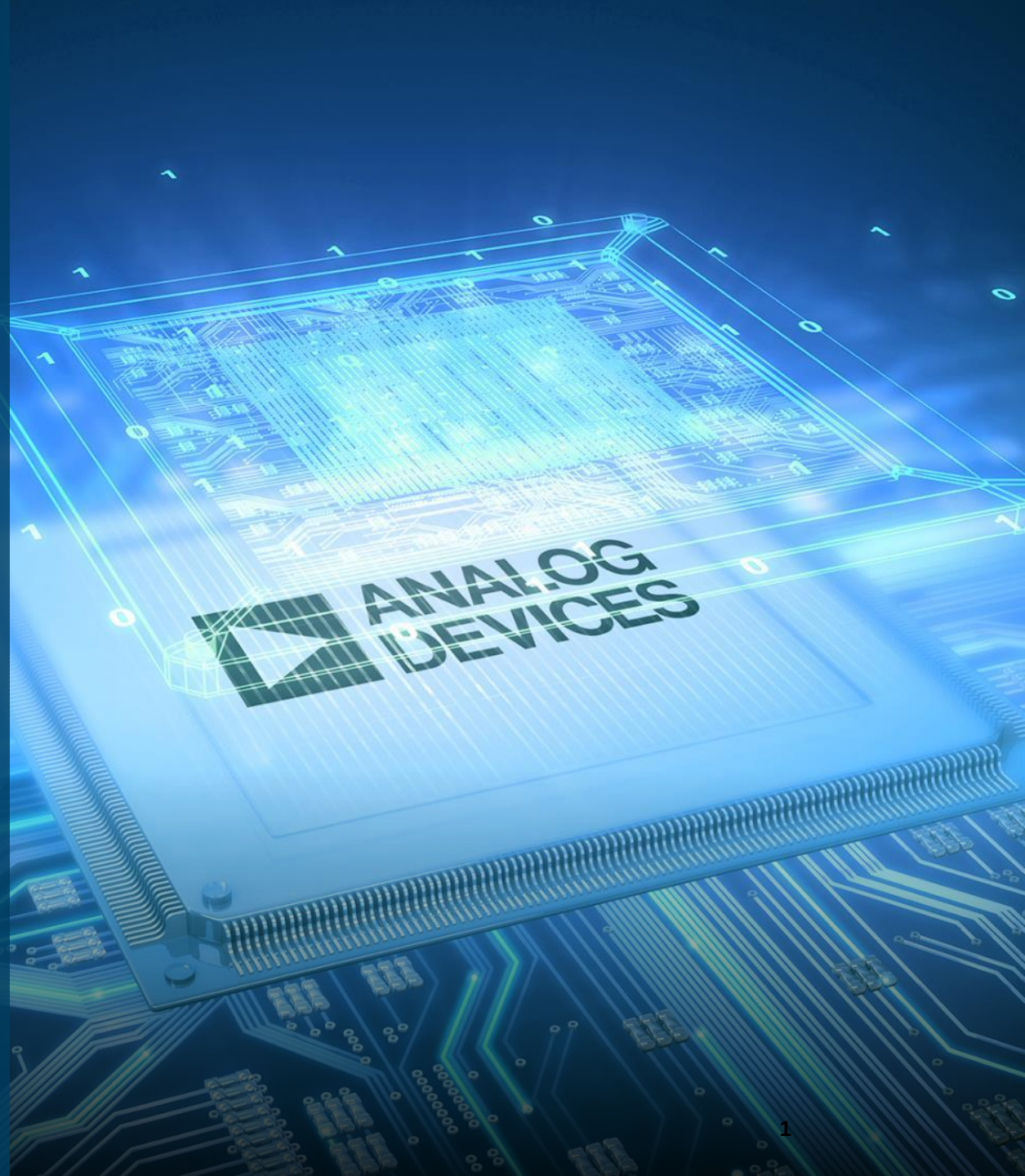
ANALOG DEVICES

AHEAD OF WHAT'S POSSIBLE™

Silent Switcher Regulators: High Efficiency with Ultralow EMI

TONY ARMSTRONG

Product Marketing Director



12/13/2018

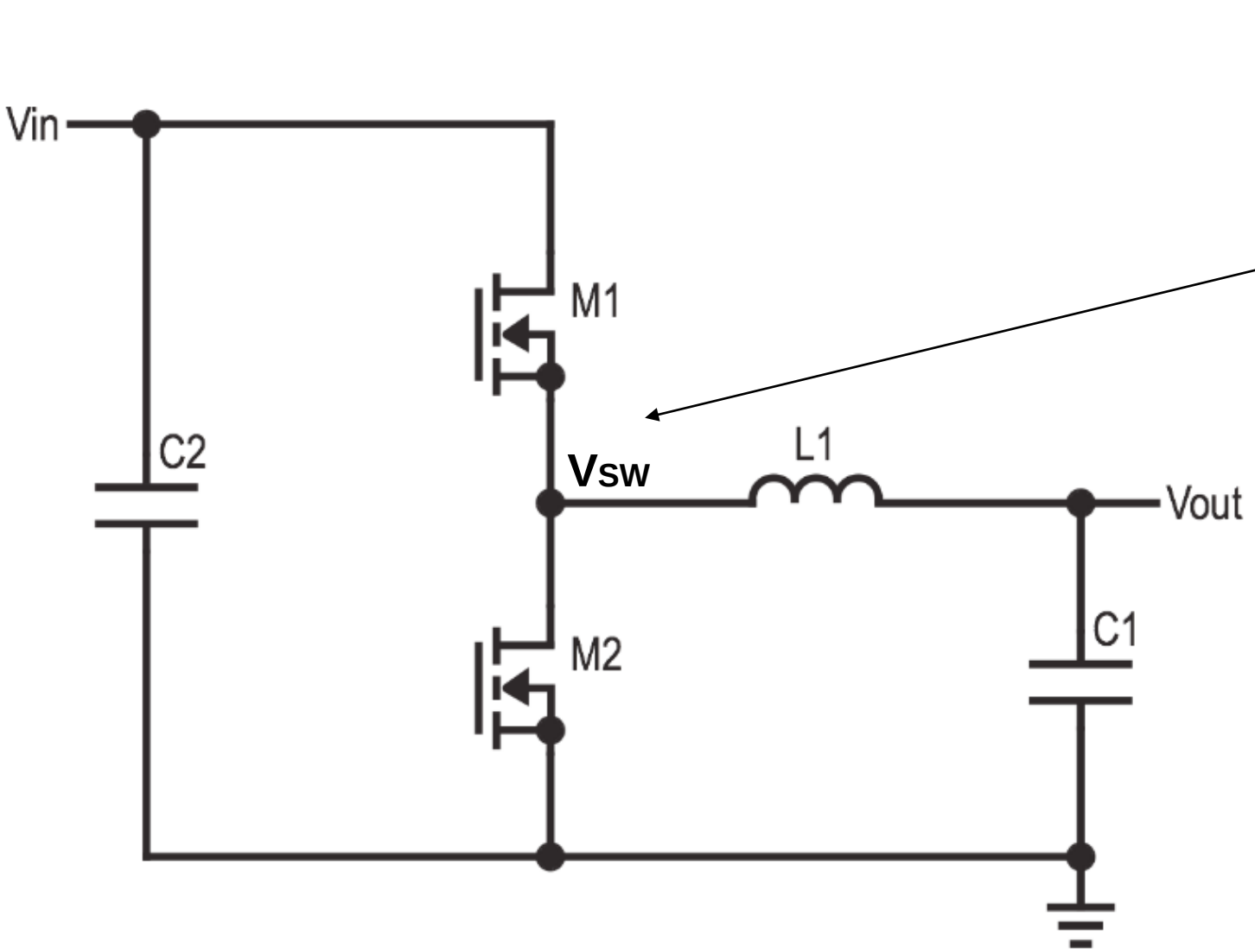
Agenda

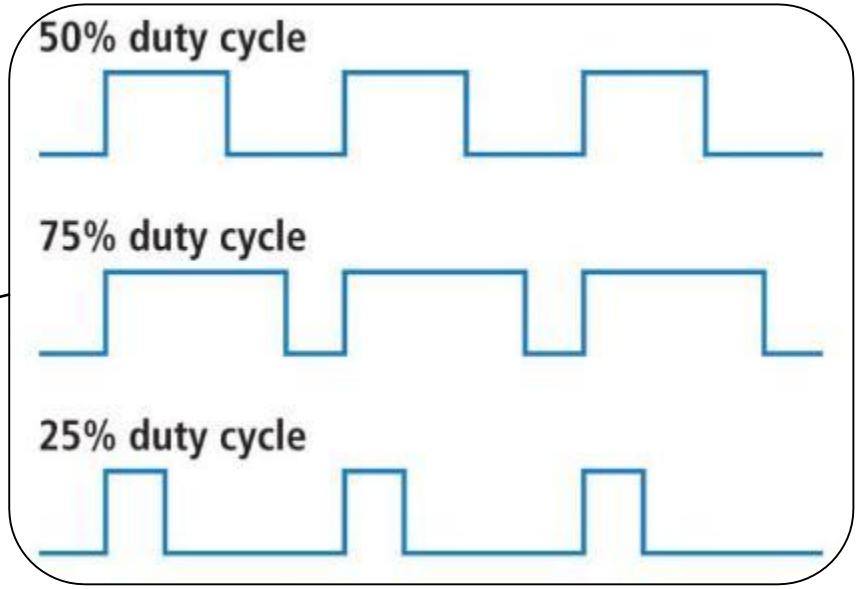
- Terminology
- Buck Regulator Basics
- Where does EMI in Switching Regulators come from?
- How to reduce high frequency noise
- How does Silent Switcher technology help solve EMI problems without compromises?
- How does a Silent Switcher work?
- Silent Switcher Packaging and Layout
- µModule Regulators with Silent Switcher 2
- Silent Switcher Product Offering

Terminology used during this presentation

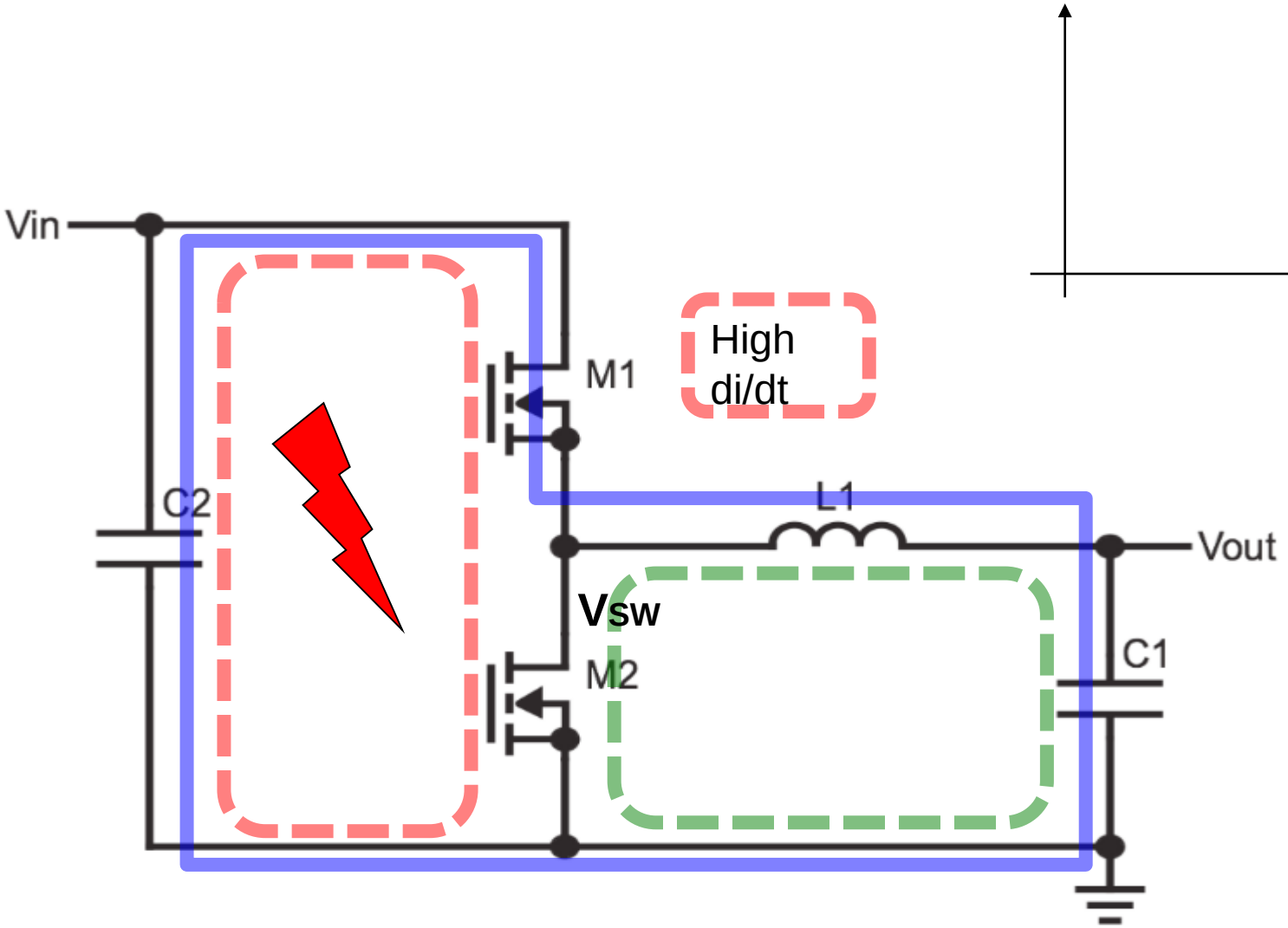
- **EMI**: Electromagnetic Interference
- **CISPR**: International standards for controlling radiated and conducted EMI
- **CISPR 32**: EMI standard for IT/multimedia equipment. Replaced older CISPR 22 standard. It is less stringent than CISPR 25.
- **CISPR 25**: EMI standard for automotive market. Increasingly important benchmark for all automotive electronics.

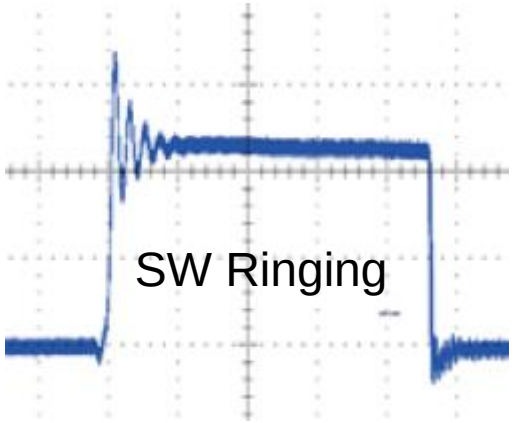
Basic Buck Circuit: DC → AC → DC





What Problem we are Trying to Solve: Noise/Ringing vs. di/dt

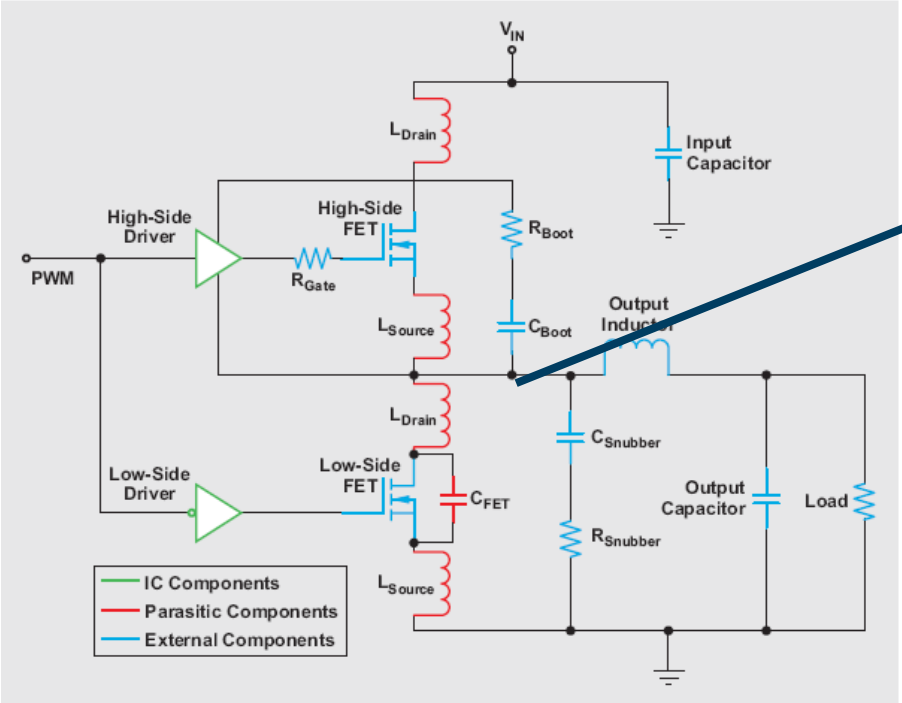


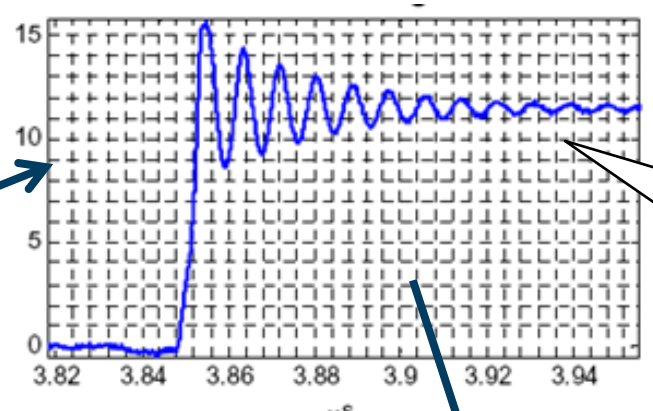


High di/dt and parasitic inductance in the switcher “hot” loop causes EM noise and SW ringing

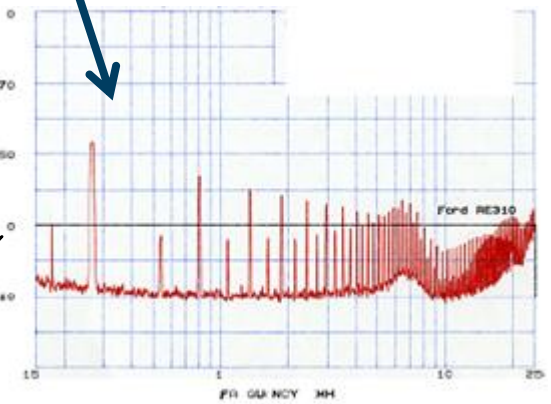
Where Does High Frequency Noise Come From?

- Switching transitions coupled through parasitic R, L, & Cs create high frequency harmonics





In the time domain, we see ringing on the switch node



In the frequency domain, we see high frequency harmonics

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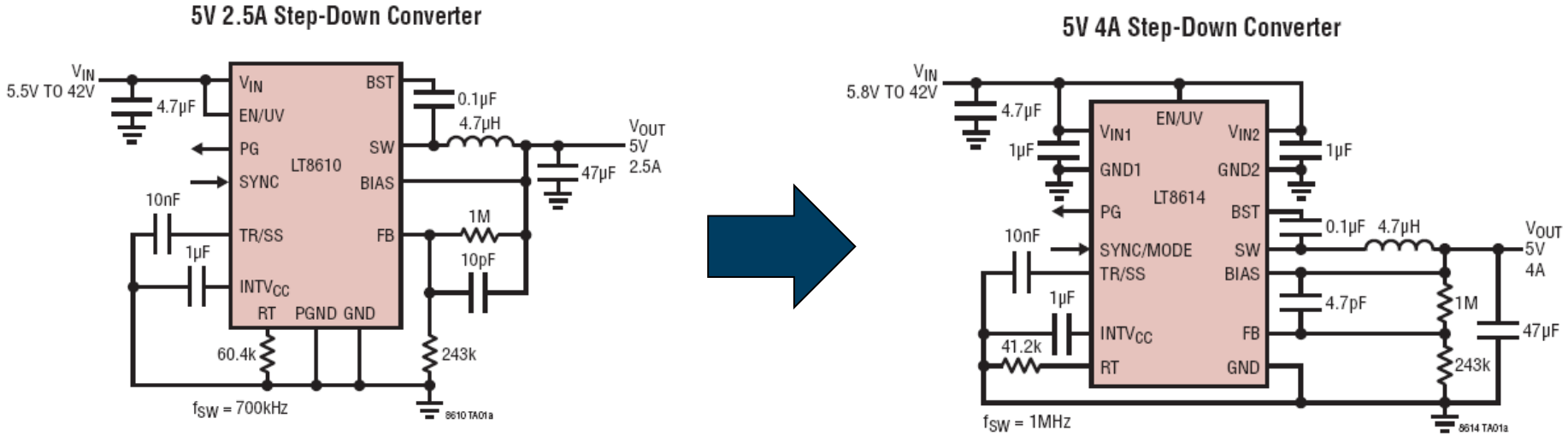
How to Reduce HF Switching Noise?

- The traditional way is to slow down the switching edges (slowing internal switch driver or adding “snubbers” externally)
  - This reduces efficiency (increased switching loss), especially when a switcher is running at high switching frequency (f_{sw})
- Why do we want to operate at high Fsw?
  - This enables the use of smaller external components (C, L). Also, Automotive applications like to switch at 2MHz to be above the AM band.
- Filter, Shielding can be employed but cist more components and PCB area
- Spread Spectrum Frequency Modulation (SSFM)
- Or, Silent Switcher technology delivers all 3 – **with no trade-offs**:
  - High Efficiency
  - High Switching Frequency
  - Low EMI

Silent Switcher

- Silent Switcher breaks the trade-off between EMI and efficiency by not needing to slow down the switch edges.



How did we take the LT8610 and make it “Silent”?

*Launched in 2012, the LT8610 was our flagship 40V buck product at the time. The LT8614 applied our Silent Switcher technology to the LT8610 base chip.

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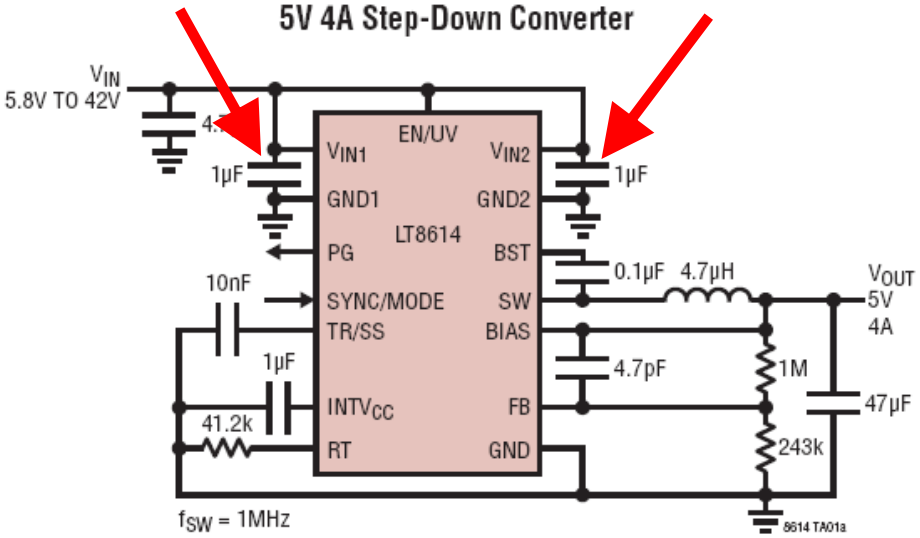
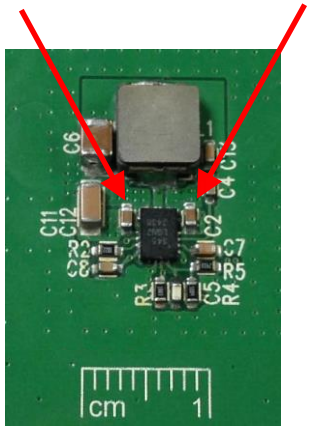
What's behind Silent Switcher?

- We reduce the magnitude of the harmonics by eliminating parasitics (**no more long bond wires**)
- We reduce the energy in the harmonics by splitting the "hot loops" into **two lower powered loops**
- We prevent the EMI from propagating by having the fields from the **two loops cancel** each other out
- Internal switch drivers minimize switching power loss producing **fast, clean switching edges**
- Two Input Caps arranged **to cancel magnetic fields –** as illustrated below**:**



Demo board



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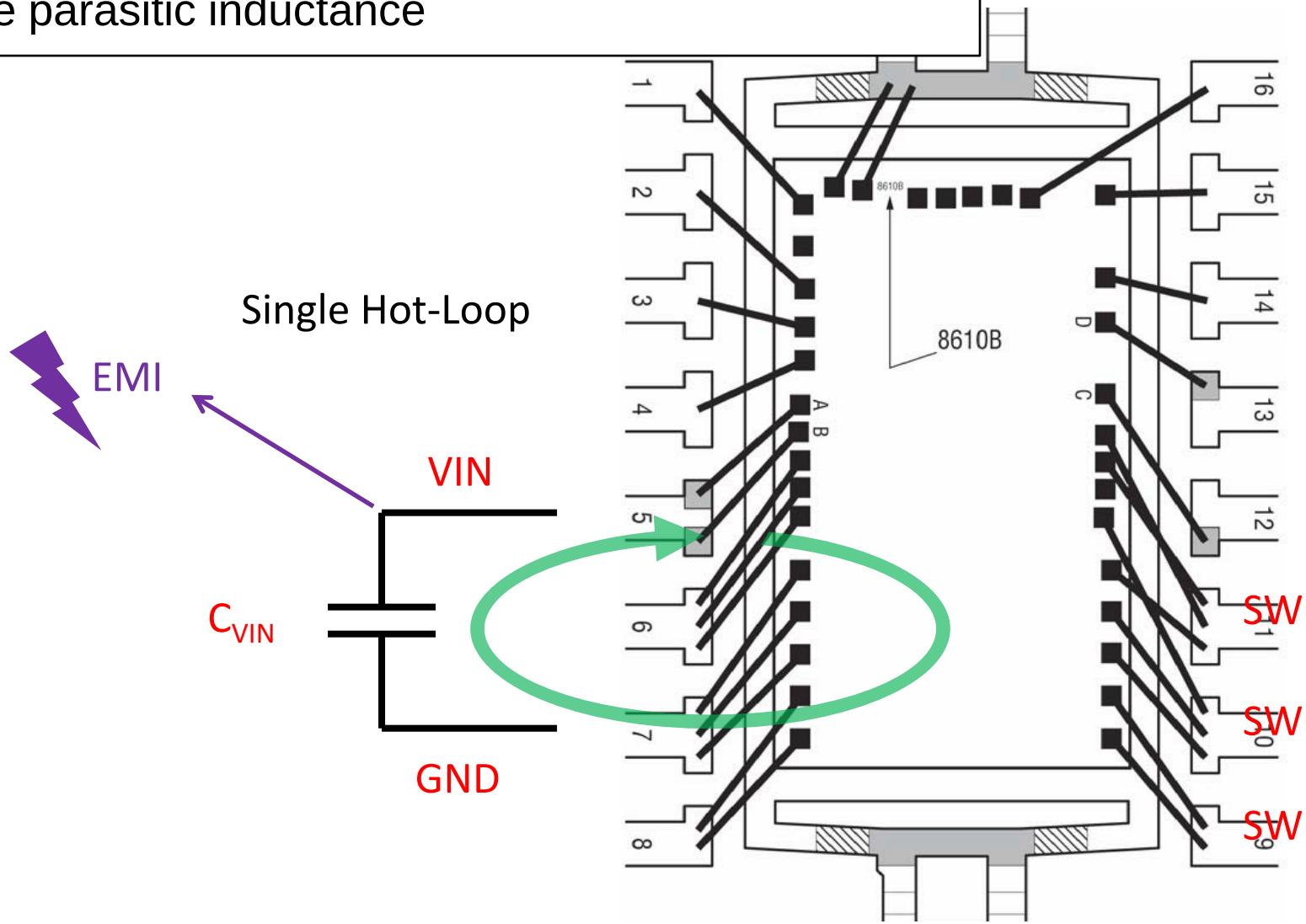
Normal Switching Regulator: LT8610

In the LT8610, we have a single high current loop and relatively long bond wires with large parasitic inductance



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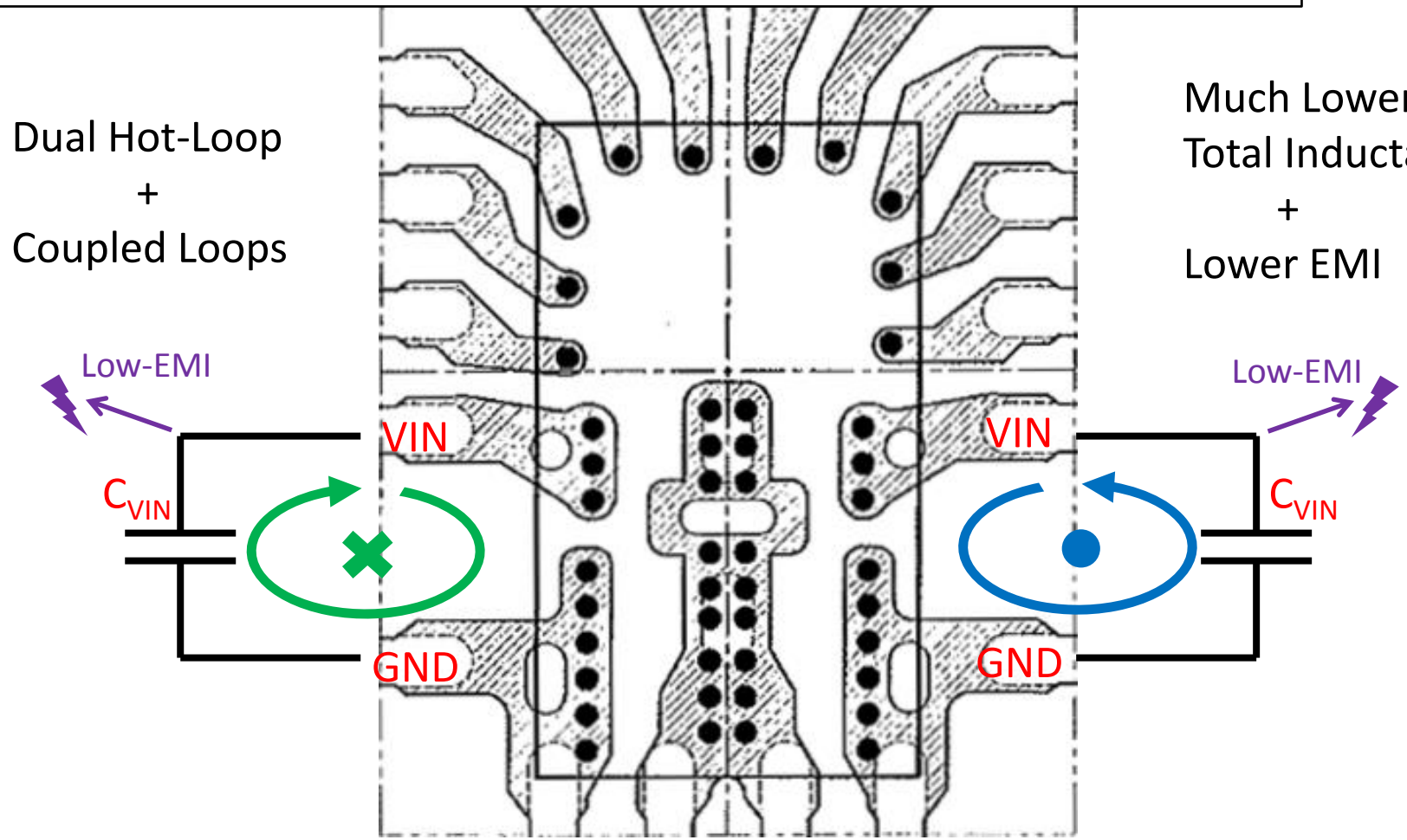
Silent Switcher Regulator: LT8614

In the LT8614, we reduce the parasitic inductance by using copper pillar flip chip packaging and split the current into two lower power, cancelling hot loops



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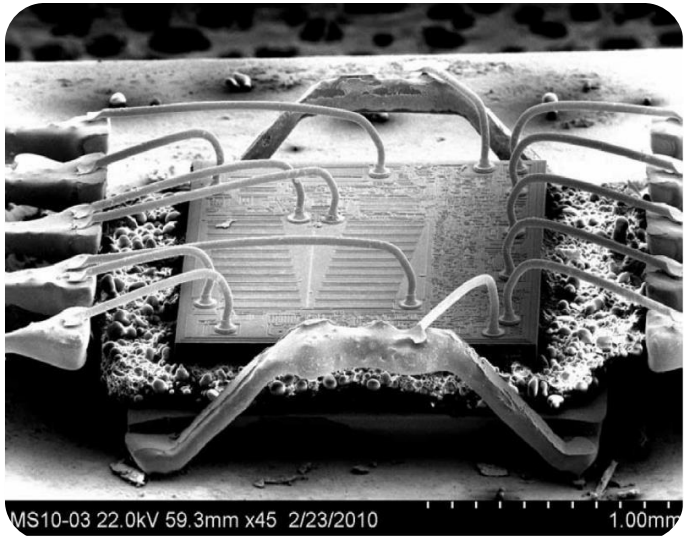
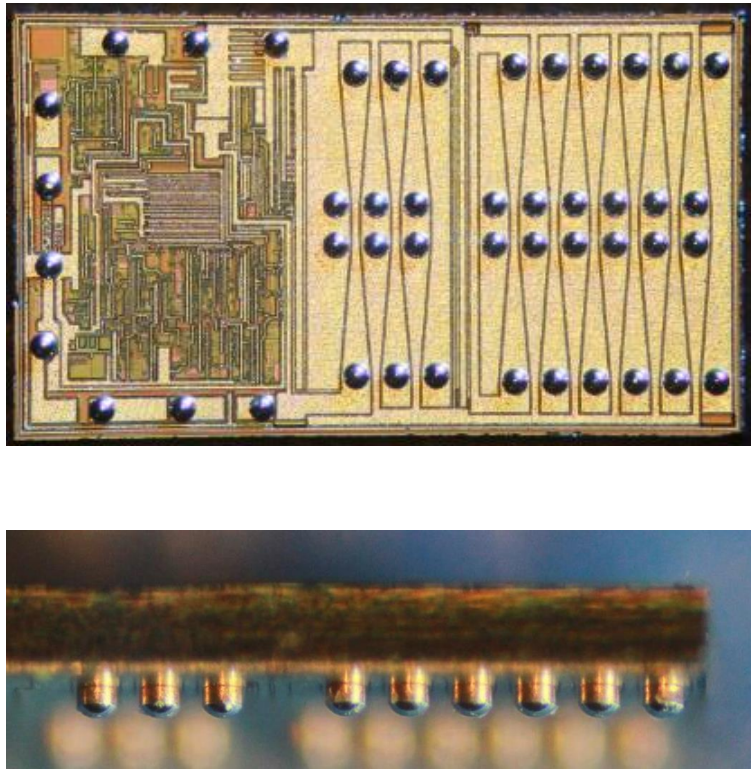
Reducing Package Parasitic Inductance



Bond wires (parasitic R, L)



Copper Pillars

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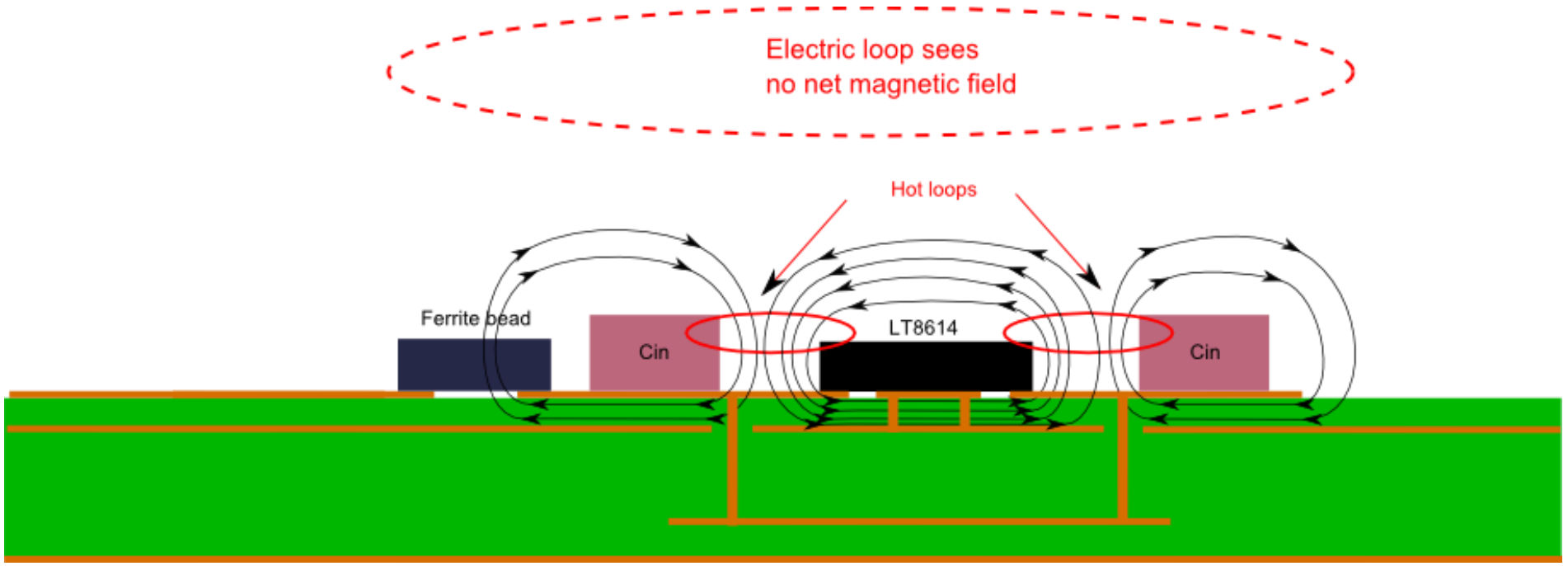
Cancelling Hot Loops

- The two high current loops cancel each other's magnetic field, almost like enclosing the circuit in a metal box



Silent Switcher: Patent

(12) **United States Patent**
Shtargot et al.

(10) **Patent No.: US 8,823,345 B2**
(45) **Date of Patent: Sep. 2, 2014**

(54) **MAGNETIC FIELD CANCELLATION IN SWITCHING REGULATORS**

(71) Applicant: **Linear Technology Corporation**, Milpitas, CA (US)

(72) Inventors: **Leonard Shtargot**, Campbell, CA (US); **Daniel Cheng**, Mountain View, CA (US); **John Gardner**, Berkeley, CA (US); **Jeffrey Witt**, Oakland, CA (US); **Christian Kueck**, Luedinghausen (DE)

(73) Assignee: **Linear Technology Corporation**, Milpitas, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 156 days.

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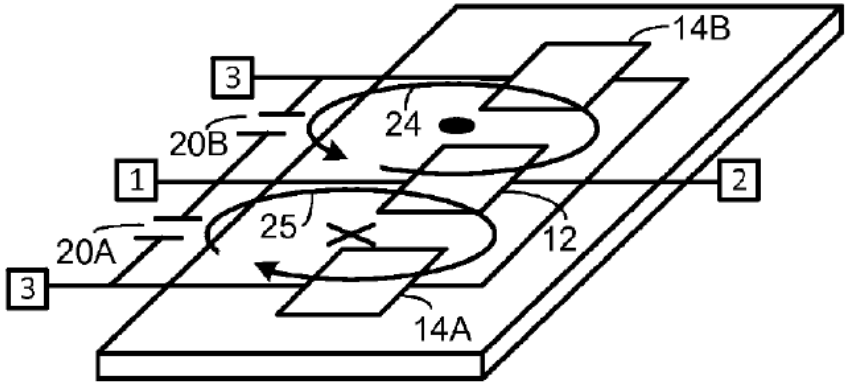

Fig. 2B

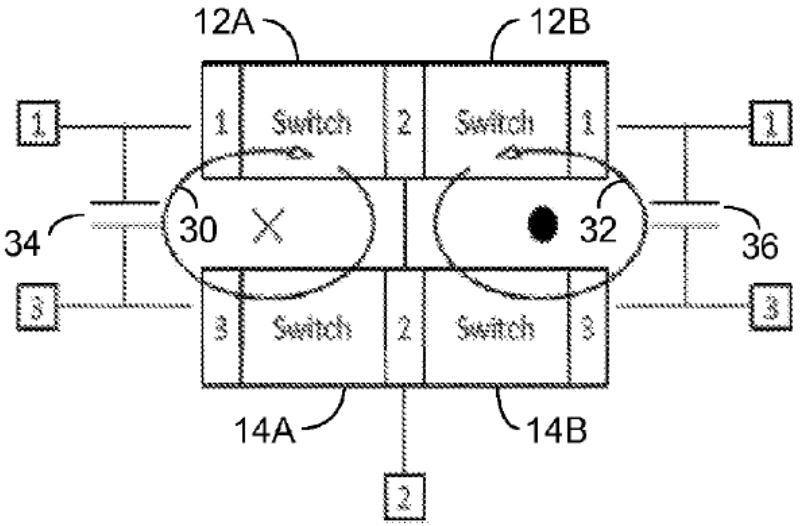

Fig. 3A

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Silent Switcher 1: Copper Pillar Flip-Chip and Magnetic Cancellation

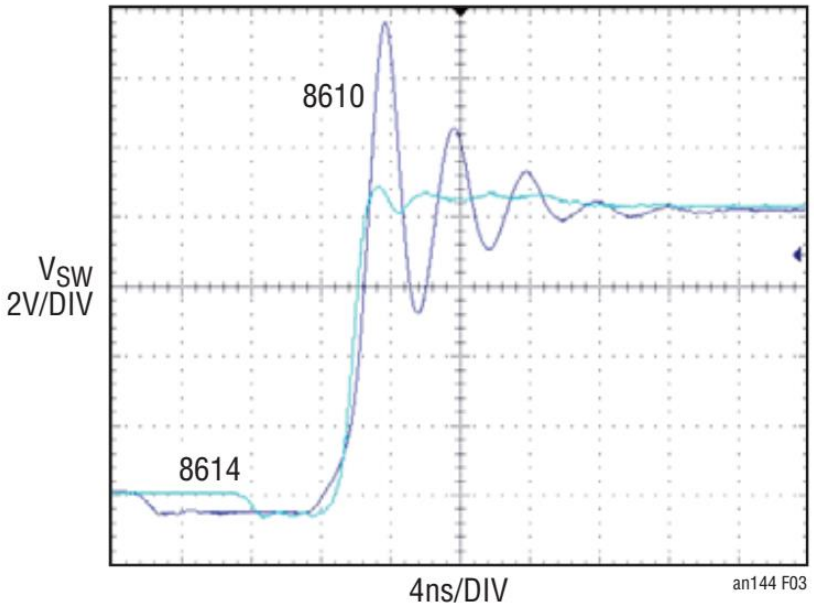


Figure 3. LT8610 and the LT8614, Switch Node Rising Edge Both at 8.4V_{IN}, 3.3V_{OUT} at 2.2A

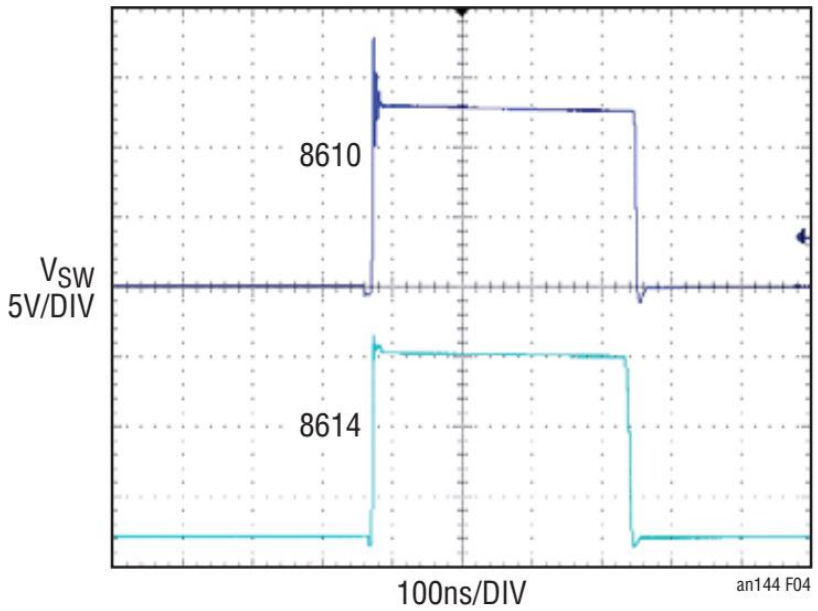


Figure 4. LT8610 and the LT8614, Both at 13.2V_{IN}, 3.3V 2.2A out

LT8610: Wire-bonded in MS16E
LT8614: Silent Switcher 1: Magnetic cancellation + Copper Pillar Flip-Chip

Silent Switcher 1 EMI Results

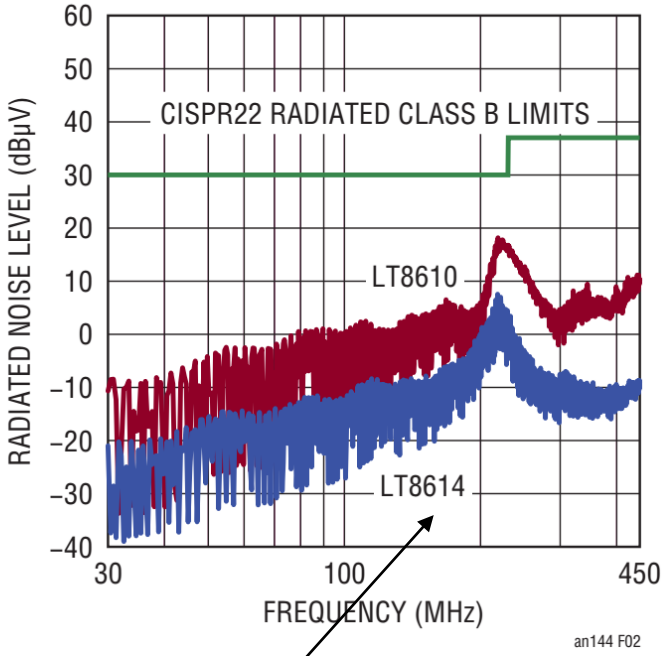
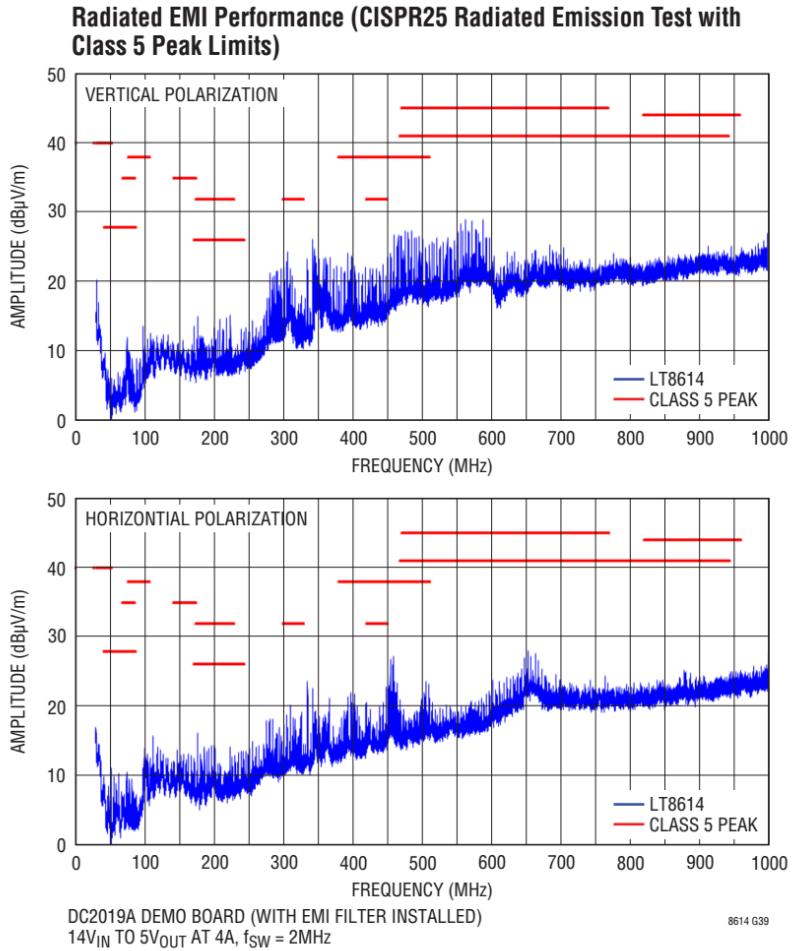


Figure 2. LT8610 and LT8614 700kHz 14V to 3.3V 2A Radiated EMI in GTEM Corrected for OATS

LT8614 Silent Switcher provides 10-20dB improvement over the LT8610!



LT8614 passes the most stringent CISPR25 Class 5 Limits

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LT8640: Next Generation LT8614

- Redesigned IC with Silent Switcher in mind to improve high frequency efficiency
- Spread Spectrum Frequency Modulation (SSFM)

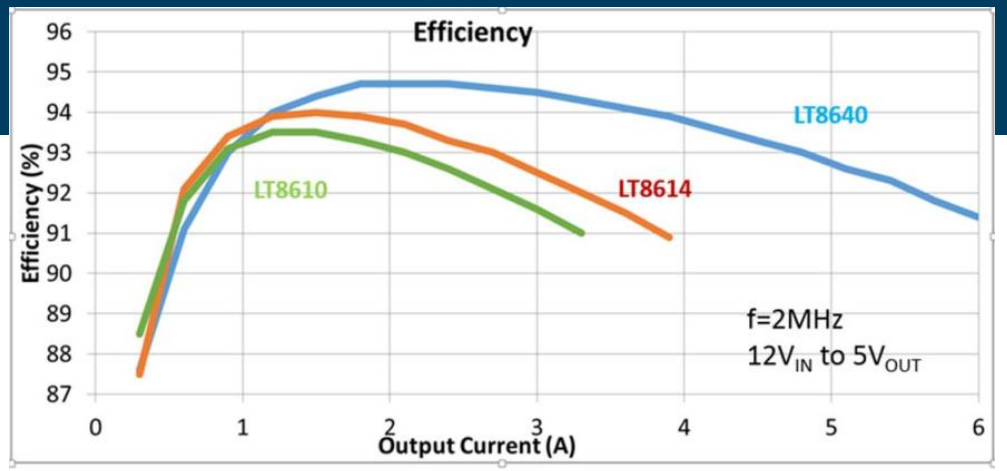
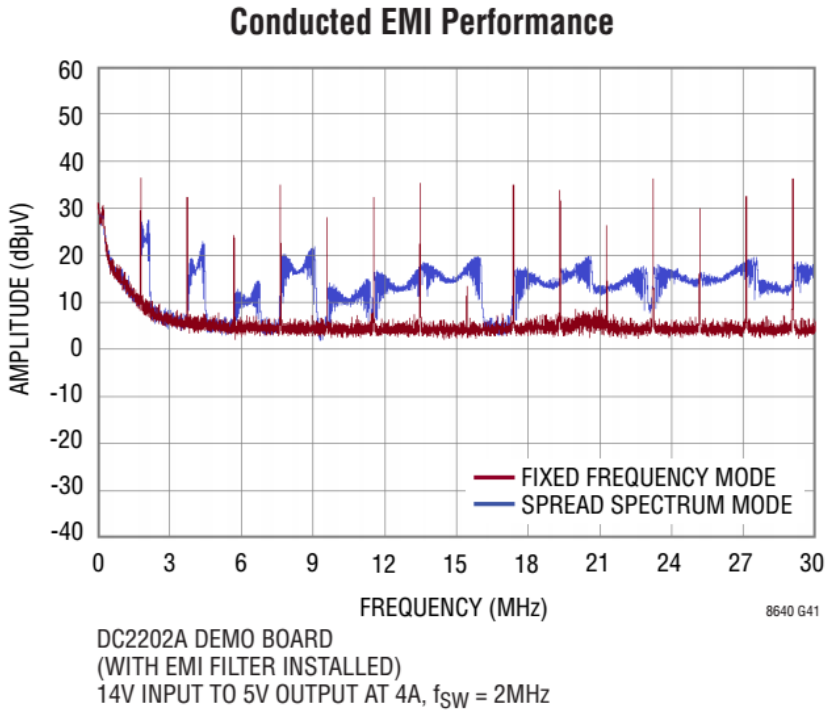
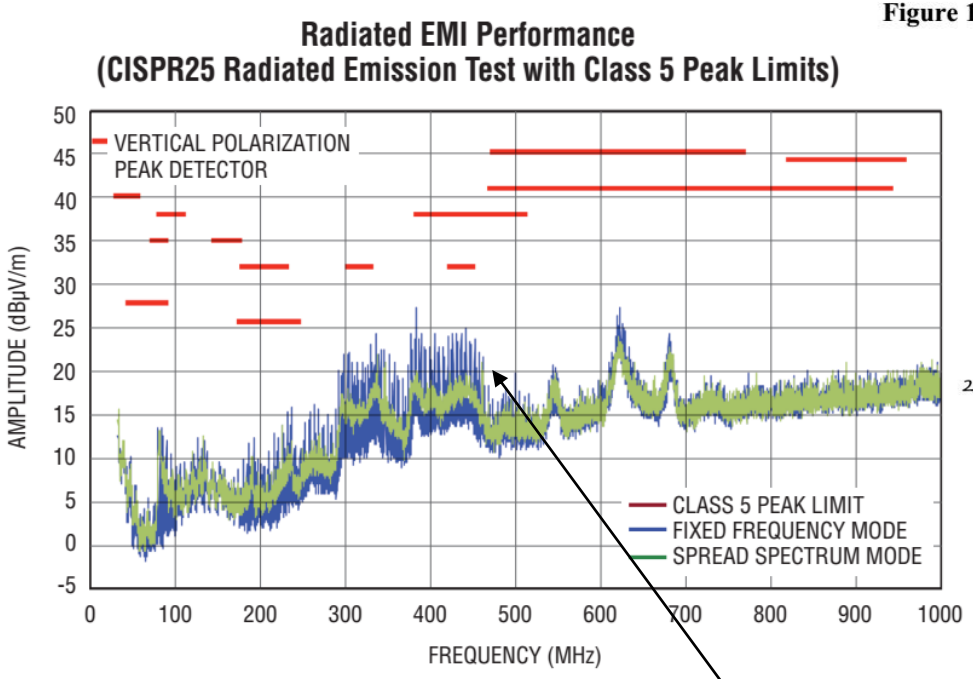
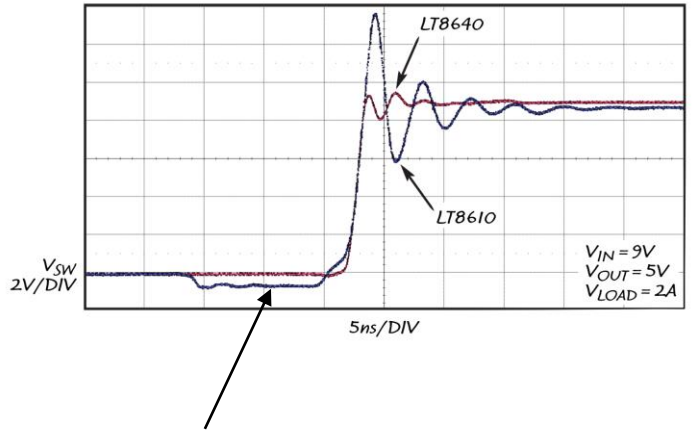


Figure 1. Efficiency Comparison with f_{SW}=2MHz



DC2202A DEMO BOARD
(WITH EMI FILTER INSTALLED)
14V INPUT TO 5V OUTPUT AT 4A, f_{SW} = 2MHz





Removed non-overlap time for improved switching loss

SSFM further reduces EMI!

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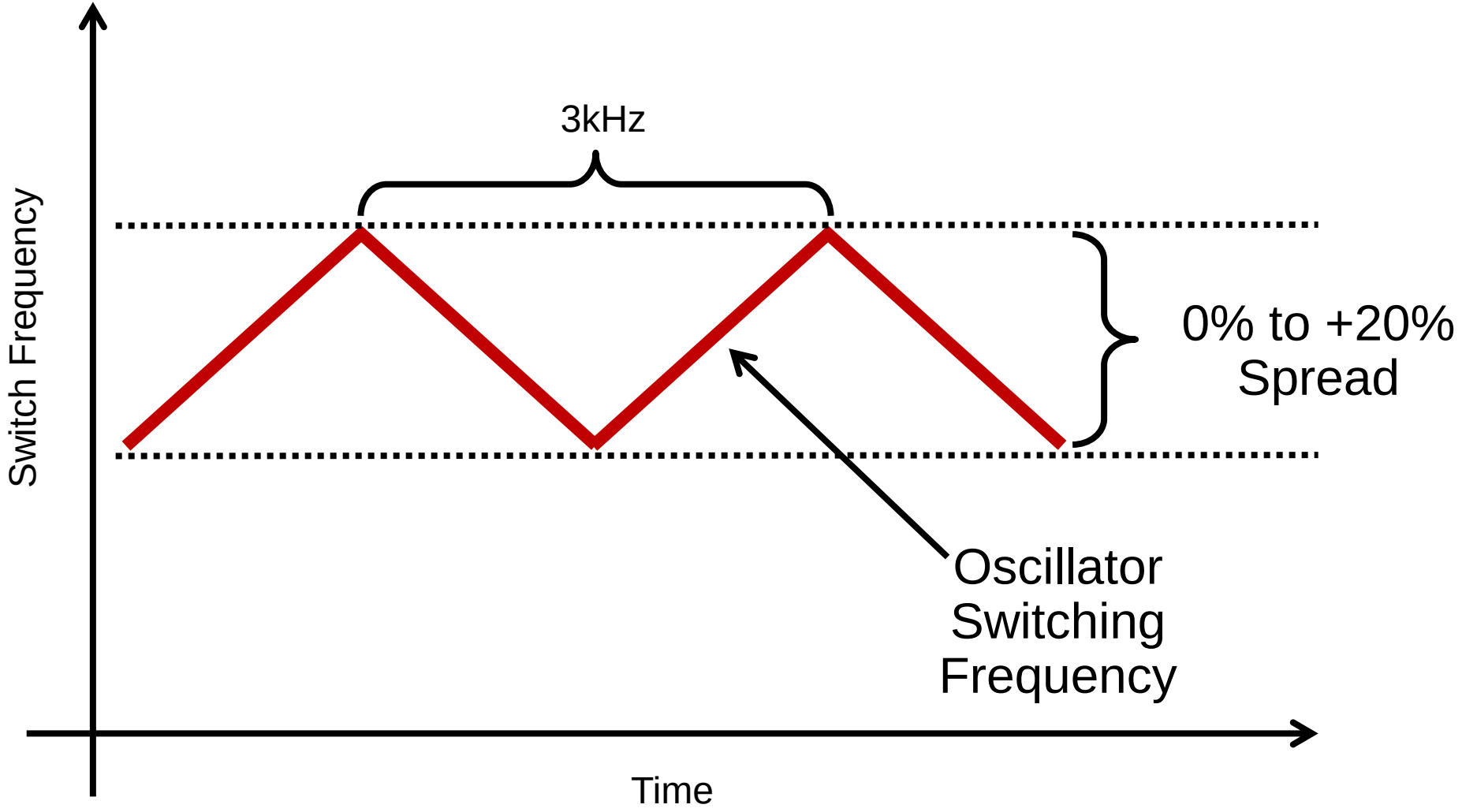
Spread Spectrum Frequency Modulation (SSFM)



Silent Switcher is the best Trade Off between EMI & Efficiency

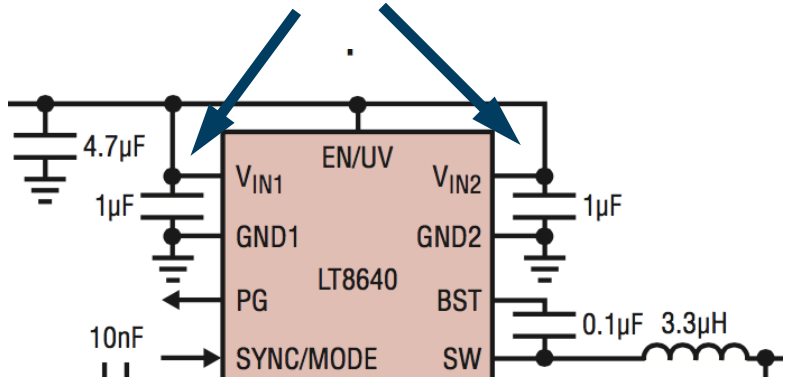
Silent Switcher allows us to break the trade-off between EMI and Efficiency and have **BOTH**:

- Ultralow EMI emissions
- High Efficiency at High Switching Frequencies

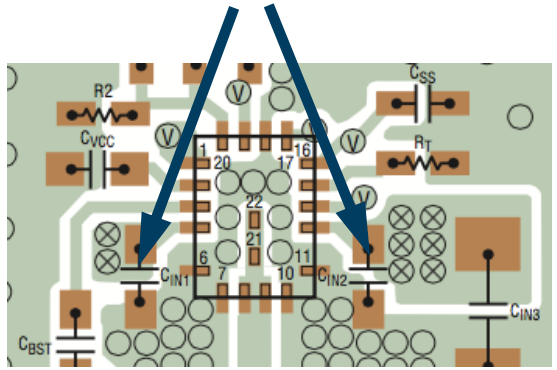
Silent Switcher Is Still PCB Layout Dependent…

- Even with schematic and layout recommendations showing that the input capacitors are to be placed as close as possible to the IC on both sides, customers still make mistakes…

Schematic

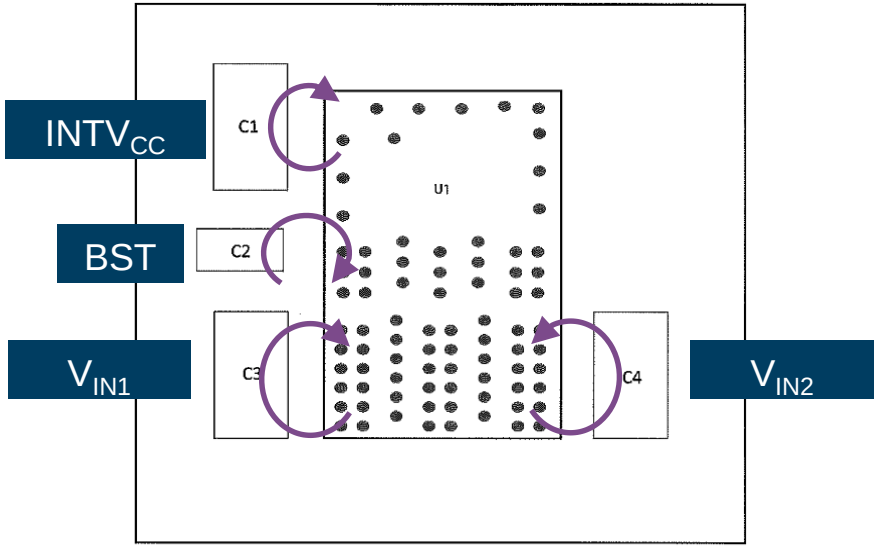


Recommended layout

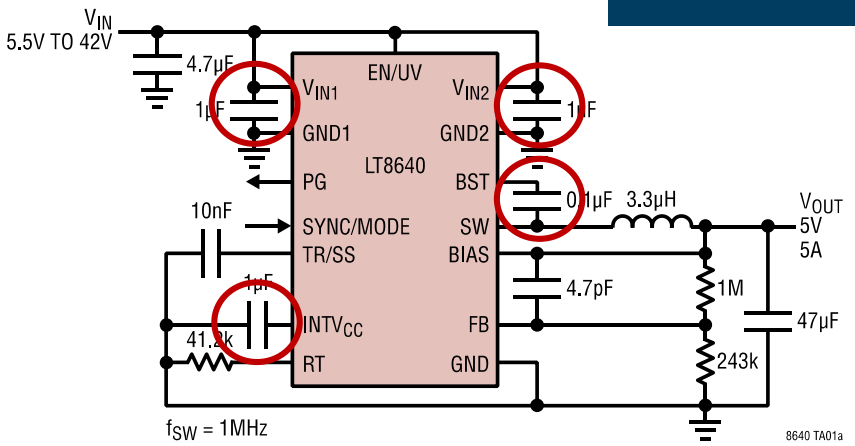


Silent Switcher 2 – The Next Generation

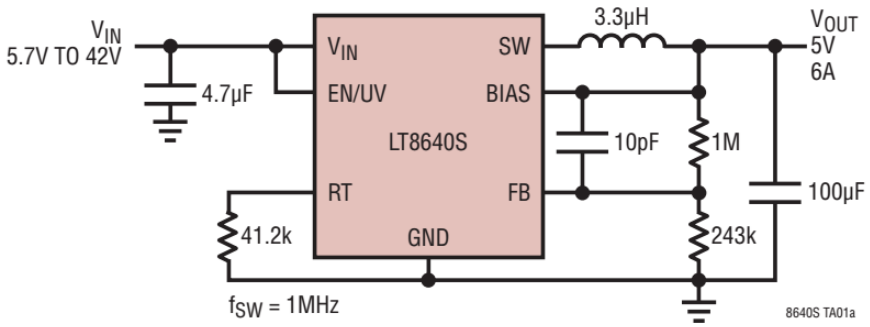
- Integrated capacitors inside a new LQFN package
- All hot loops and ground plane inside = Lower EMI
- Fewer external components, smaller solution size



Eliminates PCB Layout Sensitivity!



LT8640: Capacitors External



LT8640S: Capacitors Internal
"S" suffix = Silent Switcher 2

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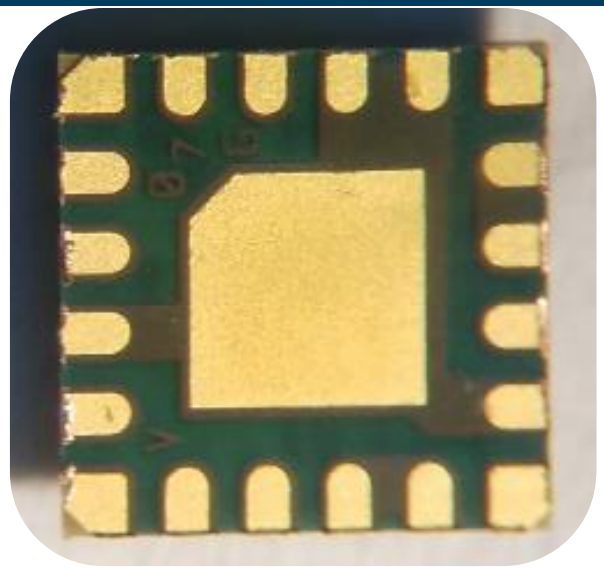
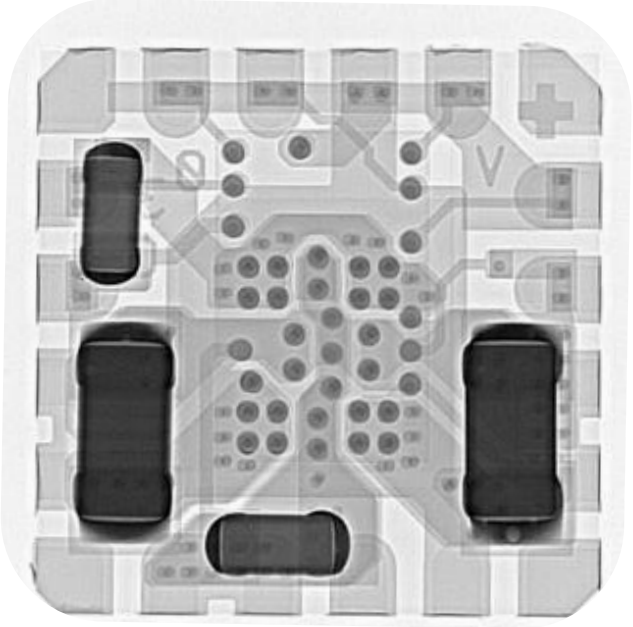
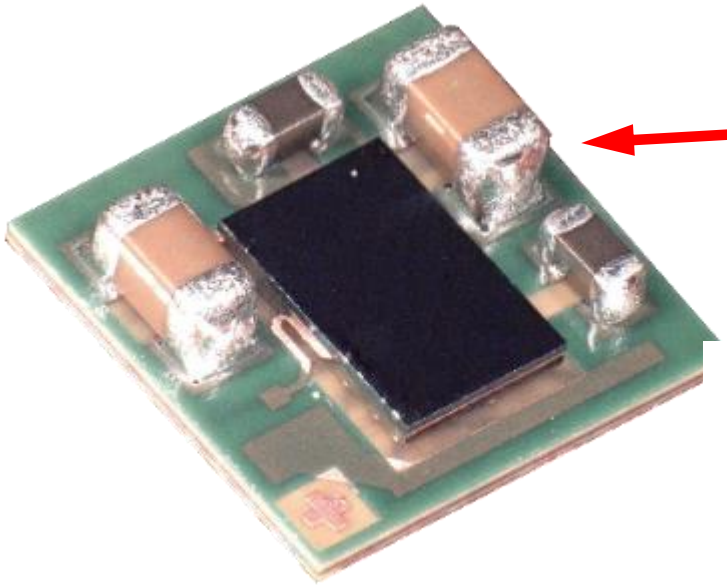
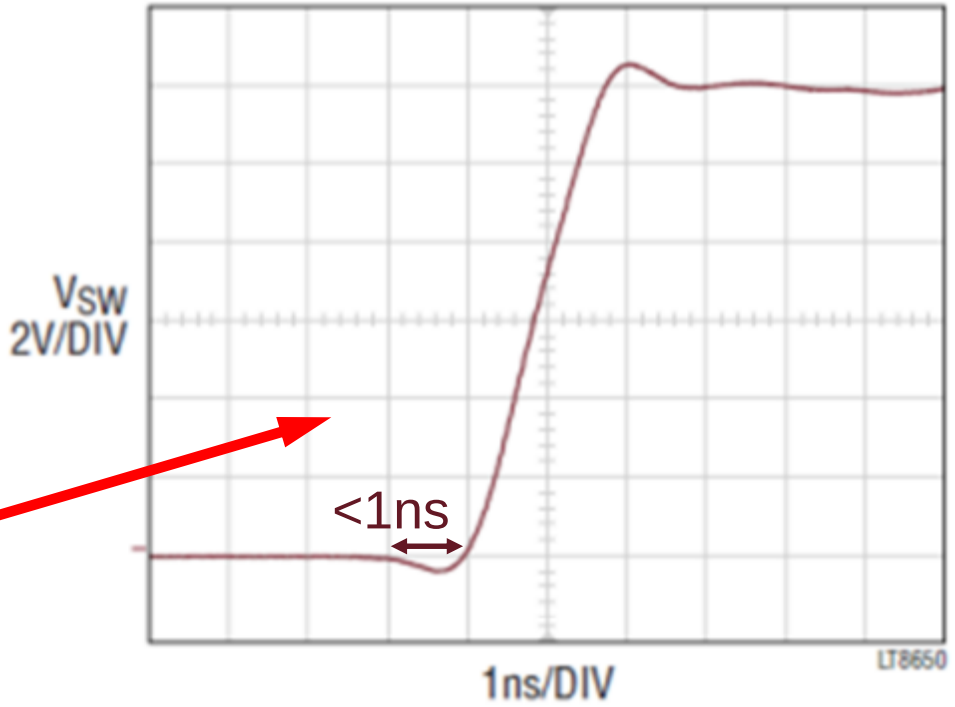
Silent Switcher 2: Including Key Capacitors In-Package







All high di/dt stays in package: customer PCB layout is now non-critical



Fast & Quiet
Switch Transitions

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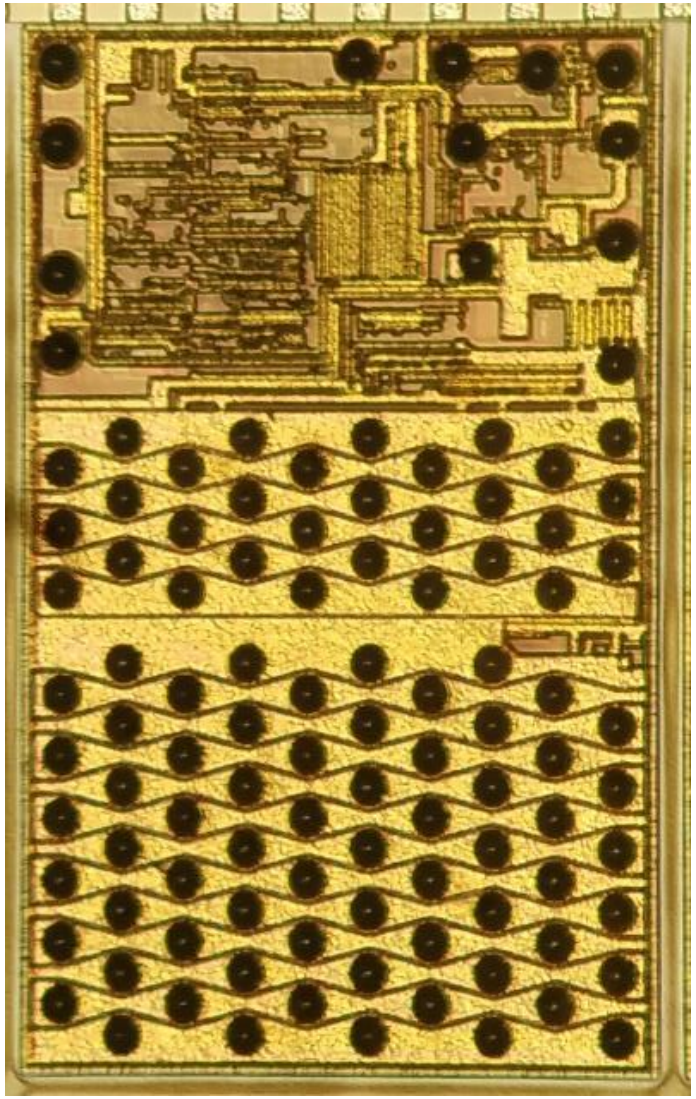
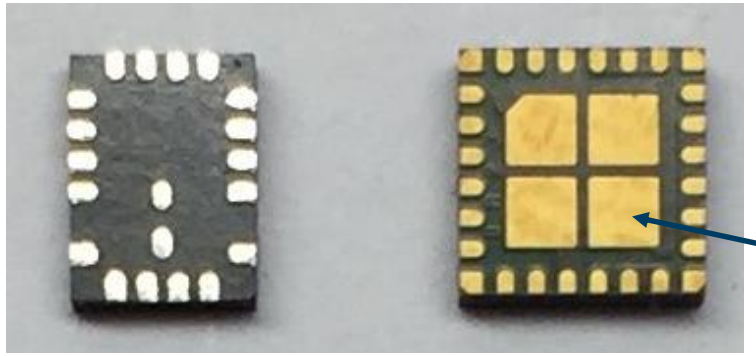
Silent Switcher 2: LQFN Packaging

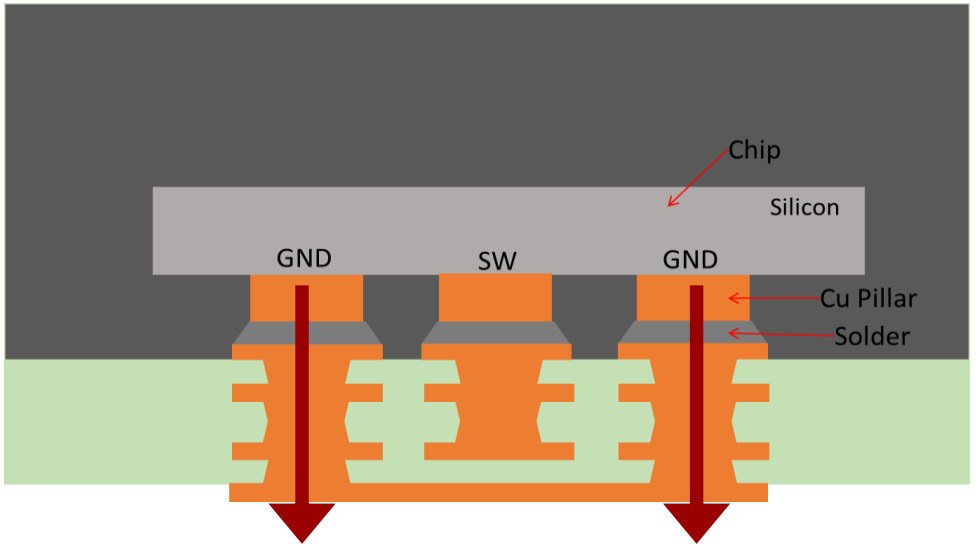


- More Copper Pillars
- Better Thermals
- Higher Efficiency



LT8640
QFN Flip-Chip
Silent Switcher 1

LT8640S
LQFN Flip-Chip
Silent Switcher 2



Heat Directly Out Back Paddle

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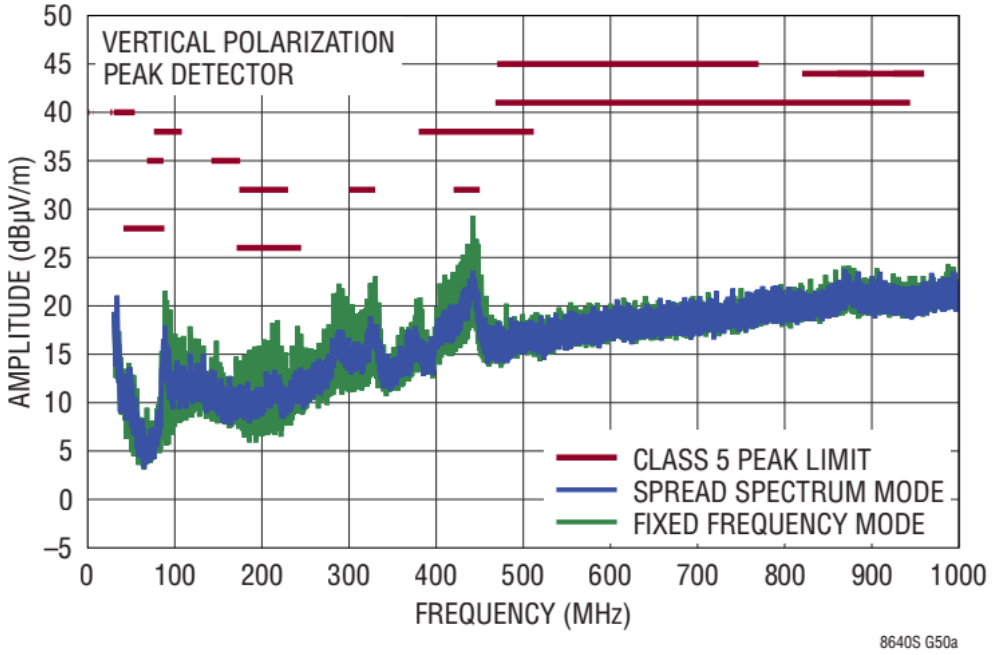
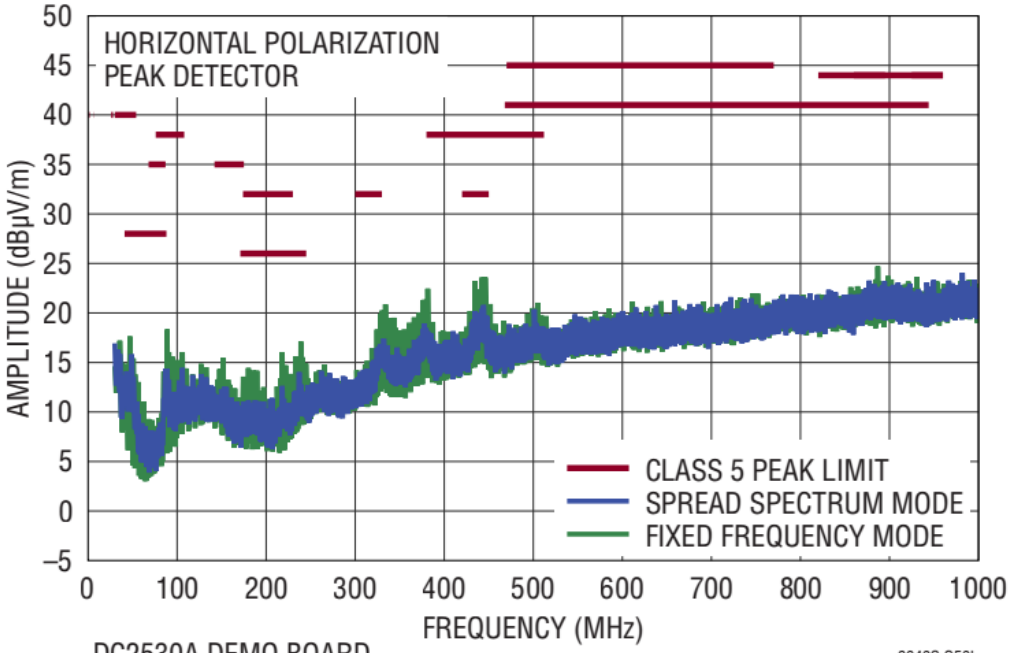
Silent Switcher 2 EMI Performance

Radiated EMI Performance
(CISPR25 Radiated Emission Test with Class 5 Peak Limits)





DC2530A DEMO BOARD
(WITH EMI FILTER INSTALLED)
14V INPUT TO 5V OUTPUT AT 4A, f_{SW} = 2MHz

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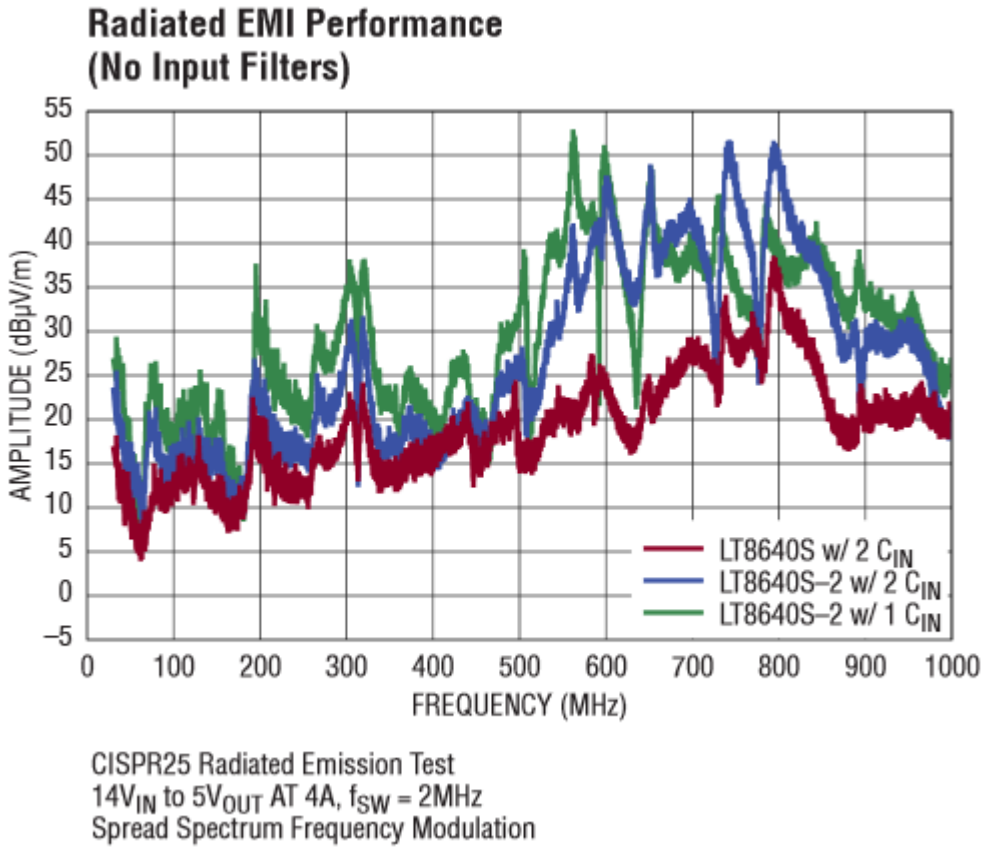
Silent Switcher Comparison - Radiated EMI Performance



Note: Input filters removed to better highlight differences

No Magnetic Cancellation
1 Cap Removed

LT8640S-2: Internal Caps Removed
External: 1 x 1µF 0603

Silent Switcher w/
External Caps only

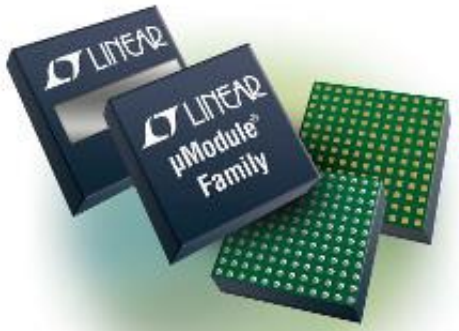
LT8640S-2: Internal Caps Removed
External: 2 x 1µF 0603

Silent Switcher w/
Internal & External Caps

LT8640S: 2 x 0.1µF 0402
External: 2 x 1µF 0603

µModule Regulators can Incorporate Silent Switcher 2 Technology

- All of this is hidden inside!
- Simplicity, reliability, performance, power density



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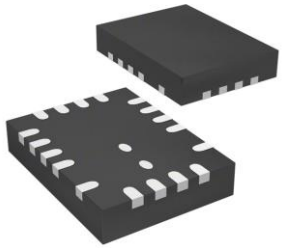
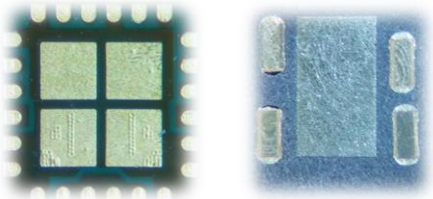
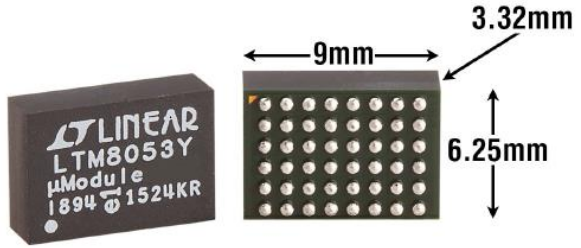
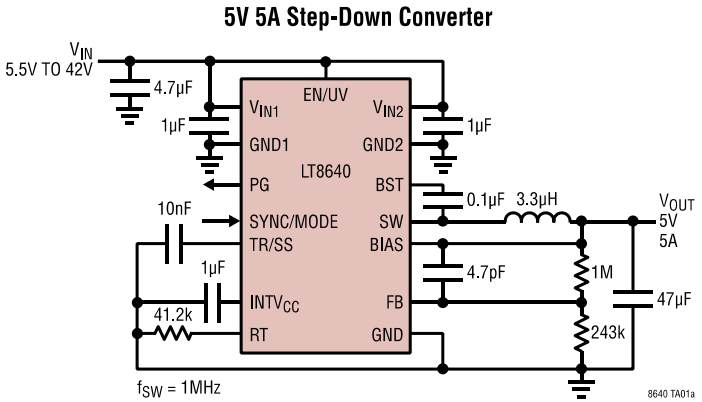
Integration Options: IC / +C_{IN} / +C_{IN} +L

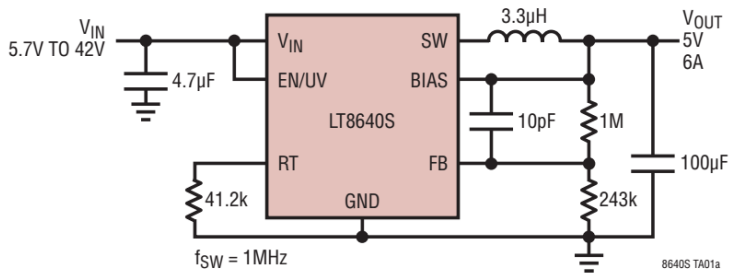




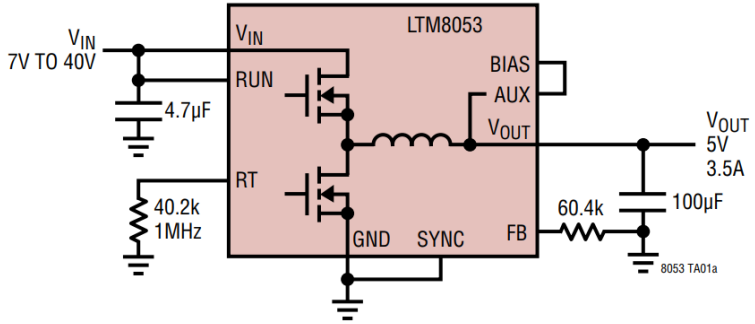




LT8640
Capacitors External
Silent Switcher 1 in QFN



LT8640S
Capacitors Internal
Silent Switcher 2 in LQFN



LTM8053
Fully Integrated µModule
Silent Switcher BGA

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Silent Switcher Monolithic Buck Product Selection

- If $V_{OUT} < V_{INmin}$, choose a Buck
- Choose the smallest buck with:
  - $V_{INabsmax} > V_{INmax}$
  - I_{OUT} requirement met
- Strategy: Best Performance! Silent Switchers especially separate themselves from the competition when customer needs:
  - Low EMI,
  - High efficiency at high switching frequencies (1MHz+), or
  - Small physical solution size
- Price ($) Tradeoff: µModule > SS2 > SS1 > Non-SS
- Product Selection Table is arranged by V_{IN} rating: Generally, **40V** for automotive[12V Batt] / industrial[24V rail], **20V** for telecom[12V rail], **60V** for trucks[24V Batt] / industrial[48V rail], **5V** for all markets [intermediate rail to core]

Silent Switcher Monolithic Buck Products [40V Family]

Part	V_{IN}	I_{OUT}	Package	Silent Sw	Samples	Release
Single Channel 40V Bucks						
LT8608S	42	1.5	3x2 LQFN	SS2	2019 Q1	2019 Q3
LT8609S	42	2	3x3 LQFN	SS2		Released
LT8640S/LT8643S	42	6	4x4 LQFN	SS2		Released
LT8638S	40	10	5x4 LQFN	SS2	2018 Q4	2019 Q3
LT8648S	40	15	7x4 LQFN	SS2	Now	2019 Q1
LT8614	42	4	3x4 QFN	SS1		Released
LT8640	42	5	3x4 QFN	SS1		Released
LT8640	42	6	MSE16	SS1	2018 Q4	2019 Q?
LT8636/LT8637	42	6	4x3 LQFN	SS1	2018 Q4	2019 Q3
LT8610A	42	3.5	MSE16	Non-SS		Released
Dual Channel 40V Bucks						
LT8653S	42	2+2	4x3 LQFN	SS2	Now	2018 Q4
LT8650S	42	4+4	6x4 LQFN	SS2		Released
LT8650SP	42	7+7	6x4 LQFN	SS2	Now	2019 Q?
LT8616	42	2.5+1.5	FE28, 6x3 QFN	Non-SS		Released

Silent Switcher Monolithic Buck Products [5V, 20V Family]

Part	V_{IN}	I_{OUT}	Package	Silent Sw	Samples	Release
Single Channel 5V Bucks						
LTC3310S	5.5	10	3x3 LQFN	SS2		Released
LT8644S	8	15	4x4 LQFN	SS2	Now	2019 Q1
LTC3307	5.5	3	2x2 LQFN	SS1	Now	2018 Q4
LTC3308	5.5	4	2x2 LQFN	SS1	Now	2018 Q4
LTC3309	5.5	6	2x2 LQFN	SS1	Now	2018 Q4
Dual Channel 5V Bucks						
LTC3315	5.5	2+2	2x2 LQFN	Non-SS	Now	2018 Q4
Single Channel 20V Bucks						
LT8642S	18	10	4x4 LQFN	SS2		Released
LTC7151S	20	15	5x4 LQFN	SS2		Released
LTC7150S	20	20	6x5 BGA	SS2		Released
Dual Channel 20V Bucks						
LT8652S	18	8+8	7x4 LQFN	SS2	Now	2018 Q4
LTC3636	20	6+6	4x5 QFN	SS1		Released

Silent Switcher Monolithic Buck Products [60V Family]

Part	V_{IN}	I_{OUT}	Package	Silent Sw	Samples	Release
Single Channel 60V Bucks						
LT8645S/LT8646S	65	8	6x4 LQFN	SS2		Released
LT8641	65	3.5	3x4 QFN	SS1		Released
LT8620	65	2	3x5 QFN, MSE16	Non-SS		Released

Silent Switcher µModule Products

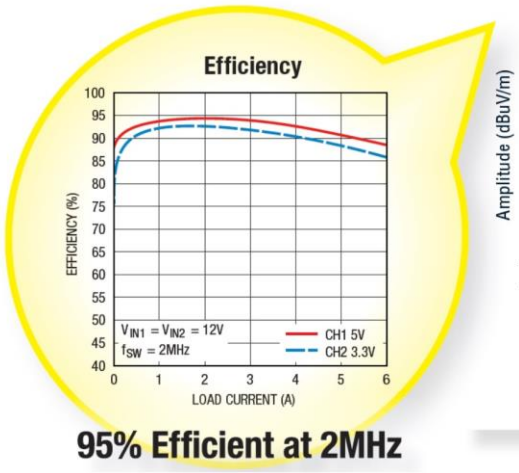
Part	V_{IN}	V_{OUT}	I_{OUT}	Package	Comments
125°C Commercial/Industrial					
LTM8074	40	12	1.2	4x4 BGA	
LTM8063	40	15	2	6.25x4 BGA	
LTM8065	40	18	2.5	6.25x6.25 BGA	
LTM8053	40	18	3.5	9x6.25 BGA	Current Sharing
LTM8073	60	15	3	9x6.25 BGA	Current Sharing
150°C Automotive					
LTM8002	40	15	2.5	6.25x6.25 BGA	FMEA Pinout
LTM8003	40	15	3.5	9x6.25 BGA	FMEA Pinout

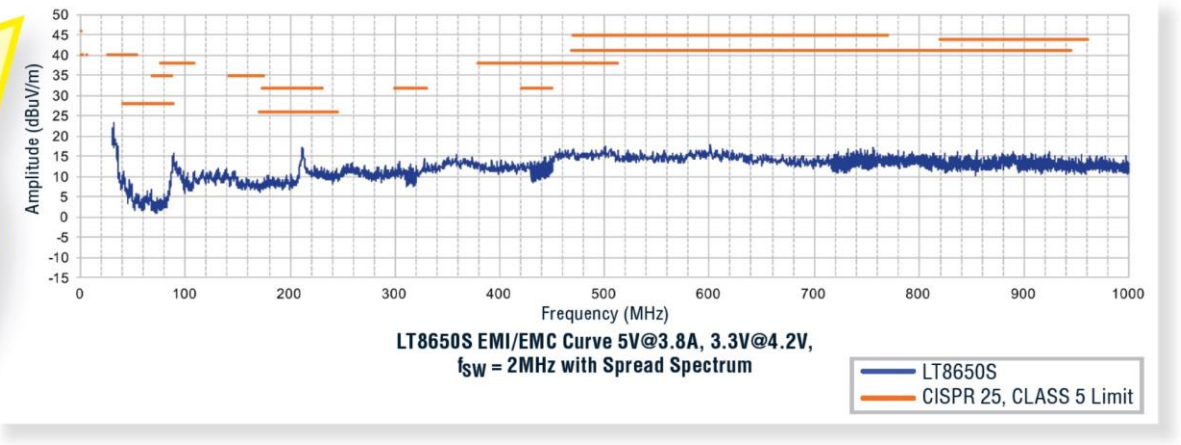
Summary : Silent Switcher 2 Benefits

Silent Switcher® 2 Architecture:

- High efficiency even at high switching frequency
- Internal bypass capacitors reduce radiated EMI
- Eliminates PCB layout sensitivity
- Optional spread spectrum modulation
- Saves board space and layers

Low EMI on any PCB !





NEW: https://www.analog.com/media/en/technical-documentation/lt-journal-article/PbLJournal-V1N1-00-df-LT8650S-HuaBai_DongWang_YingCheng.pdf

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