EMI Sources & Optimization on Step-Down Converter

Author: Ralf Ohmberger
Presenter: Sky Chen

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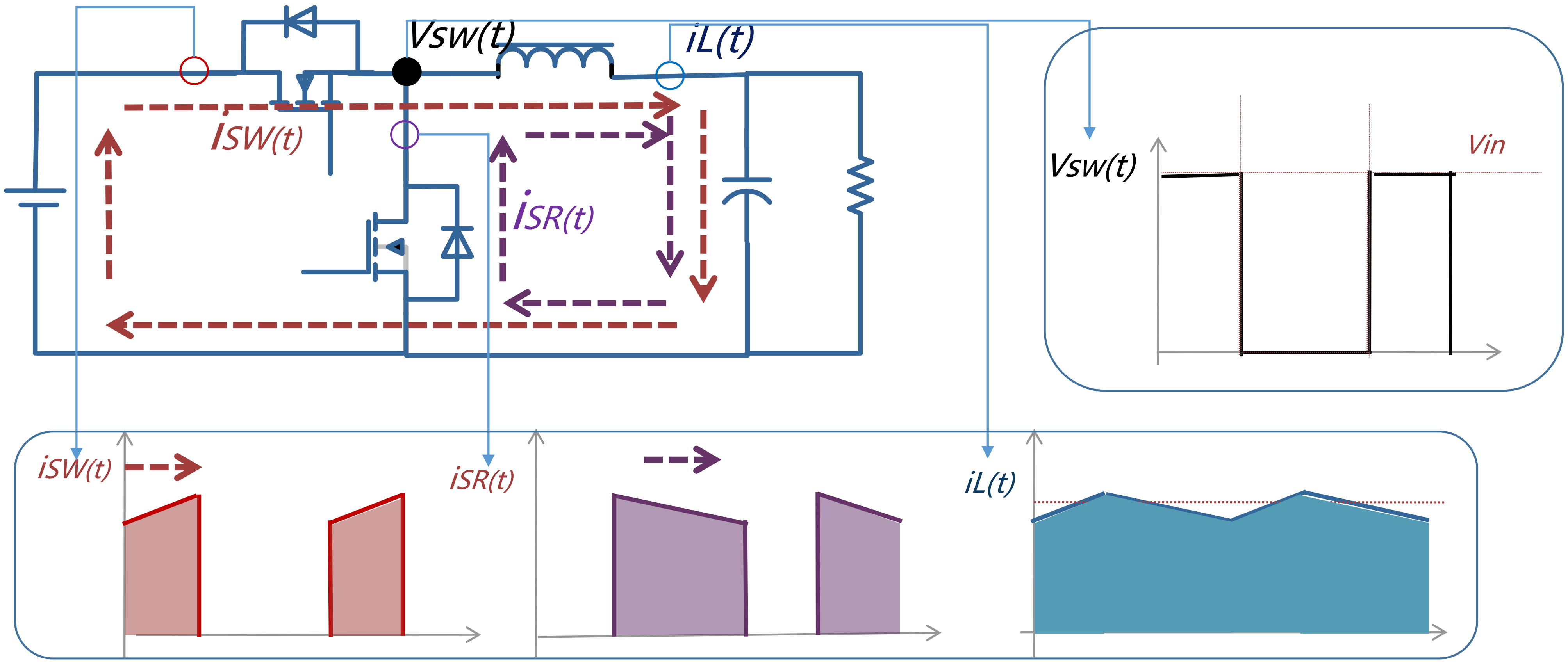
Agenda

- EMI Sources of Step-down Converter
- SW-node Waveform Measurements and Influence on EMI Performance
- EMI Tips
- Example on EMI Performance Optimization

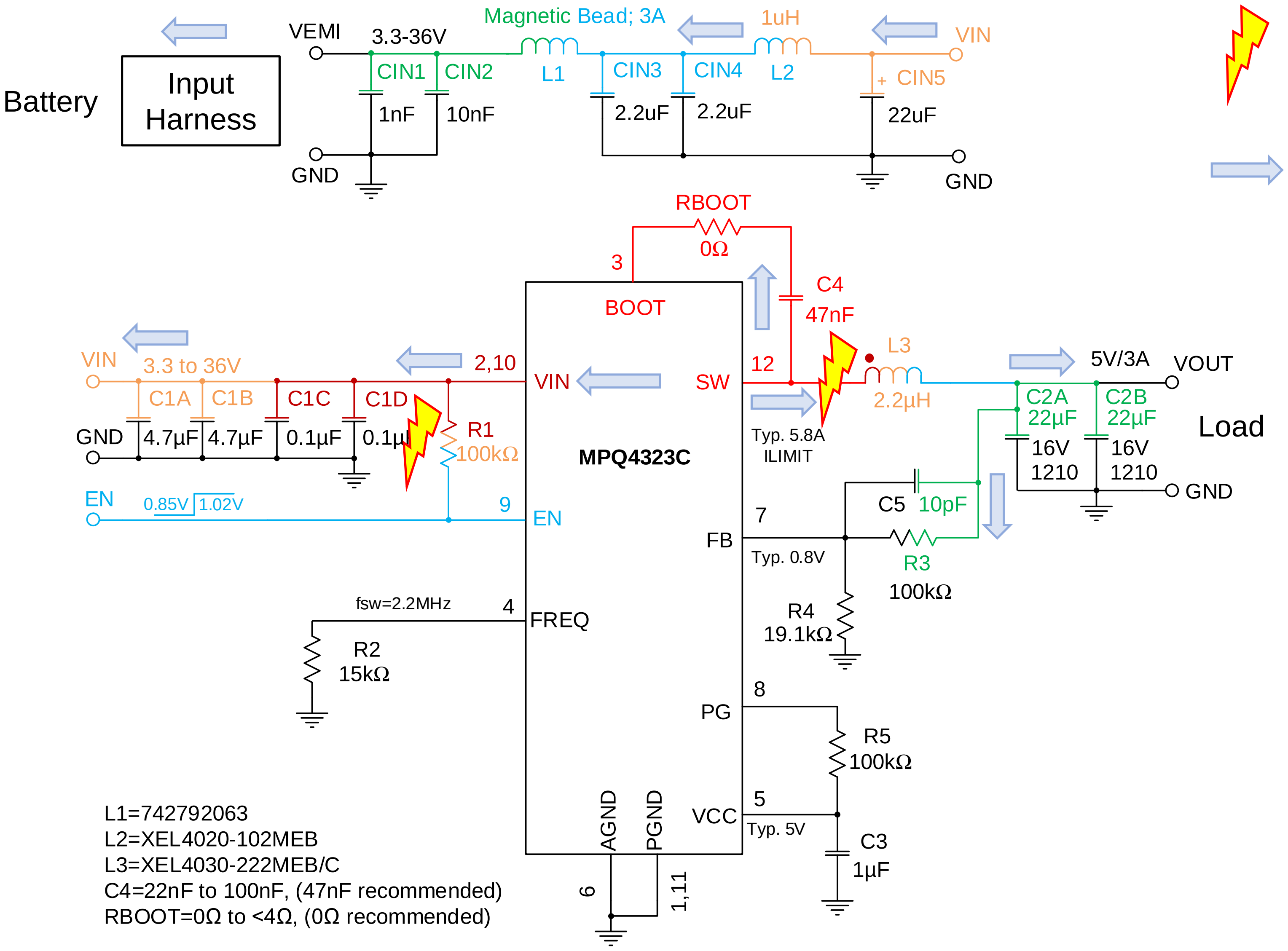
Step-Down Converter – EMI Sources

Refresh of Buck voltage and current waveform



- V_{IN} hot-loop ➔ fast current change $\frac{di}{dt}$, H-field
- SW-node ➔ fast voltage change $\frac{du}{dt}$, E-field

Step-Down Converter – EMI Sources



- Major EMI Emissions Source ➔ SW-node & Vin hot-loop
- Emission Flow Direction

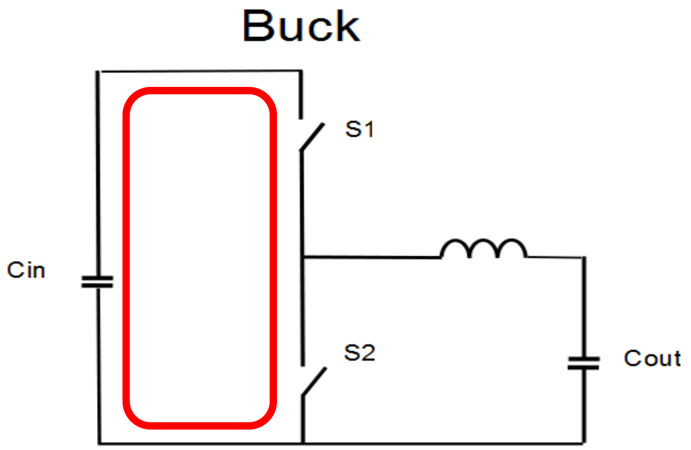
Typical ranking for EMI noise

Emissions Severity	
1.	highest
2.	
3.	Emissions
4.	
5.	
6.	lowest

Step-Down Converter – EMI Sources

- V_{IN} hot-loop MLCCs ➔ fast current change $\frac{di}{dt}$, H-field
- SW-node ➔ fast voltage change $\frac{du}{dt}$, E-field

Find correct Vin fast di/dt loop



$$E = \frac{263e^{-16} \times f^{2} \cdot I \cdot A}{r}$$

E: electro magnetic field energy

A: loop area of the high di/dt current path

Decrease VIN hot-loop energy

- Choose synchronize Buck converter with built-in MOSFET
- Place small package/ capacitance input caps as close to IC VIN/GND pin as possible
- Device with built-in Cin (MPQxxxxM)
- Symmetrical placement of input caps on layout

Step-Down Converter – EMI Sources

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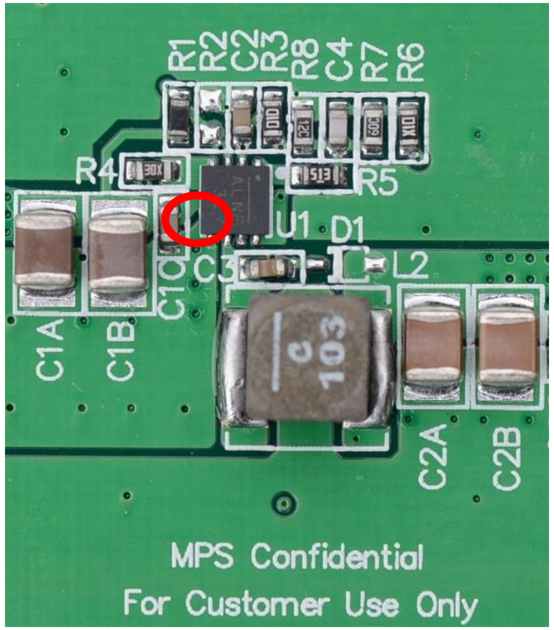
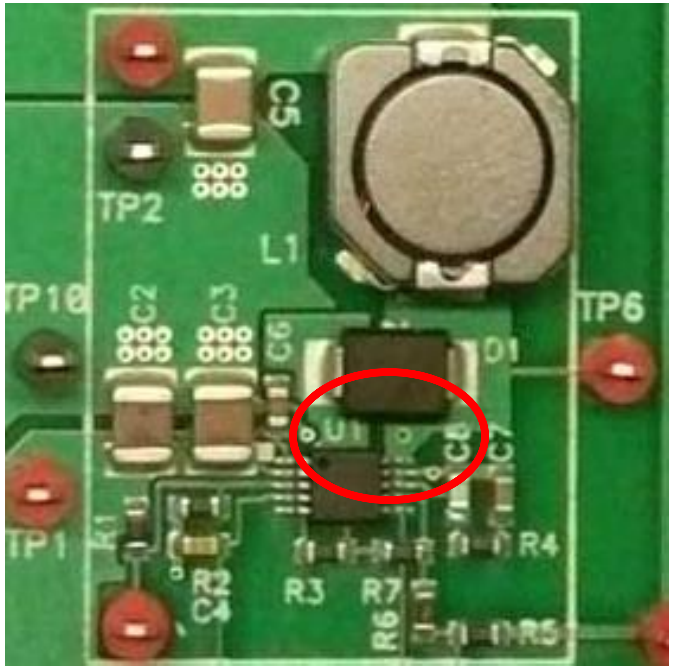
Decrease VIN hot-loop energy

➢ Choose synchronize Buck converter with built-in MOSFET

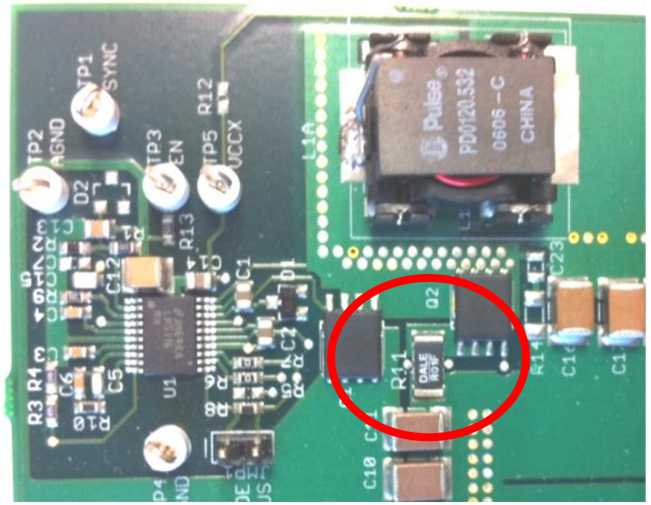
SYNC Buck solution with built-in MOSFET



Non-SYNC Buck solution with external diode



Controller solution with external HS & LS MOSFET

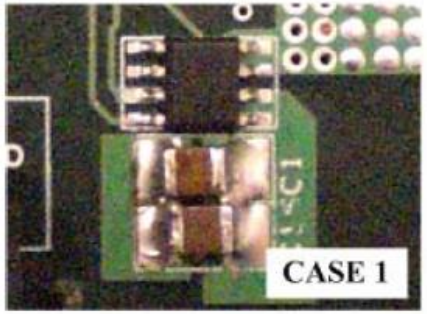


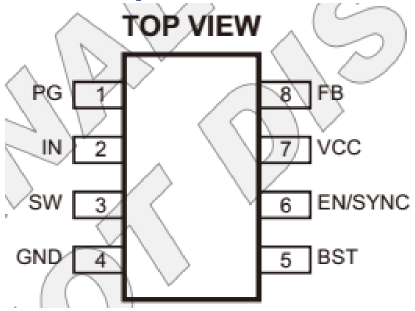
Step-Down Converter – EMI Sources

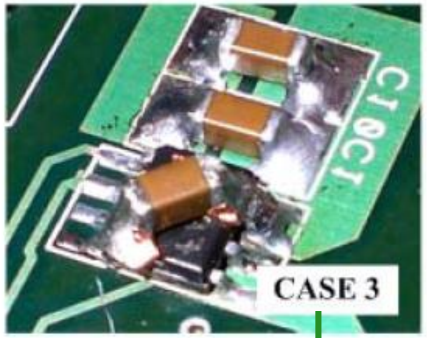
- V_{IN} hot-loop MLCCs ➔ fast current change $\frac{di}{dt}$, H-field
- SW-node ➔ fast voltage change $\frac{du}{dt}$, E-field

Decrease VIN hot-loop energy

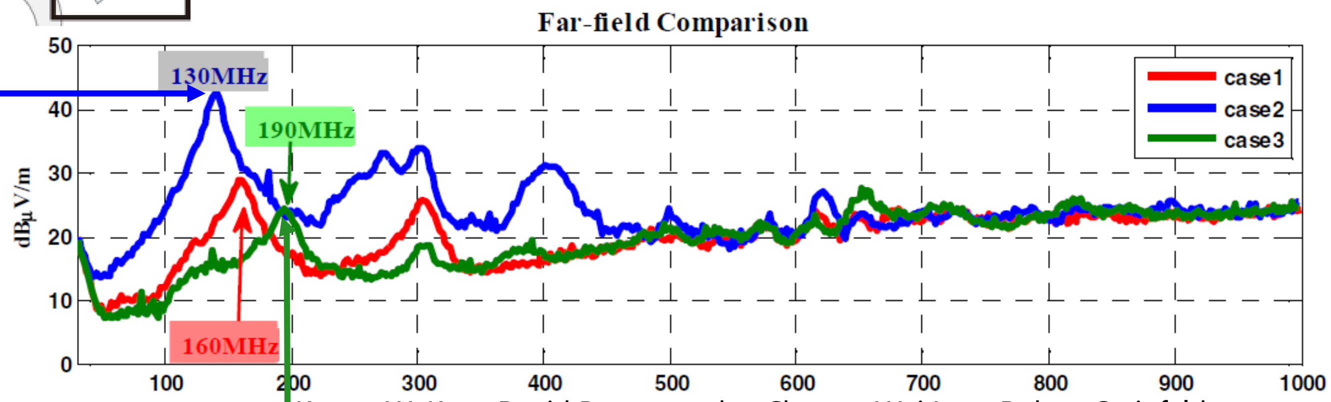
➢ Place small package/capacitance CIN (with small ESL) as close to IC VIN/GND pin as possible







Different CIN placement influence on EMI results



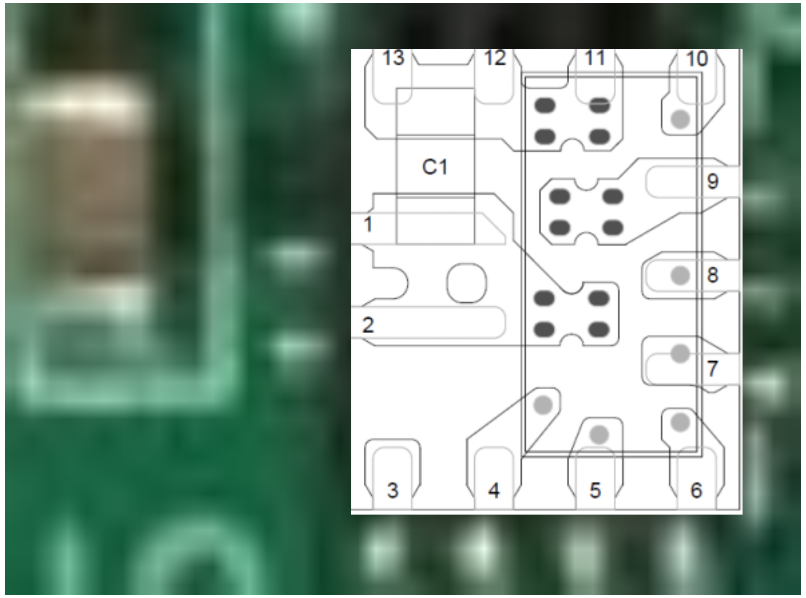
Keong W. Kam, David Pommerenke Cheung-Wei Lam, Robert Steinfeld
EMI Analysis Methods for Synchronous Buck Converter EMI Root Cause Analysis

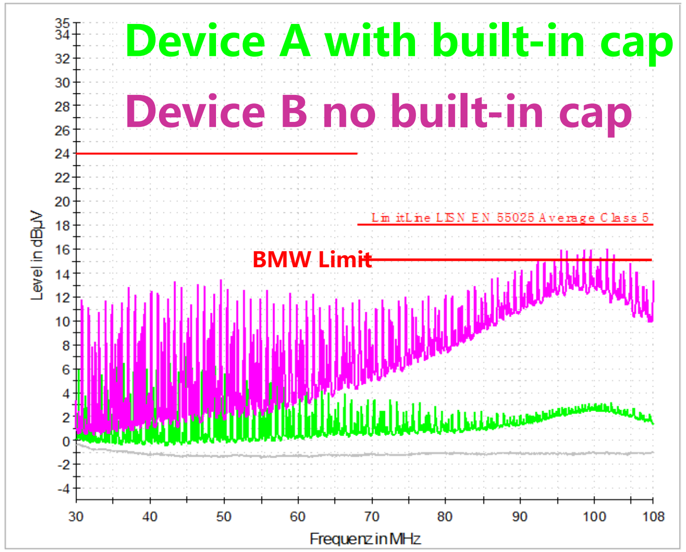
Step-Down Converter – EMI Sources

- V_{IN} hot-loop MLCCs ➔ fast current change $\frac{di}{dt}$, H-field
- SW-node ➔ fast voltage change $\frac{du}{dt}$, E-field

Decrease VIN hot-loop energy

➢ Choose device with built-in small input cap (MPQxxxxM)





CE Average: 30MHz to 108MHz
BW=120kHz

Step-Down Converter – EMI Sources

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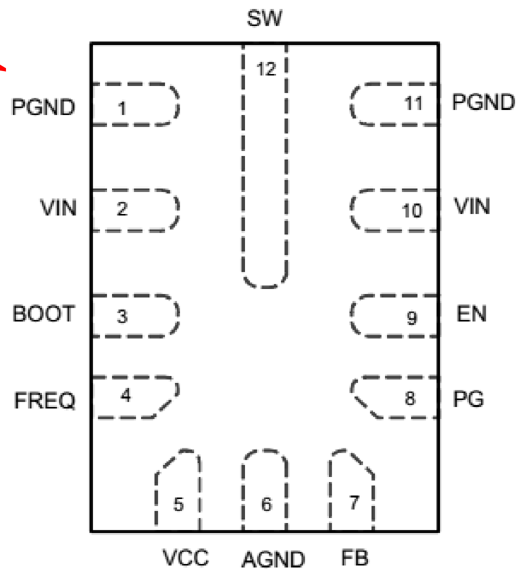
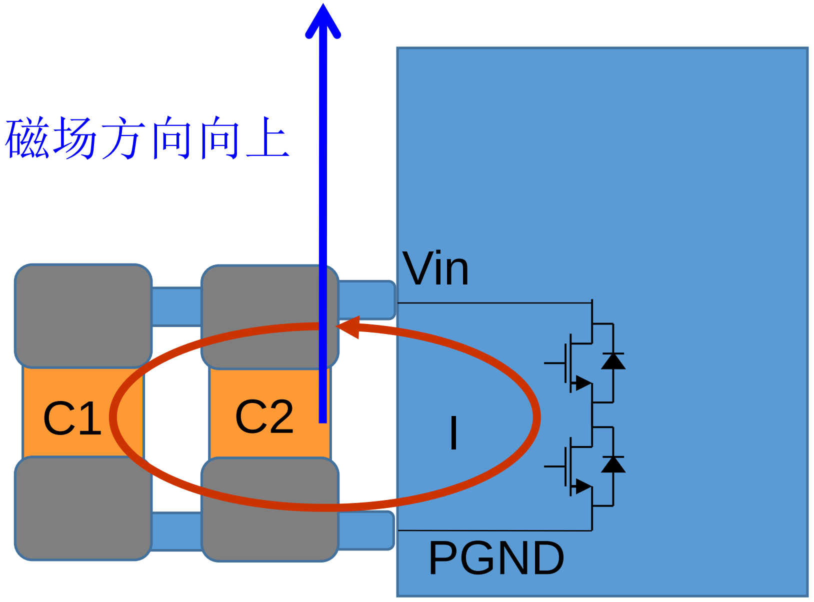
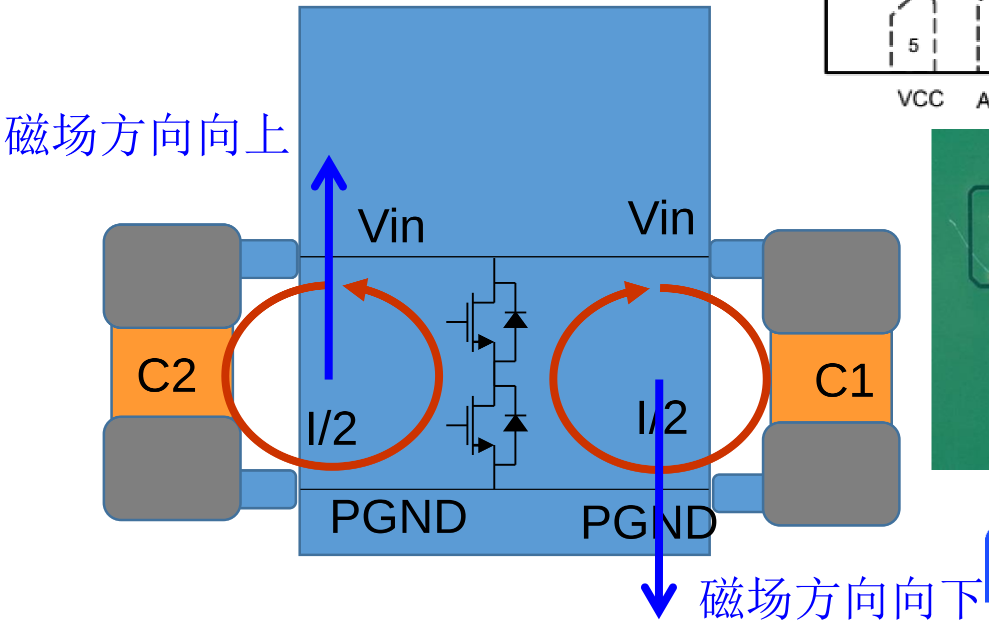
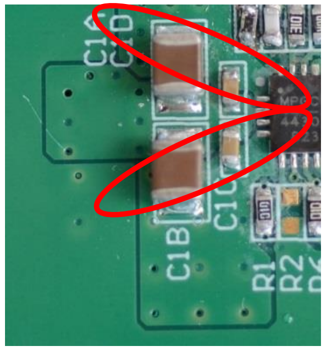


Decrease VIN hot-loop energy

➢ Symmetrical placement of input caps on layout







Step-Down Converter – EMI Sources

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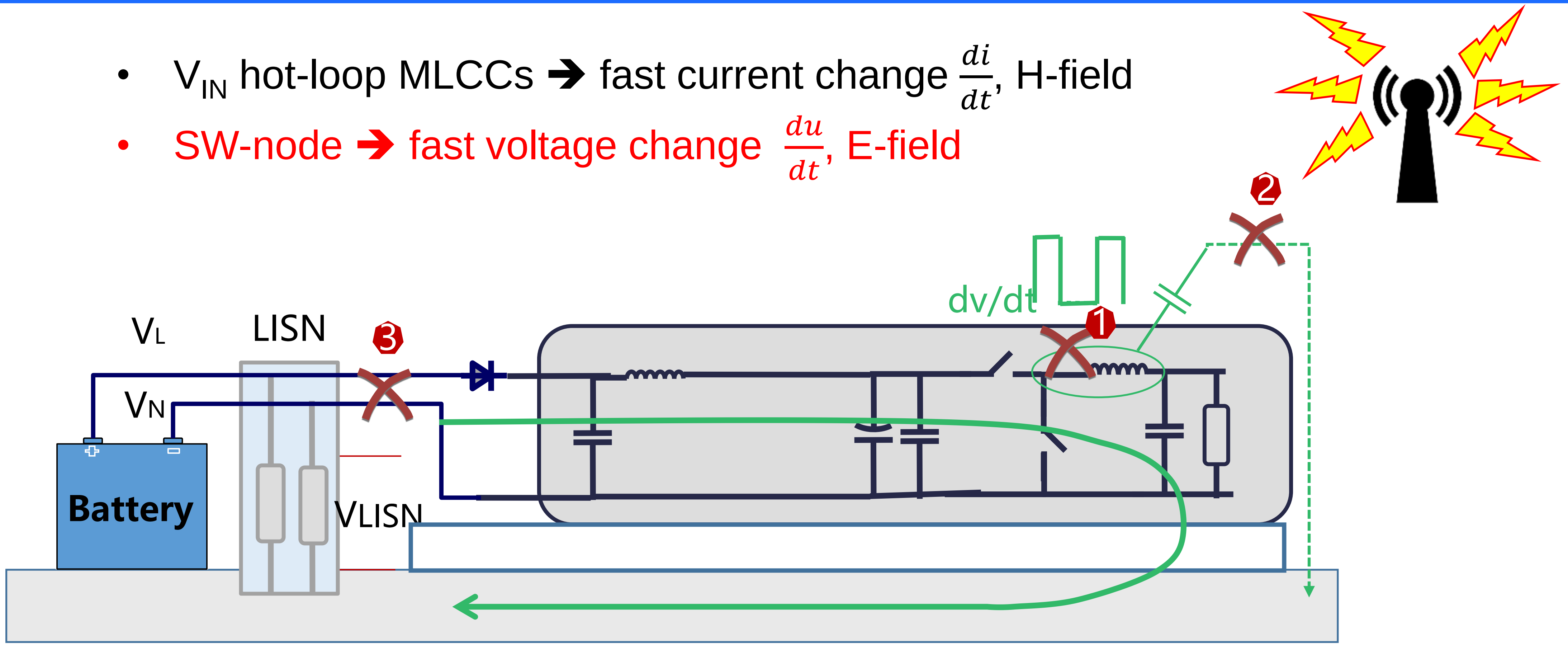


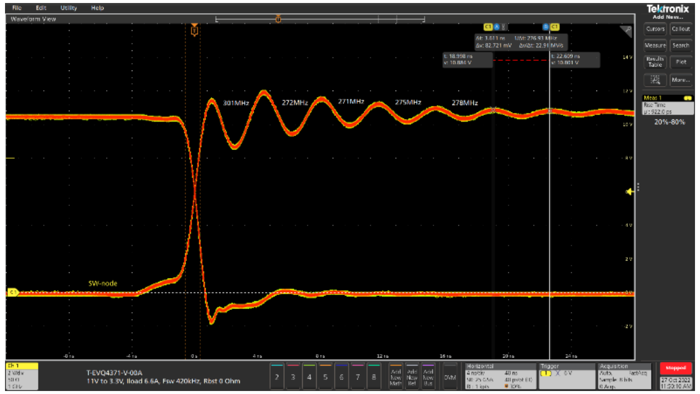
1. Decrease area of SW node, choose smaller size inductor
2. Shielding on inductor or whole SW node
3. Add common mode choke

Agenda

- EMI Sources of Step-down Converter
- SW-node Waveform Measurements and Influence on EMI Performance
- EMI Tips
- Example on EMI Performance Optimization

SW-node Waveform Measurements and Influence on EMI

The EMI character of a step-down converter PCB is predictable by the SW-node voltage waveform (hard to measure VIN hot loop current)



SW-node waveform information:

- ➢ Switching frequency (typ. 300kHz to 2.5MHz)
- ➢ SW rising and falling time (typ. 0.5ns to 3ns)
- ➢ Frequency (typ. 100MHz to 1GHz) and amplitude of resonance in the rising and falling edge

SW-node waveform measurement method:

- ➢ With a high bandwidth oscilloscope
- ➢ Connect the probe with the lowest parasitic inductance (small loop, coaxial cable)
- ➢ FFT on the oscilloscope or with external mathematic

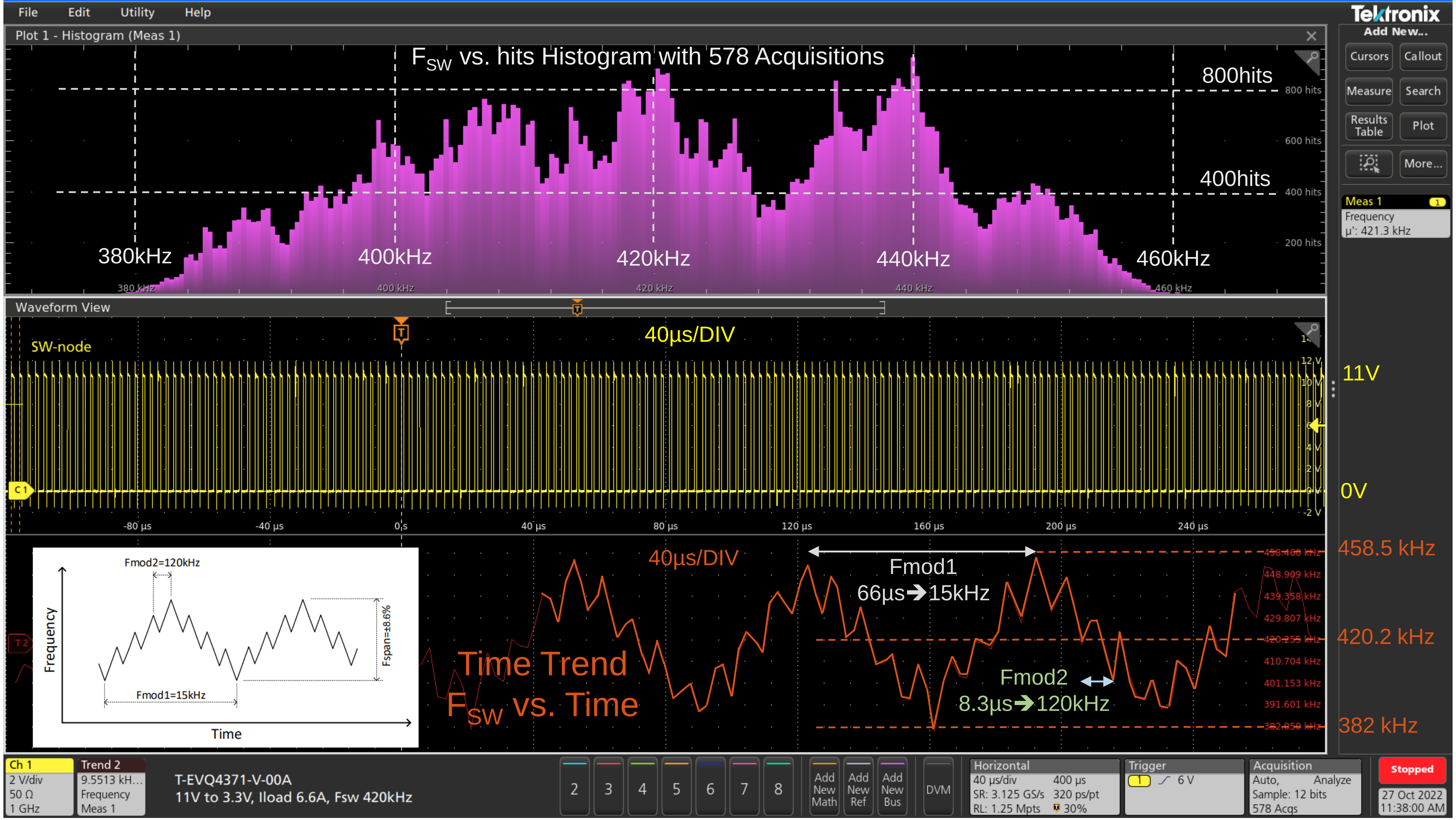
SW-node Waveform Measurements and Influence on EMI

Example for a SW-node waveform measurement

MPQ4371

36V, 6A-11A Low EMI
Synchronous Step-Down
Converters, with ZDP™
AEC-Q100 Qualified

MPQ4371 SW-node Waveform

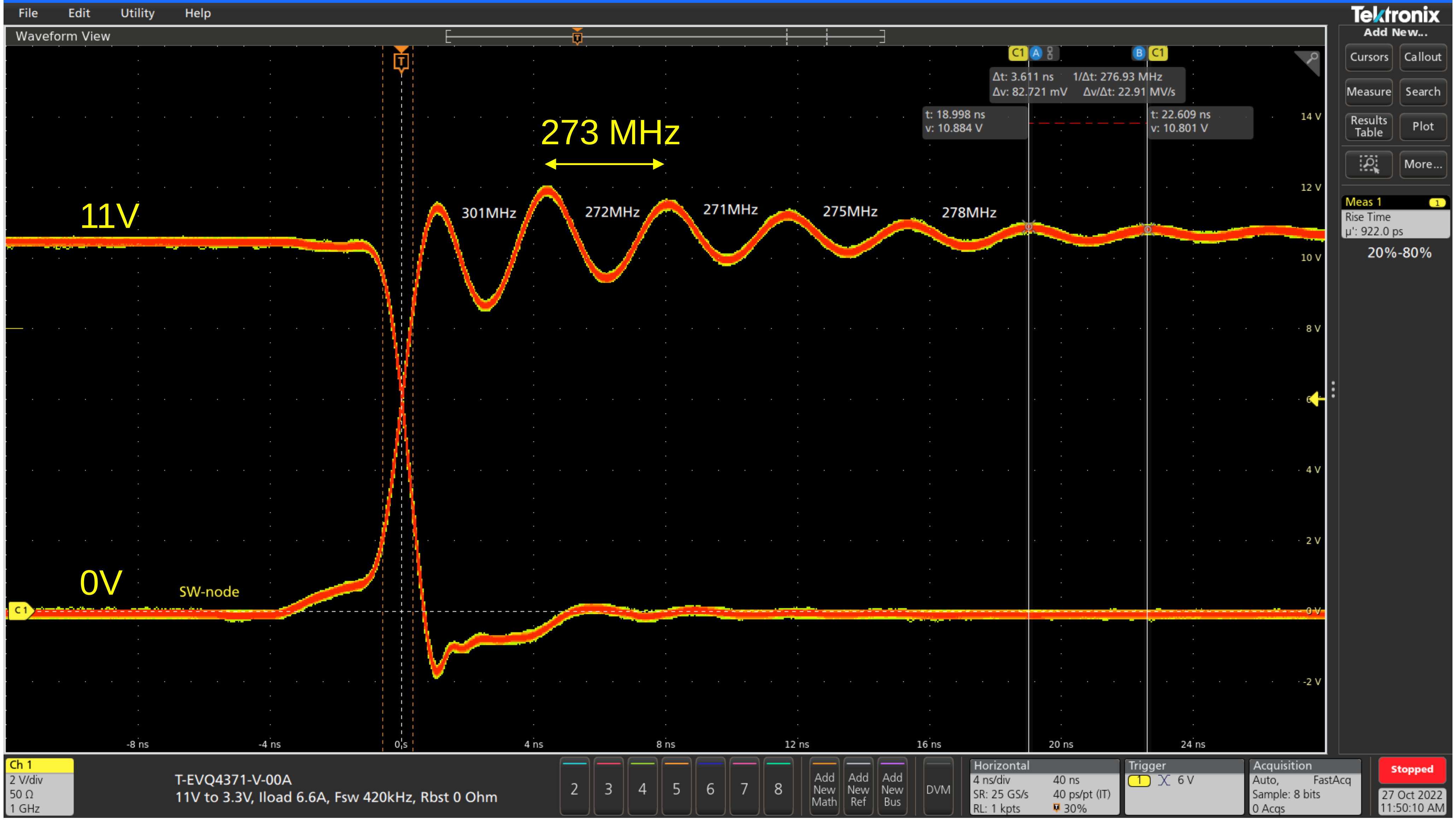


SW-node analysis with the oscilloscope

SW-node information.

F_{SW}=420 kHz with FSS Modulation

MPQ4371 SW-node Waveform

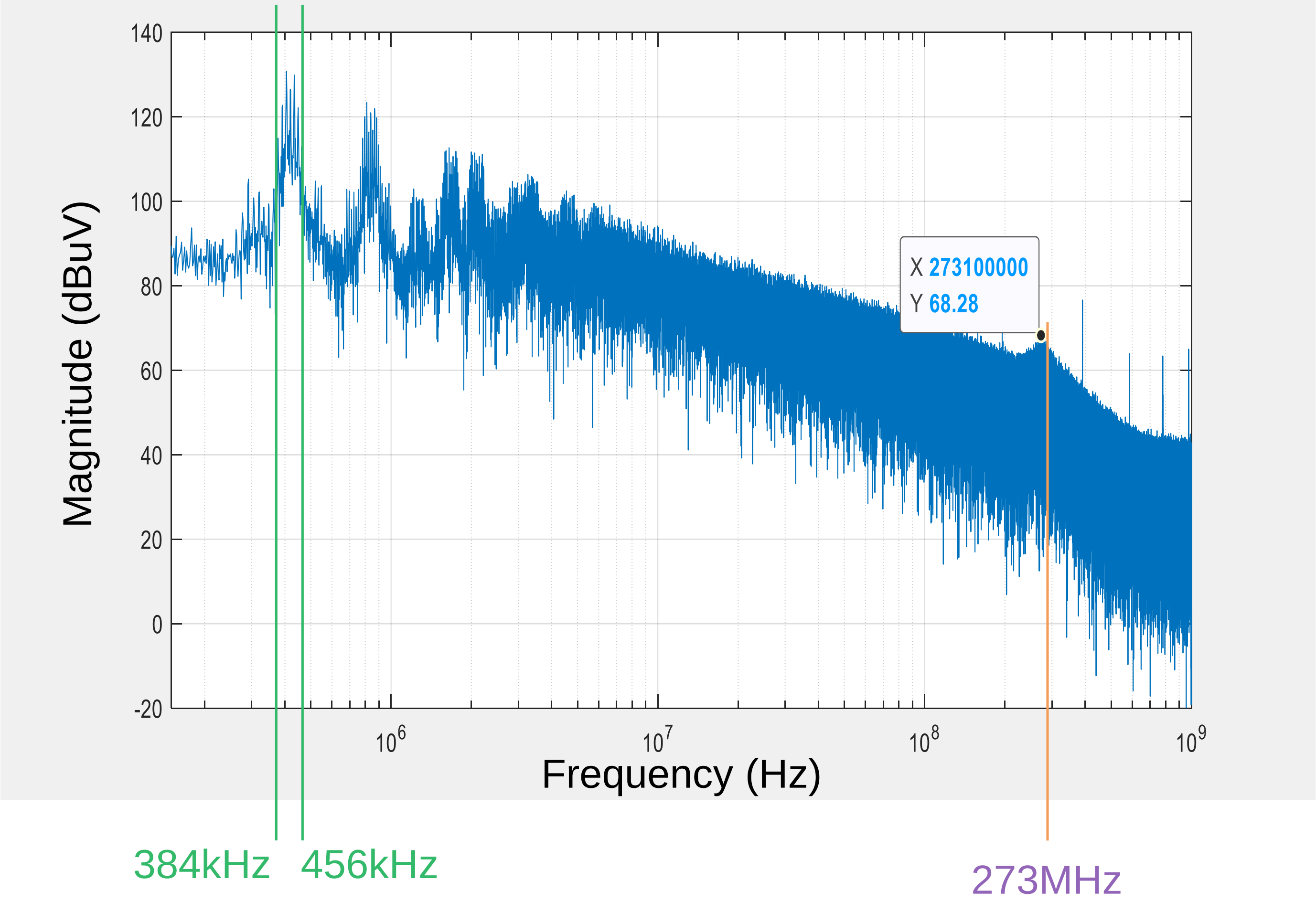


SW-node information

Rising/falling time=~1ns

~250-300 MHz resonance frequency with max 2V amplitude

MPQ4371 SW-node Fast Fourier Transformation



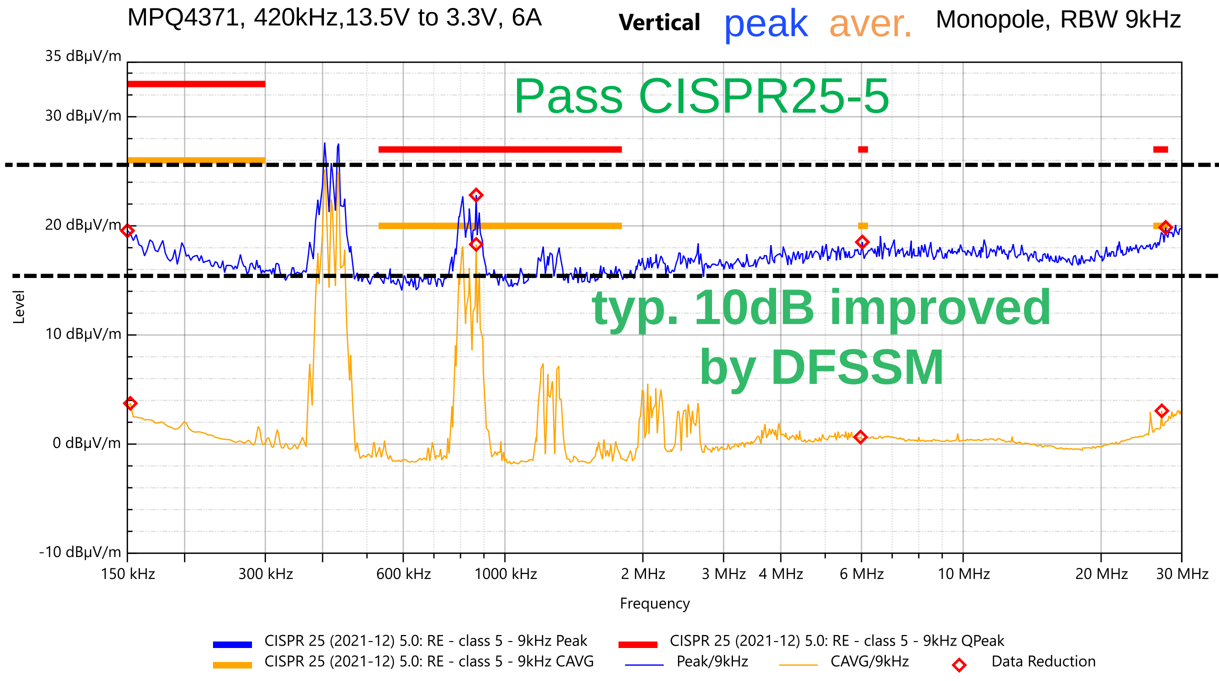
MPQ4371 **Dual Spread Spectrum Frequency Modulation for low EMI**

F_{SW}=420kHz ±8.6% ➔ 384kHz to 456kHz

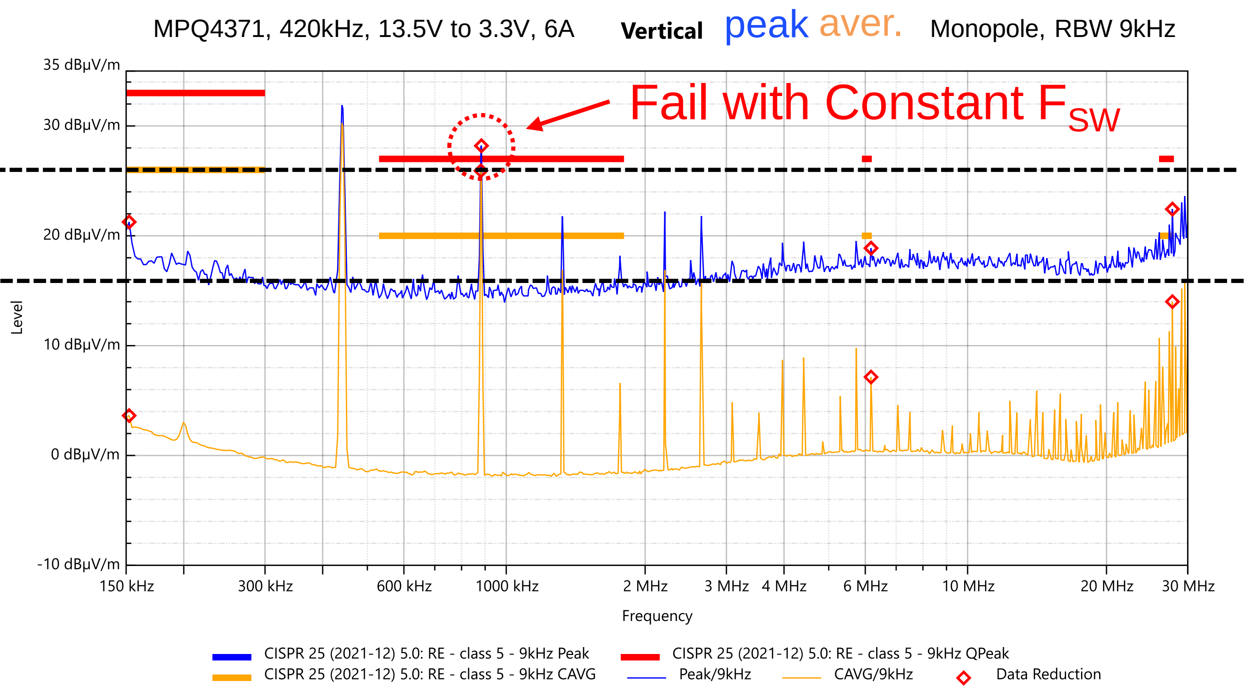
$F_{RESONANCE}$=250-300MHz

The rising resonance 273MHz can be found in the FFT of the SW-node

MPQ4371 Radiated Emission CISPR25-5 2021-12 (Monopole)

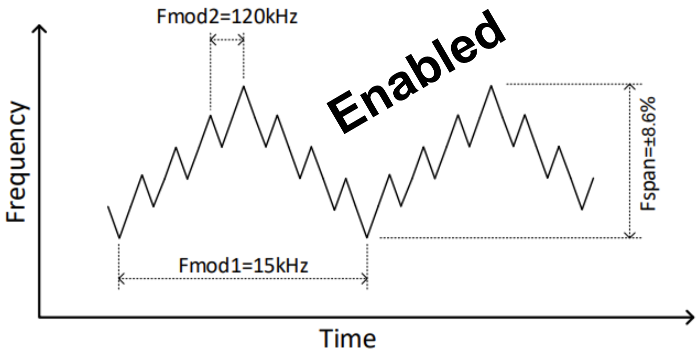


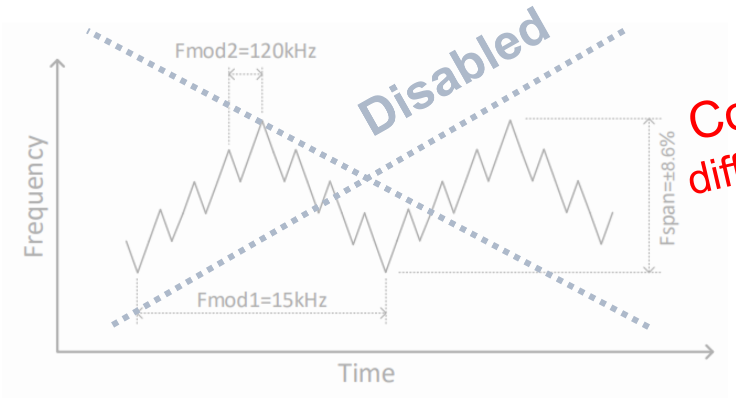
MPQ4371 with FSS



MPQ4371 Constant F_{SW}

Dual SSFM avoids here the need of shielded inductors or PCB, reduce costs.





Constant F_{SW}=420kHz difficult to pass CISPR-25-5 with the 2nd. Harmonic 840kHz, AM Radio

MPQ4371 Radiated Emission CISPR25-5 2021-12

Why not pass CISPR25-5 at constant F_{SW}=420kHz?

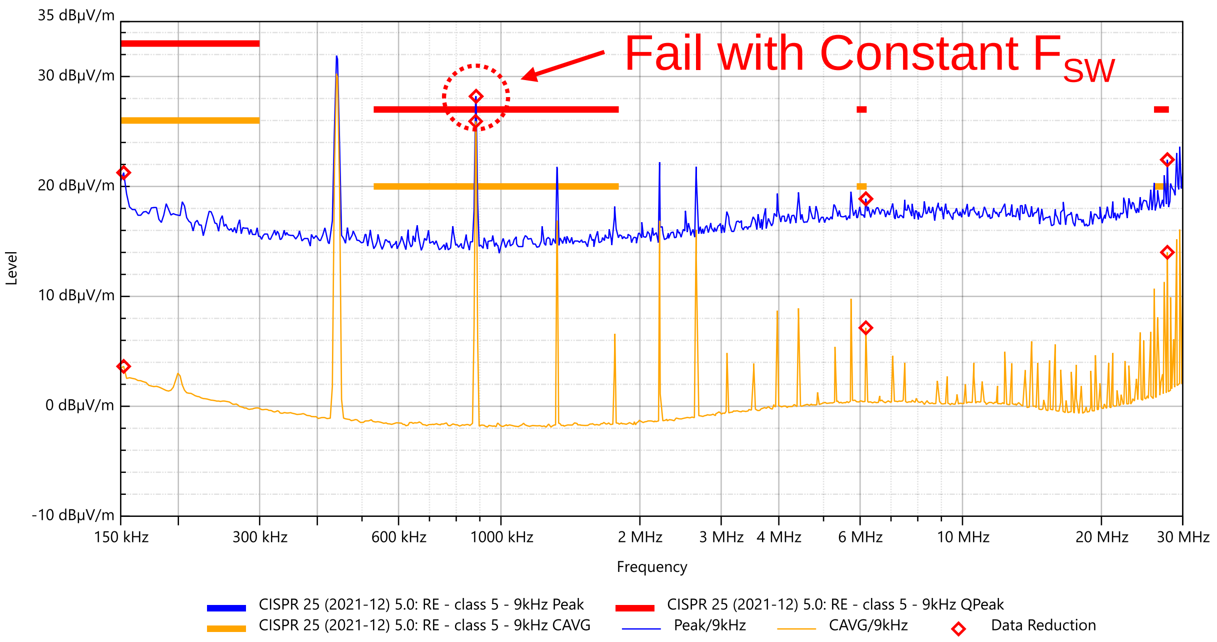
A 11A device must use a larger switching inductance at a lower F_{SW}=420 kHz to keep power dissipation low.

The 1st. harmonic (420 kHz) operates in the unlimited dBµV/m range. The 2nd. harmonic (840kHz) slightly exceeds the AM radio range.

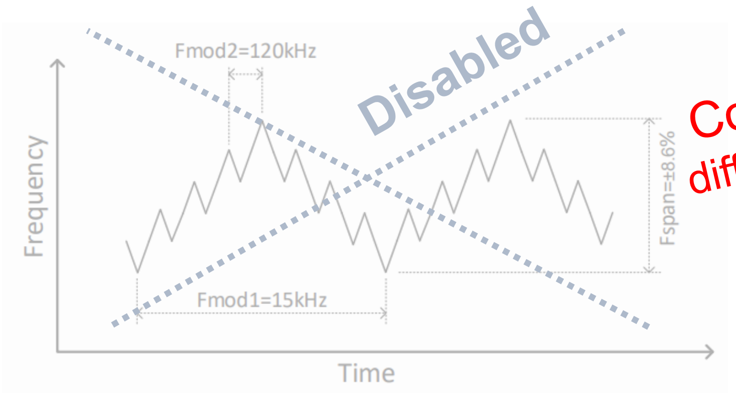
The 150k-30MHz RE source is often the SW-node and inductor. This RE does not come from the IC or from the EMI filter. Constant F_{SW} in high current devices often requires metal shielding.

Solutions:

- small SW-node cooper on layout
- select a flat inductor
- place the output MLCCs close as possible to this inductance (shield) or select a special metal shielded inductance.
- **choose IC with FSS feature.**

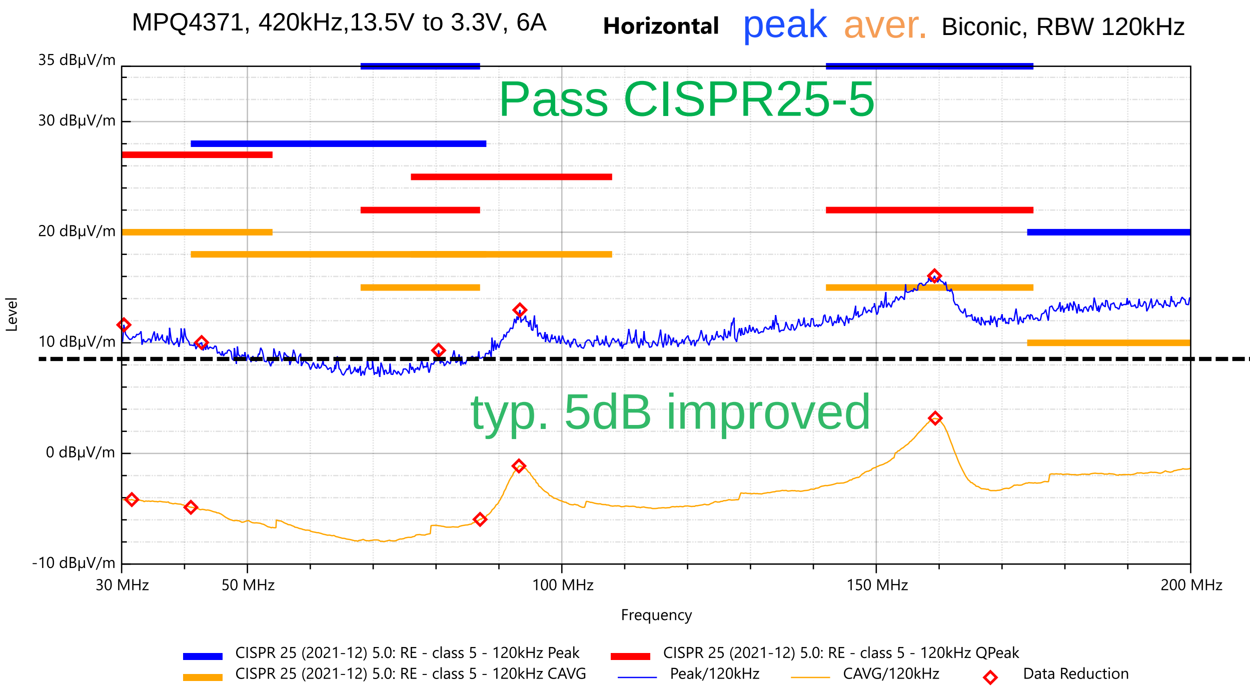


MPQ4371 Constant F_{SW}

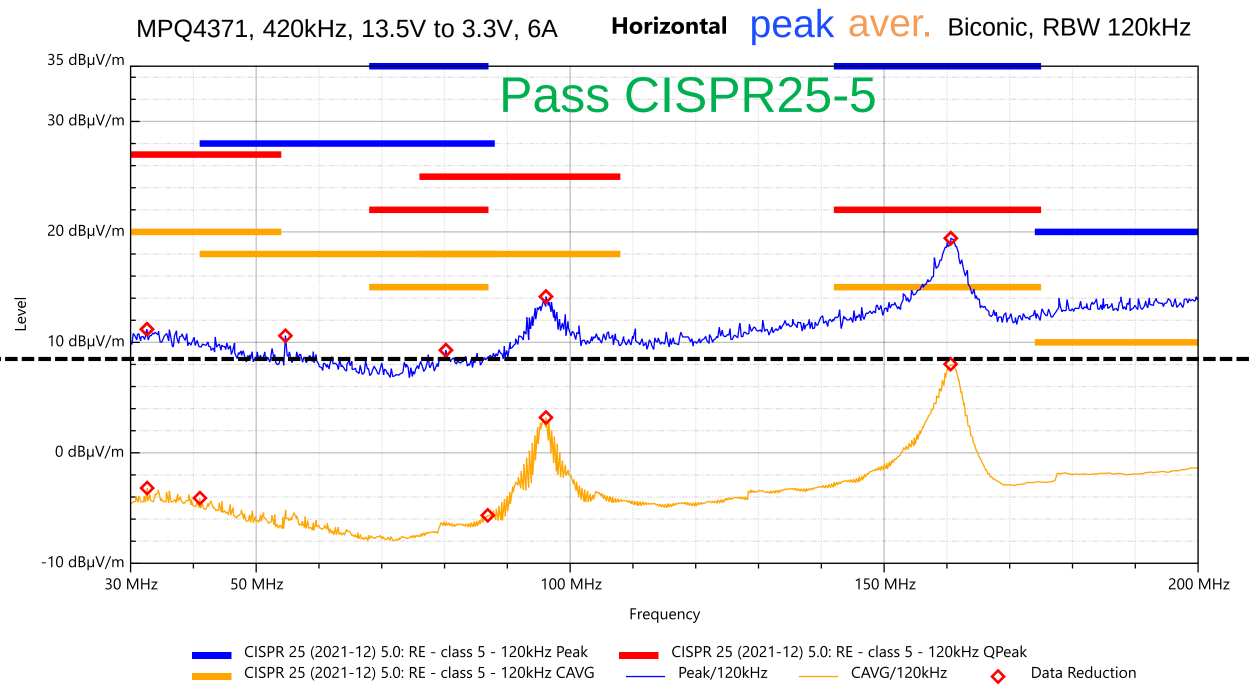


Constant F_{SW}=420kHz difficult to pass CISPR-25-5 with the 2nd. Harmonic 840kHz, AM Radio

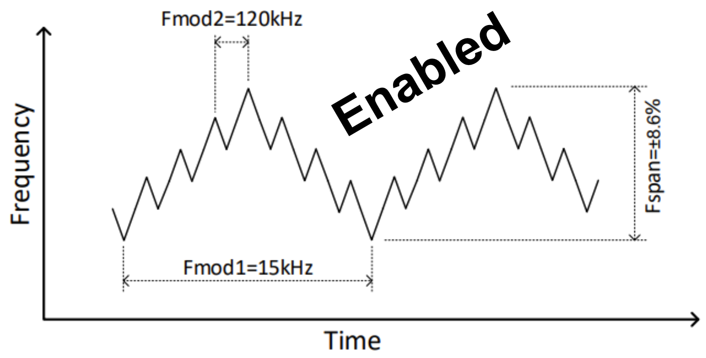
MPQ4371 Radiated Emission CISPR25-5 2021-12 (30M-200MHz)

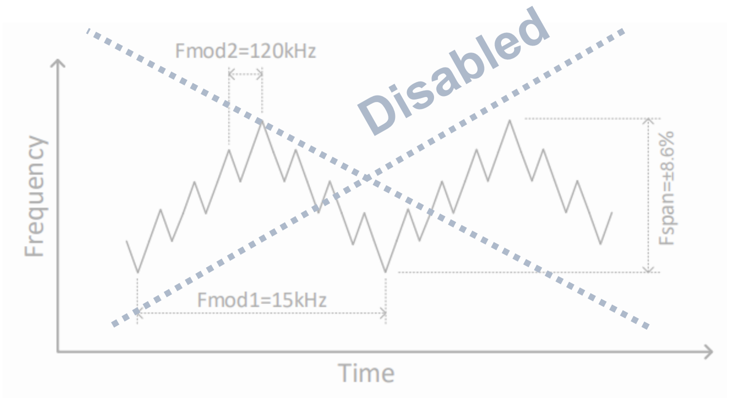


MPQ4371 with FSS

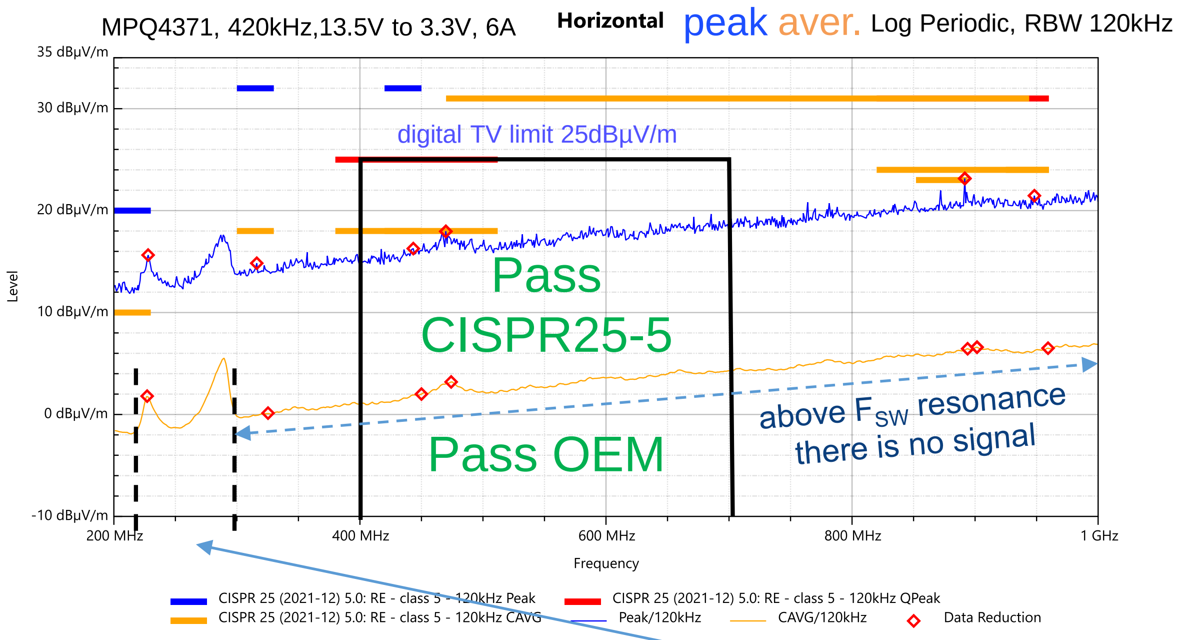


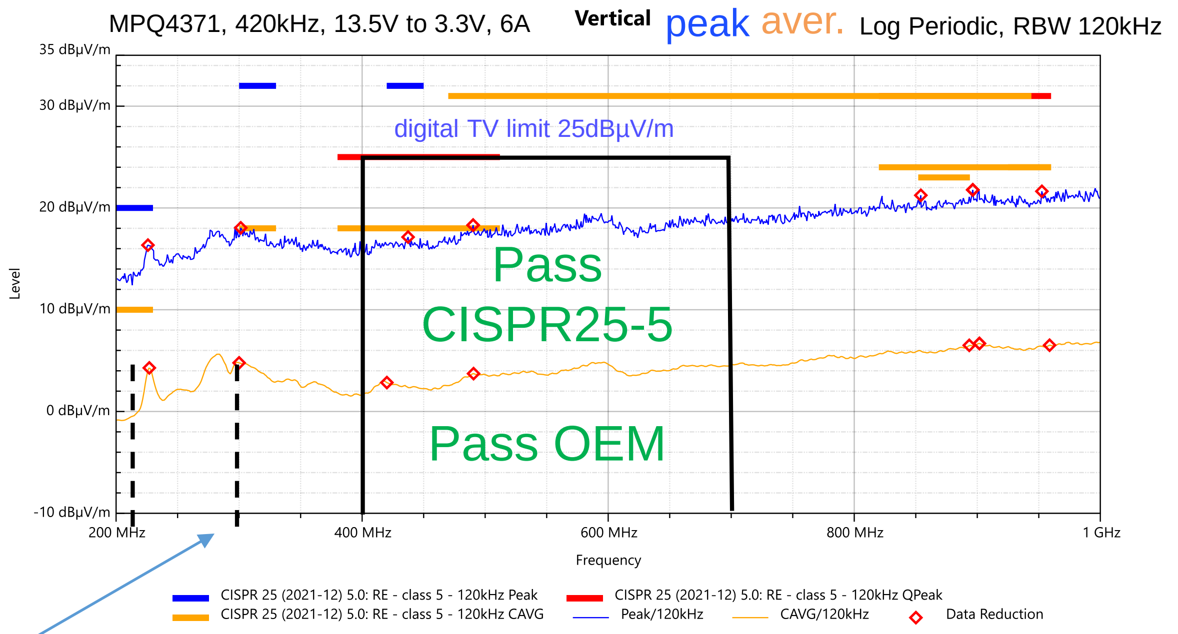
MPQ4371 Constant F_{SW}





MPQ4371 Radiated Emission CISPR25-5 2021-12 (200M-1GHz)





MPQ4371 SW-node resonance range **around 200M-300MHz**

> 300 MHz there is no significant emission and the signal align with the spectrum analyzer noise floor.

As an example, for a difficult to meet OEM EMI specification: the box black shows a digital TV range with a max. peak 25dBµV/m limit within 400 MHz to 710 MHz .

MPQ4371 SW-node Waveform and EMI Performance

Conclusion about MPQ4371

- The dual spread spectrum frequency modulation is a great advantage with high currents, F_{SW} fundamental and harmonics are strongly suppressed.
- MPQ4371 has a very nice rising and falling edge.
- The RE noise is below the 250-300MHz switching resonance, very clean at 400M-710MHz TV band which has strict limit line.

SW-node Comparison of Step-Down Converters

Example for a SW-node

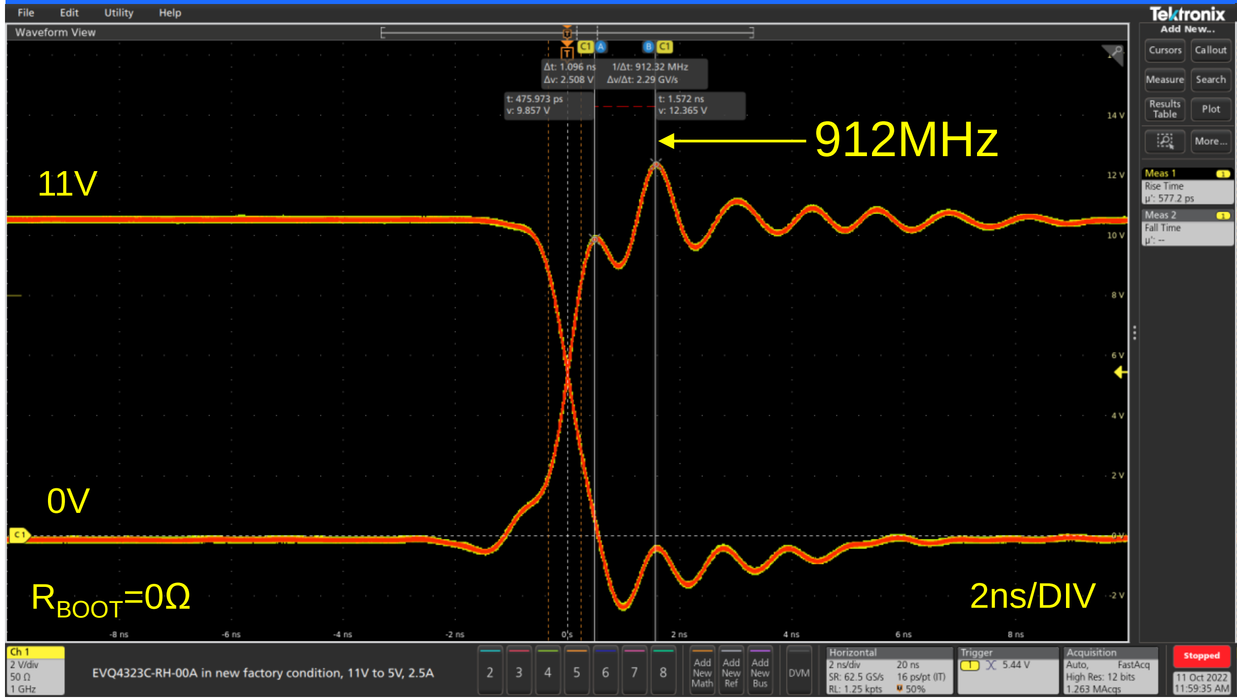
MPQ4323C (high efficiency 3A)
vs.
MPQ4323M, (high efficiency 3A, Module)

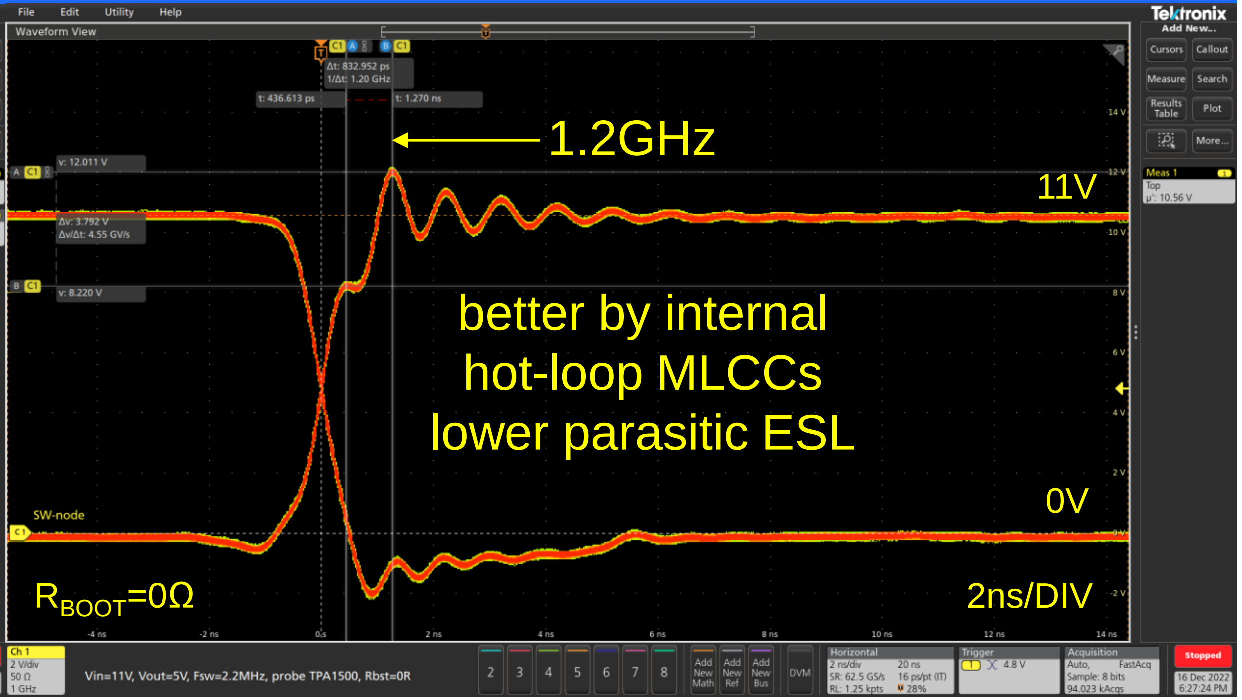
The module has internal V_{IN} hot-loop MLCCs

MPQ4323C	MPQ4323M
42V Load Dump Tolerant, 3A Ultra-Compact Synchronous Step-Down Converter, AEC-Q100 Qualified	42V Load Dump Tolerant, 3A Ultra-Compact, Low-IQ Synchronous Step-Down Converter, AEC-Q100 Qualified

EVQ4323C

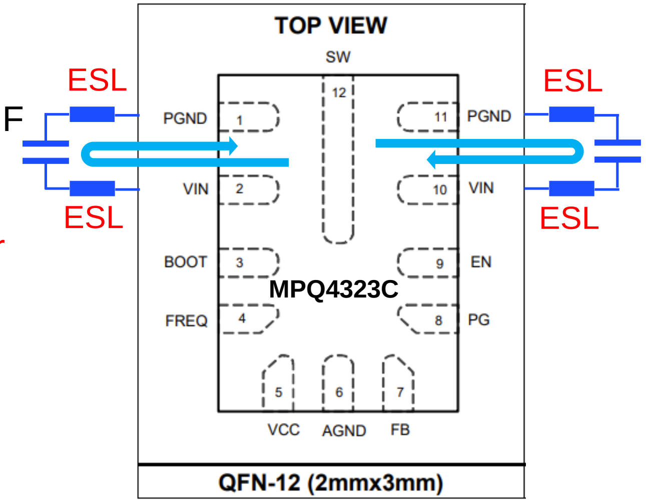
EVQ4323M

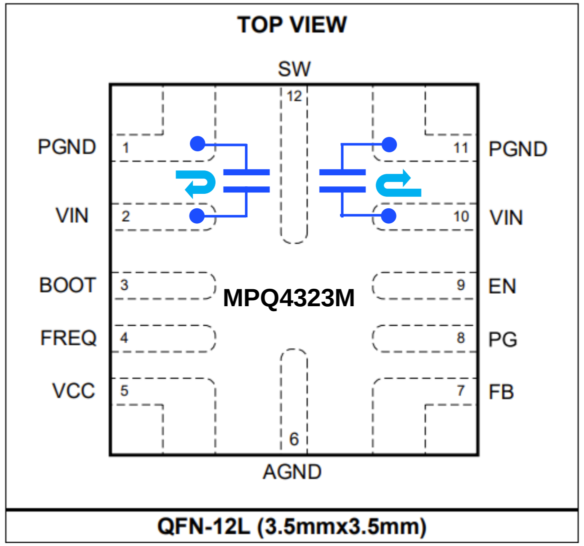




MPQ4323C ***external*** hot-loop 100nF MLCCs.

- Resonance amplitude higher
- Hot-loop di/dt current area larger ➔ EMI disadvantage





MPQ4323M ***internal*** hot-loop 100nF MLCCs.

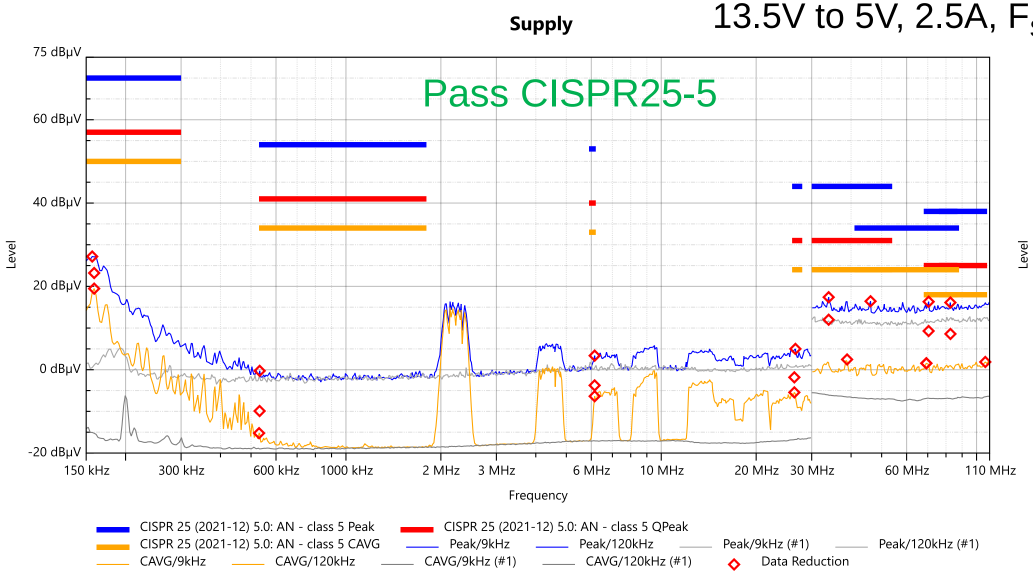
- Resonance amplitude lower
- Hot-loop high di/dt currents on smaller PCB area ➔ EMI advantage

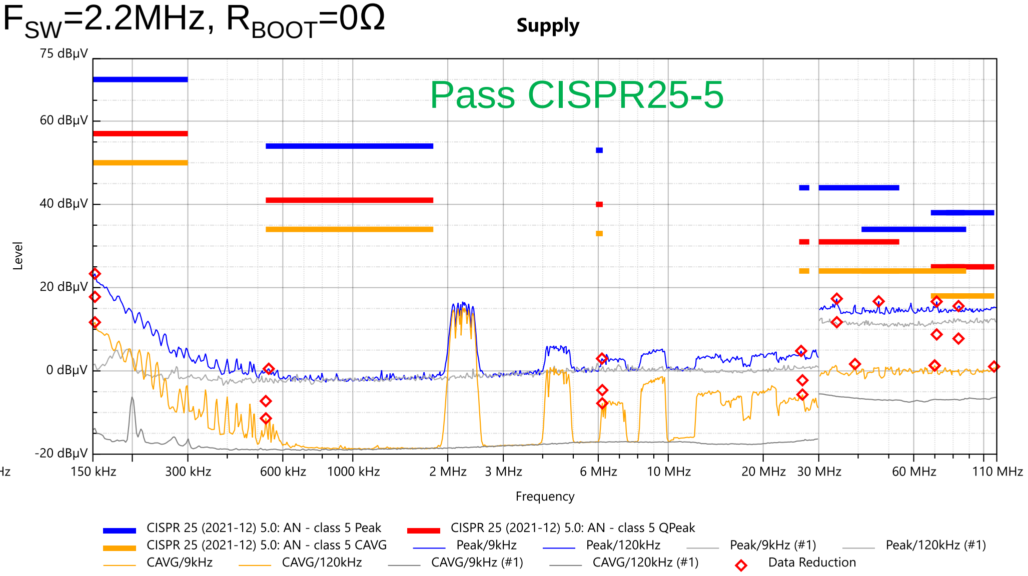
Conducted Emissions (150k-108MHz) EVQ4323C vs. EVQ4323M

EVQ4323C

EVQ4323M

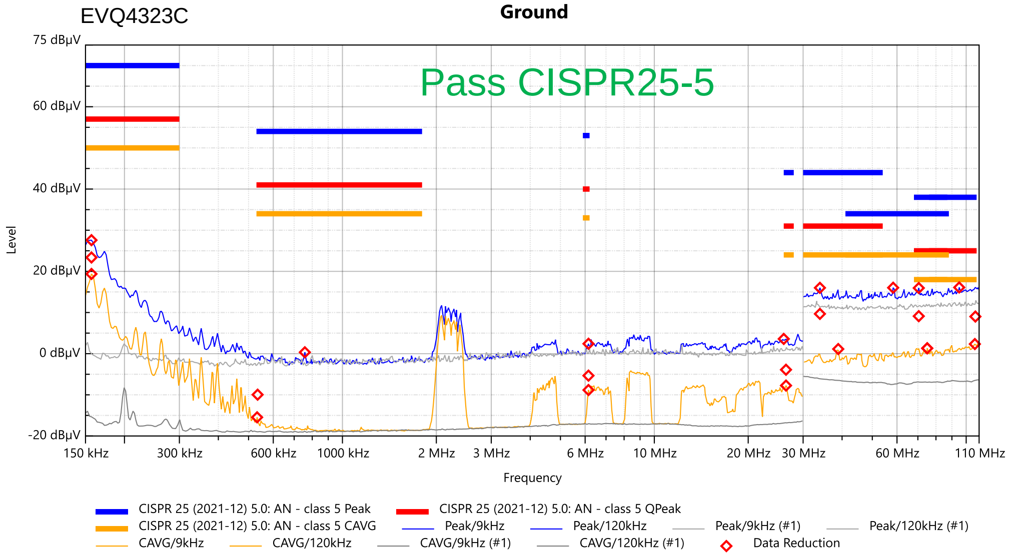
13.5V to 5V, 2.5A, F_{SW}=2.2MHz, R_{BOOT}=0Ω



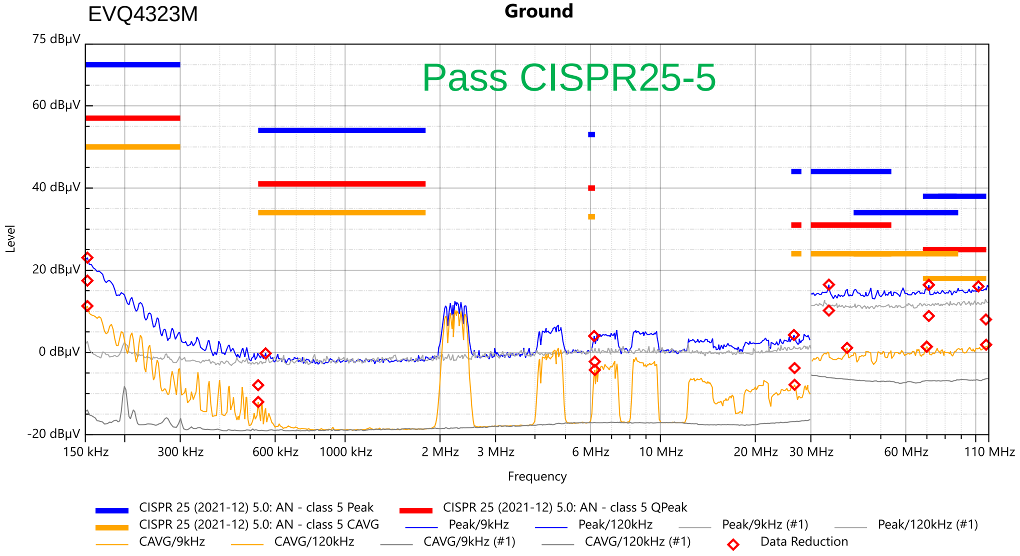


Blue Peak
Orange Average
Grey Noise Level
Conducted Emission, wires 20cm

EVQ4323C



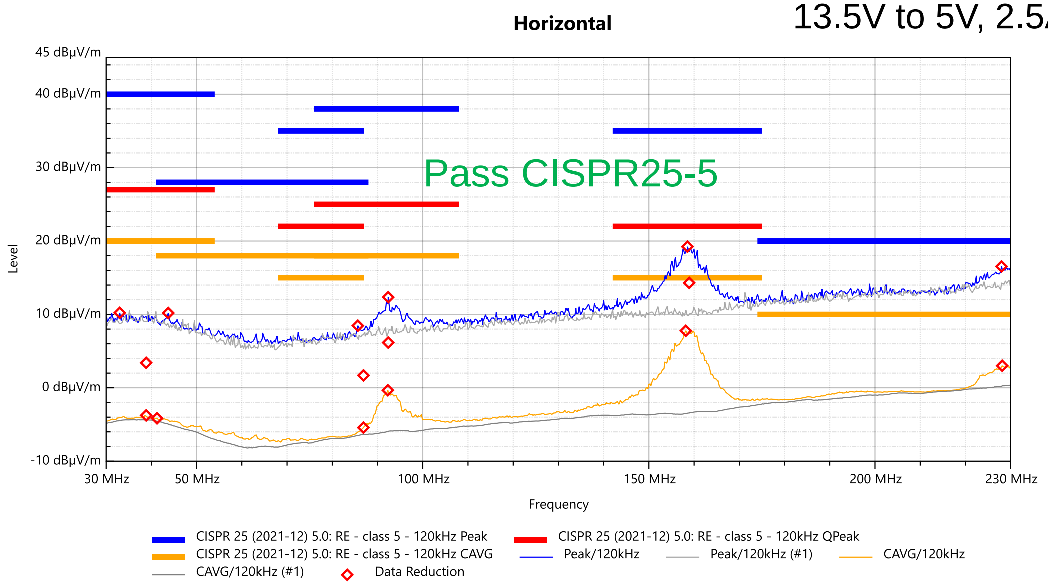
EVQ4323M

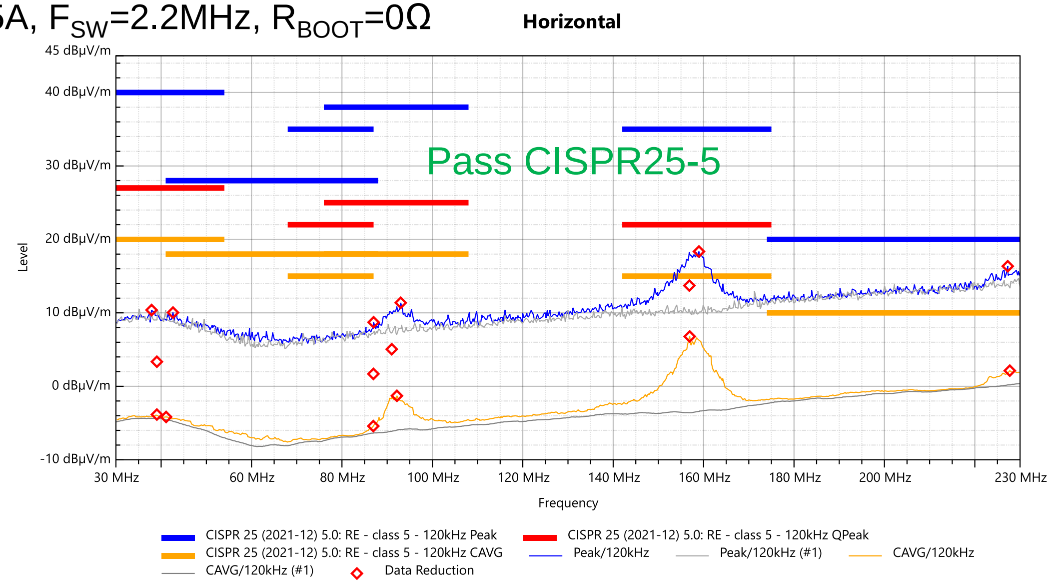


Radiated Emissions (30M-200MHz) EVQ4323C vs. EVQ4323M

EVQ4323C | EVQ4323M

13.5V to 5V, 2.5A, F_{SW}=2.2MHz, R_{BOOT}=0Ω





Blue Peak

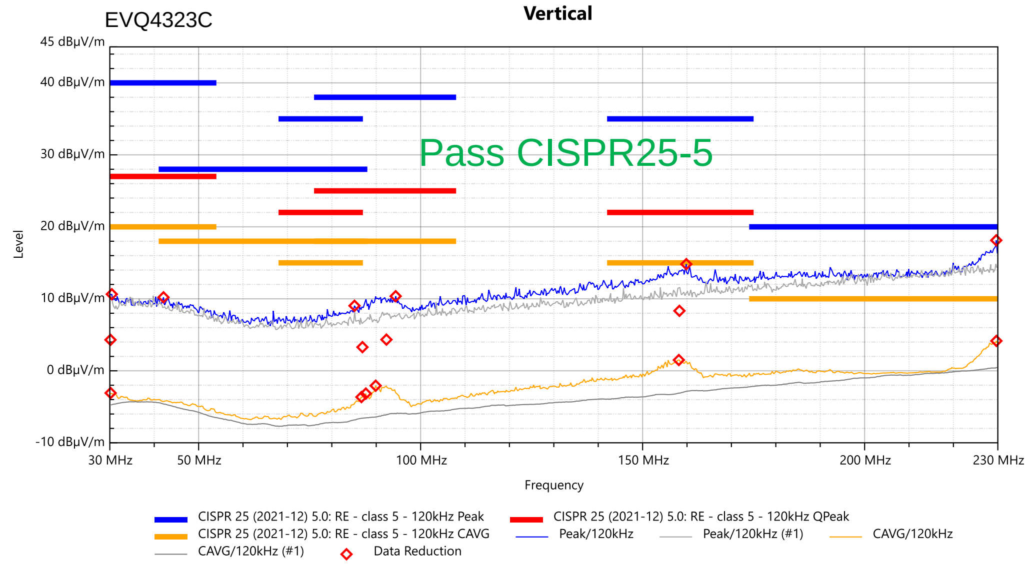
Orange Average

Grey Noise Level

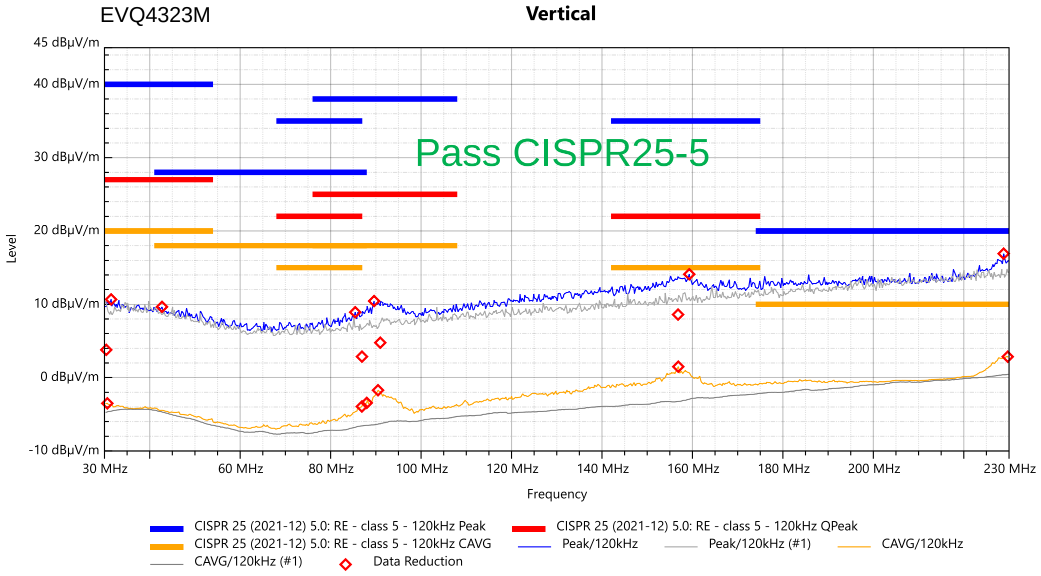
Biconical Antenna

Radiated Emission, wires 200cm

EVQ4323C



EVQ4323M



RF energy is not found in this medium frequency range

$F_{RESONANCE}$>800MHz

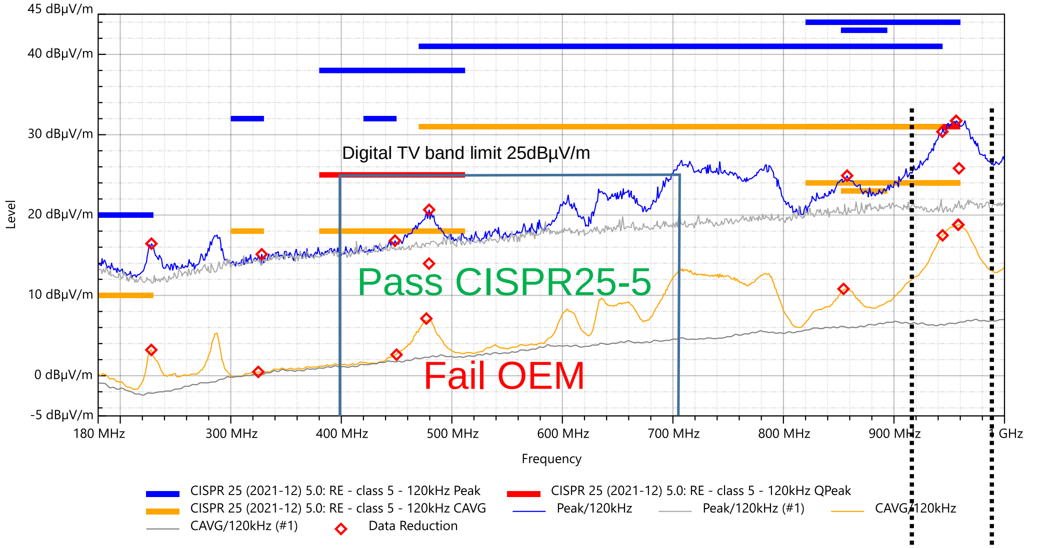
Radiated Emissions (200M-1GHz) EVQ4323C vs. EVQ4323M

EVQ4323C

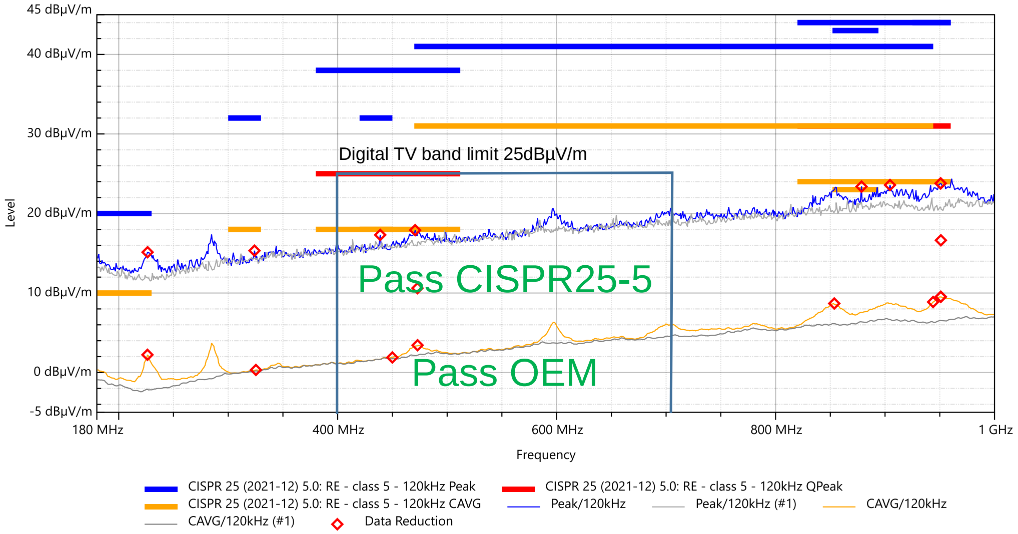
EVQ4323M

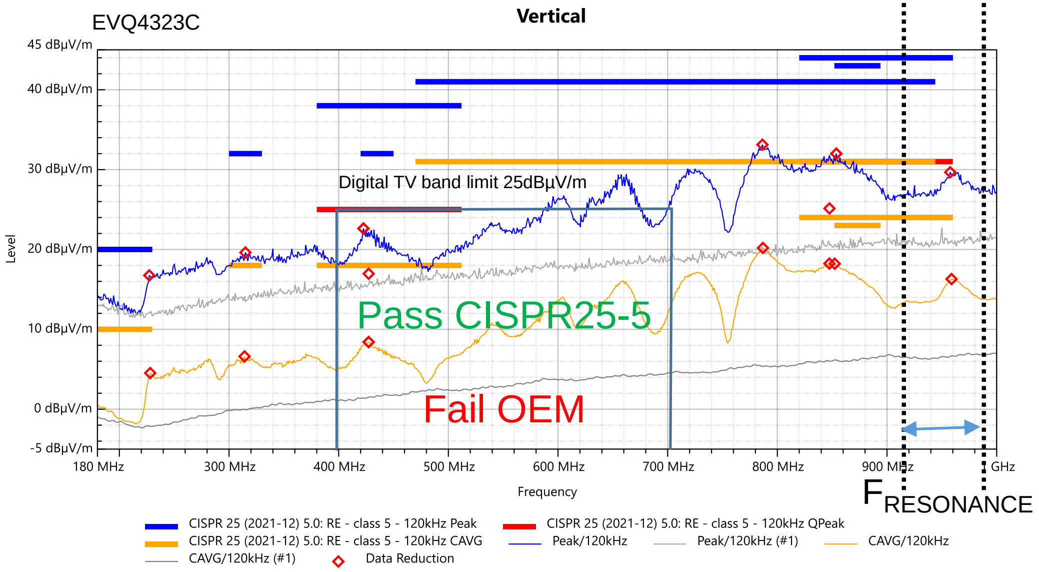
13.5V to 5V, 2.5A, F_{SW}=2.2MHz, R_{BOOT}=0Ω

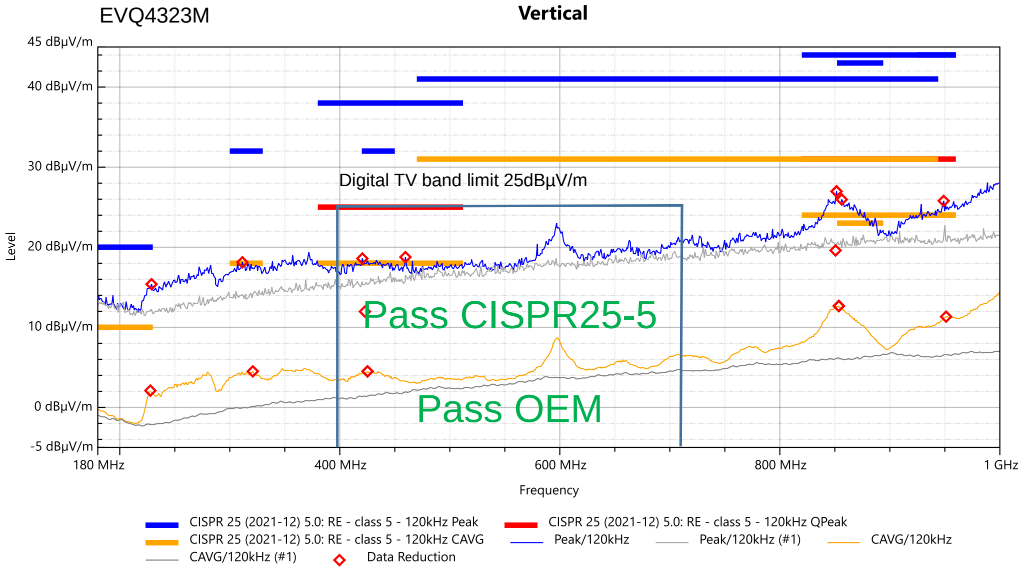
Horizontal



Horizontal







Blue Peak
Orange Average
Grey Noise Level

Log Antenna

Radiated Emission, wires 200cm

EVQ4323C can pass CISPR25 Class5, but requires filter modification to pass this special TV OEM specification.

The energy of $F_{RESONANCE}$ approx. 900MHz can be found in this frequency range

The Modul M has a large EMI improvement due to smaller VIN hot-loop

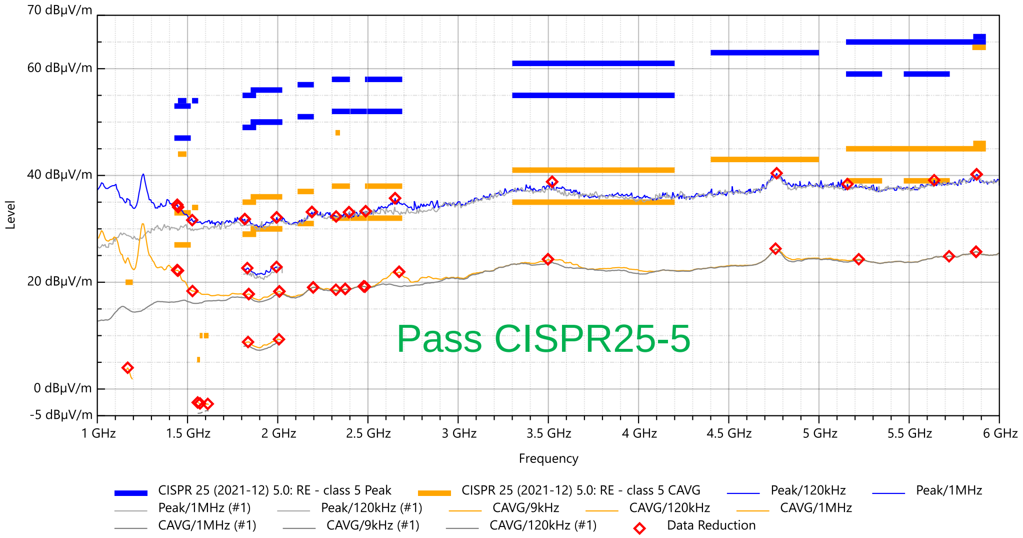
Radiated Emissions (1G-6GHz) EVQ4323C vs. EVQ4323M

EVQ4323C

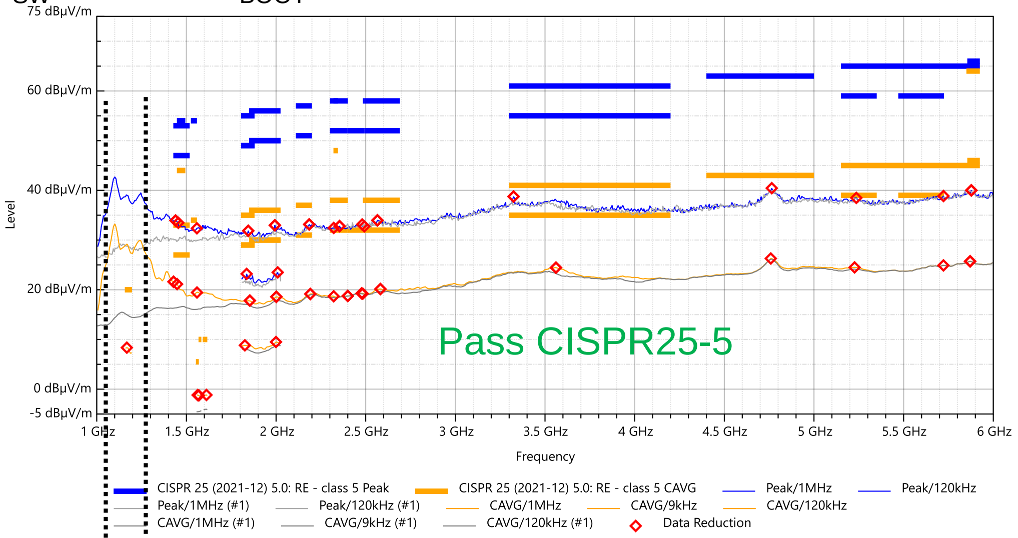
EVQ4323M

13.5V to 5V, 2.5A, F_{SW}=2.2MHz, R_{BOOT}=0Ω

Horizontal



Horizontal

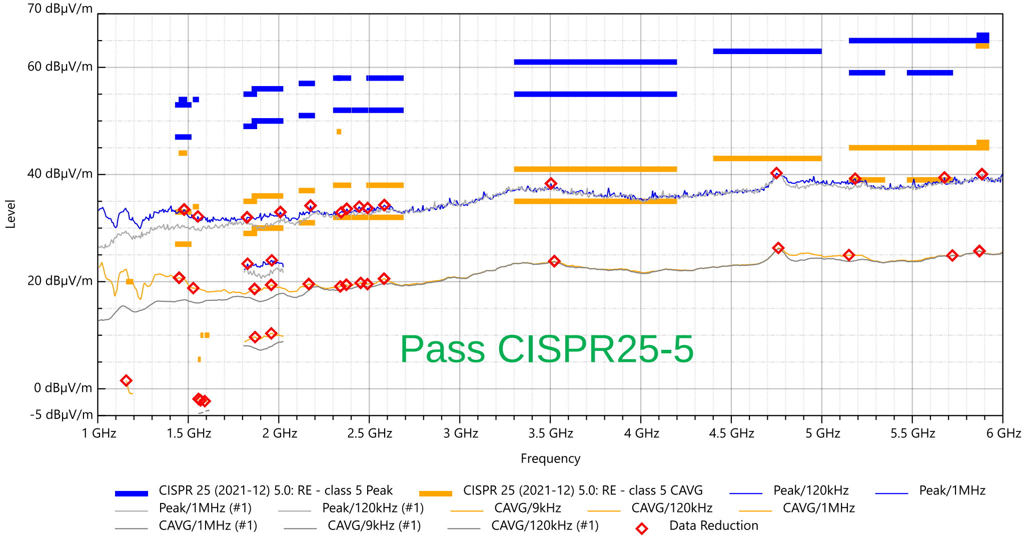


Blue Peak
Orange Average
Grey Noise Level
Horn Antenna
Radiated Emission, wires 200cm

No obvious noise above ~1.2GHz $F_{RESONANCES}$ at 1G-6GHz range

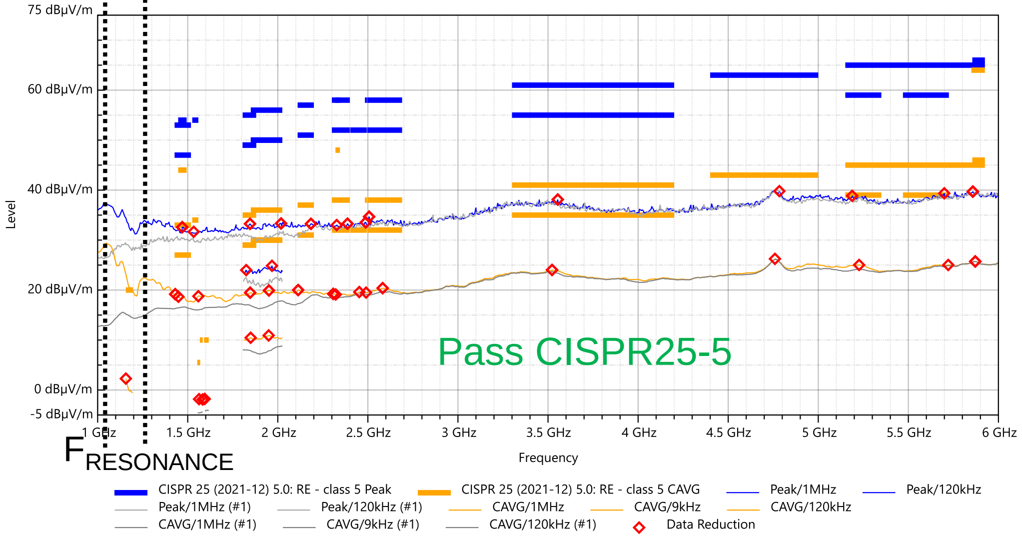
EVQ4323C

Vertical



EVQ4323M

Vertical



$F_{RESONANCE}$

Agenda

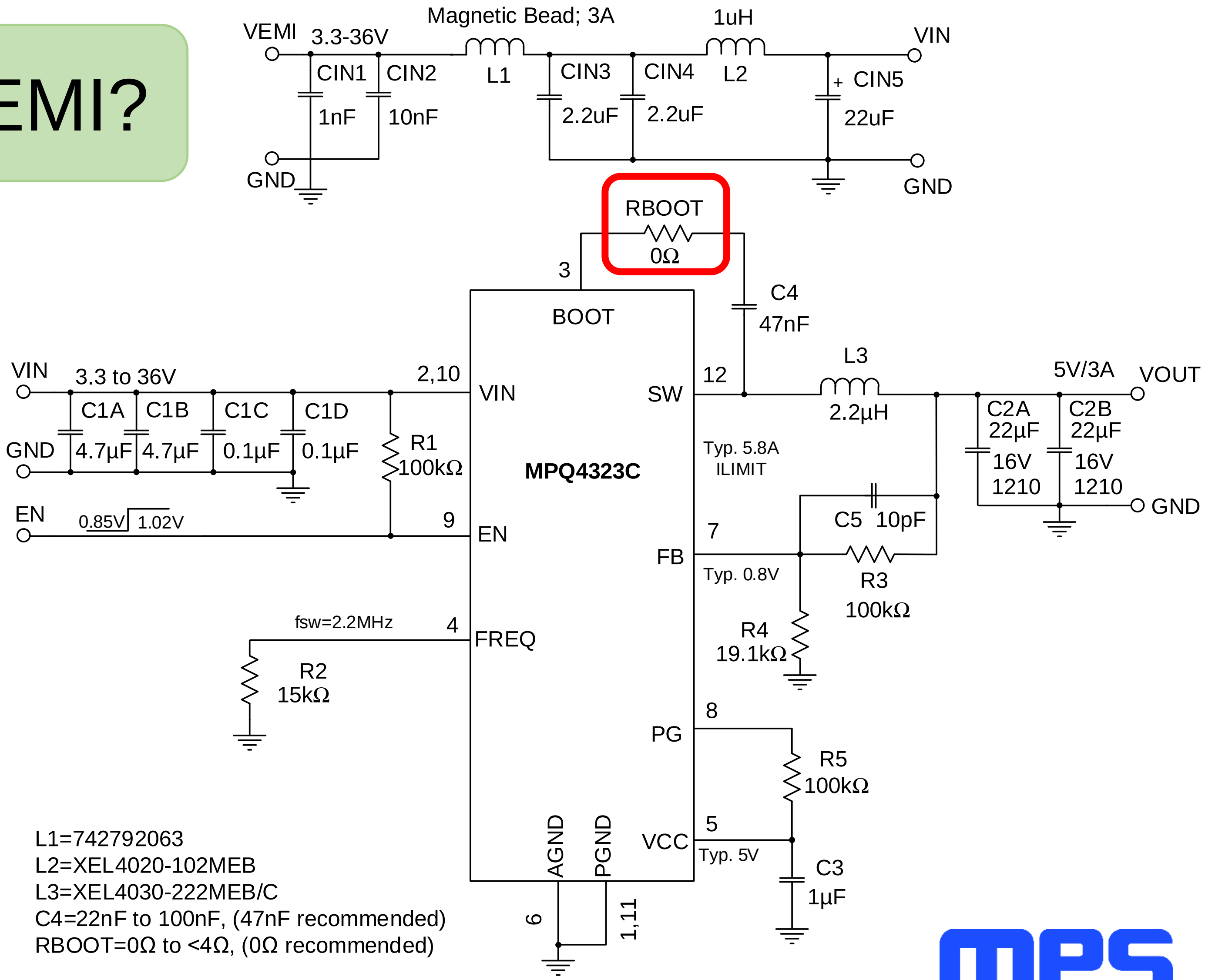
- EMI Sources of Step-down Converter
- SW-node Waveform Measurements and Influence on EMI Performance
- EMI Tips
- Example on EMI Performance Optimization

Increasing R_{BOOT} to Improve EMI?

Increasing R_{BOOT} to improve EMI?

(from datasheet MPQ4323C)

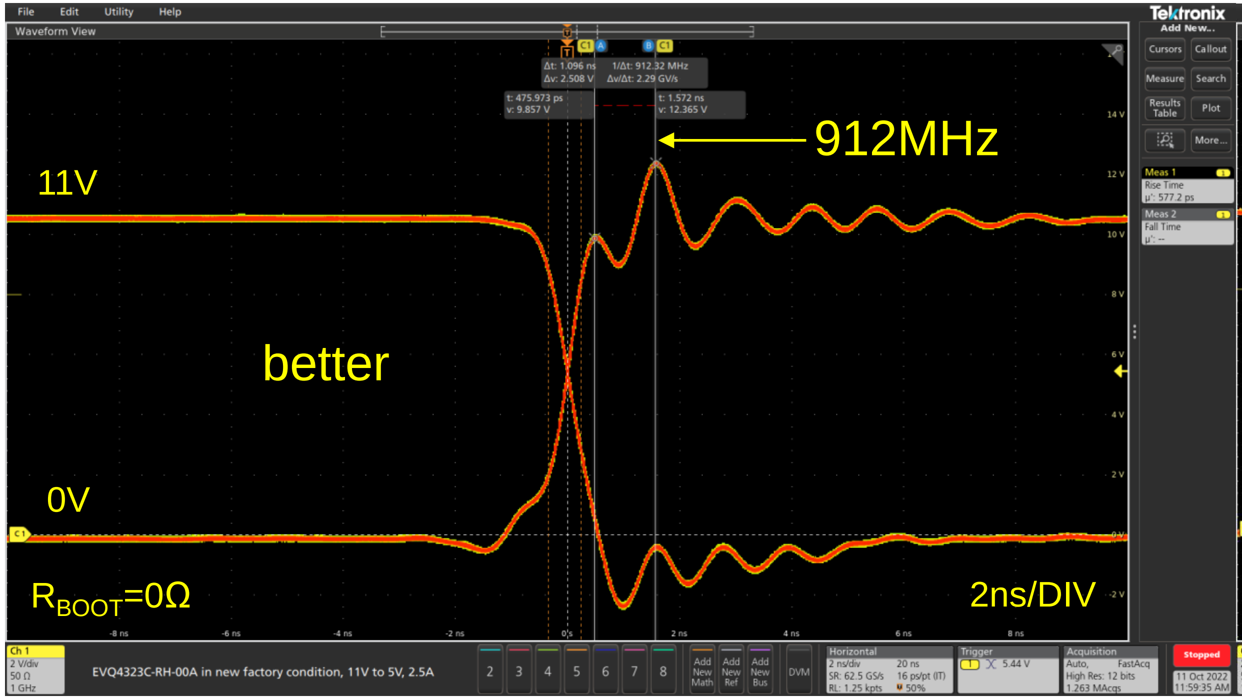
It is not recommended to place a resistor (R_{BOOT}) in series with C4, unless there is a strict EMI requirement. R_{BOOT} helps enhance EMI performance and reduce voltage stress at high input voltages, but it also generates additional power consumption and reduces efficiency. When R_{BOOT} is necessary, it should be below 4Ω.

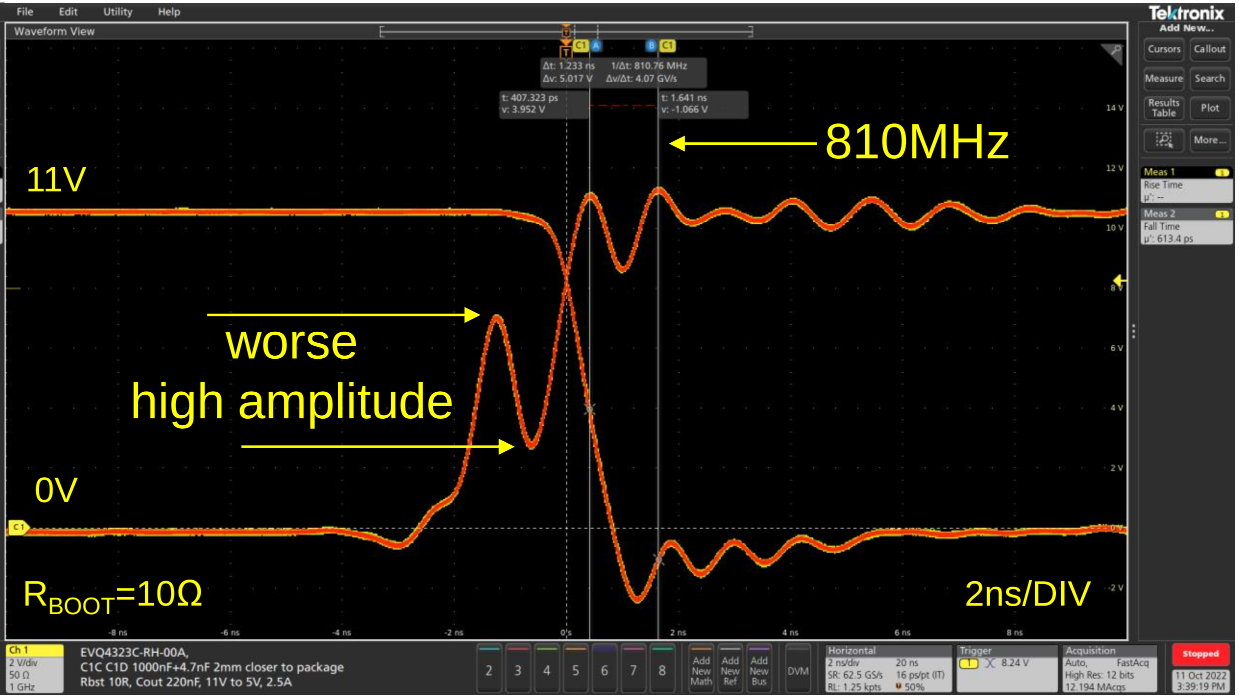


Increasing R_{BOOT} to Improve EMI?

EVQ4323C R_{BOOT}=0Ω

EVQ4323C R_{BOOT}=10Ω





MPQ4323C datasheet has a recommendation maximum R_{BOOT}<4Ω

Increasing R_{BOOT} too much can worsen EMI

➔ check the SW-node

➔ check datasheet for R_{BOOT}

- increasing R_{BOOT} to 10Ω (not a recommend, too large value), the resonance amplitude moves into the rising edge, this can degrade the switching performance between High Side and Low Side MOSFET, in a worst case scenario a short-cut between both MOSFETs can happen.

- The resonance amplitude has increased ➔ worsen EMI.

Increasing R_{BOOT} to Improve EMI?

Increasing R_{BOOT} to improve EMI?

Conclusion

Pro – increasing R_{BOOT} ➔ lowers SW-node rise/fall time (small effect compared to SW-node resonance).
Pro – increasing R_{BOOT} ➔ lowers SW-node resonance frequency

Contra - increasing R_{BOOT} ➔ decrease efficiency.
Contra - increasing R_{BOOT} ➔ degrades SW-node waveform performance.
Contra - increasing R_{BOOT} ➔ can increase resonance amplitude.

➢ increasing R_{BOOT} is one of the method worth to try, but is not a guaranteed EMI improvement.

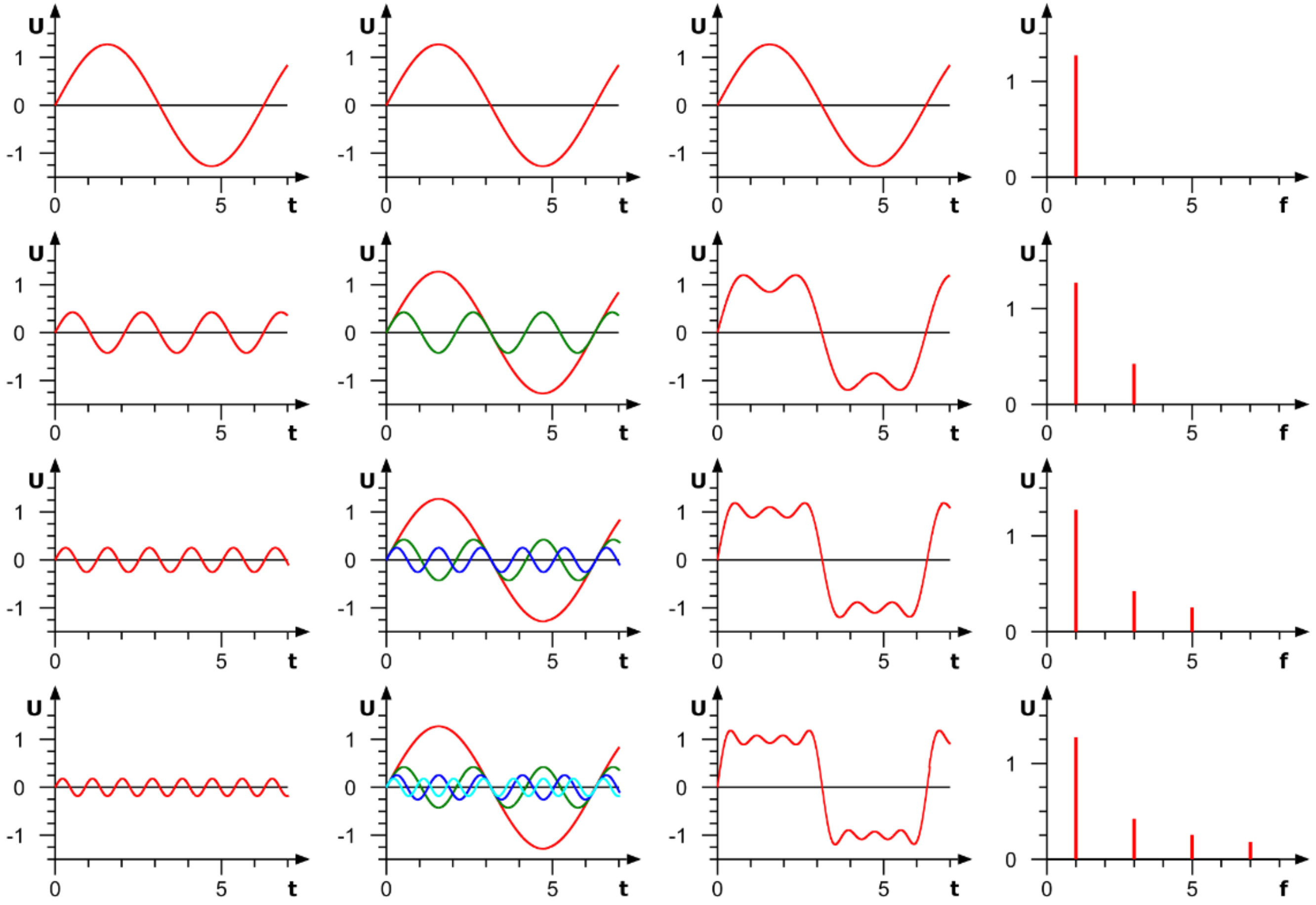
MPS

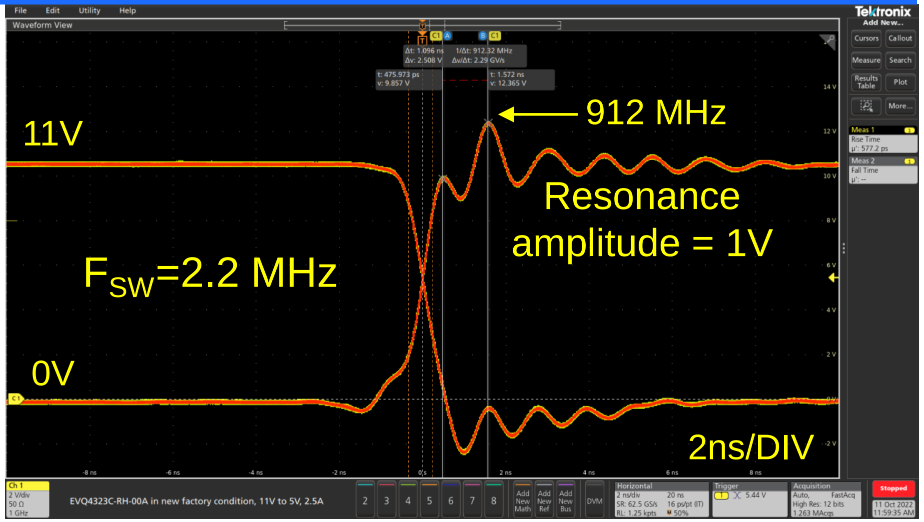
Amplitude of the Resonance Frequency - Impact on EMI

Why does the amplitude of the resonance frequency of the SW-node have a greater impact on EMI than harmonic of switching frequency?

Amplitude of the Resonance Frequency - Impact on EMI

EVQ4323C SW-node Fourier Analysis





$$\frac{912\ MHz}{2.2\ MHz} = 415^{th}.\ \text{harmonic}$$

$$11\text{V} \cdot \frac{4}{\pi} \cdot \frac{\sin(415 \cdot x)}{415} = 34\ \text{mV}\ (415^{th}.\ \text{harmonic})$$

The 34mV amplitude of the 415th. harmonic is much lower than the measured 1V amplitude

Amplitude of the Resonance Frequency - Impact on EMI

$$\text{measured resonance amplitude (t)} = \mathbf{1V} * \sin(2 * \pi * 912MHz * t)$$

$$\text{ideal square wave } 415^{th}\text{. harmonic (t)} = \mathbf{34mV} * \sin(2 * \pi * 912MHz * t)$$

The resonance amplitude and the frequency:

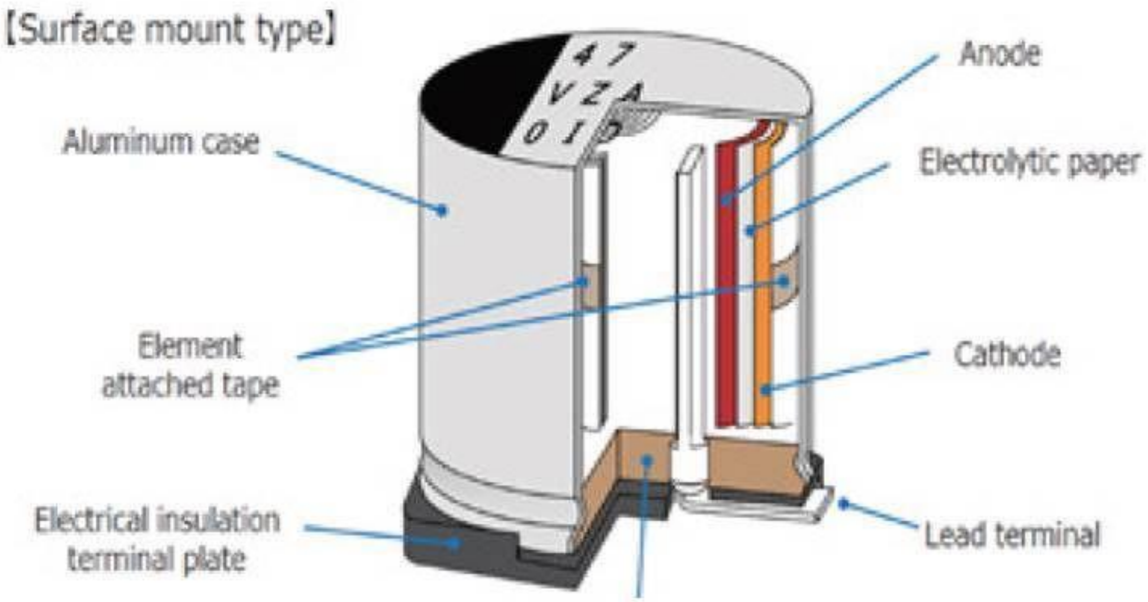
- has a much greater impact on EMI than harmonic of square PWM frequency

Electrolytic in the Input Filter

An electrolytic in the input filter
can radiate EMI

Electrolytic in the Input Filter

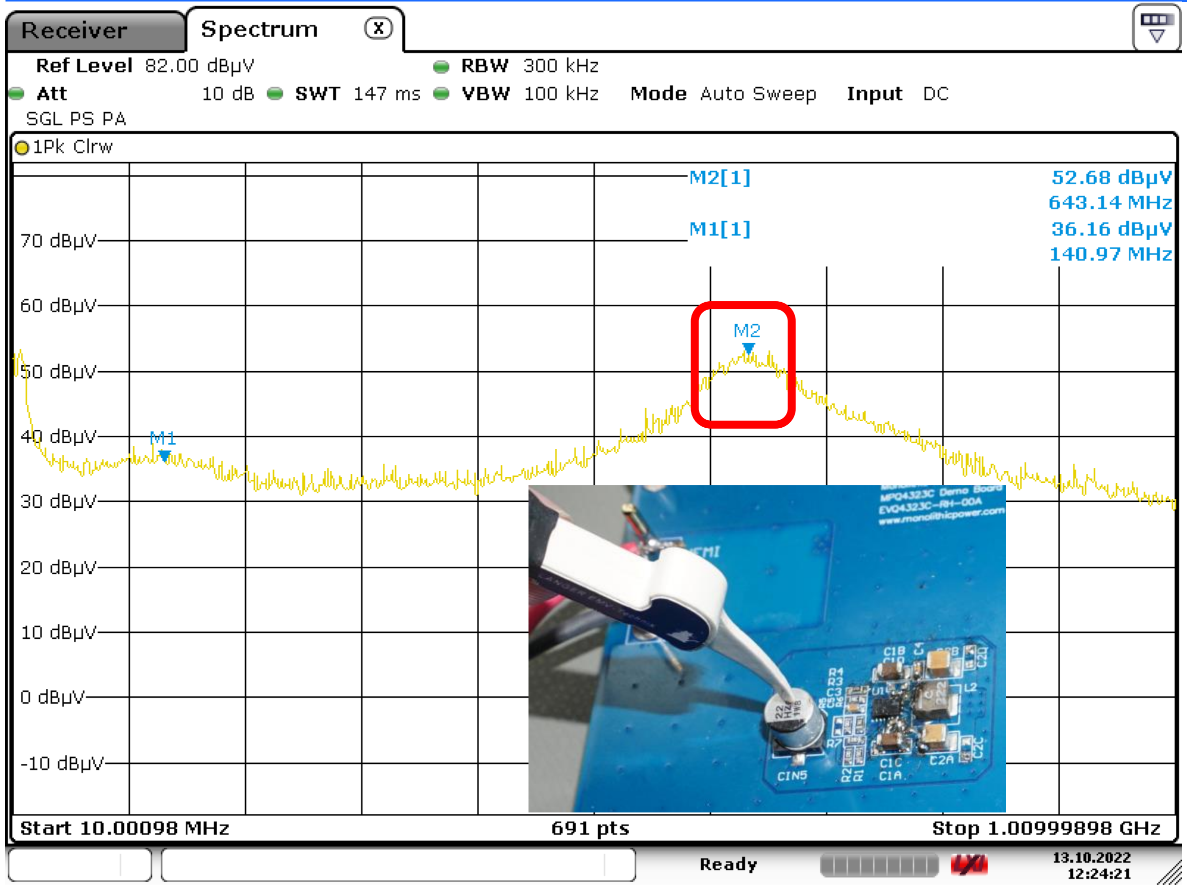
Electrolytic and its housing



Electrolytic on EVQ4323C connected to VIN hot-loop MLCCs

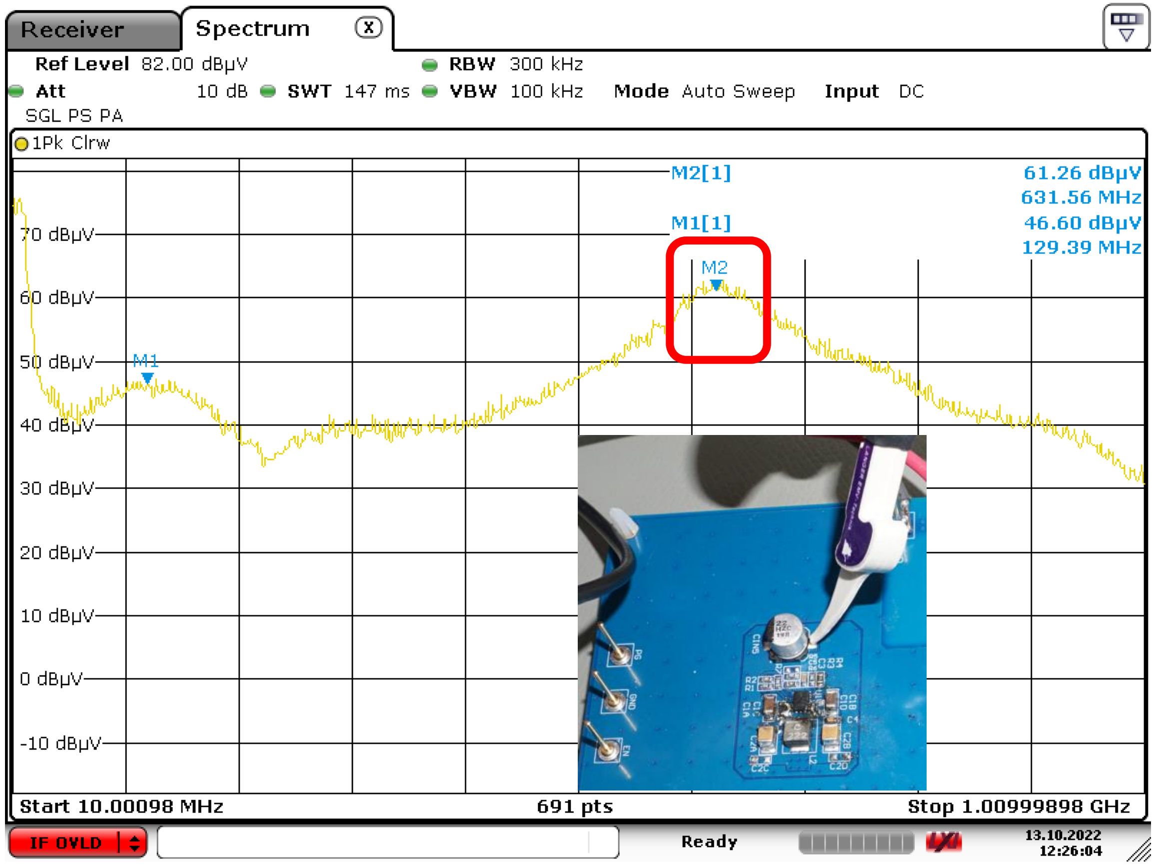
- An electrolytic capacitor has a parasitic capacitance between the anode and the aluminum housing.
- The parasitic capacitance is conductive at higher frequencies.
- Any high frequency applied on the anode pin will radiate on the housing as antenna to the environmental.

H-field probe on the housing and on the anode pin



Date: 13.OCT.2022 12:24:21

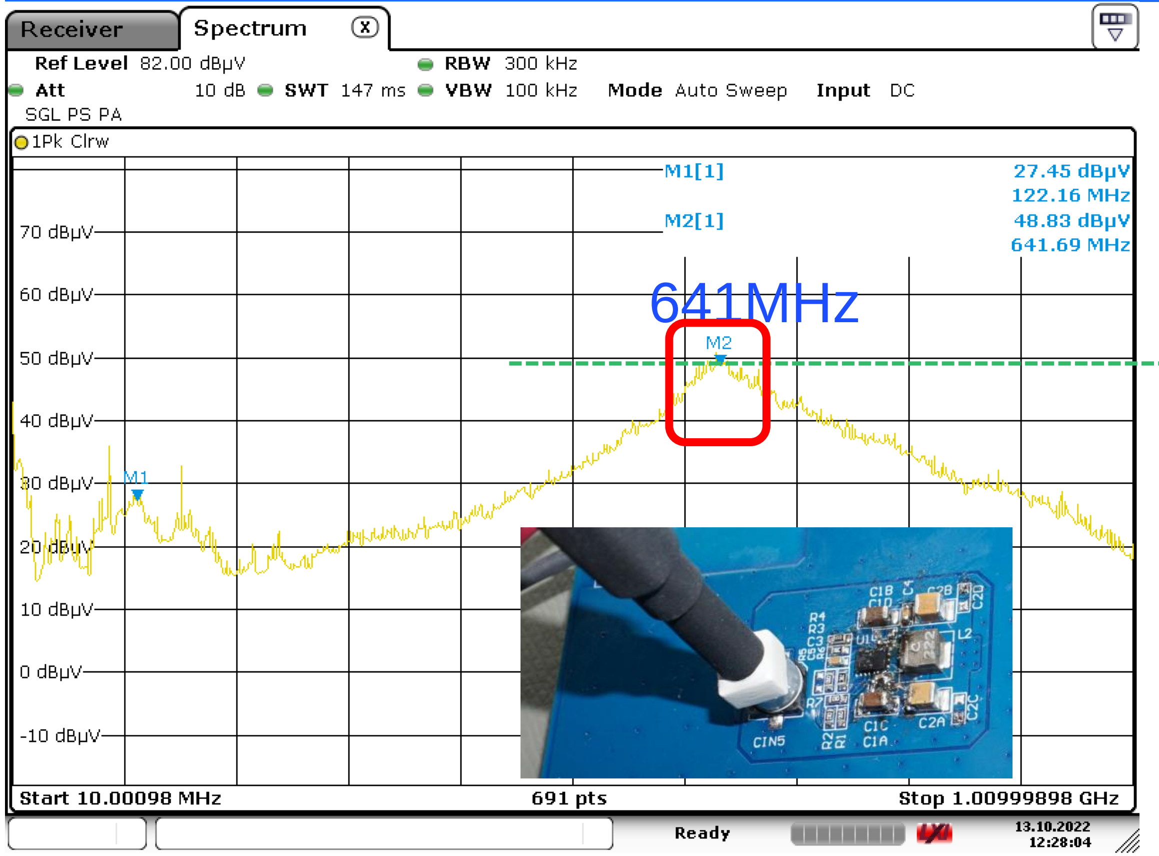
H-field on the electrolytic **housing**



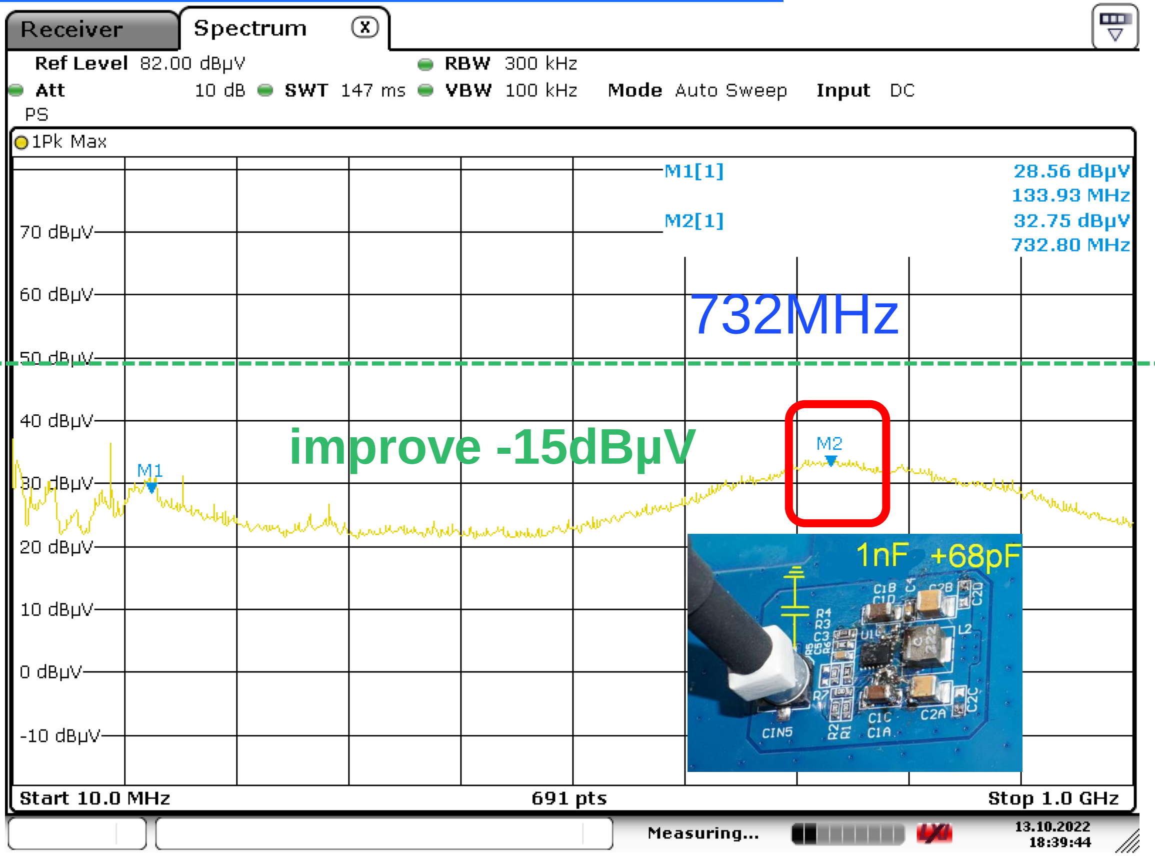
Date: 13.OCT.2022 12:26:04

H-field on the electrolytic **anode pin**

E-field probe on the electrolytic housing



Date: 13.OCT.2022 12:28:04



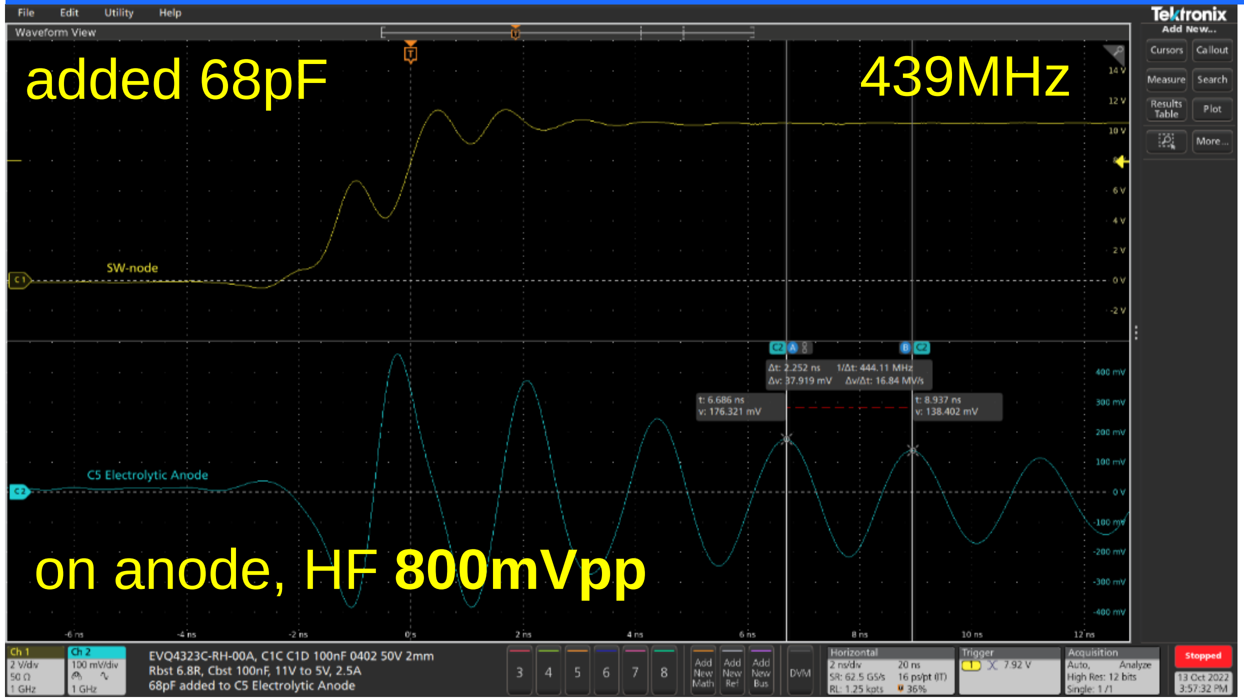
Date: 13.OCT.2022 18:39:44

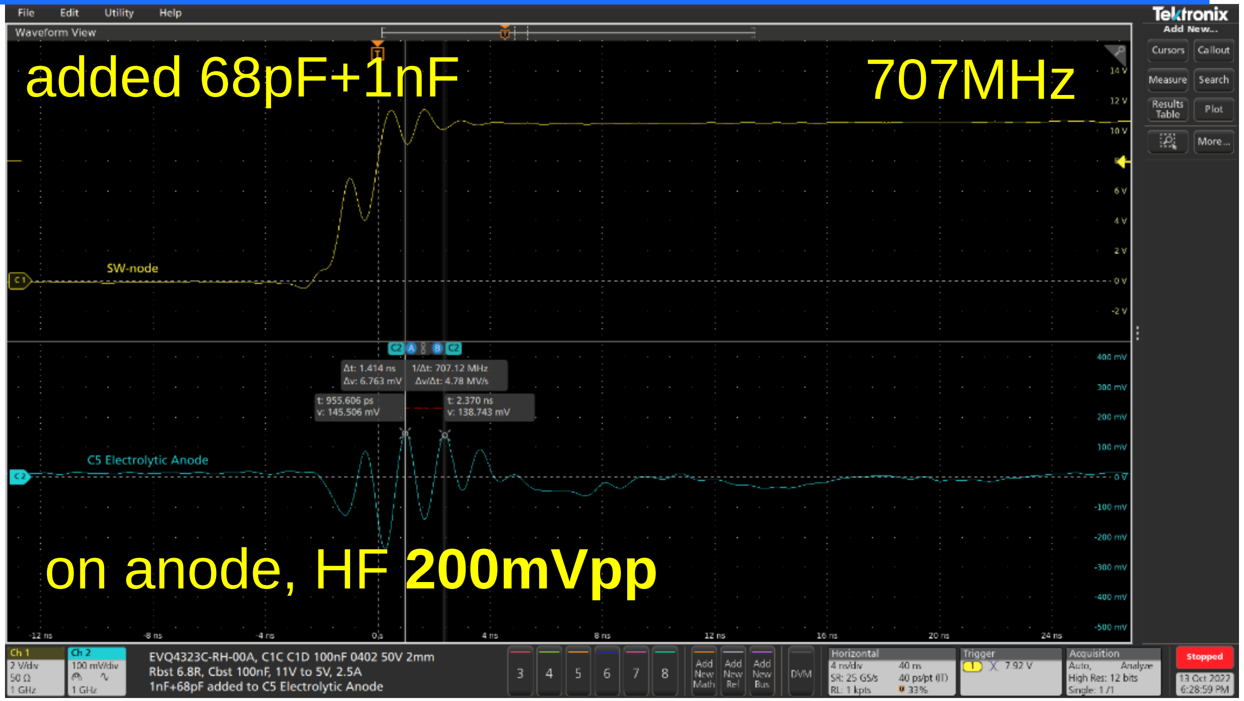
E-field on the electrolytic **housing**

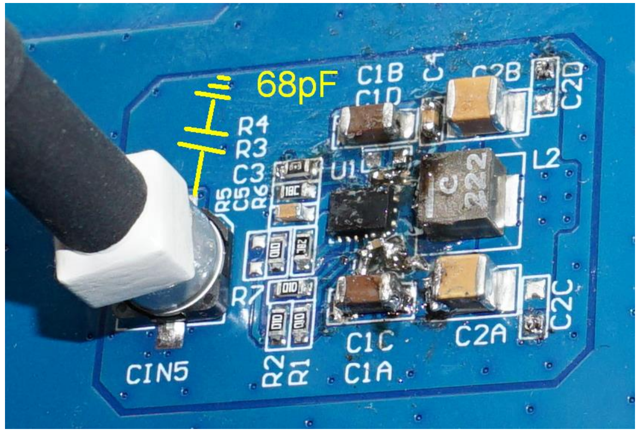
E-field on the electrolytic **housing**

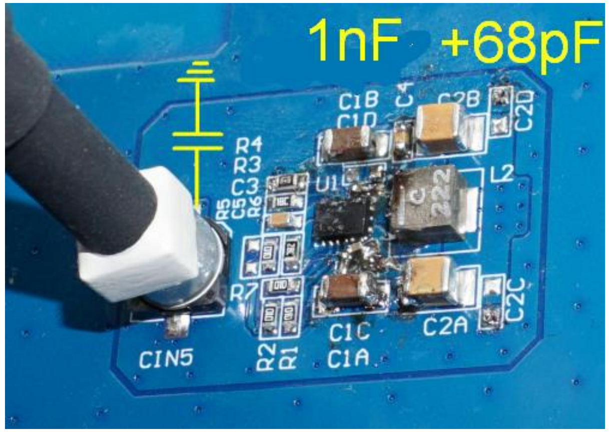
Added **1nF+68pF** MLCC, shifts the resonance to another region.

Electrolytic in the Input Filter









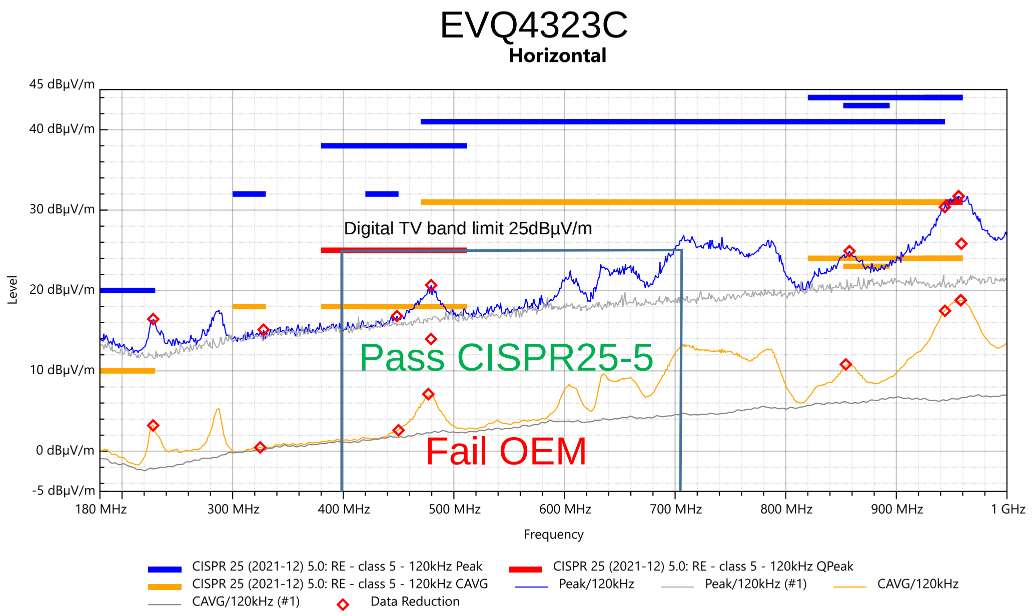
The selected MLCC has a high influence on the trace resonance, can reduce EMI peaks.

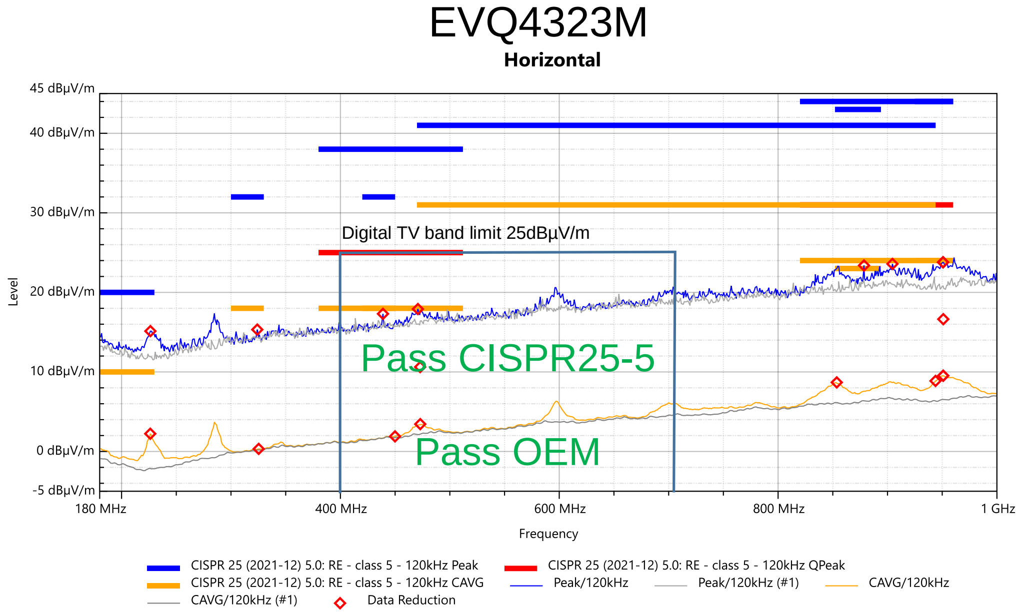
The self-resonance behavior of the VIN trace can be affected by added MLCCs

Agenda

- EMI Sources of Step-down Converter
- SW-node Waveform Measurements and Influence on EMI Performance
- EMI Tips
- Example on EMI Performance Optimization

Modifications on EVQ4323C to pass OEM digital TV band

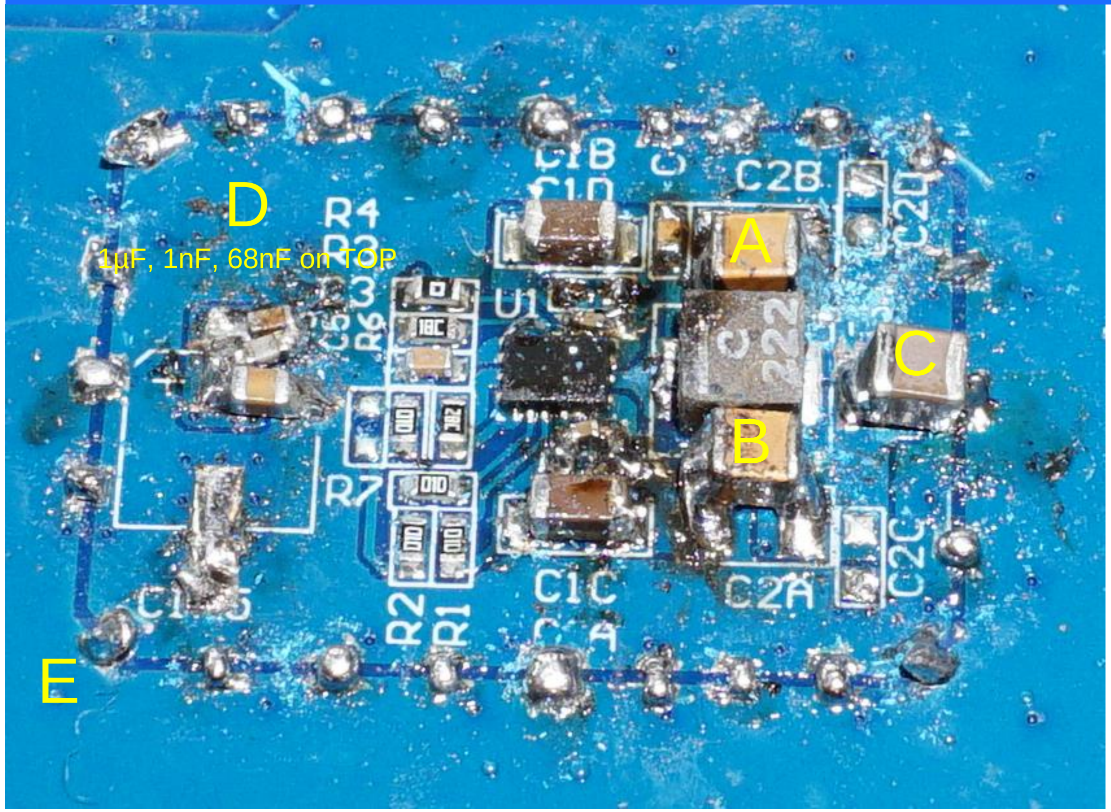




Next experiment shows modifications on EVQ4323C to pass EMI OEM TV band request

- MPS EVQs in default condition are optimized for CISPR25 Class5, not for OEM.
- “M” version fulfill both, can save your time, prevent many external MLCCs and simplify the layout design.

Modifications on EVQ4323C to pass OEM digital TV band



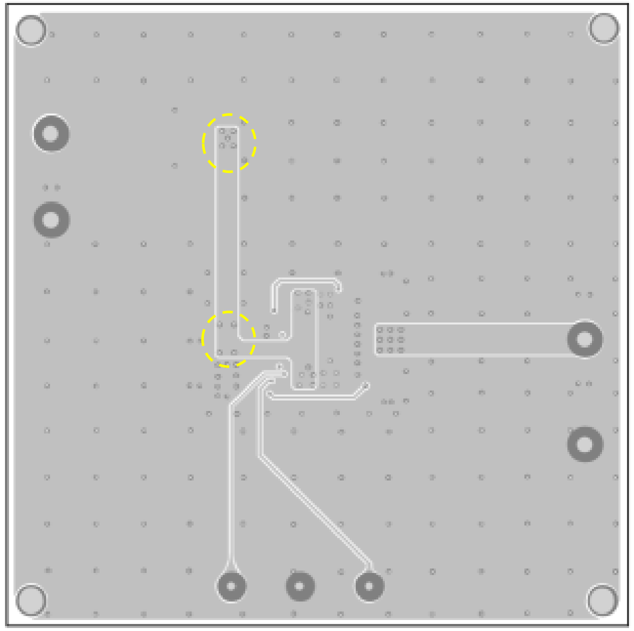


Figure 6: Mid-Layer 2

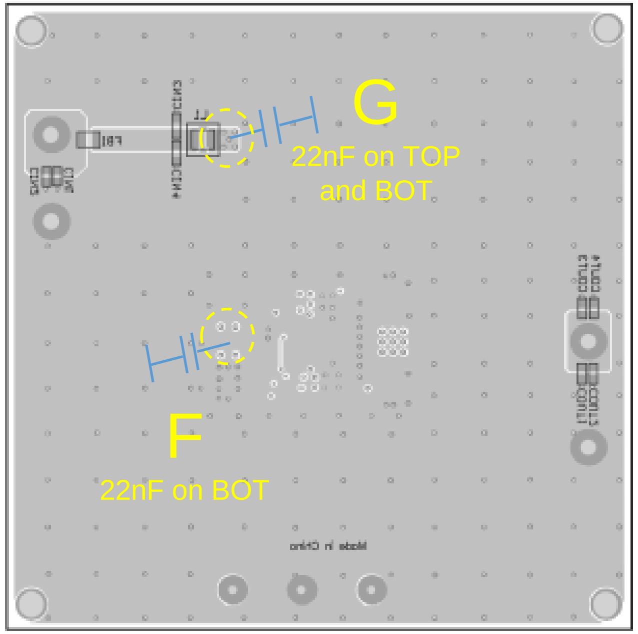
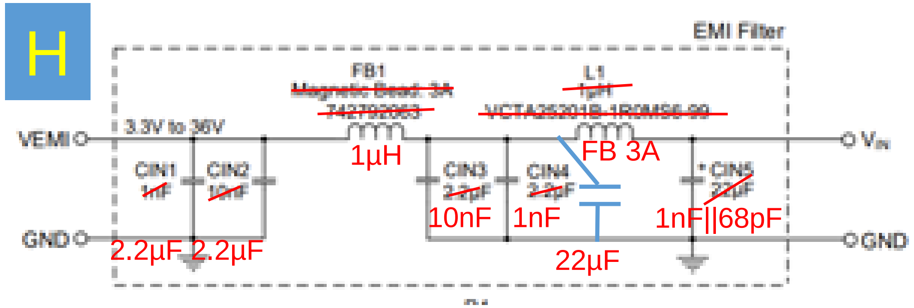


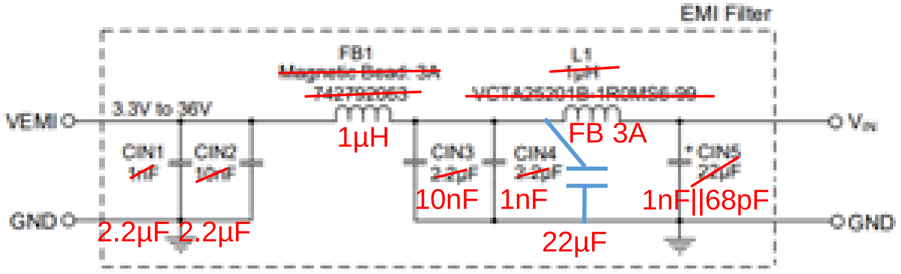
Figure 7: Bottom Layer and Bottom Silk



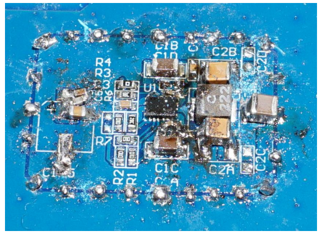
Filter reversed in direction

- **A, B** moving the V_{OUT} MLCCs closer to the inductance, improves EMI shielding of the inductance.
- **C** add MLCC 1210 22µF, 25V, improved shielding of the inductance.
- **D** remove E-cap, add 1uF+1nF+68pF MLCCs.
- **E** shorting the inner GND to outer GND, Island is not necessary on all layouts for EMI.
- **F** MLCC 0603, 22nF on BOT, bypass 5 vertical V_{IN} vias.
- **G** MLCC 0603, 22nF on TOP and BOT, bypass four vertical V_{IN} vias.
- **H** Adjust input filter parameters

Modifications on EVQ4323C to pass OEM digital TV band



Filter reversed in direction



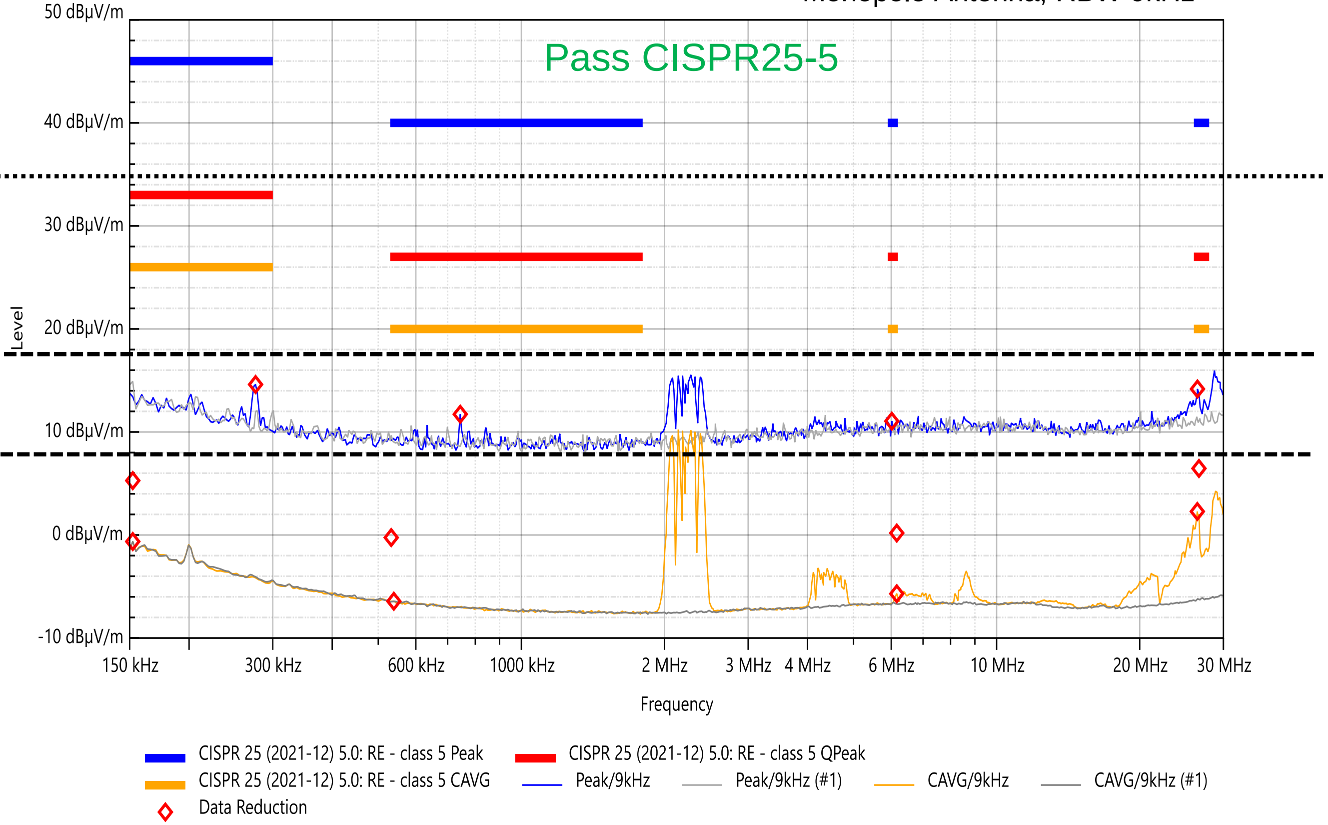
V_{IN}=13.5V, V_{OUT}=5V, F_{SW}=2.2MHz, I_{LOAD}=2.5A, R_{BOOT}=0Ω

Blue Peak Orange Average

EVQ4323C Default

Vertical

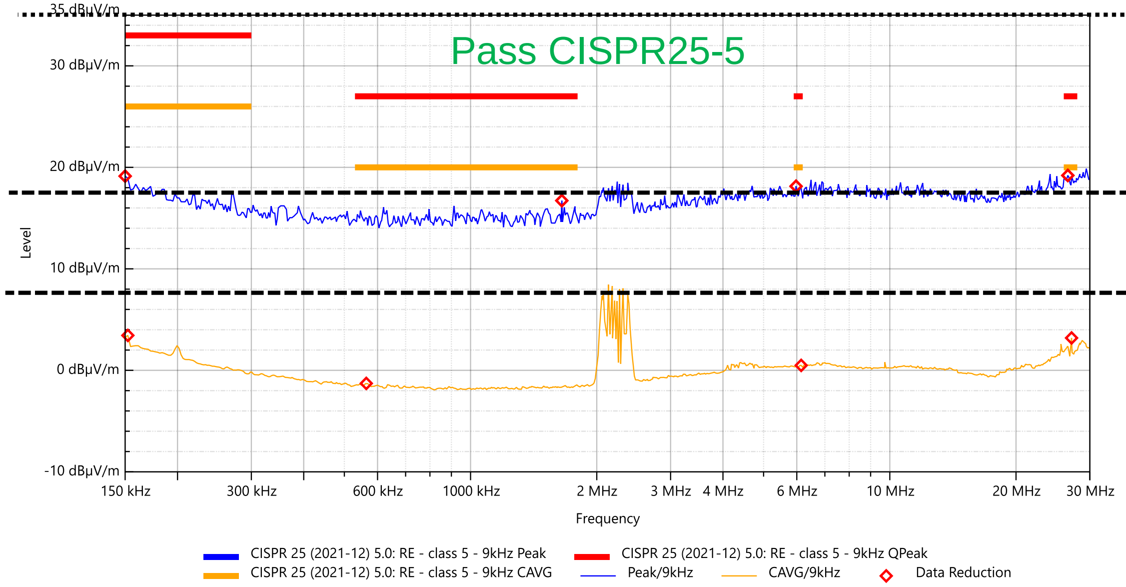
Monopole Antenna, RBW 9kHz



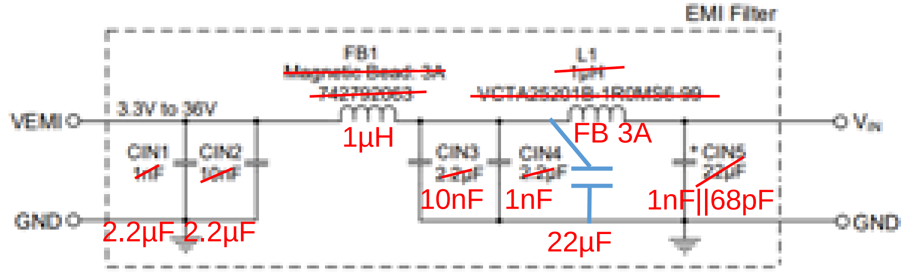
EVQ4323C Modified

Vertical

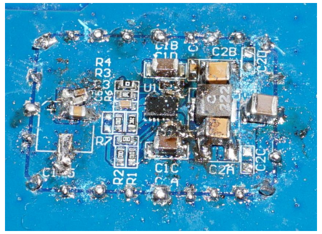
Monopole Antenna, RBW 9kHz
(spectrum analyzer protected)



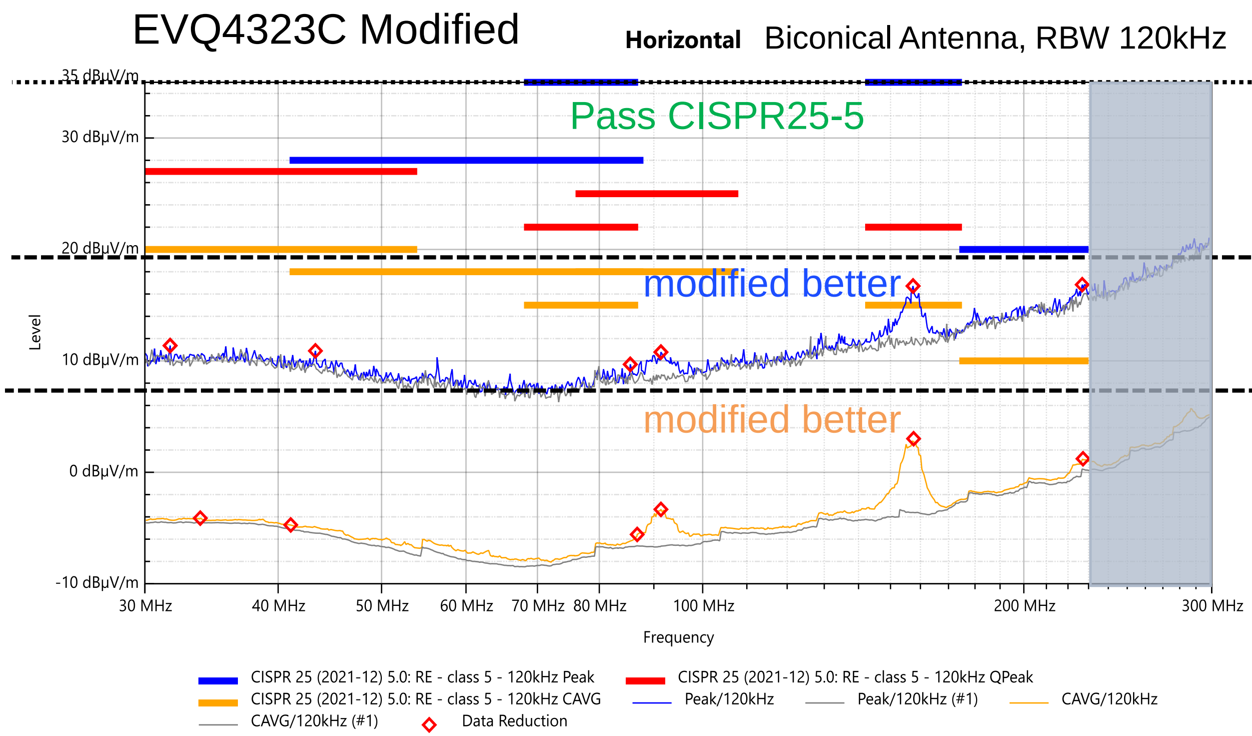
Modifications on EVQ4323C to pass OEM digital TV band

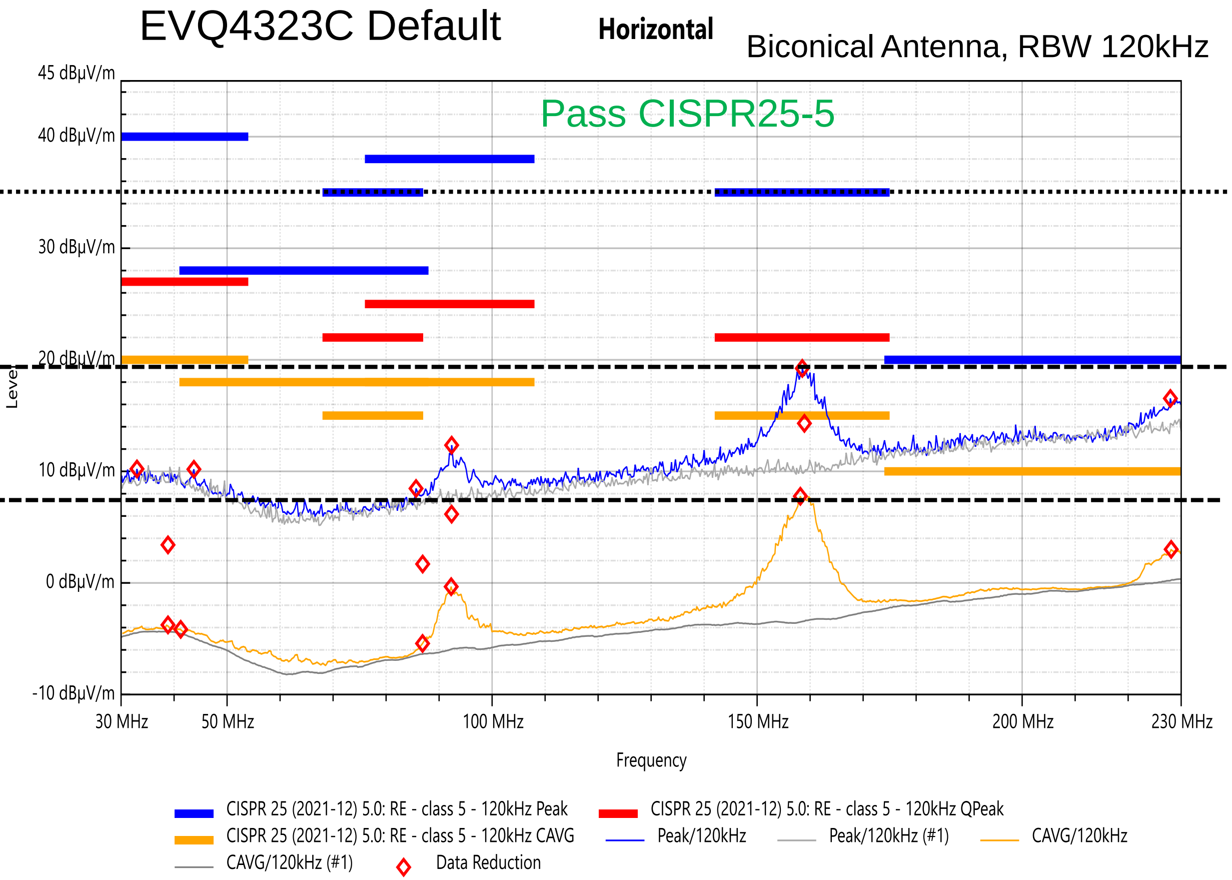


Filter reversed in direction

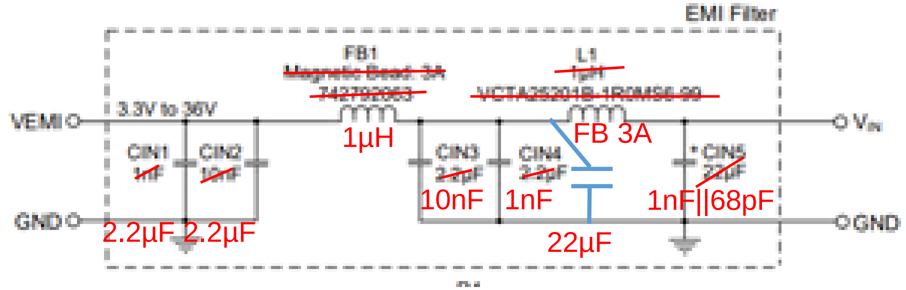


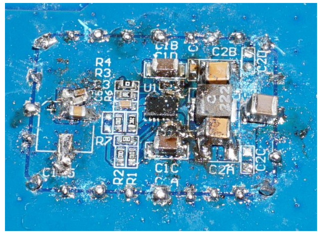
V_{IN}=13.5V, V_{OUT}=5V, F_{SW}=2.2MHz, I_{LOAD}=2.5A, R_{BOOT}=0Ω,
Blue Peak Orange Average





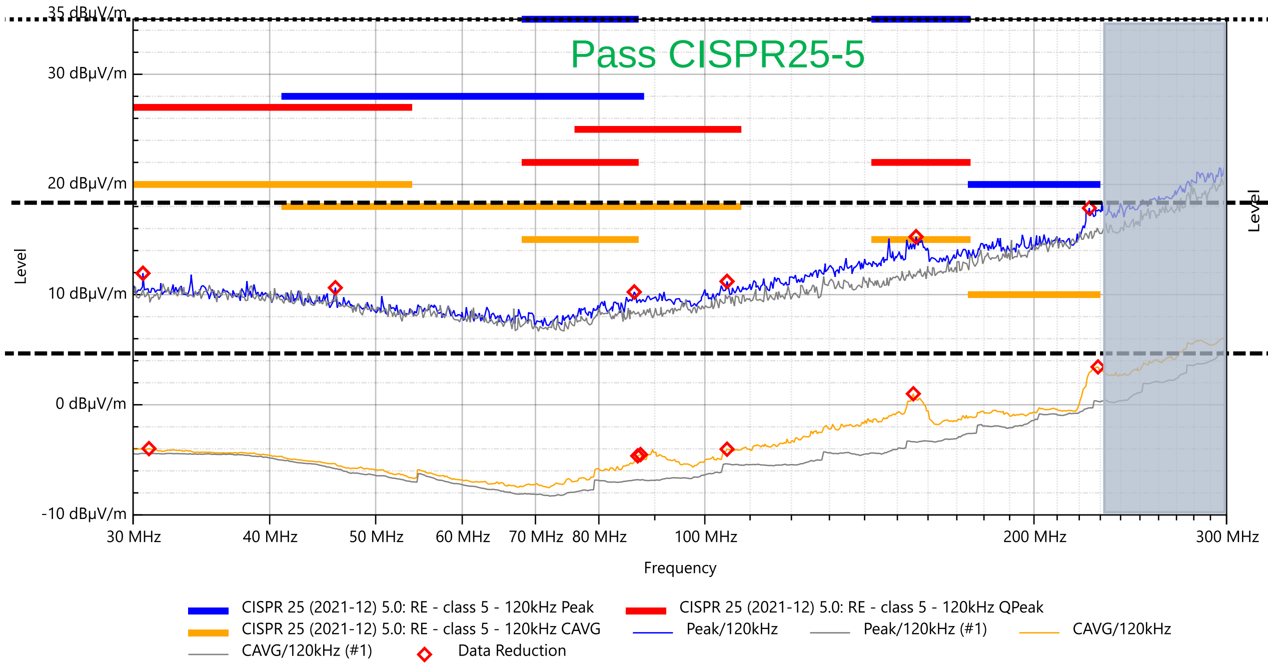
Modifications on EVQ4323C to pass OEM digital TV band



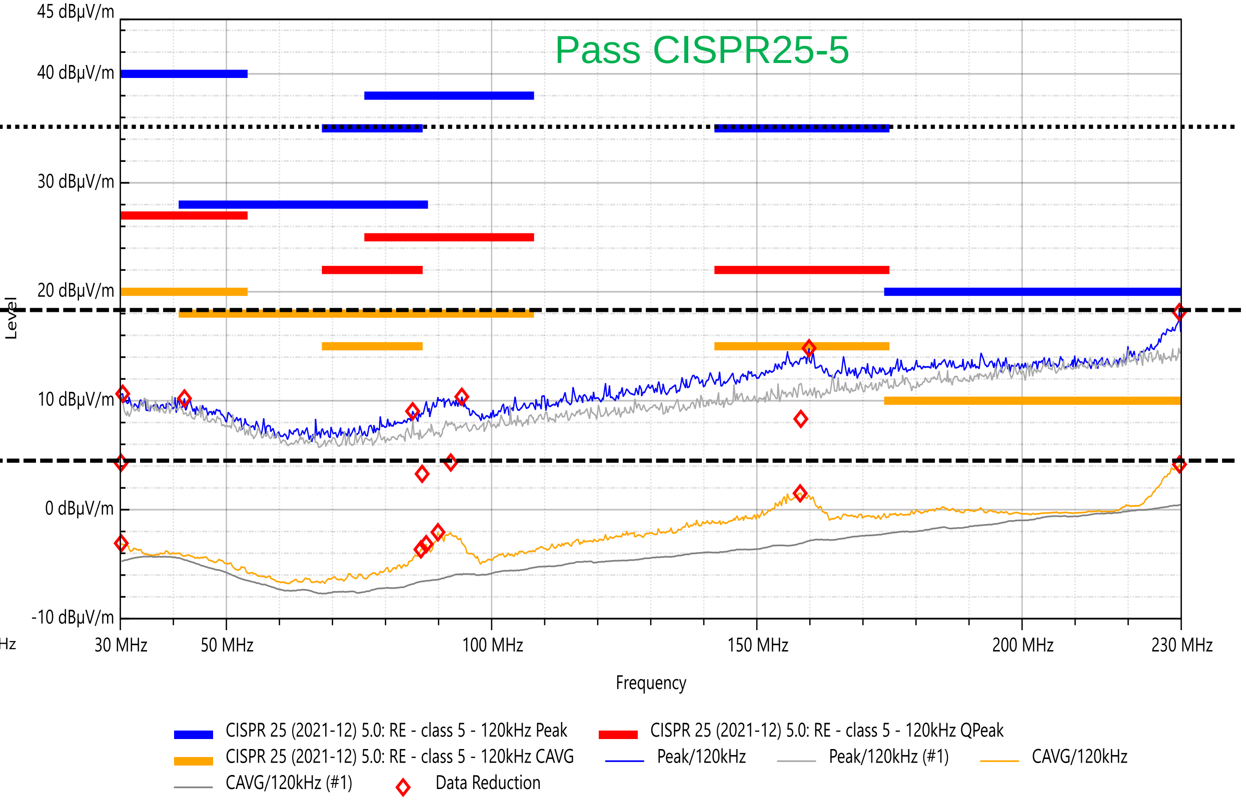


V_{IN}=13.5V, V_{OUT}=5V, F_{SW}=2.2MHz, I_{LOAD}=2.5A, R_{BOOT}=0Ω,
Blue Peak Orange Average

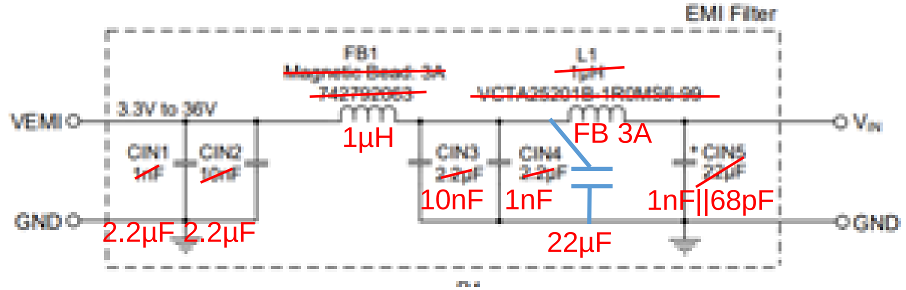
EVQ4323C Modified **Vertical** Biconical Antenna, RBW 120kHz

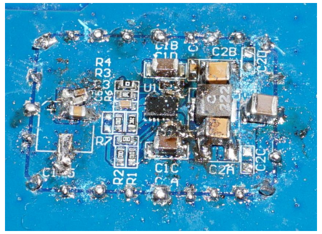


EVQ4323C Default **Vertical** Biconical Antenna, RBW 120kHz



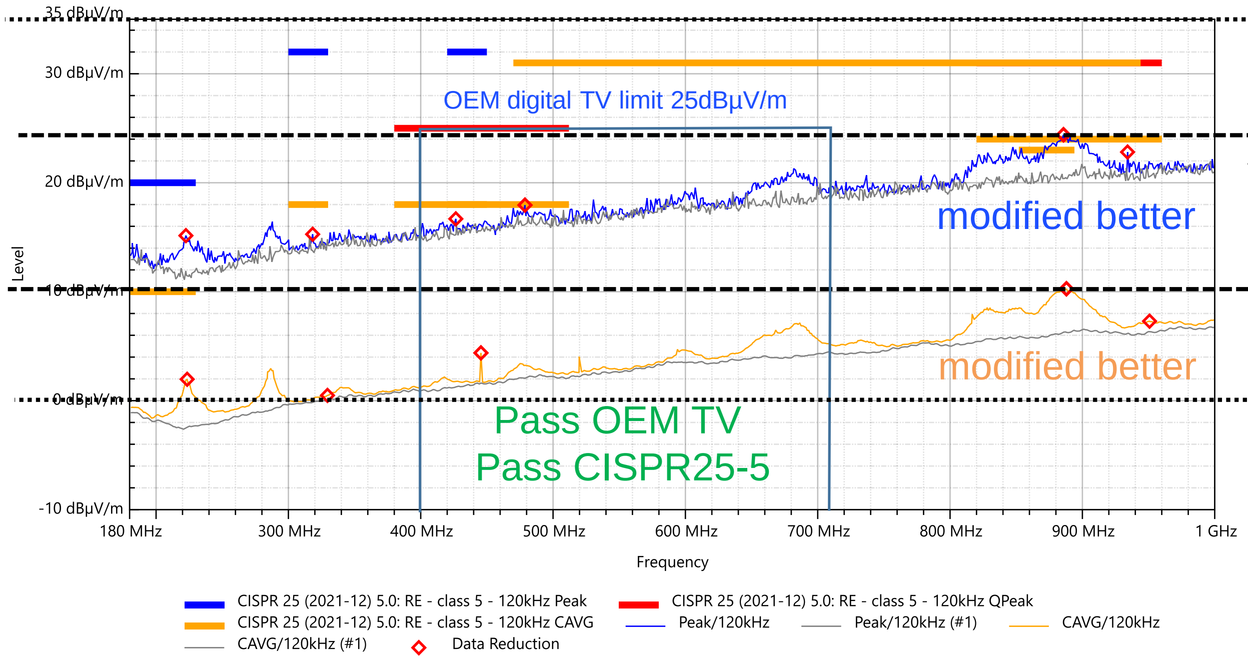
Modifications on EVQ4323C to pass OEM digital TV band



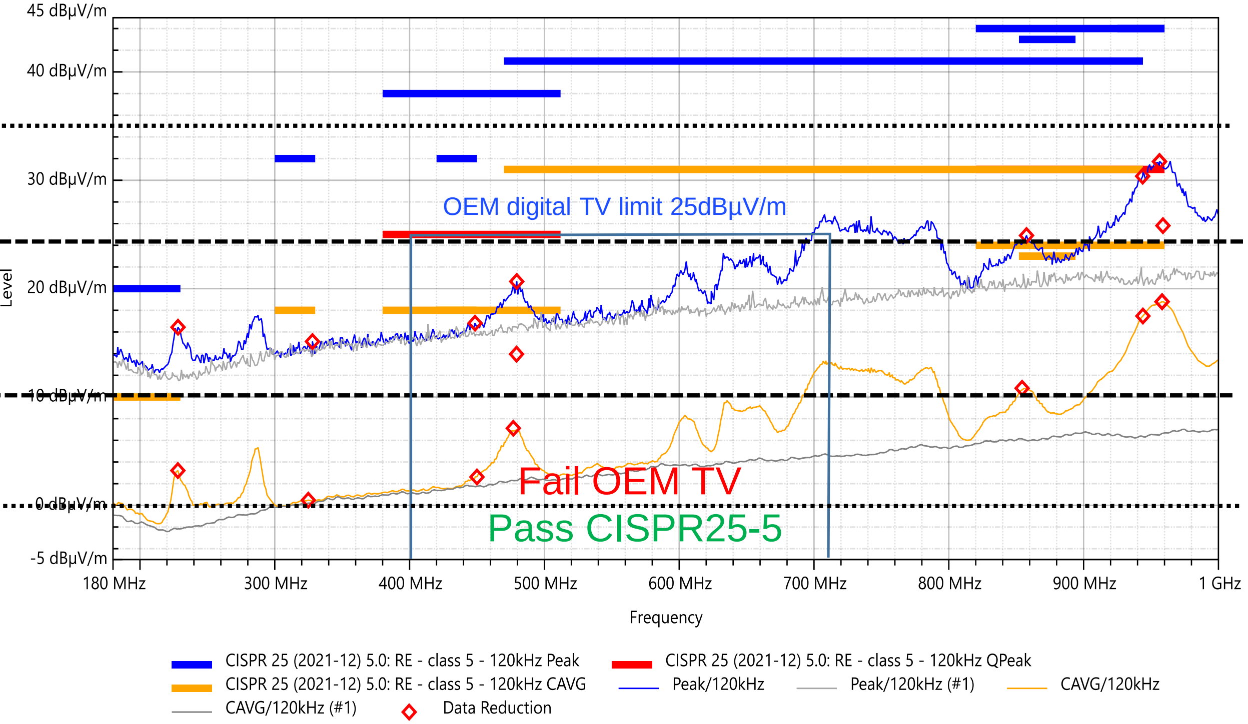


V_{IN}=13.5V, V_{OUT}=5V, F_{SW}=2.2MHz, I_{LOAD}=2.5A, R_{BOOT}=0Ω,
Blue Peak Orange Average

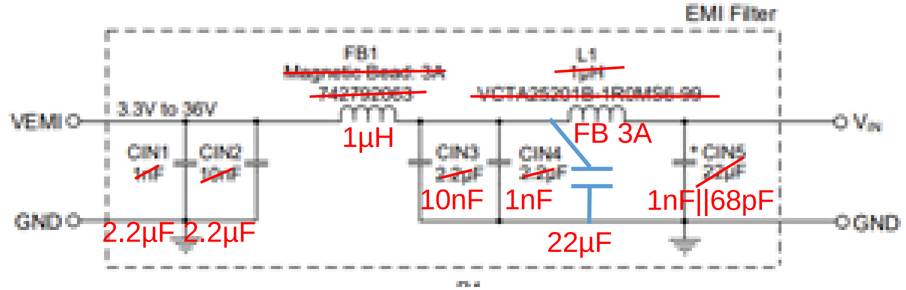
EVQ4323C Modified **Horizontal** Log Per. Antenna, RBW 120kHz

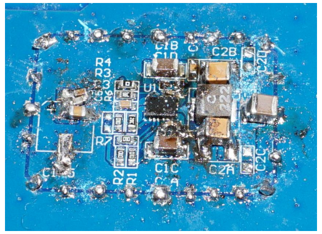


EVQ4323C Default **Horizontal** Log Per. Antenna, RBW 120kHz



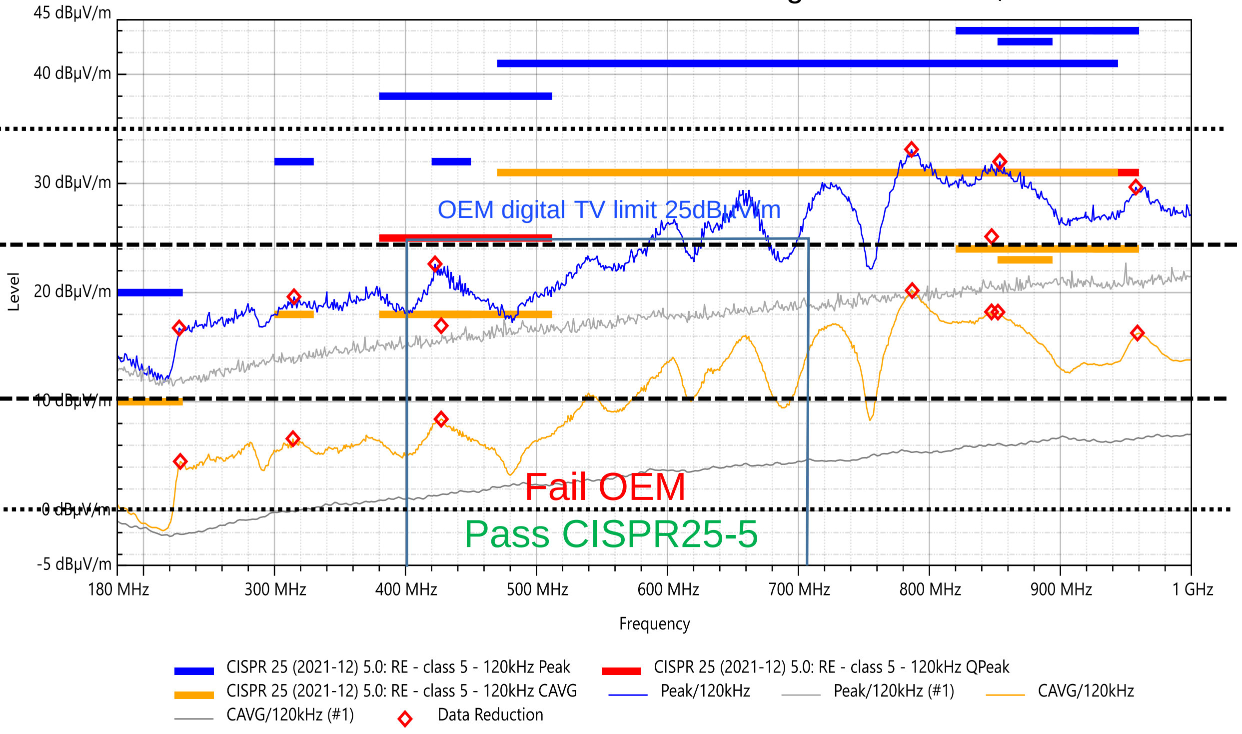
Modifications on EVQ4323C to pass OEM digital TV band



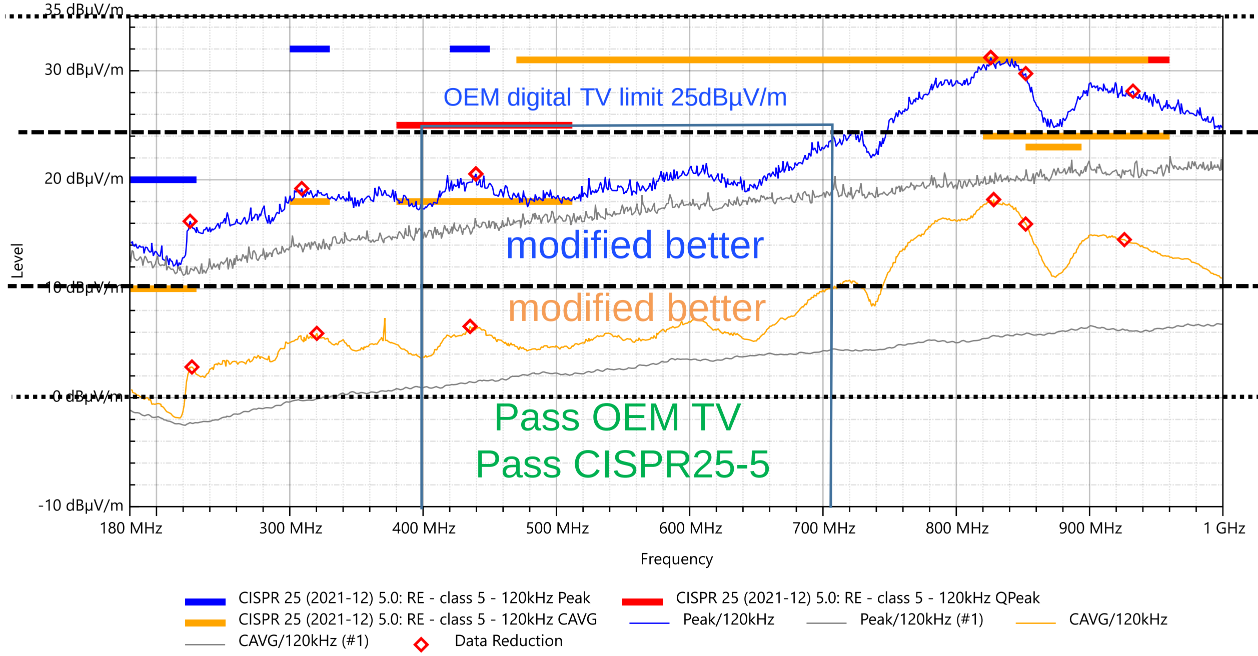


V_{IN}=13.5V, V_{OUT}=5V, F_{SW}=2.2MHz, I_{LOAD}=2.5A, R_{BOOT}=0Ω,
Blue Peak Orange Average

EVQ4323C Default **Vertical** Log Per. Antenna, RBW 120kHz



EVQ4323C Modified **Vertical** Log Per. Antenna, RBW 120kHz



Now pass OEM digital TV
400MHz to 710MHz

MPS

Conclusion

- VIN hot-loop and SW-node are the mainly EMI sources of Step-down Converter
- Measure and Compare the SW-node waveforms to predict the EMI character
- Some EMI tips
- Optimize the layout and the passive part selection for the required EMI specification

Questions and Feedback

Thank you!