Automotive EMI Demystified

Black Magic Busted

Speaker: Christian Kueck

Oct 2nd, 2018

MPS

Speaker Intro: Christian Kueck

- Senior FAE supporting automotive Tier-1 customers throughout Germany
- Over two decades of experience managing EMI challenges
- Deeply involved in the definition and compliance testing of our leading AEC-Q100 power management solutions.
- 22 years at Linear Technology
  - Strategic Marketing Manager for Europe - Product definition and product support for PSU and LED circuits
  - Field Application Engineer
- Additional:
  - Design Engineer, Quality Assurance, Materials Engineer
- Microelectronics. Dipl. Ing., Elektrotechnik University of Dortmund

Automotive EMI Demystified – Agenda

- Analyzing the Typical Power Stage
- Magnetic Coupling & Demo Video
- Key Loops
- Layout Hints
- Audience Q&A

Analyzing the Typical Power Stage

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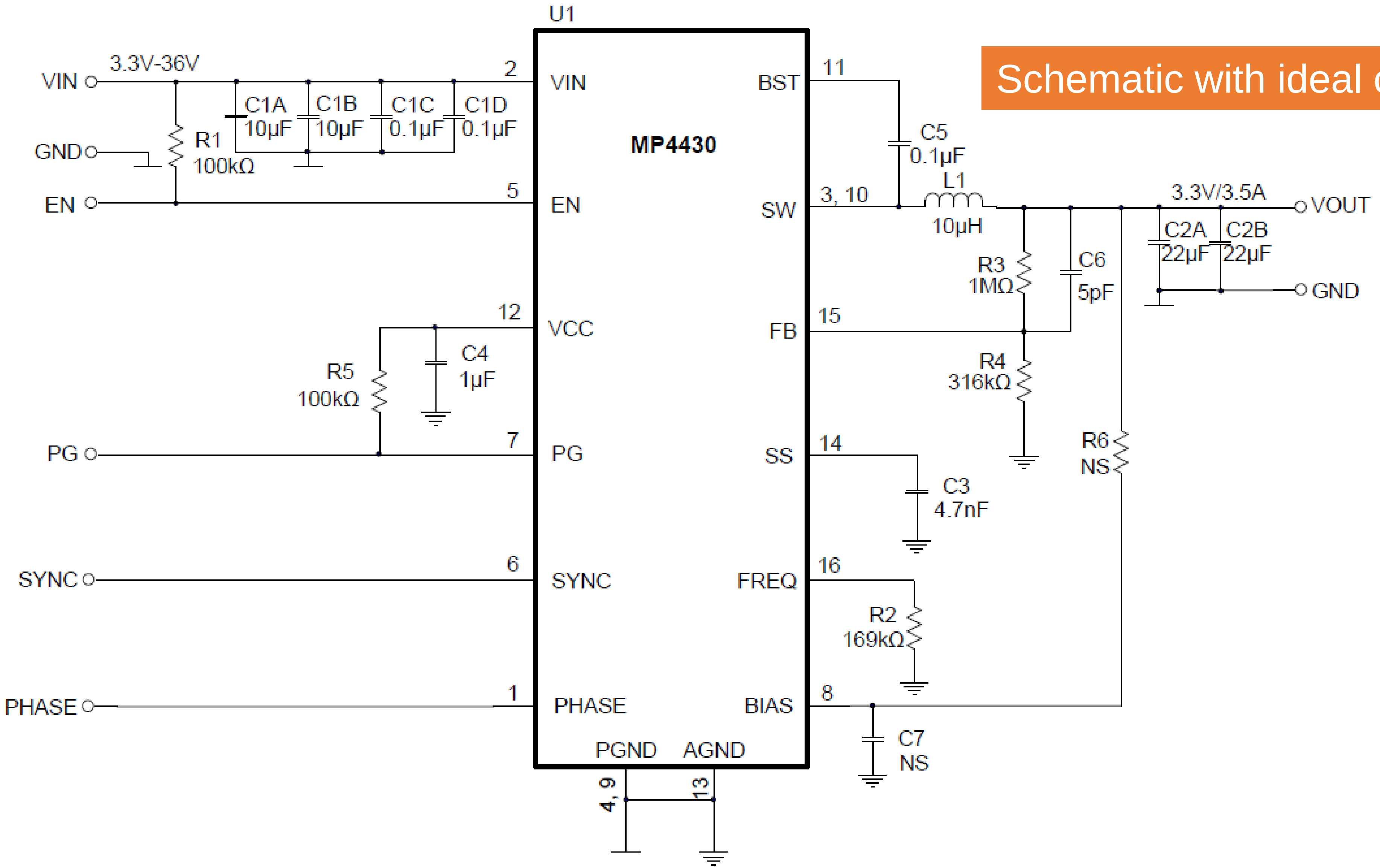
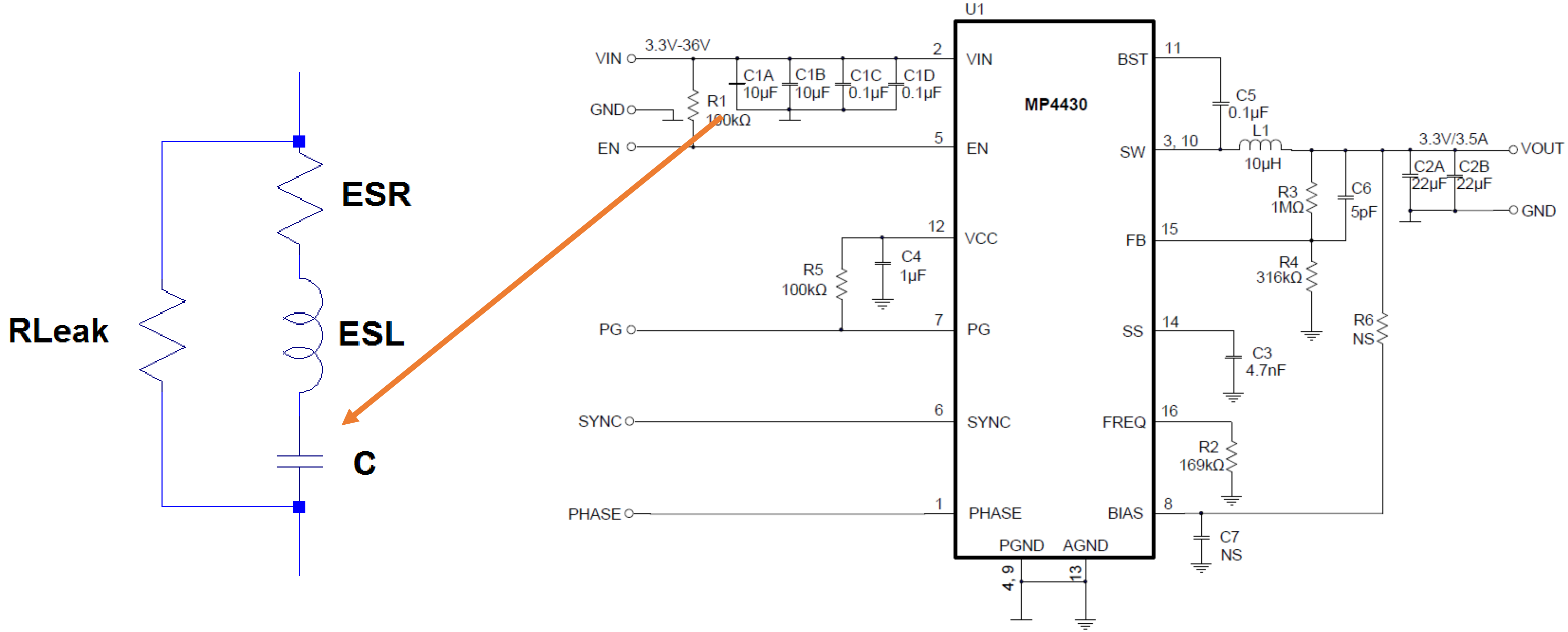
Typical Power Supply Schematic

Schematic with ideal components



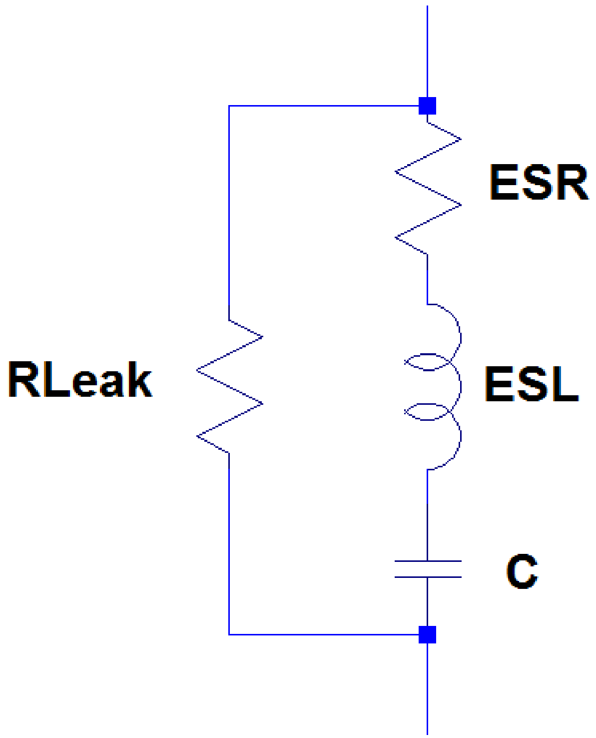
Component Parasitics

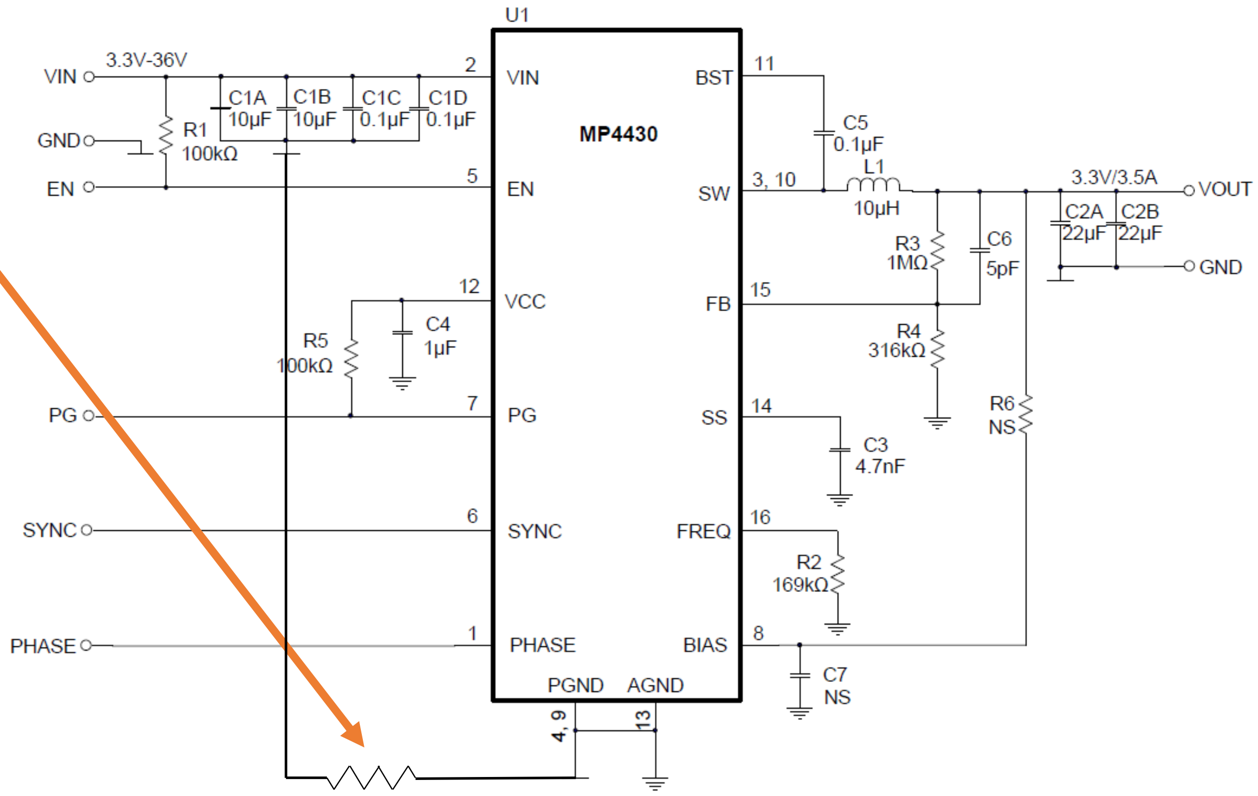
Parasitic elements – still concentrated components



PCB Resistance

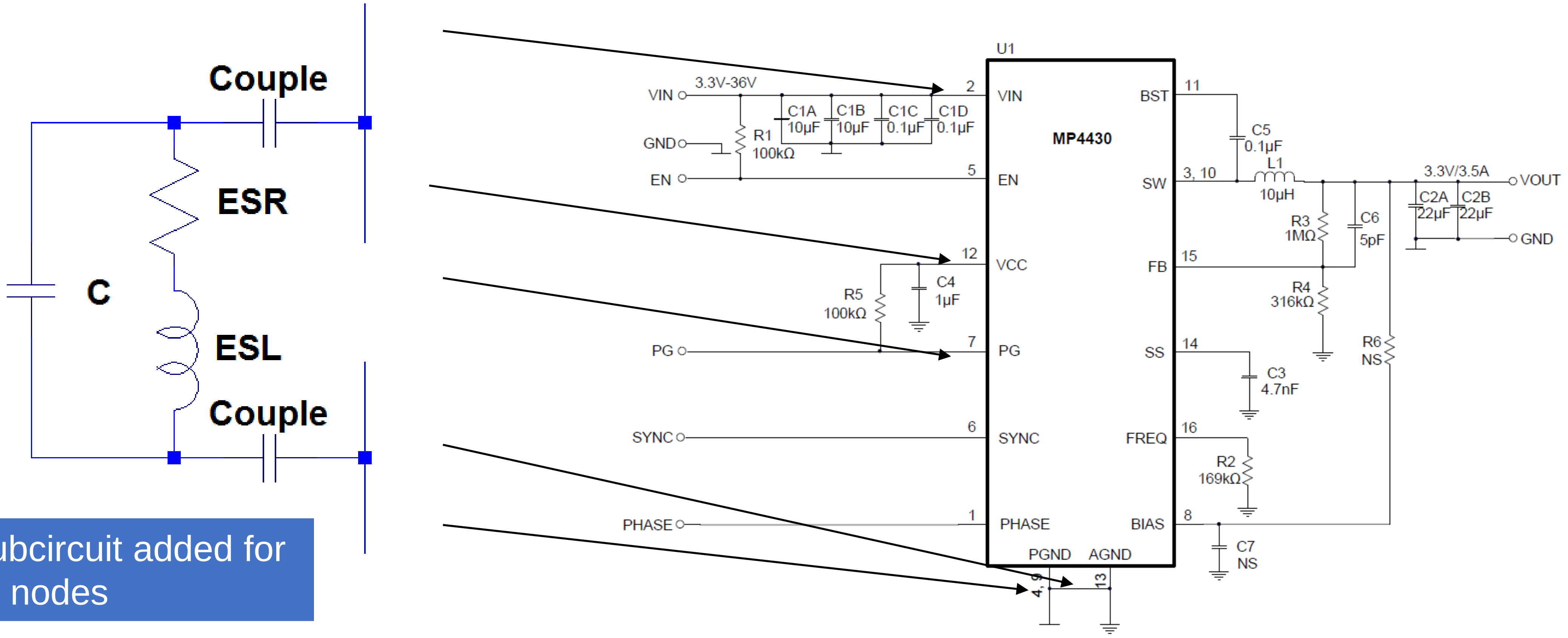
With PCB resistance added





Additional PCB Parasitics

Additional inductive, capacitive and resistive PCB parasitics

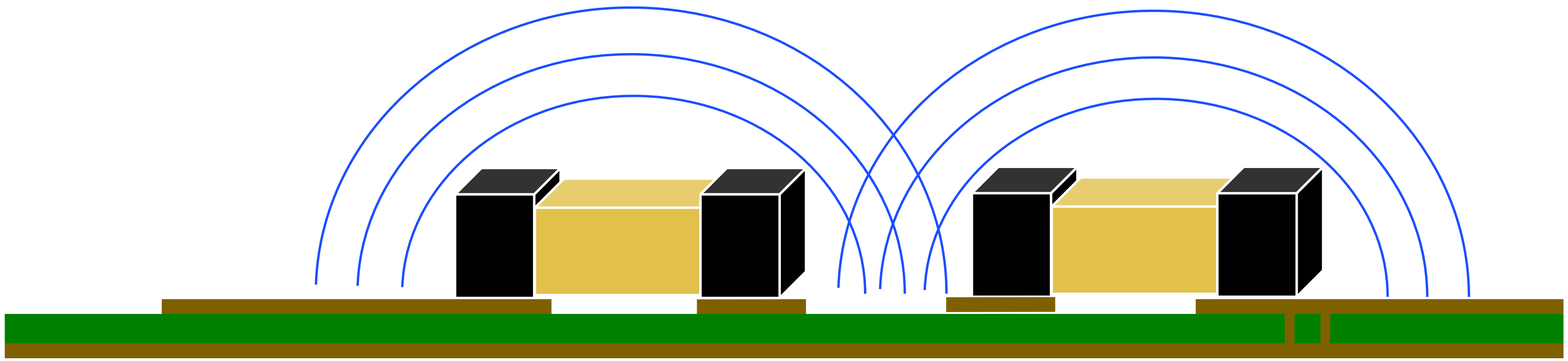


Subcircuit added for all nodes

Electric Fields & Near-Field Coupling

E-Field, capacitive near-field coupling of components and PCB added.

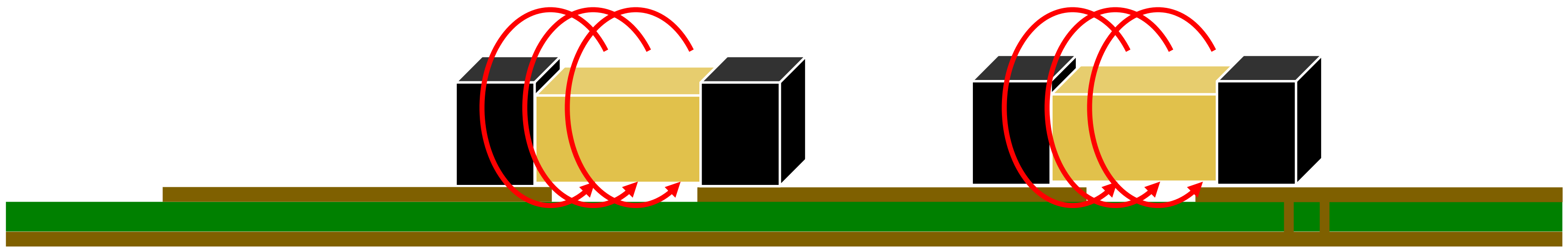
All traces and components couple like capacitor plates.
More as higher elevated above PCB, larger area, higher AC amplitude and as higher their AC resistance to GND is.



Magnetic Fields

H-Field/magnetic near-field coupling and shielding of components and PCB added.

Traces and components couple like transformer windings.
More as higher their median conduction path is elevated above a conducting plane and as longer it is. Induced voltage goes linear up with frequency.

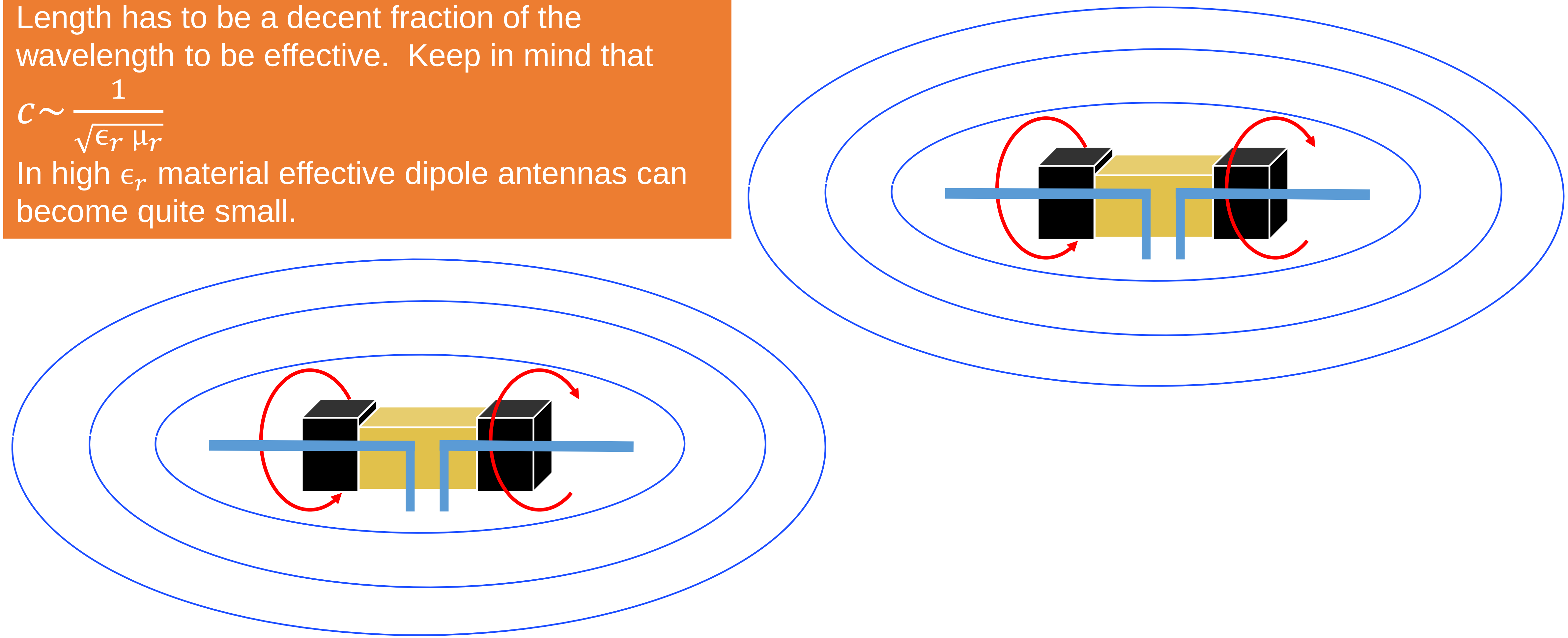


Electromagnetic Far-Field Radiation & Reception

Traces and components act as dipole radio antennas.
Length has to be a decent fraction of the wavelength to be effective. Keep in mind that

$$c \sim \frac{1}{\sqrt{\epsilon_r \, \mu_r}}$$

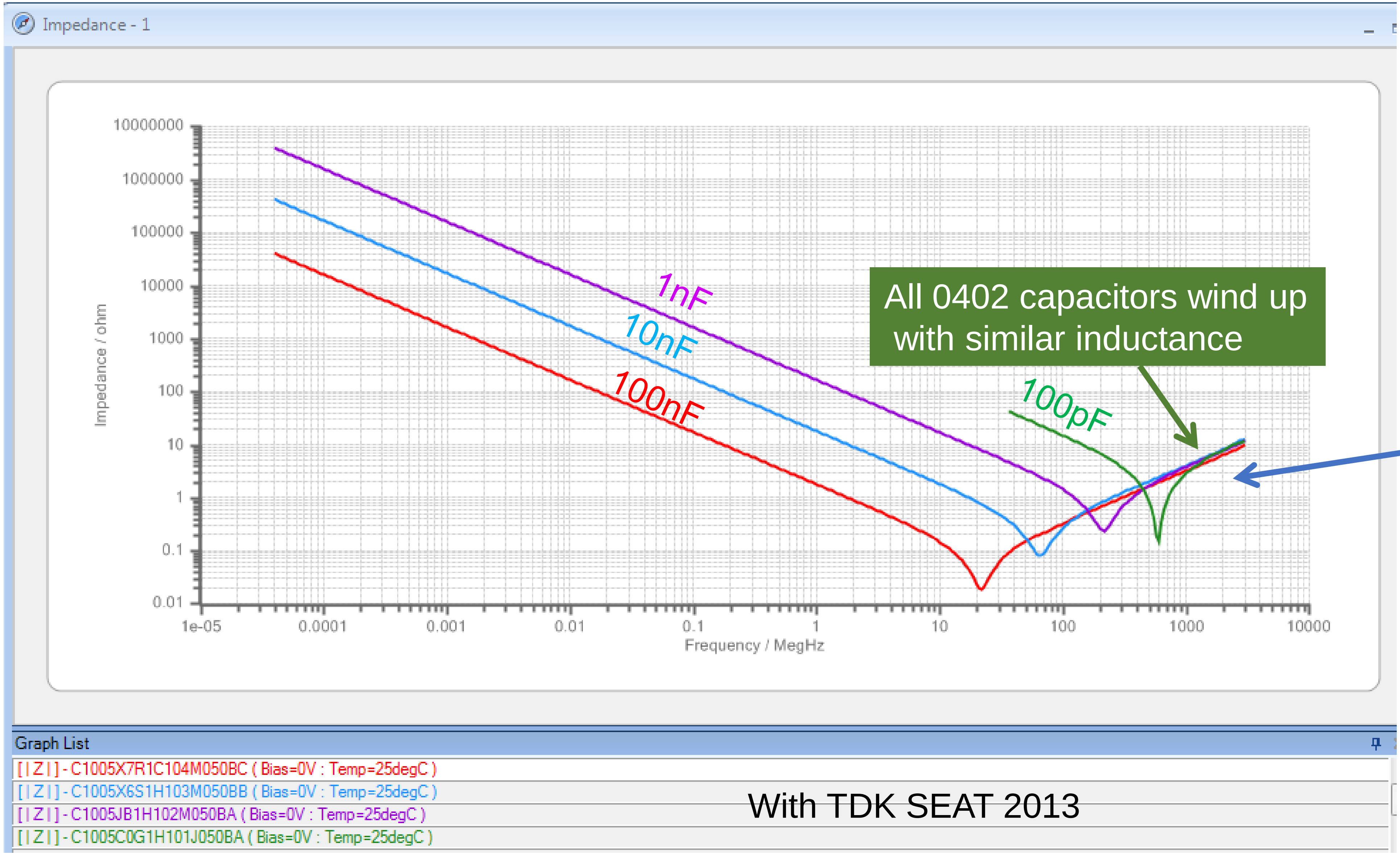
In high ϵ_r material effective dipole antennas can become quite small.



How Do I Balance All These Influences?

- There is hope.
- Not all effects are relevant in all components.
- We will concentrate on the dominant effects first for non-isolated DC-DC converters

Capacitor Impedance

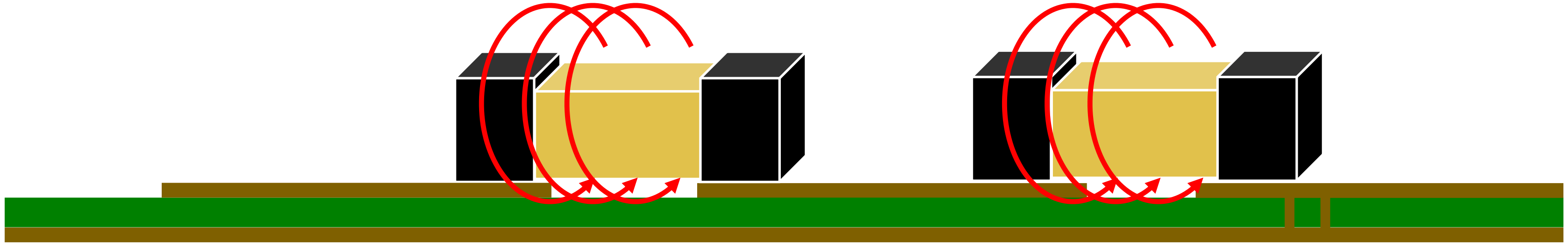


With TDK SEAT 2013

Even if they are inductive, the impedance is still low and they work as bypass elements

Capacitor Magnetic Coupling

From an EMI view, the bigger problem of capacitors is that they couple near-field magnetics like two transformer windings. That’s a wide band (GHz) coupling path and defeats their filter function.



Sources

E-Fields are created by (AC) voltages.

H-Fields or magnetic fields are created by currents.

Current always flows in circles / closed loops.
They never end in ground planes or a nail in the flower pot….
So **hunt for the full circle.**

Magnetic Coupling & Demo Video

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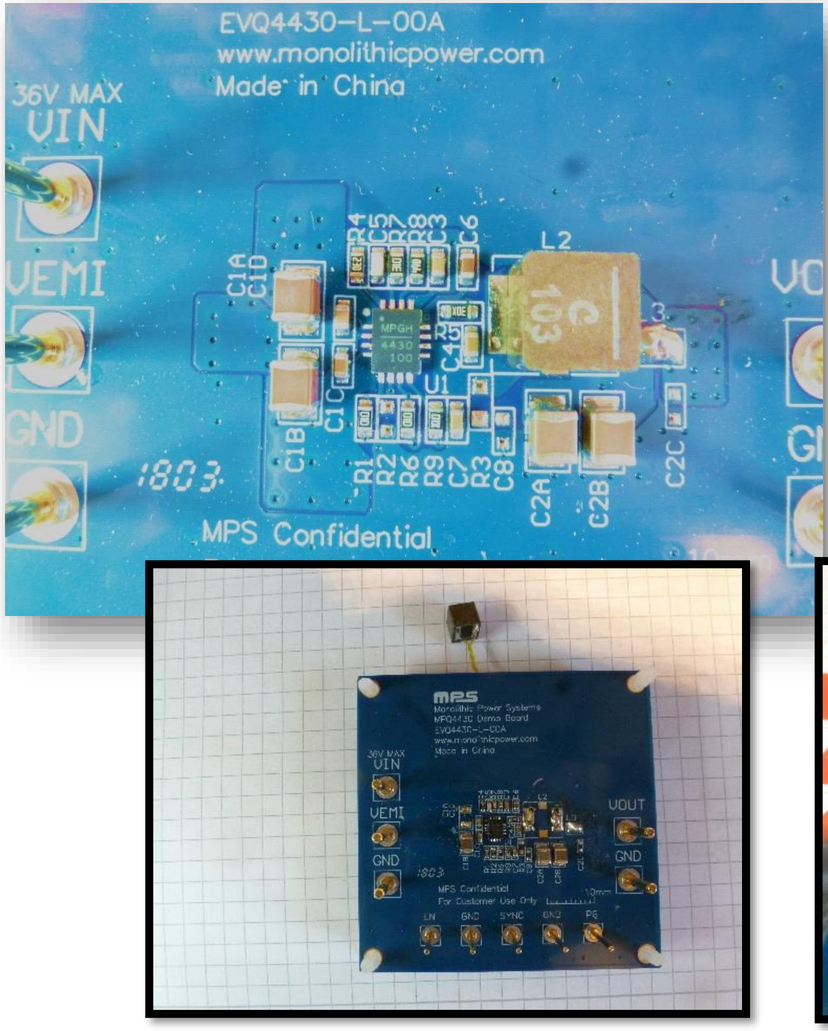
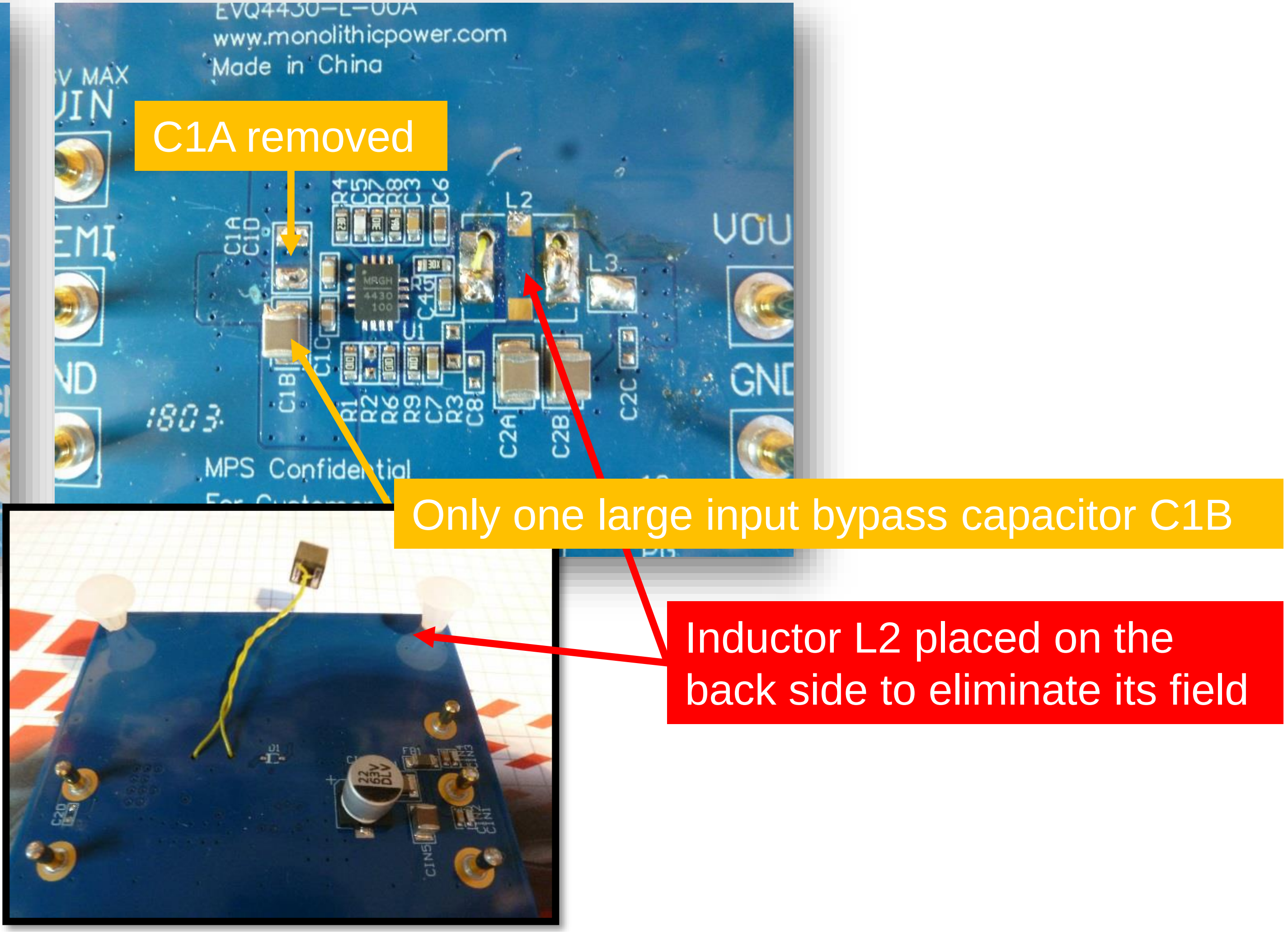
Example – MPQ4430 Buck Converter EVB Modified to Show Capacitor Coupling

Standard EVB

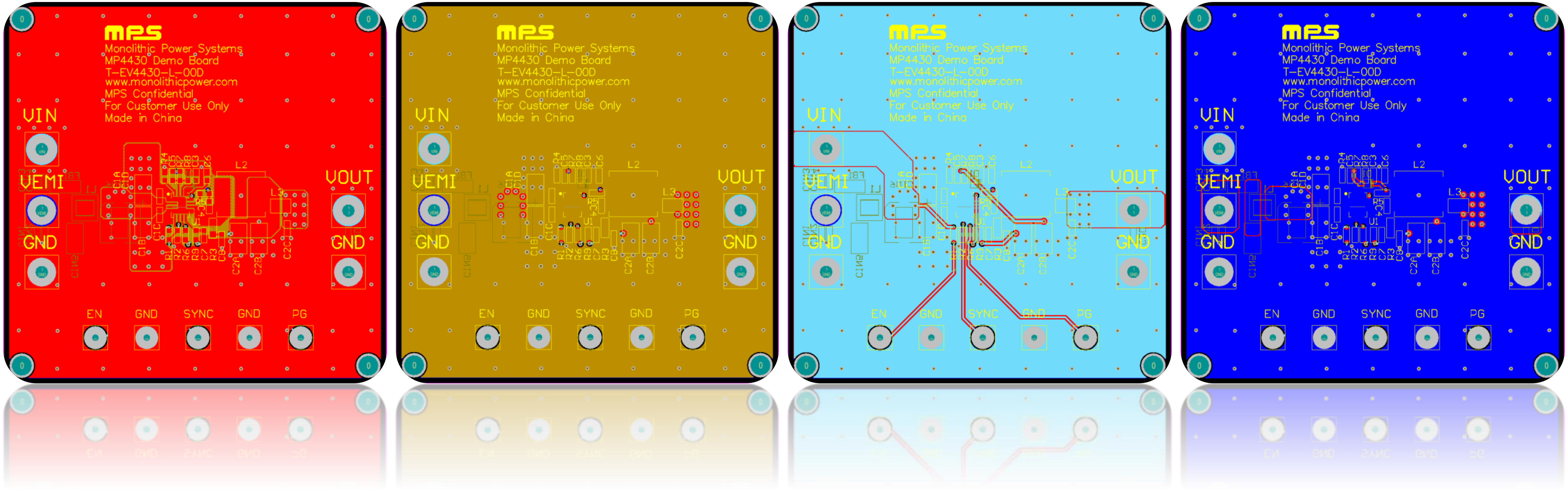


Modified EVB

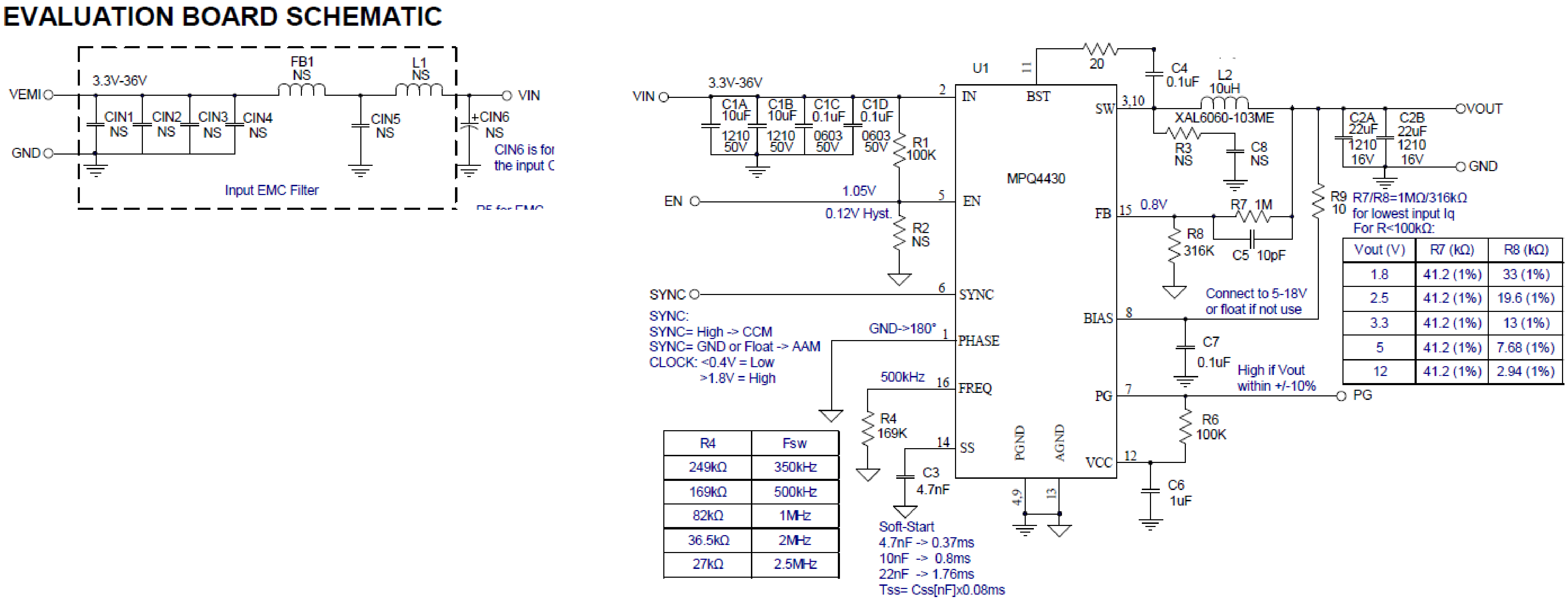


MPQ4430 Buck Converter EVB 4-Layer PCB

Layout of this 4-layer board – Top, Inner1, Inner2, bottom



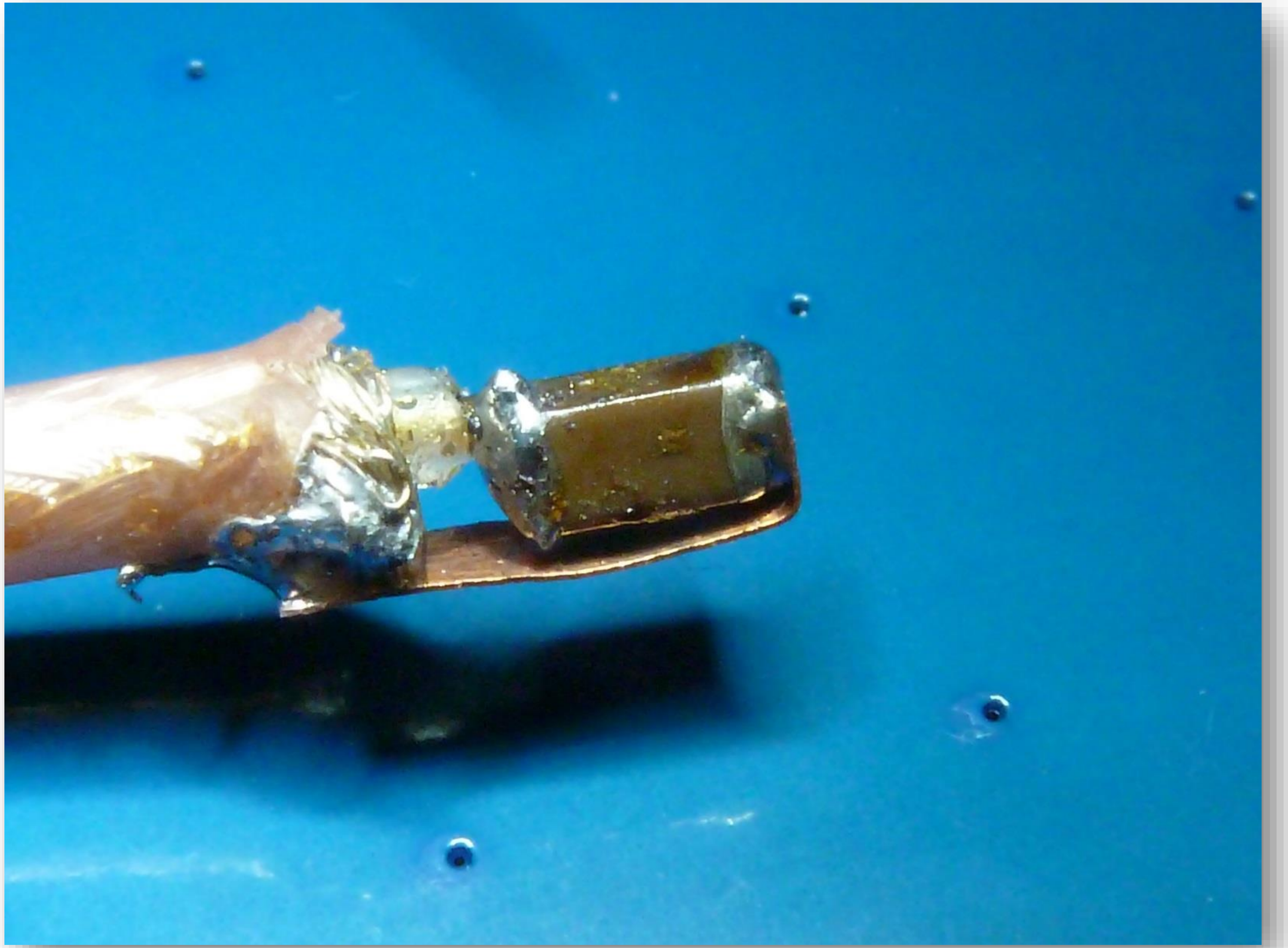
MPQ4430 Buck Converter Schematic



R4	Fsw
249kΩ	350kHz
169kΩ	500kHz
82kΩ	1MHz
36.5kΩ	2MHz
27kΩ	2.5MHz

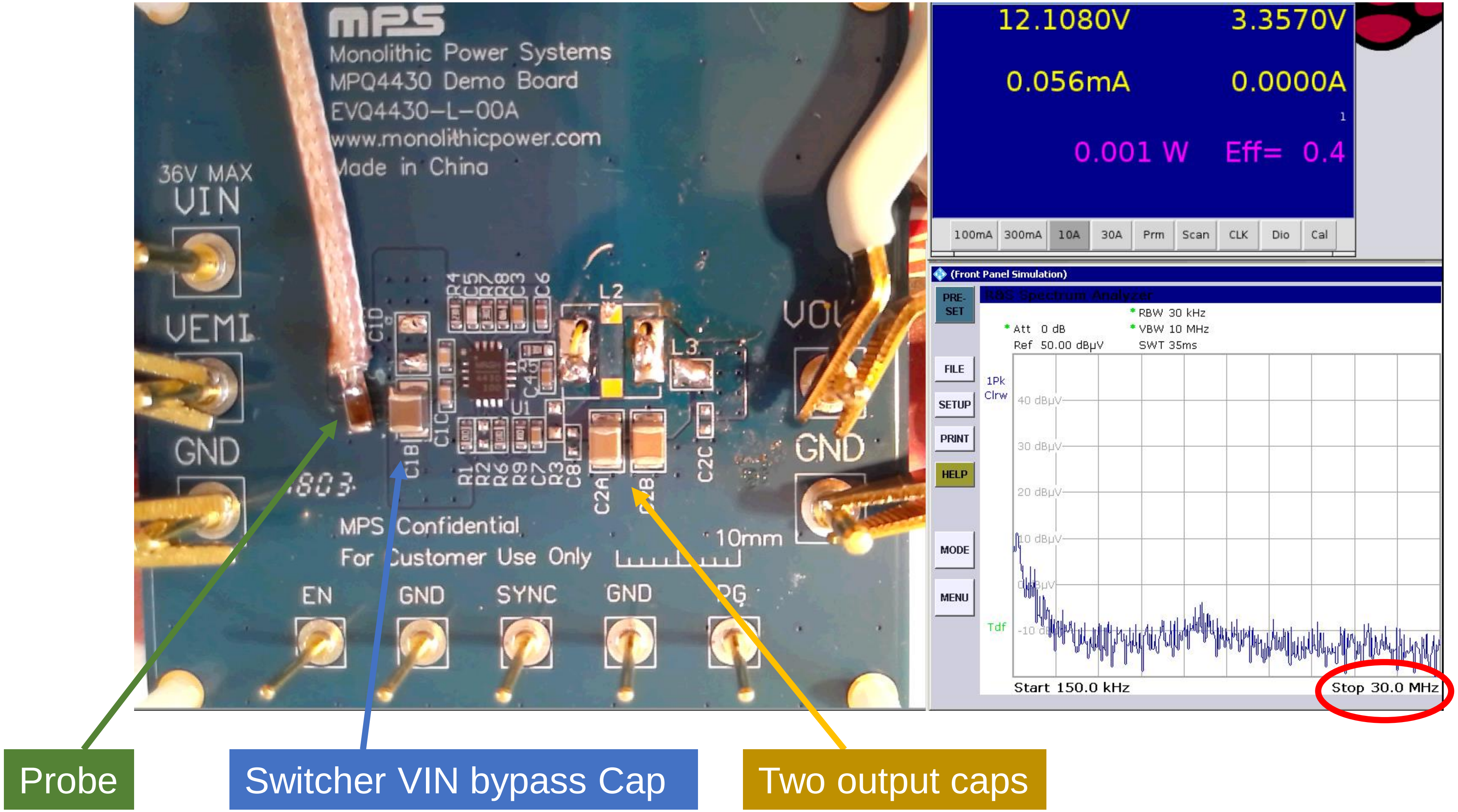
Vout (V)	R7 (kΩ)	R8 (kΩ)
1.8	41.2 (1%)	33 (1%)
2.5	41.2 (1%)	19.6 (1%)
3.3	41.2 (1%)	13 (1%)
5	41.2 (1%)	7.68 (1%)
12	41.2 (1%)	2.94 (1%)

0805 MLCC Capacitor Probe

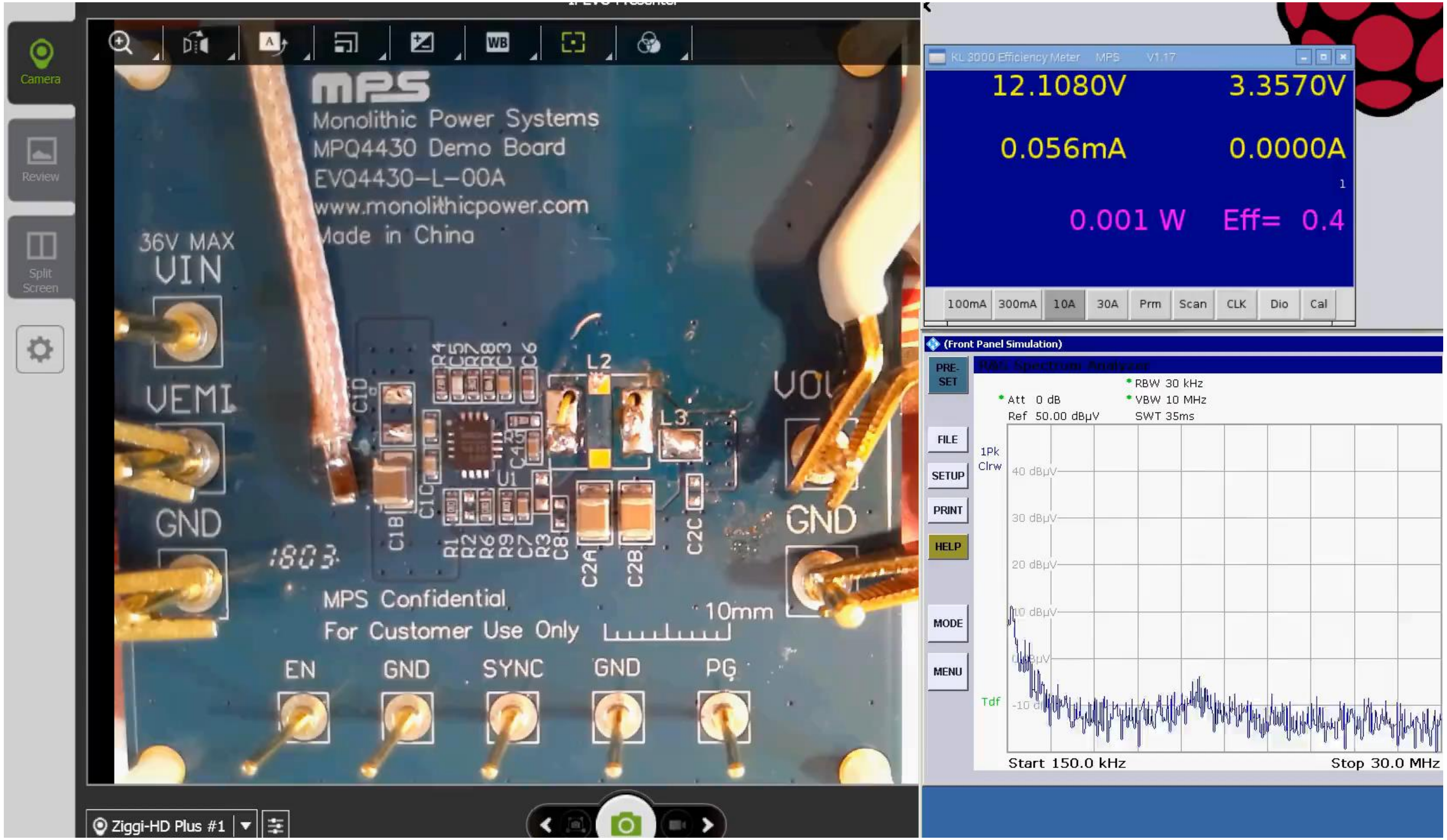


Pick-up formed like what a capacitor will see on the board.

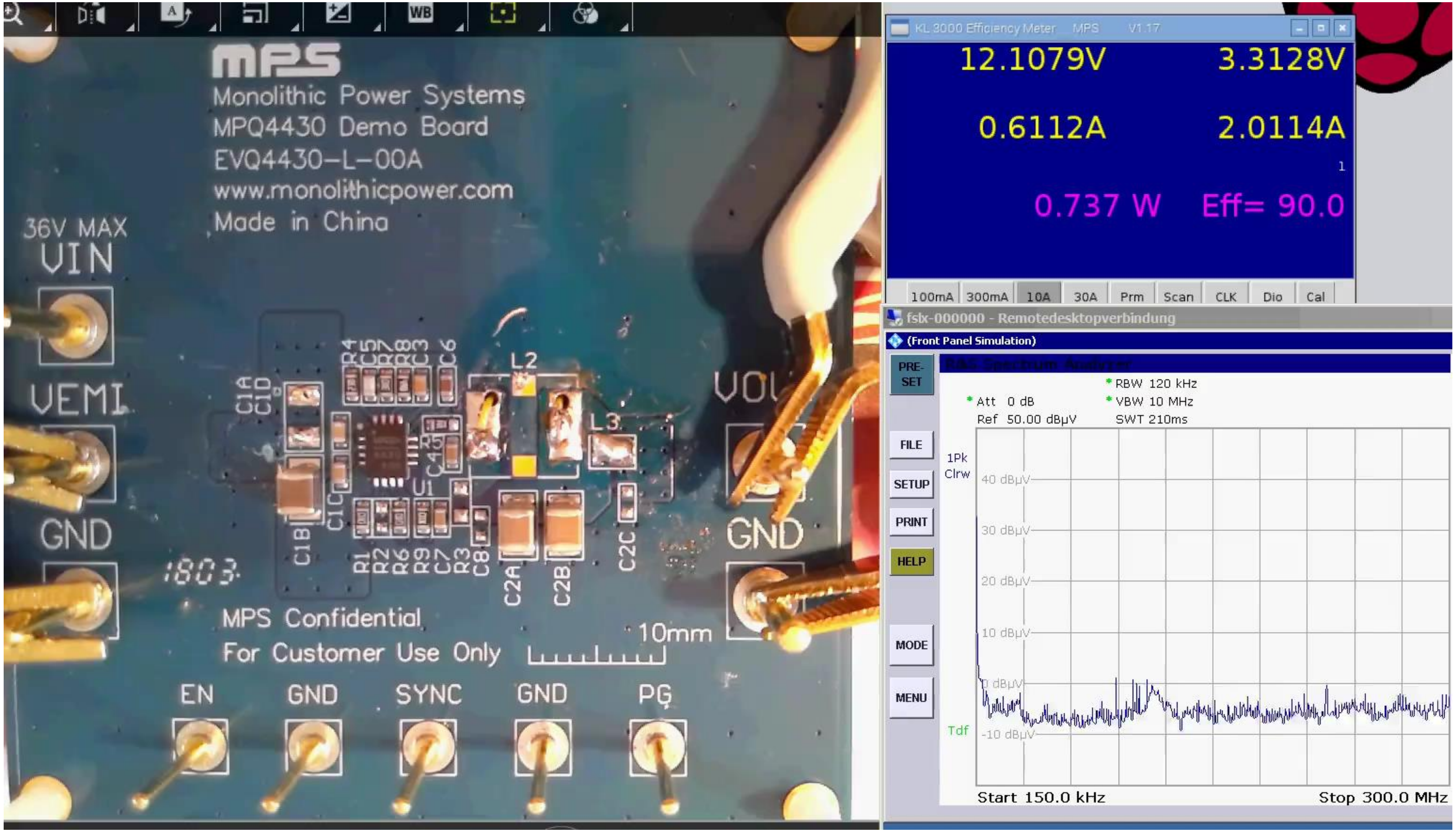
Buck Converter Capacitor Magnetic Coupling to 30MHz



Buck Converter Capacitor Magnetic Coupling to 30MHz



Buck Converter Capacitor Magnetic Coupling to 300MHz



Buck Converter Capacitor Magnetic Coupling

Why is the magnetic field amplitude and bandwidth so much higher on the input bypass caps?

Key Loops

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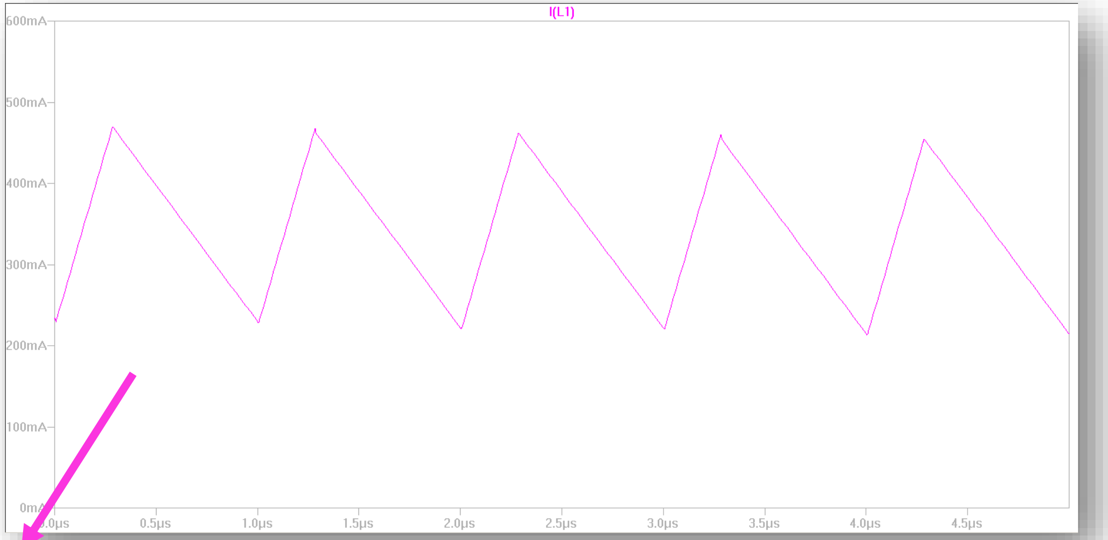
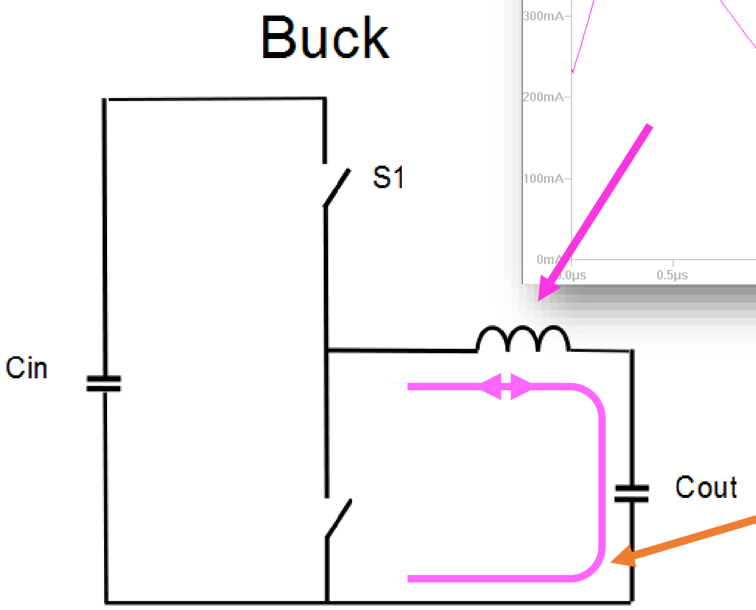
Synchronous Buck Converter – Inductor Loop

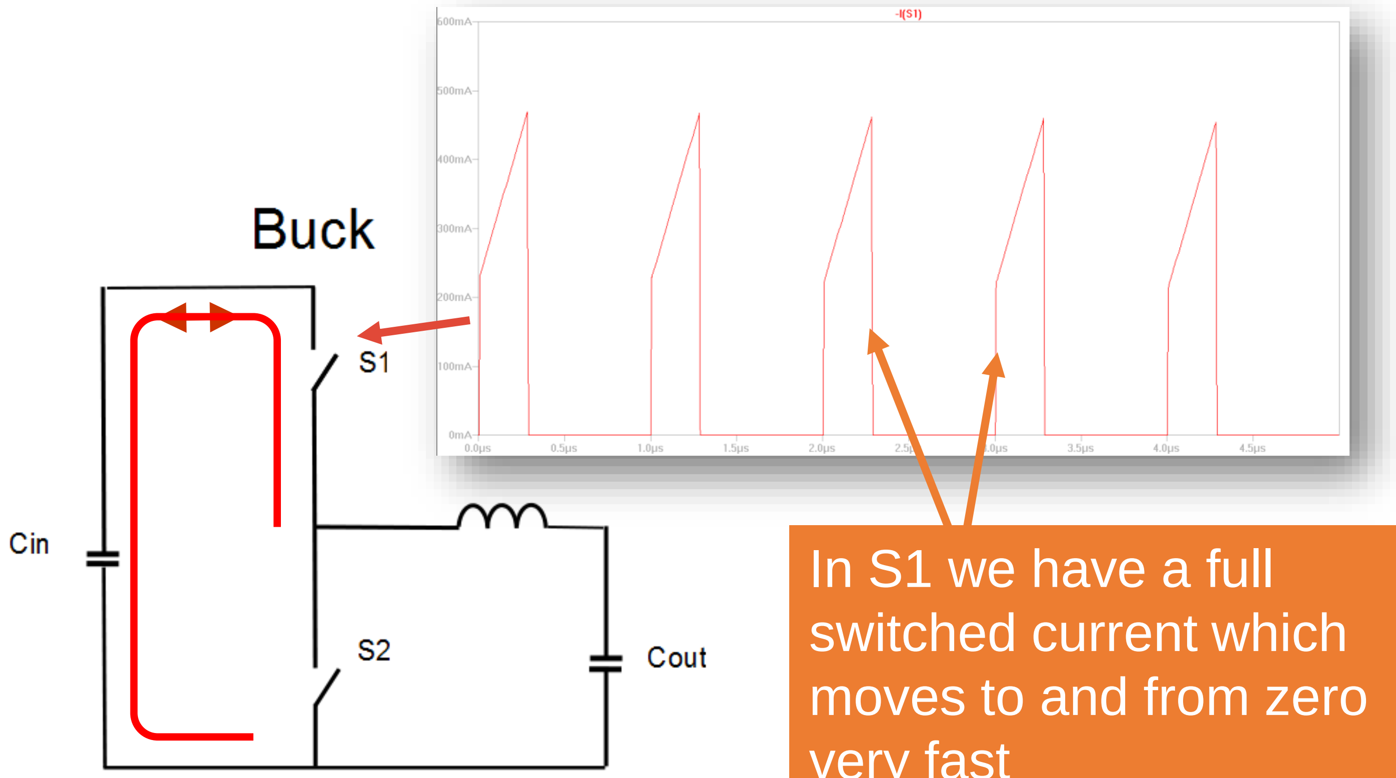




The triangular inductor current will flow here

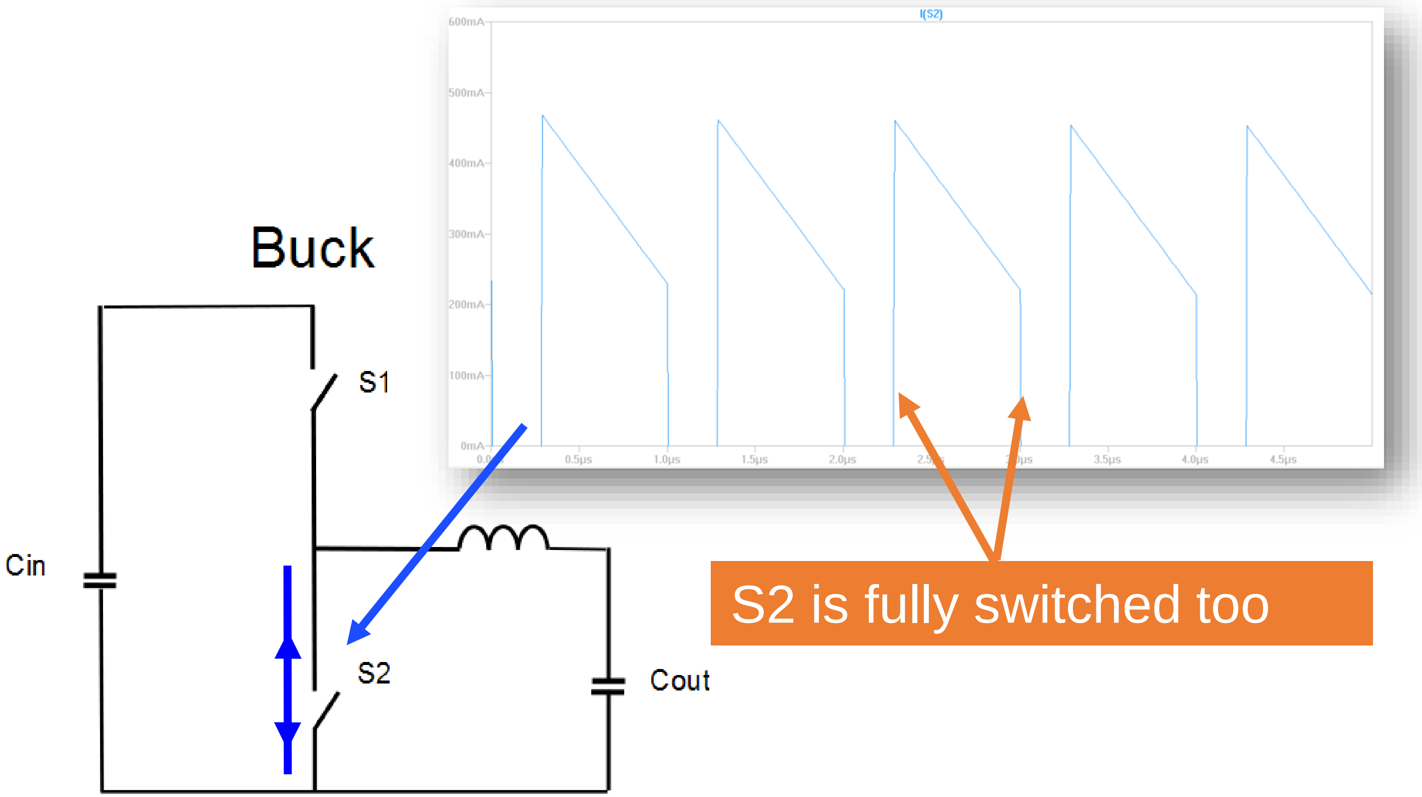
Harmonics of triangular waveforms decay for higher frequency with N^2 N =harmonic number

Synchronous Buck Converter – High Side



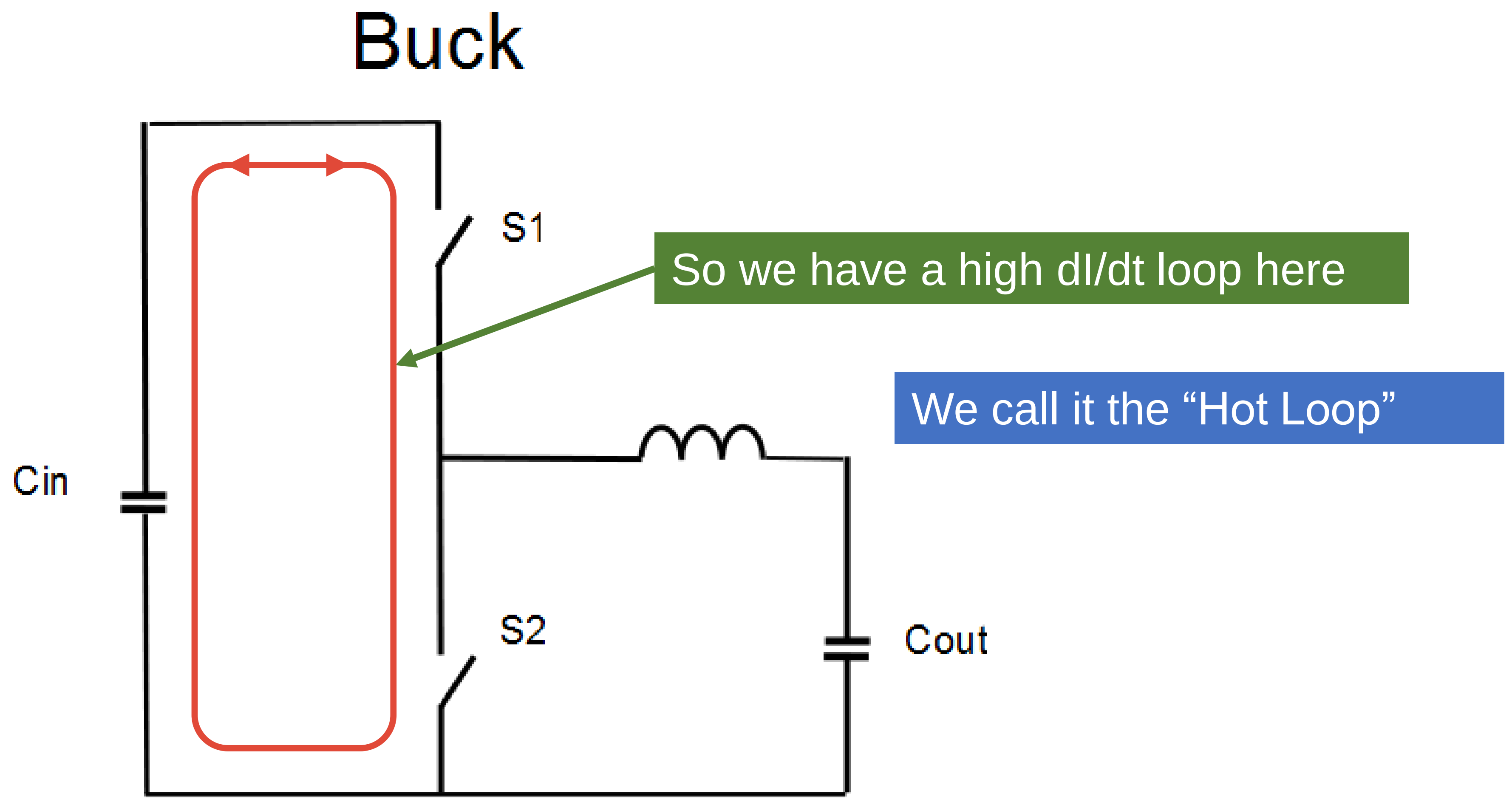
In S1 we have a full switched current which moves to and from zero very fast

Synchronous Buck Converter – Low Side

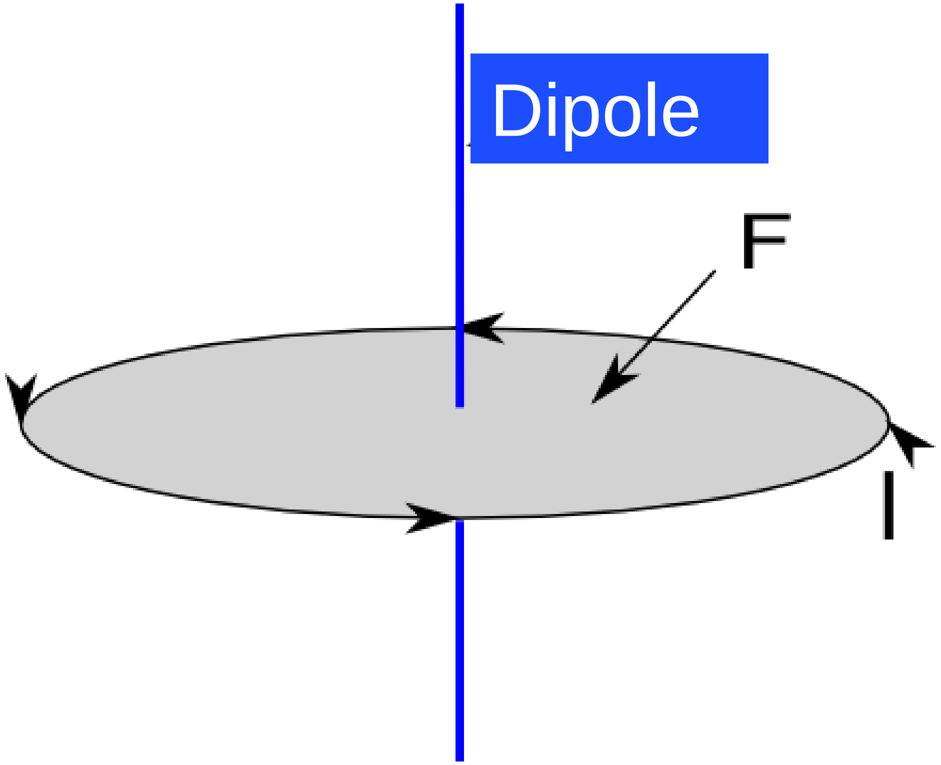


Harmonics of rectangular waveforms decay for higher frequency only with N

Buck Converter – High + Low Side



Magnetic Antennas



Every trace on your PCB transports AC current

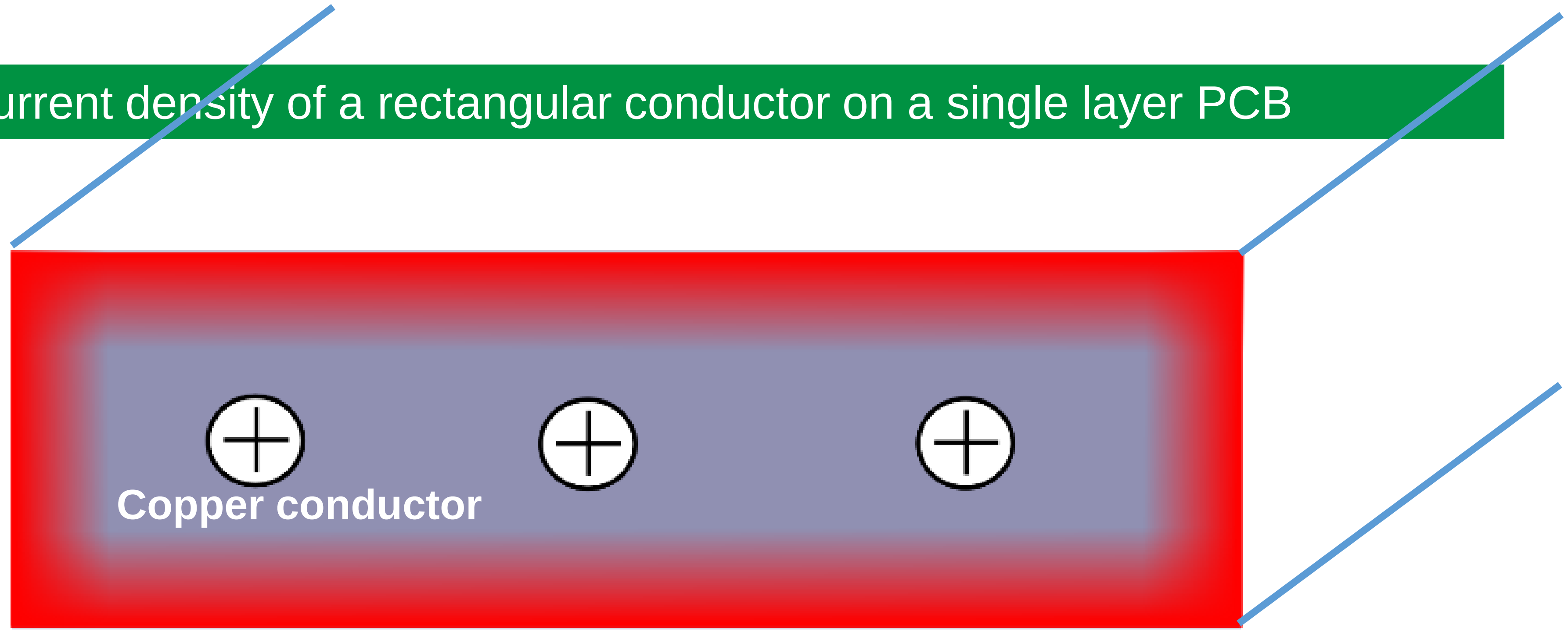
If you create AC current, it forms a **magnetic dipole** antenna

That radiates in the same way that an **electric dipole** does

Radiation goes up proportional to area and current

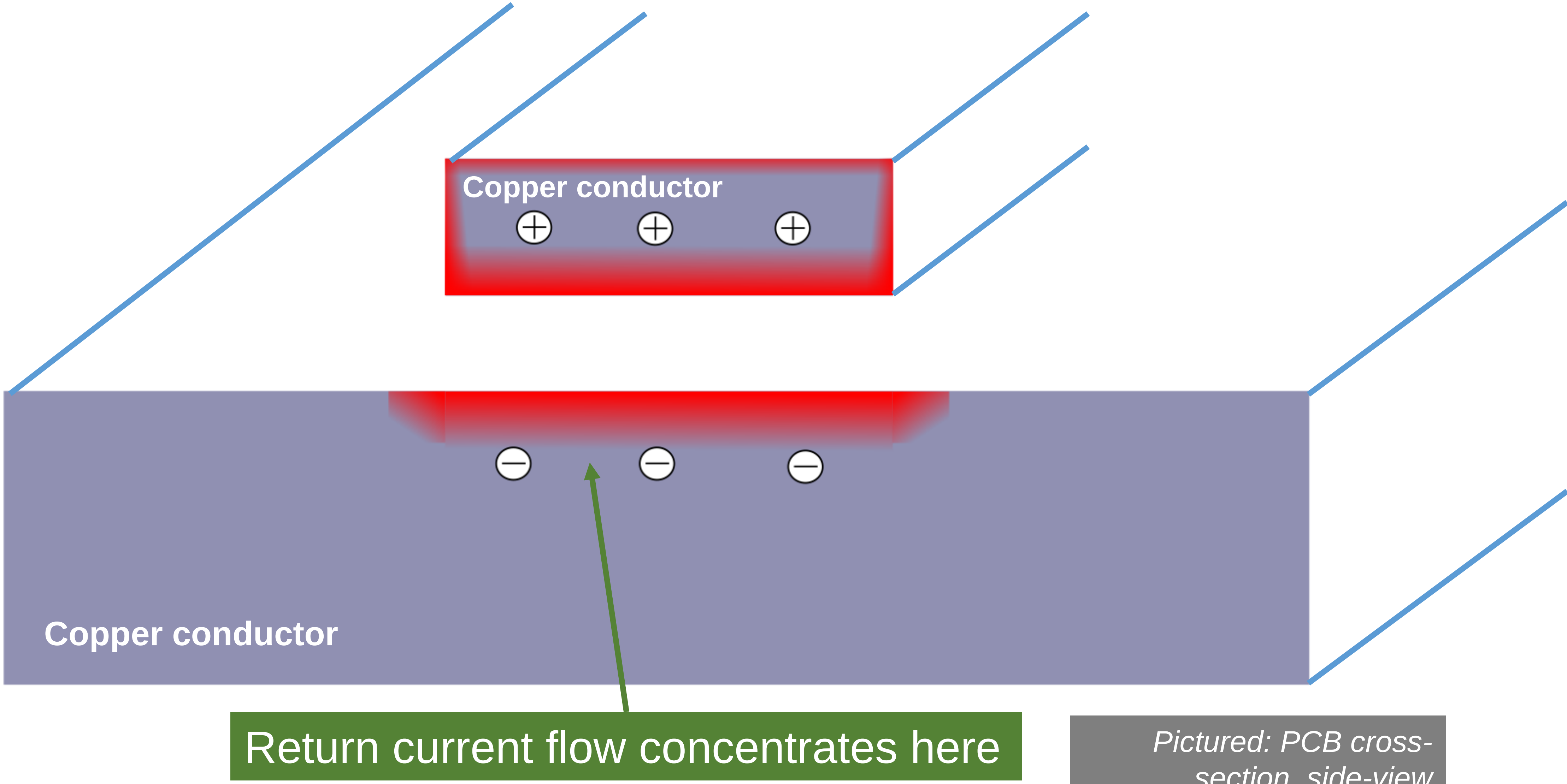
Skin and Proximity Effect

Current density of a rectangular conductor on a single layer PCB



Pictured: PCB cross-section, side-view

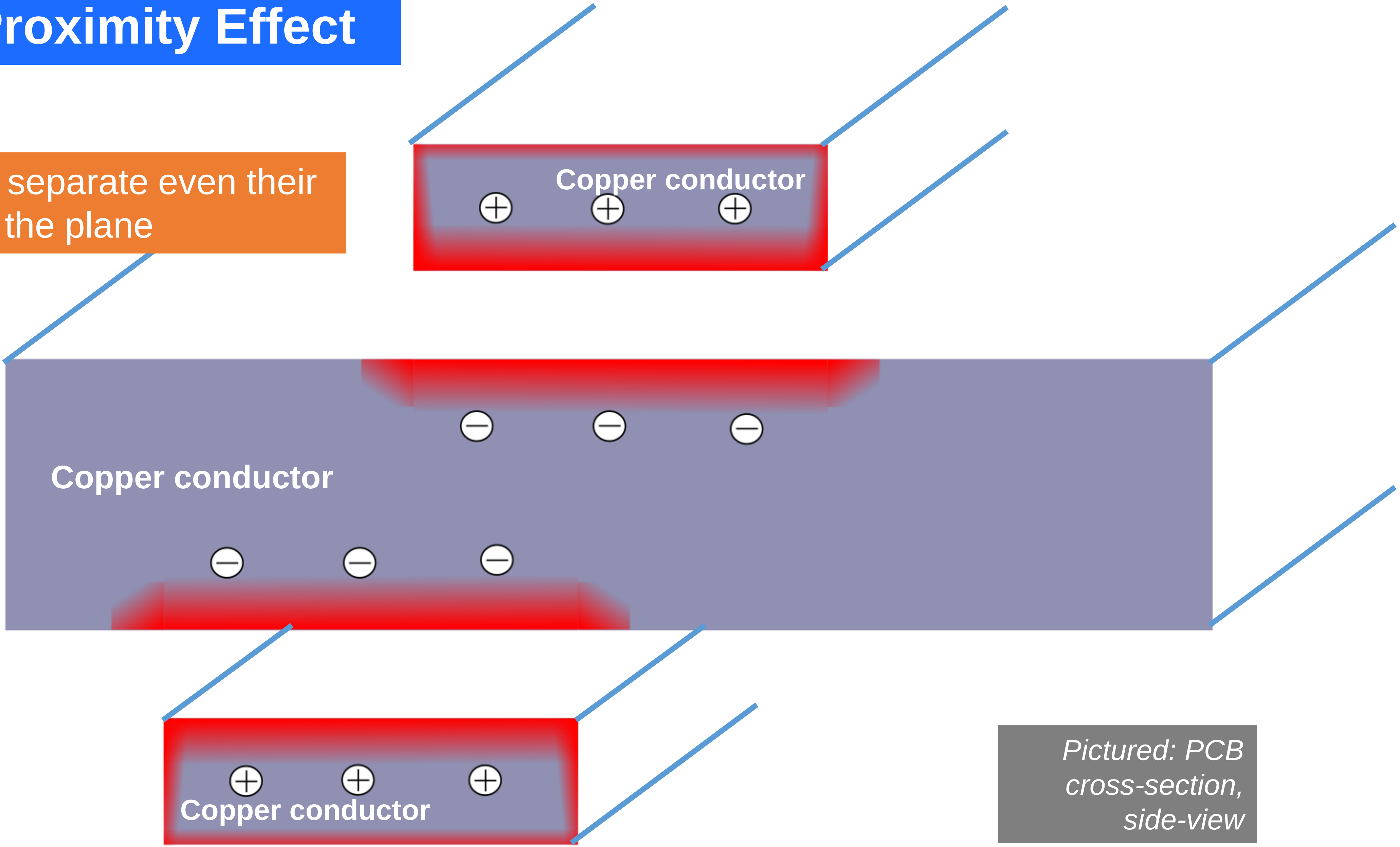
Skin and Proximity Effect – Shielding Effect of Conductive Planes



Pictured: PCB cross-section, side-view

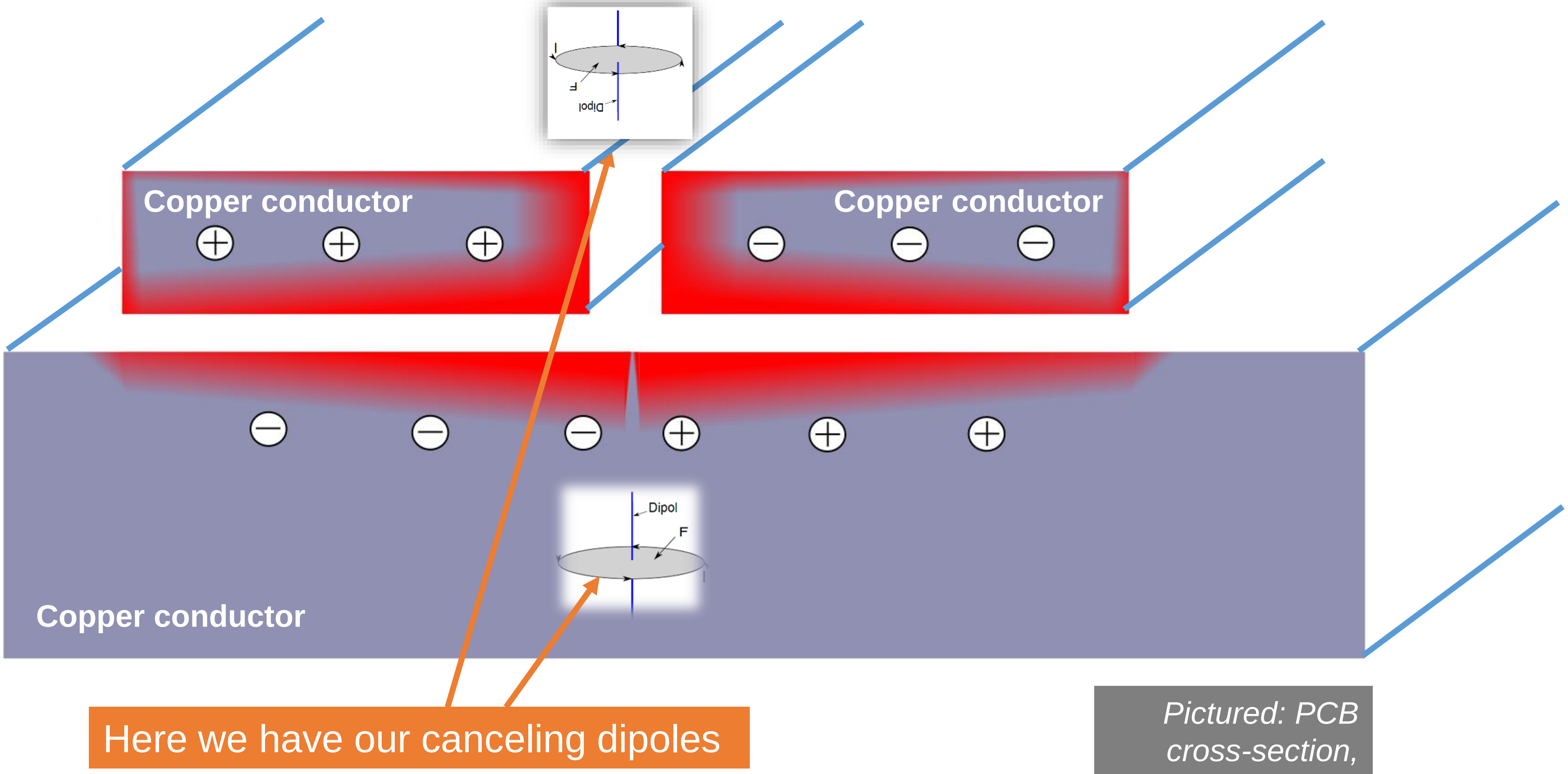
Skin and Proximity Effect

Multi-layer will separate even their return flows in the plane



Pictured: PCB cross-section, side-view

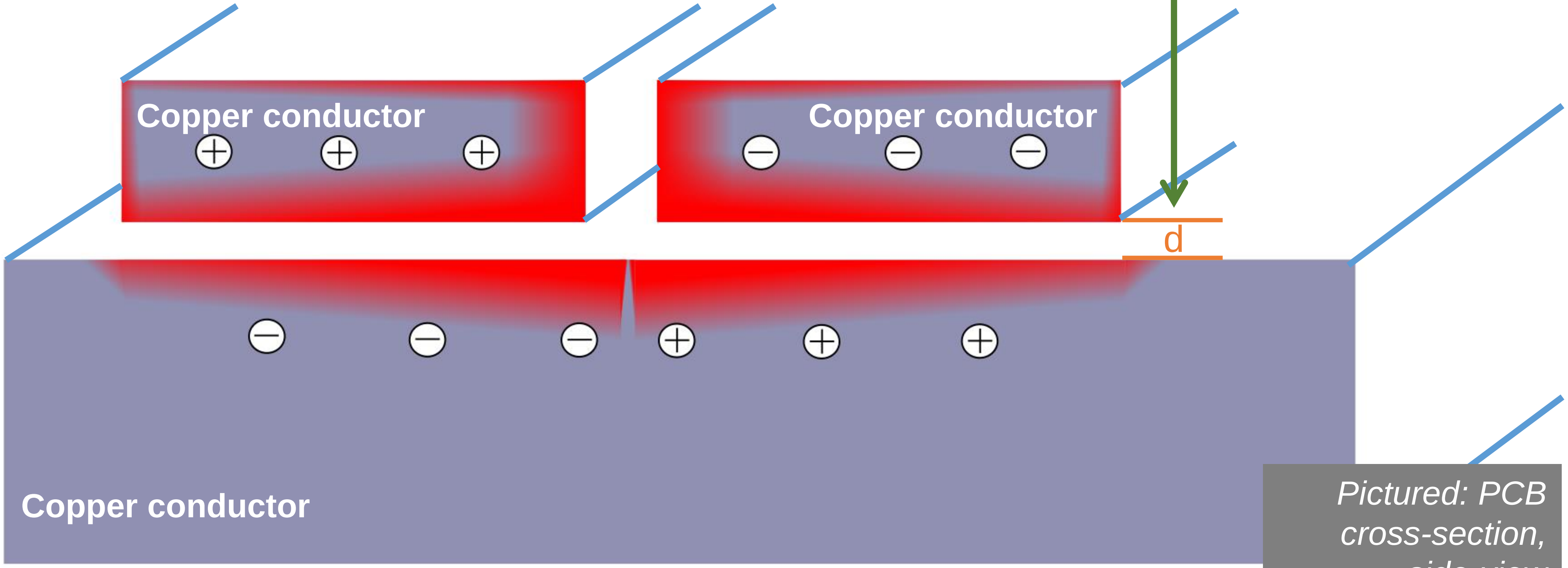
Eddy Currents – Canceling Dipoles



Pictured: PCB cross-section, side-view

Magnetic Antennas

For any given aspect ratio,
cutting [d] in half reduces the radiated field by 6dB



Pictured: PCB cross-section, side-view

Eddy Current Demonstration (Video)

Eddy Currents – Cancellation Effect

Eddy currents can cancel the original magnetic excitation field

They do it better when the eddy current conducting plane and the original magnetic excitation field are closer

Cancellation works better with:

Low profile components (flat, short and wide)

A solid ground plane without gaps and holes under and near the excitation field

Layout Hints

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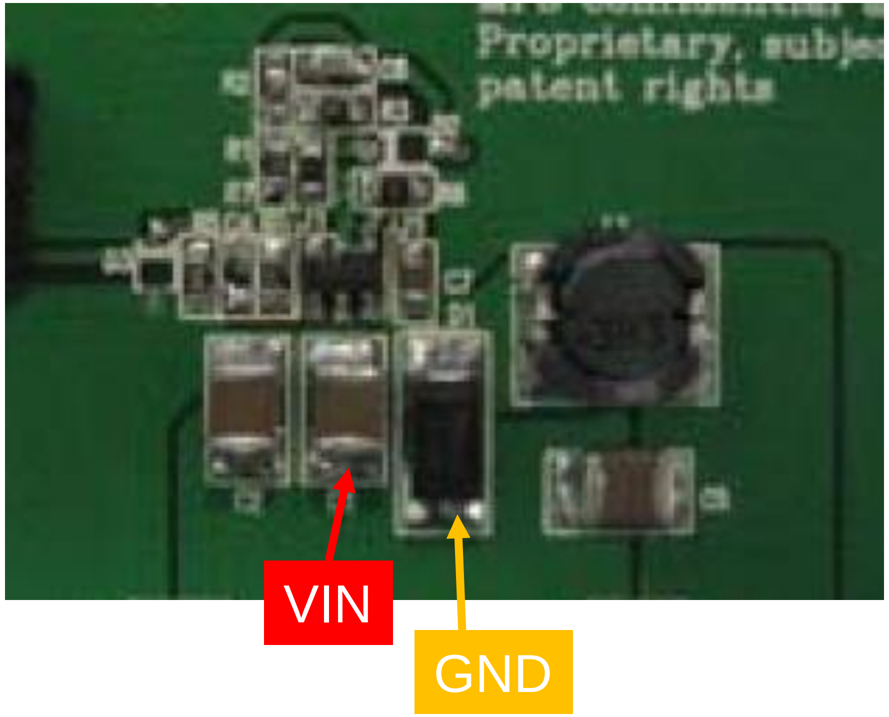
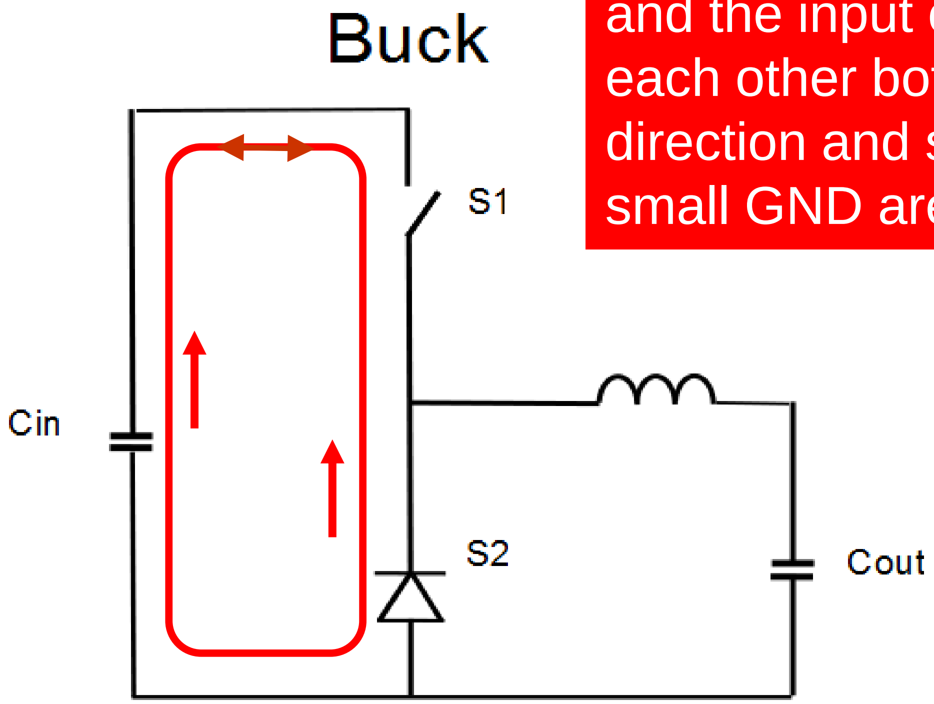
Identify the Hot Loop

Identify the hot loop and
make it as small in diameter as possible

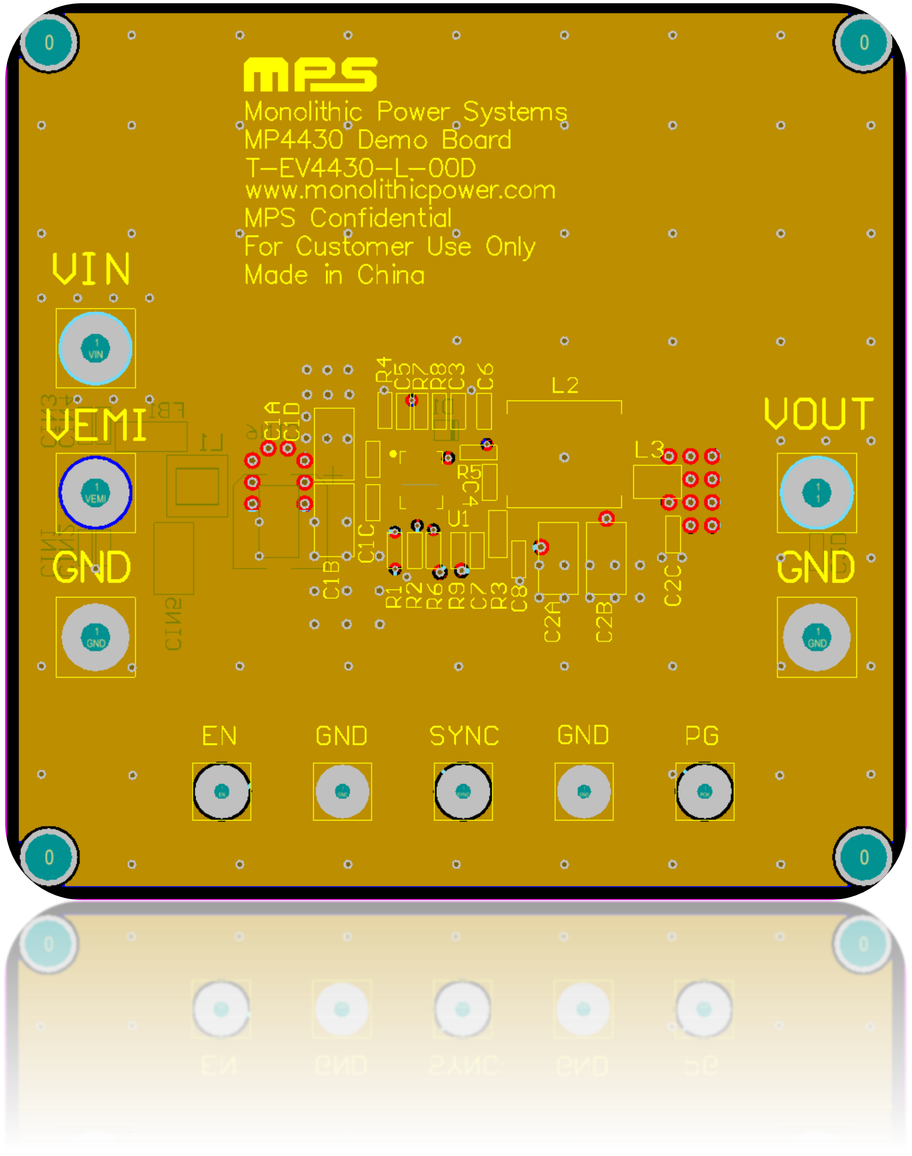
For example, in a non-synchronous buck place the freewheeling diode and the input capacitor close to each other both pointing in the IC direction and share a common small GND area.



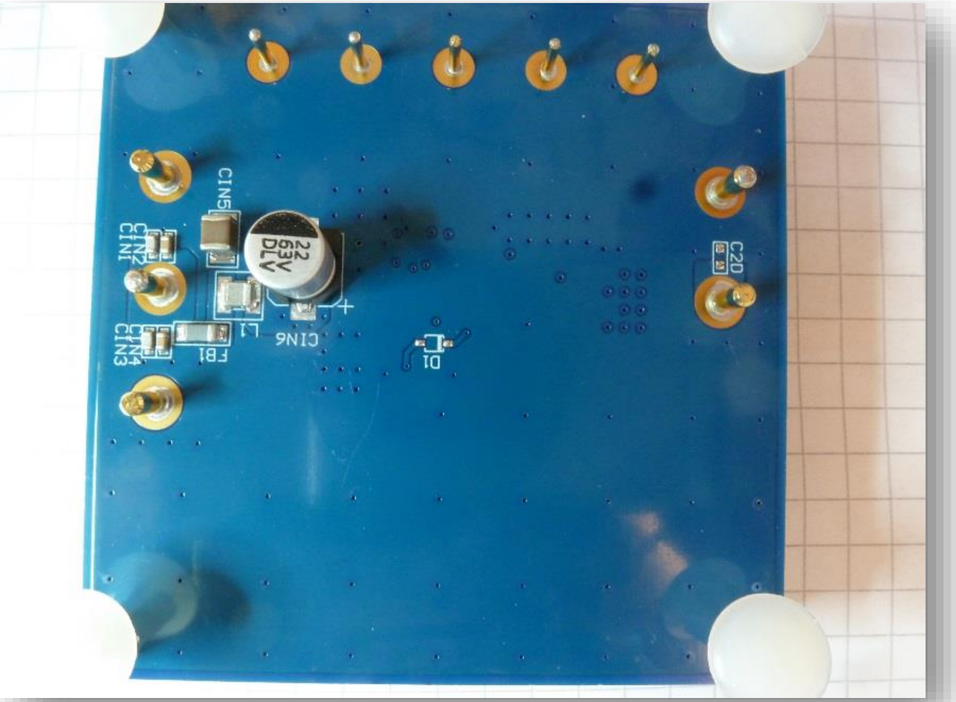


Solid Ground Plane

Place a solid plane under the hot loop, filters etc



Input Filter Placement



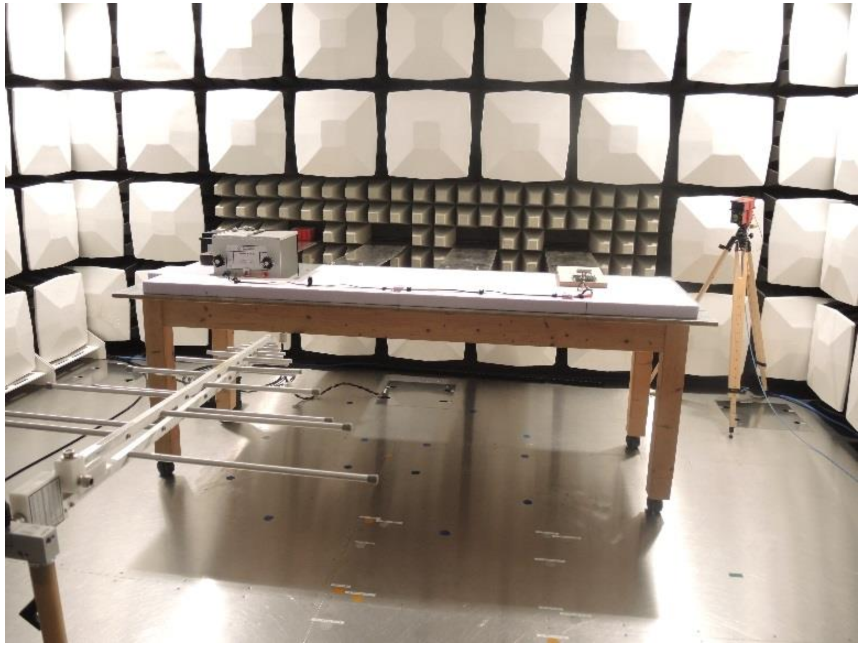
Place your input filter as far away from magnetic and E-field radiators like the hot loop. For this reason we often put the EMI input filter on the backside.

If you can’t move it as far away from the input bypass caps and place a “quiet” GND plane under the filter

4^{th} order EMI filters (2 inductors) work out smaller than 2^{nd} order filters with only one larger inductor. We should know by now why physical smaller lower profile components work better…

Radiated vs Conducted EMI

Radiated EMI measured with antenna



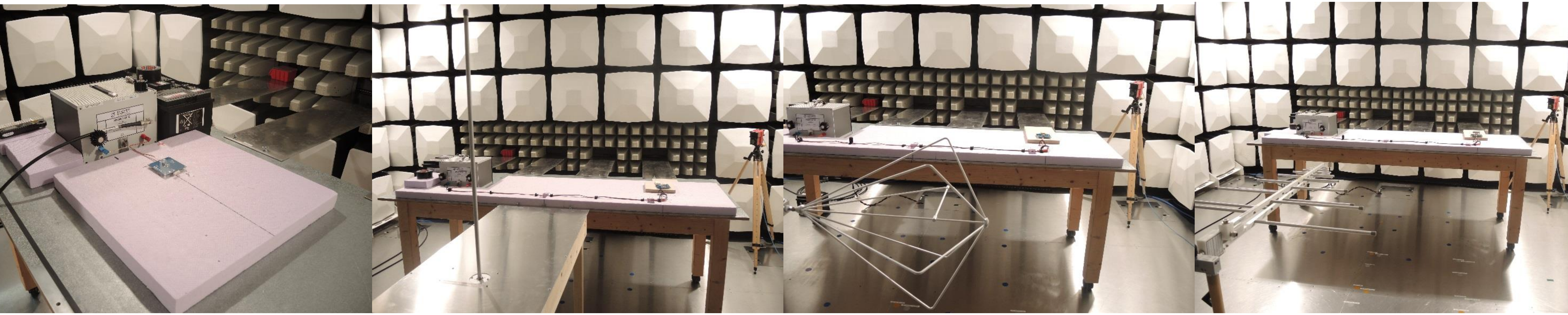
Conducted EMI measured through the cable with a LISN*

You will see significant energy differences *only* as long the fields keep close to the wiring harness, which is up to single-digit MHz when harness length is at least in the range of some 10cm to meters.

*Line Impedance Stabilization Network

Radiated and Conducted EMI

Up to a few MHz circuits behave like their SPICE simulation.
If you're hunting an EMI problem on the **fundamental or first few harmonics,** you can still think as SPICE with concentrated components.



Above a few MHz for all EMI measures, **magnetic field** and **electric field coupling between components and PCB traces** dominates.
Thus, the EMI measures above a few MHz are the same for radiated and conducted emissions.

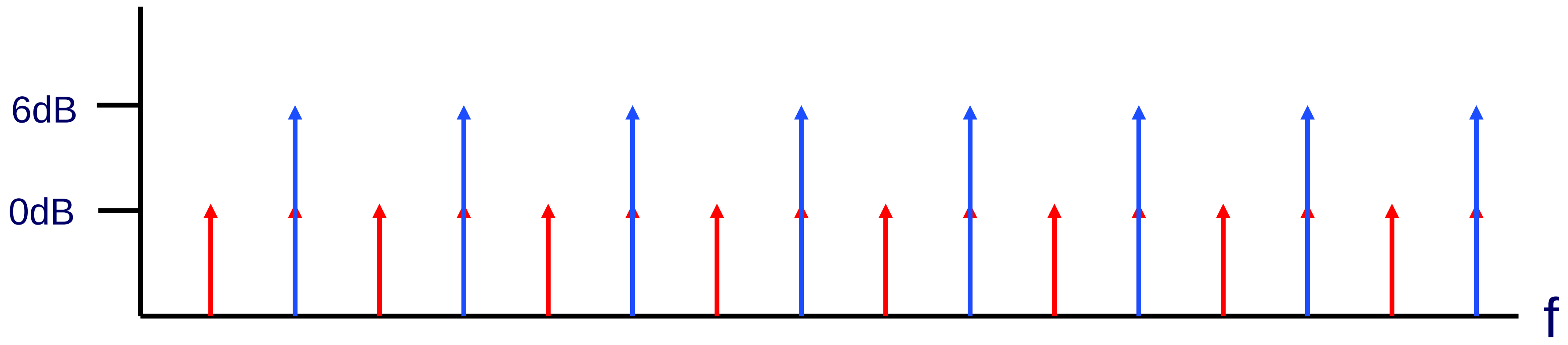
Switching Frequency Effect on EMI

If we **double the switching frequency**, we **double the number of switch transitions**, so we double the EMI energy.

That is 3dB more (power is 10*Log(2))

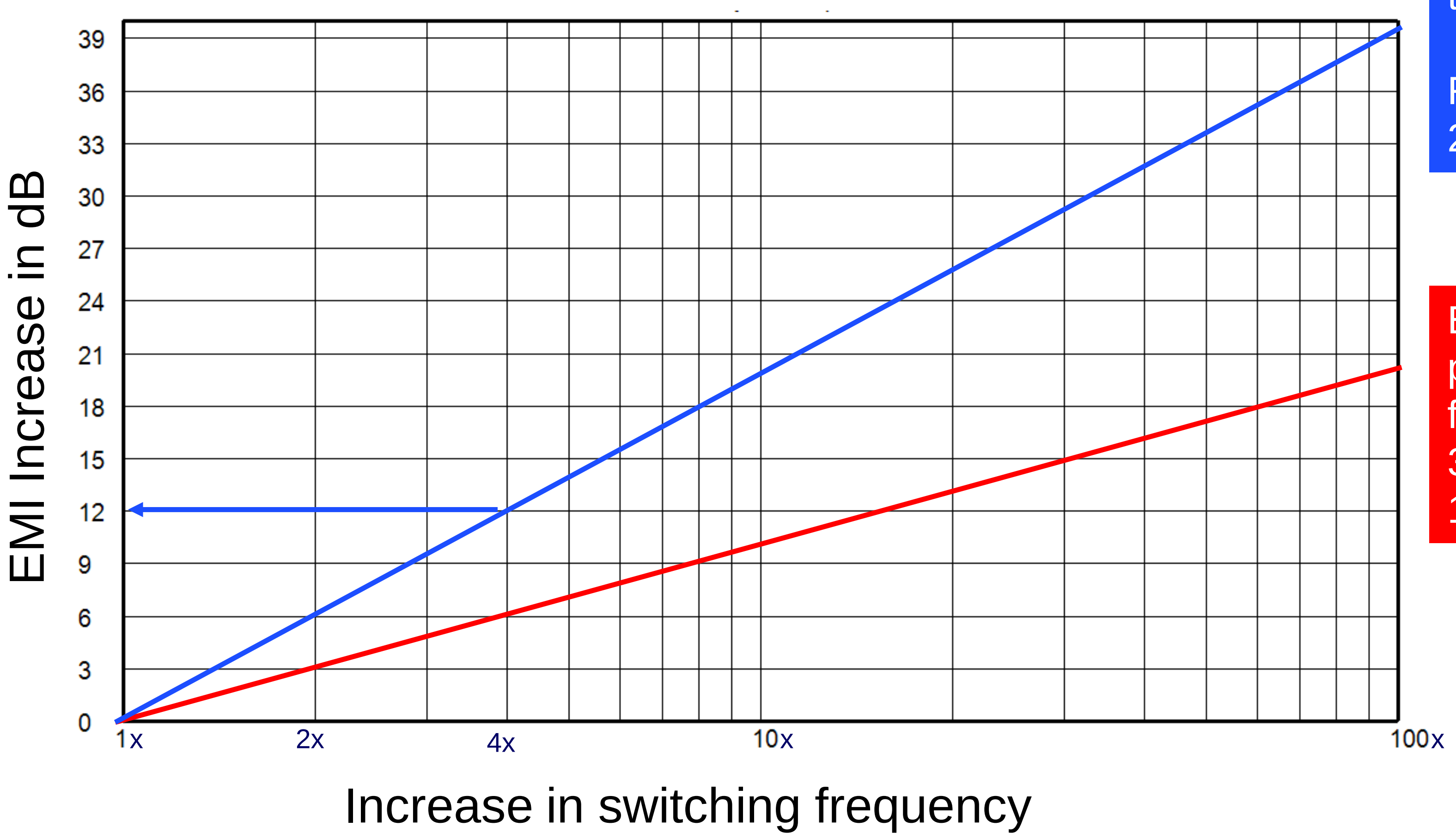
But with **double the frequency** you have now only **half the bins** to locate this energy.

As a result, **the spurs have 6dB more amplitude per doubling the frequency**



Switching Frequency Effect on EMI

If all stays the same except the switching frequency



With fixed frequency for every doubling only half the bins are available for the energy

Result is 6dB/octave = 20db/decade

EMI energy is proportional to switching frequency
3db/octave = 10db/decade

Conclusion

Make your **hot loops** as small as possible.

Place a **solid ground** under the hot loop, EMI filters, inductors etc.

Use **multi-layer boards with thin dielectric** between top and the next GND layer

For stringent automotive EMI, **use 4th order EMI filters (two inductors) with small components**

Use a switching frequency no higher then necessary if you switch voltages like 14V or more. (For POL style voltages with 5V or 3.3V input higher switching frequencies create much less problems)

Use near-field probes for EMI trouble shooting

Above a few MHz, you will not find the EMI problems in the “SPICE” schematic

Look for **magnetic** and **electric field coupling**

Q&A

New MPS EMI test center in Hangzhou, China
Additional labs to be built in Detroit, Germany & Shanghai