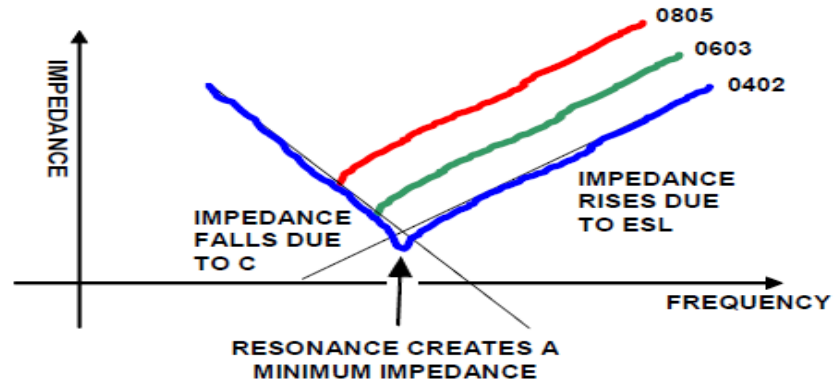


FIGURE 9. IMPEDANCE OF AN ACTUAL CAPACITOR (NON-IDEAL) IN DIFFERENT SURFACE-MOUNT PACKAGES

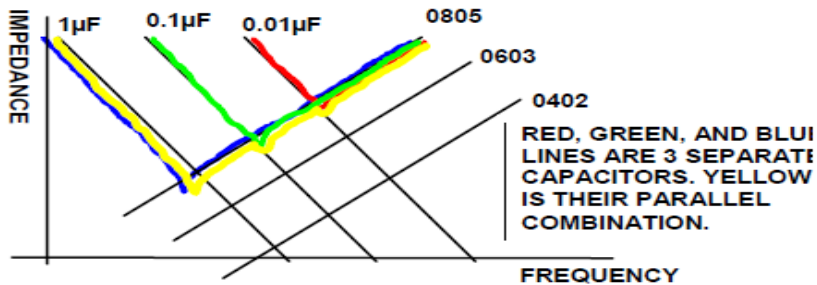


FIGURE 10. IMPEDANCE OF THREE CAPACITORS, THE SAME SURFACE-MOUNT PACKAGES

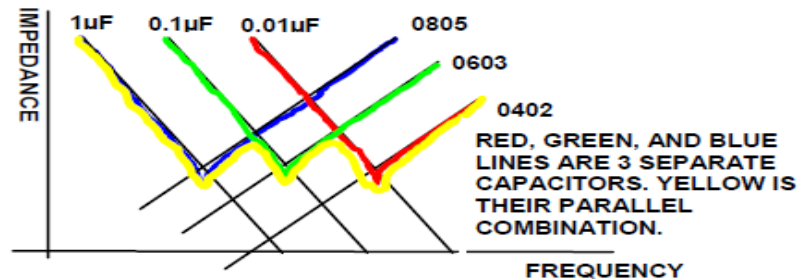
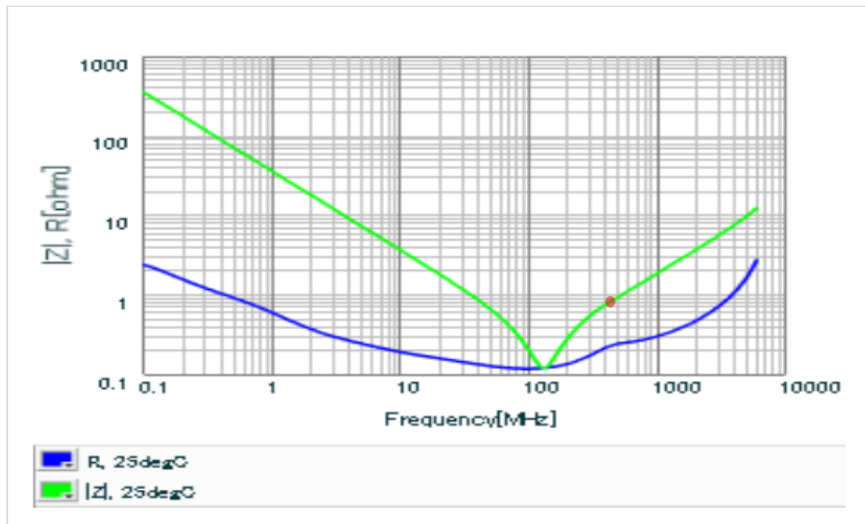


FIGURE 11. IMPEDANCE OF THREE CAPACITORS, SCALED SURFACE-MOUNT PACKAGES

Filter Capacitors

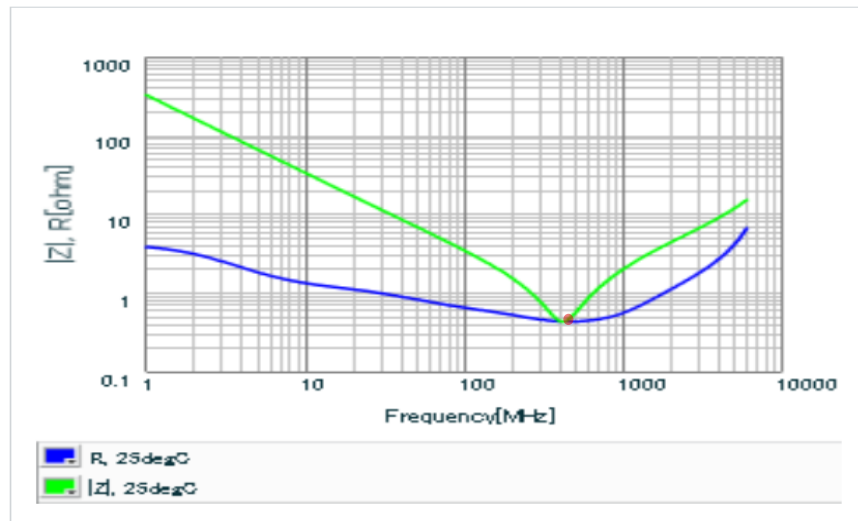
- 4700 pF, 0402 size

▪ Frequency characteristics (ESR, Impedance)

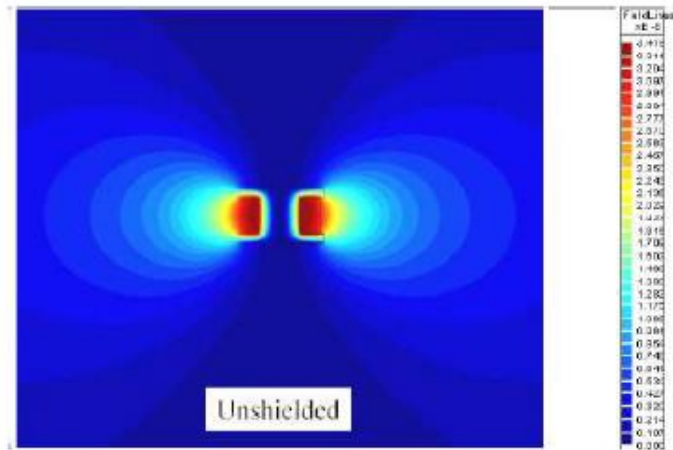
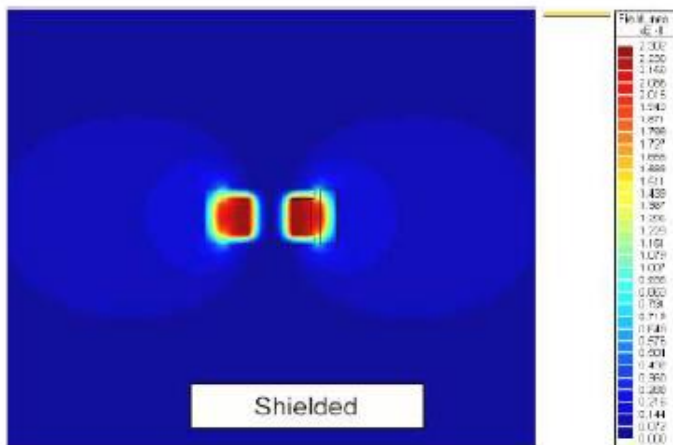


- 470 pF, 0402 size

▪ Frequency characteristics (ESR, Impedance)



Inductor

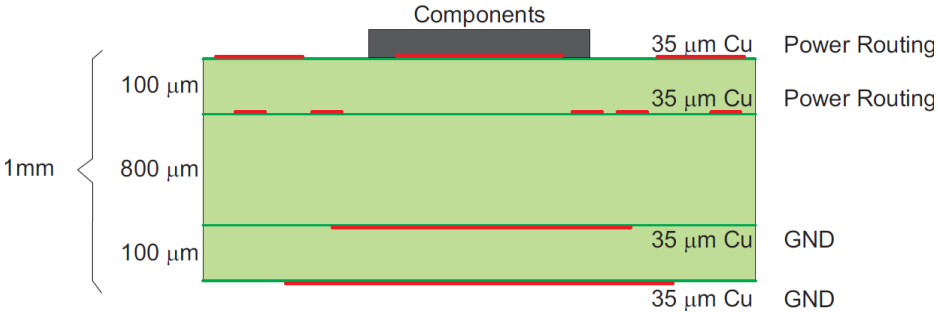


PCB Layout Structures

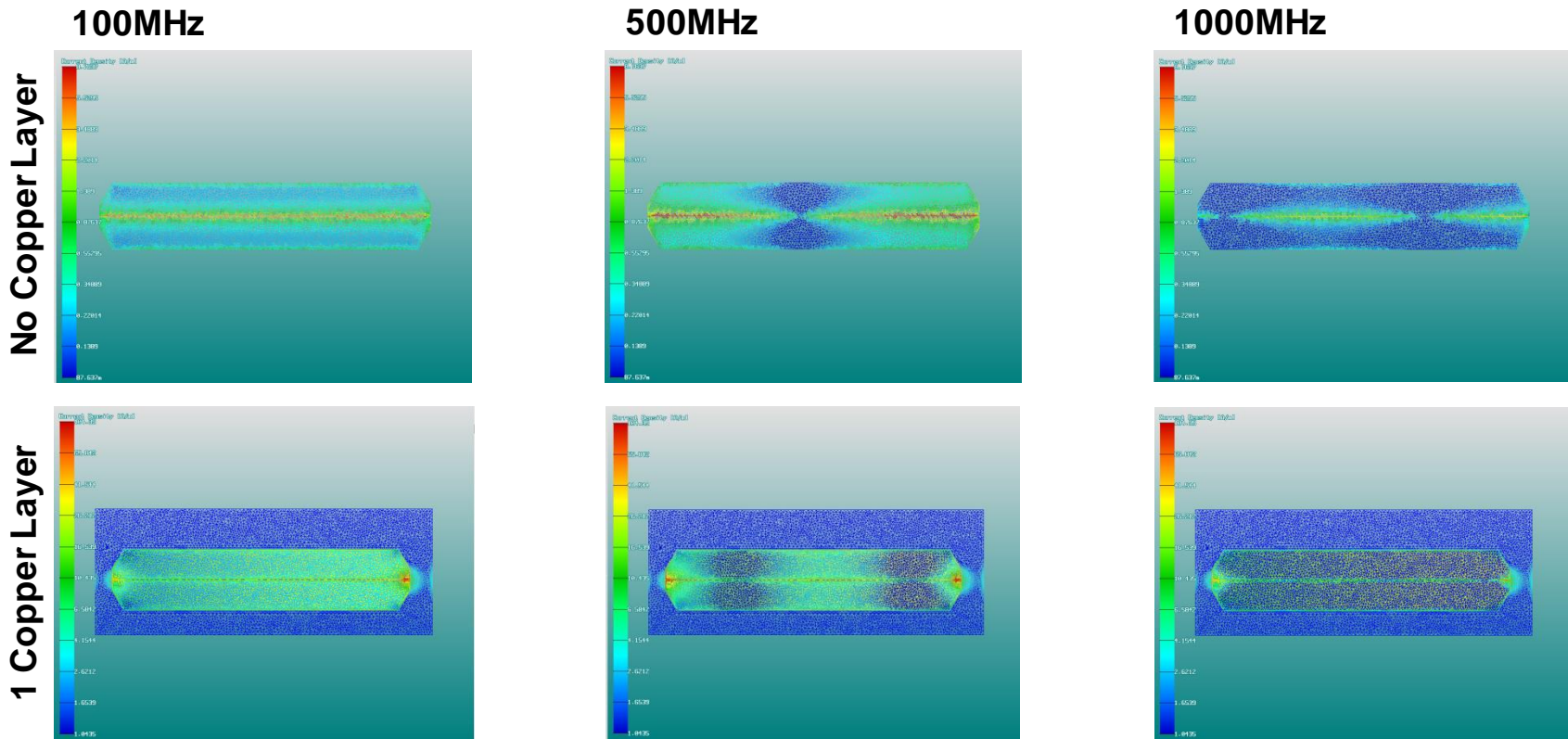
PCB Simulations – Routing on Top Layer only



	Inductance
0 Copper Layer	73,7 nH
1 Copper Layer (100µm distance)	3,37 nH
1 Copper Layer (50µm distance)	2,03 nH
2 Copper Layer	3,37 nH



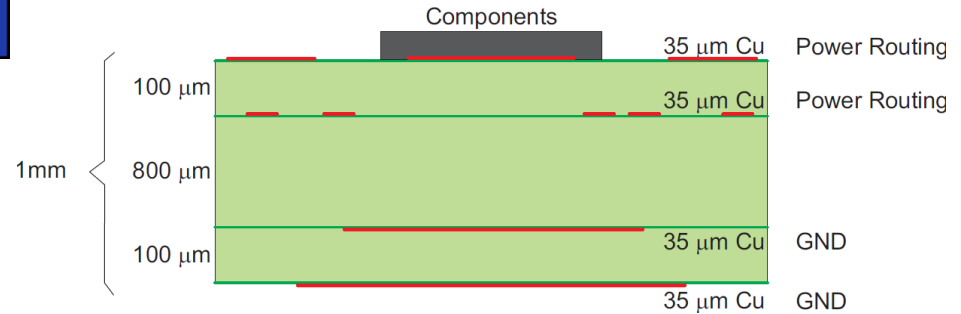
PCB Simulations – Routing on Top Layer only



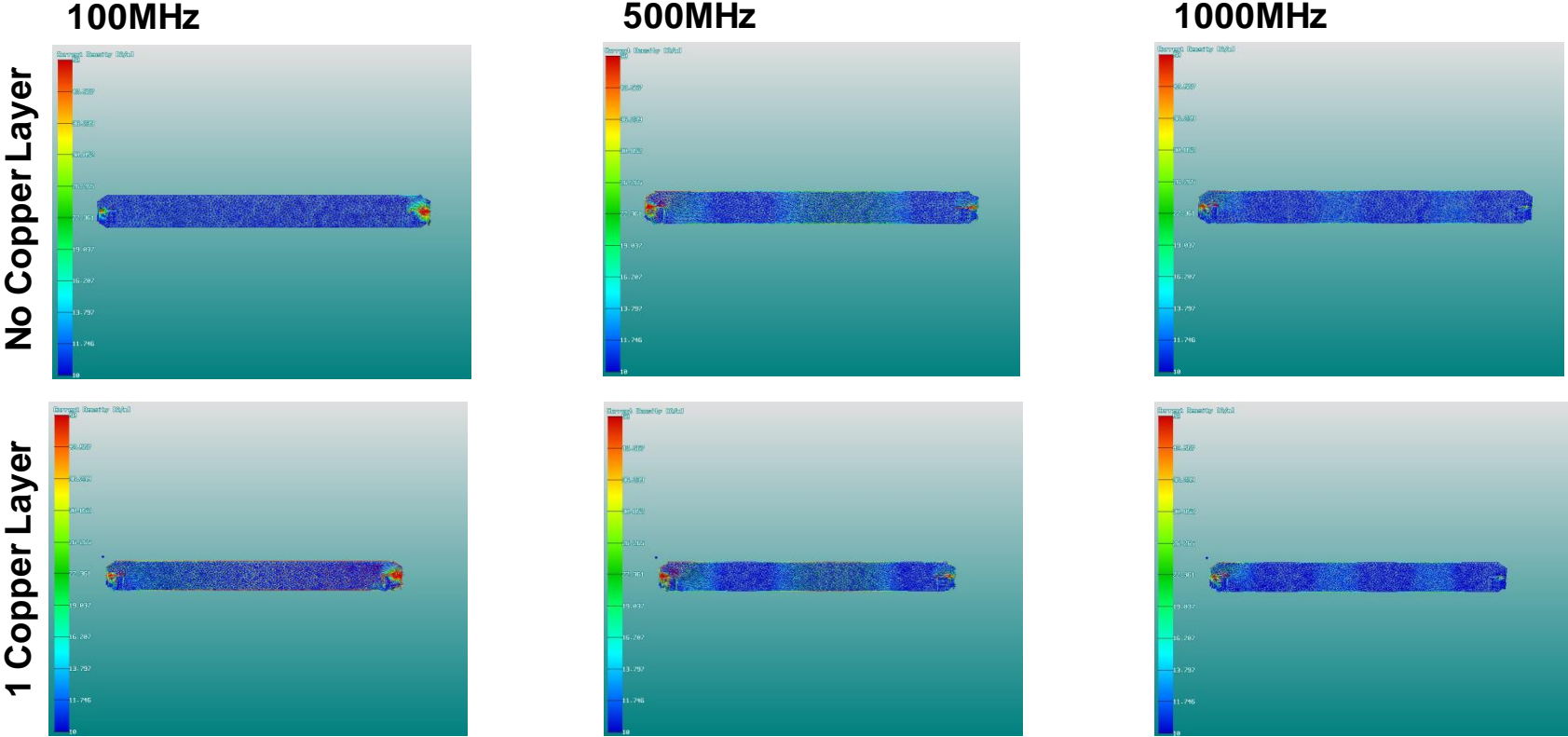
PCB Simulations – Routing on 2 Signal Layers



	Inductance
0 Copper Layer	2,215 nH
1 Copper Layer (640 μm distance)	2,19 nH
1 Copper Layer (320 μm distance)	2,16 nH
2 Copper Layer	2,18 nH

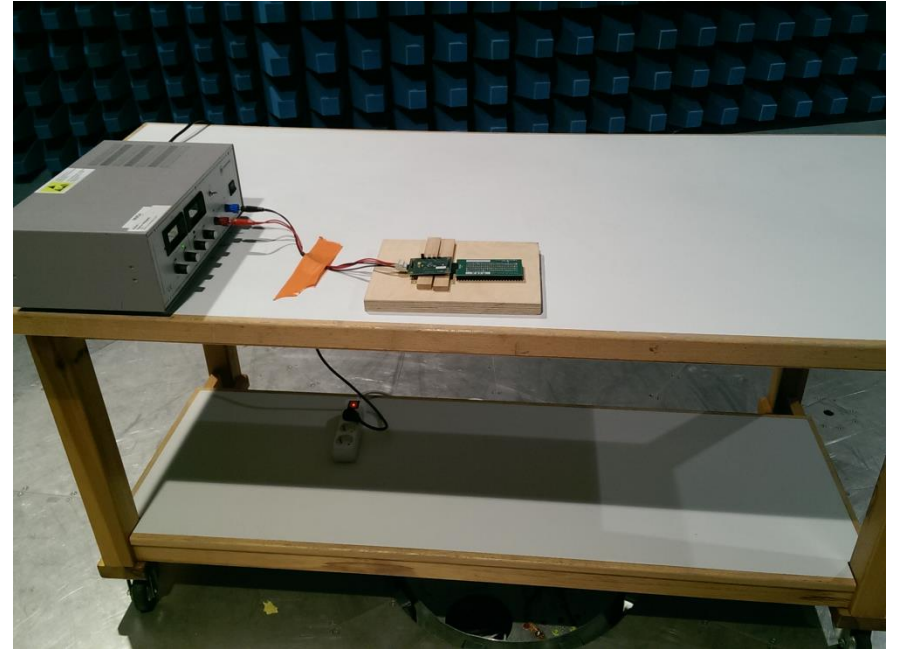
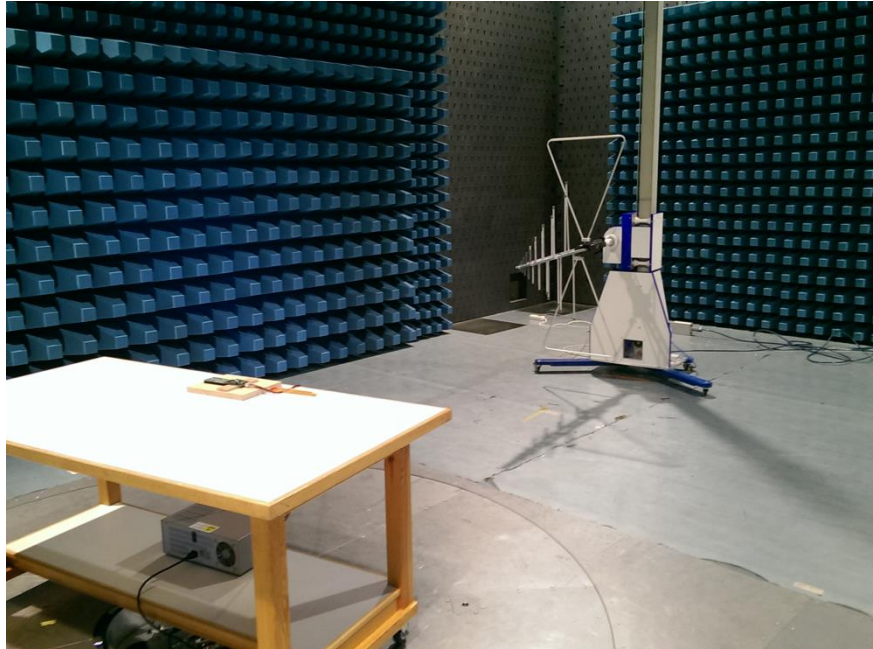


PCB Simulations – Top Layer only - Routing



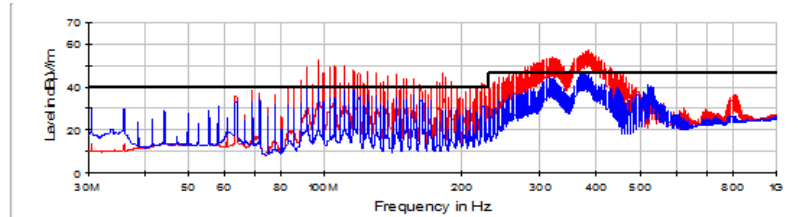
EMI Measurements

Setup – CISPR22 (Industrial)

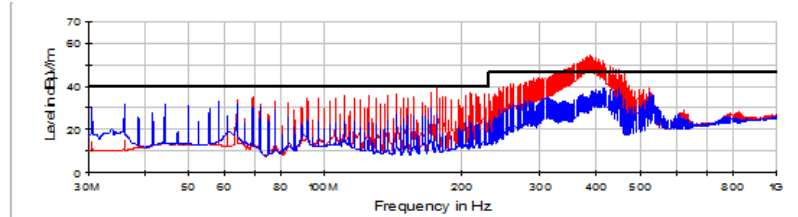


Measurement Examples

different input connection

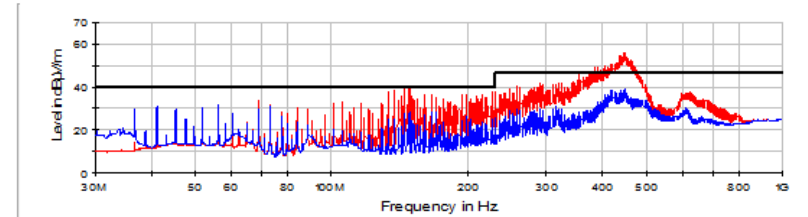


— Preview Result 1H-QPK
— Preview Result 1V-QPK
* Critical_Freqs QPK
— EN 55022 (2010) 6.1 Radiated disturbance 3m Class B QP
* Final_Result QPK

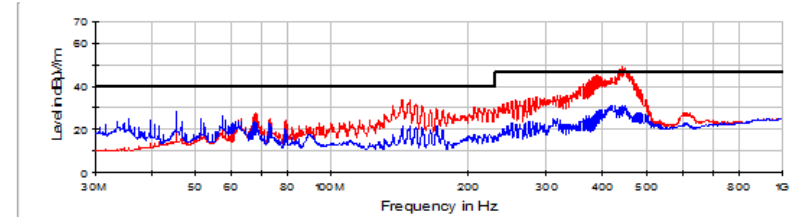


— Preview Result 1H-QPK
— Preview Result 1V-QPK
* Critical_Freqs QPK
— EN 55022 (2010) 6.1 Radiated disturbance 3m Class B QP
* Final_Result QPK

different supply voltages



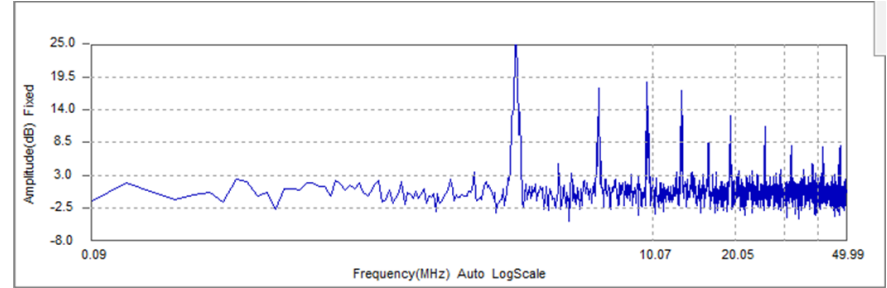
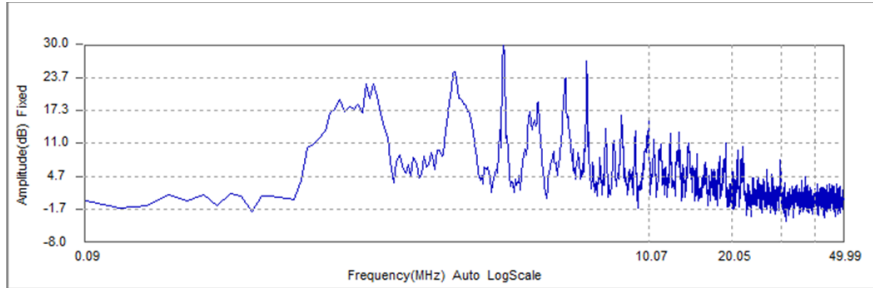
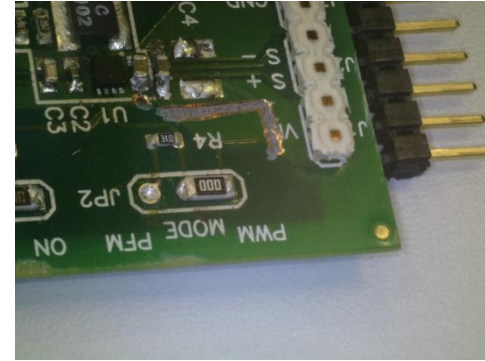
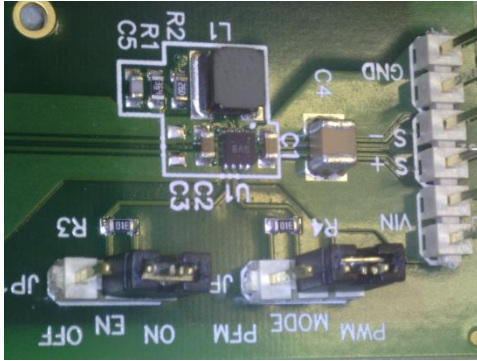
— Preview Result 1H-QPK
— Preview Result 1V-QPK
* Critical_Freqs QPK
— EN 55022 (2010) 6.1 Radiated disturbance 3m Class B QP
* Final_Result QPK



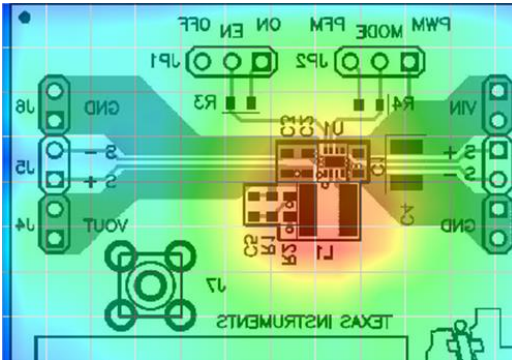
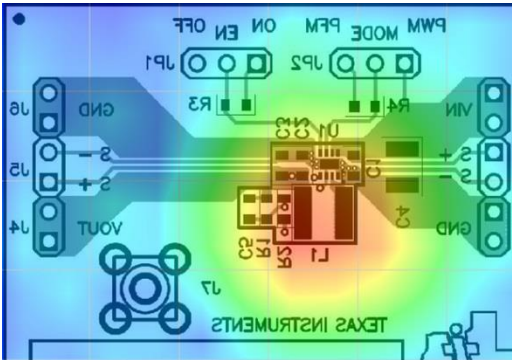
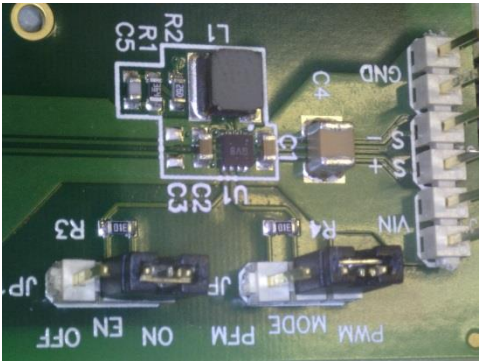
— Preview Result 1H-QPK
— Preview Result 1V-QPK
* Critical_Freqs QPK
— EN 55022 (2010) 6.1 Radiated disturbance 3m Class B QP
* Final_Result QPK

Detailed Analysis

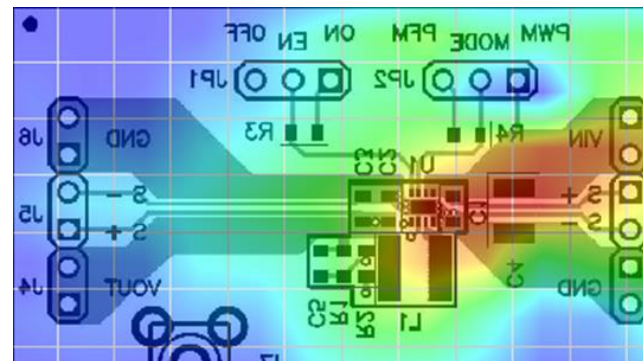
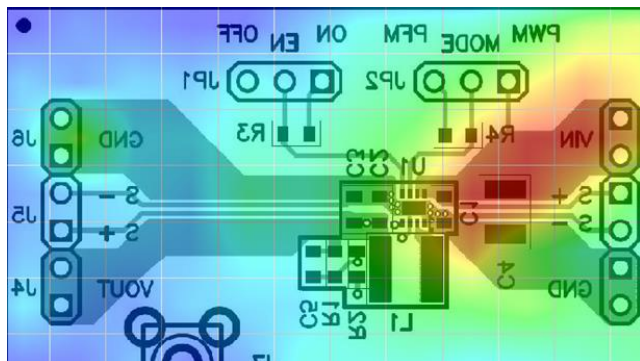
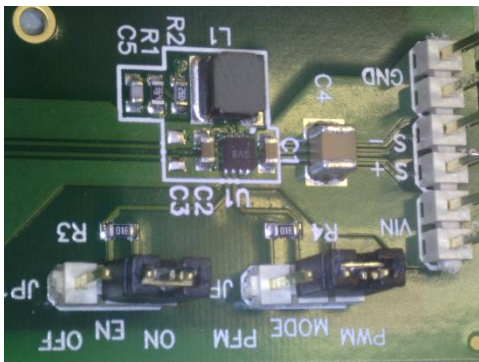
Layout and component selection



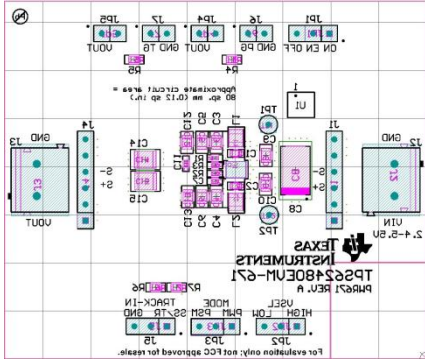
Layout and Component Selection



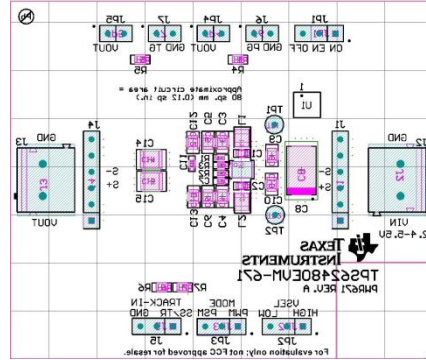
Layout and Component Selection



Component Selection and Placement

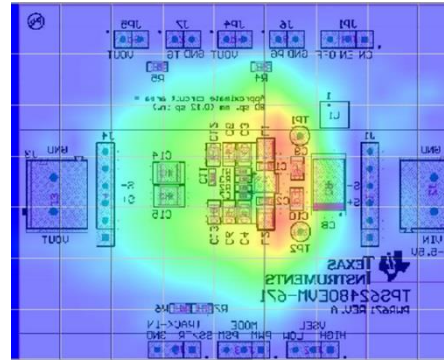
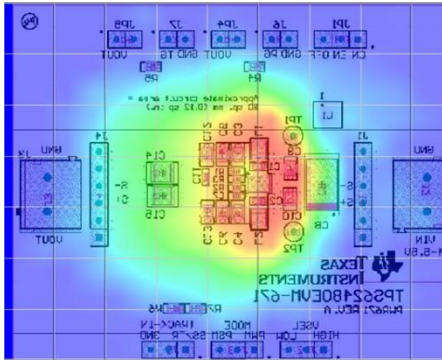


C1, C2	22 uF, 0603 size
C9, C10	not assembled

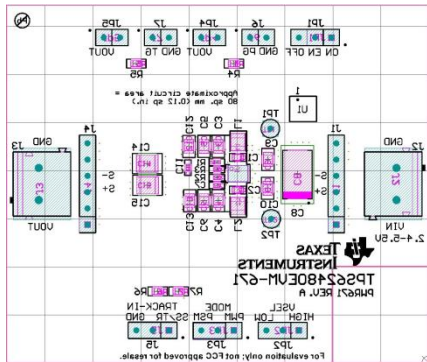


C1, C2	470 pF, 0402 size
C9, C10	22 uF, 0603 size

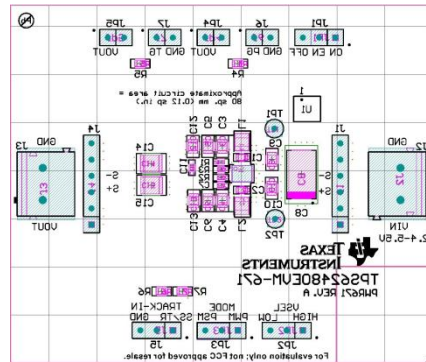
Switching Frequency



Component Selection and Placement

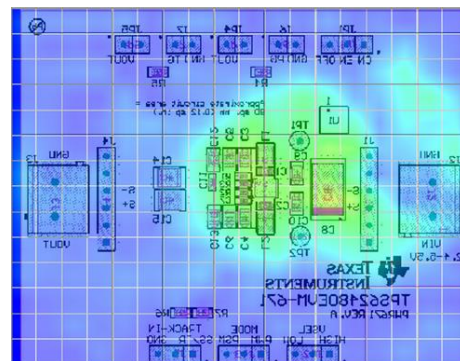
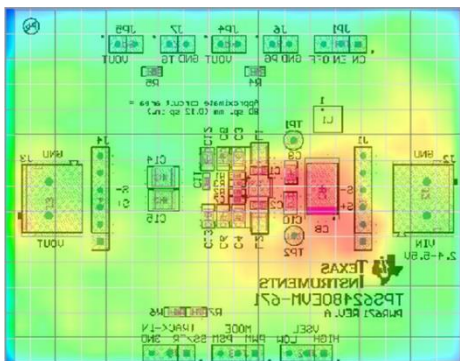


C1, C2	22 uF, 0603 size
C9, C10	not assembled



C1, C2	470 pF, 0402 size
C9, C10	22 uF, 0603 size

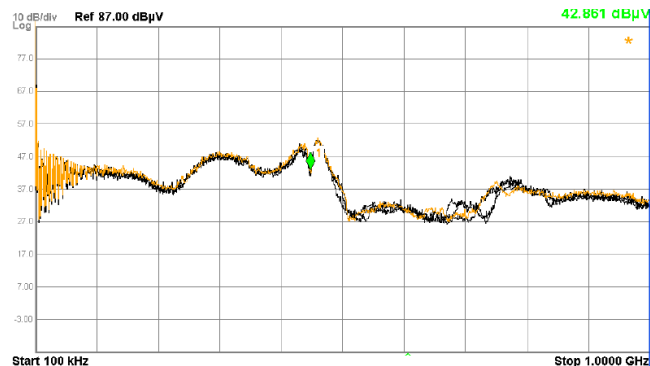
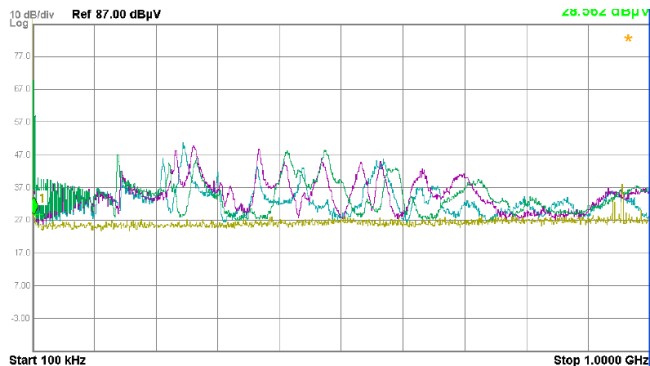
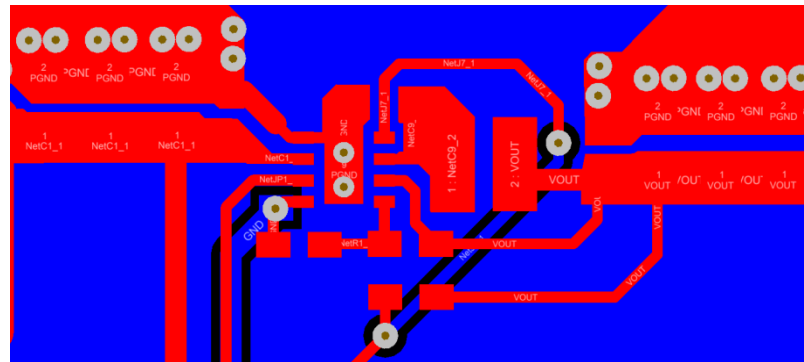
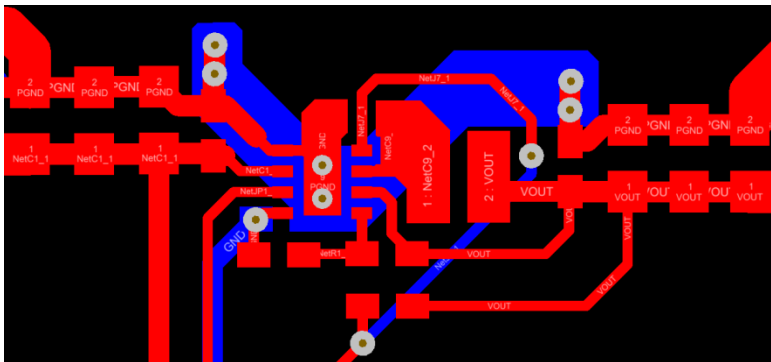
400 MHz range



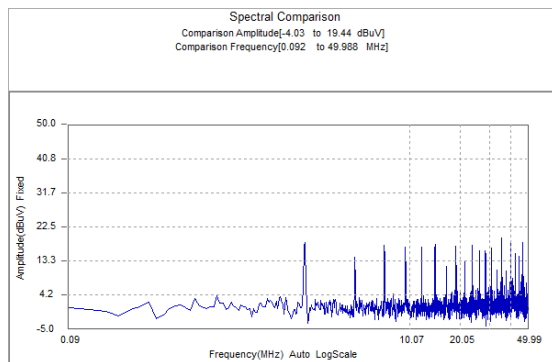
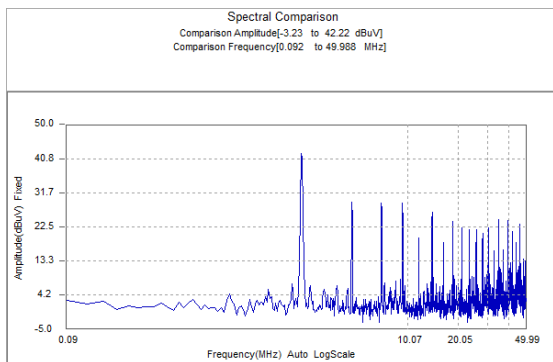
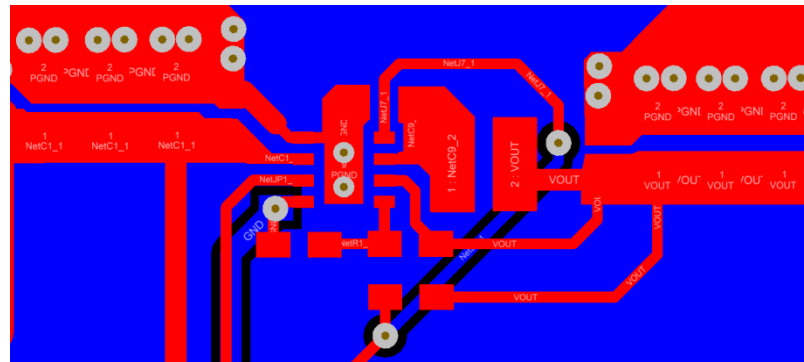
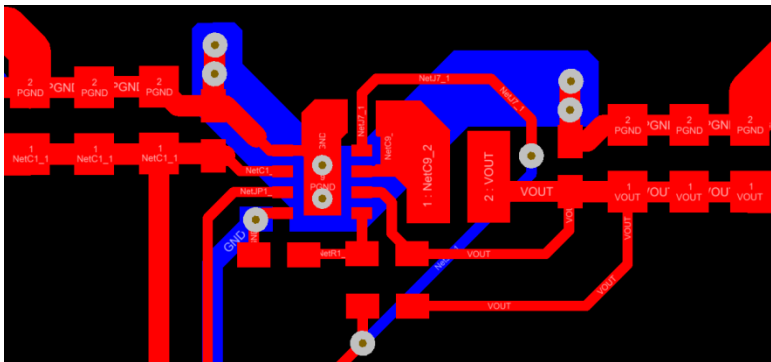
Mitigation Strategies

Shielding Layers

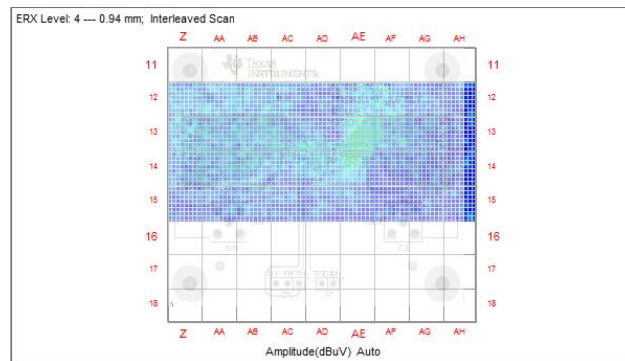
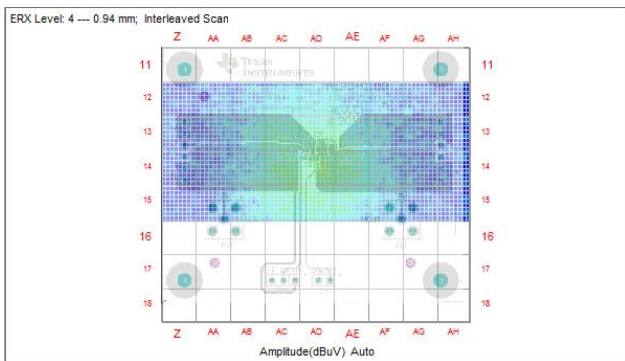
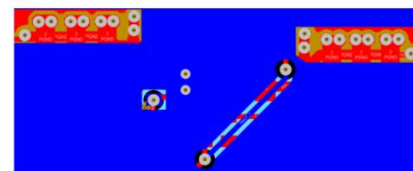
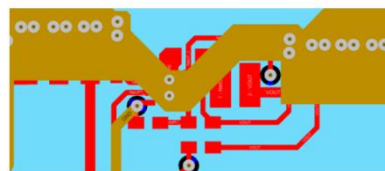
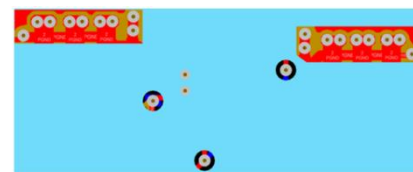
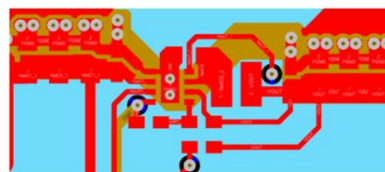
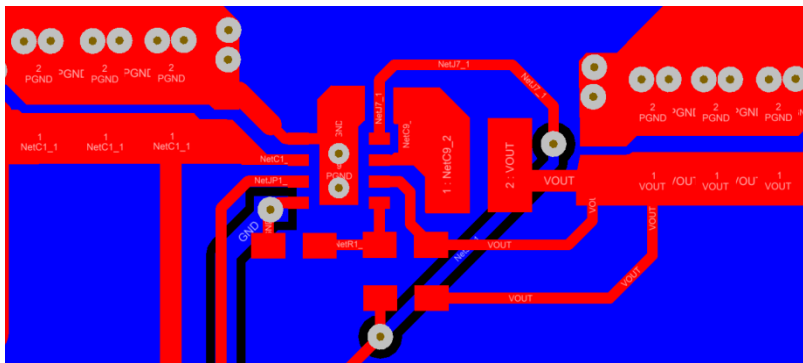
Shielding Layer



Shielding Layer

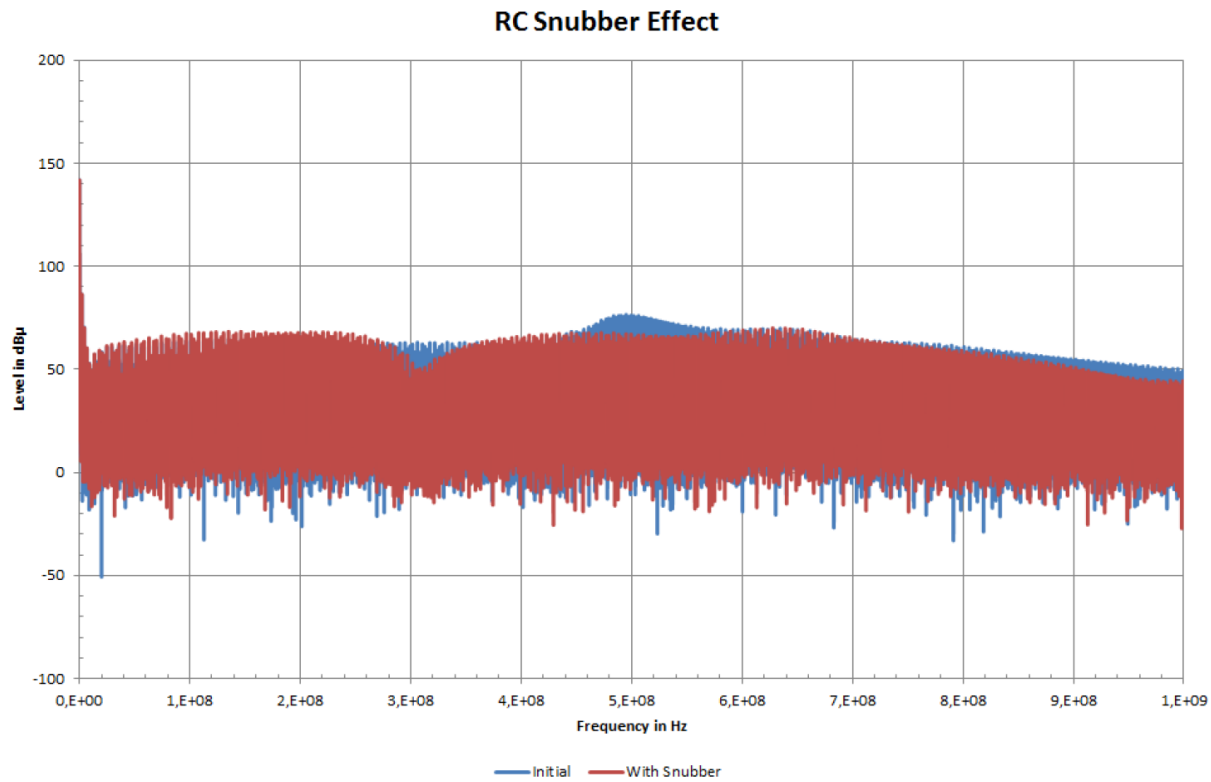


Shielding Layer



Snubber at the Switch Node

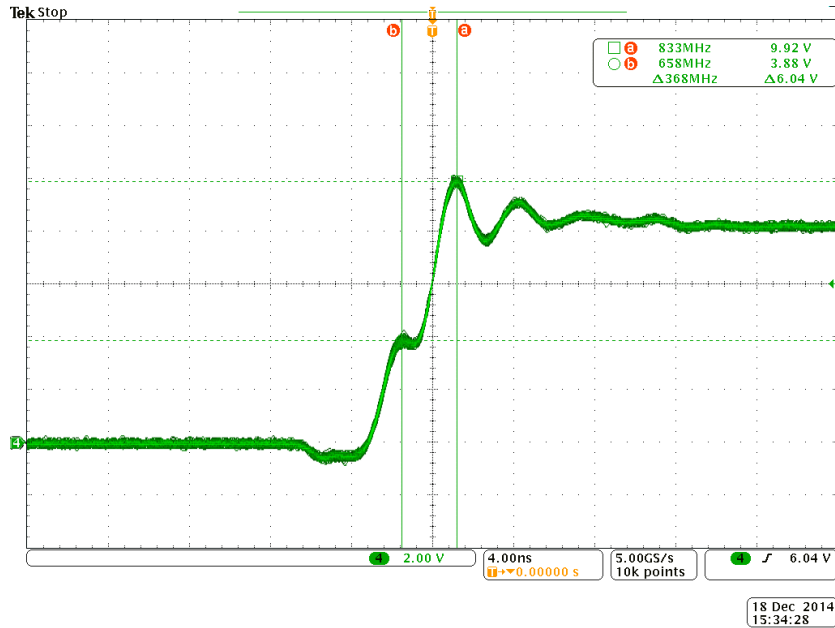
Snubber



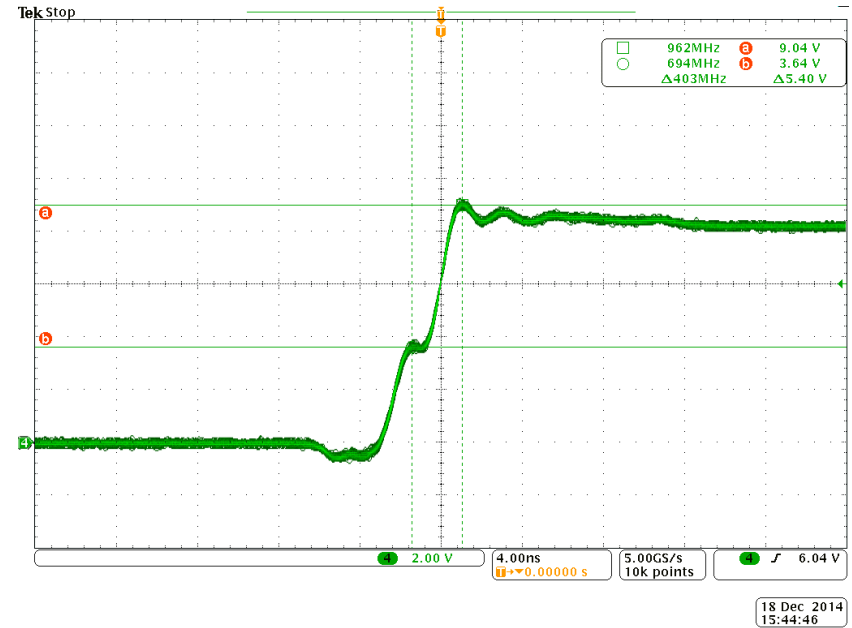
Input Capacitor Design

Switching Noise and Overshoots

Default Assembly

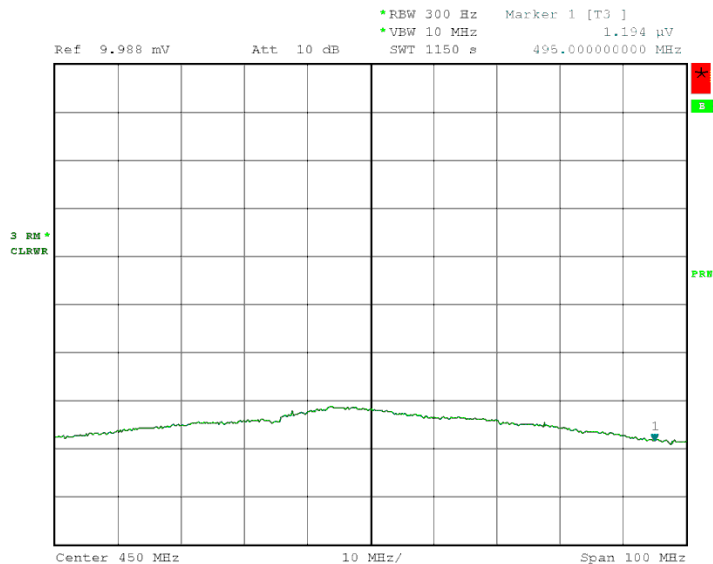


470 pF 0402 Capacitor at the Input



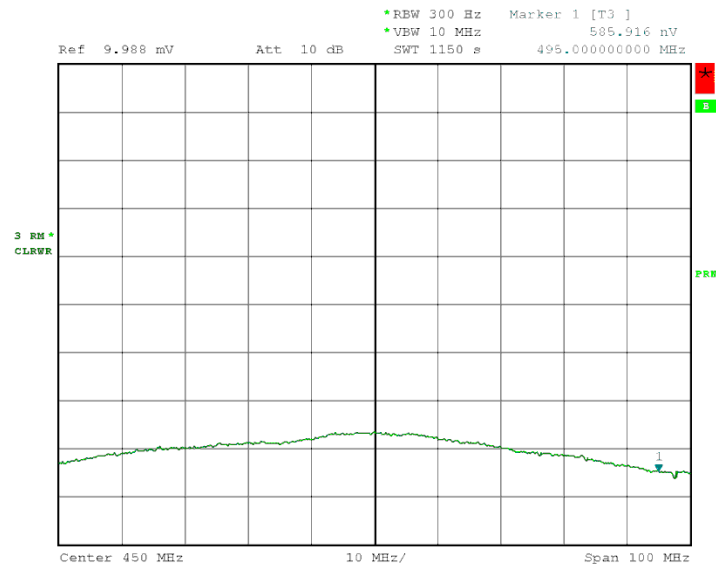
Switching Noise

Oscilloscope probe connected



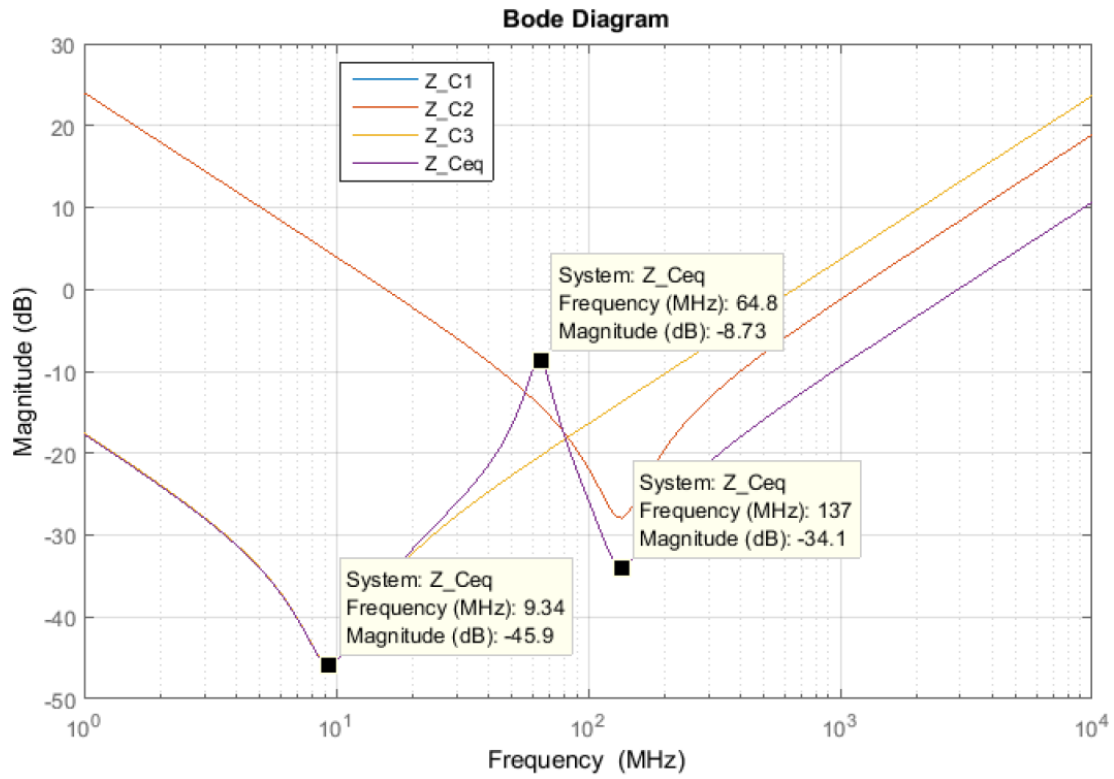
Date: 9.APR.2014 12:03:54

Oscilloscope probe not connected

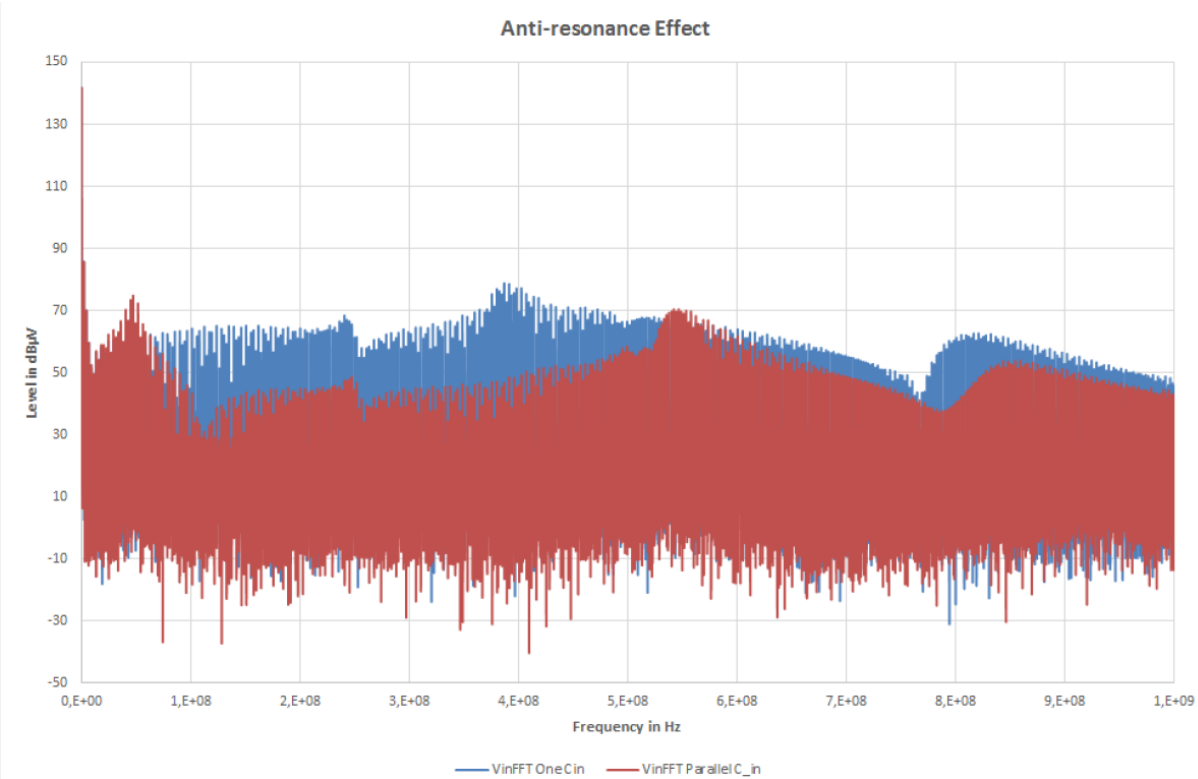


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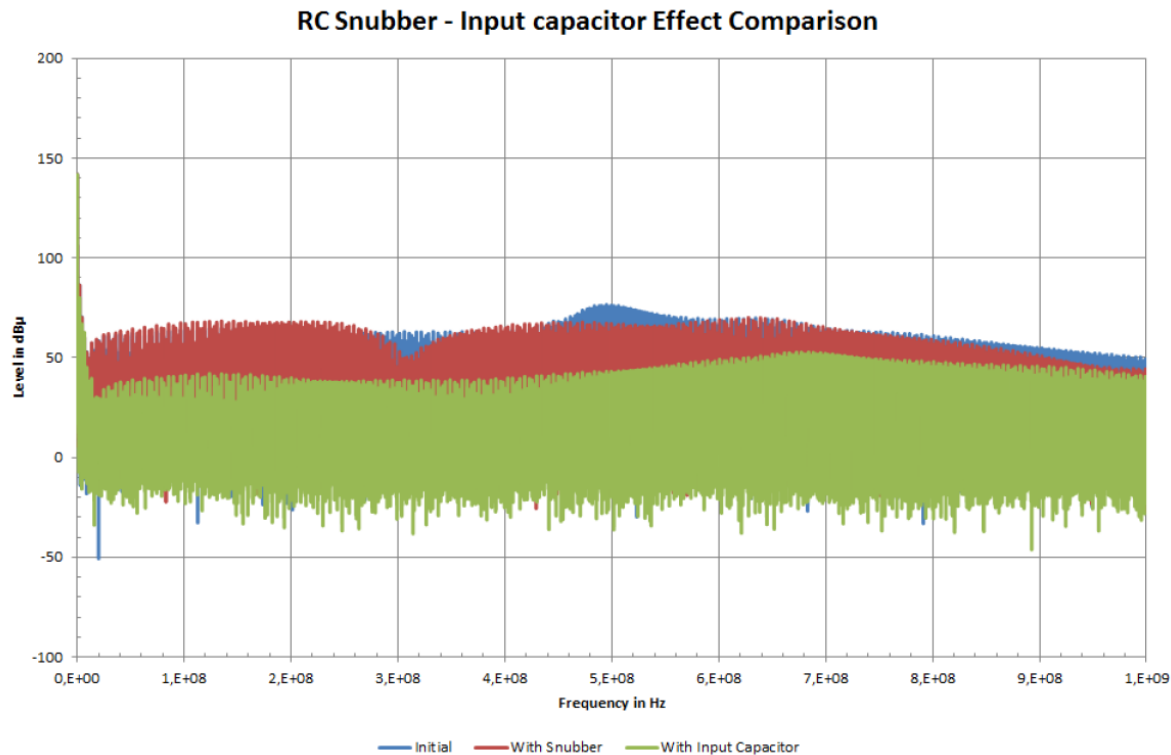
Resonance Effects in the Input Capacitors



Resonance Effects in the Input Capacitors

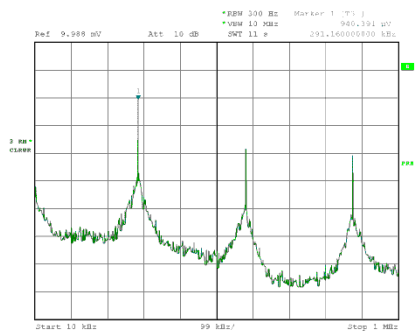


Comparison

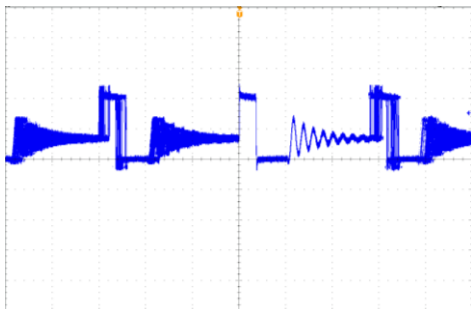


Spread Spectrum ?

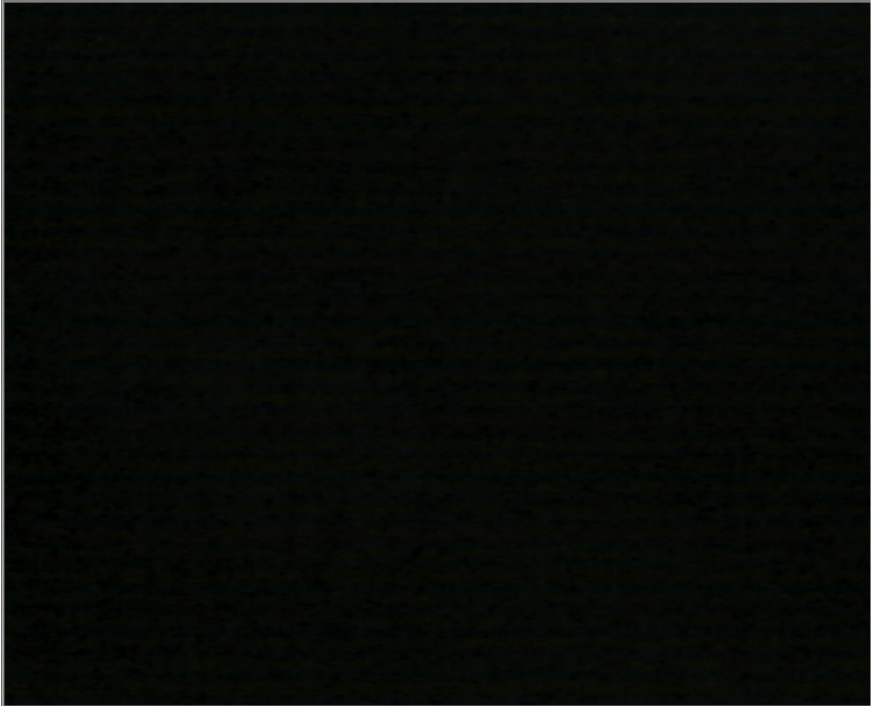
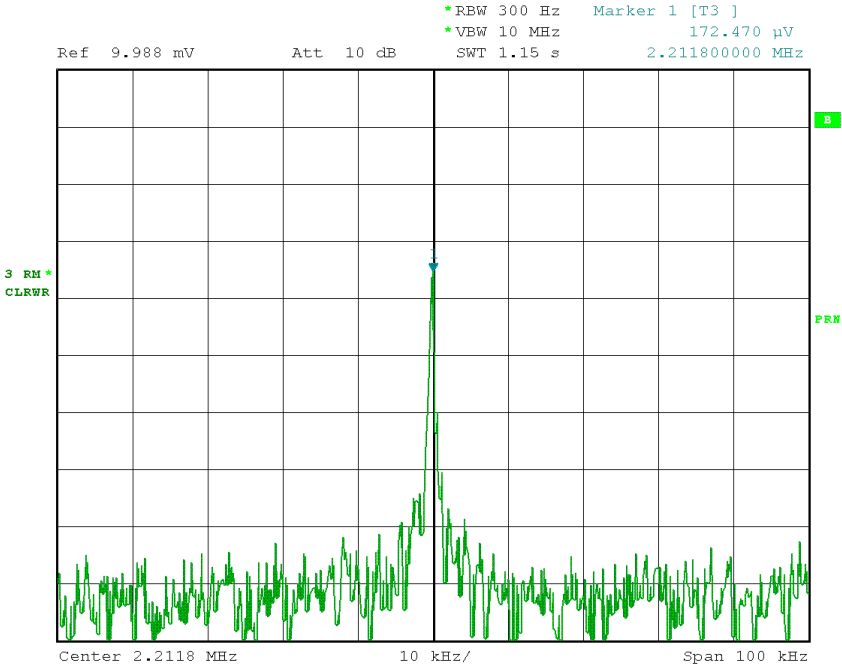
Waveforms and Spectrum



Date: 9.APR.2014 09:48:56



Fixed Frequency Operation



Date: 9.APR.2014 09:04:35

Thank you