Power Supply Design Seminar

(Demo Hall Presentation)

Designing Low-EMI Power Converters for Industrial & Automotive Systems

TI Literature Number: **SLUP362**

Power Seminar topics and online power training modules are available at:ti.com/psds

TEXAS INSTRUMENTS

Designing Low-EMI Power Converters for Industrial & Automotive Systems

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Agenda

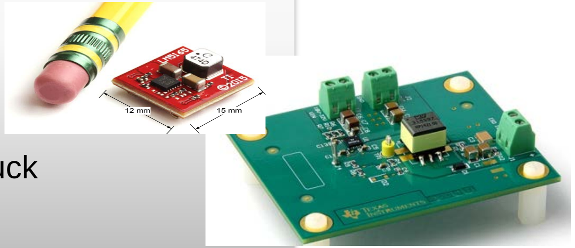
- Key features of Wide Input Voltage (Wide VIN) Automotive and Industrial DC/DC Converters
- Techniques for reducing emissions in Switching Power Supplies
- EMI Mitigation by proper PCB Layout
- Spread Spectrum
- Slew Rate Control
- Input EMI filter design
- WEBENCH EMI tool

Wide Vin DC-DC Leadership

Synchronous Switchers

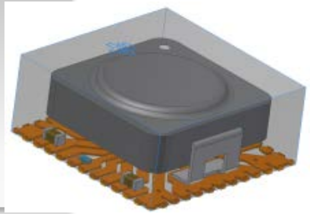
- Synchronous regulators - up to 40V operation
- 2.2MHz switching frequency options
- Very Low (µA) no-load quiescent current
- LM536xx 0.65A to 3.5A 2.1MHz
- Coming Soon: LMR23610/25/30 1A, 2.5A, 3A

Specialty Buck Regulators



- Synchronous regulators, up to 100V operation
- Fly-Buck support: smallest multi-output bias supplies
- LM5160A and LM5161 65V and 100V Sync Buck / Fly-Buck
- Coming soon: LM5165/6 Ultra-low Sync Buck
  - 65V, 150mA/500mA versions w/ 10uA standby Iq

Wide Vin Buck Regulator Power Modules



- Integrated inductor modules with input range to 60V
- Proven EMI performance
- LMZ34202 and LMZ36002   4.5V to 42V or 60V at 2A

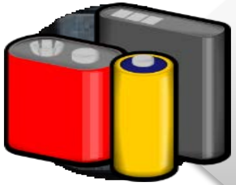
Wide Vin DC-DC Leadership

Buck-Boost, Boost Controllers

- Synch & non-synch buck-boost controllers up to 75Vin & 200W
- Stackable, multi-phase synchronous boost controllers
- LM5175-Q1 USB PD (Type C) reference designs in progress
- Coming soon: LM5170 - the first 48<->12 bidirectional controller

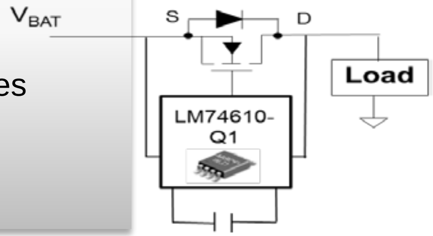
Buck Controllers

- The only 100V buck controller in the TI portfolio
- Emulated Current Mode simplifies high step-down & high current
- LM5140/1 Dual/single 2.2MHz buck controllers - 3.8-65Vin, 2.2MHz, 30µA Iq, phase interleaved, EMI reduction

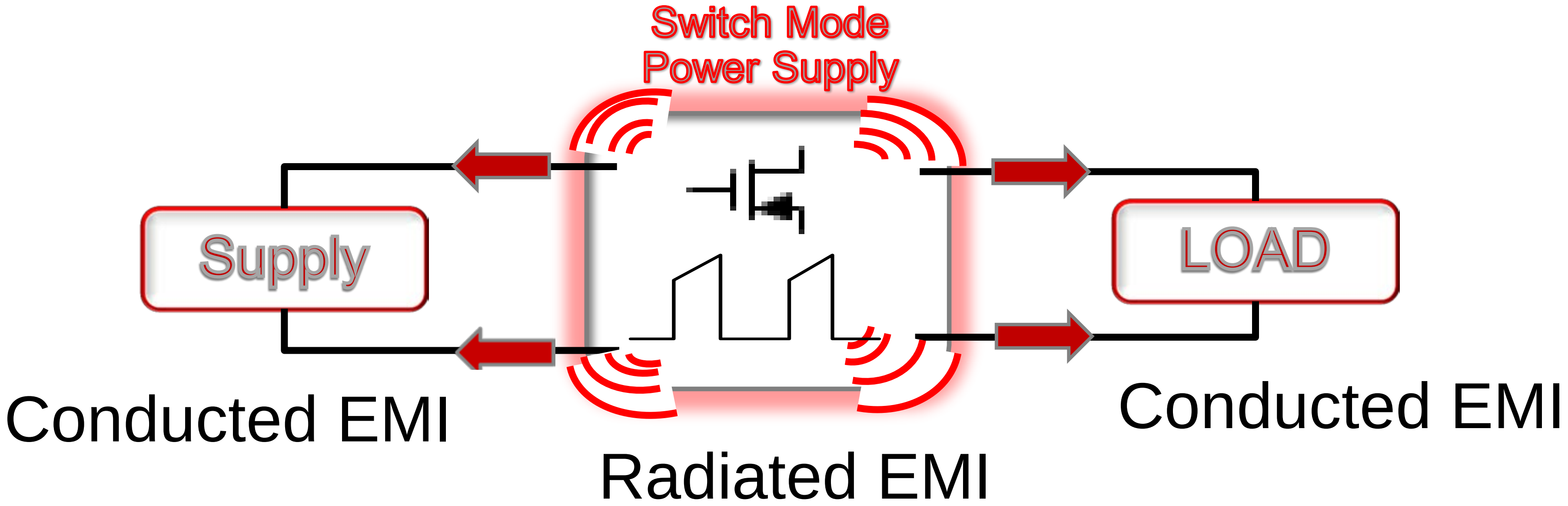


Smart Diode Controllers

- Replaces reverse voltage protection diode with NFET to reduce losses
- Ideal diode for wired OR' applications with multiple power sources
- No ground connection required – zero quiescent current
- LM74610 / LM74670

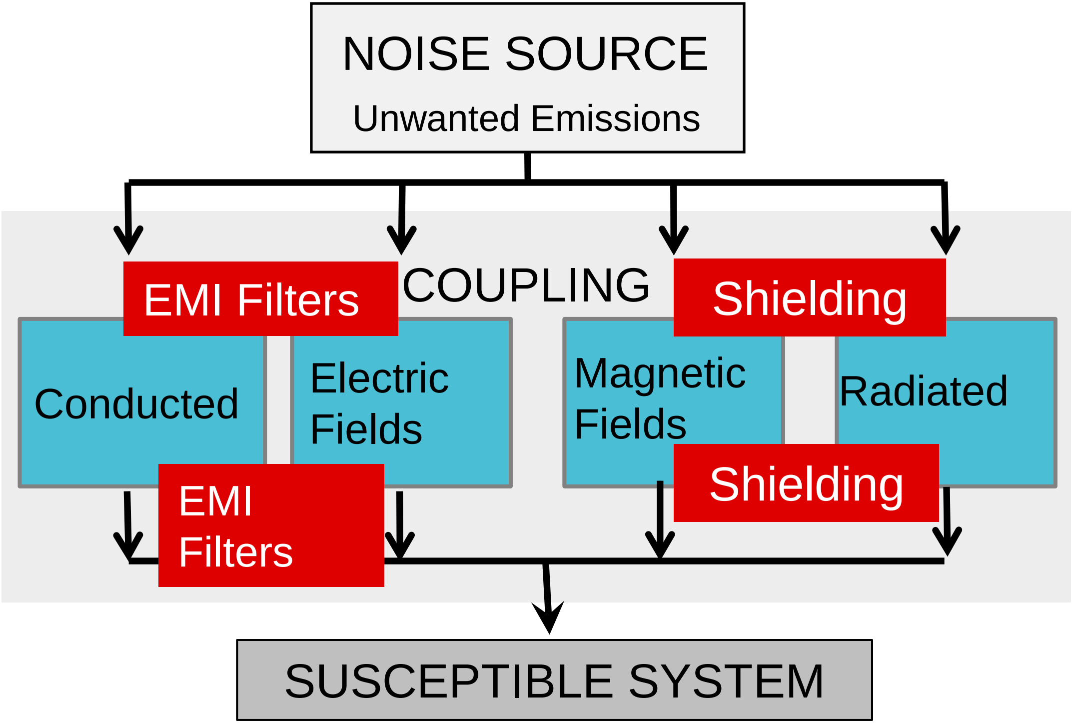


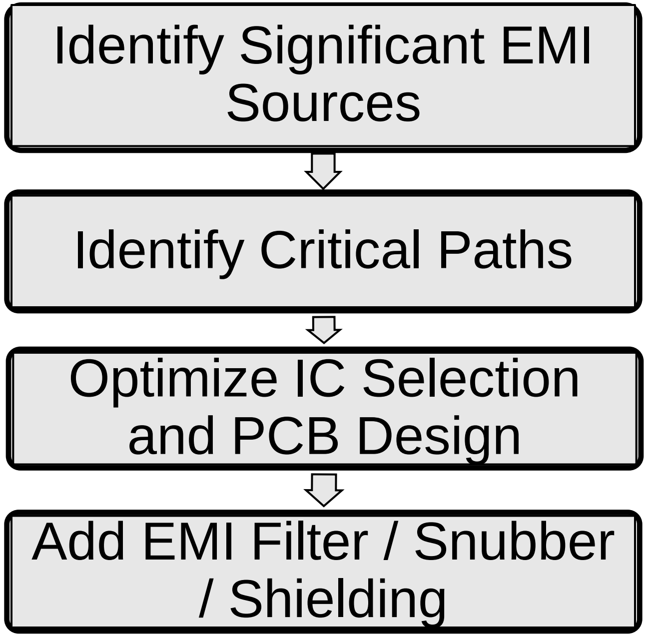
EMI in Switch Mode Power Supplies



GOAL: **EMI** Noise Generation ↓ **EMC** Noise Compatibility ↑

Engineering Approach To Mitigate EMI





Steps To Mitigate EMI In PCB Design

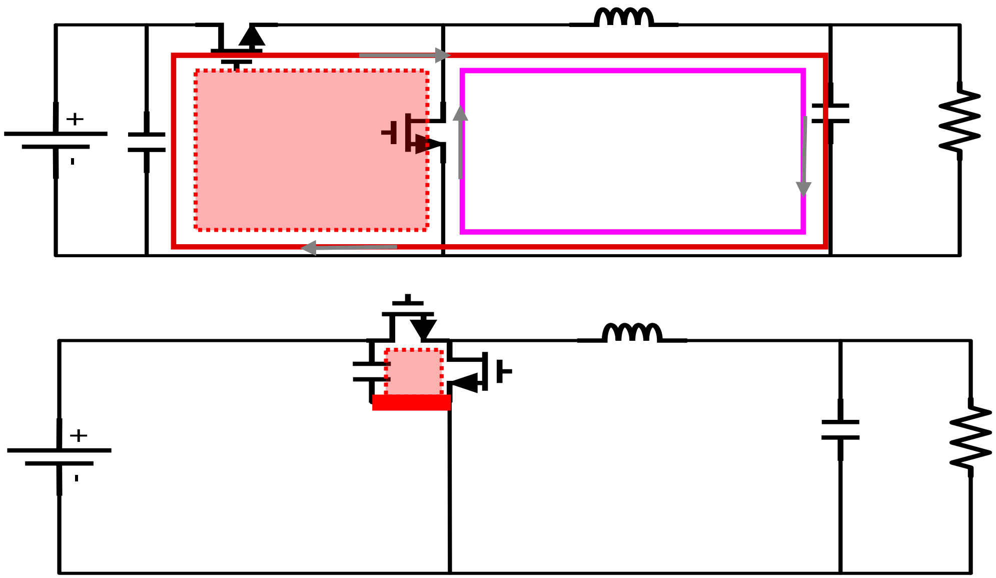
Identify the high di/dt nodes and paths

Reduce high di/dt loop area (inductance)

Protect sensitive circuits from noise

What Can We Do In PCB Layout?

Buck Converter



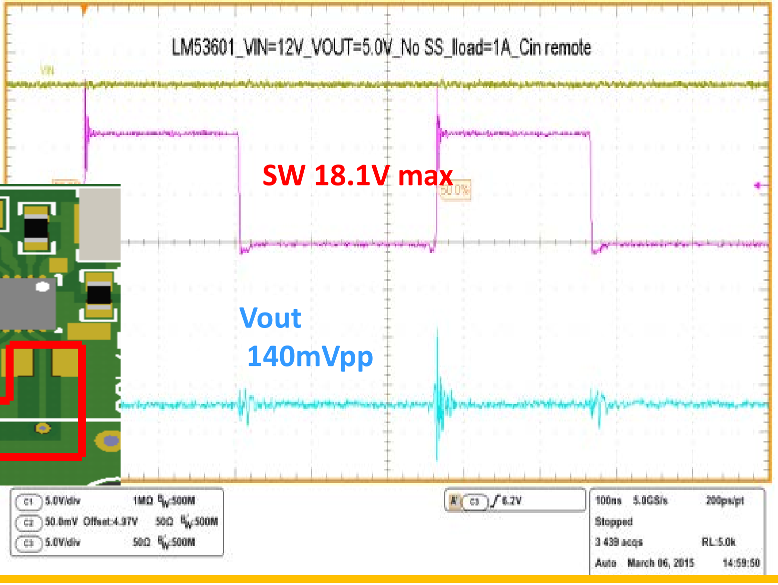
- Minimize critical path area
- Separate noisy ground path from quiet ground

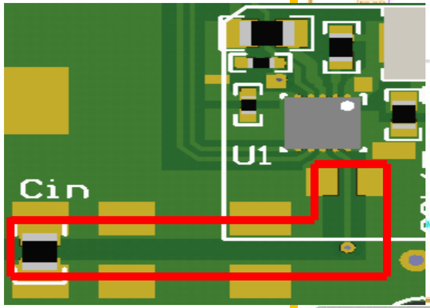
Critical Path Area Comparison

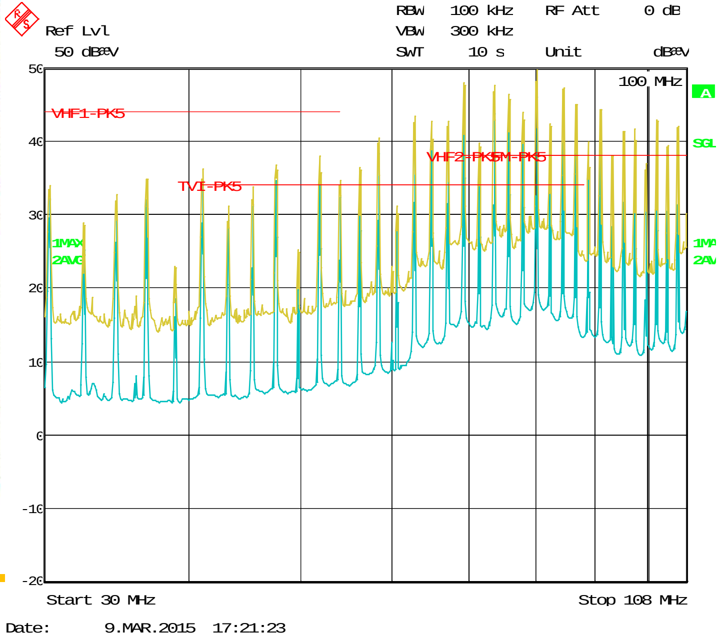
Critical Path Area Reduction | Grounding

High di/dt Caps

- Buck Regulator comparison with Cin location (single Cin, ~3 times larger area)







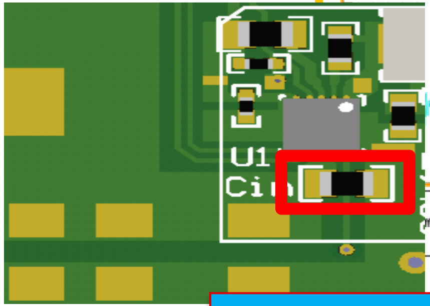
Yellow trace is Peak measurement and Blue trace is Average.

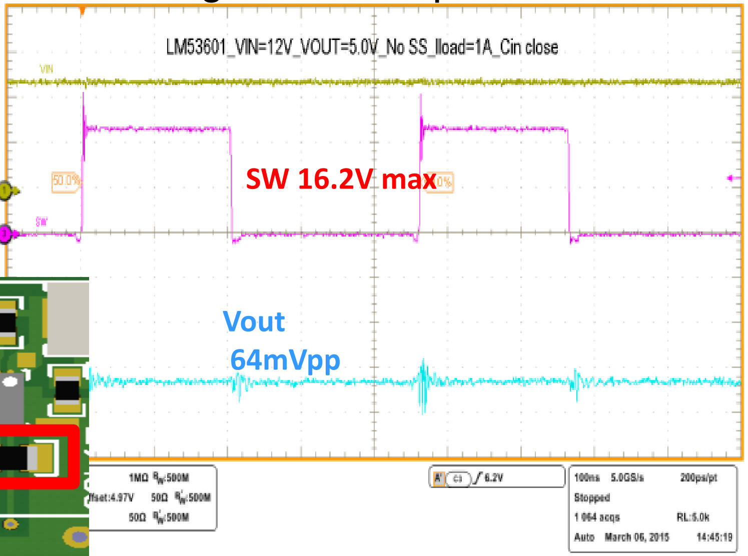
Critical Path Area Comparison

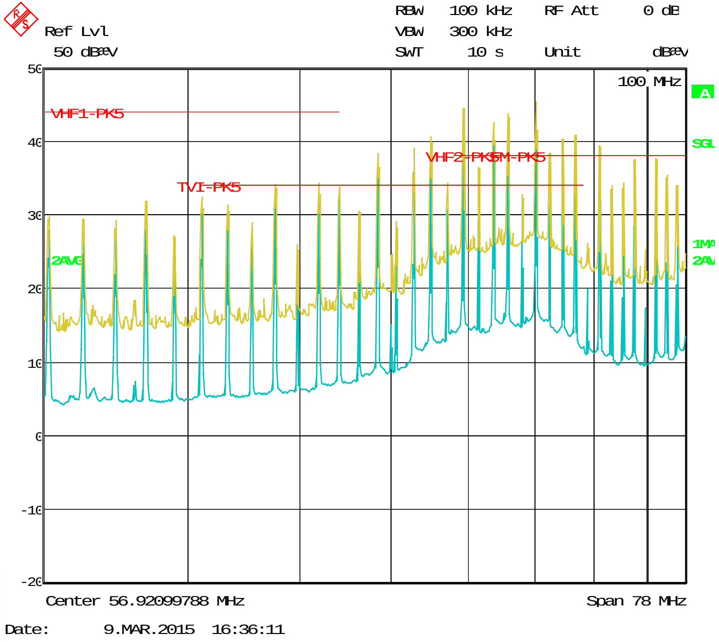
Critical Path Area Reduction | Grounding

High di/dt Caps

- Buck Regulator Comparison with Cin location (single Cin, smaller loop area)



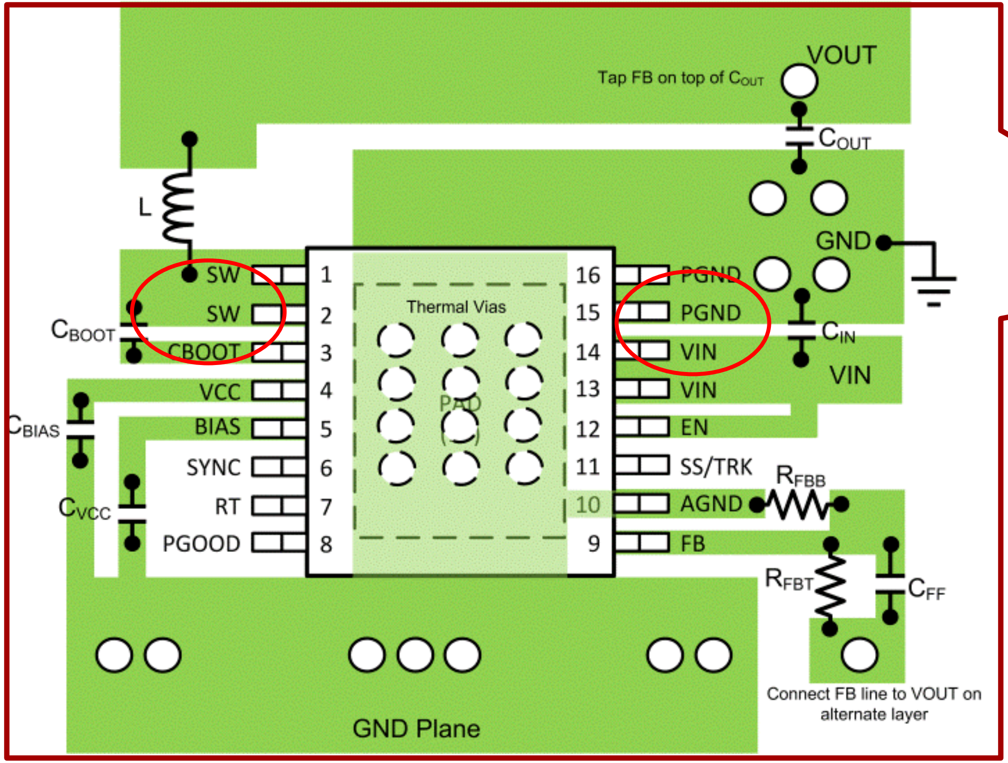


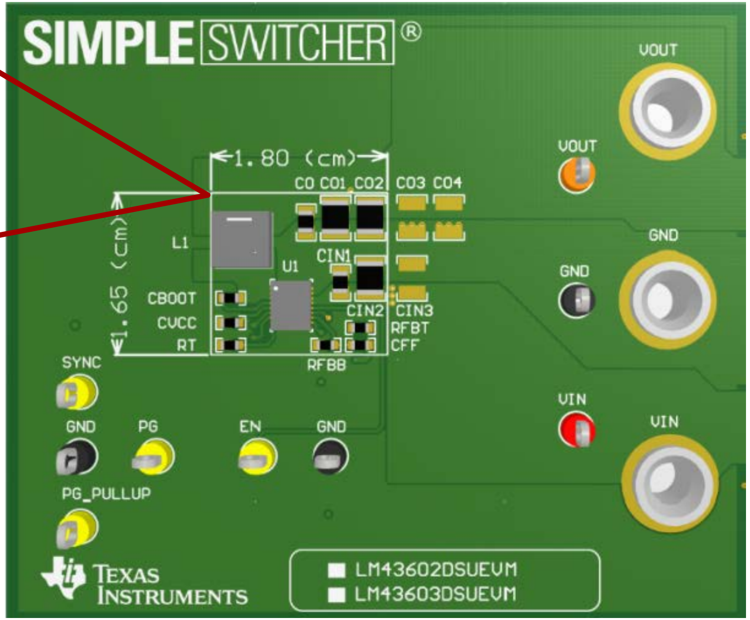


Comparison	SW max (V)	Vout p2p (mV)	EMI peak (dBµV)
Smaller Area	16.2	64	45
Larger Area	18.1	140	50

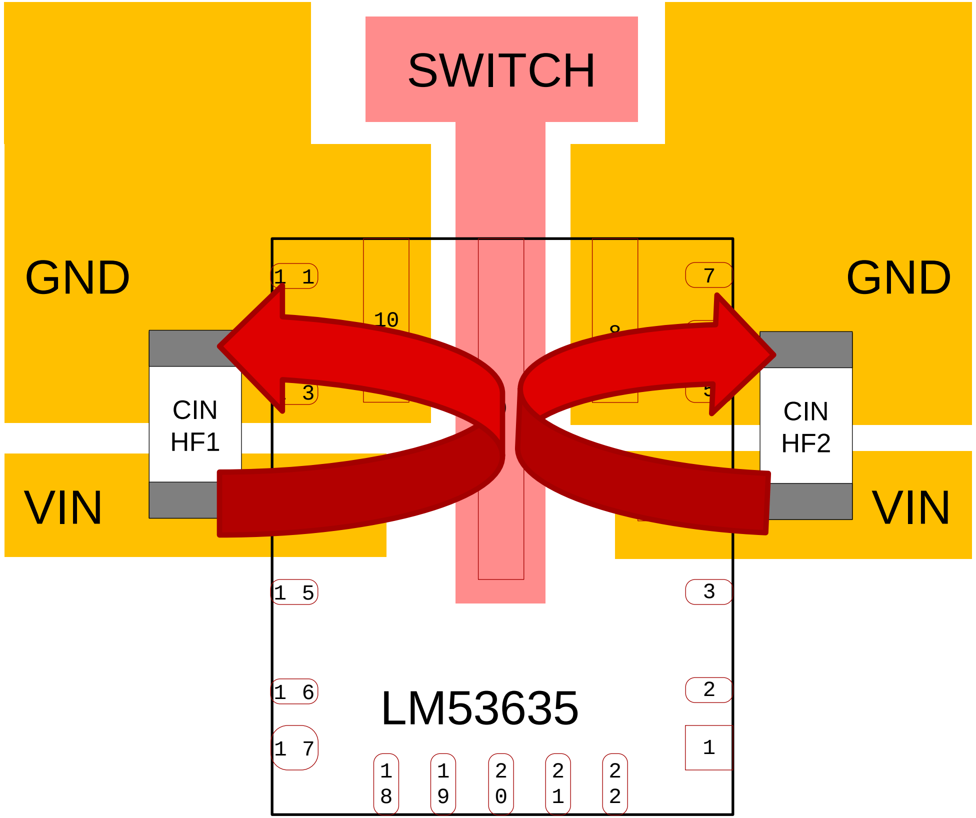
PINOUT Designed With Performance In Mind

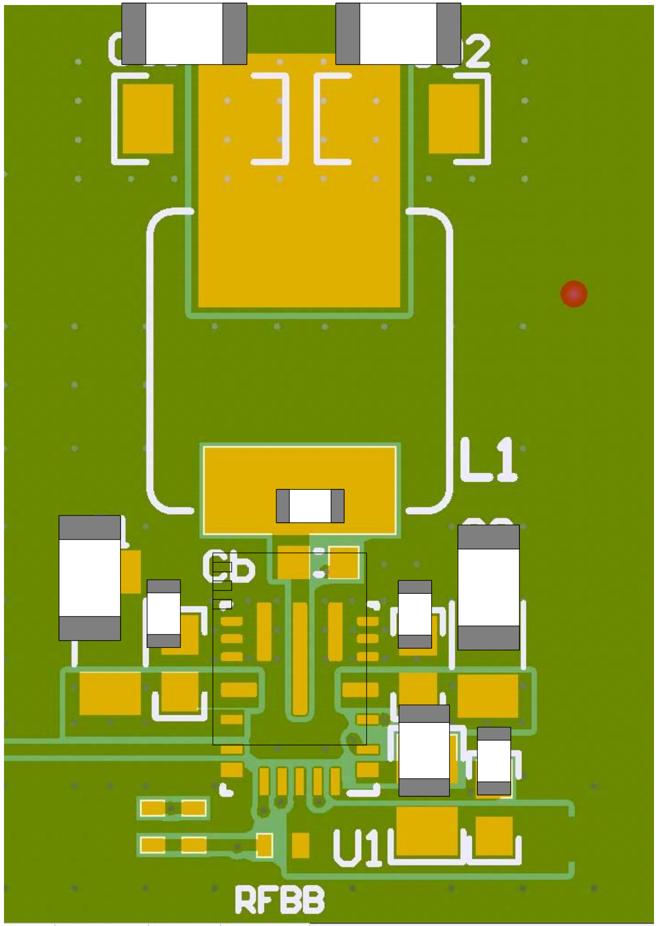
Compact, Low EMI, Good Thermal Performance
for Industrial applications





Parallel input cap placement for Automotive Applications

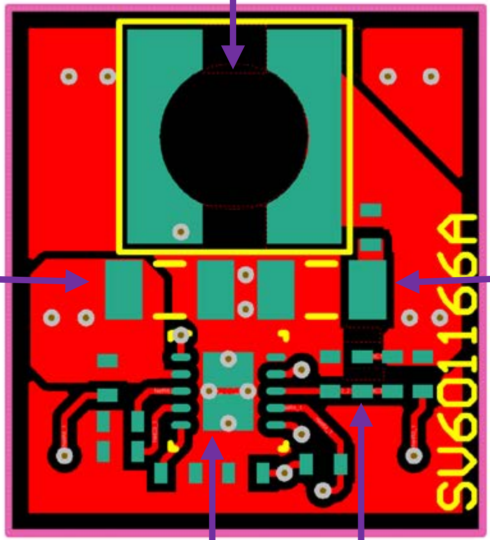




PCB Layout Tips…for High Current Buck Controller Applications

Remove copper between inductor pads to reduce parasitic capacitance

Keep Input Cap close to LM5165



Output Cap

µPower Converter IC

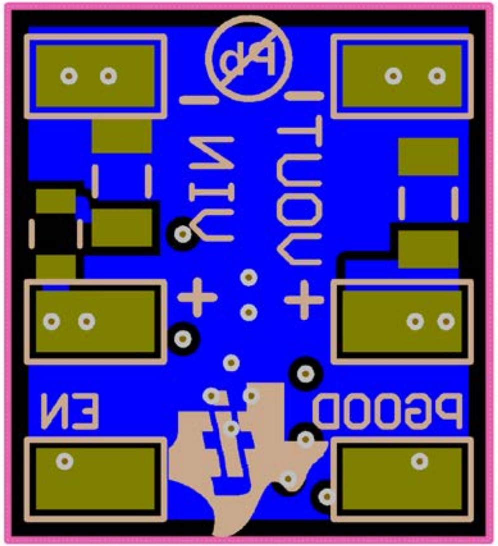
Position Feedback Resistors close to FB & GND pins

Full layer ground plane under converter top side layout provides H-field cancellation

GND Terminal

Input Terminal

EN Terminal



GND Terminal

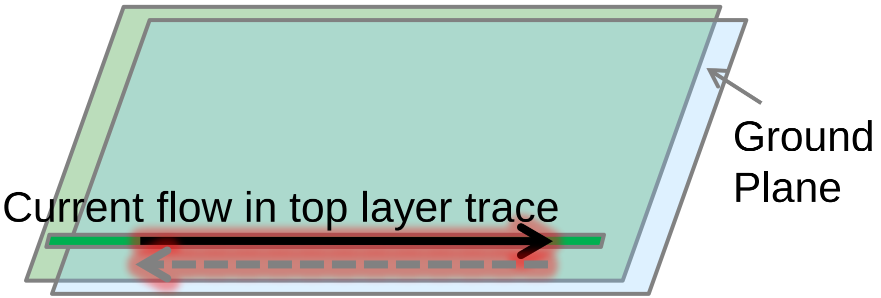
Output Terminal

PGOOD Terminal

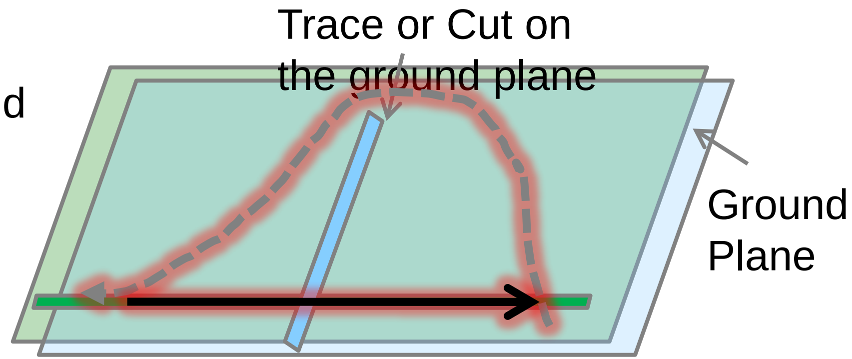
EMI Mitigation by PCB Layout

Critical Path Loop Reduction	Grounding

- Ground Plane
  - o Return Current Takes The Least IMPEDANCE Path
  - o Unbroken Ground Plane Provides Shortest Return Path – Image current return path

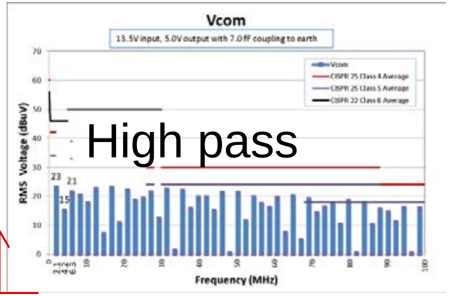


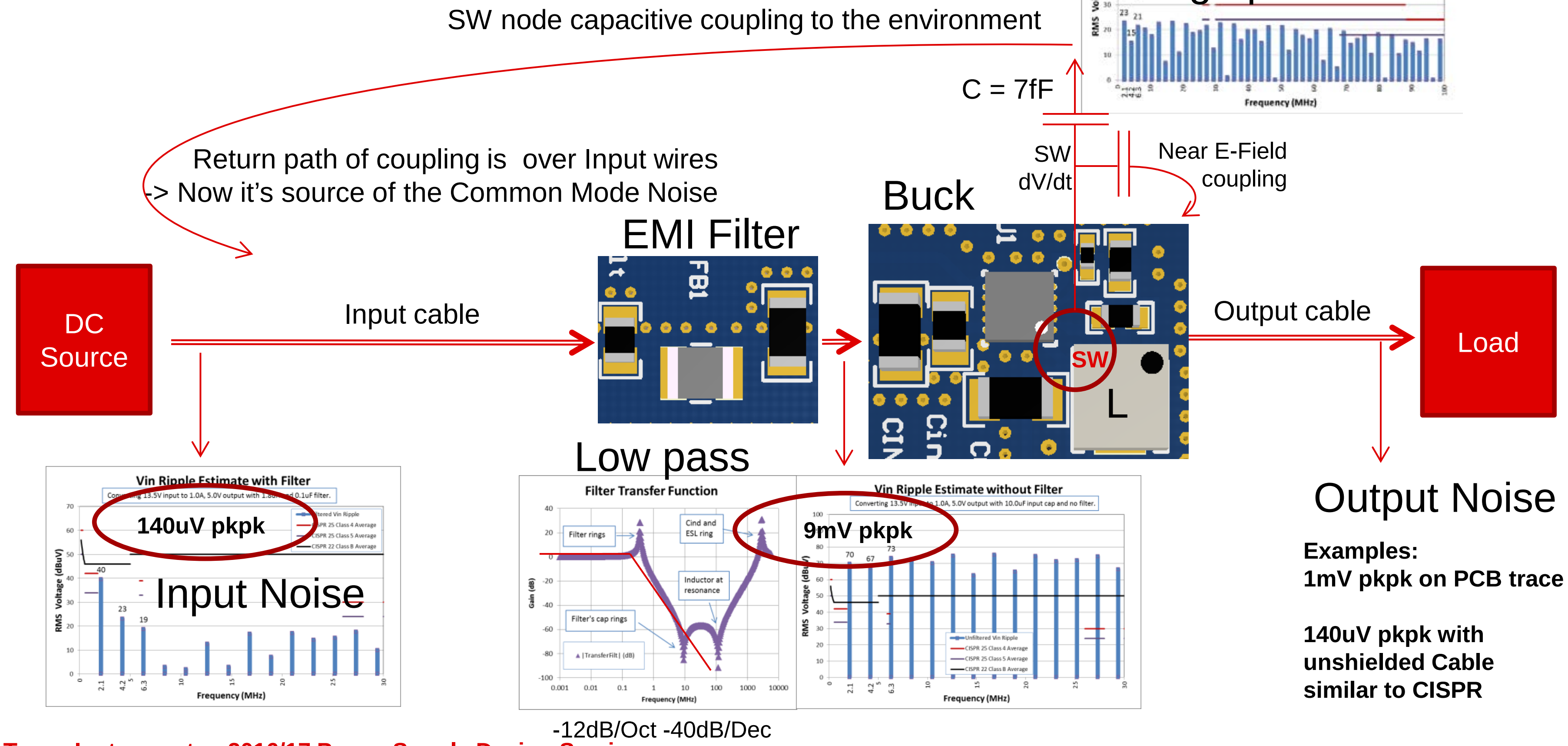
Return current path in unbroken ground plane directly under path
Area minimized, B field minimized



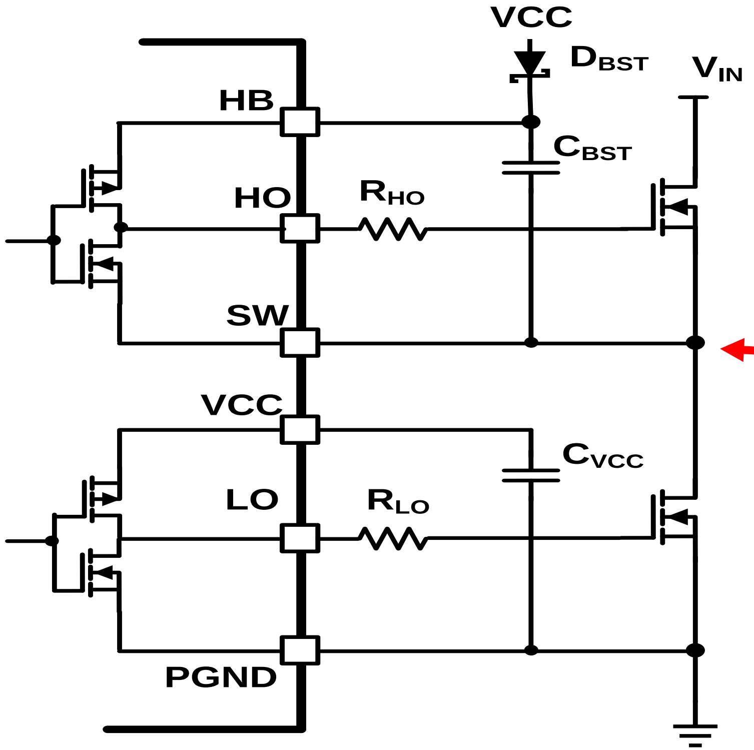
Return current path enclose much larger area if the direct path is blocked

What makes a low EMI Buck

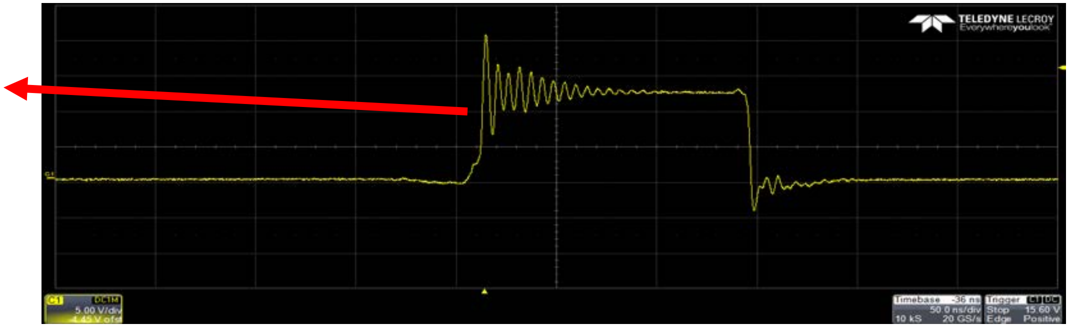




Buck Switch Node Voltage Ringing Due to Circuit Parasitics

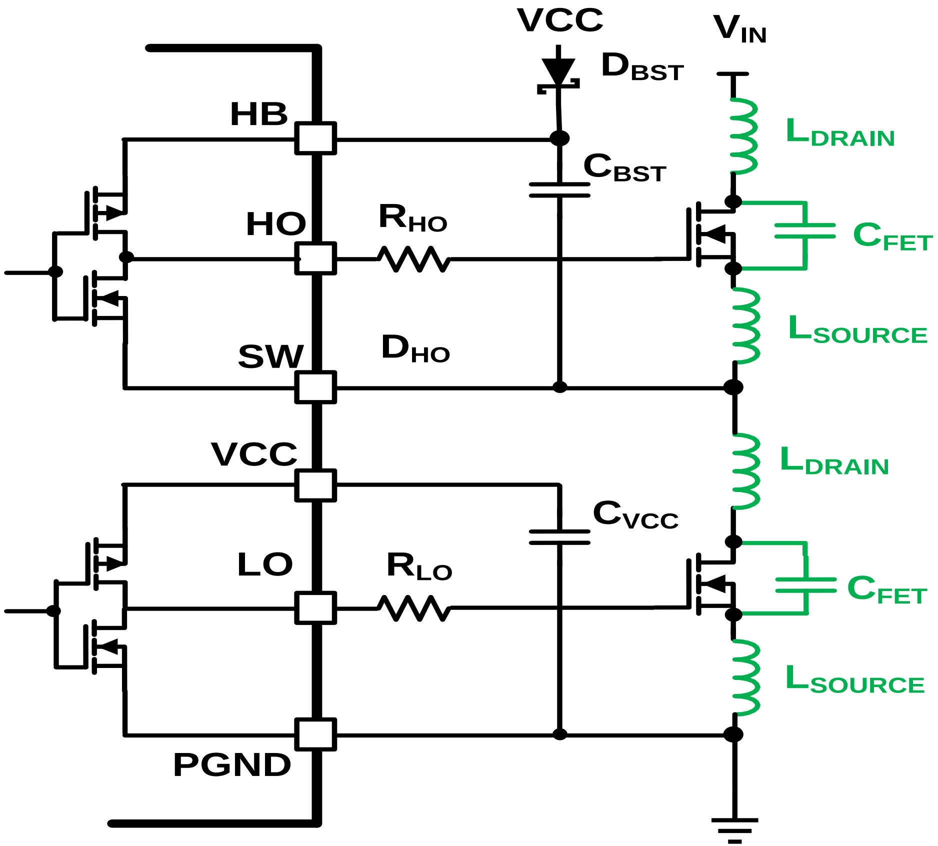


Switch node ringing generates EMI in the FM Band> 30 MHz

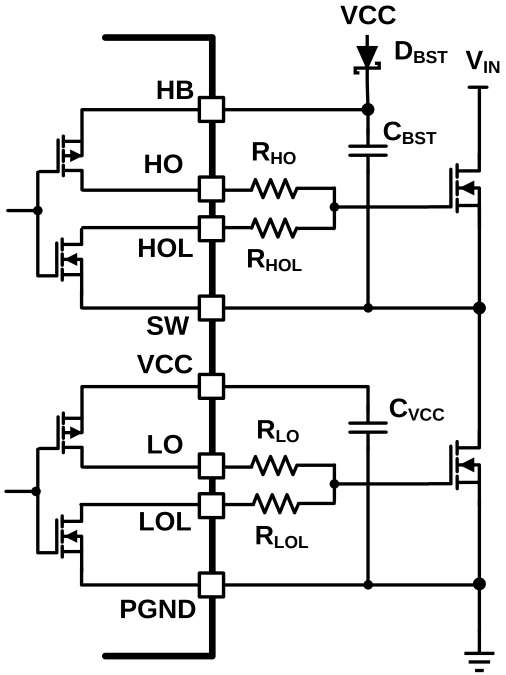


FET Package and PBC Parasitics

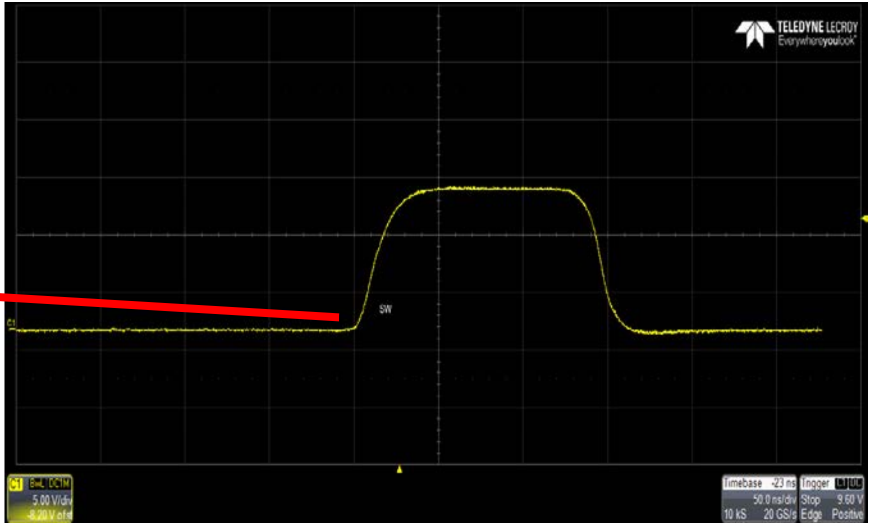
- MOSFET package inductance, and capacitance
- PCB inductance and capacitance



Buck Switch Node Waveform with Slew Rate Control No Snubber



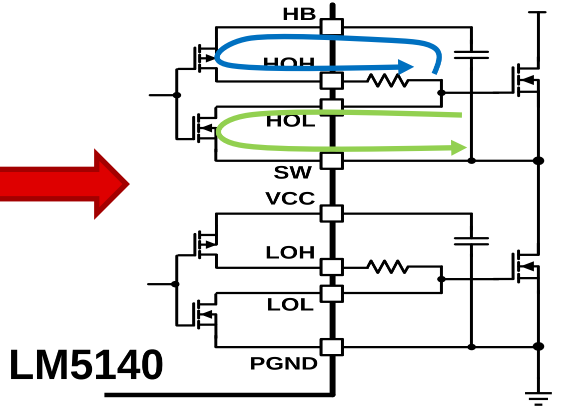
Using slew rate control the switch node ringing is eliminated



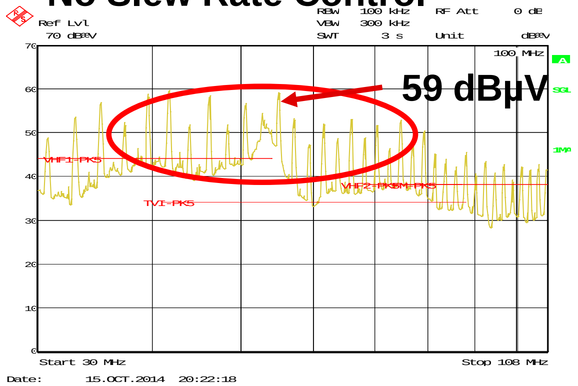
R_{HOH}=10 ohms
R_{HOL}=0 ohms
L_{LOH}=10 ohms
R_{LOL}=10 ohms

Benefits of LM5140 Gate Driver Slew Rate Control

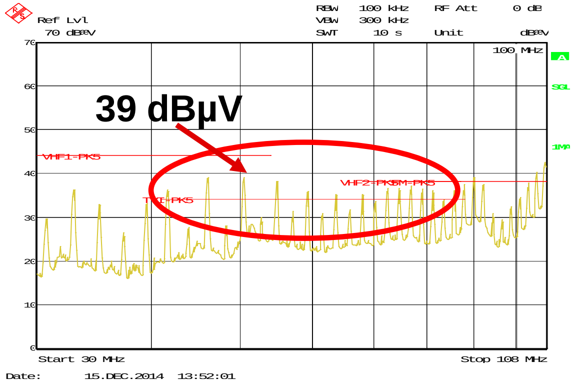
- High and Low Side FET Drivers have separate source and sink pins allowing the turn-on and turn-off times to be independently controlled via series resistors
- Optimizing gate drive slew rate reduces EMI with ~1% reduction in efficiency (as measured on LM5140 EVM)



No Slew Rate Control



With Slew Rate Control

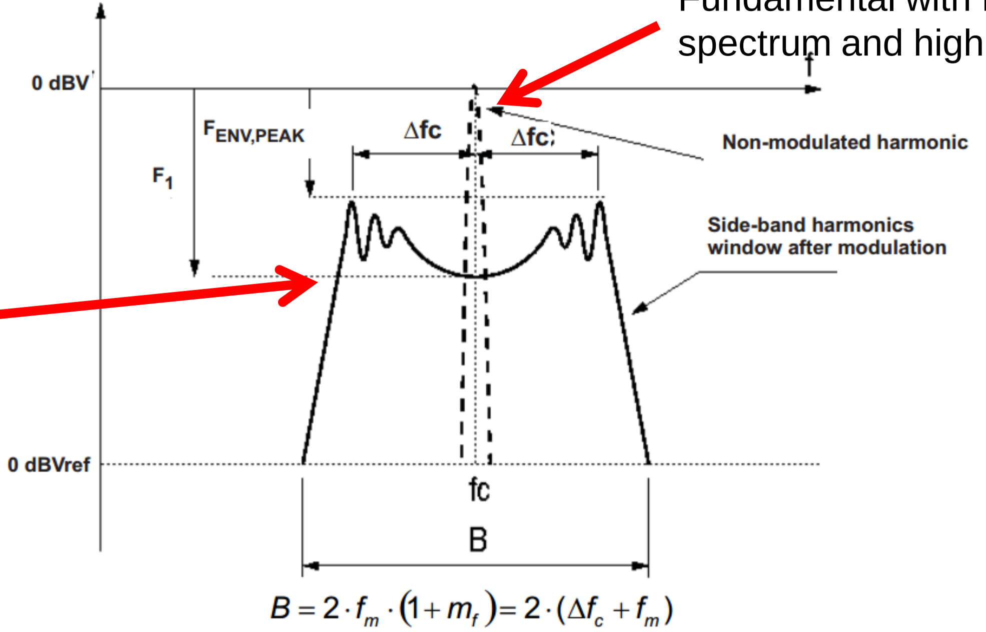


Measured on LM5140 Standard EVM: 2.2MHz, 3.3V/5.0Vout

Spread spectrum/Dithering – What is it?

- Spread spectrum is a means of reducing EMI interference by dithering the switching regulator frequency, in the case of LM53600/53601, by +/-4%. This has the effect of widebanding the noise spectrum and reducing the fundamental energy, as shown

Fundamental with narrow spectrum and high amplitude

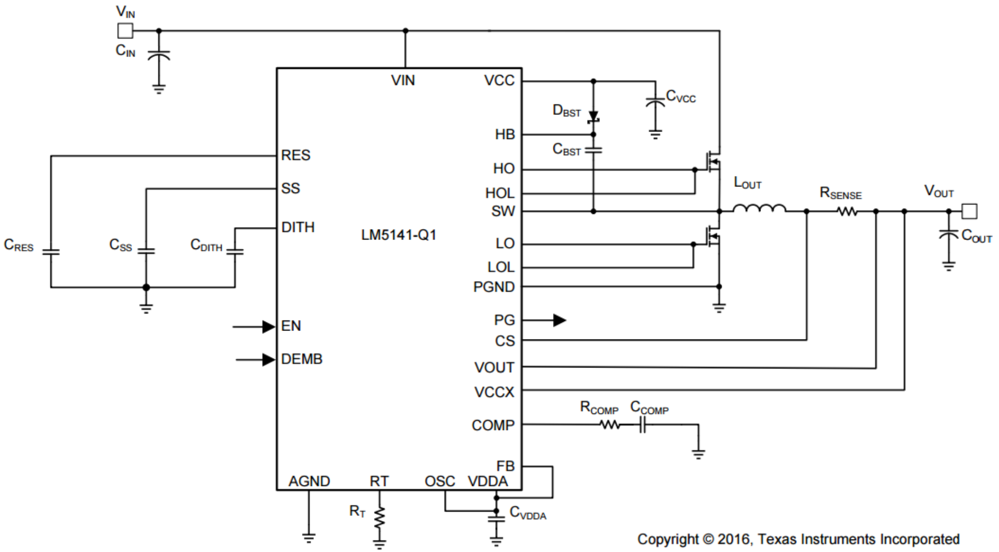


Spread spectrum reduces the fundamental signal energy and the overall peak value while widening the spectrum

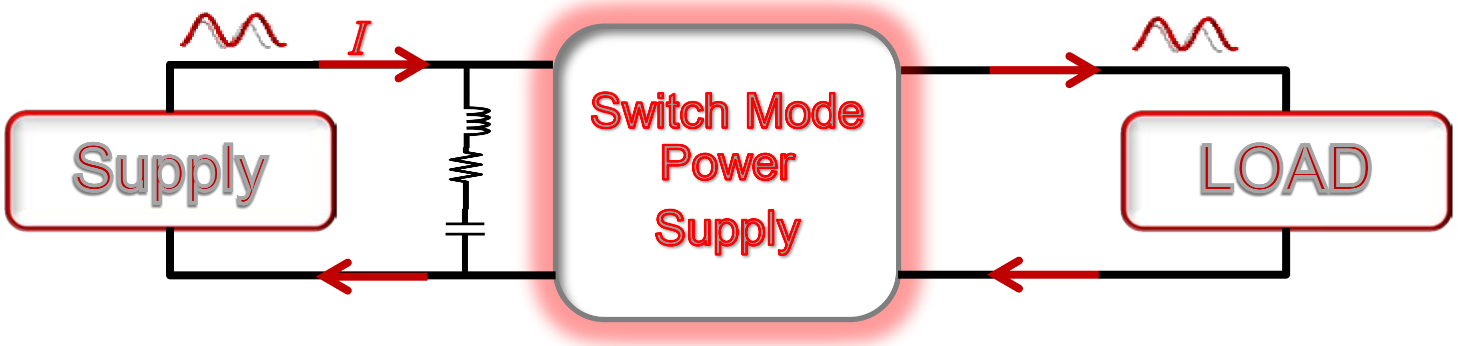
Combining Slew Rate Control and Spread Spectrum

- Wide Input voltage range: 3.8V to 65V (Abs Max 70V)
- Fixed output 3.3V, 5V, or adjustable from 1.5V-15V
- Fixed 2.2MHz, or 440 kHz oscillator; frequency can be shifted from the fundamental via RT pin resistor setting
  - RT adjustment range 300kHz-500kHz, or 1.8MHz-2.53MHz
- EMC features:
  - Spread Spectrum selectable
  - Gate drive slew rate control
  - Synchronizable to external clock
  - FPWM mode disables skip mode at light load assuring operation at fixed frequency

Simplified Schematic



Differential Mode Conducted EMI



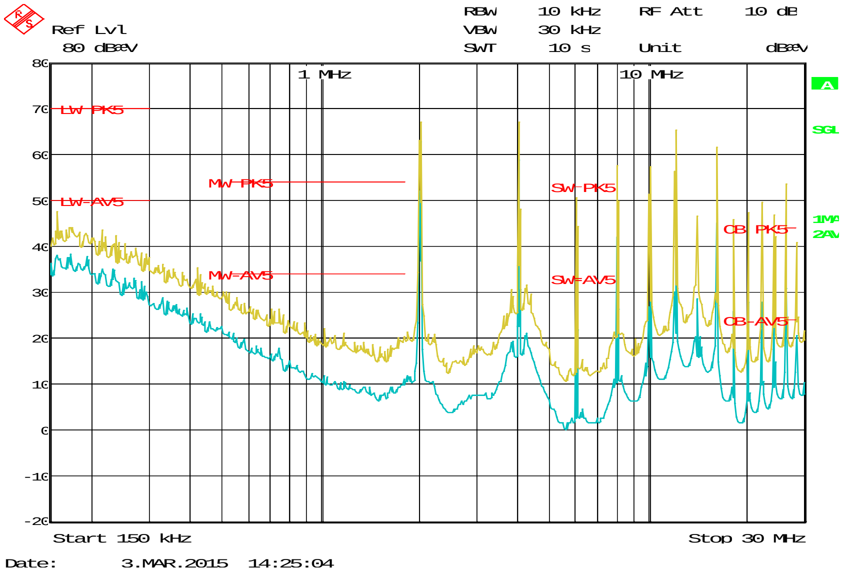
- Differential Mode Conducted EMI
  - In DC-DC converter topology differential mode noise usually dominates common mode
  - Involves the Normal Operation of the Circuit
  - Only Related to CURRENT, not voltage
  - For example, with the same power level Buck converter, lower input voltage means higher input current, thus worse conducted EMI
- Why we care?
  - Excessive Input and/or Output Voltage Ripple can compromise operation of Supply and/or Load

Input Filter Design for Conducted EMI

There are two basic requirements for the conducted EMI filter:

- Meet noise attenuation requirement (i.e. CISPR 25)
- Not interfere with the normal operation of the SMPS converter

Conducted EMI plot LM53603 without Input Filter



Example of a Buck regulator

- No input filter
- Fails CISPR 25 regulation limits

But how do we estimate how much filter attenuation to add?

Necessary Input Filter Attenuation

Methods of estimating the filter attenuation prior to making a certified measurement with a LISN (Line Impedance Stabilization Network) and Spectrum Analyzer

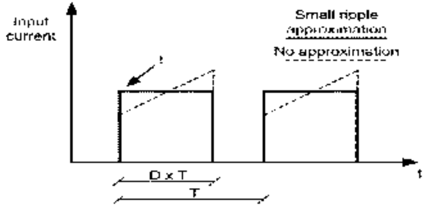
- **Method 1 – estimation using oscilloscope measurement**
  - Measure the input ripple voltage using a wide bandwidth scope and calculate the attenuation.

$$|Att|_{dB} = 20 \times \log\left(\frac{VinRipple_{pk-pk}}{1\mu V}\right) - V_{MAX}$$

  - V_{MAX} is the allowed dBμV noise level for the particular EMI standard.

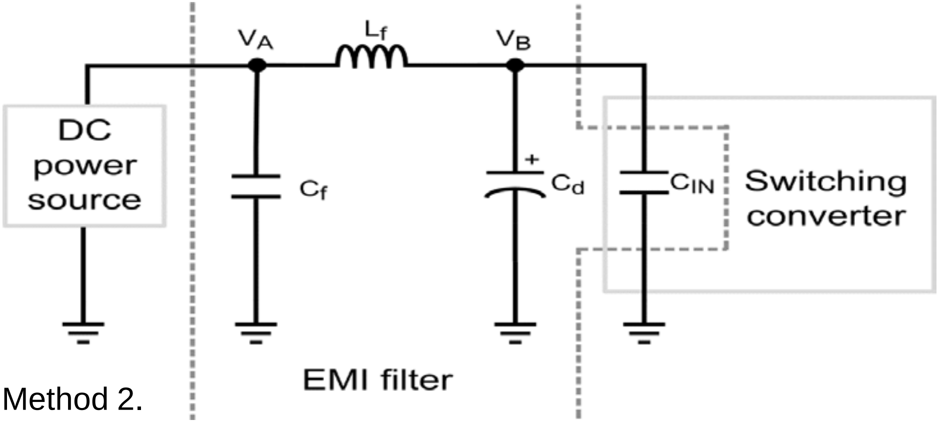
- **Method 2 – Estimation using the first harmonic of input current**
  - Assume the input current is a square wave (small ripple approximation)

$$|Att|_{dB} = 20 \log\left(\frac{\frac{I}{\pi^2 f_s C_{IN}} \sin(\pi D)}{1\ \mu V}\right) - V_{max}$$



  - VMAX is the allowed dBμV noise level for the particular EMI standard.
  - CIN is the existing input capacitor of the Buck converter.
  - D is the duty cycle , I is the output current, Fs is the switching frequency

Typical Conducted EMI Filter



Follow the design steps described in AN-2162.

- Calculate the required attenuation using Method 1 or Method 2.
- Capacitor **CIN** represents the existing capacitor at the input of the switching converter.
- Inductor **Lf** is usually between 1µH and 10µH, but can be smaller to reduce losses if this is a high current design.
- Calculate capacitor **Cf**. Use the larger of the two values (Cfa and Cfb) below:

$$C_{fa} = \frac{C_{IN}}{C_{IN}L_f(2\pi f_s/10)^2 - 1} \qquad C_{fb} = \frac{1}{L_f}\left(\frac{10^{|Att|_{dB}/40}}{2\pi f_s}\right)^2$$

- Capacitor **Cd** and its ESR provides damping so that the Lf Cf filter does not affect the stability of the switching converter.

$$C_d \geq 4 \times C_{IN} \qquad ESR_d \approx \sqrt{L_f/C_{IN}}$$

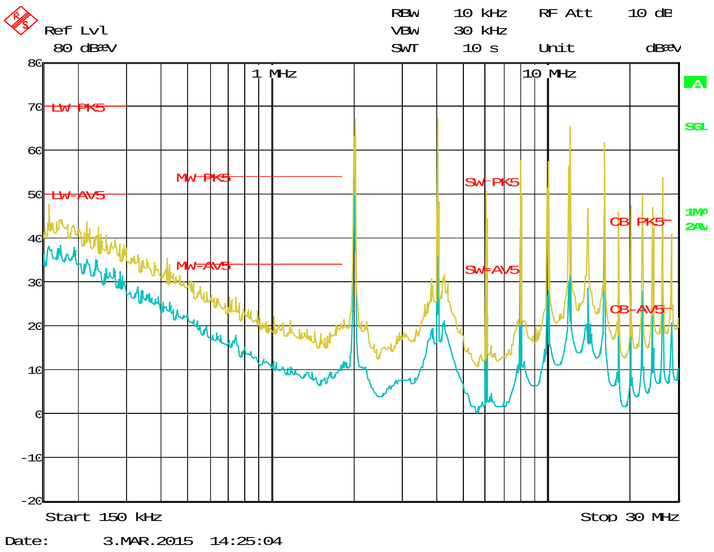
Conducted EMI Before and After Filter – LM53603 – 150kHz to 30MHz

Input 13V, Output 5V@3A, resistor load, CISPR 25 CE setup

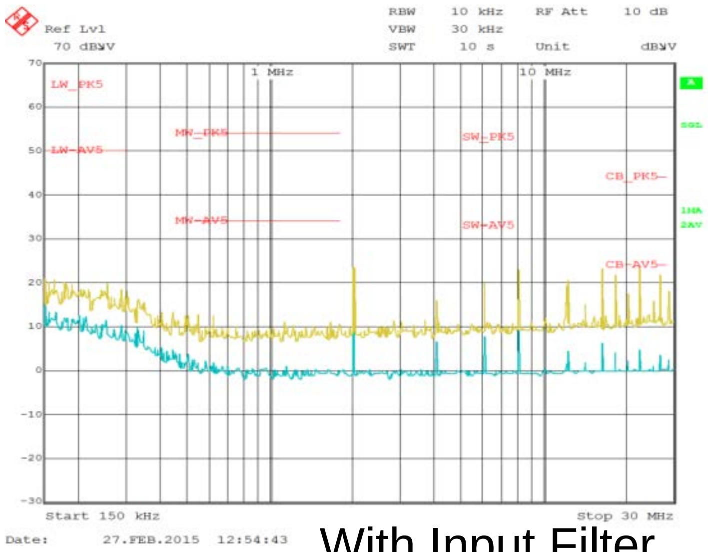
Red Line: Class 5 Limits (Peak/Average Detection)

Yellow: Peak detection result, Blue: Average detection result

Using guidelines on the previous slides the filter was implemented and Conducted EMI retaken

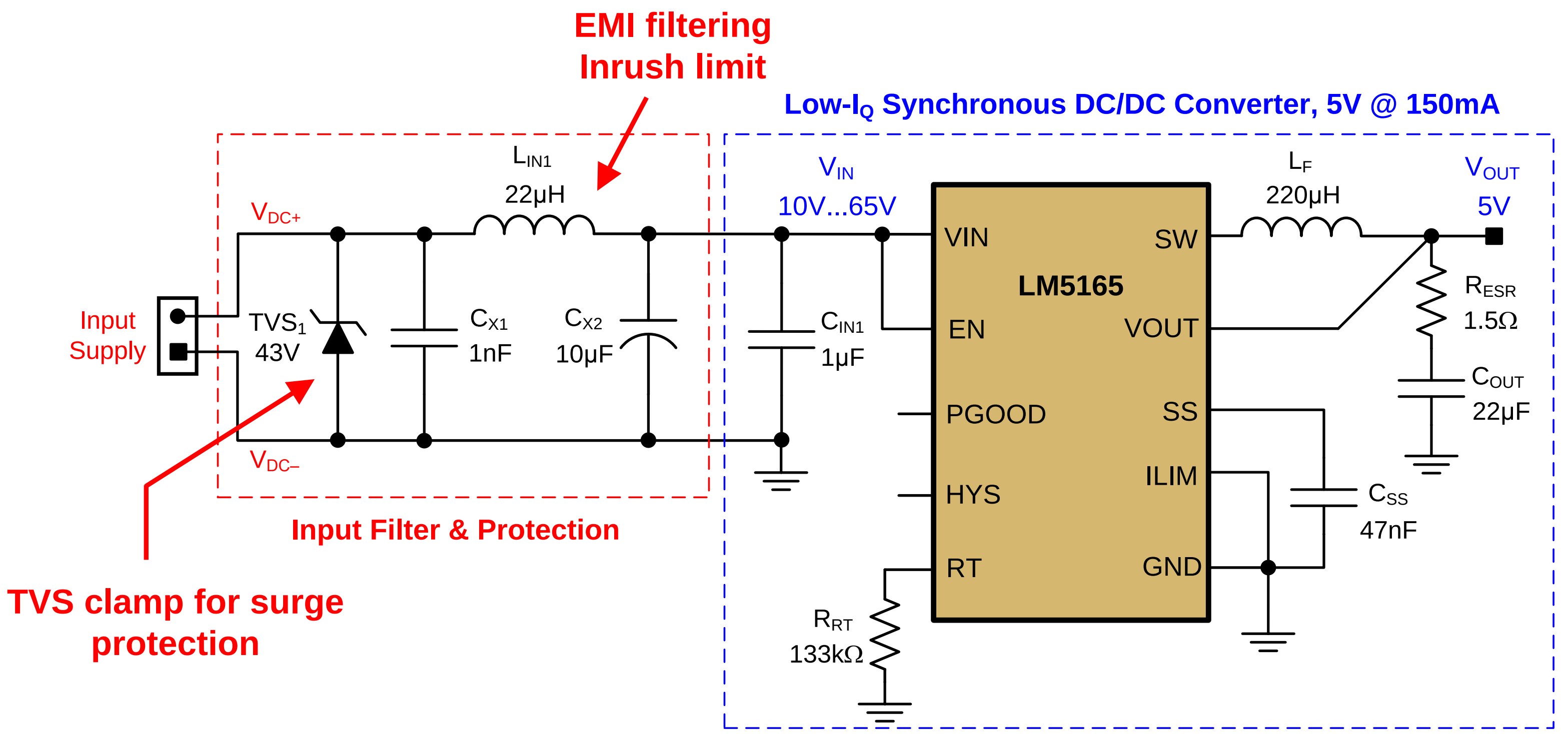


No Input Filter



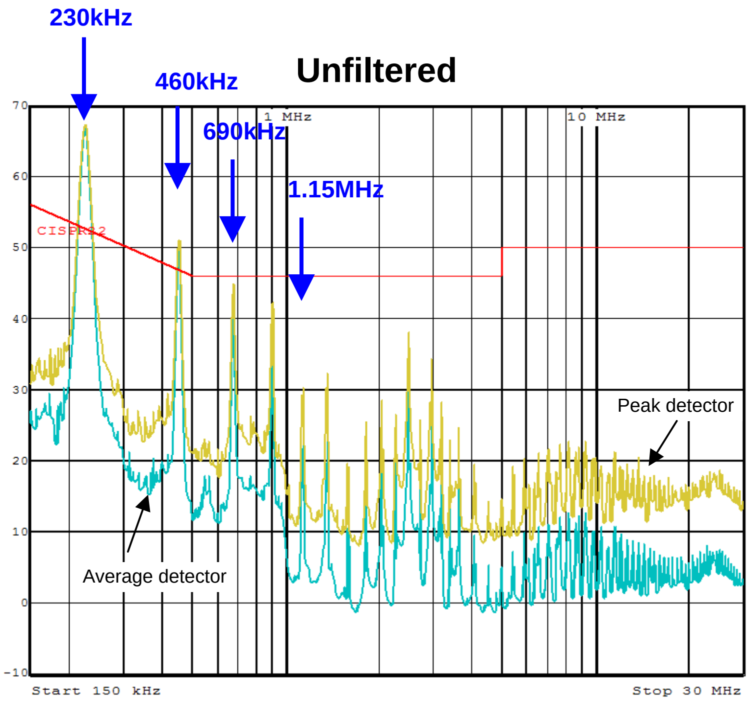
With Input Filter

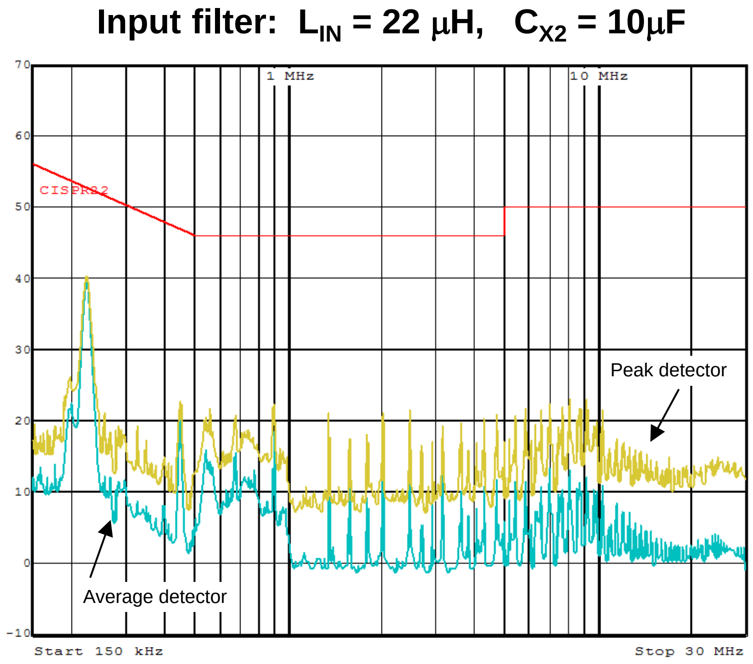
COT Converter with EMI Input Filter



Conducted EMI Plots: CISPR 22 Class B (150kHz → 30MHz)

Input 13.5V, Output **5V** @ **100mA**, COT mode, Resistive load, CISPR **22** CE setup



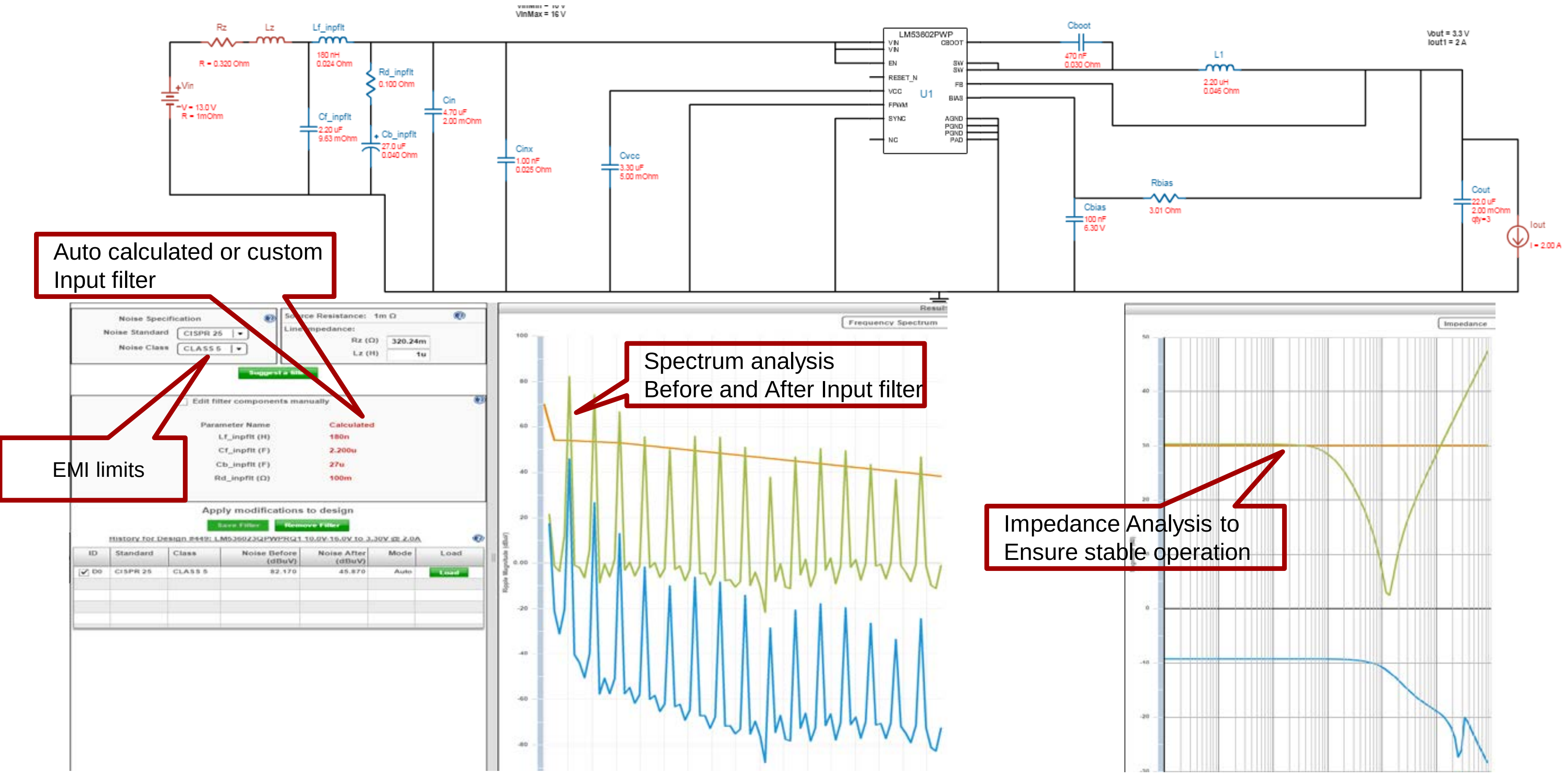


Red Lines Class B Limits (Peak & Average detection)

Yellow Peak detection result

Blue Average detection result

Conducted EMI Filter Design Tool- Webench



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Korea	080-551-2804
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