EMI Seminar 2017

KTH

21 February

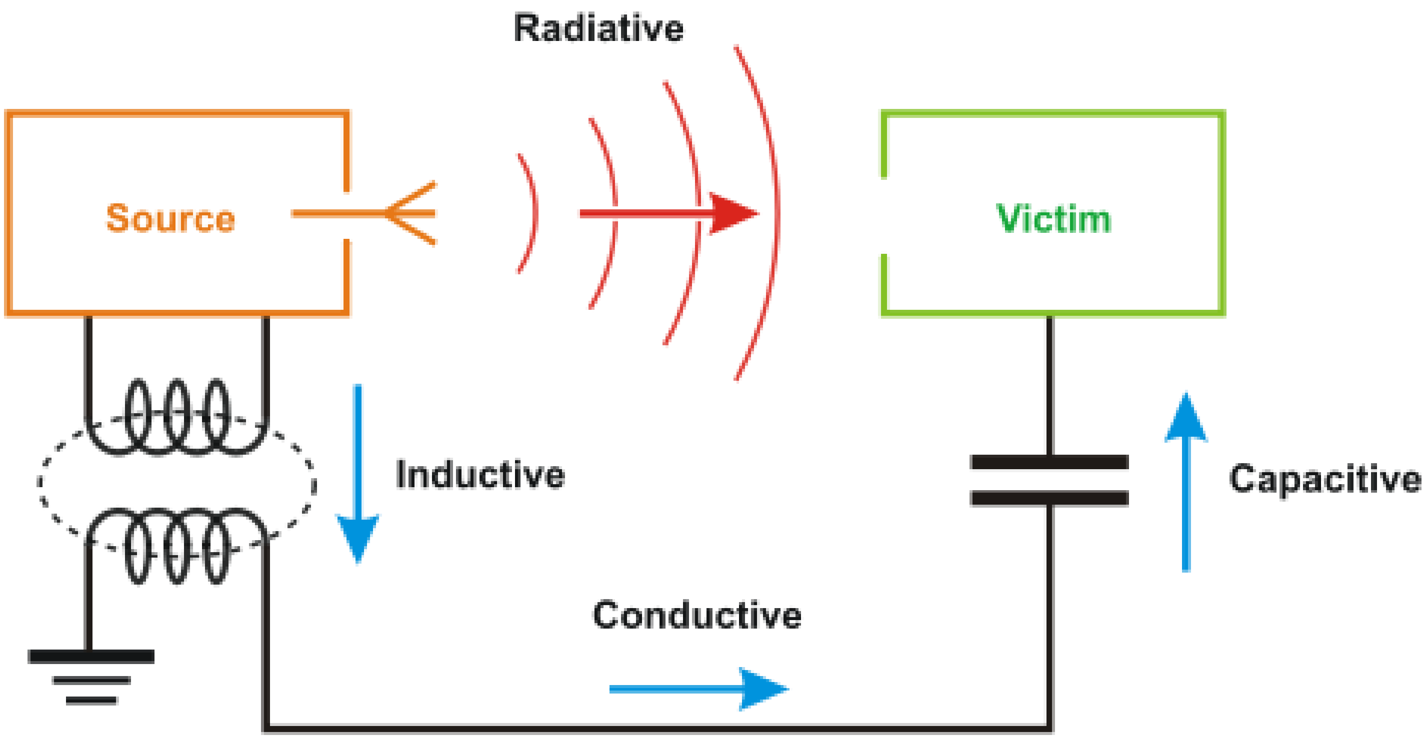
By Thomas Ginell

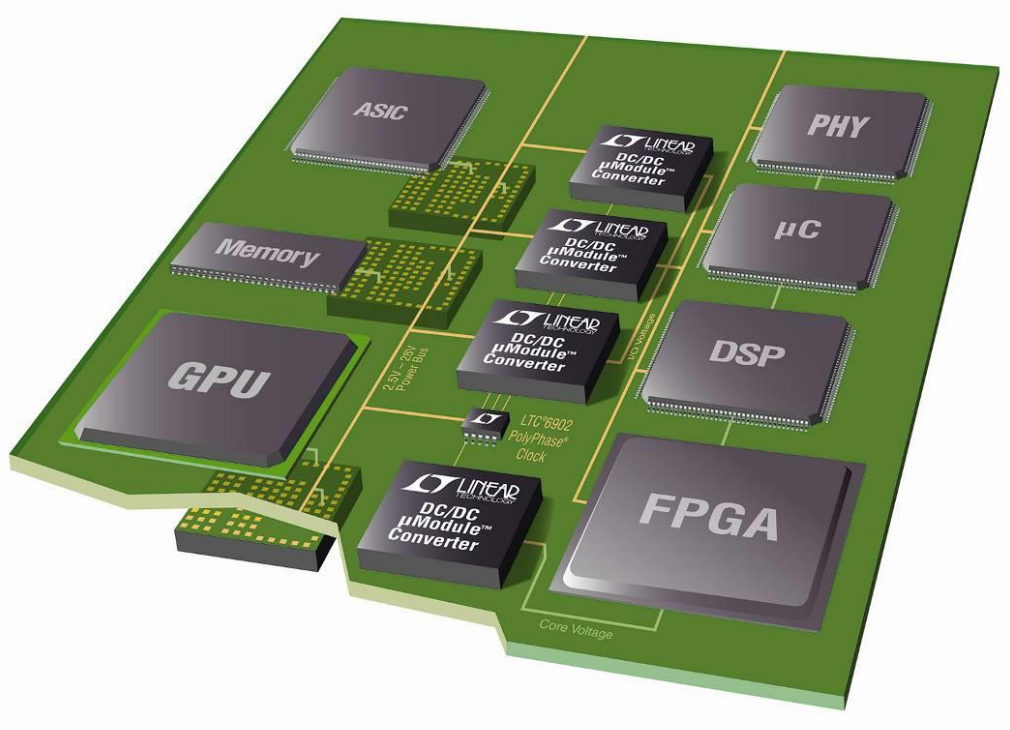
ANALOG EXCELLENCE

INNOVATION LED RECOVERY

- Basic switch mode power design
- Circuit EMI, ripple, noise, component behavior
- Basic electromagnetics

Electromagnetic Interference





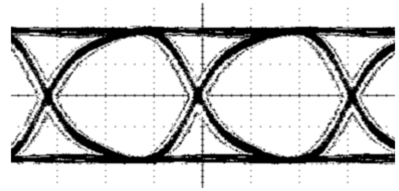
Hardware

Needs

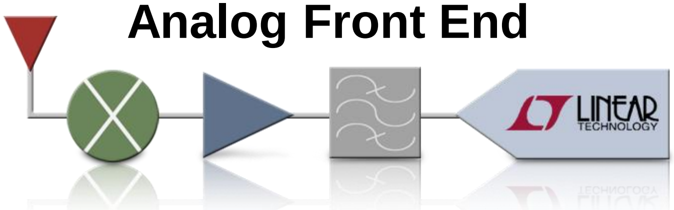
POWER

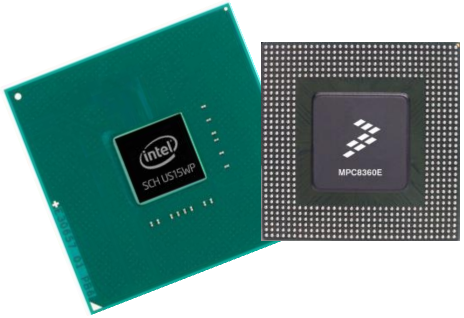
FPGA

High Speed Data Interface

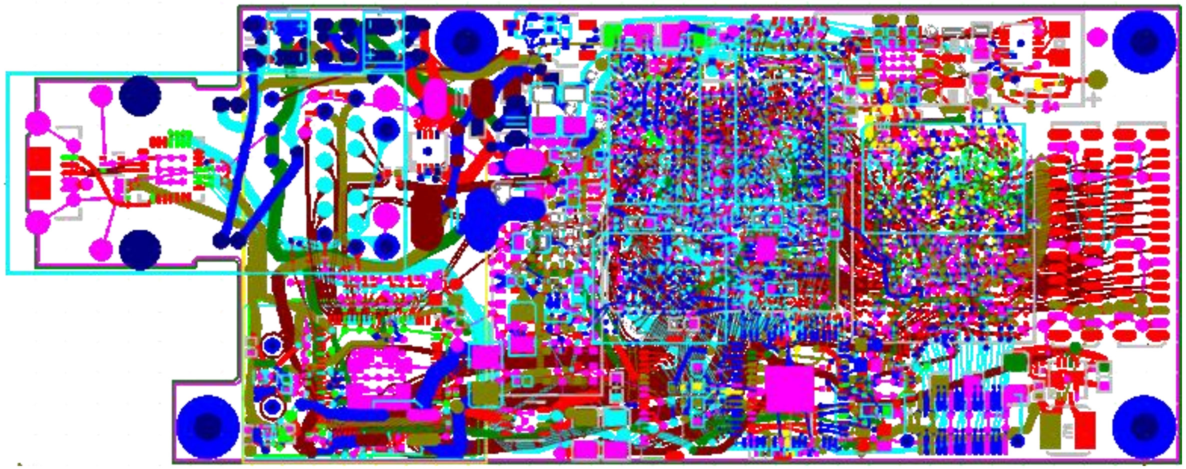


Analog Front End



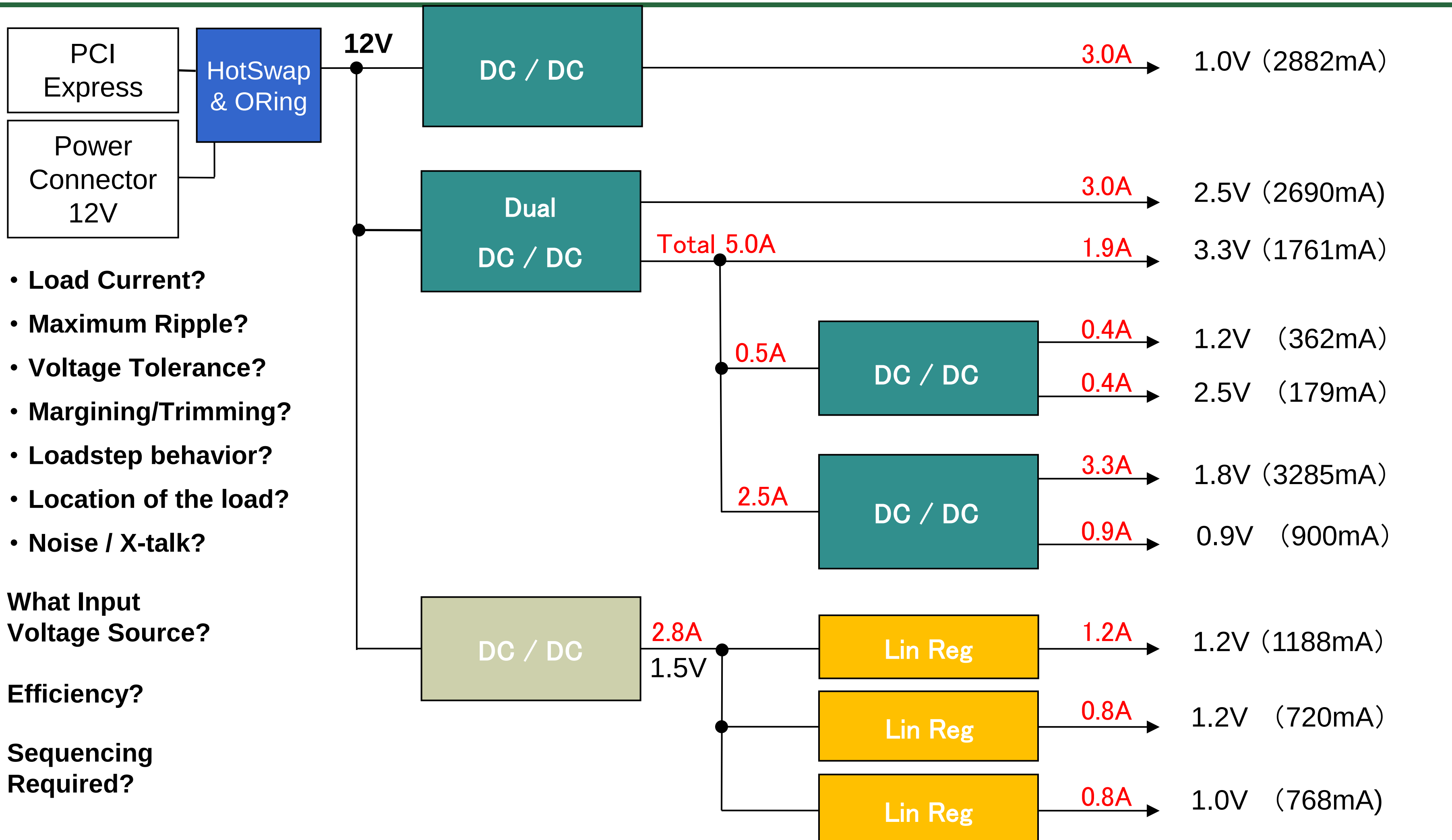


Processor
DSP



And everything has to fit in here !

Detailed Voltage Rail Map



- **Load Current?**
- **Maximum Ripple?**
- **Voltage Tolerance?**
- **Margining/Trimming?**
- **Loadstep behavior?**
- **Location of the load?**
- **Noise / X-talk?**

What Input Voltage Source?

Efficiency?

Sequencing Required?

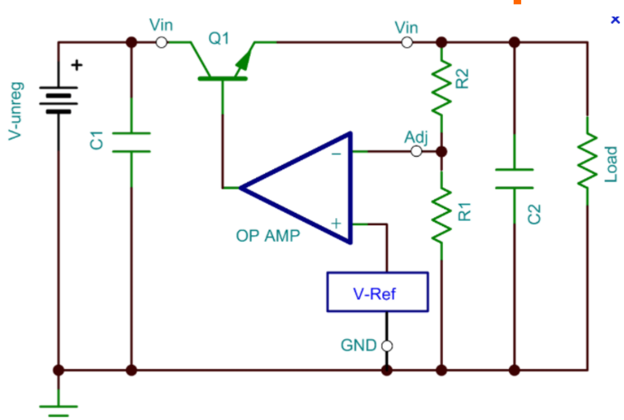
What Rails should be kept separately?

Which Part to Choose?

Linear Regulator

- Easy to design and use
- No magnetics
- Low noise
- **Low efficiency**

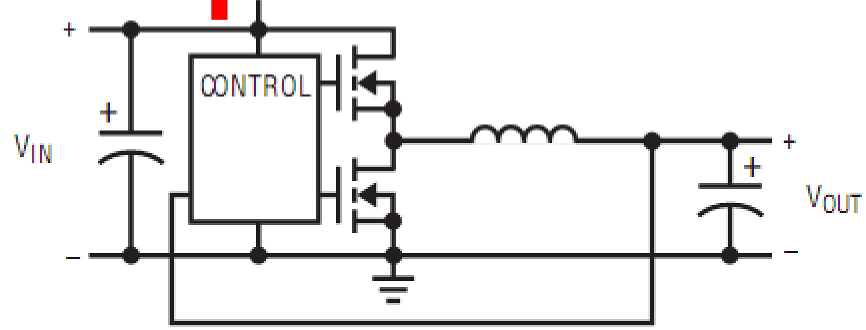
Heat   Power consumption



Switching Regulator

- High efficiency
- Small - no heat sinks!
- **Switching noise**
- **More complicated**

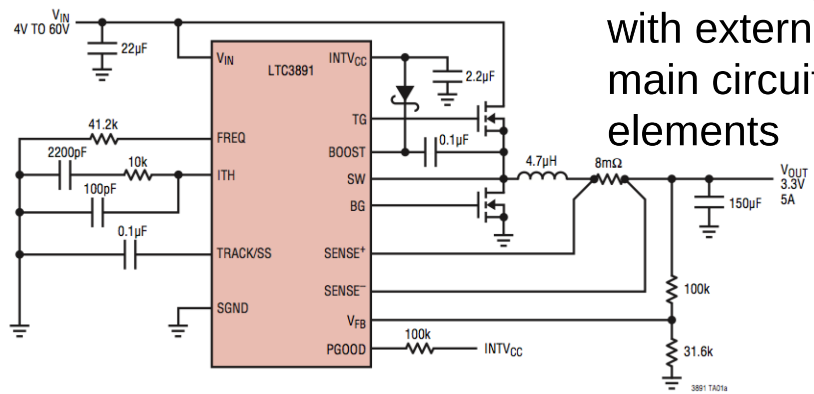
How much more complicated ?



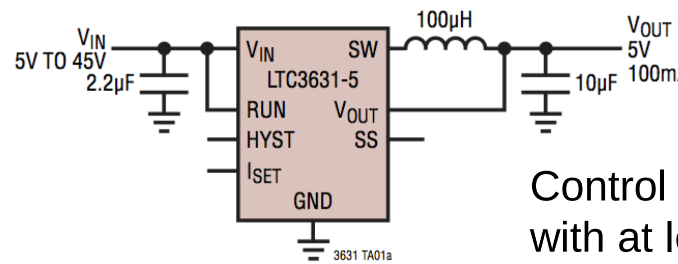
Levels of integration

Control chip with external main circuits elements

Controller

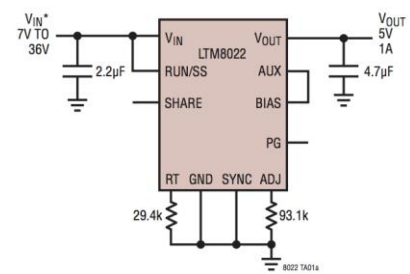


Monolithic



Control chip with at least one integrated power switch

µModule



Fully integrated DC/DC converter only add bulk capacitance

Complexity of design

Controller

- Output and input filter
  - Capacitor size and ratings
- Inductor dimensioning
  - Saturation current
  - Core losses
  - Copper losses
- Switches dimensioning
  - Voltage rating
  - Current rating
  - Rdson vs Qg
- Layout
  - **Complex !**

Monolithic

- Output and input filter
  - Capacitor size and ratings
- Inductor dimensioning
  - Saturation current
  - Core losses
  - DC losses
- Layout
  - Medium complexity !

µModule

- Pick the part
  - Fits spec yes/no?
- Layout
  - Piece of cake !

Switch mode supply

What frequency should I choose ?

48kHz **150kHz** **300kHz** **500kHz** **2MHz**

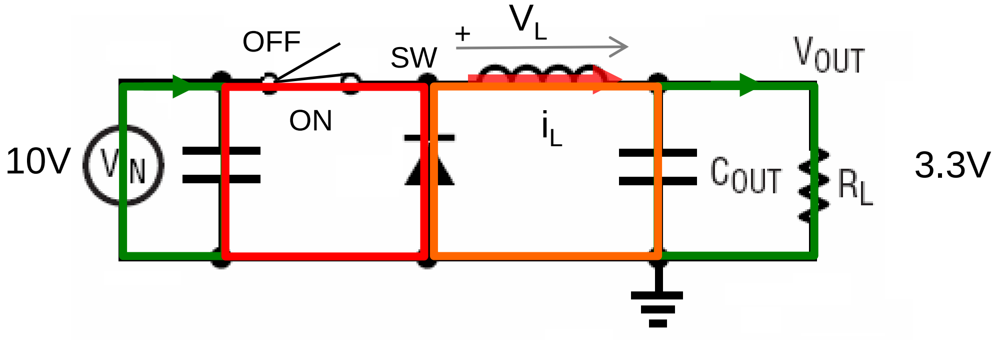
Switching frequency

Switching losses

But first some basics

- What is a switch mode regulator?
- Lets have a look at a step down converter (Buck)

Buck Converter Step down

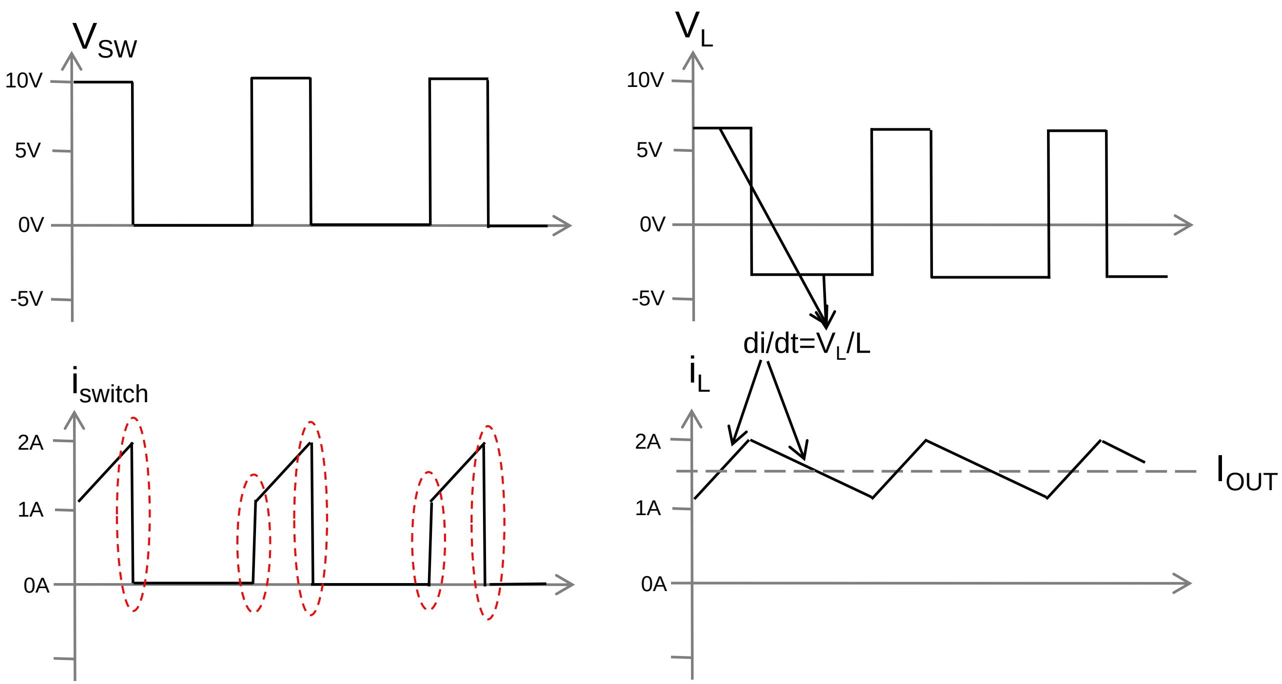


From EMI point off view:

DC currents, no worries...?

AC loop moderate di/dt

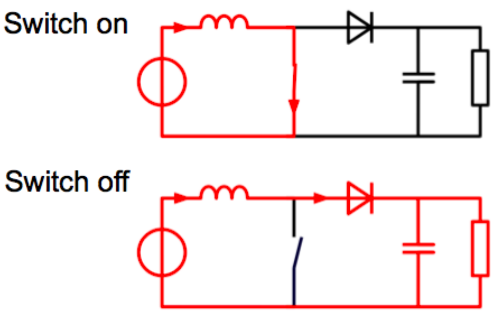
AC loop high di/dt CAUTION !



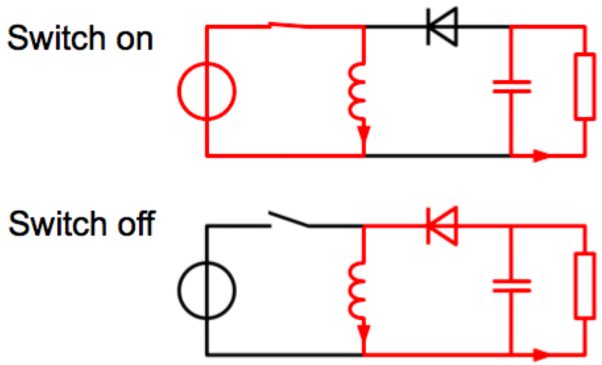
Details: AN19, AN44

Other topologies

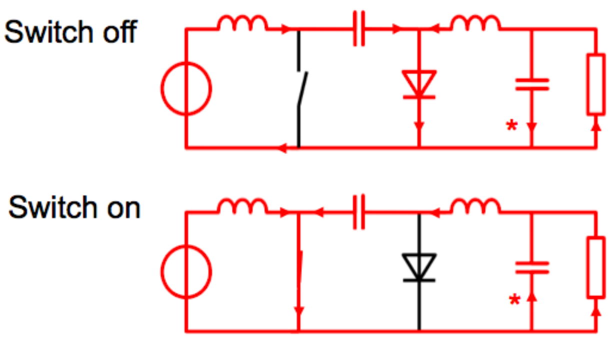
Boost converter



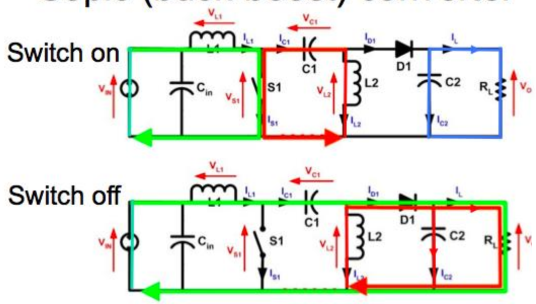
Inverting converter

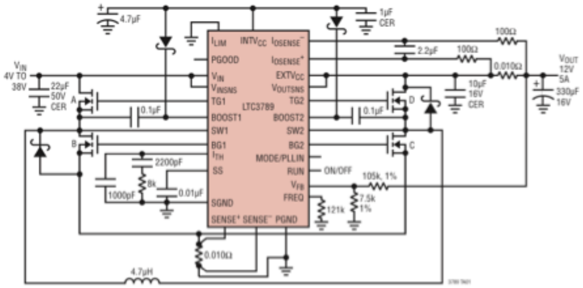


Ćuk inverting converter

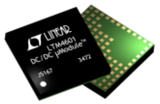


Sepic (buck-boost) converter





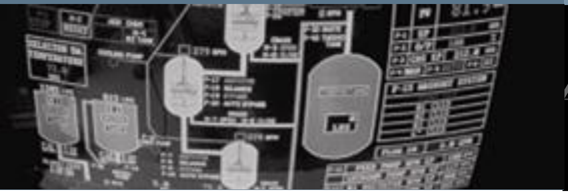
+ Isolated converter topologies



EMI and filtering for DC/DC converters

Thomas Ginell
Field Application Engineer

Linear Technology Corporation

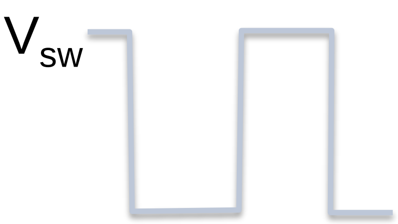


LINEAR TECHNOLOGY

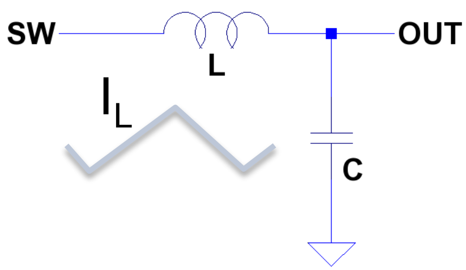
EMI

- Application voltage quality requirements
- On board interference
- Emmision
  - Radiated
  - Conducted

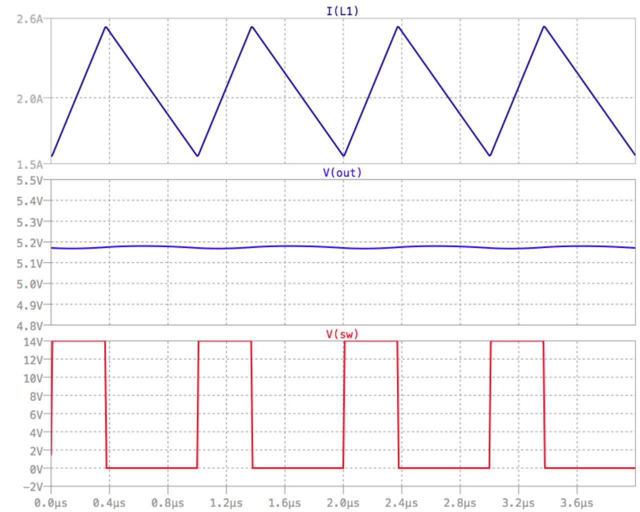
Output ripple

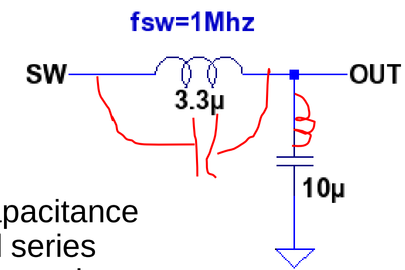


Buck example

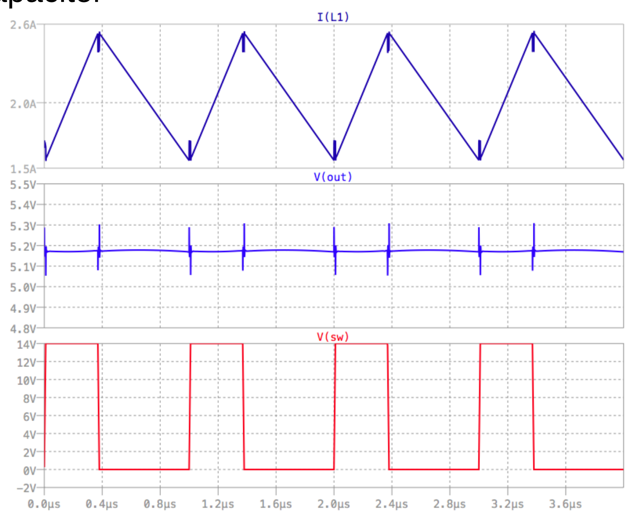


No parasitics waveform (esr 2mohm)

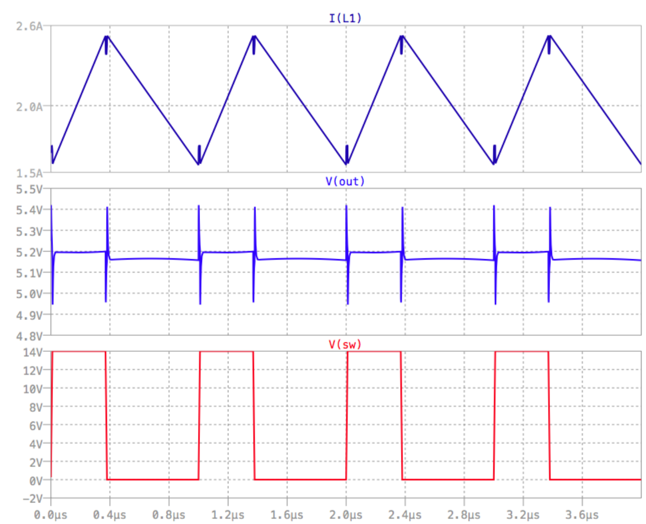




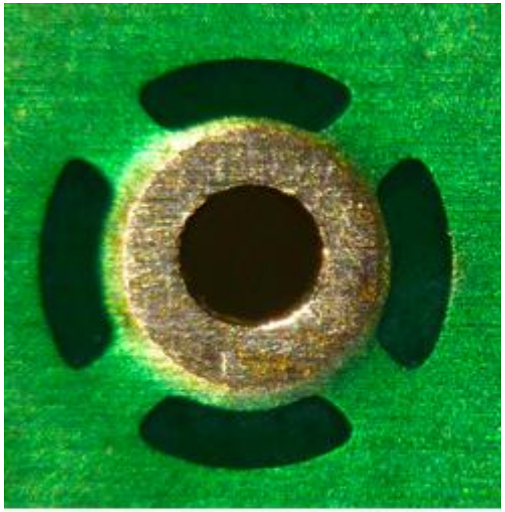
Add parallel capacitance to inductor and series inductance to capacitor

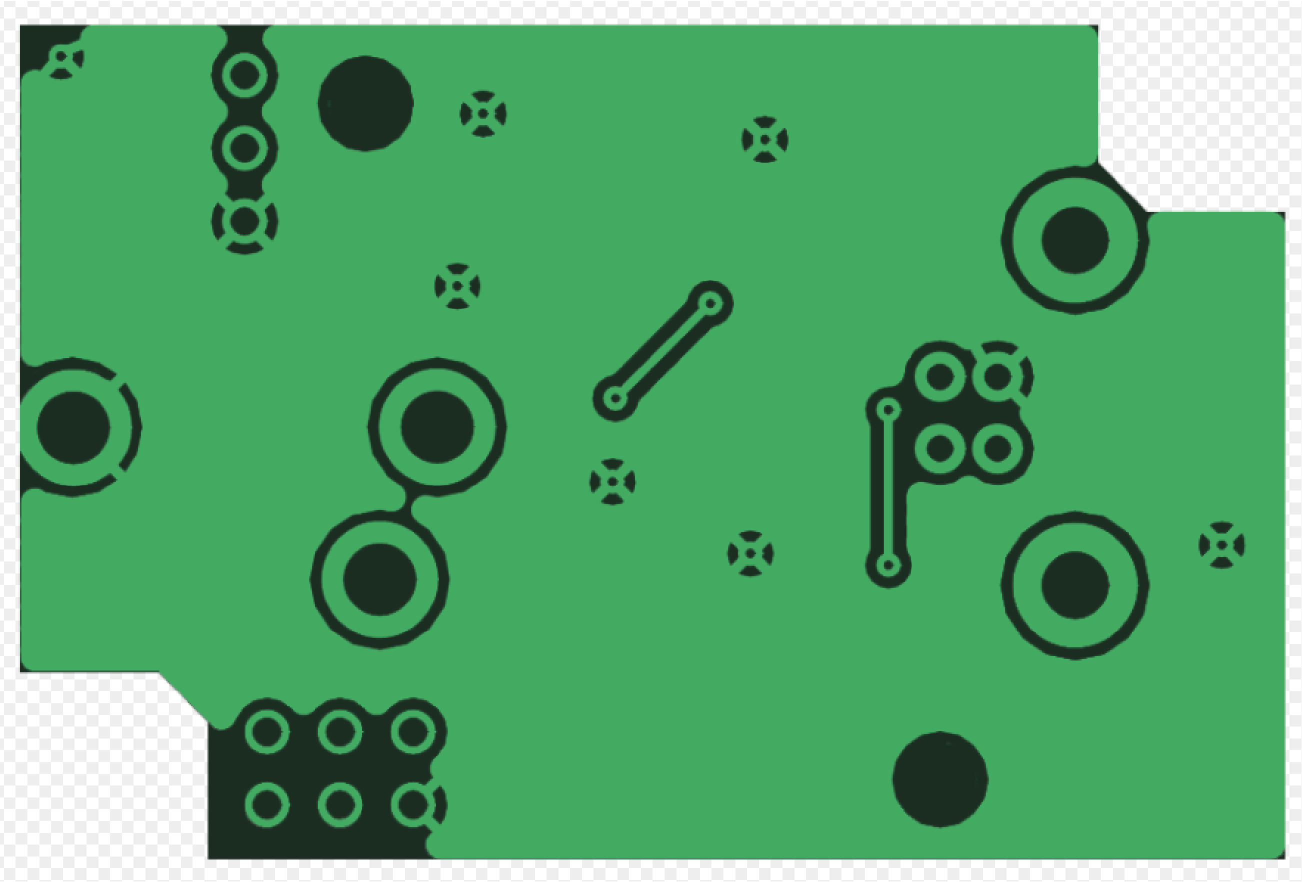


Also use vias and thermal relief for decoupling capacitor



Thermal relief

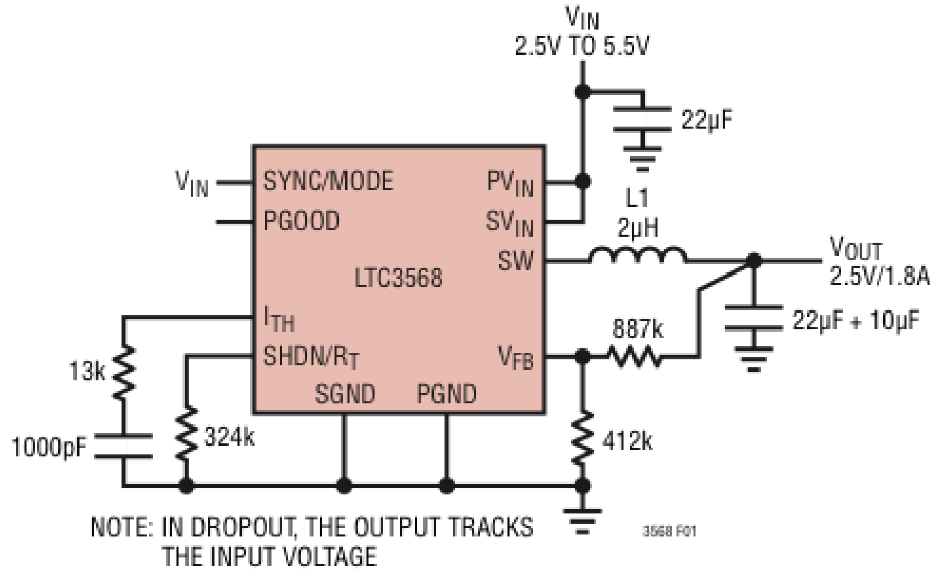


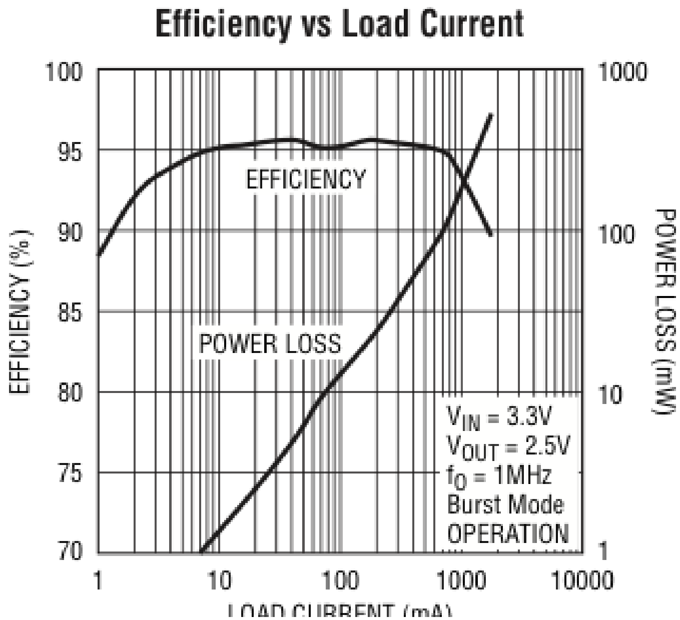


New example

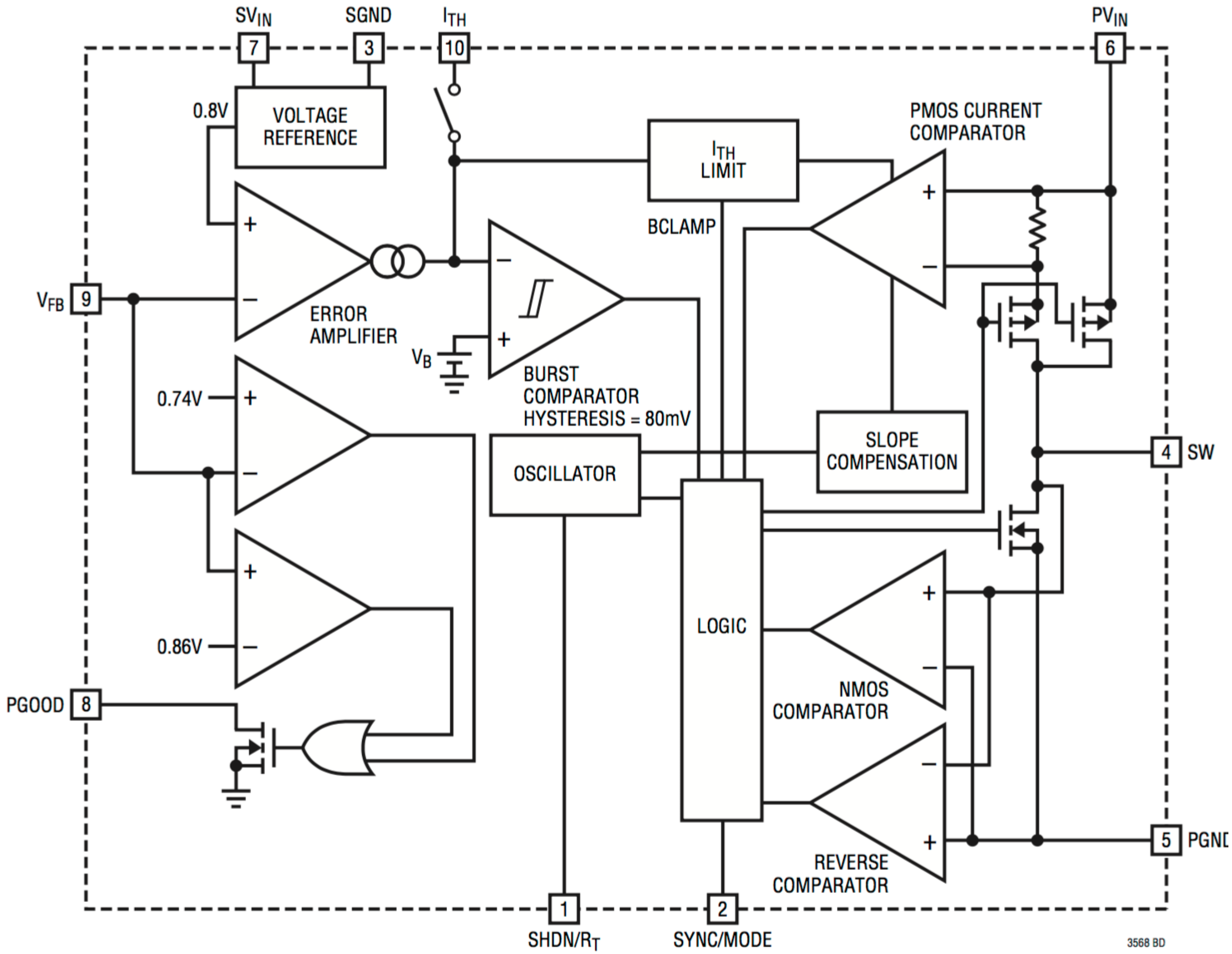
- LTC3568
- 2MHz switching frequency

TYPICAL APPLICATION





LTC3568 block diagram



Chose output capacitor

- 0201 (0603 metric)
- 0402 (1005 metric)
- 0603 (1608 metric)
- 0805 (2012 metric)
- 1008 (2520 metric)
- 1206 (3216 metric)
- 1210 (3225 metric)
- 1806 (4516 metric)
- 1812 (4532 metric)
- 2010 (5025 metric)
- 2512 (6432 metric)

comparison

0.1x0.1 mm

1x1mm

1x1 cm

Metric code	Imperial code
0402	01005
0603	0201
1005	0402
1608	0603
2012	0805
2520	1008
3216	1206
3225	1210
4516	1806
4532	1812
5025	2010
6332	2512

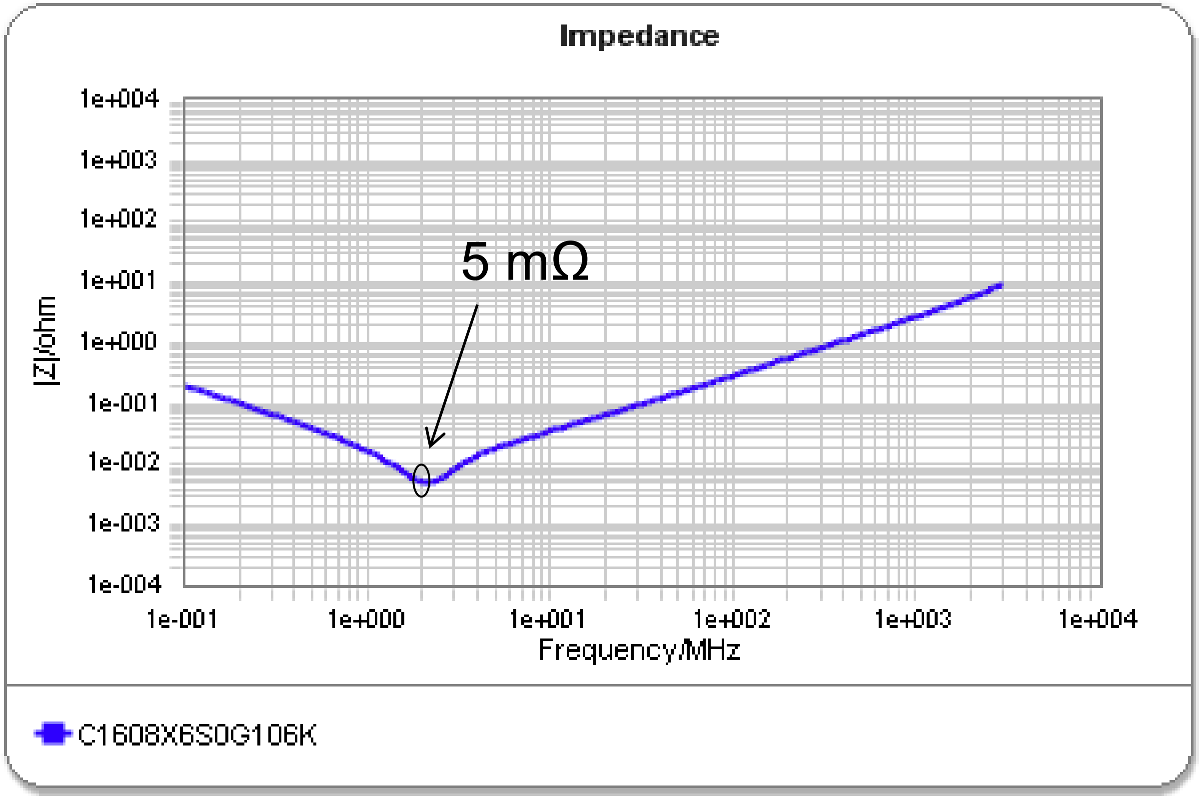
Actual size

utput

2

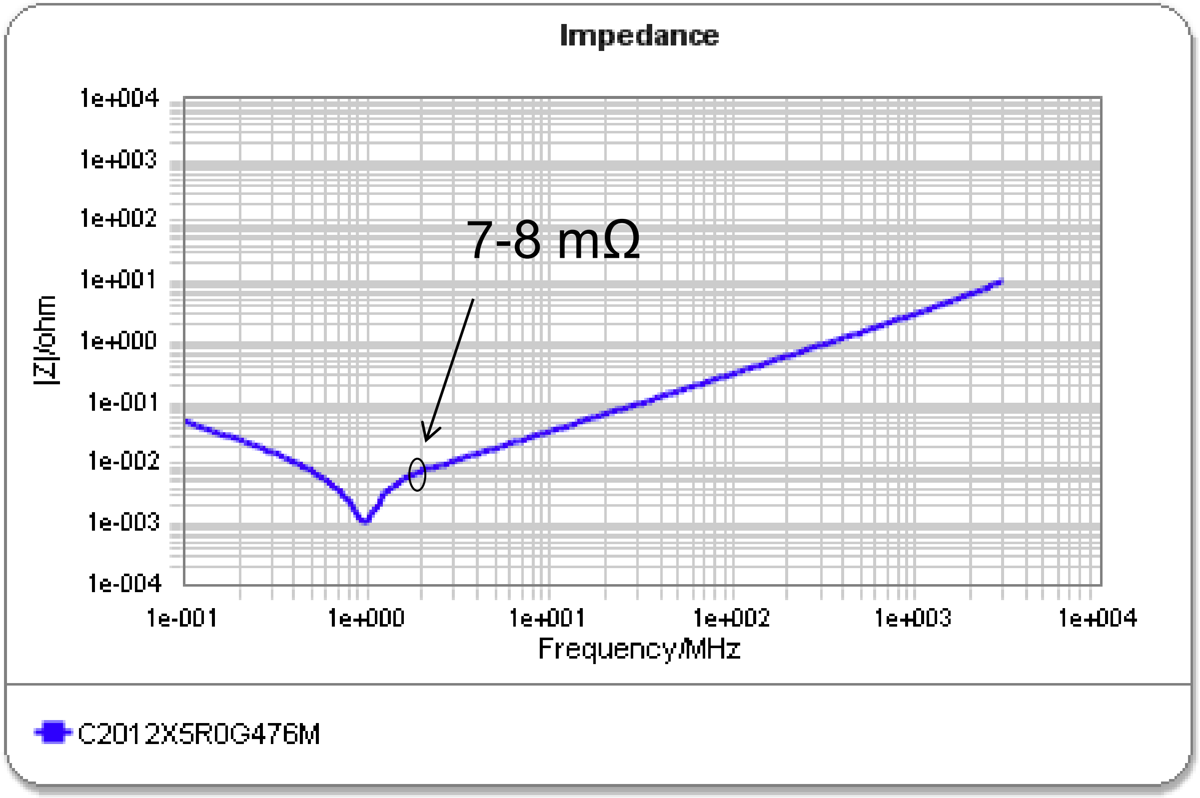
2

4V 10uF X6S


Impedance
1e+004
1e+003
1e+002
1e+001
1e+000
1e-001
1e-002
1e-003
1e-004
|Z|/ohm
5 mΩ
1e-001
1e+000
1e+001
1e+002
1e+003
1e+004
Frequency/MHz
C1608X6S0G106K


ESR
C
ESL

4V 47uF X5R

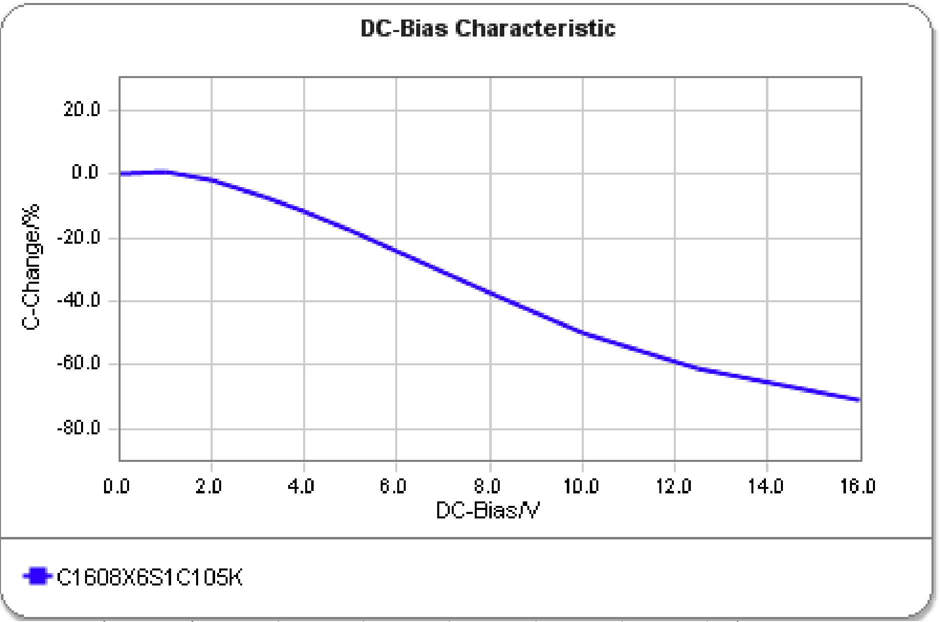

Impedance
1e+004
1e+003
1e+002
1e+001
1e+000
1e-001
1e-002
1e-003
1e-004
|Z|/ohm
7-8 mΩ
1e-001
1e+000
1e+001
1e+002
1e+003
1e+004
Frequency/MHz
C2012X5R0G476M

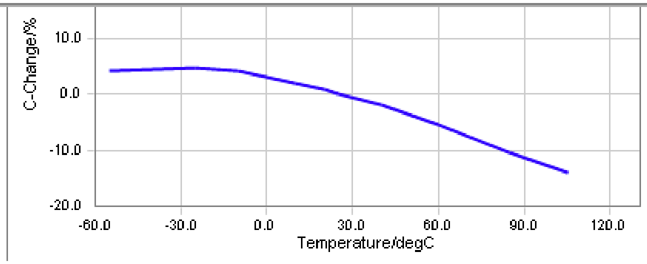

ESR
C
ESL

Beware !

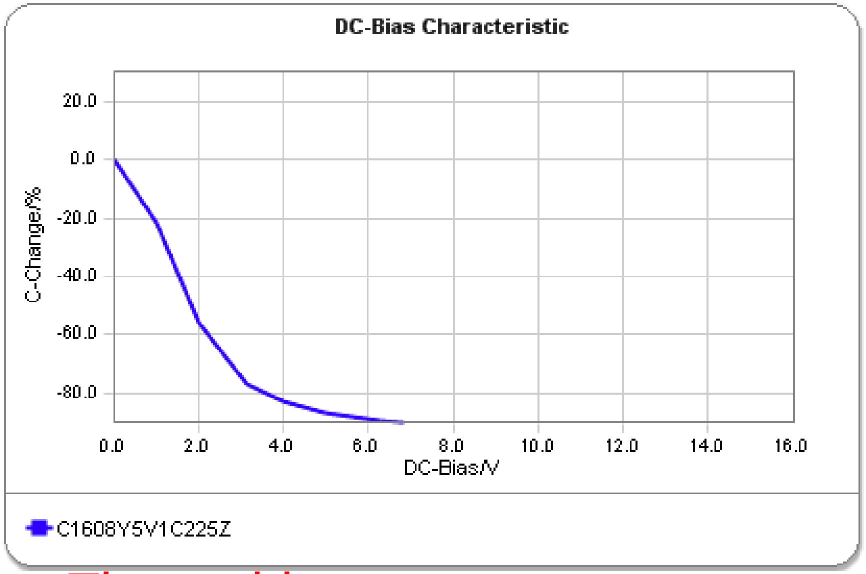
Bias dependency !

16V X6S +/- 10%

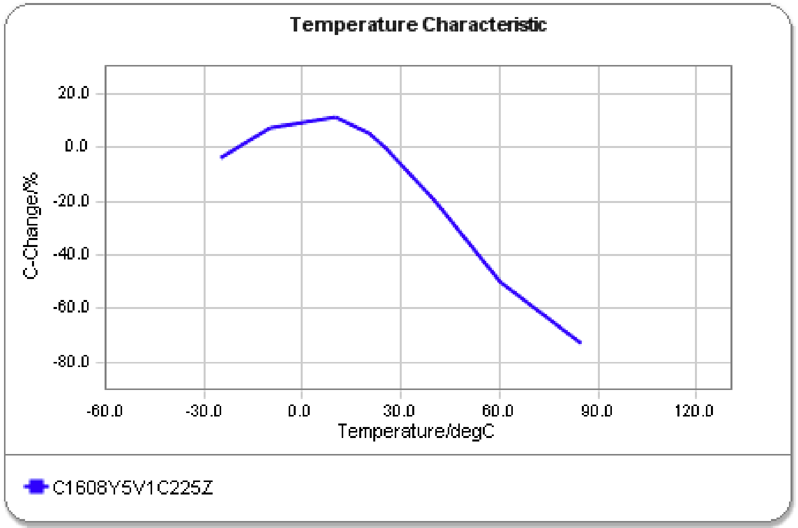




16V Y5V +80% -20%

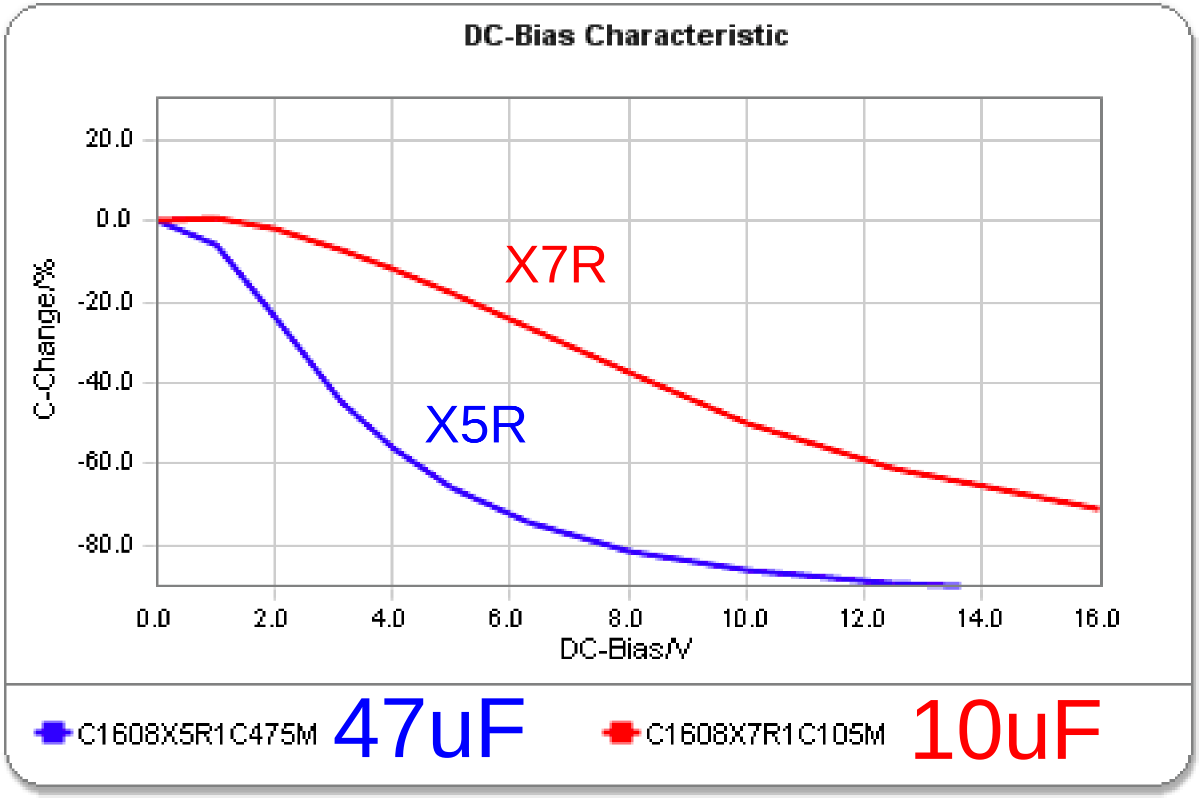


Then add temperature dependency



X7R vs X5R

Same size, 0603

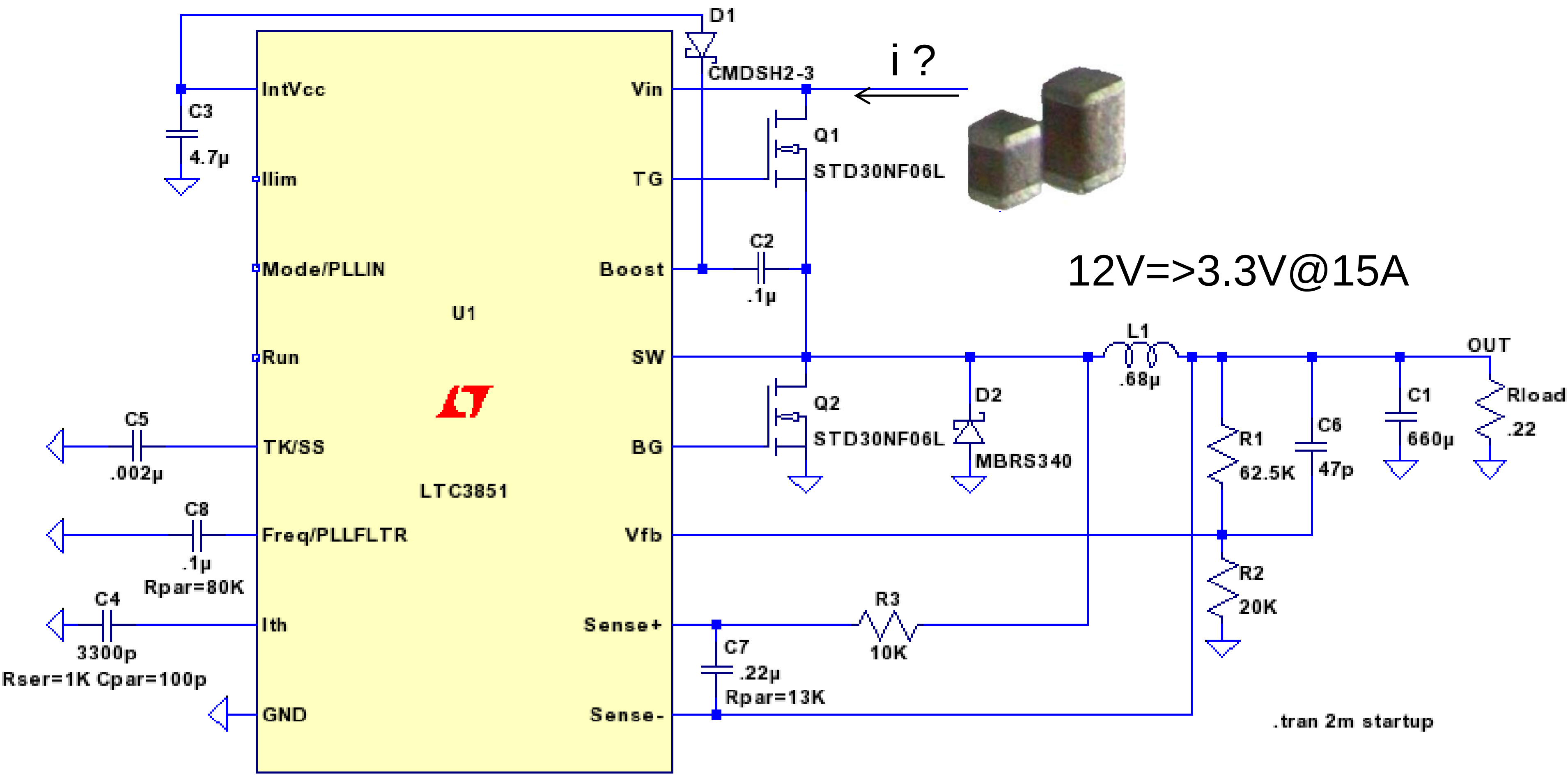


BUT, the X5R cap is almost 5 times larger to start with

X5R cap still almost 2x capacitance at 5V !

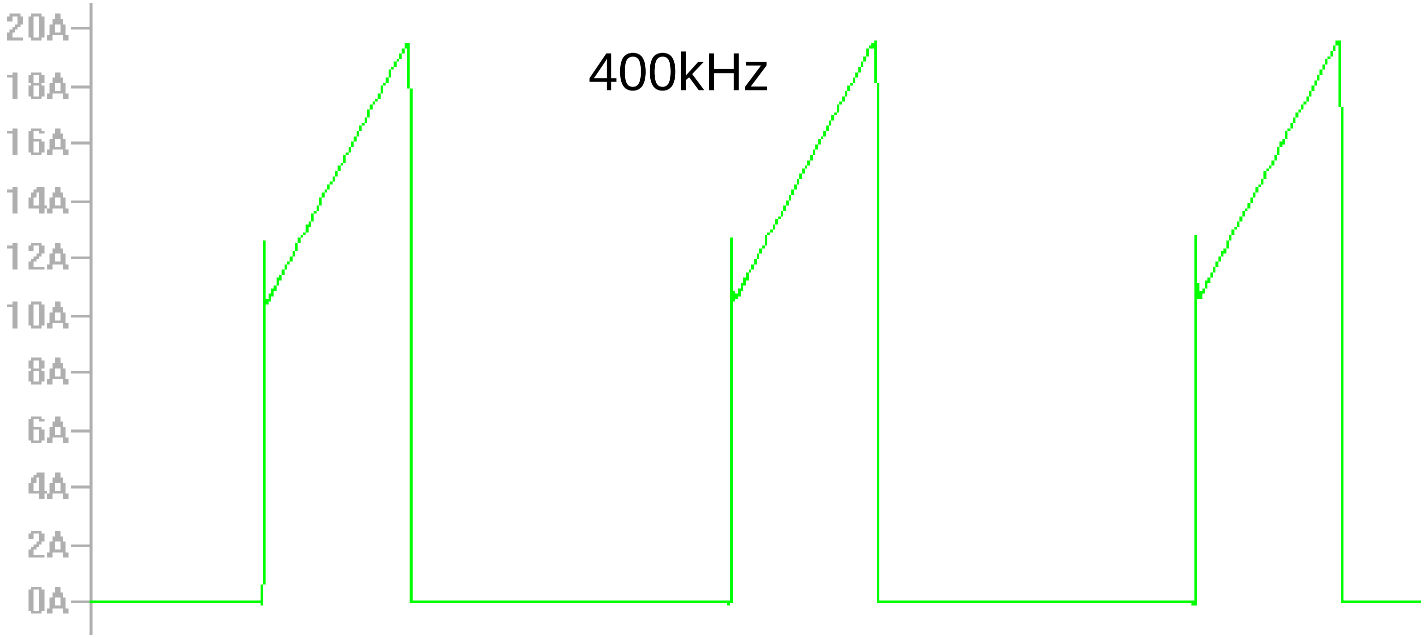
Input ripple

Buck example



Buck input current (from decoupling cap)

12V=>3.3V@15A

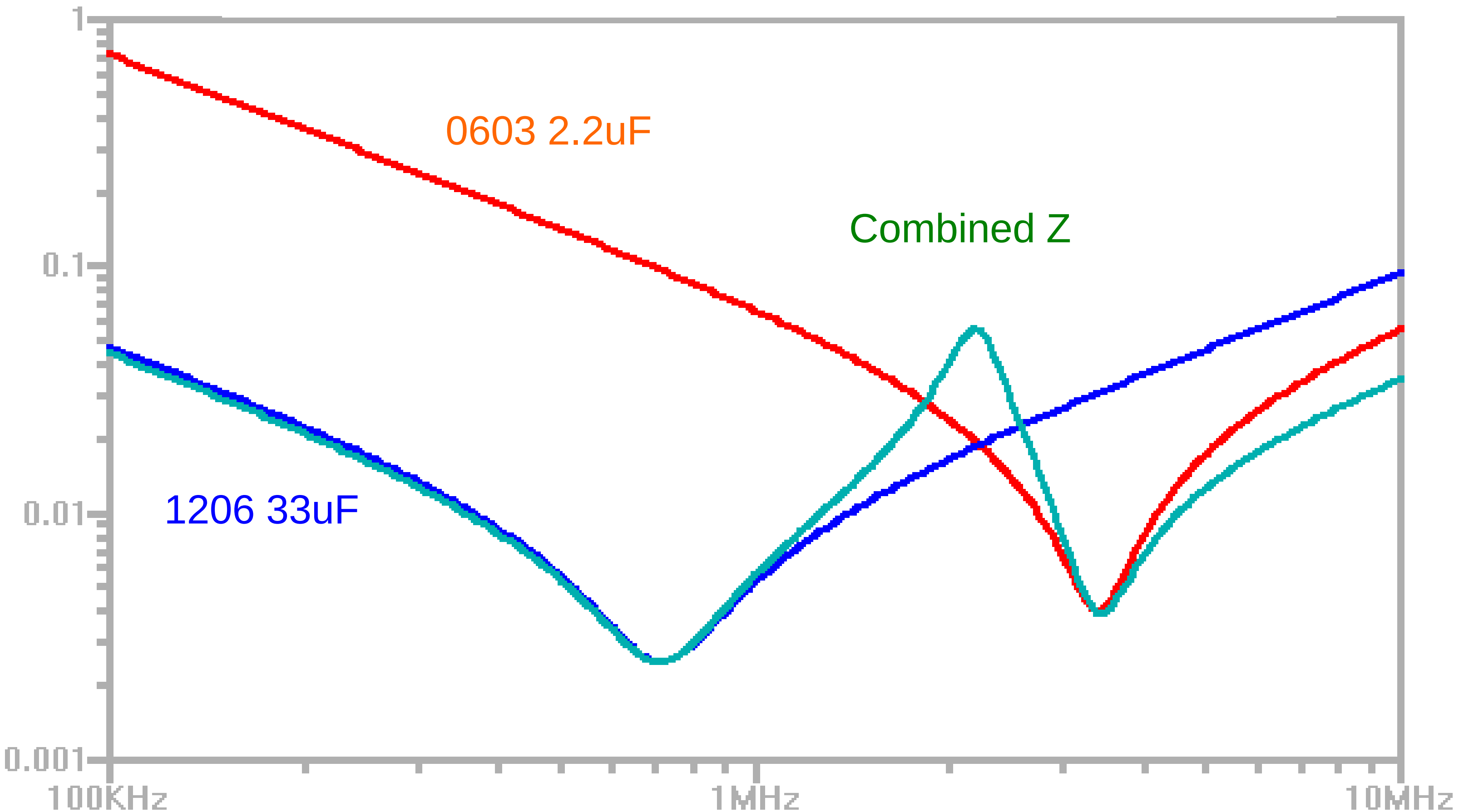


Decoupling

- Small ceramic capacitor:
  - 0603 25V 2.2uF esr 4mΩ L=1nH
- Large ceramic capacitor
  - 1206 25V 33uF esr 2.5mΩ L=1.5nH

LINEAR TECHNOLOGY

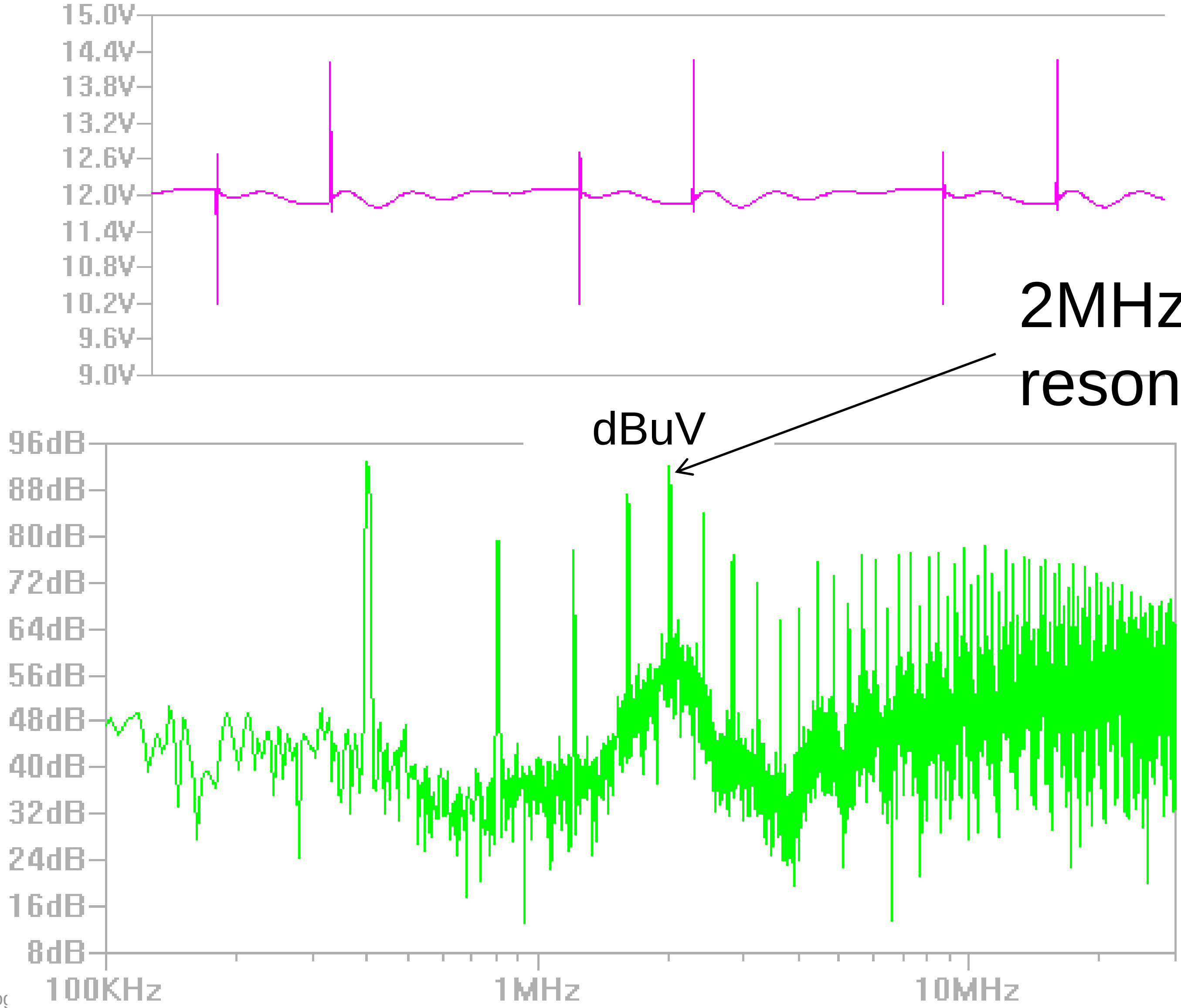
Filter capacitor Z



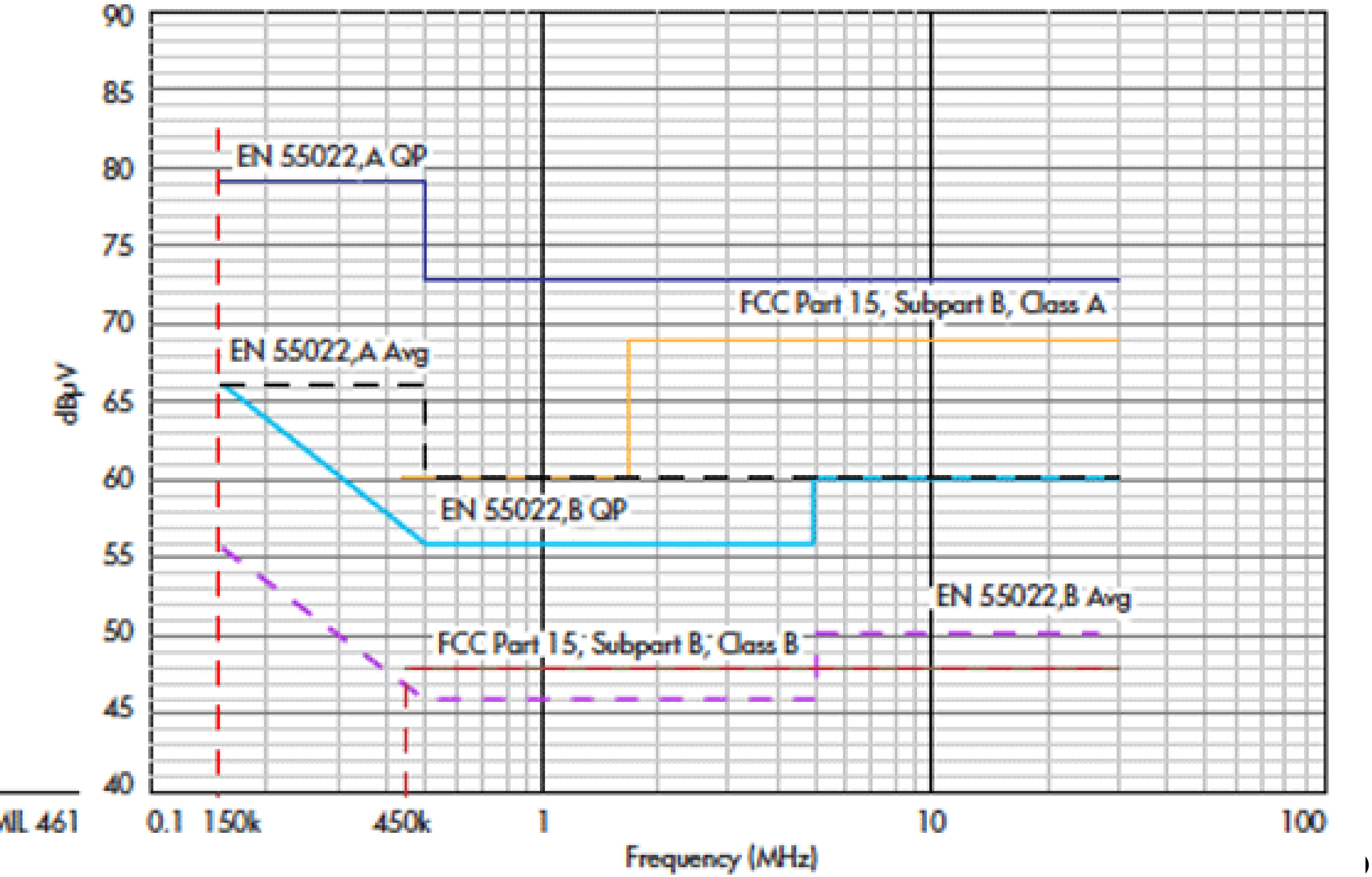
Filter capacitors Z

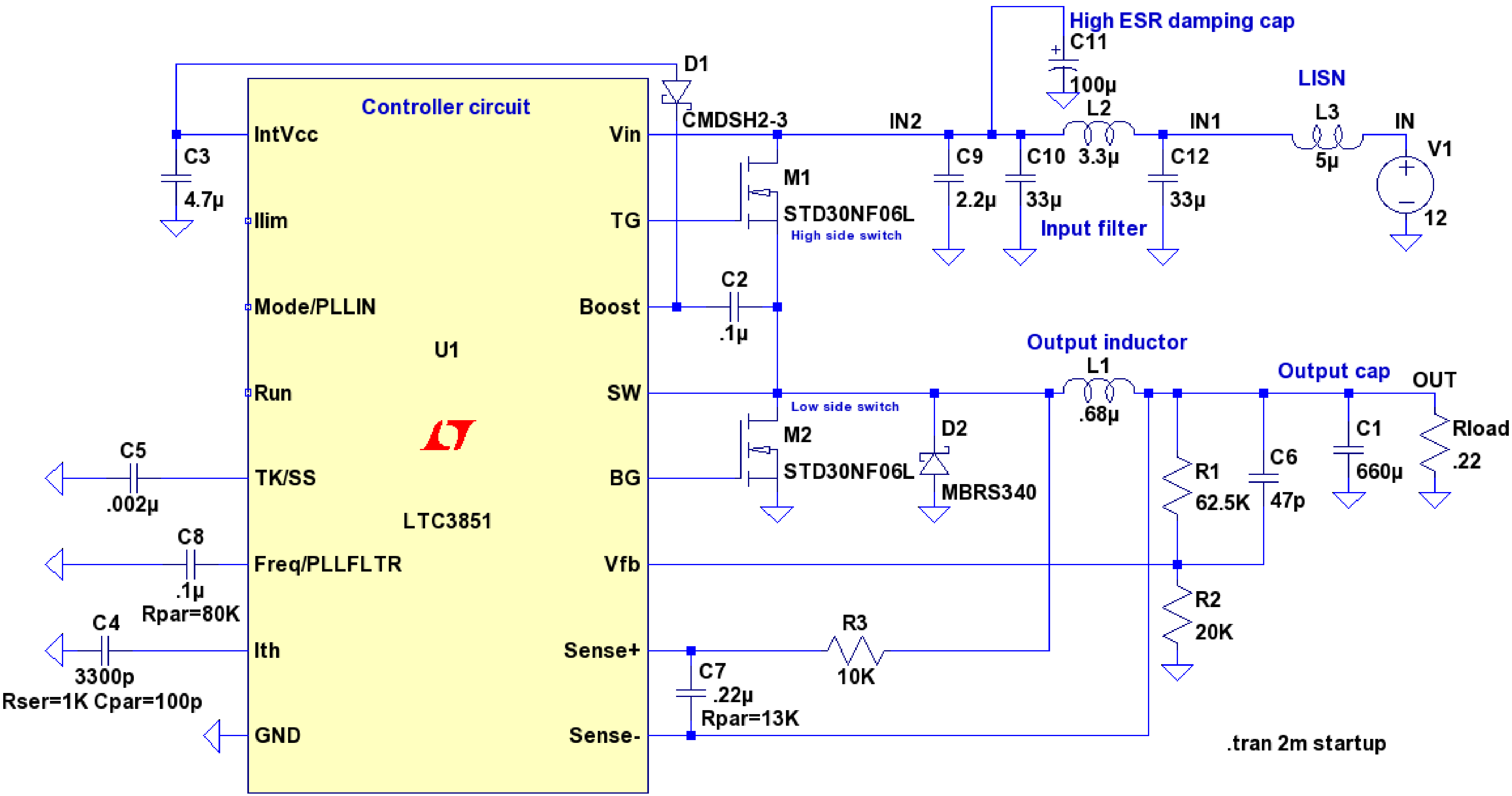
- Use multiple package and capacitor sizes to combine their Z:s
  - Above might not be true, be smart?!?
- Its easy to simulate the low frequency behavior for EMI purposes
  - REALLY !
  - (150kHz-30MHz for EMI, higher for Decoupling)
  - LTspice from Linear Technology
    - Free
    - Easy to use
    - The most used spice simulator in the world
    - Fast, stable, accurate

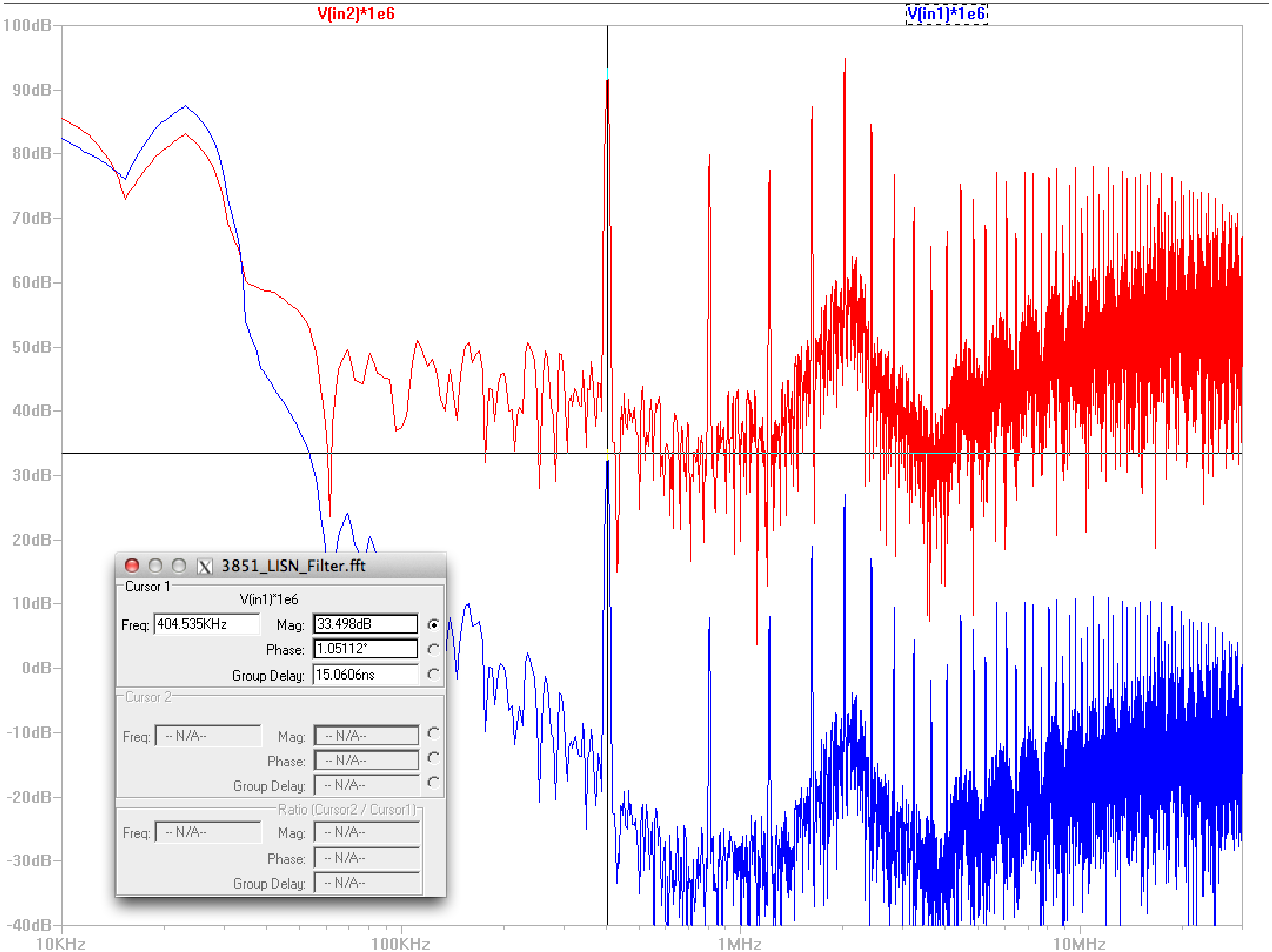
How does the input voltage look on the input cap



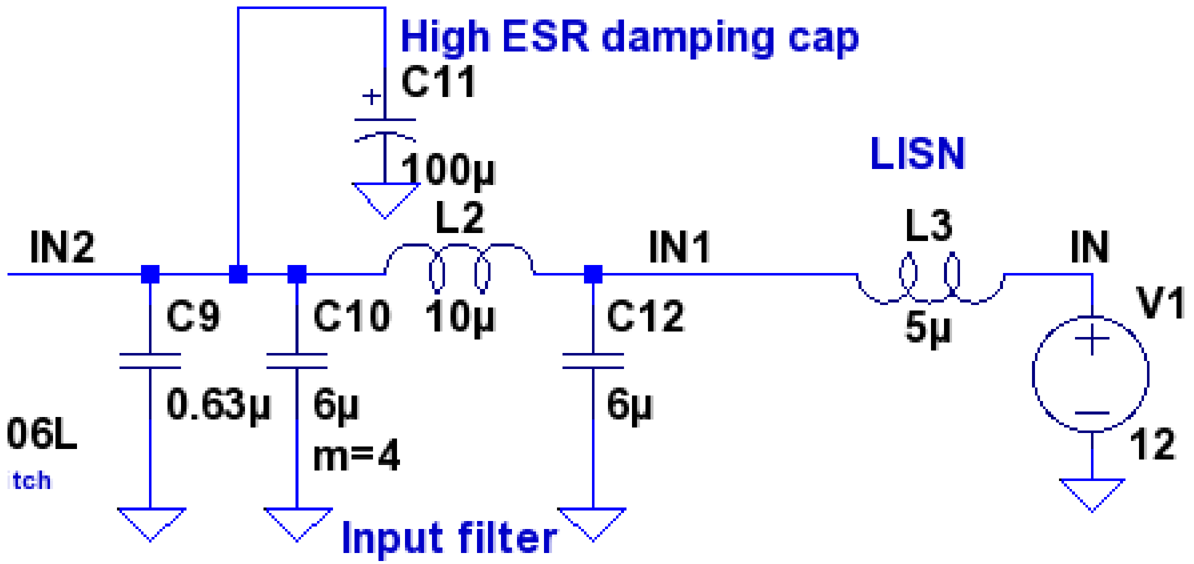
Standard limits



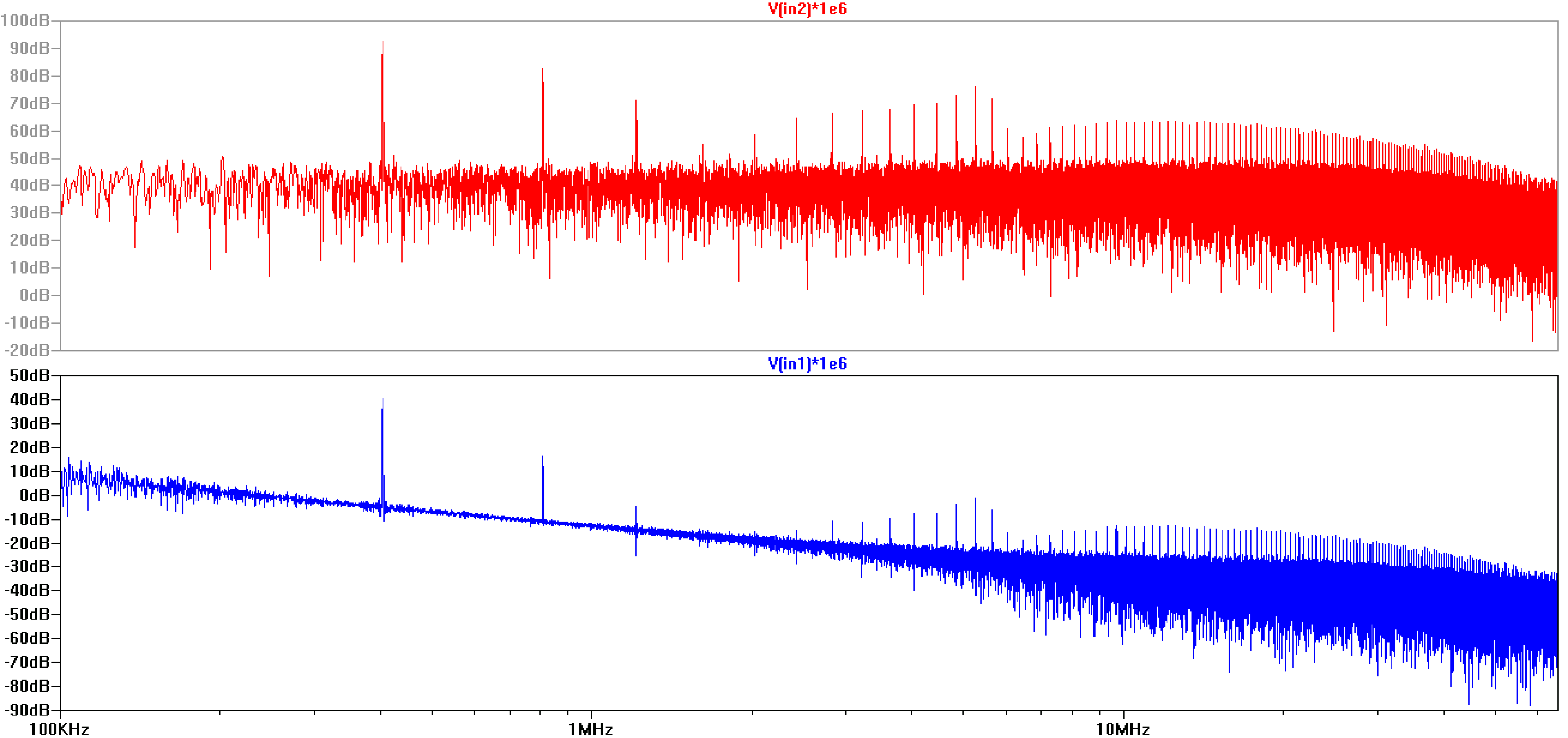

High ESR damping cap
C11
100µ
LISN
D1
CMDSH2-3
IN2
L2
3.3µ
IN1
L3
5µ
IN
V1
12
Controller circuit
IntVcc
Vin
C3
4.7µ
M1
STD30NF06L
High side switch
C9
2.2µ
C10
33µ
C12
33µ
Input filter
Ilim
TG
Mode/PLLIN
Boost
C2
.1µ
U1
Output inductor
L1
.68µ
Output cap
OUT
Run
SW
Low side switch
M2
STD30NF06L
D2
MBRS340
C1
660µ
Rload
.22
R1
62.5K
C6
47p
C5
.002µ
TK/SS
BG
LTC3851
C8
.1µ
Rpar=80K
Freq/PLLFLTR
Vfb
R2
20K
C4
3300p
Rser=1K Cpar=100p
Ith
Sense+
R3
10K
C7
.22µ
Rpar=13K
GND
Sense-
.tran 2m startup


V(in2)*1e6
V(in1)*1e6
100dB
90dB
80dB
70dB
60dB
50dB
40dB
30dB
20dB
10dB
0dB
-10dB
-20dB
-30dB
-40dB
10KHz
100KHz
1MHz
10MHz
3851_LISN_Filter.fft
Cursor 1
V(in1)*1e6
Freq: 404.535KHz
Mag: 33.498dB
Phase: 1.05112°
Group Delay: 15.0606ns
Cursor 2
Freq: -- N/A--
Mag: -- N/A--
Phase: -- N/A--
Group Delay: -- N/A--
Ratio (Cursor2 / Cursor1)
Freq: -- N/A--
Mag: -- N/A--
Phase: -- N/A--
Group Delay: -- N/A--

But you need to use DC bias derating

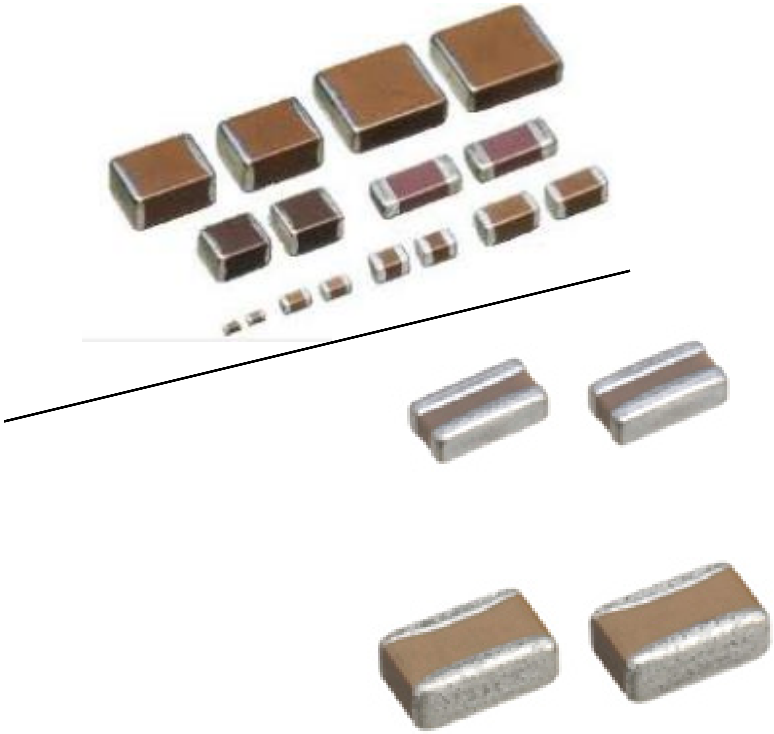


New result


V(in2)*1e6
100dB
90dB
80dB
70dB
60dB
50dB
40dB
30dB
20dB
10dB
0dB
-10dB
-20dB
V(in1)*1e6
50dB
40dB
30dB
20dB
10dB
0dB
-10dB
-20dB
-30dB
-40dB
-50dB
-60dB
-70dB
-80dB
-90dB
100KHz
1MHz
10MHz

Decoupling strategy

- Keep impedance low over frequency
  - Beware of parallel resonance !
- Some capacitor package parasitic inductances
  - 1210 0.80nH
  - 0806 0.70nH
  - 0603 0.60nH
  - 0402 0.42nH
  - 0612 0.20nH
  - 0306 0.10nH
  - 0204 0.07nH
  - 3025 1.30nH



Layout in Deep

Switching Power Supply PCB Layout

An In Deep Look

Edited and Presented by Thomas Ginell
FAE Scandinavia

Relevant Physical Effects in Switchmode PSU

1. Skin effect
2. Proximity effect
3. Magnetic dipol antennas
4. Near field and far field effects
5. Shielding with planes, Vias
6. Energy distribution over frequency of the different loops in a switch mode PSU
7. Current flow in typical buck and boost
8. Placement and routing strategies
9. Magnetic properties of components

Inductance

Most problems on PSU layouts relate to inductance on places where you do not want it. There are only a very few places where inductance in needed.

This presentation centers how we can support the nature in its inductance avoidance strategies.

Skin effect

As lower resistance material is used as thinner the skin depth gets.

$$\delta = \sqrt{\frac{\rho}{\pi f \mu_r \mu_0}}$$

	Resistivity (Ohm * m)	1Mhz (um)	100Mhz (um)
Copper	1,68e-8	66	6,6
Tin	1,09e-7	166	16,6
10e20 doped silicon	1e-5	1600	160
uMetal	1e-7	<1	<0,1

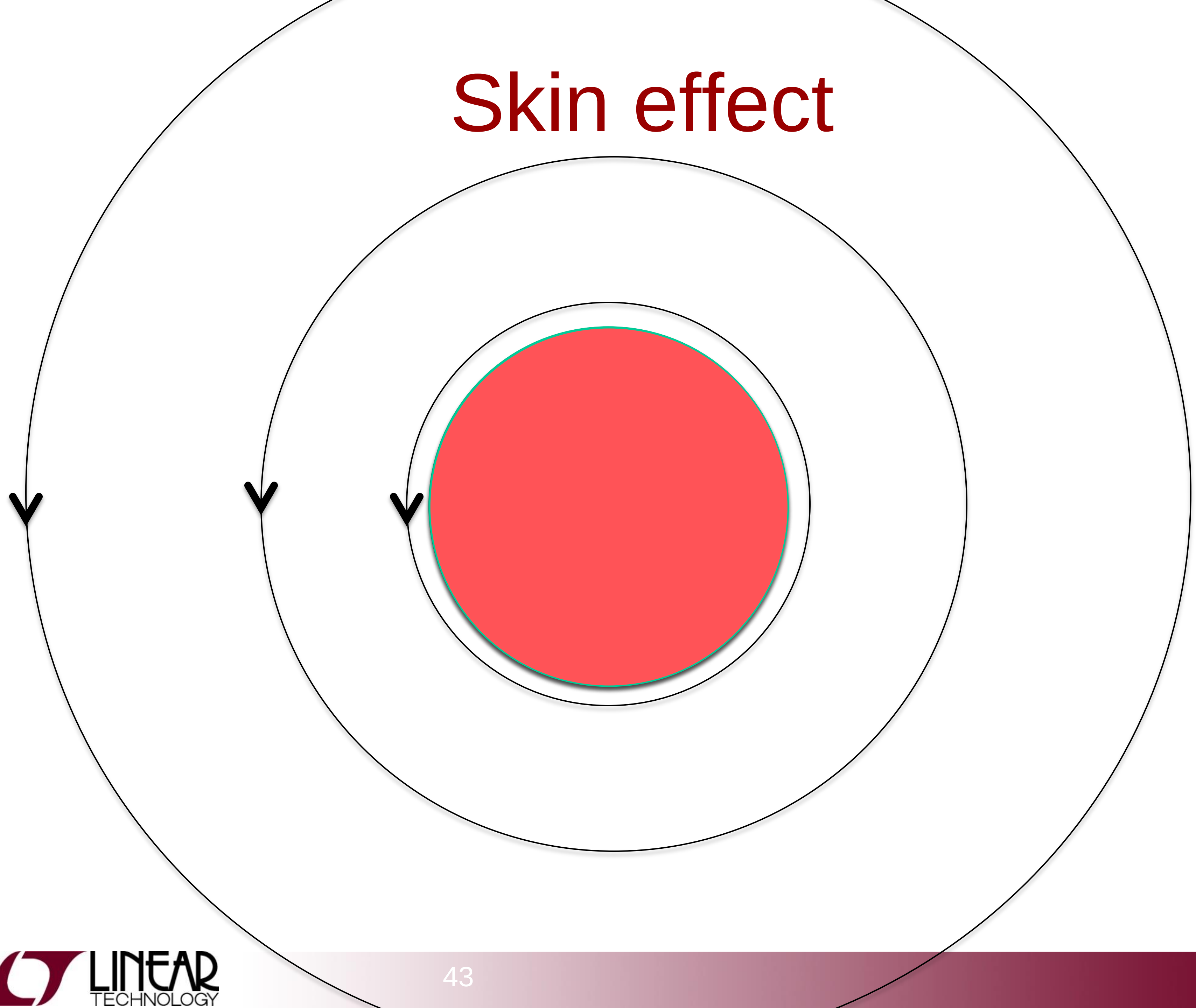
Rule 1.1

AC current will only flow at the outside of the conductor

Rule 1.4

On 35um (1oz) copper the
skin effect kicks in at about 3,5 Mhz

Skin effect

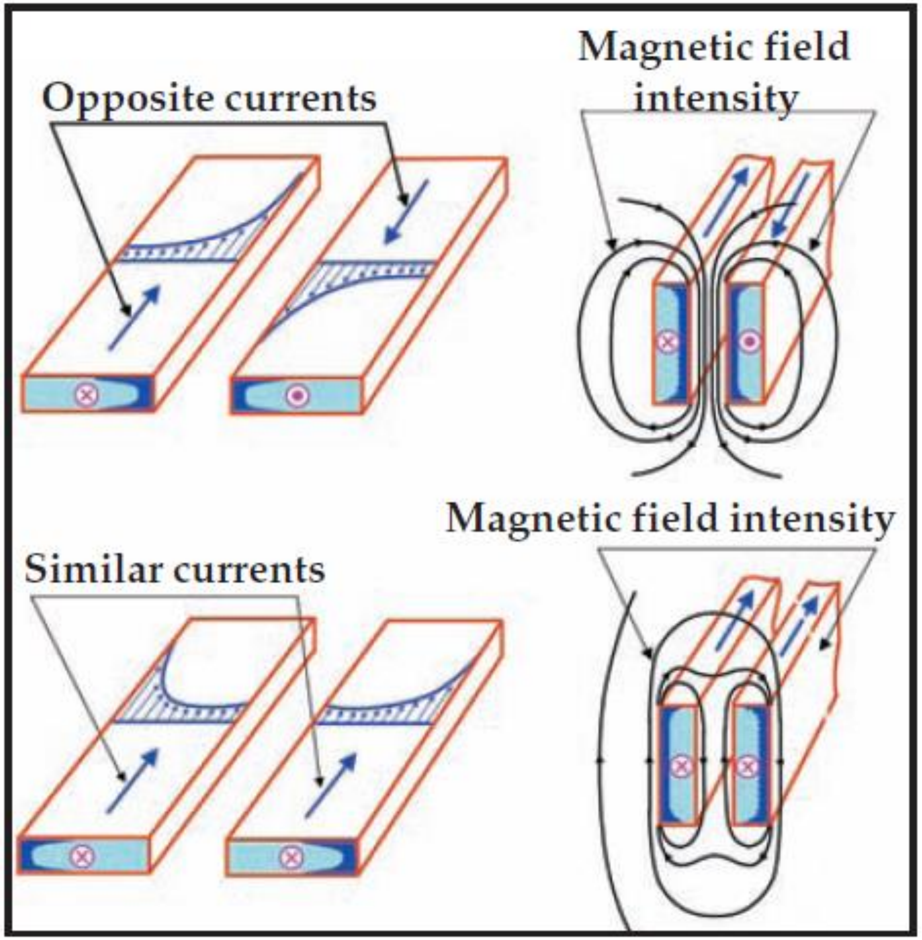


Proximity effect

Currents in the opposite direction attract each other. The same induction forces responsible for the skin effect work here in the opposite way, since the current has opposite direction.

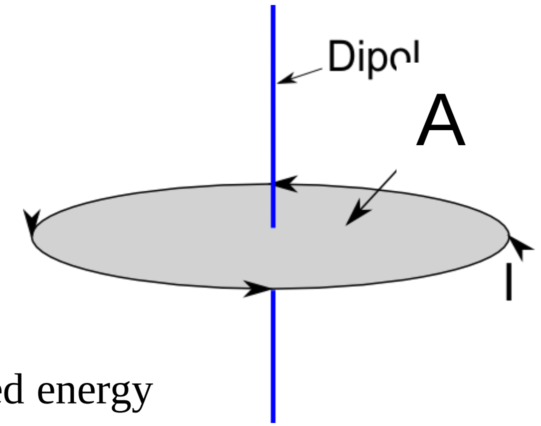
This is the typical case for currents in switchmode PSU layouts.

Currents in the same direction force themself appart as they do inside the same conductor by the skin effect.



[1]

Magnetic dipol antennas



$$R_r = \frac{320\pi^4 f^4 A^2}{c^4}$$

Since R_r is low against 377 Ohm beacuse loop pattern sizes are low against wavelengt in practical switchmode PSUs, the radiated energy will rise proportional with R_r

In Any loop your AC current will circle around, the radiated energy will increase proportional to:

f^4 and A^2

On the frequency f you can not do very much about since any filtering will reduce efficiency.

But on the loop opening F, usually isolated area on your PC Board, you can keep it as small as possible.

Rule 3.1

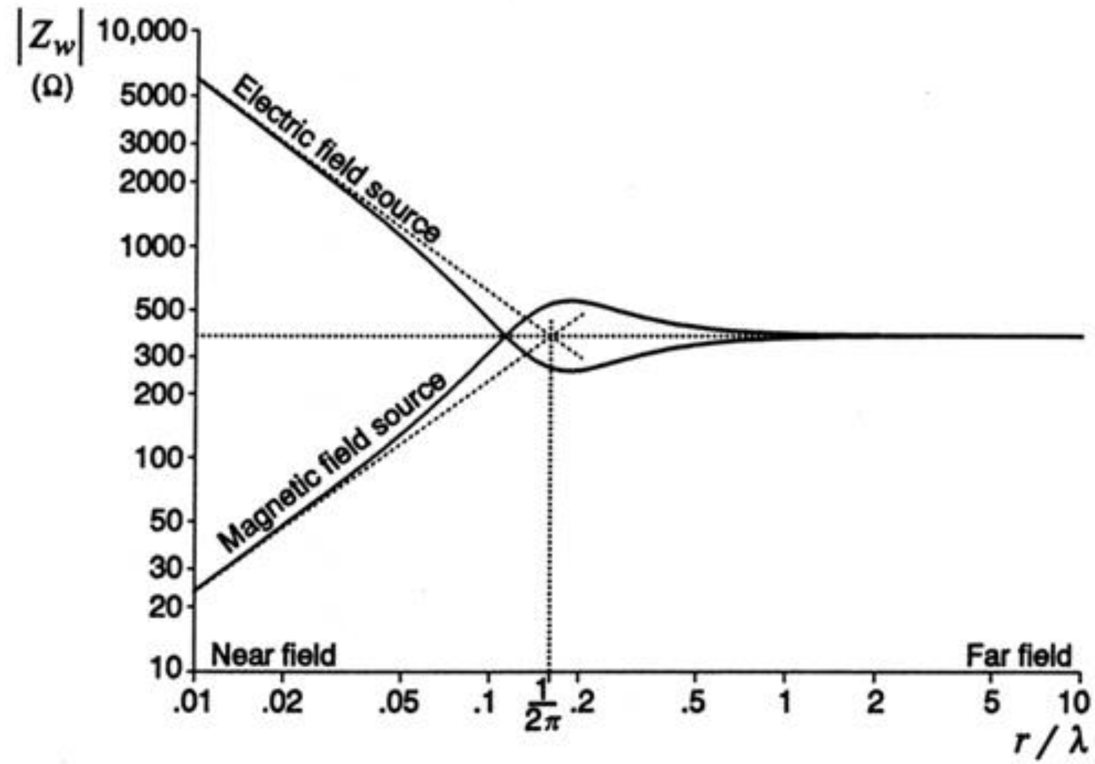
Emitted radio energy increases with the square of the loop area you create

Rule 3.2

Passive antennas have the same characteristic receiving and transmitting.

Near field versus far field

Any near field transforms itself to a far field pattern at the distance of about $\frac{\lambda}{2\pi}$ and adapts the 377 Ohm far field impedance of our Universe.

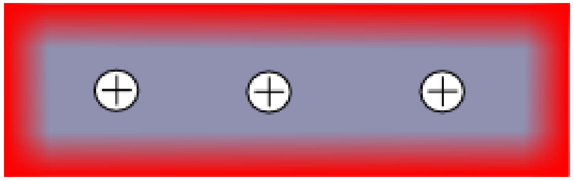


[5]

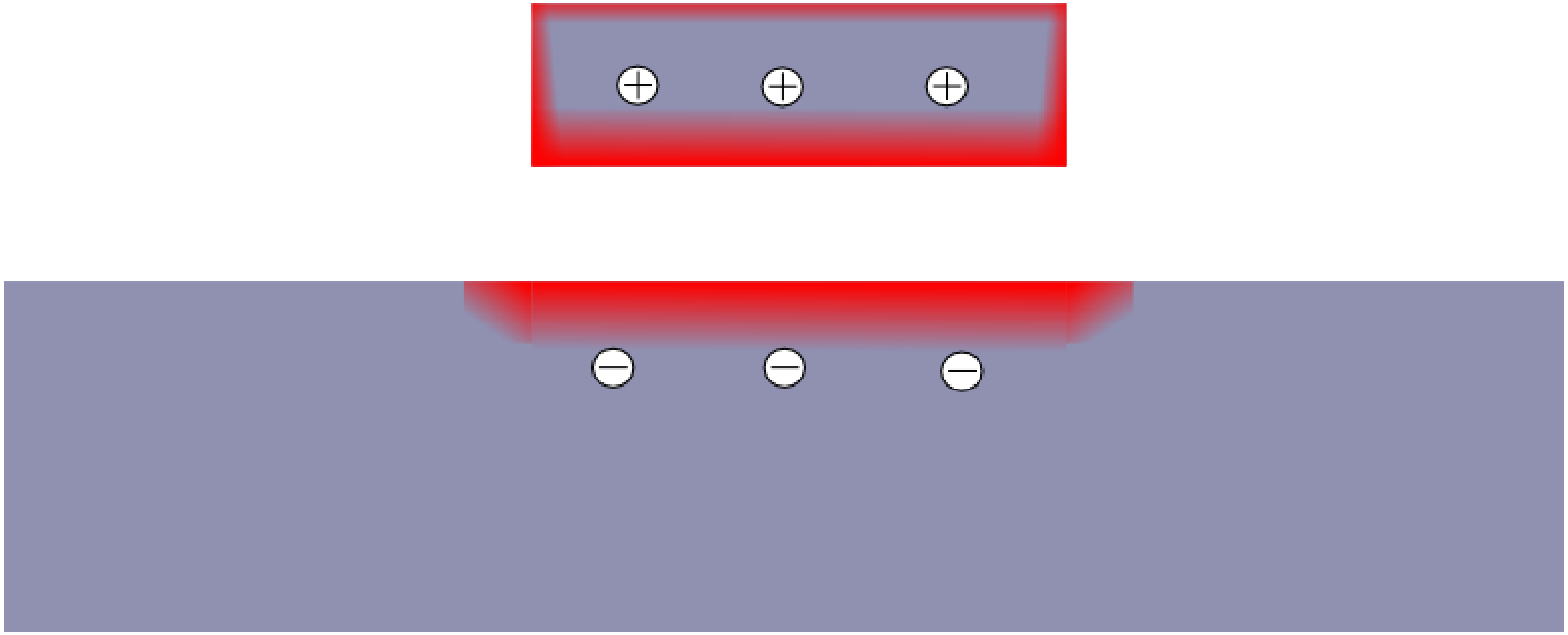
Rule 4.1

Magnetic AC fields will always find a way to turn into radio waves out of your box. So keep them as small as possible

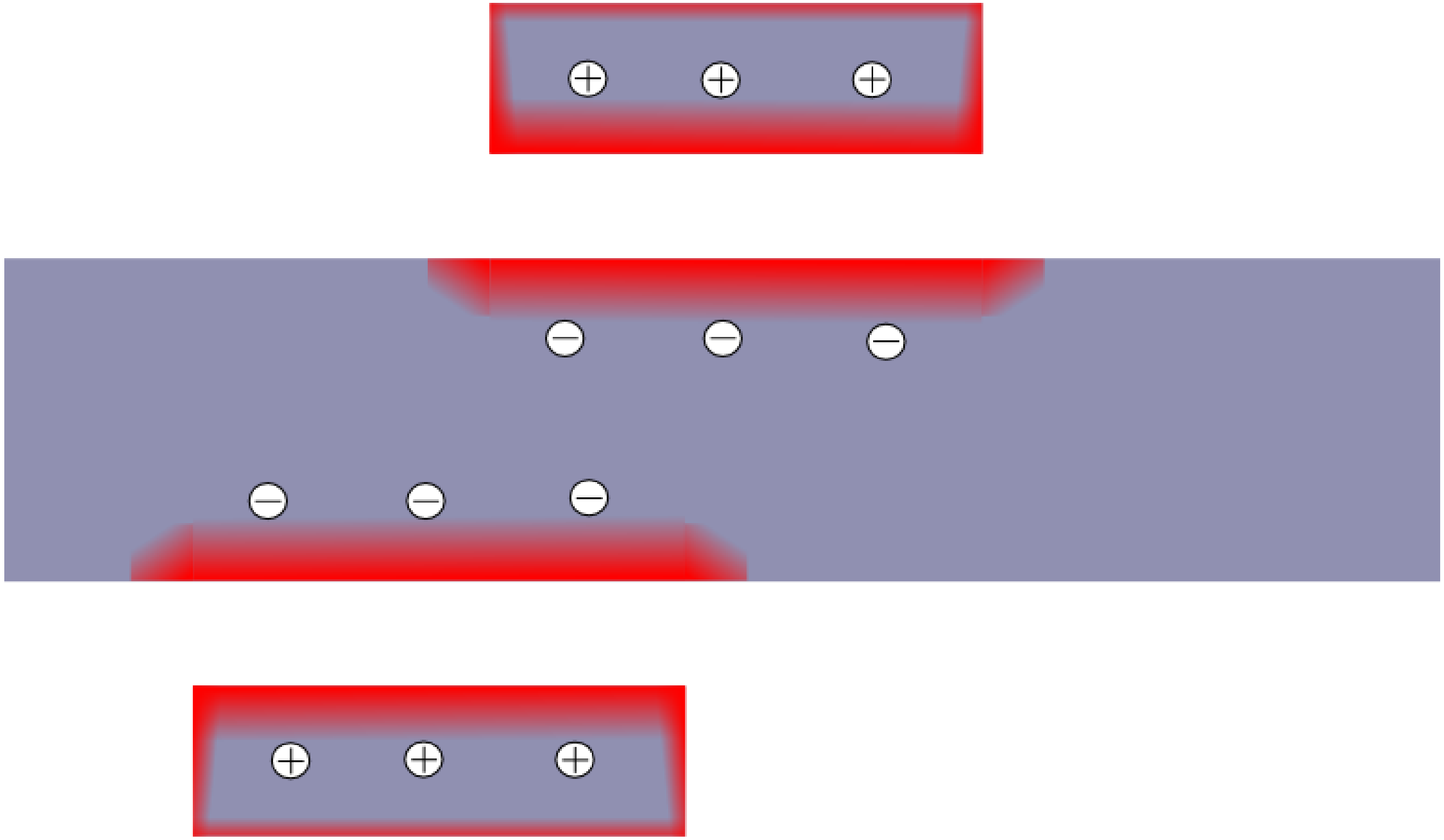
Rectangular conductor alone



Return current in plane



Return current

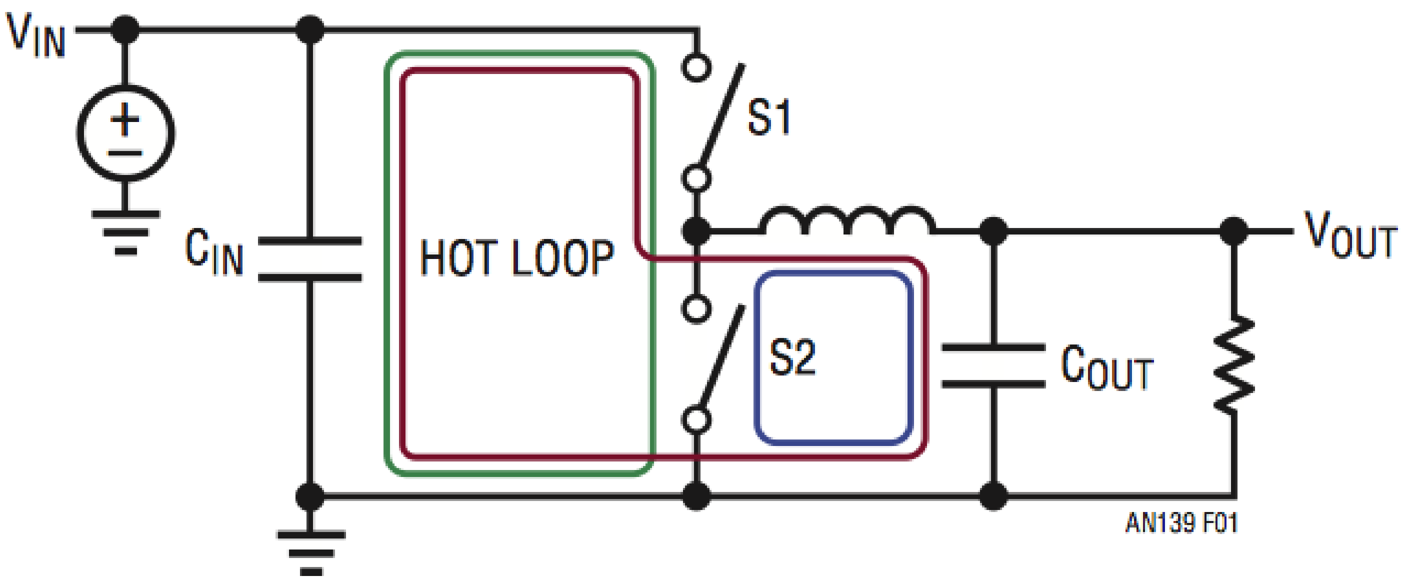


Identifying the buck hot loop

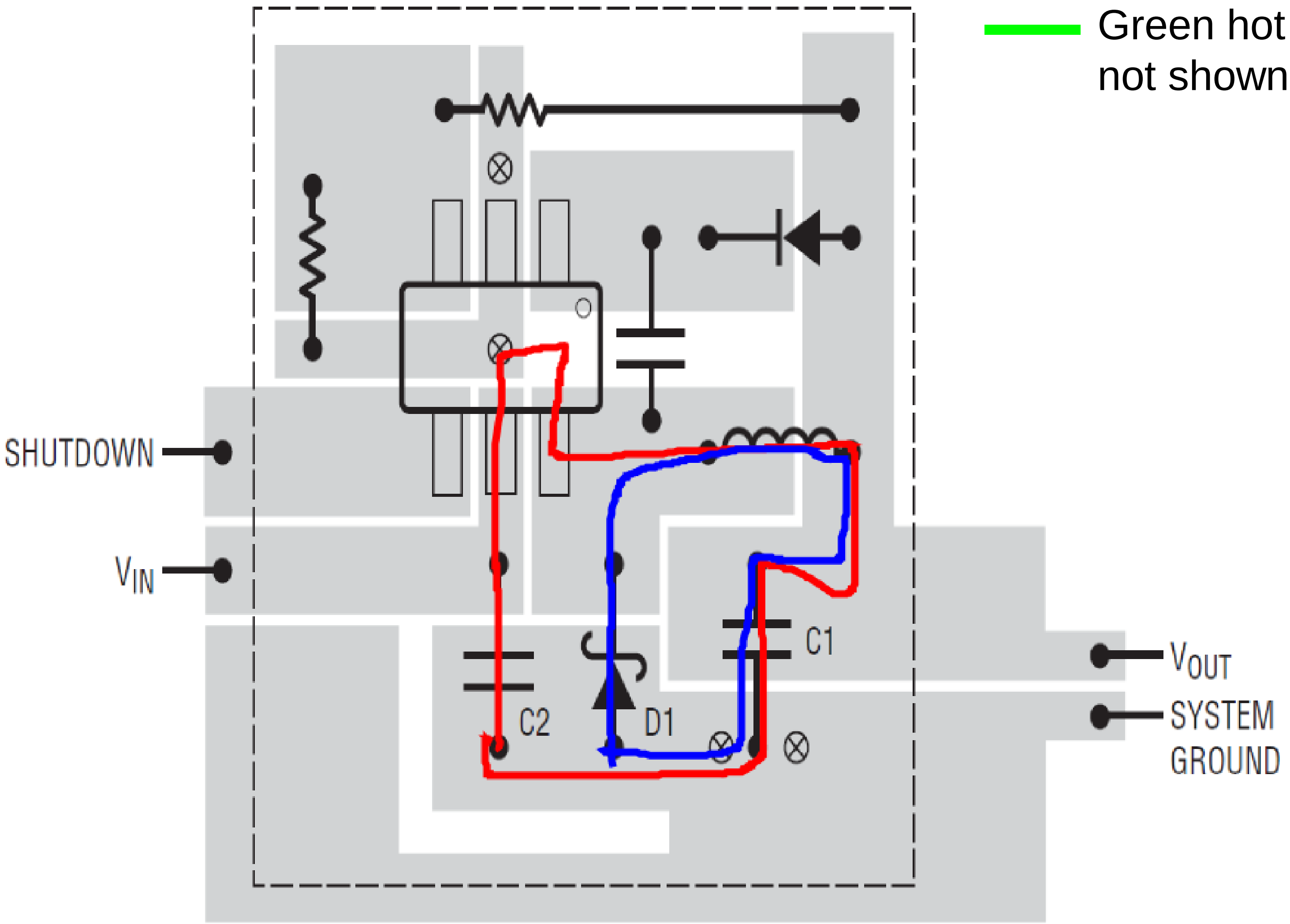
switch on

switch off

Hot loop area = area switch on - area switch off

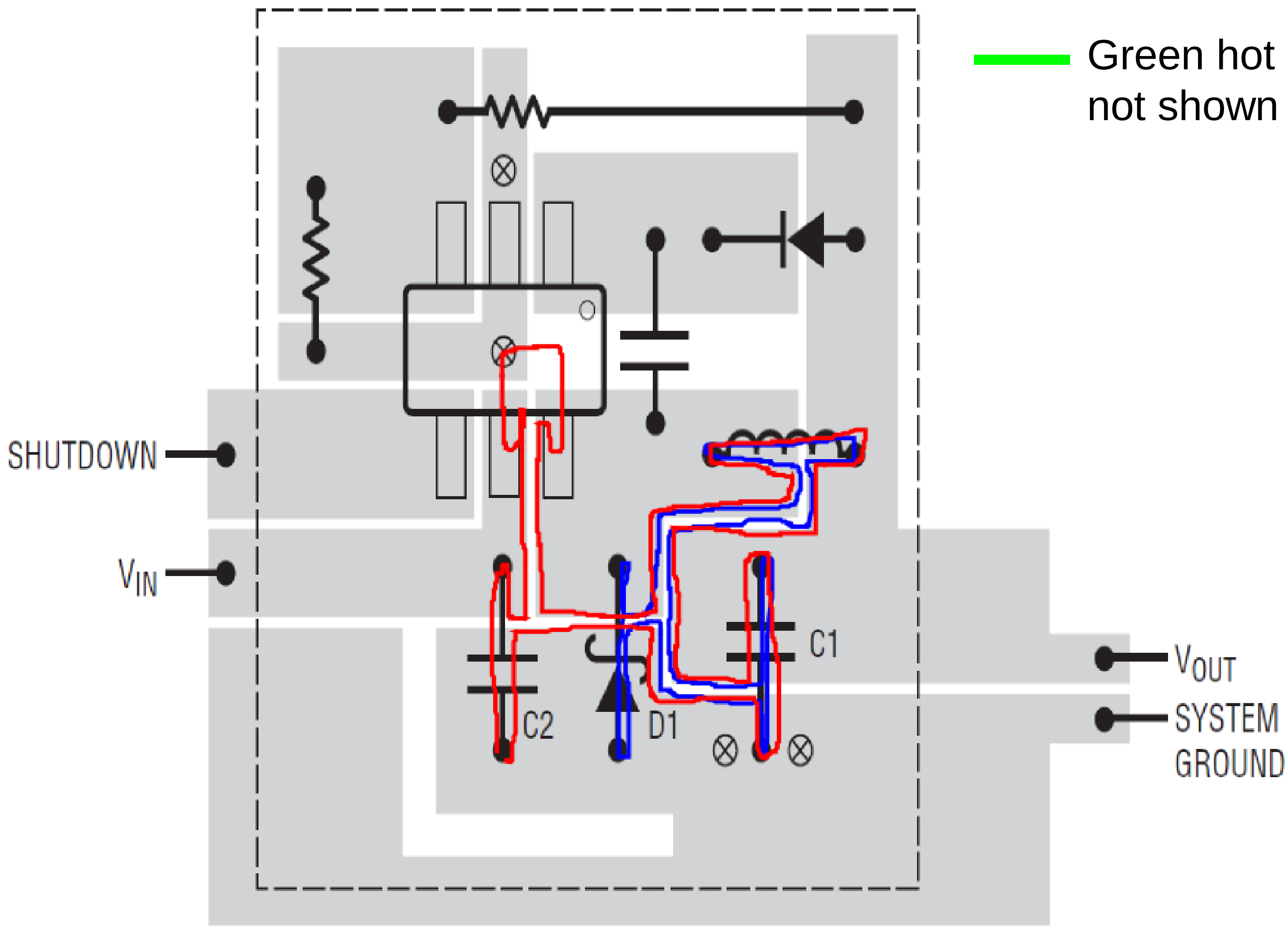


Buck hot loop <skin frequency



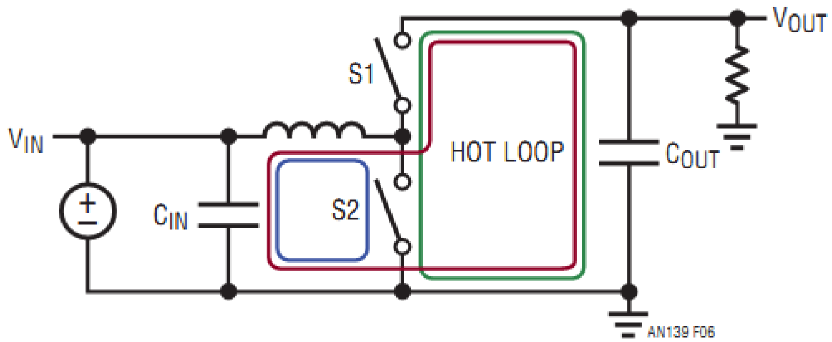
Green hot loop not shown for clarity

Hot loop >skin frequency



Green hot loop not shown for clarity

Hot loop examples



Boost

Figure 6

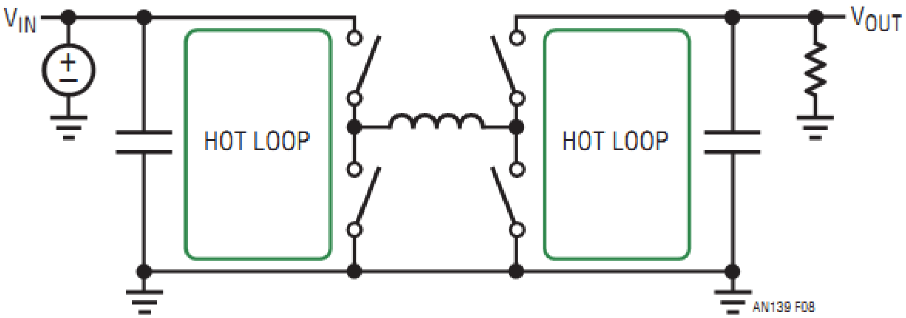


Figure 8. 4-Switch Buck-Boost

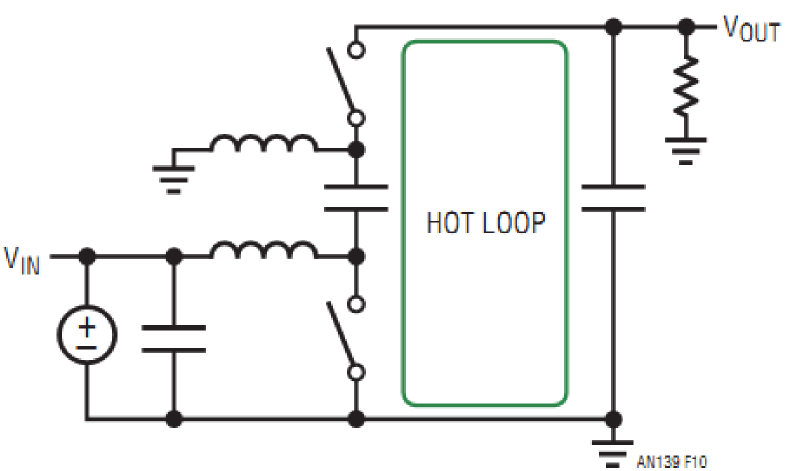


Figure 10. SEPIC

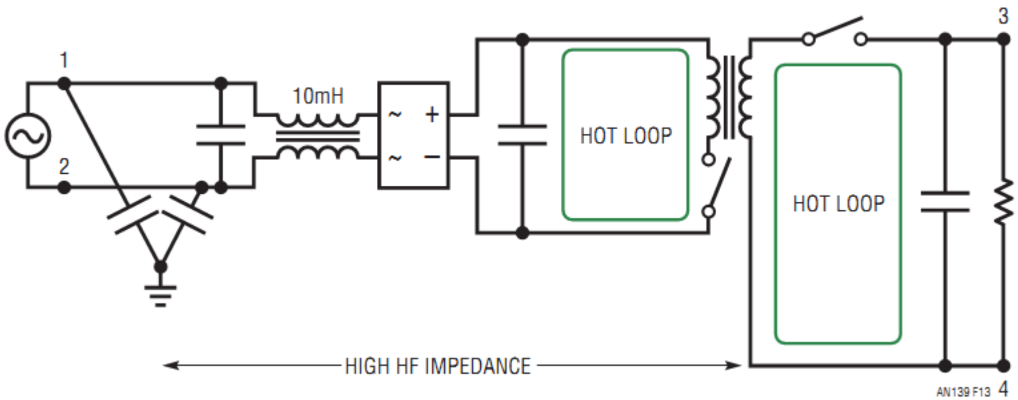


Figure 13. Isolated Offline Flyback

Other EMI sources

- Internal Vcc decoupling
  - Main switch driver
- External Switch Driver Signals

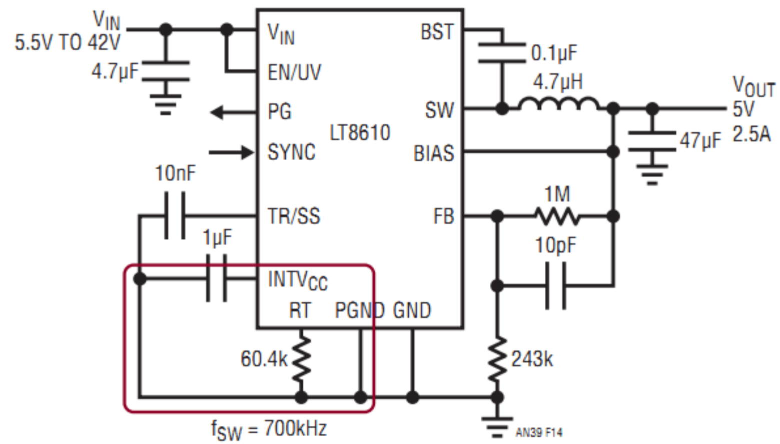


Figure 14

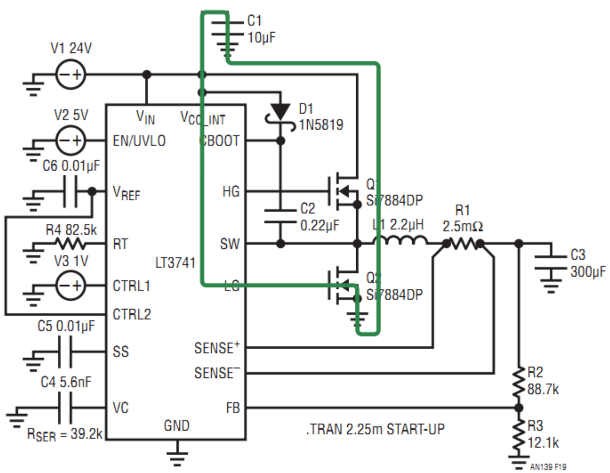


Figure 19

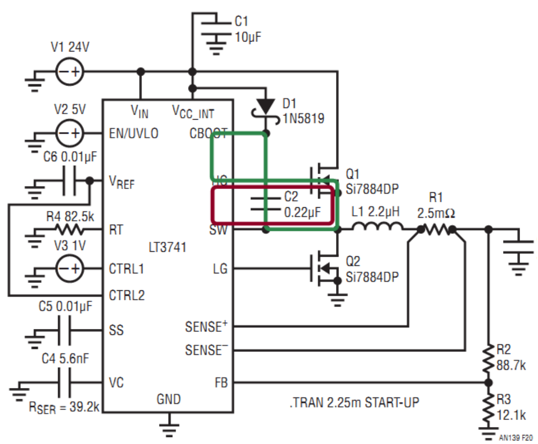


Figure 20

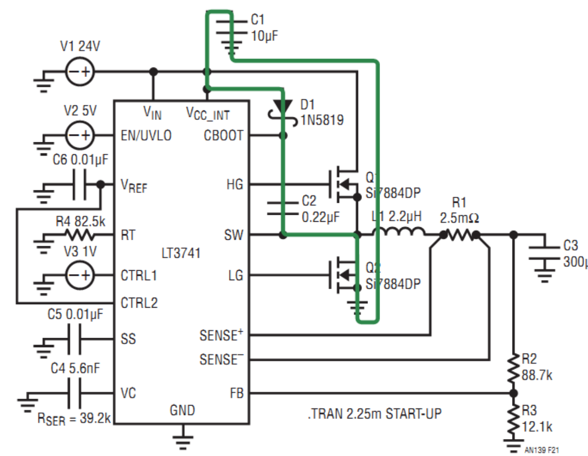
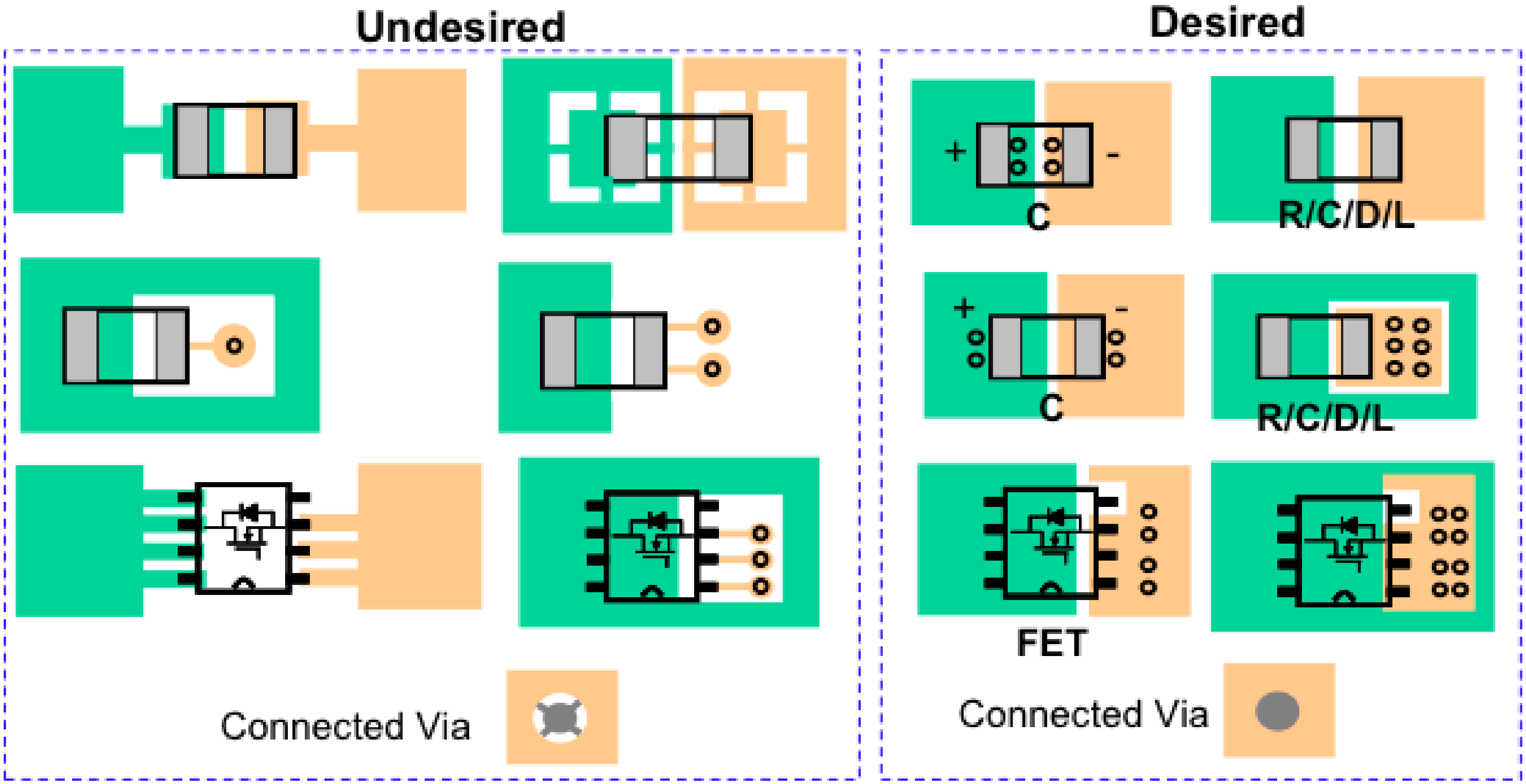
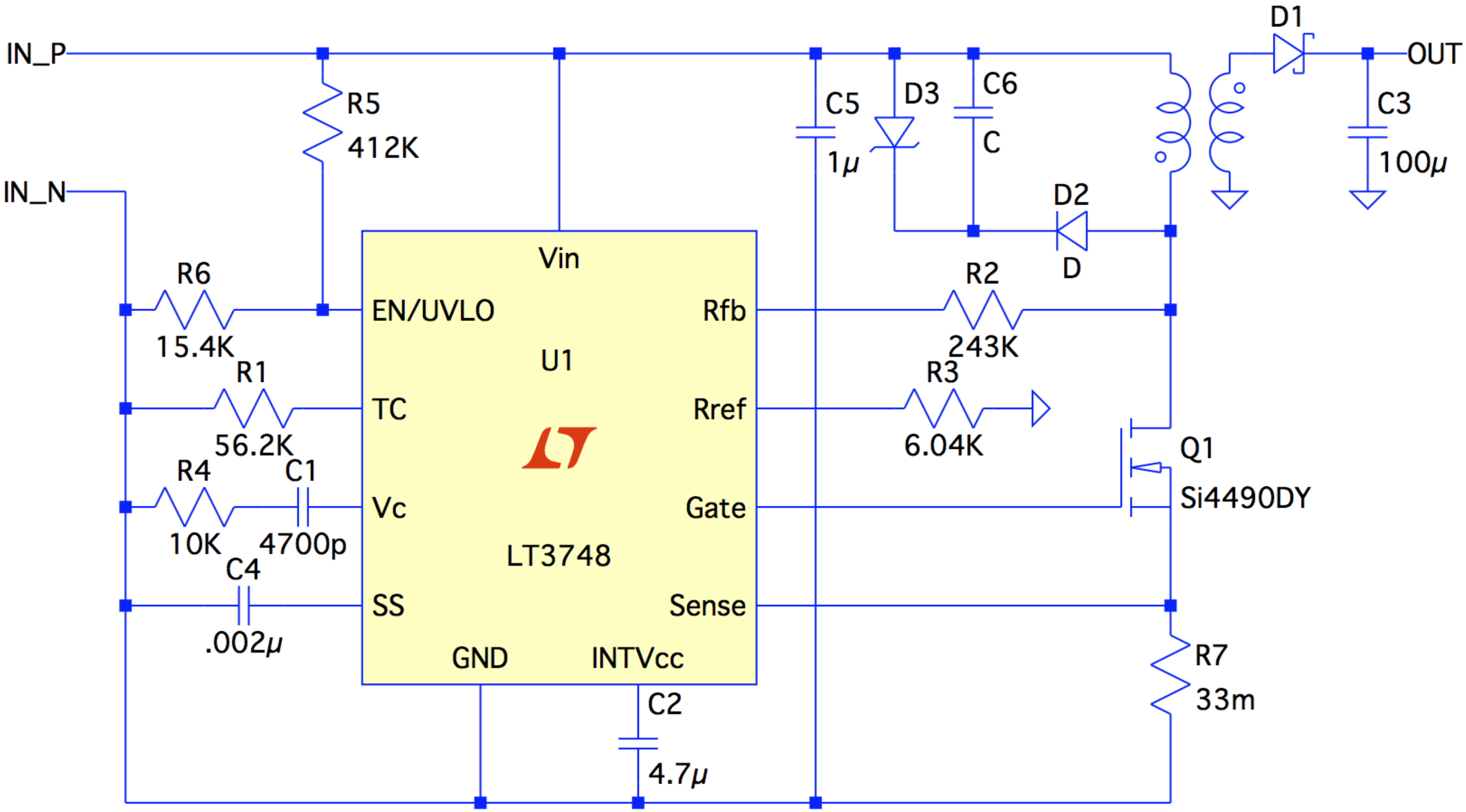


Figure 21

Power component footprints

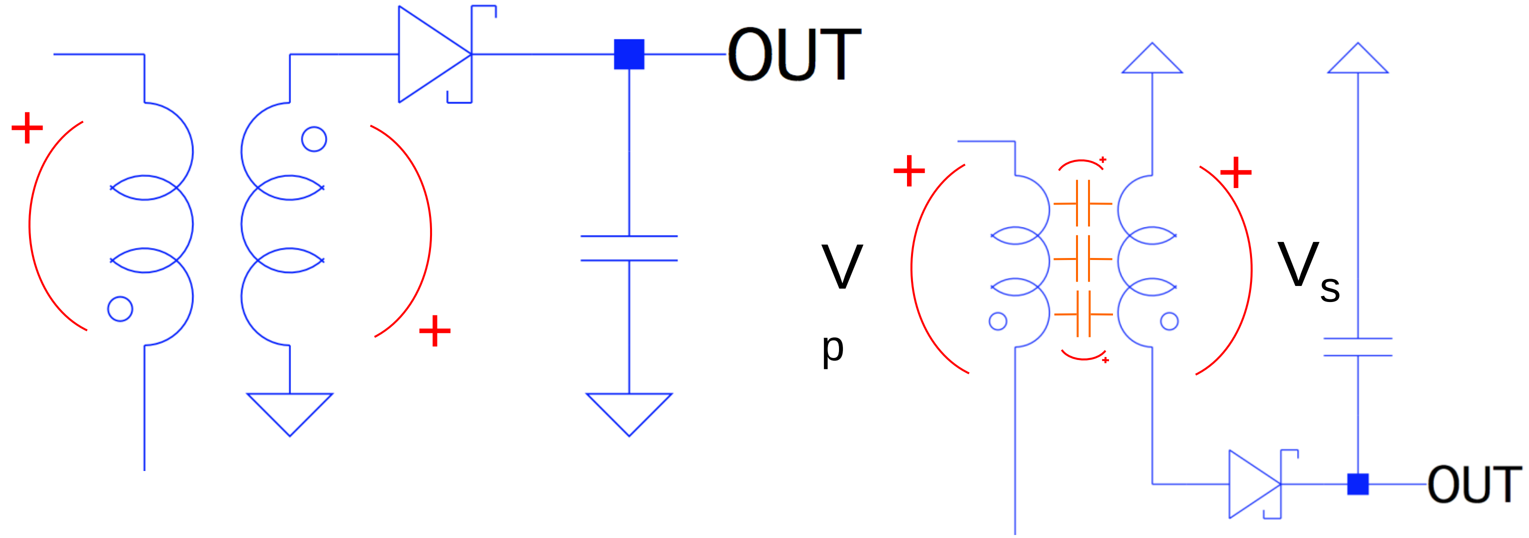


Isolated converter



LINEAR TECHNOLOGY

Transformer common mode EMI

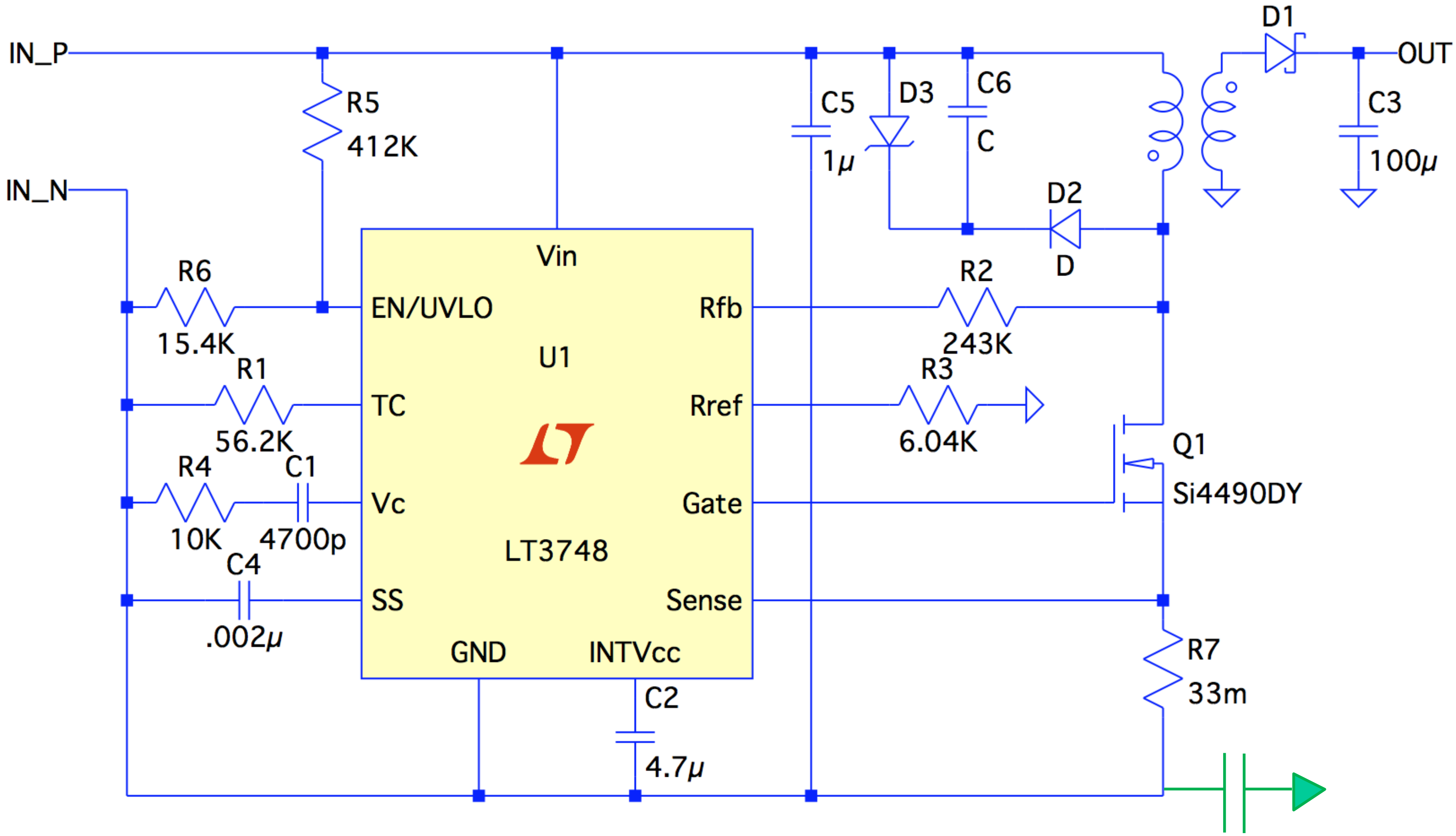


If transformer ratio is 1:1
Then Vp=Vs
If Vp changes, Vs changes with the same voltage, Voltage between any primary to secondary winding will be constant

BUT

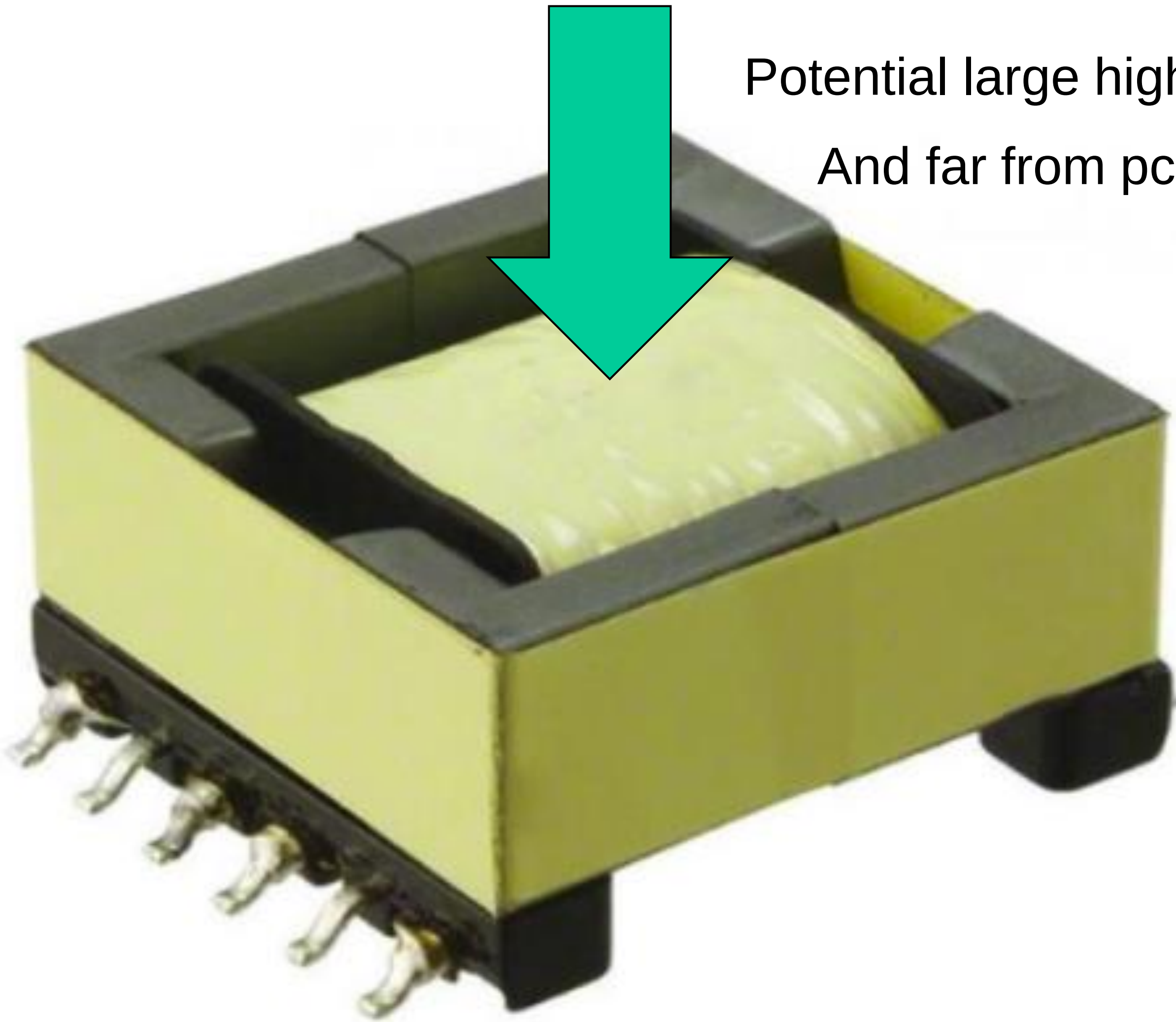
If transformer ratio is not 1:1
Voltage between primary to secondary windings will vary when total winding voltage changes.

THE MAGIC CAPACITOR



LINEAR TECHNOLOGY

Another isolated converter issue

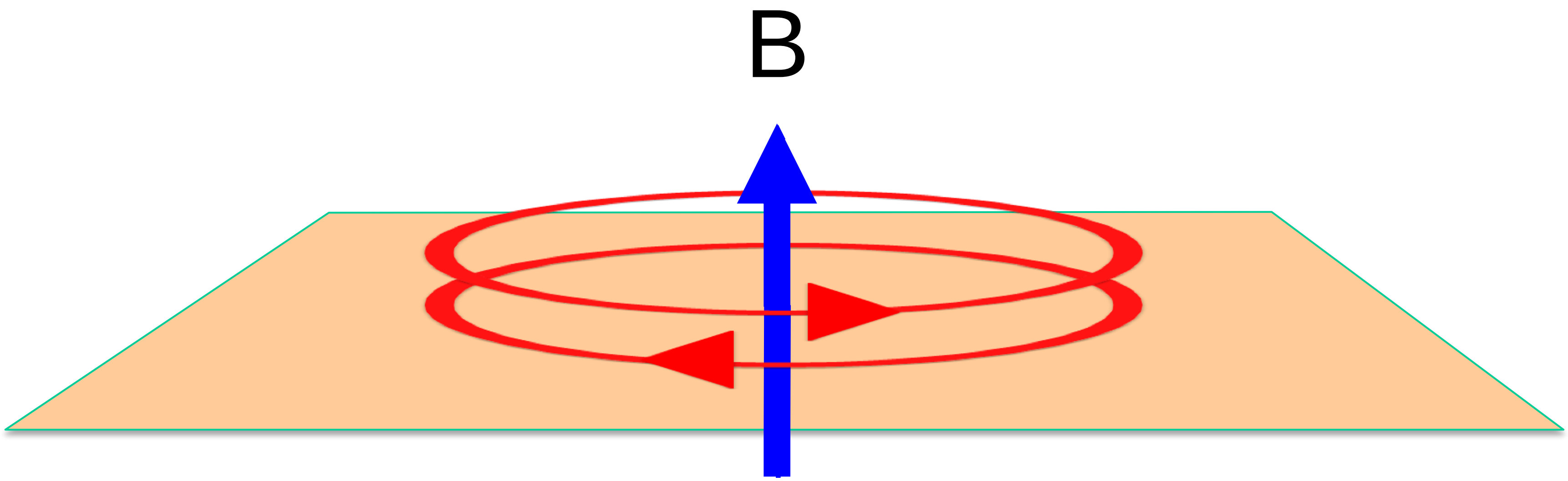


Potential large high dV/dt area

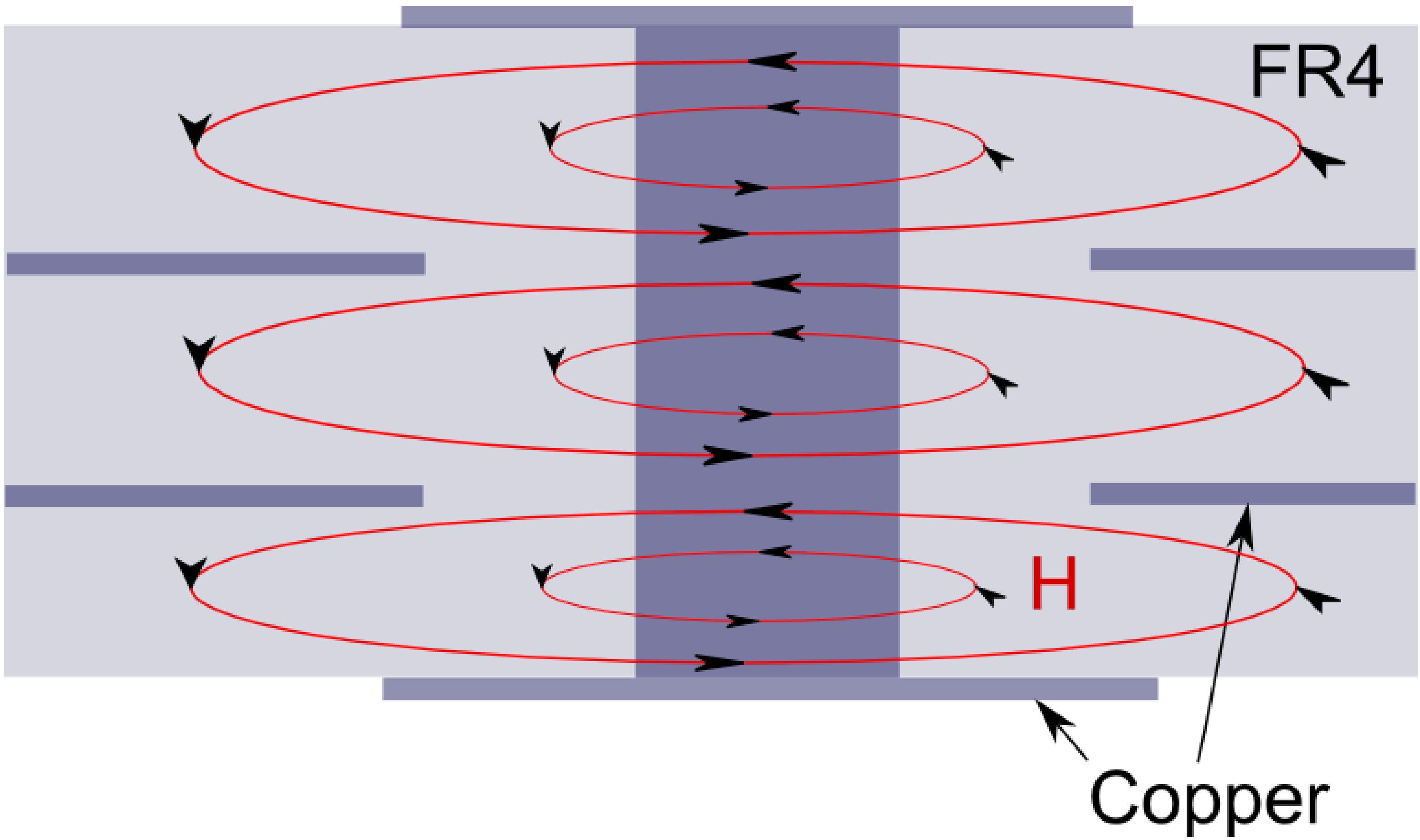
And far from pcb planes

It is an antenna rising above the pcb

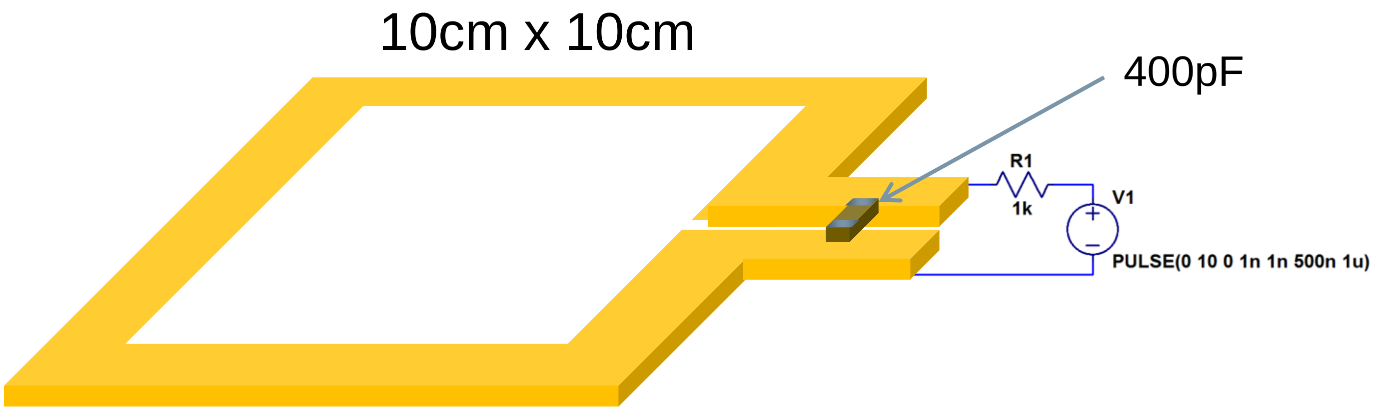
Hotloop on plane



Vias

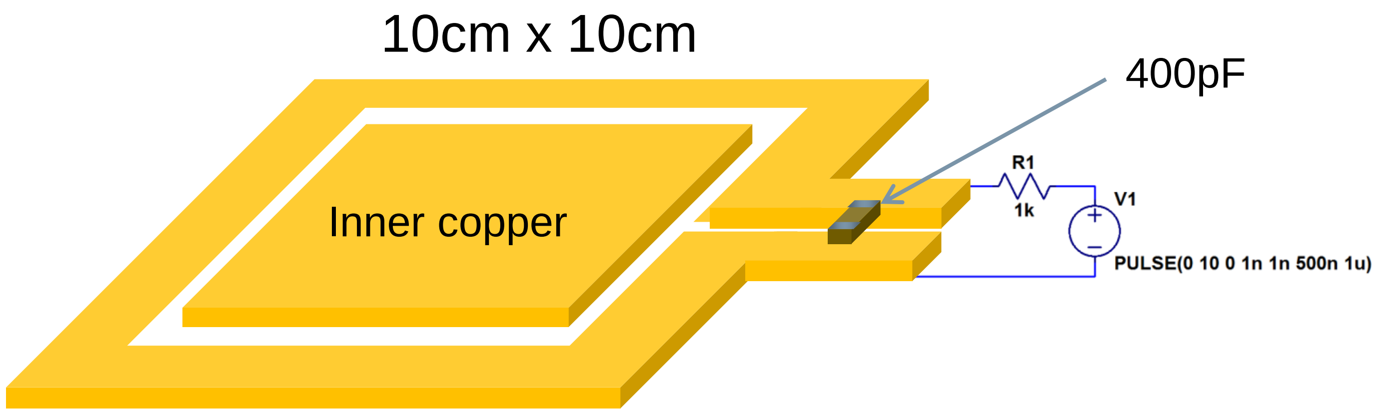


Loop short-circuit effect experiment



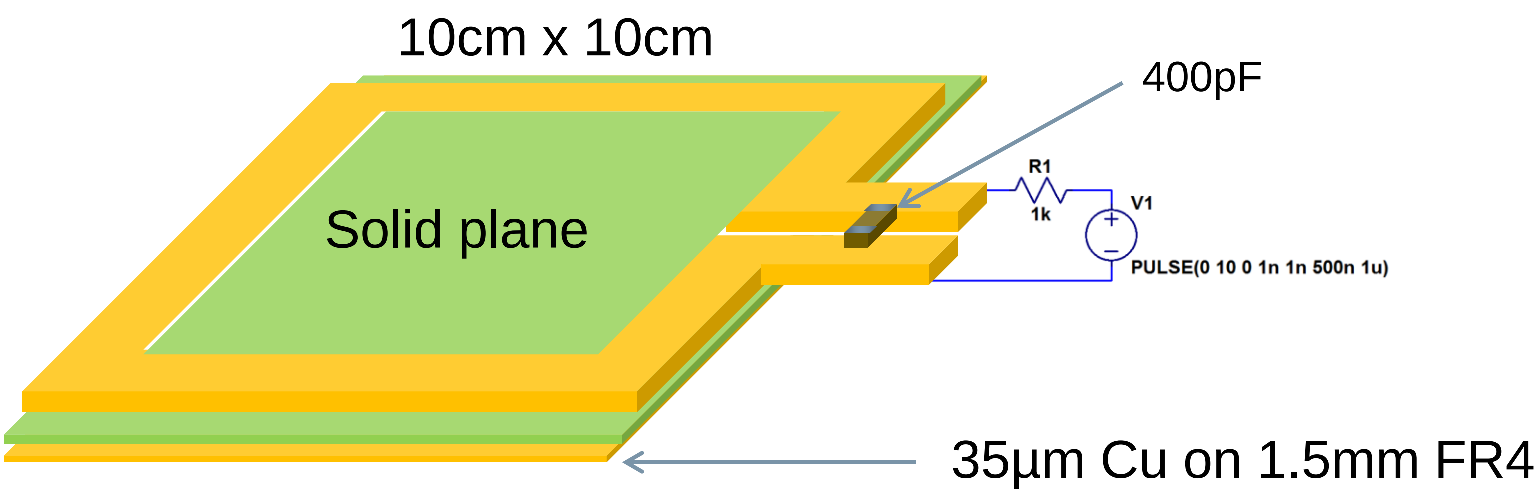
d (mm)	$f_{resonance}$ (MHz)	C (pF)	L (nH)	
n/a	18.4	400	187	Single-layer open loop

Loop short-circuit effect experiment



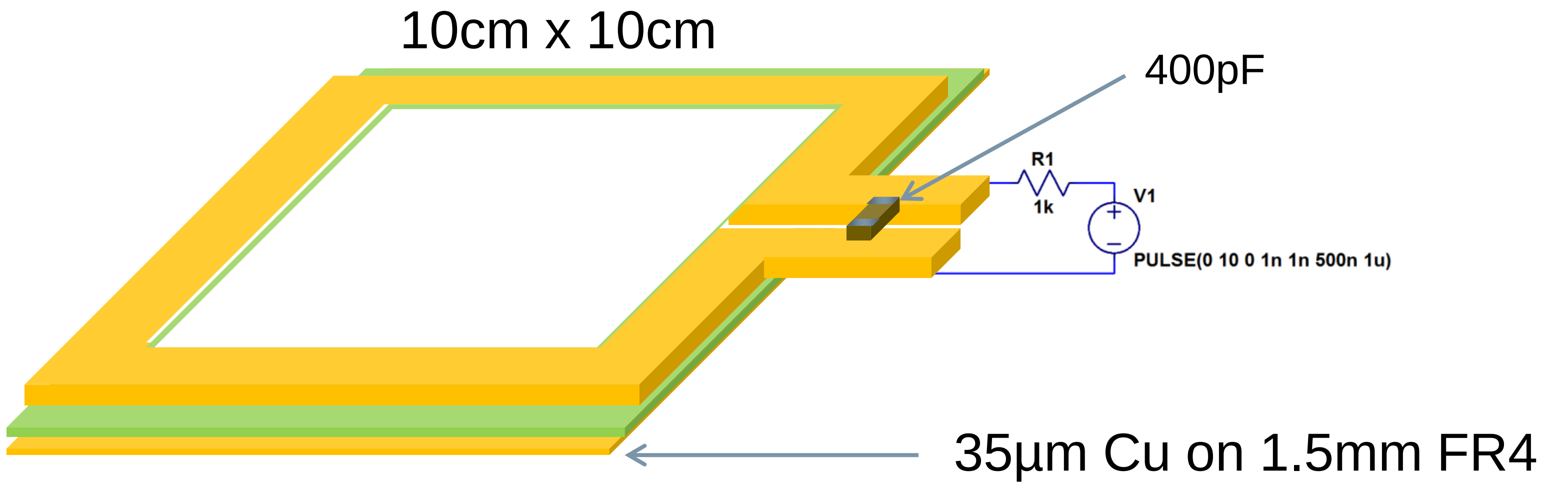
d (mm)	$f_{resonance}$ (MHz)	C (pF)	L (nH)	
n/a	18.4	400	187	Single-layer open loop
n/a	21.2	400	141	Inner copper Short-Circuit loop

Loop short-circuit effect experiment



d (mm)	$f_{resonance}$ (MHz)	C (pF)	L (nH)	
n/a	18.4	400	187	Single-layer open loop
n/a	21.2	400	141	Inner copper Short-Circuit loop
1.5	38.9	400	42	Solid Plane

Loop short-circuit effect experiment



d (mm)	$f_{resonance}$ (MHz)	C (pF)	L (nH)	
n/a	18.4	400	187	Single-layer open loop
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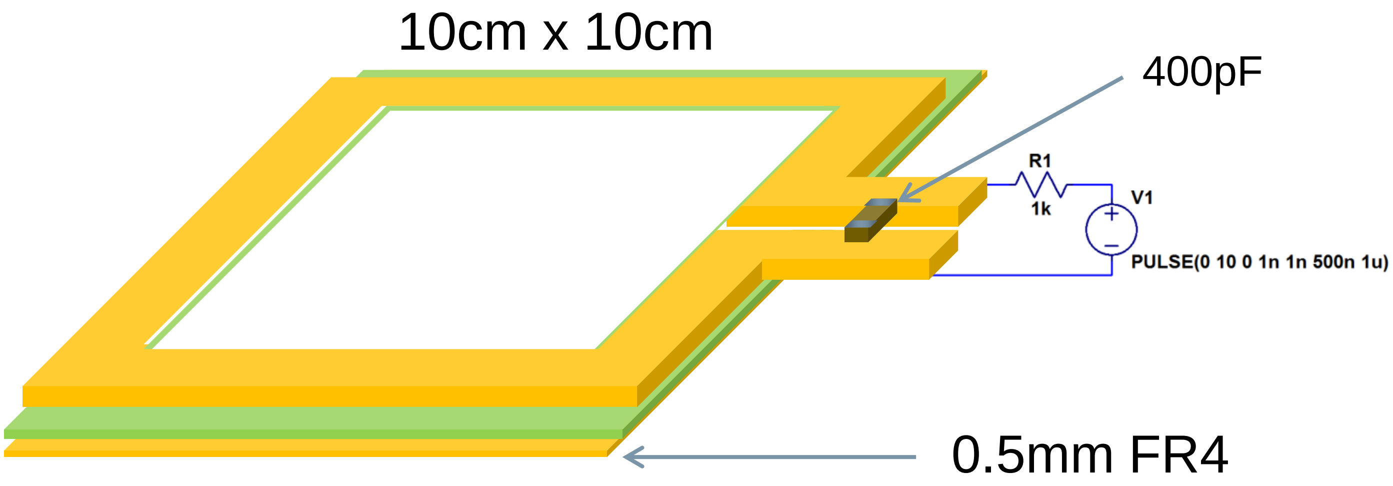
1.5	38.9	400	42	Solid Plane
1.5	34.7	400	53	Rectangular Short-Circuit loop plane

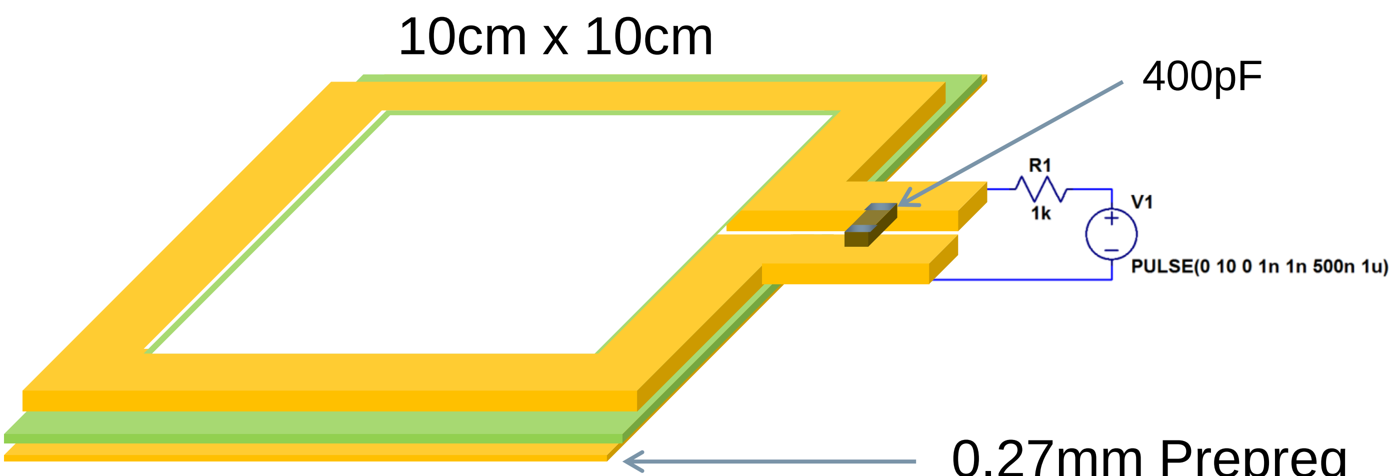
LINEAR TECHNOLOGY

Loop short-circuit effect experiment



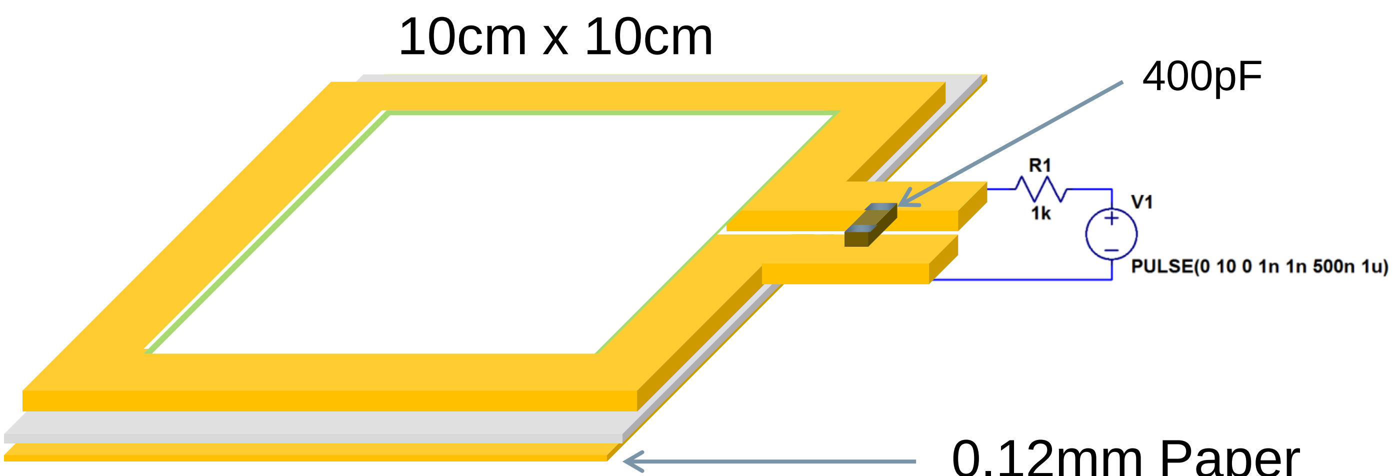
d (mm)	$f_{resonance}$ (MHz)	C (pF)	L (nH)	
n/a	18.4	400	187	Single-layer open loop
n/a	21.2	400	141	Inner copper Short-Circuit loop
1.5	38.9	400	42	Solid Plane
1.5	34.7	400	53	Rectangular Short-Circuit loop plane
0.5	52.1	400	23	Thin Rectangular

Loop short-circuit effect experiment



d (mm)	$f_{resonance}$ (MHz)	C (pF)	L (nH)	
n/a	18.4	400	187	Single-layer open loop
n/a	21.2	400	141	Inner copper Short-Circuit loop
1.5	38.9	400	42	Solid Plane
1.5	34.7	400	53	Rectangular Short-Circuit loop plane
0.5	52.1	400	23	Thin Rectangular
0.27	55	400	21	

Loop short-circuit effect experiment



d (mm)	$f_{resonance}$ (MHz)	C (pF)	L (nH)	
n/a	18.4	400	187	Single-layer open loop
n/a	21.2	400	141	Inner copper Short-Circuit loop
1.5	38.9	400	42	Solid Plane
1.5	34.7	400	53	Rectangular Short-Circuit loop plane
0.5	52.1	400	23	Thin Rectangular
0.27	55	400	21	
0.12	69	400	13	Paper

Loop short-circuit effect experiment

d (mm)	$f_{resonance}$ (MHz)	C (pF)	L (nH)	
n/a	18.4	400	187	Single-layer open loop
n/a	21.2	400	141	Inner copper Short-Circuit loop
1.5	38.9	400	42	Solid Plane
1.5	34.7	400	53	Rectangular Short-Circuit loop plane
0.5	52.1	400	23	Thin Rectangular
0.27	55	400	21	
0.12	69	400	13	Paper

- Inductance goes down with distance to next layer
- Multilayer PCB will have less inductance than 2-layer 1.5mm
- Thinner = better
- Doesn’t need to be a GND-plane

Application Note 139
October 2012

Power Supply Layout and EMI

Christian Kueck

Introduction

PC-board layout determines the success or failure of every power supply project. It sets functional, electromagnetic interference (EMI), and thermal behavior. Switching power supply layout is not black magic, but is often overlooked until it is too late in the design process. Fortunately physics is on your side. Functional and EMI requirements must be met, and in a world of trade-offs in power supply unit layout, what is good for functional stability is good for EMI. Good layout from first prototyping on does not add to cost, but actually saves significant resources in EMI filters, mechanical shielding, EMI test time and PC board runs. This application note focuses primarily on nonisolated topologies, but will examine some isolated topologies as well. You will learn to make the optimum choices regarding PC-board layout for solid power supply designs.

I remember about a dozen years ago as a customer was

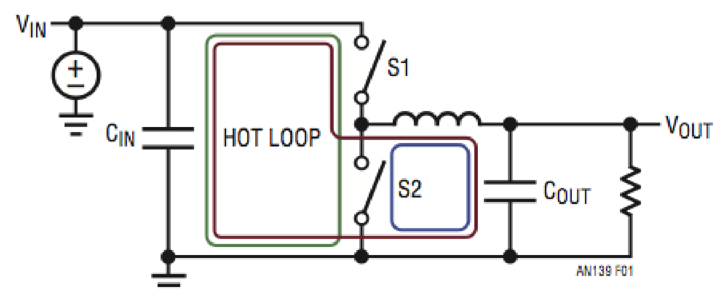


Figure 1

During the on cycle with S1 closed and S2 open, the AC current follows the red loop (Figure 1). During the off cycle, with S1 open and S2 closed, the AC current follows the blue loop. Both currents have a trapeze shape. People often have difficulty grasping that the loop producing the highest EMI is not the red nor the blue loop. Only in the green loop flows a fully switched AC current, switched from zero to I_{PEAK} and back to zero. We refer to the green loop as a hot loop, since it has the highest AC and EMI energy.

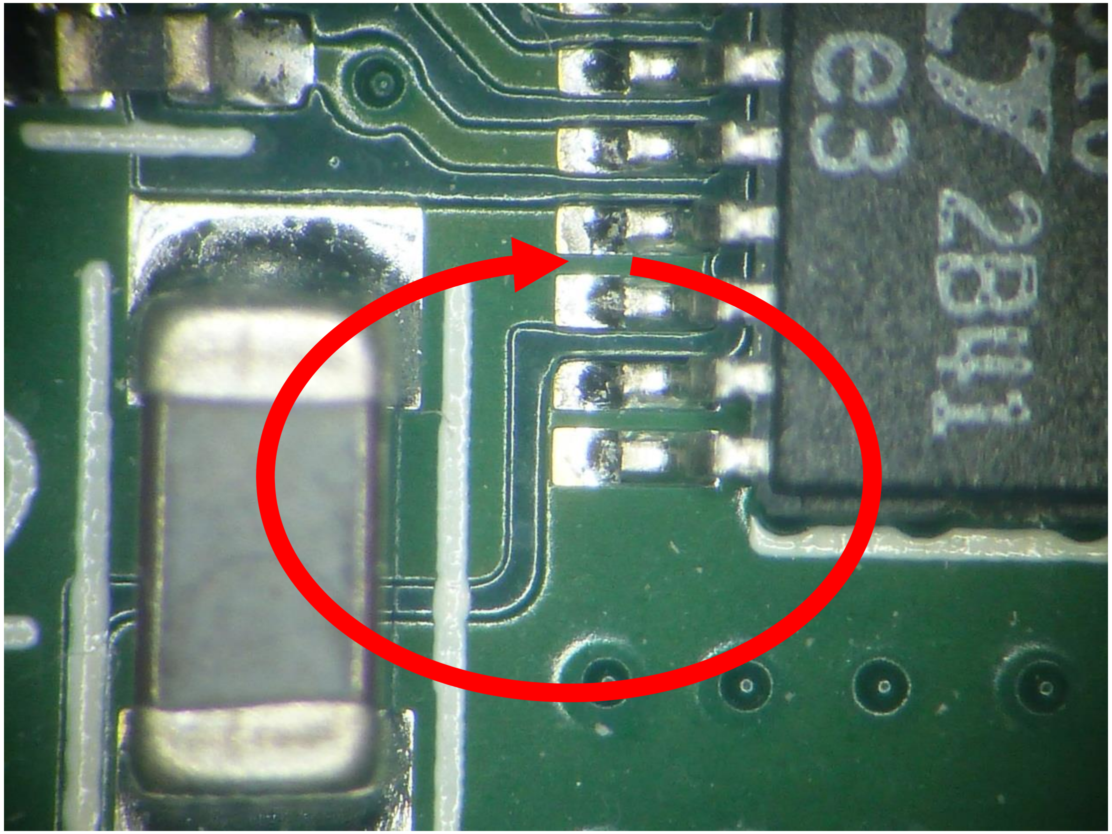
SILENCE PLEASE

Linear technology invented
noise cancelling
for switch mode regulators.

It is called Silent Switcher[1]

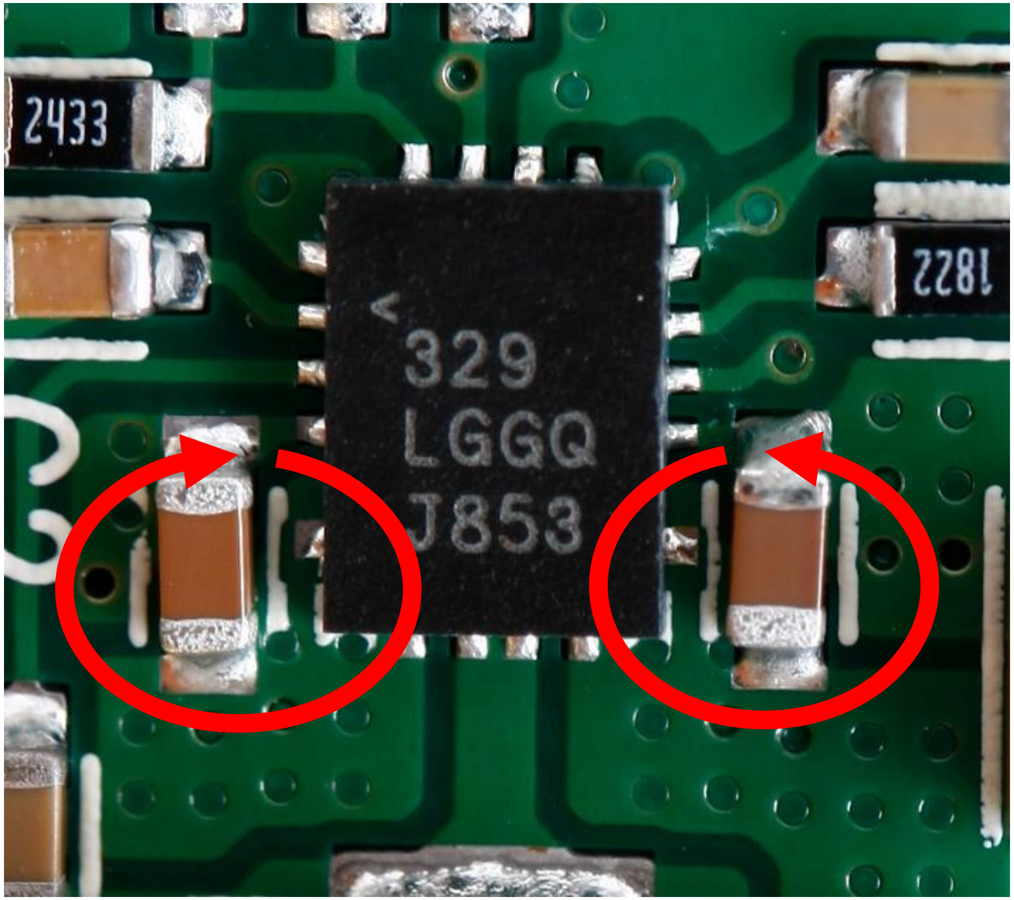
(1) Silent Switcher is a registered trade mark and Patent pending from Linear Technology Corp.

How does it work



Even on the most compact design the decoupling components with the switch have some finite dimensions and create an EMI field.

LT8614 Silent Switcher



On a Linear Technology Silent Switcher two identical decoupling loops with opposite orientation cancel each others EMI field.

LT8614 EMI Performance

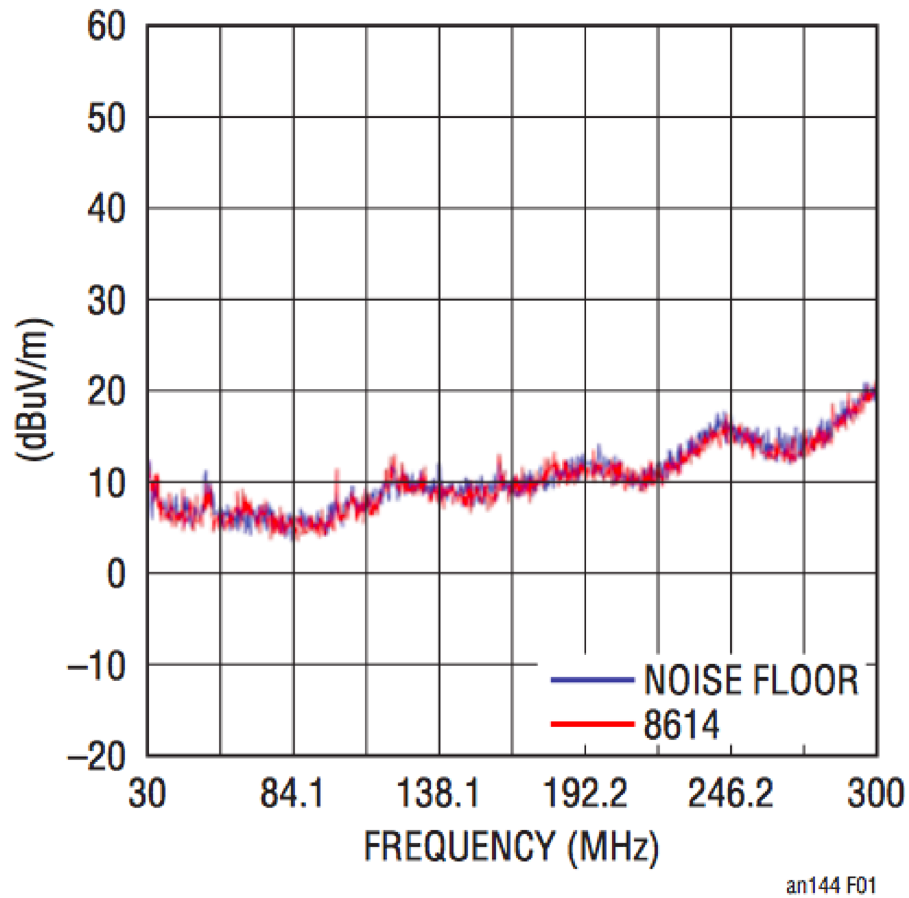


Figure 1. Noise Floor and the LT8614 Board at CISPR25 Radiated Measurement in an Anechoic Chamber

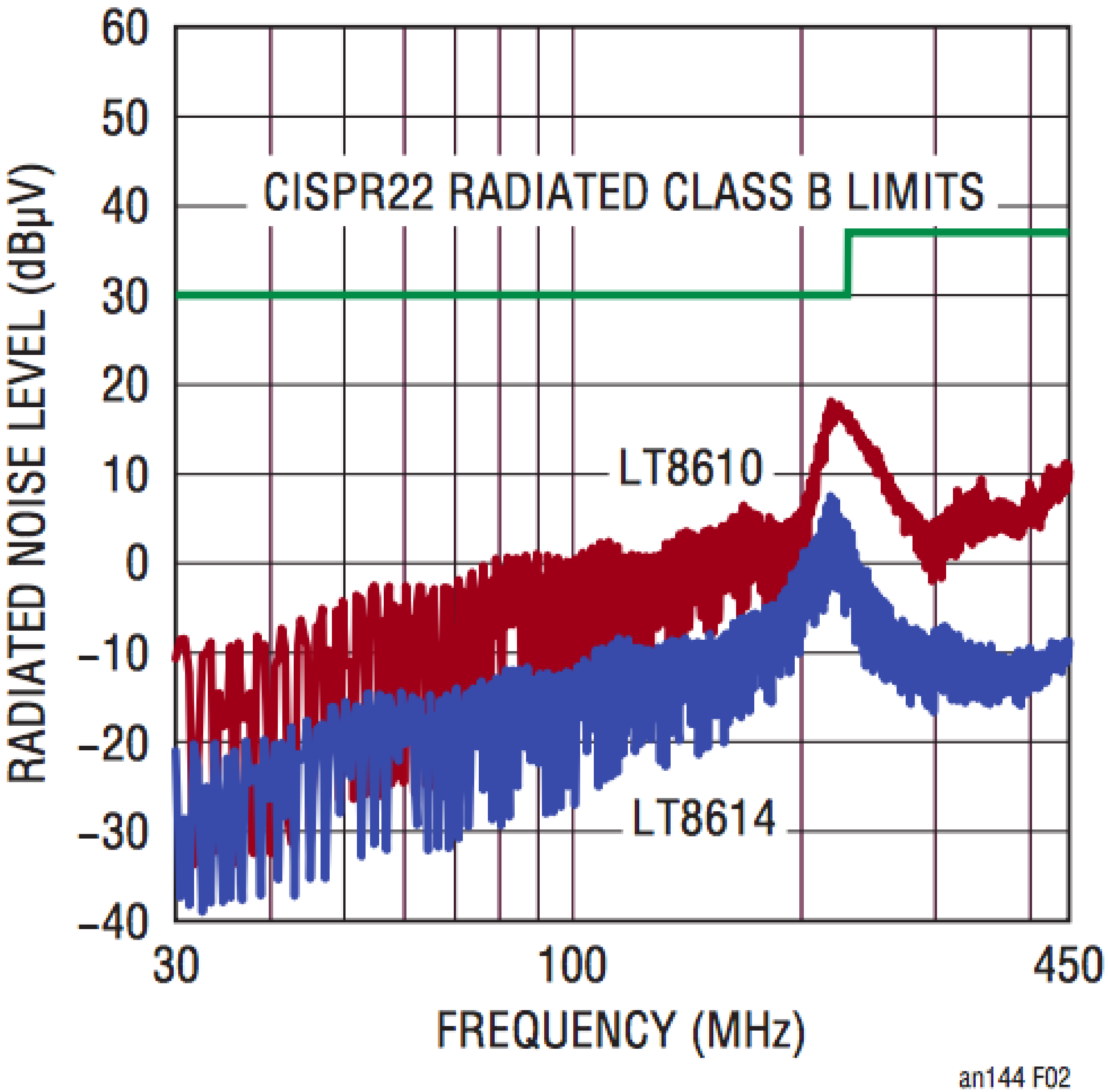


Figure 2. LT8610 and LT8614 700kHz 14V to 3.3V 2A Radiated EMI in GTEM Corrected for OATS

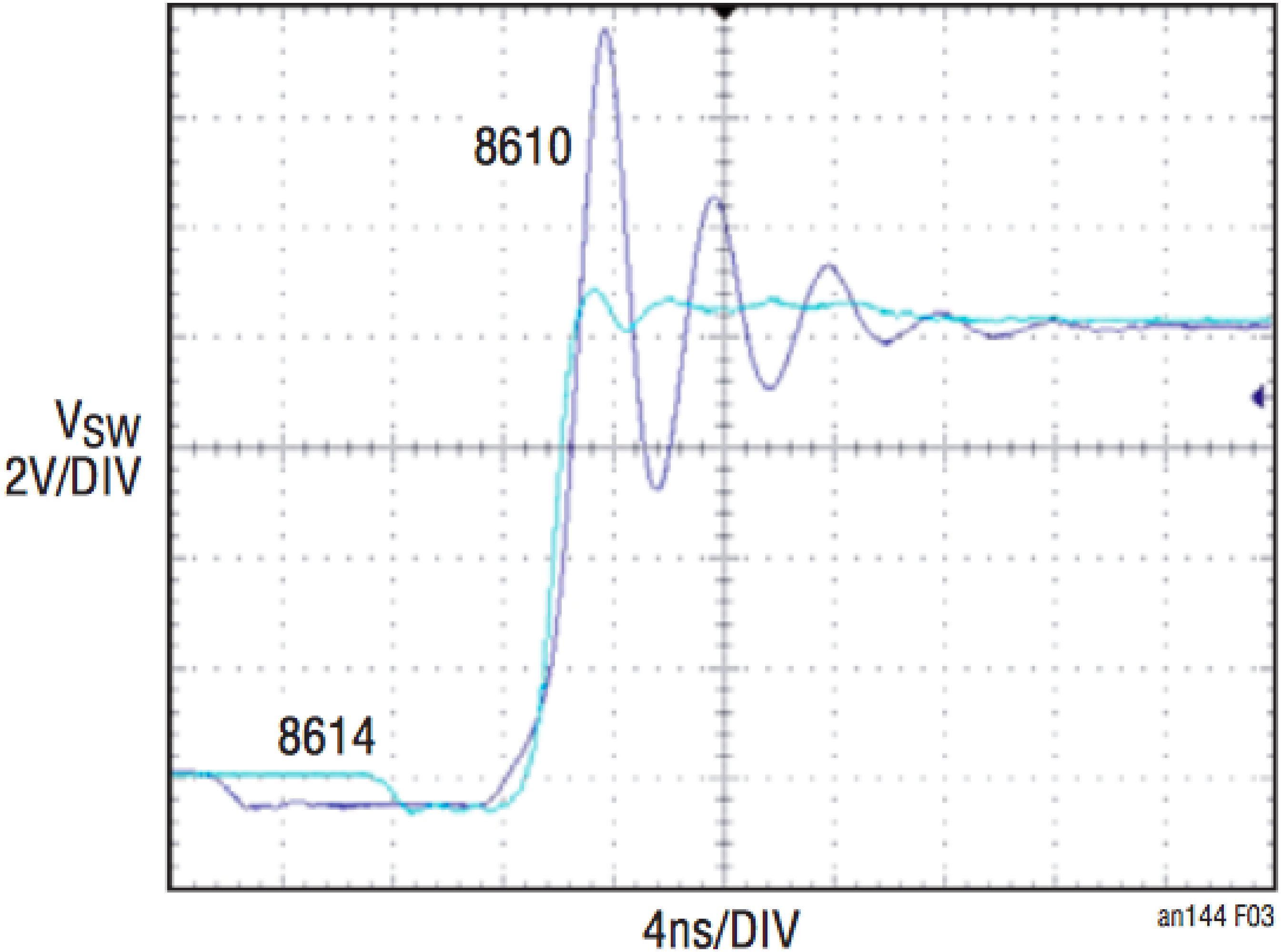
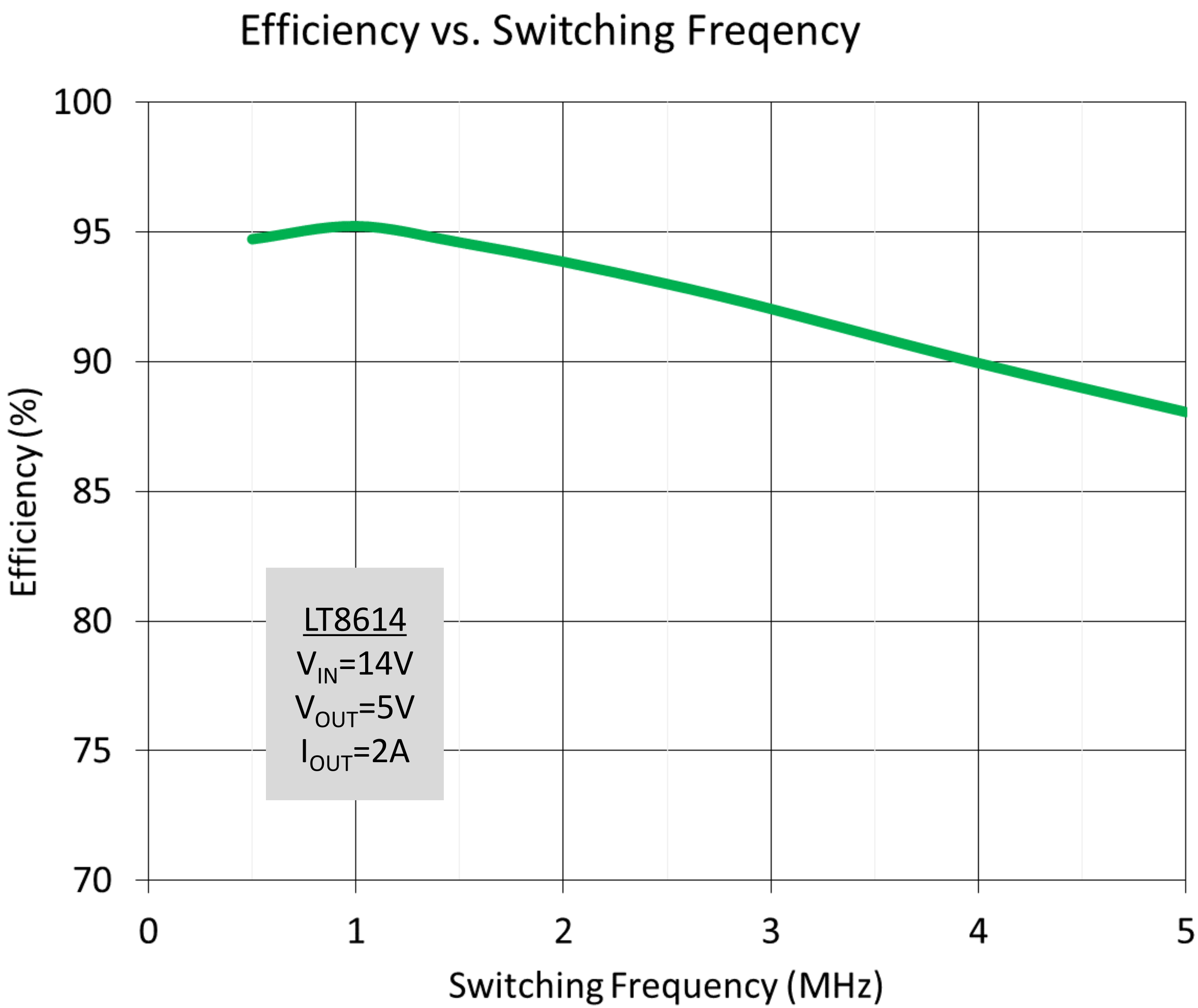


Figure 3. LT8610 and the LT8614, Switch Node Rising Edge Both at 8.4V_{IN}, 3.3V_{OUT} at 2.2A



Efficiency vs. Switching Freqency
100
95
90
85
80
75
70
Efficiency (%)
0
1
2
3
4
5
Switching Frequency (MHz)
LT8614
VIN=14V
VOUT=5V
IOUT=2A

–LT8614–

Application Note 144

November 2013

Reduce EMI and Improve Efficiency with Silent Switcher Designs

Christian Kueck

Questions ?

Thank you