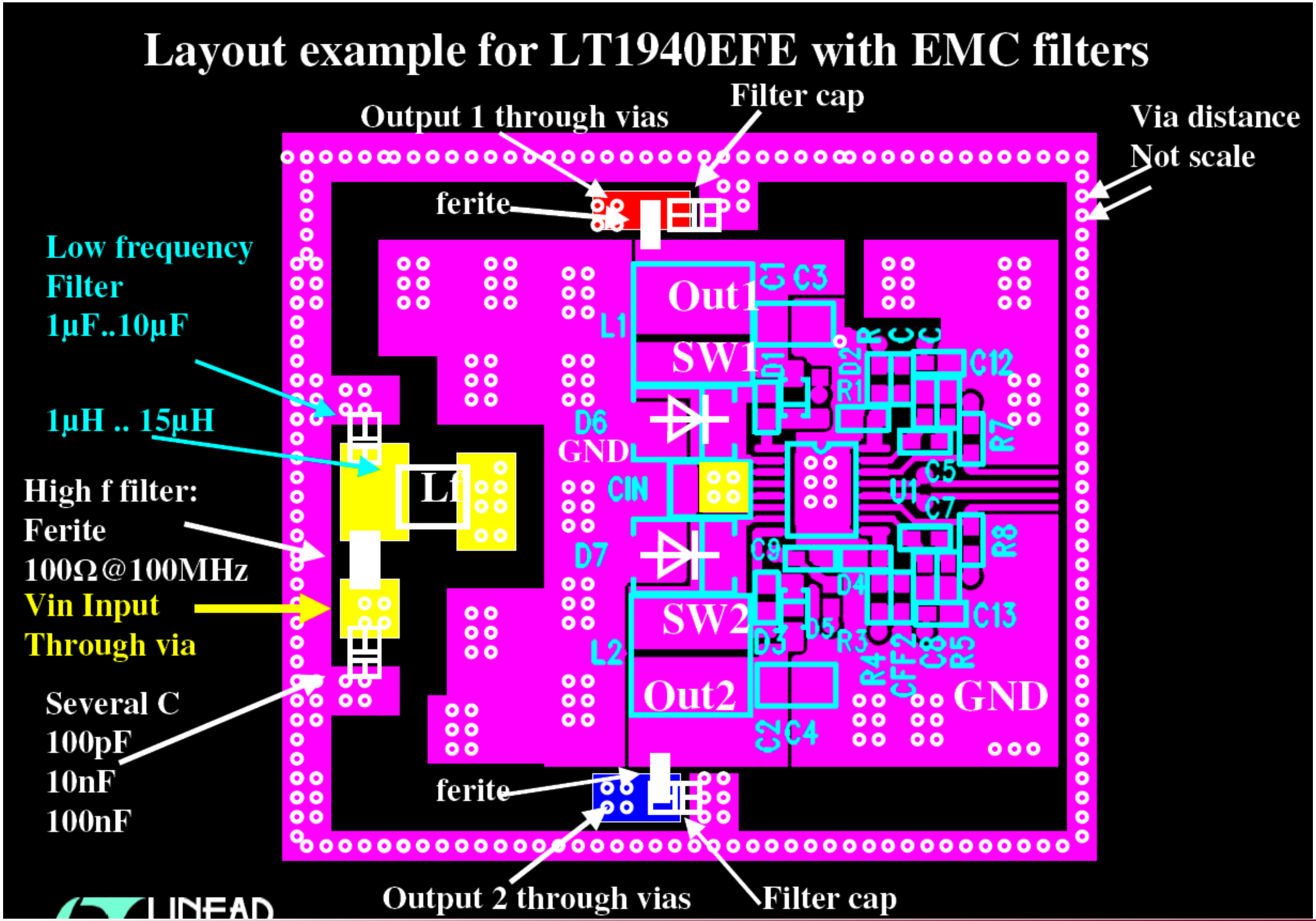
Linear Technology Corporation

Power Business Unit

EMI solution & Layout

JM Park
Field Applications Engineer

2x2A 1.1Mhz in a AM Radio



1. Why EMI Noise come from DC/DC converter?

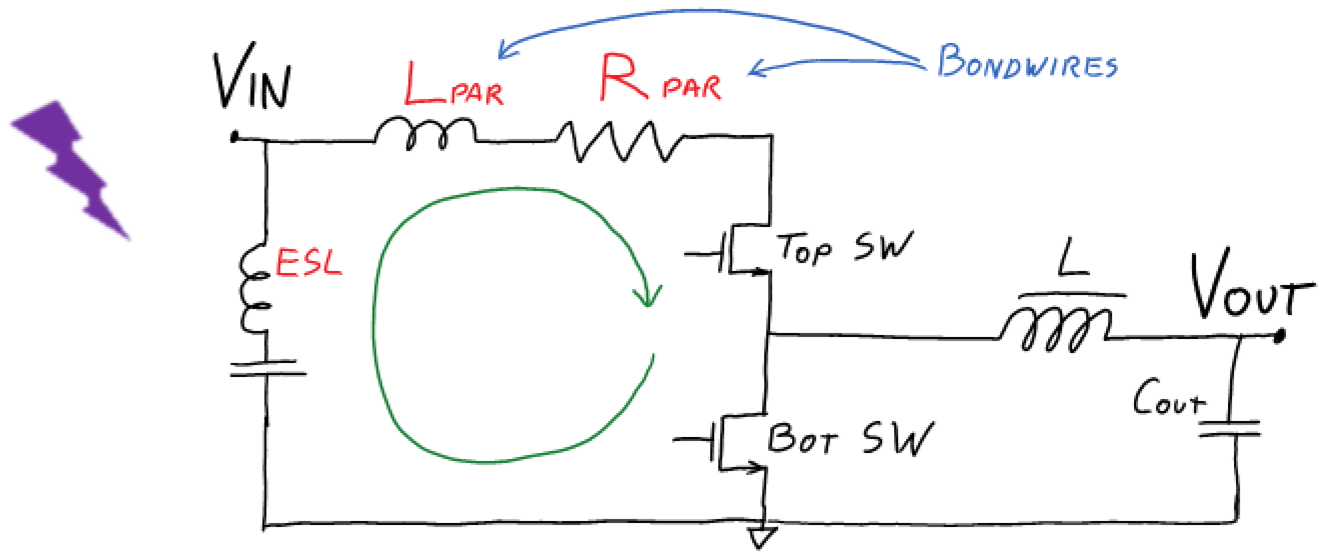
1) EMI Noise
2) EMI Noise Source on switching regulator
3) Noise Hot loop as topology

2. How to reduce EMI Noise?

1) Layout design & Filter
2) LTC EMI solution

Why EMI Noise comes from DC/DC converter?

EMI Noise



$$V_{noise} = L * di/dt$$

dBm and dBuV

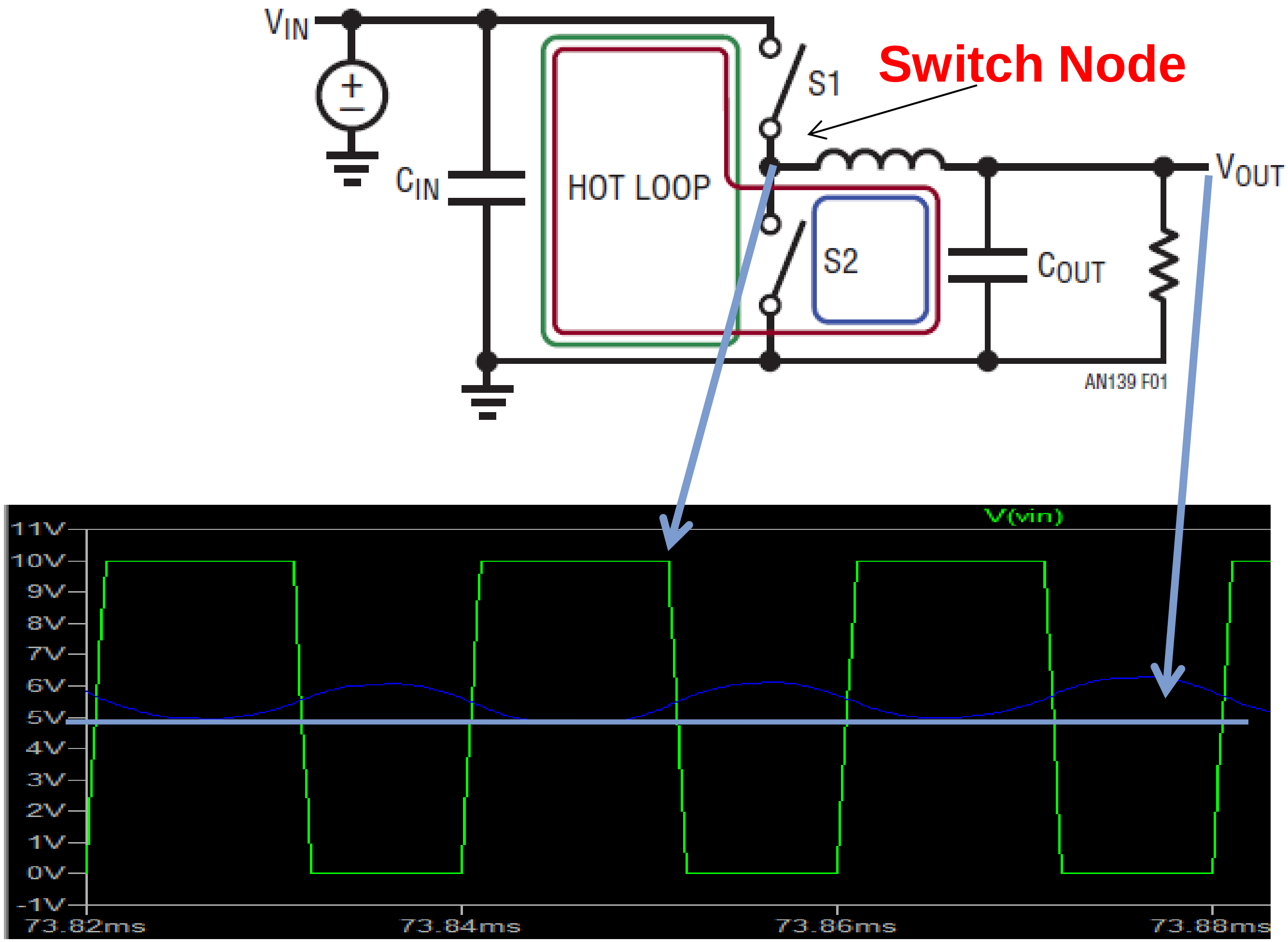
Relationship between dBm, W, dBμV, V			
dBm	W	dBμV	V
-100	0.1pW	7	2.2μV
-90	1pW	17	7μV
-80	10pW	27	22μV
-70	100pW	37	70μV
-60	1nW	47	220μV
-50	10nW	57	700μV
-47	20nW	60	1mV
-40	100nW	67	2.2mV
-30	1μW	77	7mV
-20	10μW	87	22mV
-10	100μW	97	70mV
0	1mW	107	220mV
10	10mW	117	700mV
20	100mW	127	2.2V
30	1W	137	7V

dbmW	dbuV
33	140
23	130
13	120
3	110
-7	100
-17	90
-27	80
-37	70
-47	60
-57	50
-67	40
-77	30
-87	20
-97	10
-107	1

EMI Noise Source on Switching regulator

Buck is like a L/C filter

Vin = 10V



Vout = 5V

5V

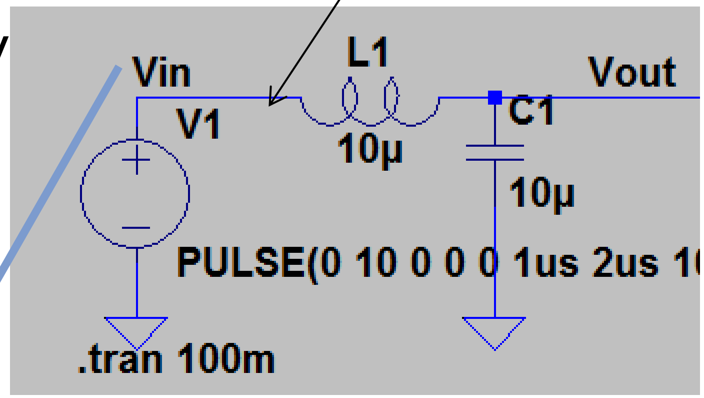
Duty = Vout / Vin

= **50%**

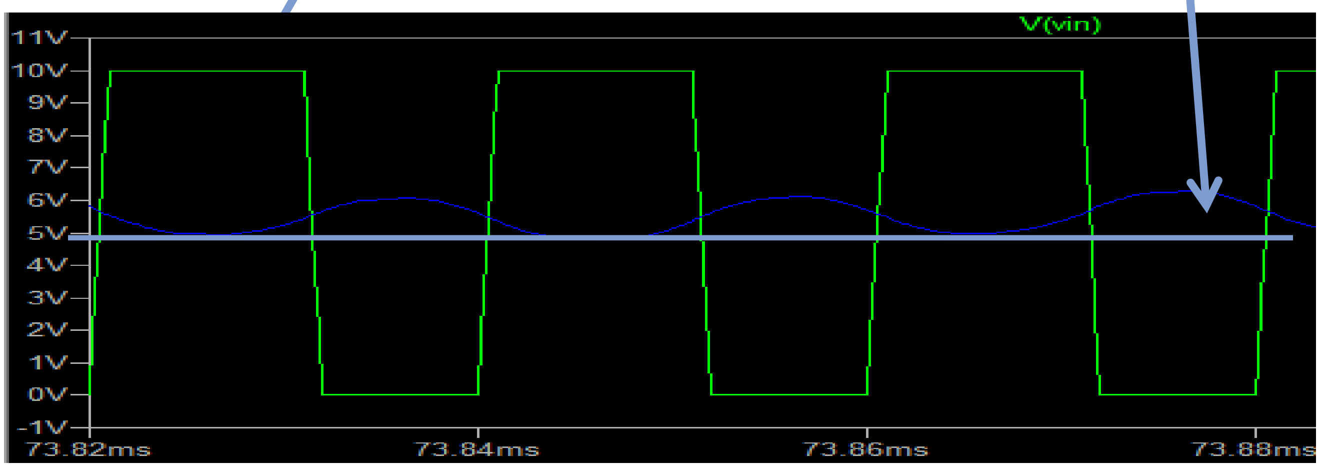
Buck is like a L/C filter

Switch Node

Vin = 10V



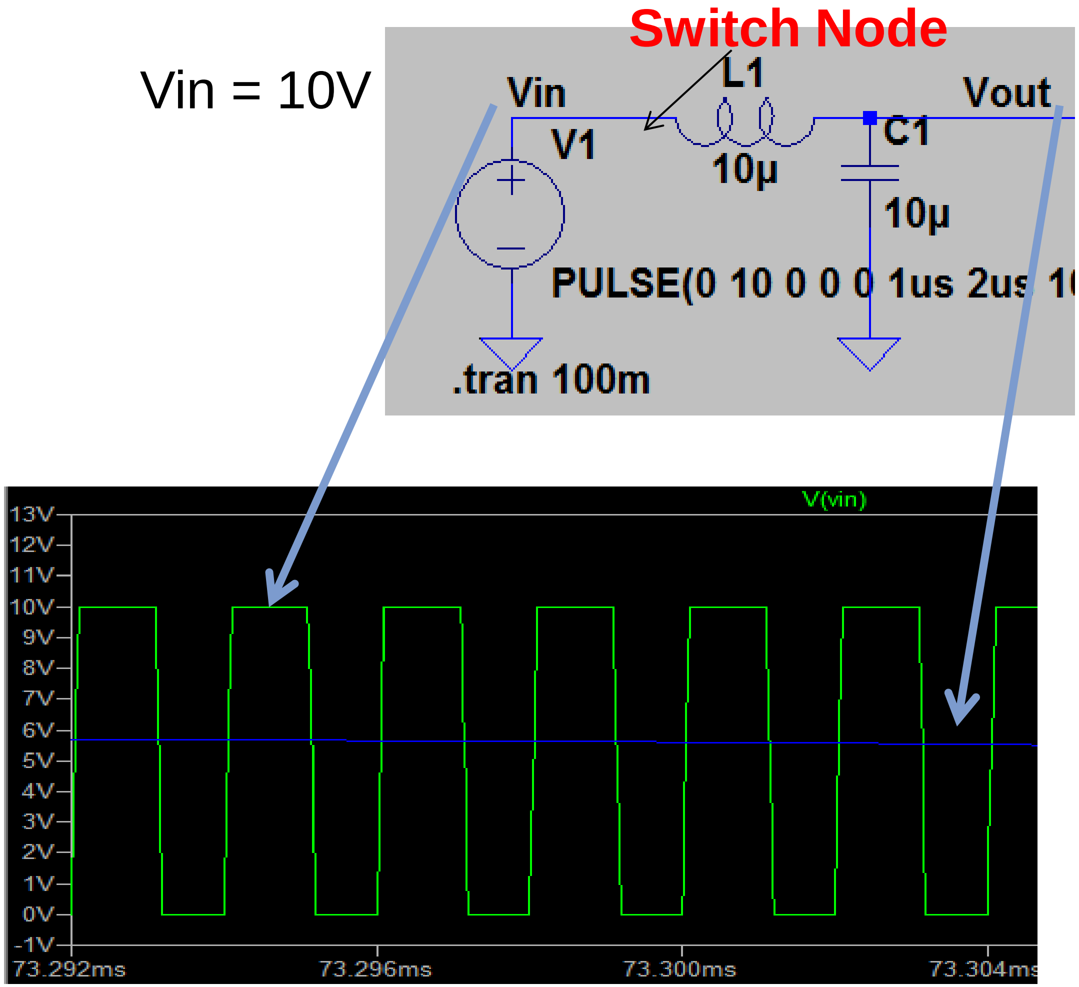
Vout = 5V



Freq : 50kHz
Ripple : 1Vp-p
Duty : 50%

Buck is like a L/C filter

Vin = 10V



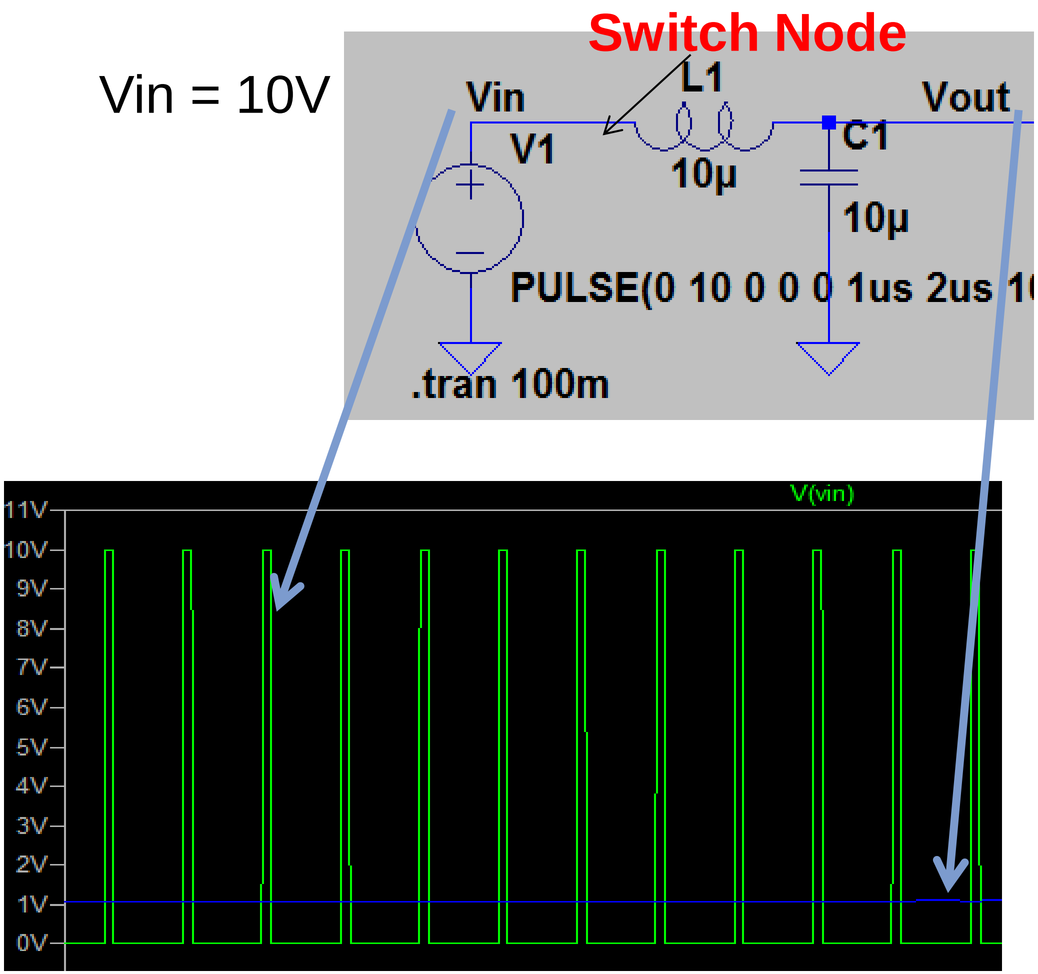
Vout = 5V

Freq : **500kHz**
Ripple : **50mVp-p**
Duty : **50%**

주파수 증가 시 ripple voltage 감소

Buck is like a L/C filter

Vin = 10V



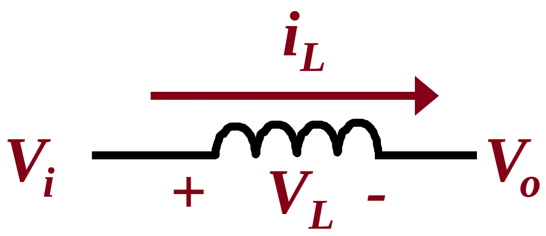
Vout = 1V

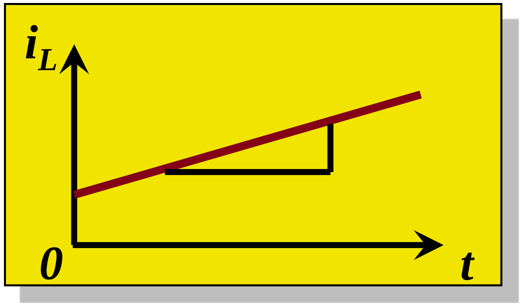
Freq : **500kHz**
Ripple : **50mVp-p**
Duty : **10%**

Duty 감소시   Vout 전압 낮아짐

Inductor Behavior

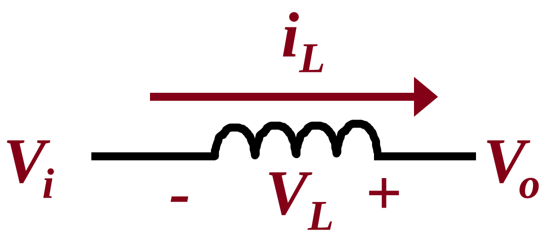
- As a positive voltage is applied ($V_i > V_o$), current through an inductor increases

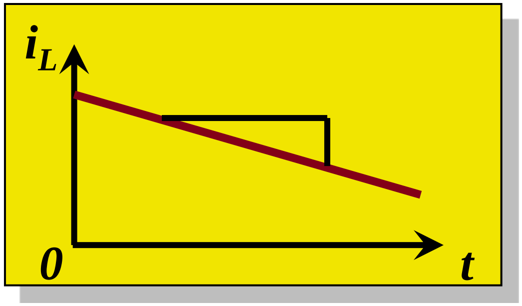




$$\frac{di_L}{dt} = \frac{+V_L}{L}$$

- If we reverse the polarity of the voltage ($V_i < V_o$), the current through the inductor decreases



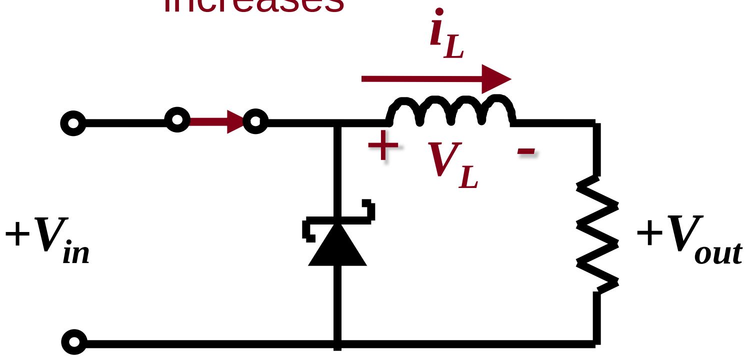


$$\frac{di_L}{dt} = \frac{-V_L}{L}$$

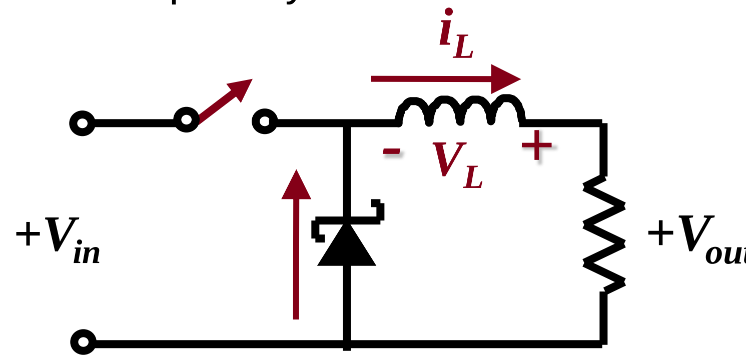
Inductors do not like instantaneous changes in current

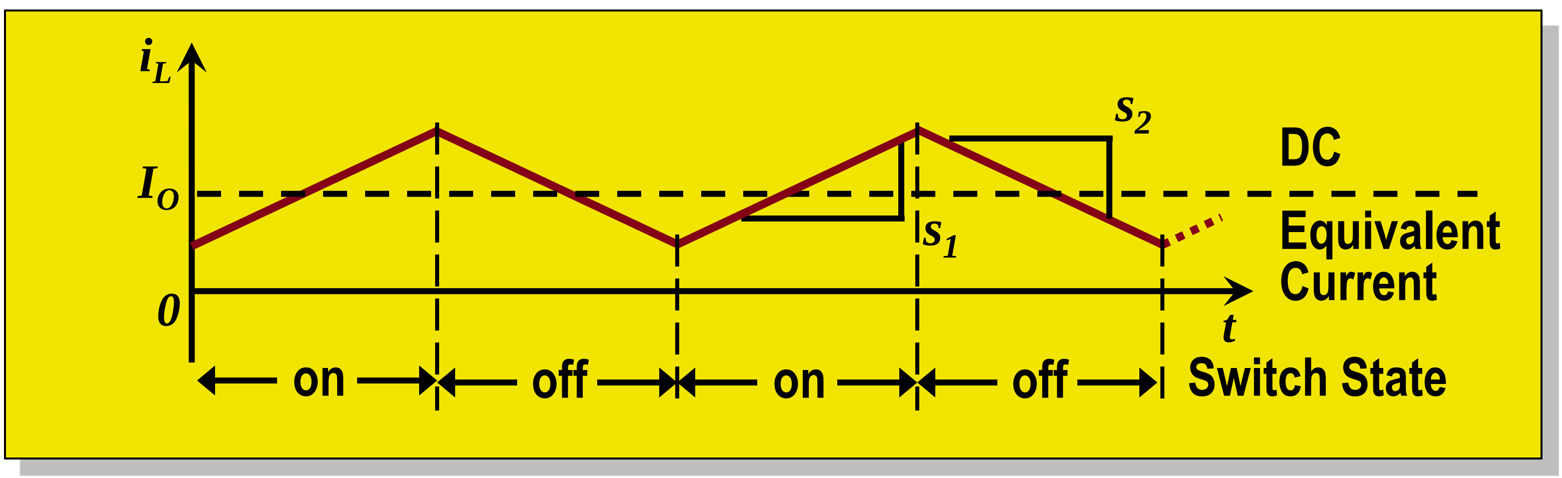
Switching an Inductor

- Switch ON
  - Current through the inductor increases



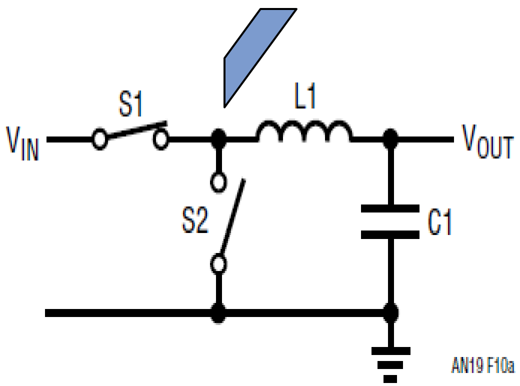
- Switch OFF
  - Current through the inductor decreases, reverses polarity



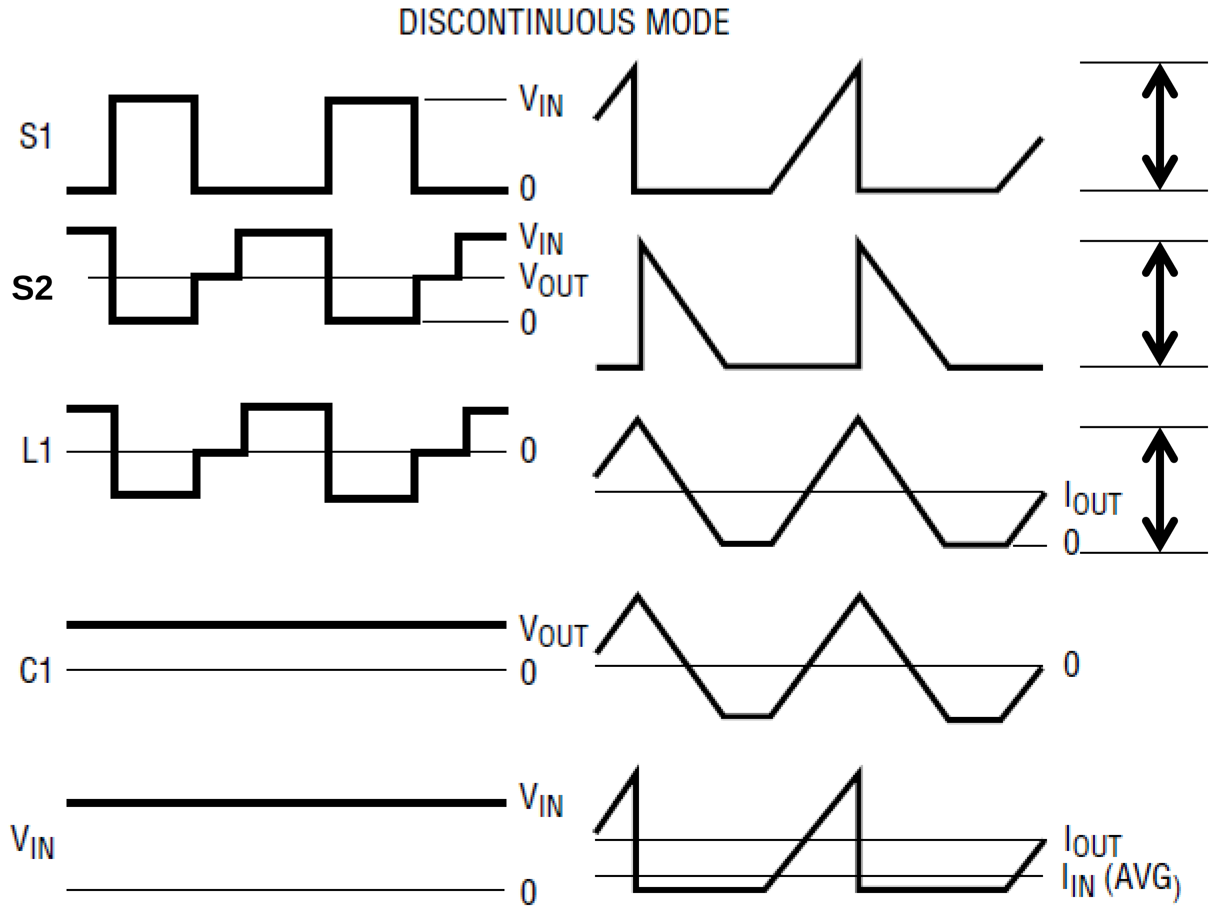


Switch current vs inductor current

Switch node Here!



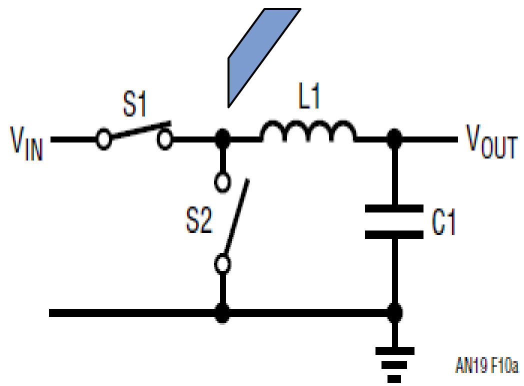
Buck Topology



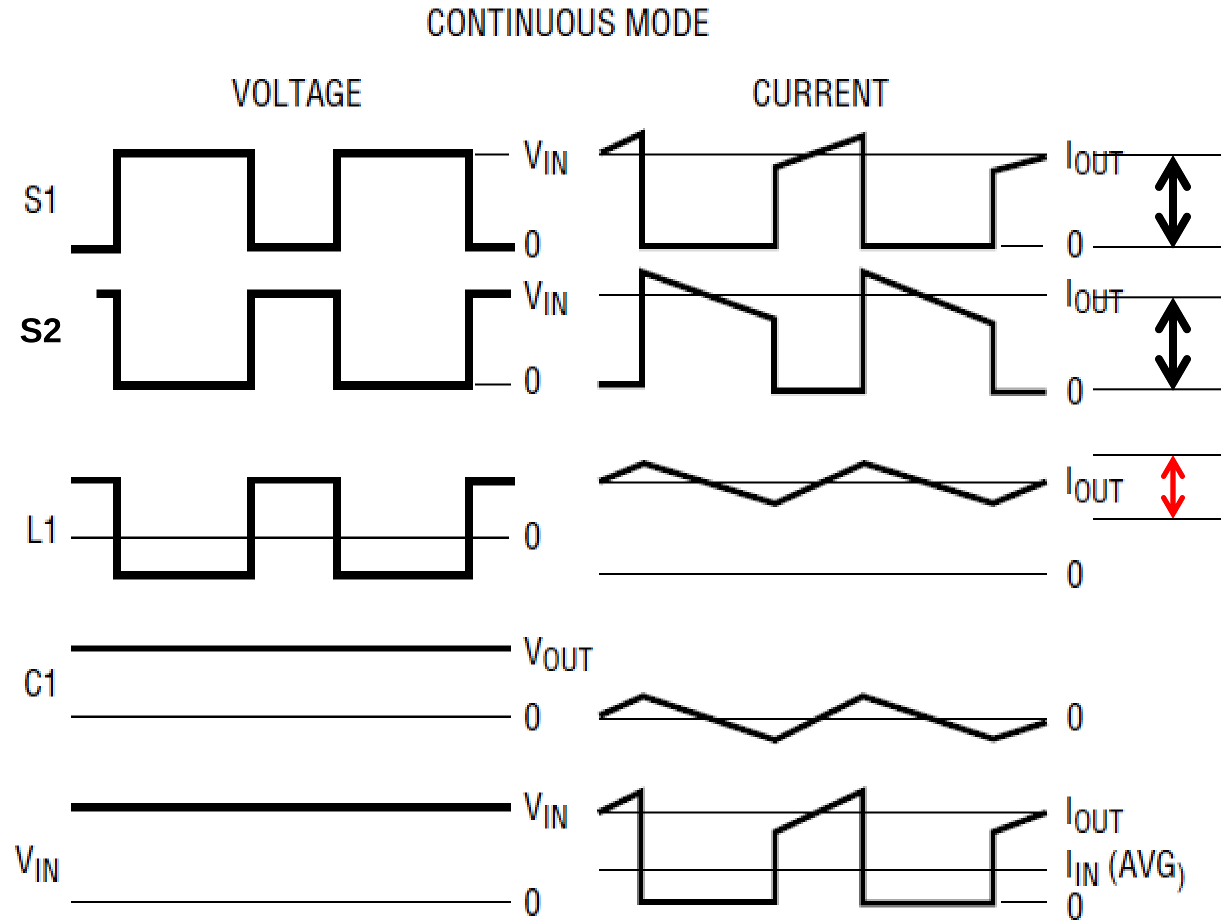
S1 전류변화 = S2 = L1 inductor 전류변화 !!

Switch current vs inductor current

Switch node Here!

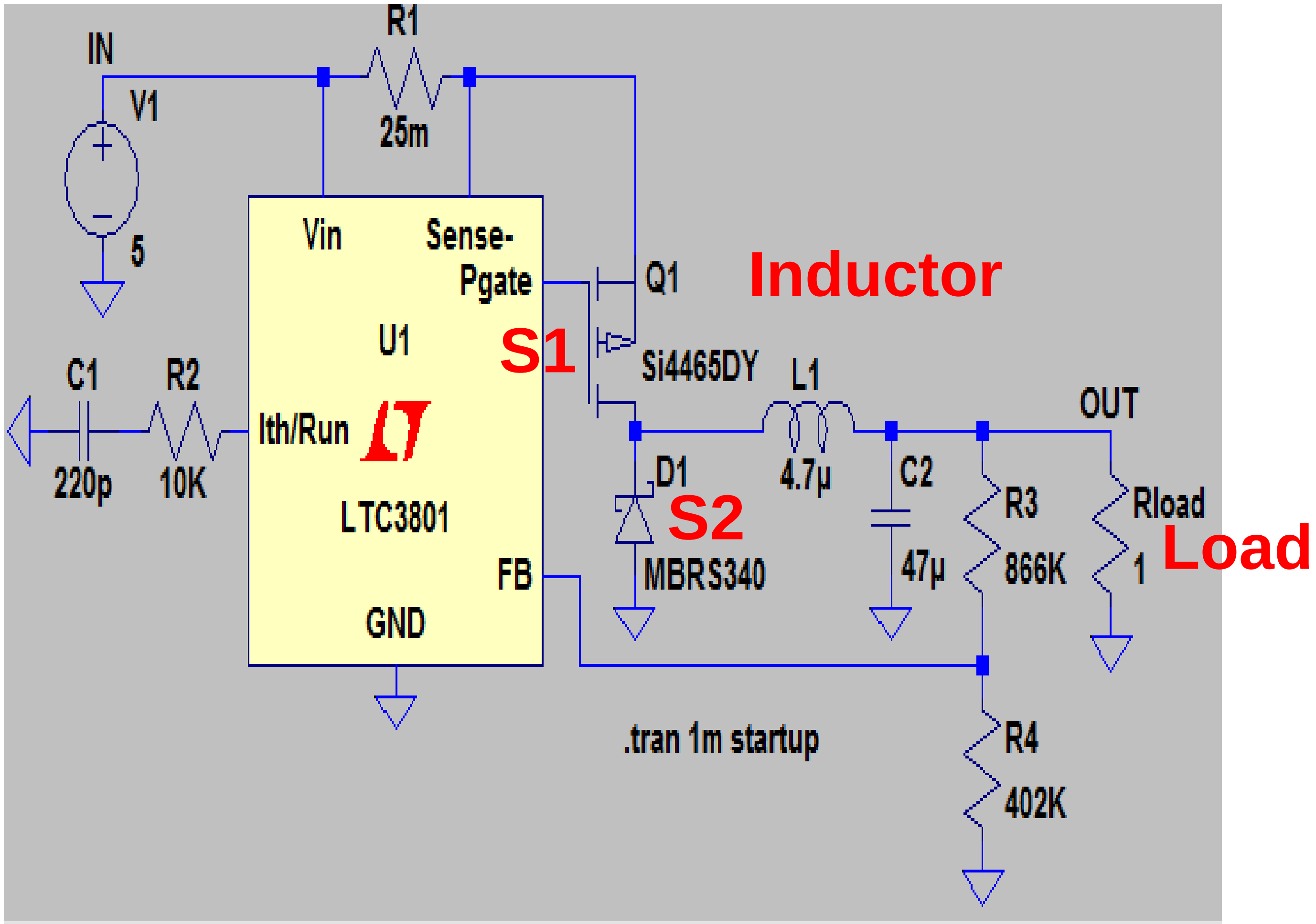


Buck Topology

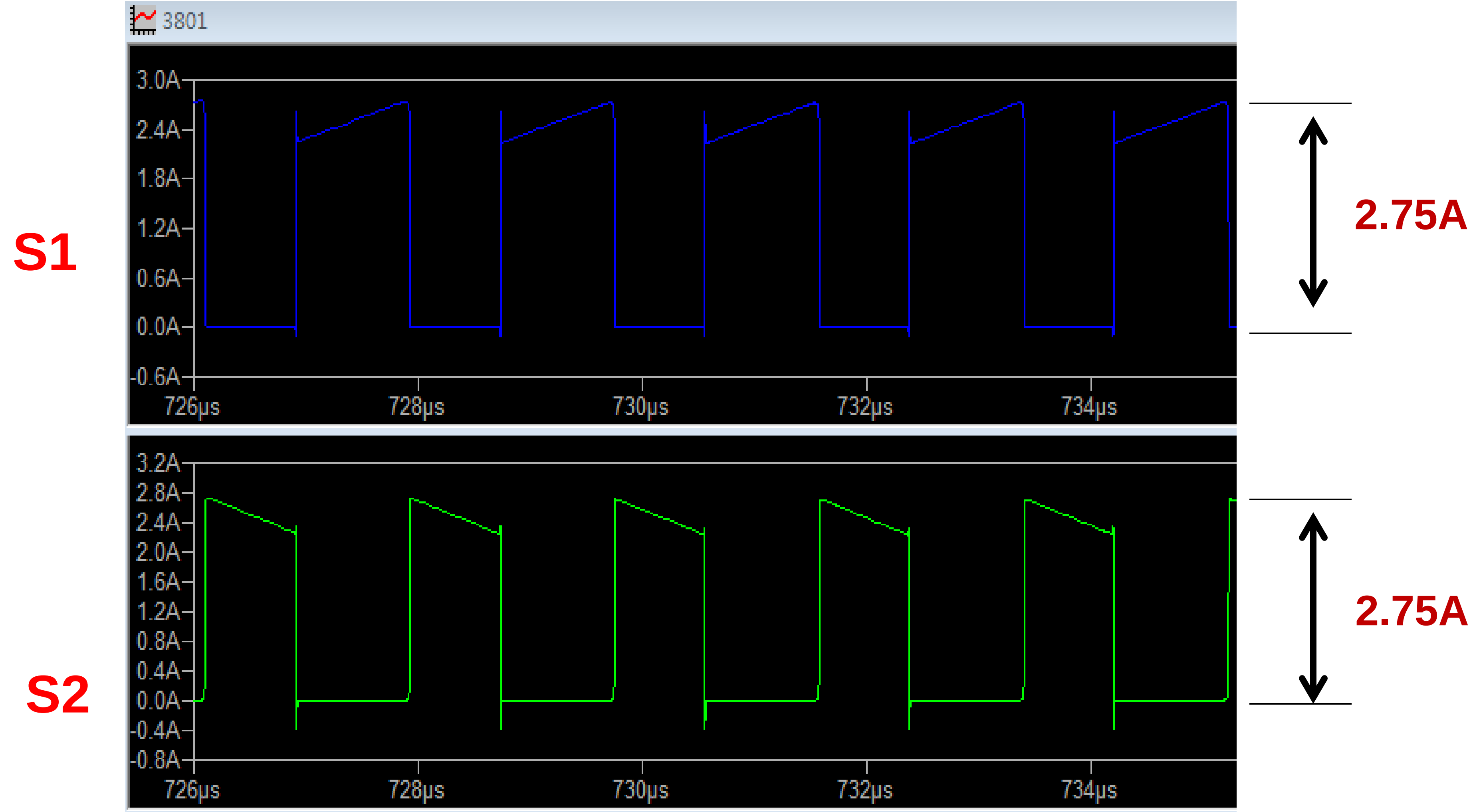


S1 전류변화 = S2 >> L1 inductor 전류변화 !!

Switch current vs inductor current

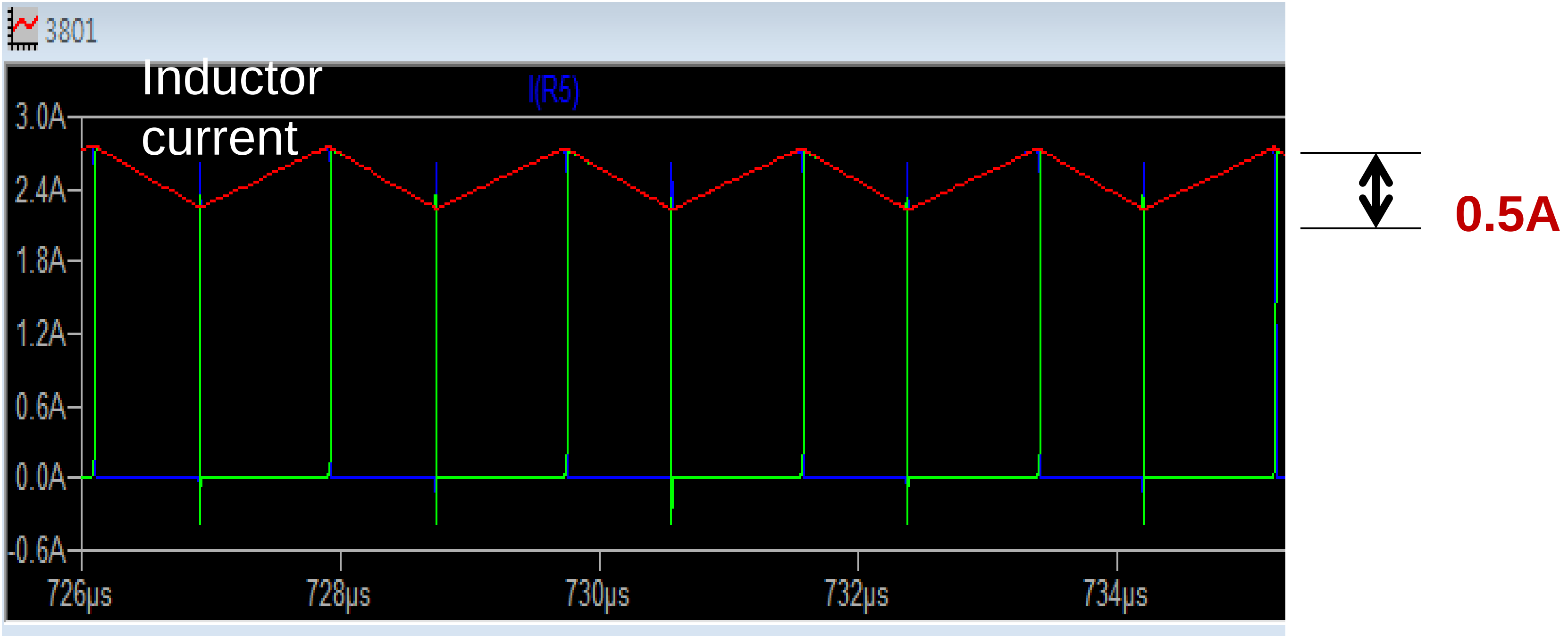


Switch current vs inductor current



di/dt = 2.75A

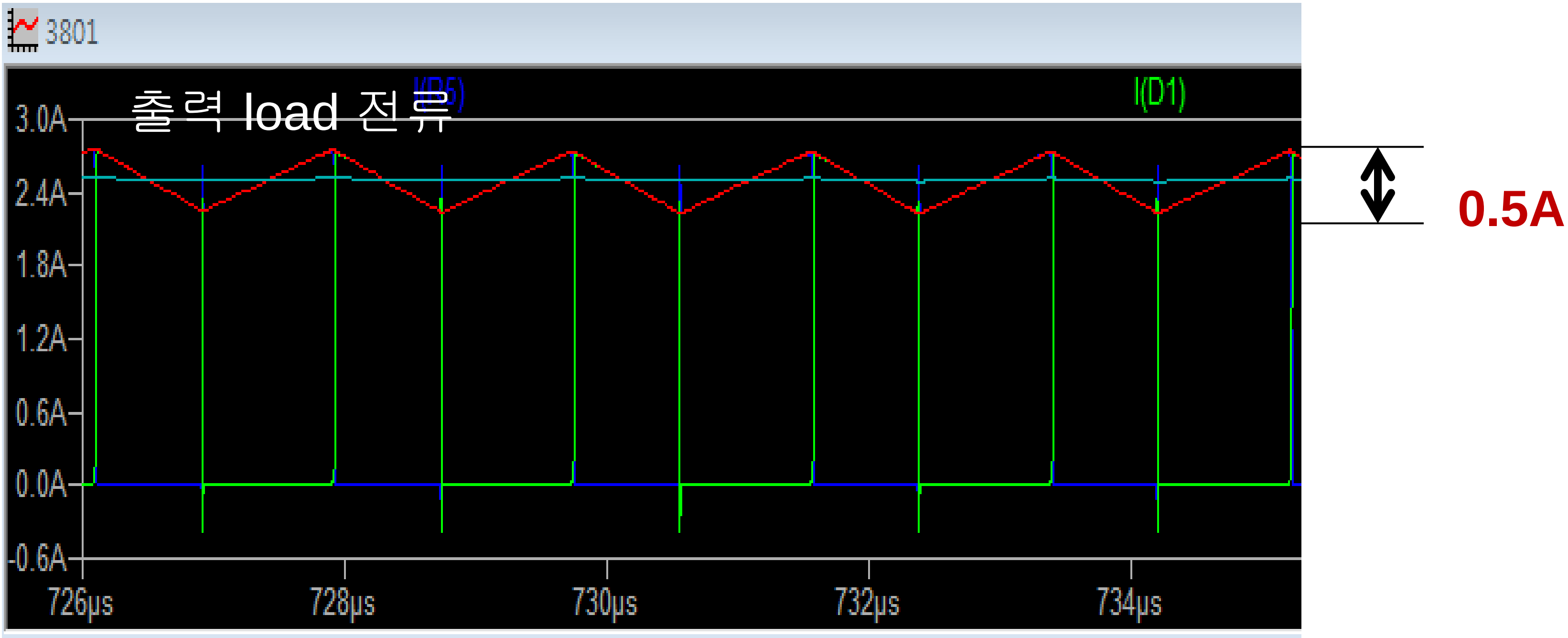
Switch current vs inductor current



S1 + S2 current waveform = output inductor current

But di/dt = 0.5A

Switch current vs inductor current



Load current = 2.5A(average inductor current)
But **di/dt** of S1&S2 is **5 times bigger than inductor current.**

Hot Loop on Buck Regulator

$$V_{noise} = L * di/dt$$

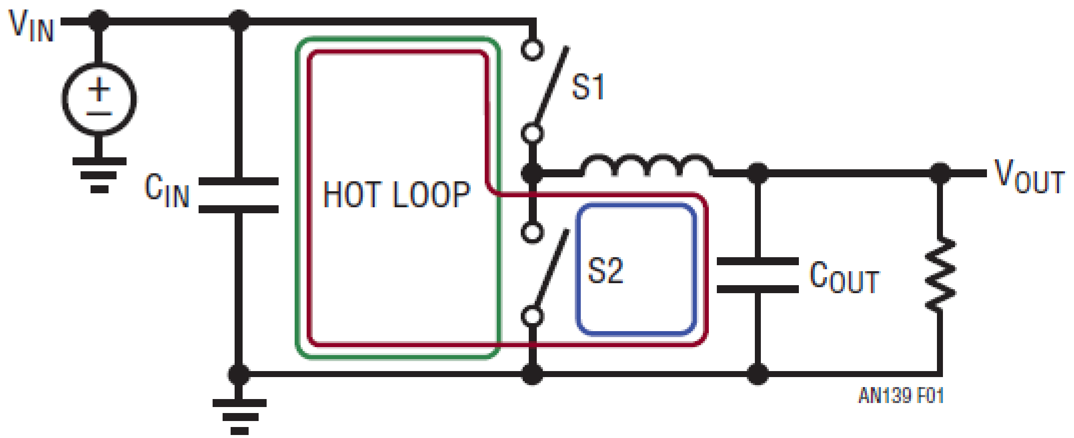


Figure 1

Hot loop area 감소 -> L 값 감소

Noise Hot loop as Topology

Hot Loop as topology

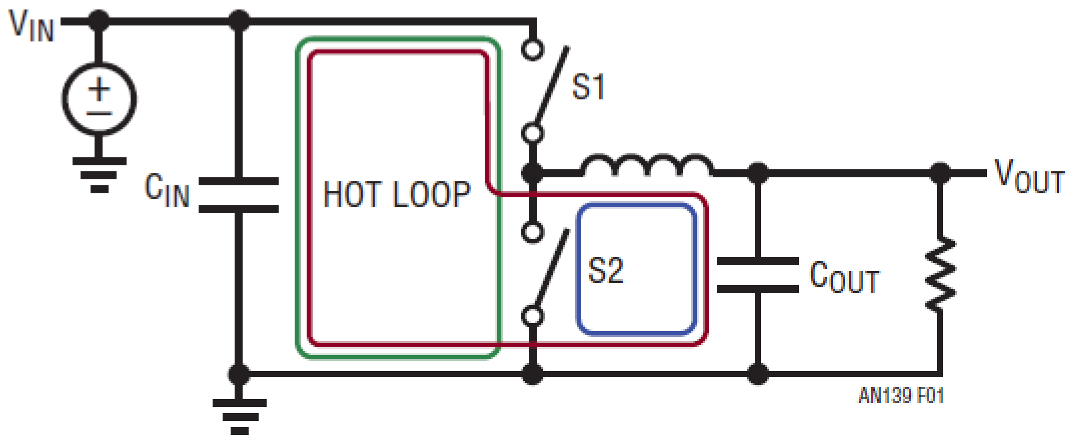
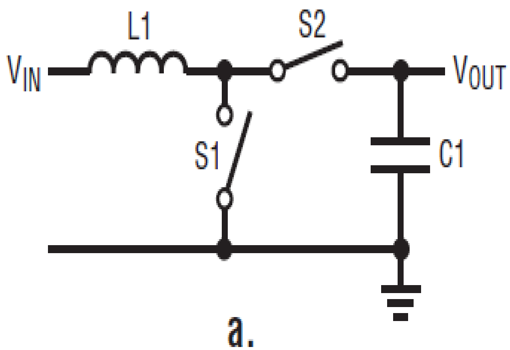


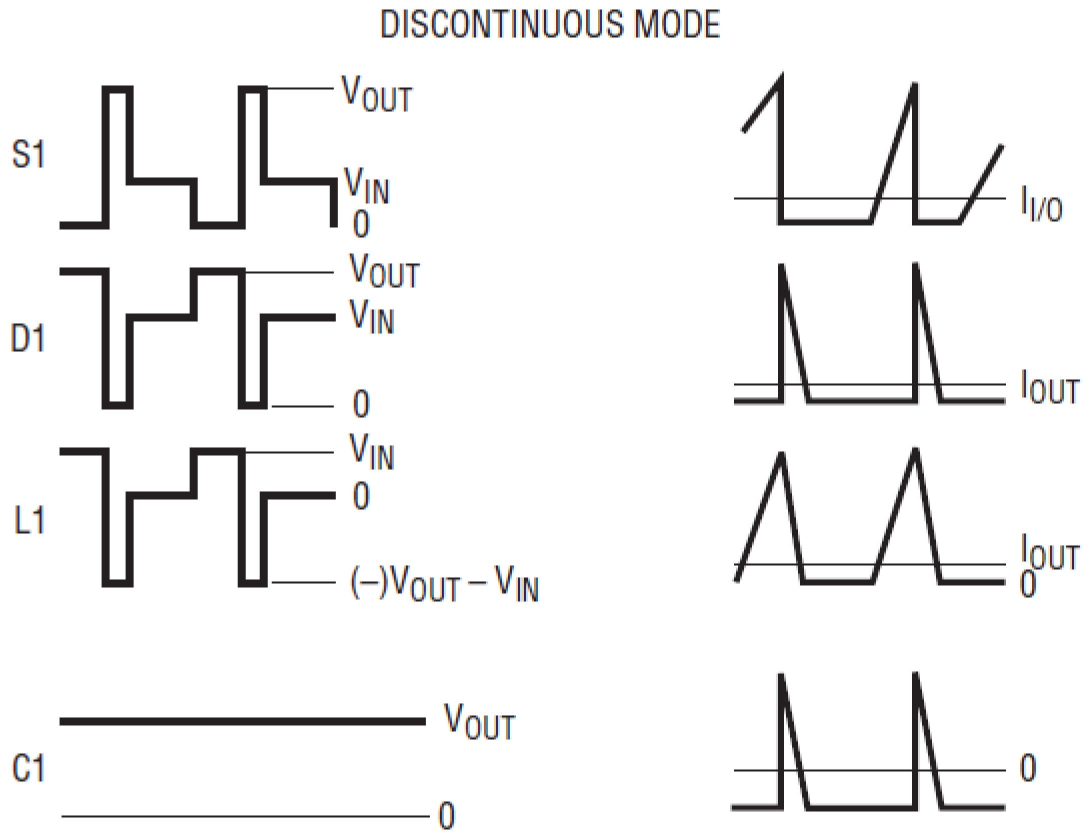
Figure 1

Buck Regulator

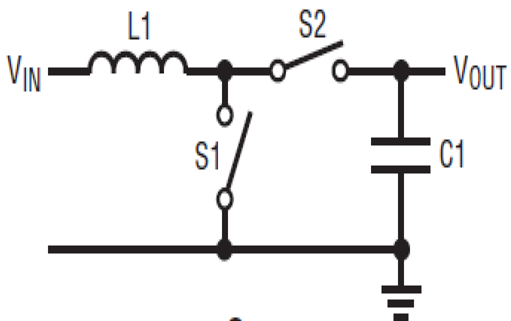
Hot Loop as Topology



Boost Topology

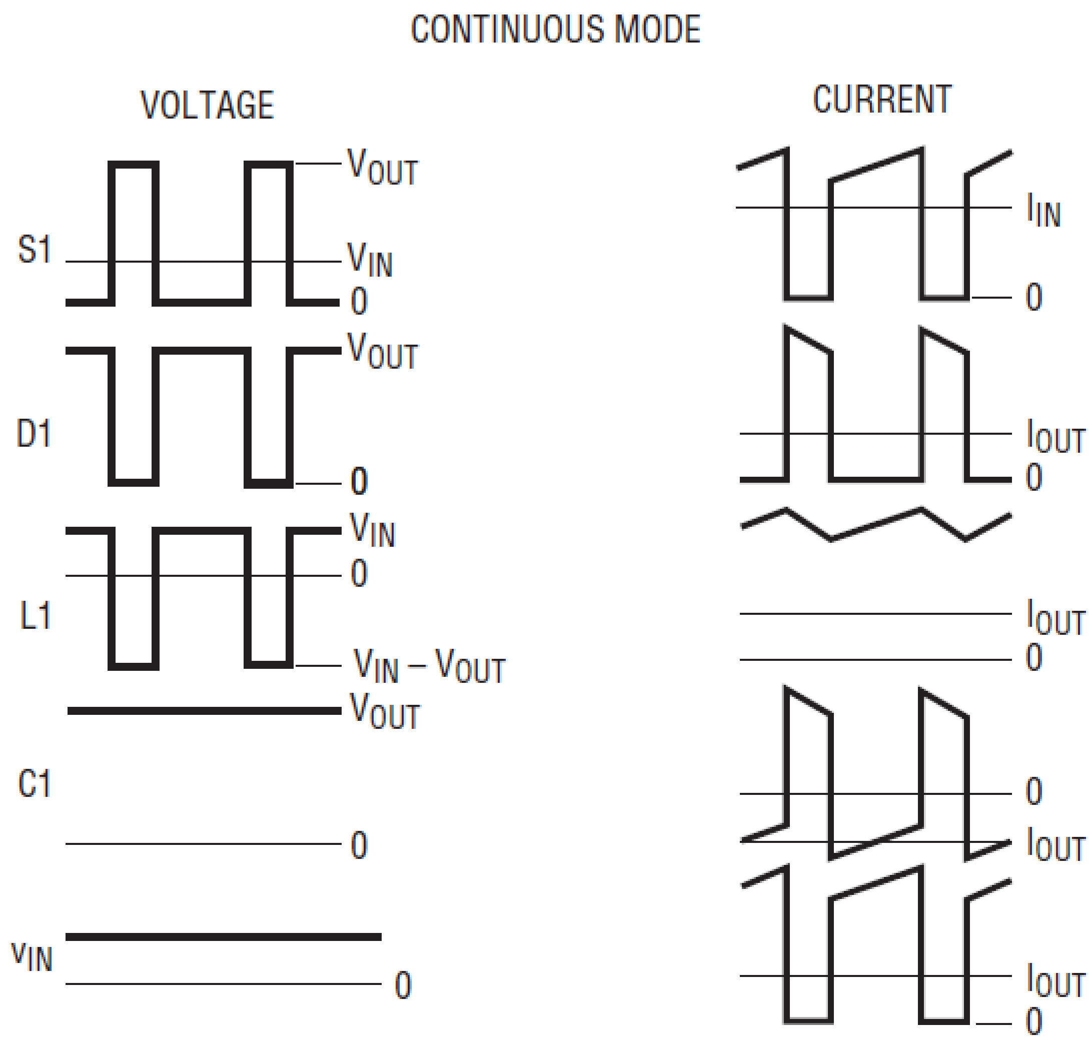


Hot Loop as Topology

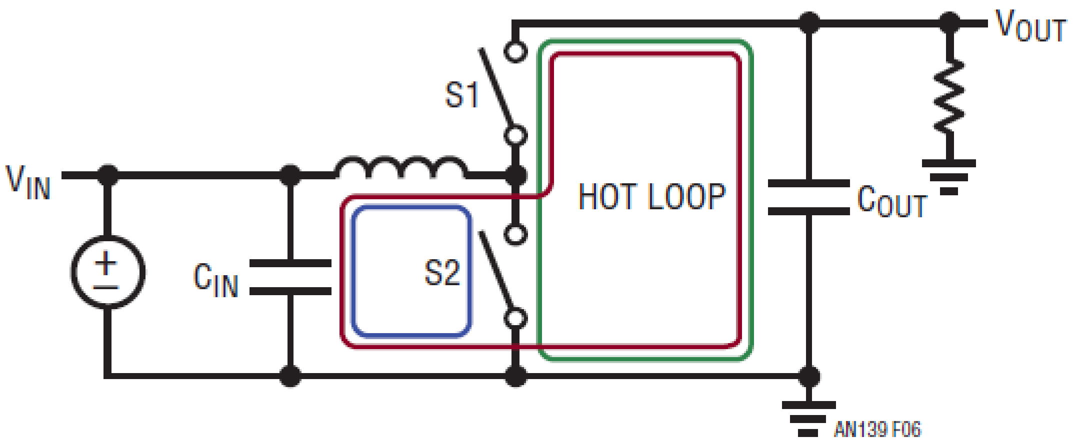


a.

Boost Topology

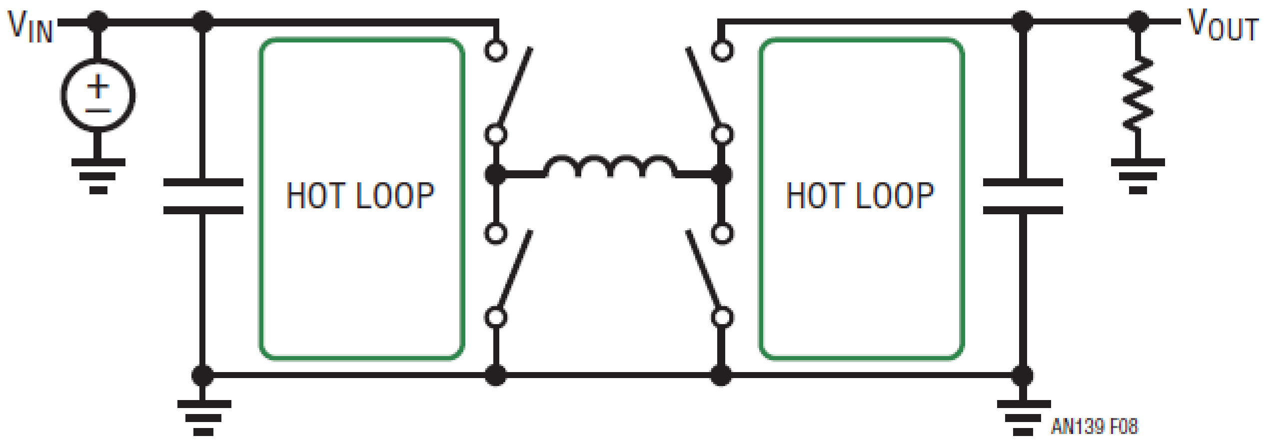


Hot Loop as Topology



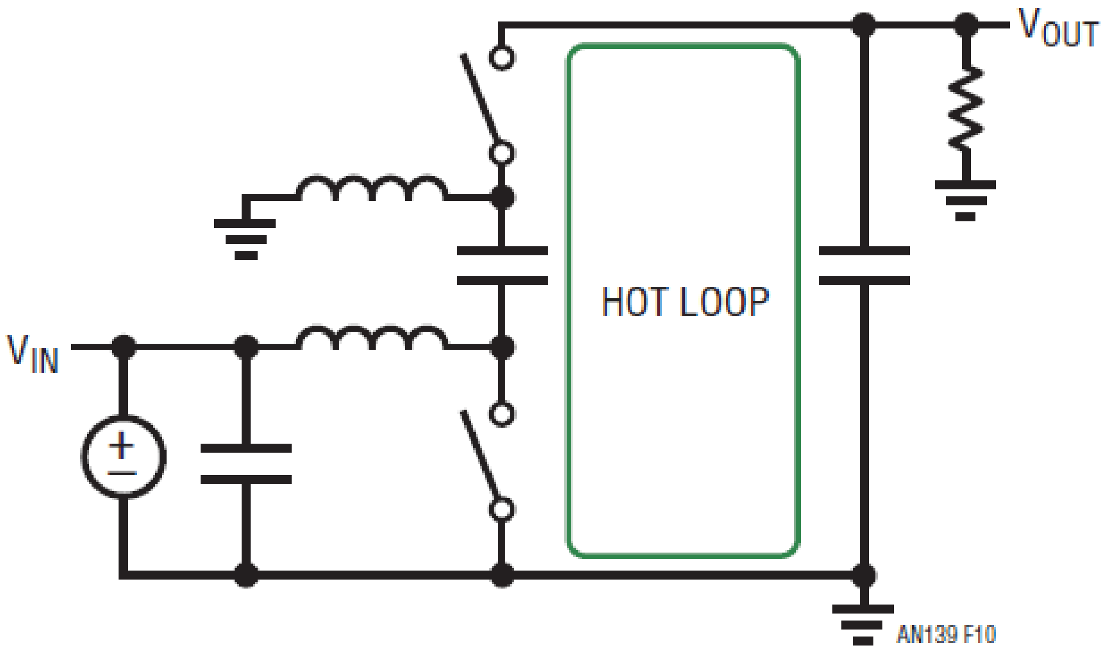
Boost Regulator

Hot Loop as Topology



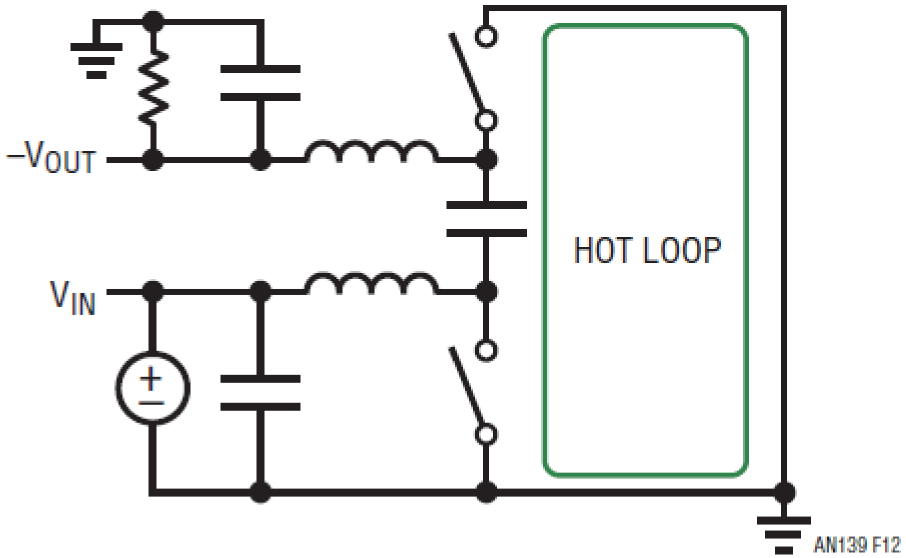
Buck-Boost Regulator

Hot Loop as Topology



Sepic Regulator

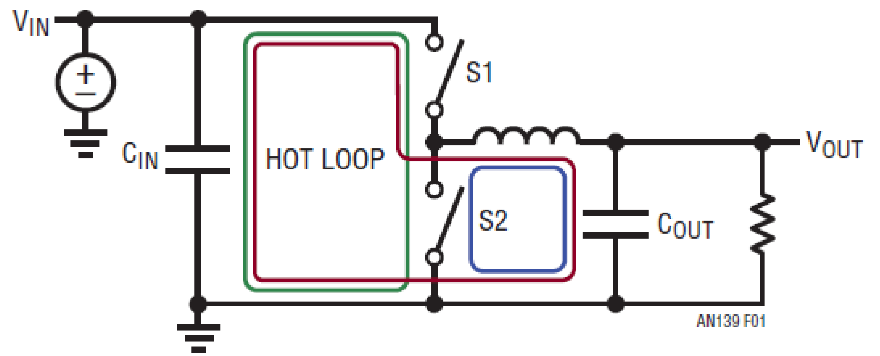
Hot Loop as Topology



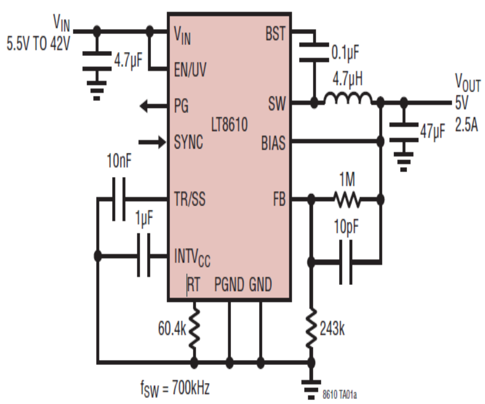
Inverting Regulator

How to reduce EMI Noise?

EMI – need to reduce Hot Loop



EMI Performance



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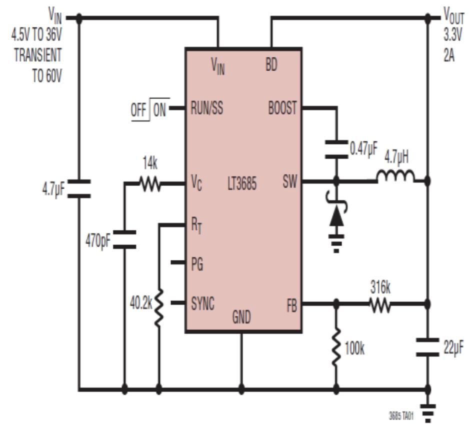

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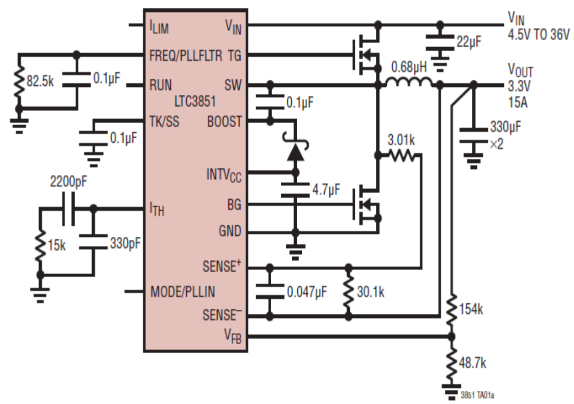
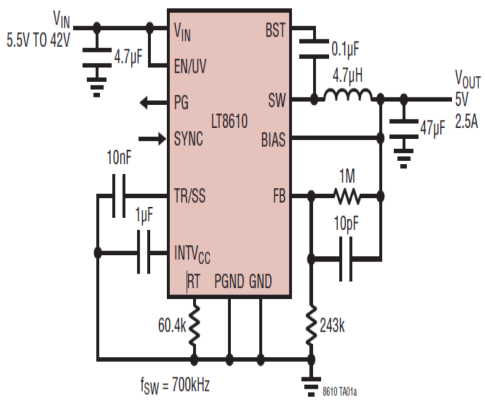


Synchronous Monolithic

Non-Synchronous Monolithic

Controller

Hot loop size = EMI Performance



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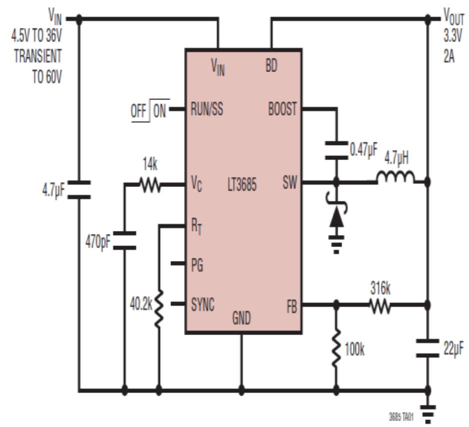

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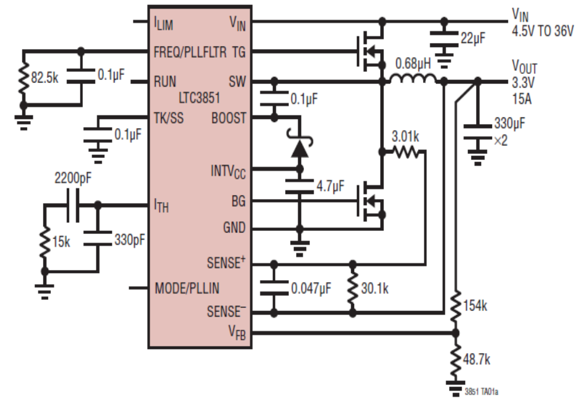
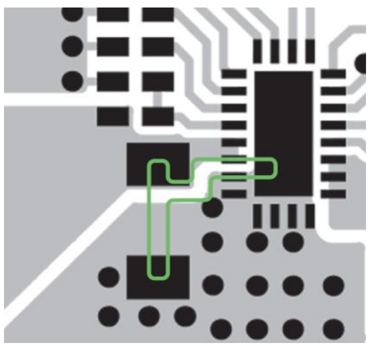
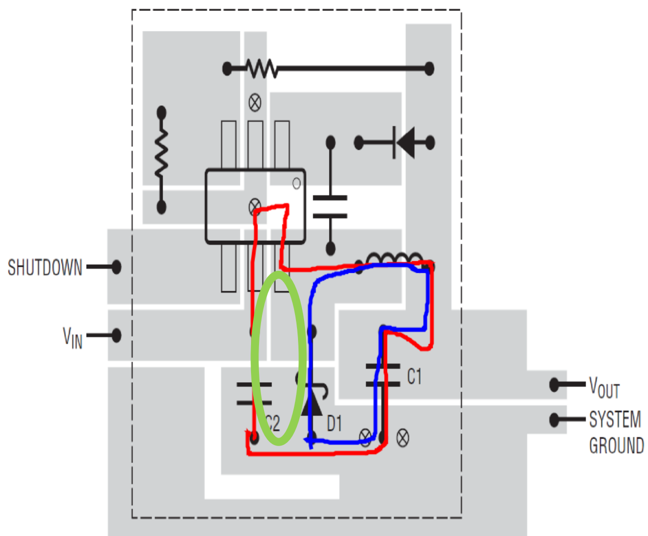
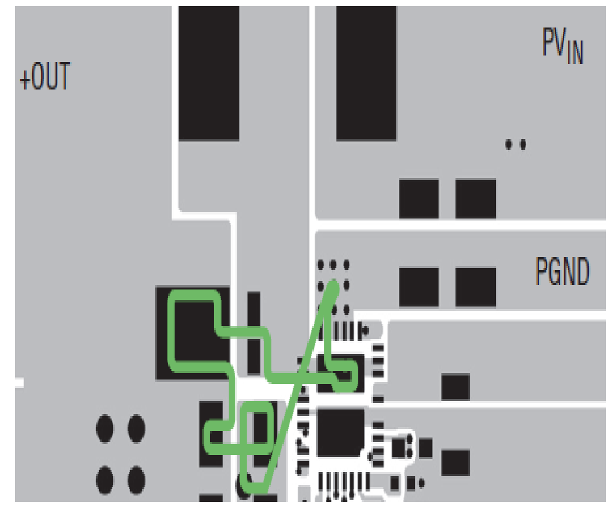








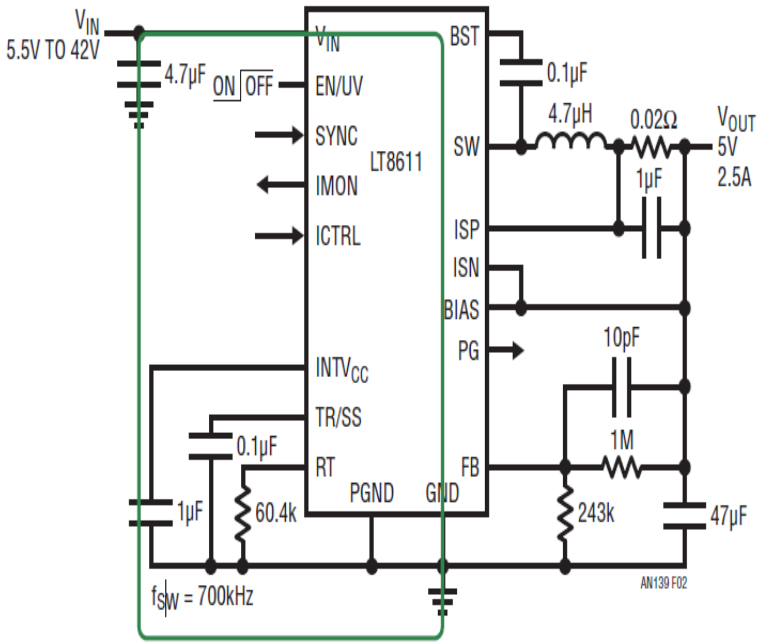
Synchronous Monolithic

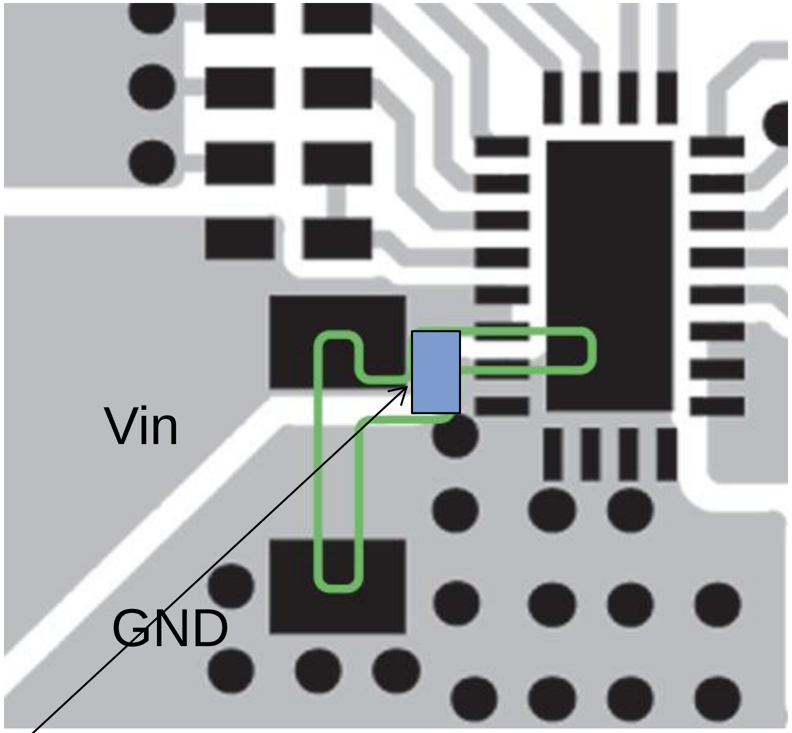
Non-Synchronous Monolithic

Controller

Layout Guide

Layout guide - Input capacitor

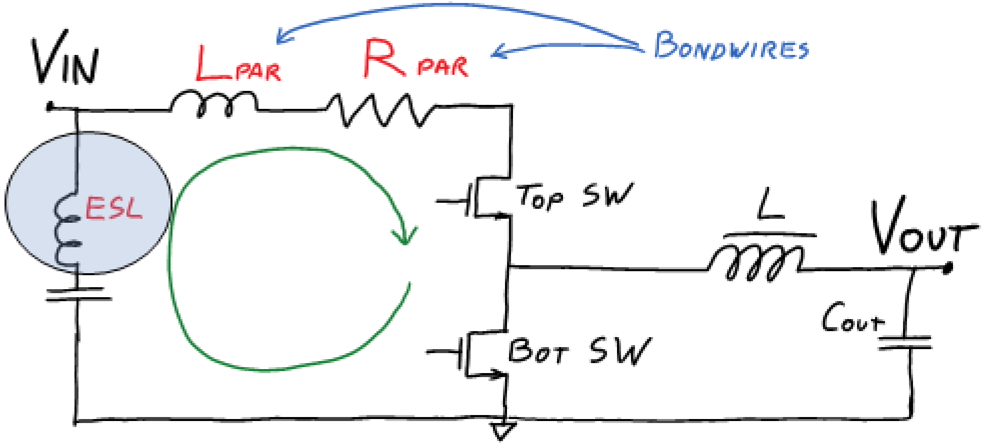


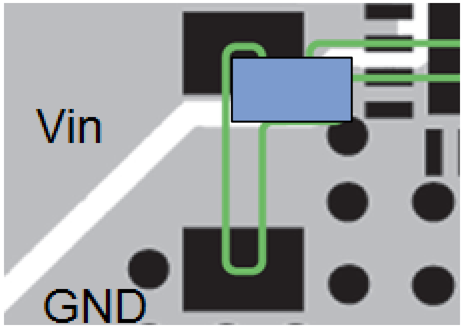


작은 입력 cap 배치 시 hot loop 더 줄일 수 있음.
0.1uF 정도 배치하면 좋음.

Layout guide - Input capacitor

$$V = L * di/dt$$





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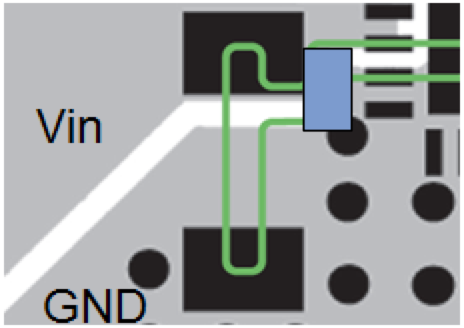
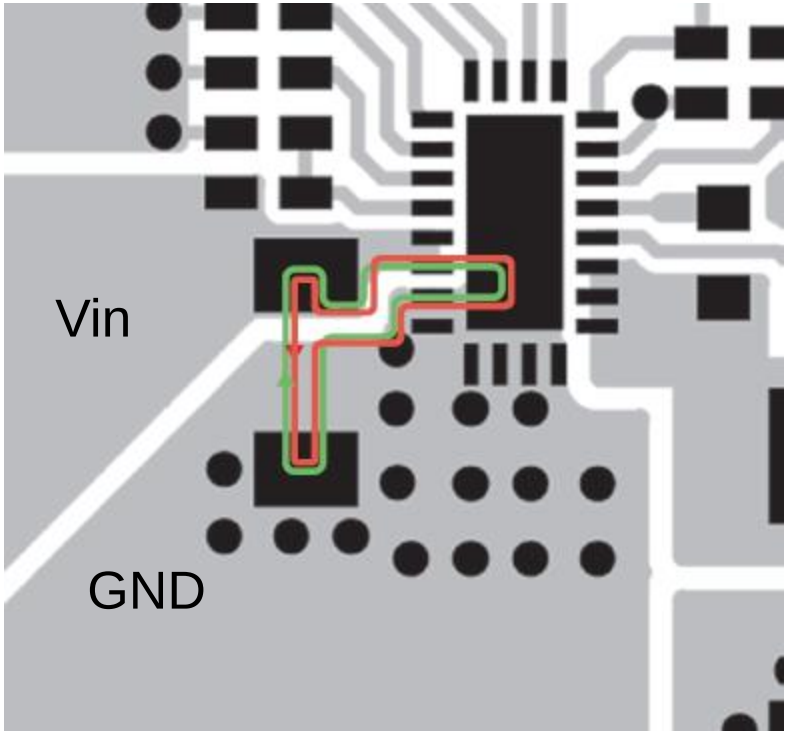
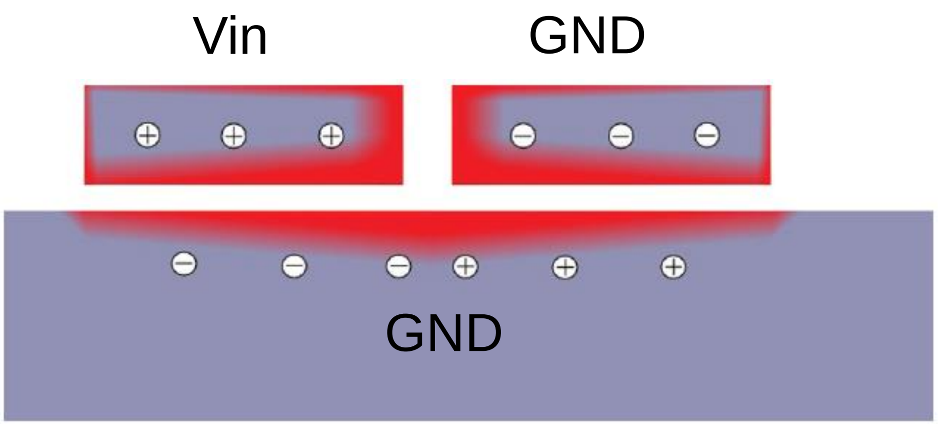


ESL 이 작은 Cap 이 더 좋음 : Capacitor 가로 면적이 넓으면 ESL이 낮음

Layout guide - GND copper

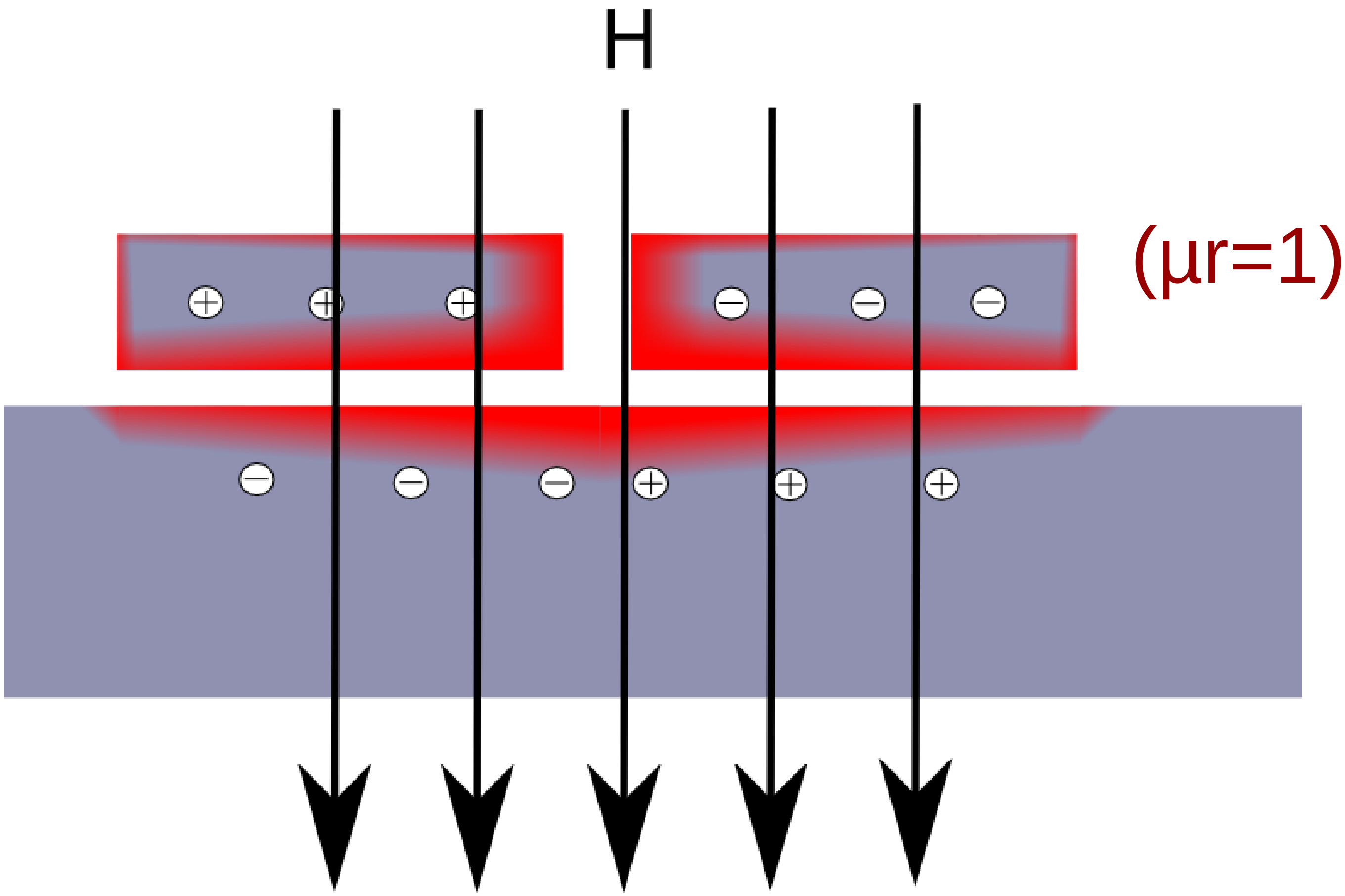




PCB 단면적 전류밀도

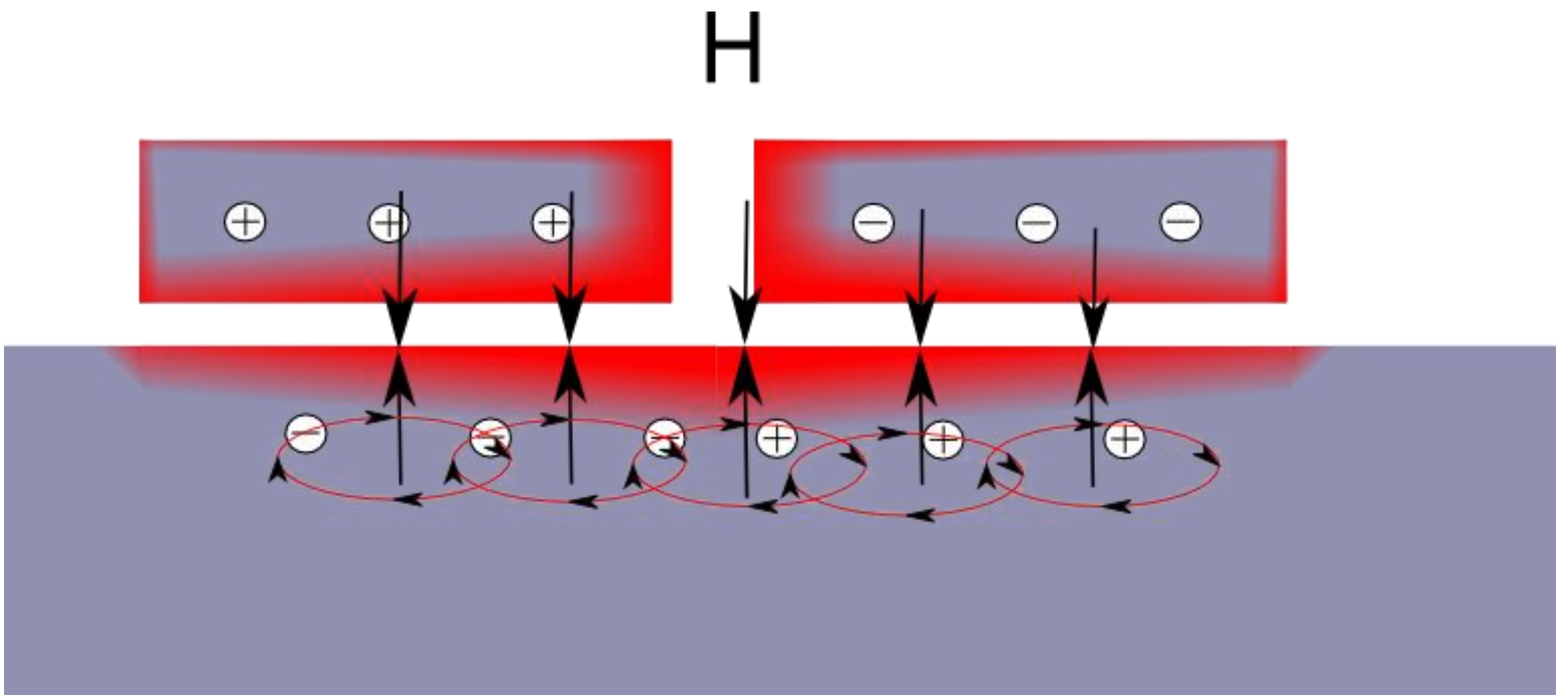
Green : Top 면 흐르는 전류(시계방향)
Red : 2nd layer GND plane 에 흐르는 전류(반 시계방향)

Layout guide - GND copper



만약 밑에 GND copper가 없다면 큰 자기장 성분이 board 안으로 들어감.

Layout guide - GND copper



도체인 GND copper 가 유도된 자기장에 의해 수직인 전류 생성, GND copper의 전류는 Top 면과 반대로 흐르는 전류.
이 Eddy current가 전체 자기장의 크기를 낮춤.

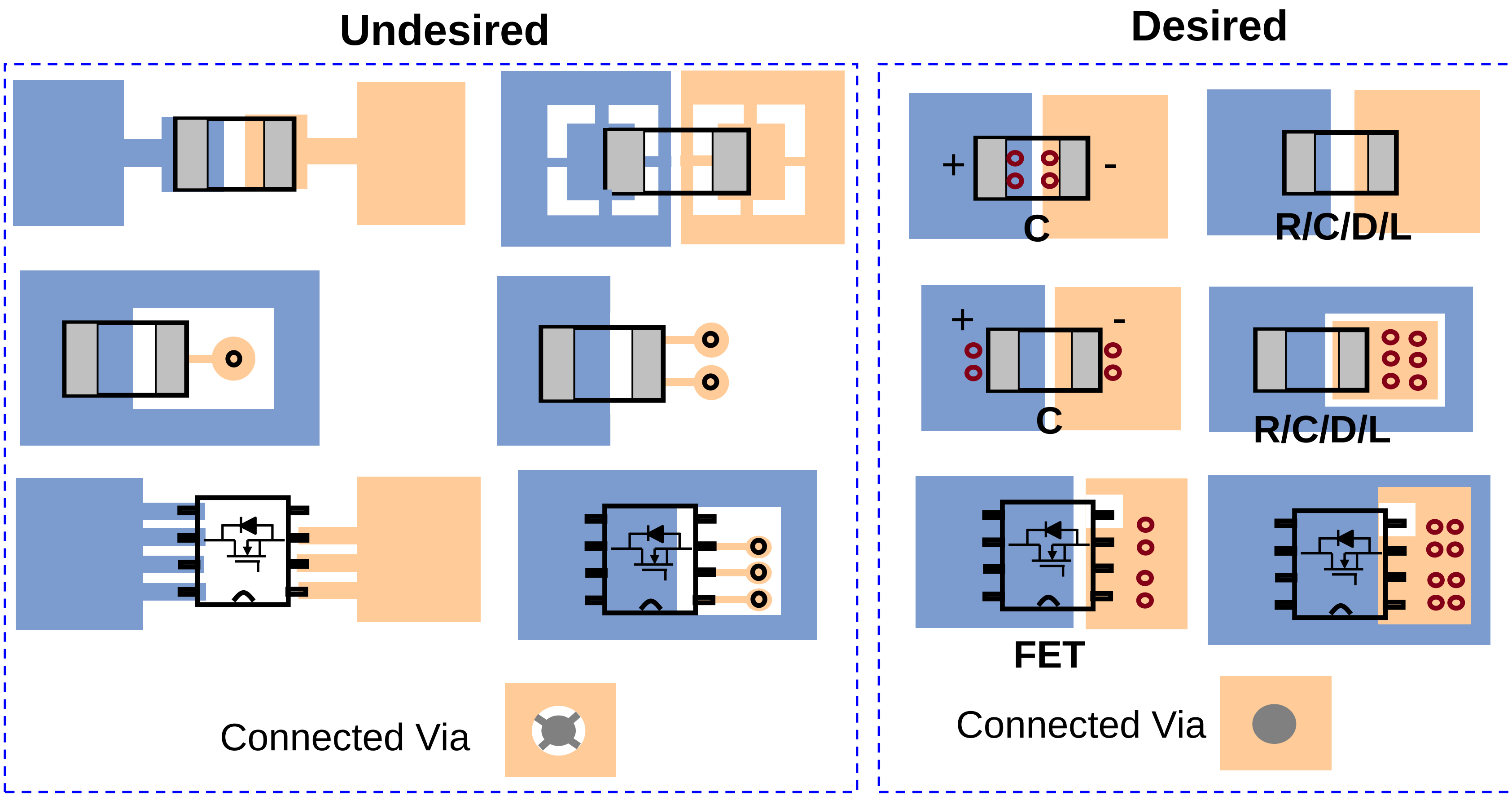
Inner GND copper layer

Table 1

d (mm)	f (MHz)	C (pF)	L (nH)		FACTOR OVER 0.12mm
	18, 4	400	187	Single-Layer Open Loop	14, 4
	21, 2	400	141	Inner Copper Short-Circuit Loop	10, 85
1, 5	38, 9	400	42	Solid Plate	3, 23
1, 5	34, 7	400	53	Rectangular Loop No Overlap	4, 08
0, 5	52, 1	400	23	Thin Rectangular	1, 77
0, 27	55	400	21		1, 61
0, 12	69	400	13	Paper	

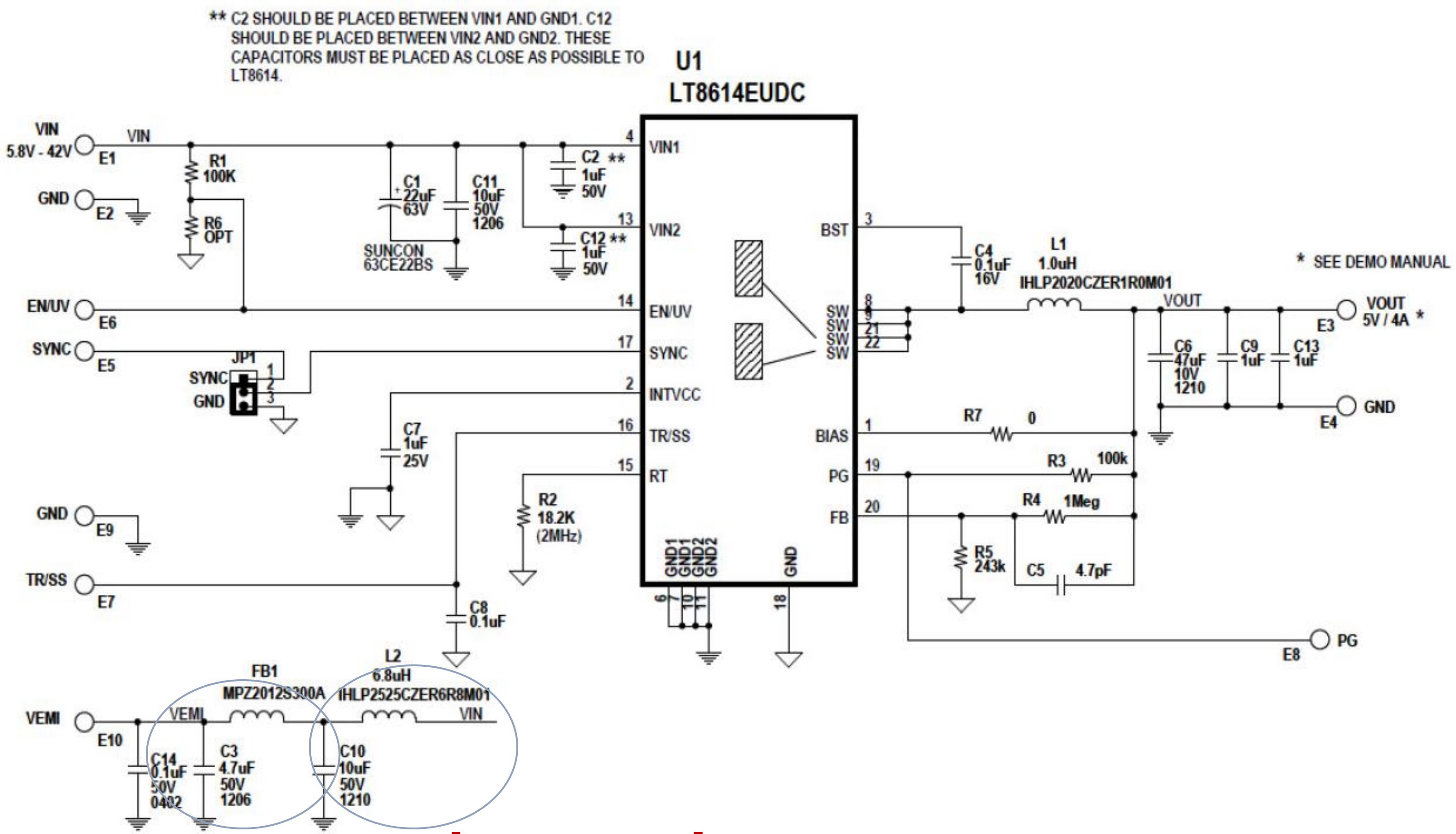
A solid plane on the next layer in a multilayer board (four layers or more) will have over 3× less inductance than a normal 1.5mm 2-layer board with a solid bottom plane, and over 14× less over a single-layer board. A solid plane with minimum distance to the hot loop is one of the most effective ways to reduce EMI.

Layout guide - Land Pattern



- **Use wide / short copper trace for power components**
- **Use multiple vias for inter-layer connections**
- **Avoid improper use of “thermal relief”**
- **Minimize resistance and inductance**

Input EMI filter



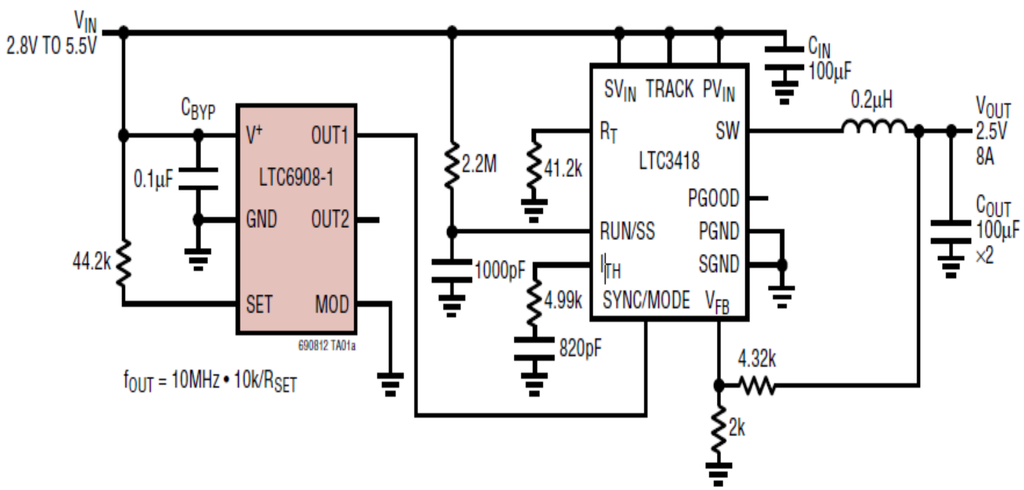
Inductor + large cap = Low Frequency filter

Bead + small cap = High frequency filter

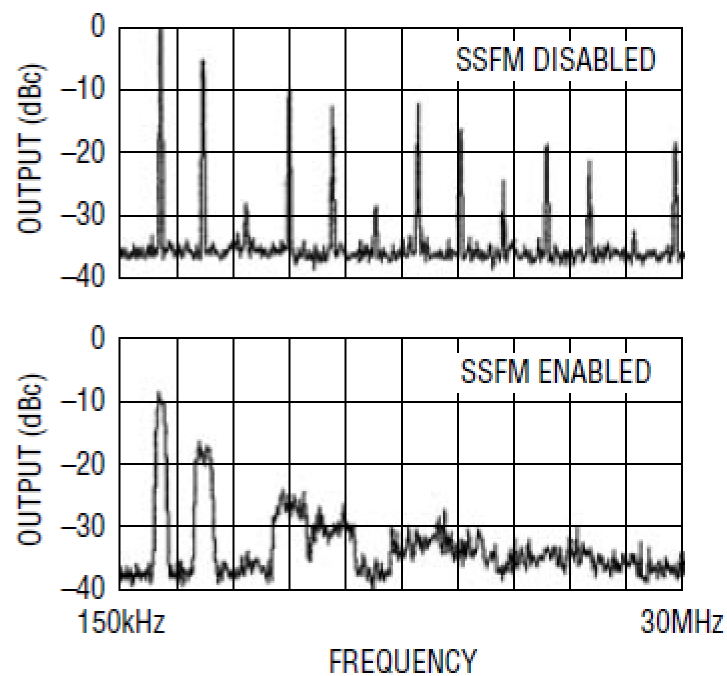
LTC EMI Solution

Spread Spectrum Oscillator

2.25MHz, 2.5V/8A Step-Down Regulator

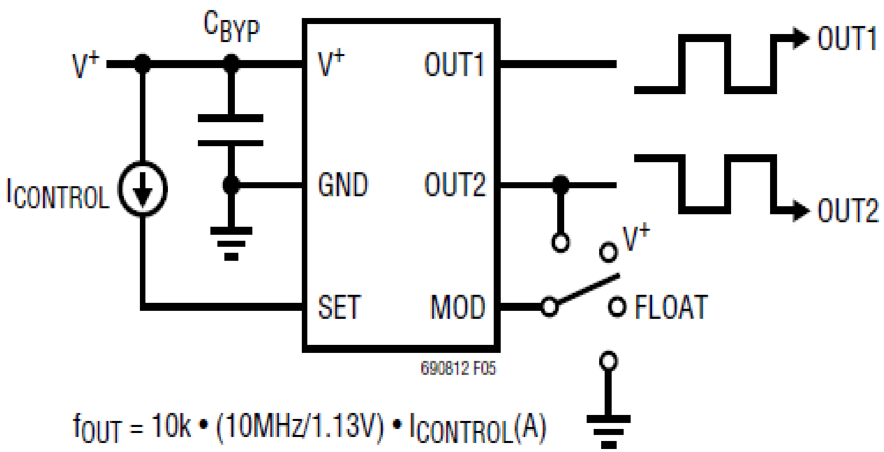


150kHz to 30MHz Output Frequency Spectrum (9kHz Res BW)

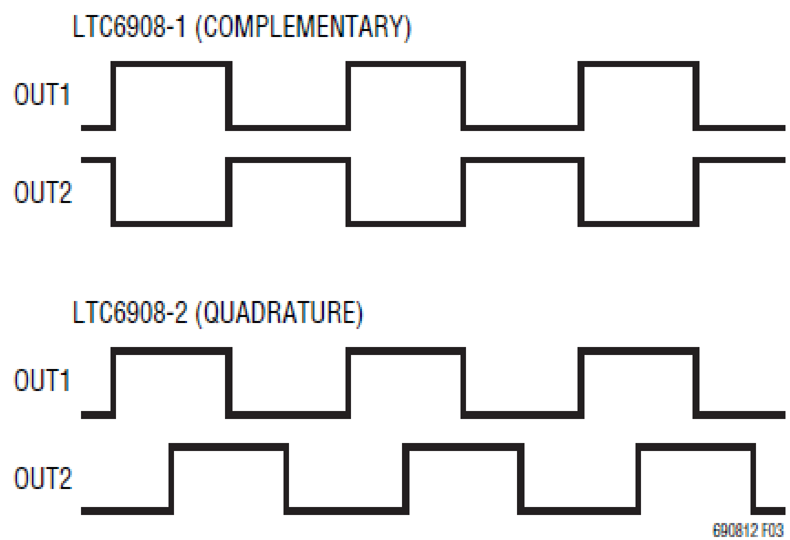


주파수 가변 및 Spread Spectrum function 으로 10dB 이상 Margin

Spread Spectrum Oscillator



$f_{OUT} = 10k \cdot (10MHz/1.13V) \cdot I_{CONTROL}(A)$



igure 3. Output Waveforms for LTC6908-1, LTC6908-2

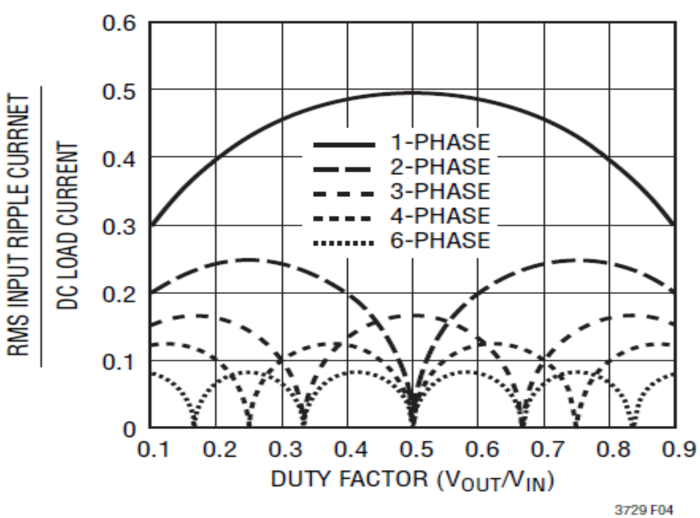
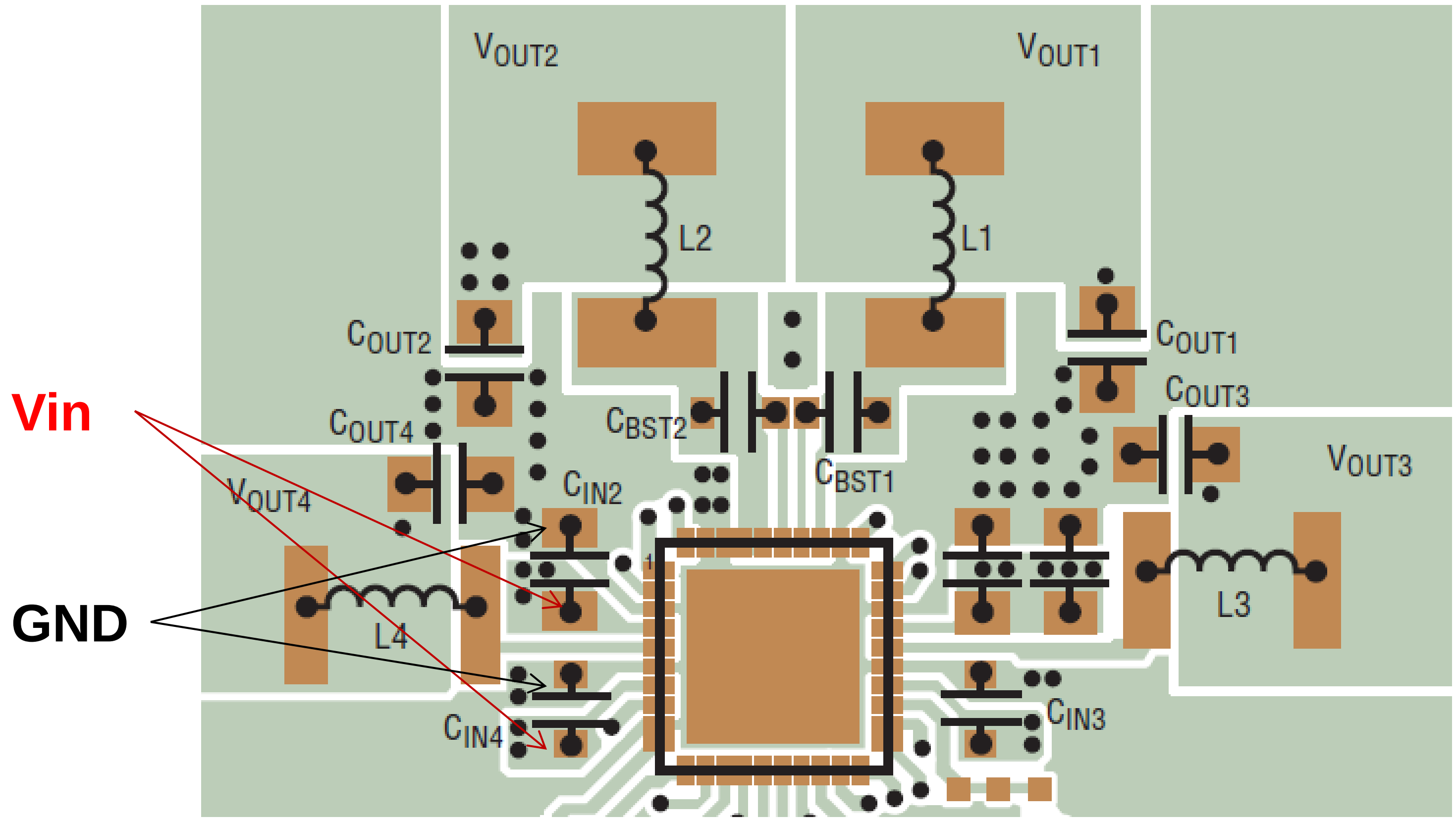


Figure 4. Normalized Input RMS Ripple Current vs Duty Factor for 1 to 6 Output Stages

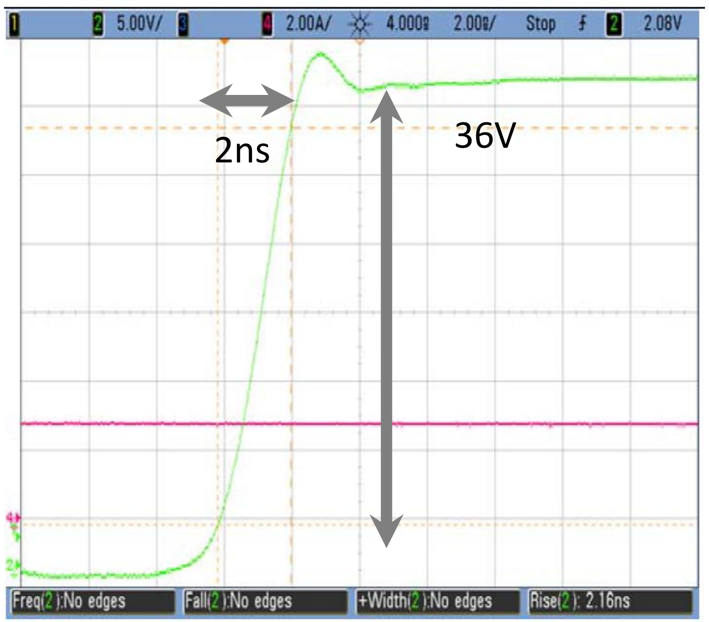
di/dt 감소!!

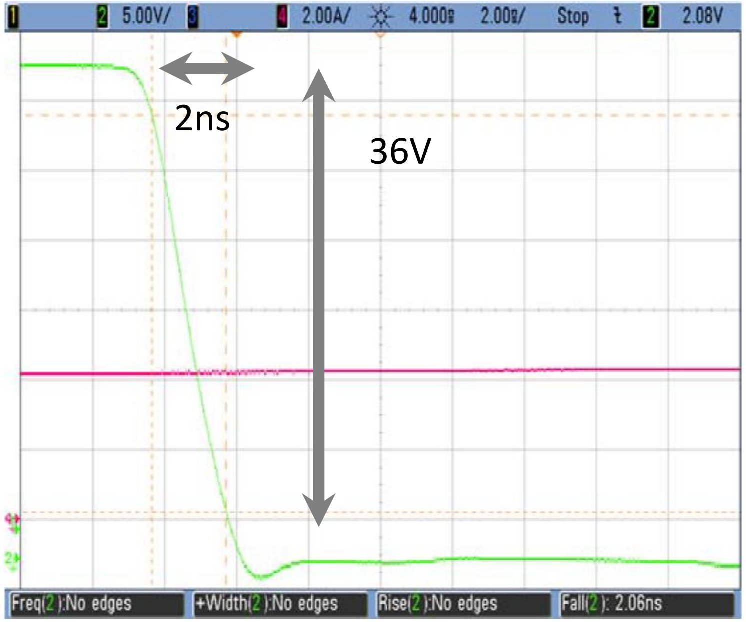
LTC Pinout Advantage

EMI and layout friendly pinouts enable perfect low RFI solutions



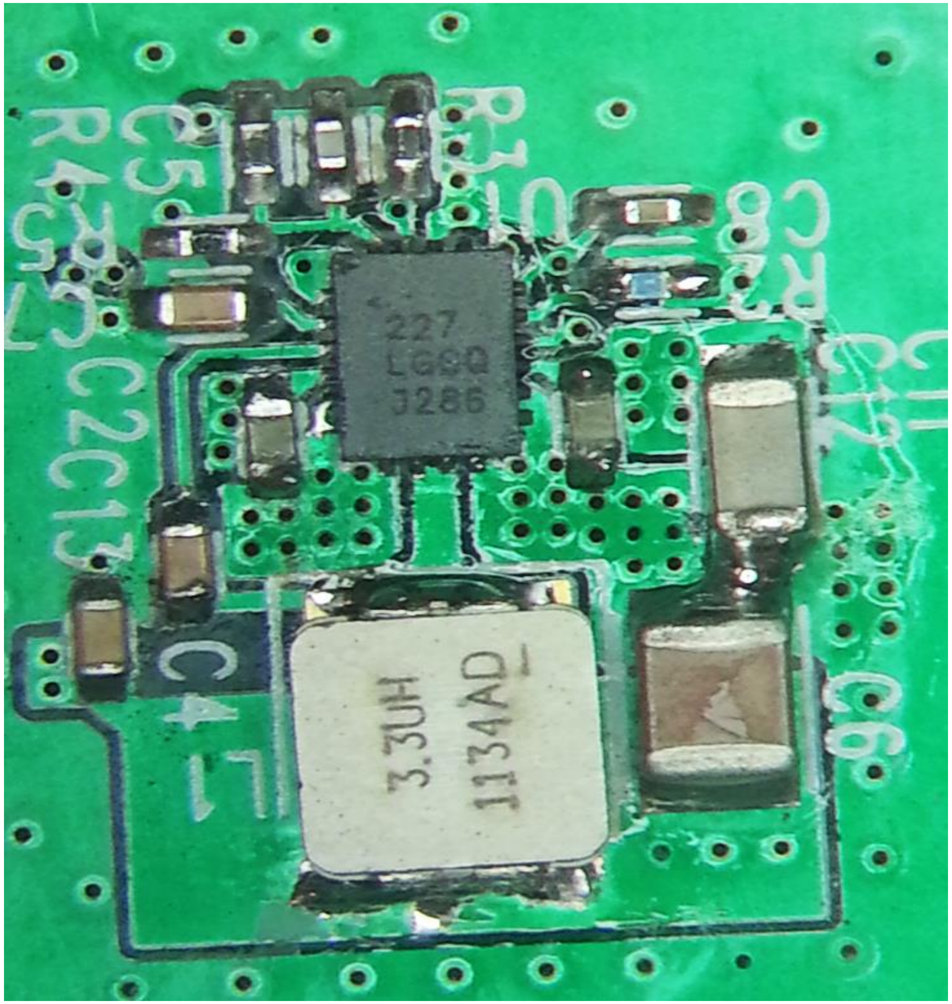
Automotive Low EMI IC's – LTC Design Advantage





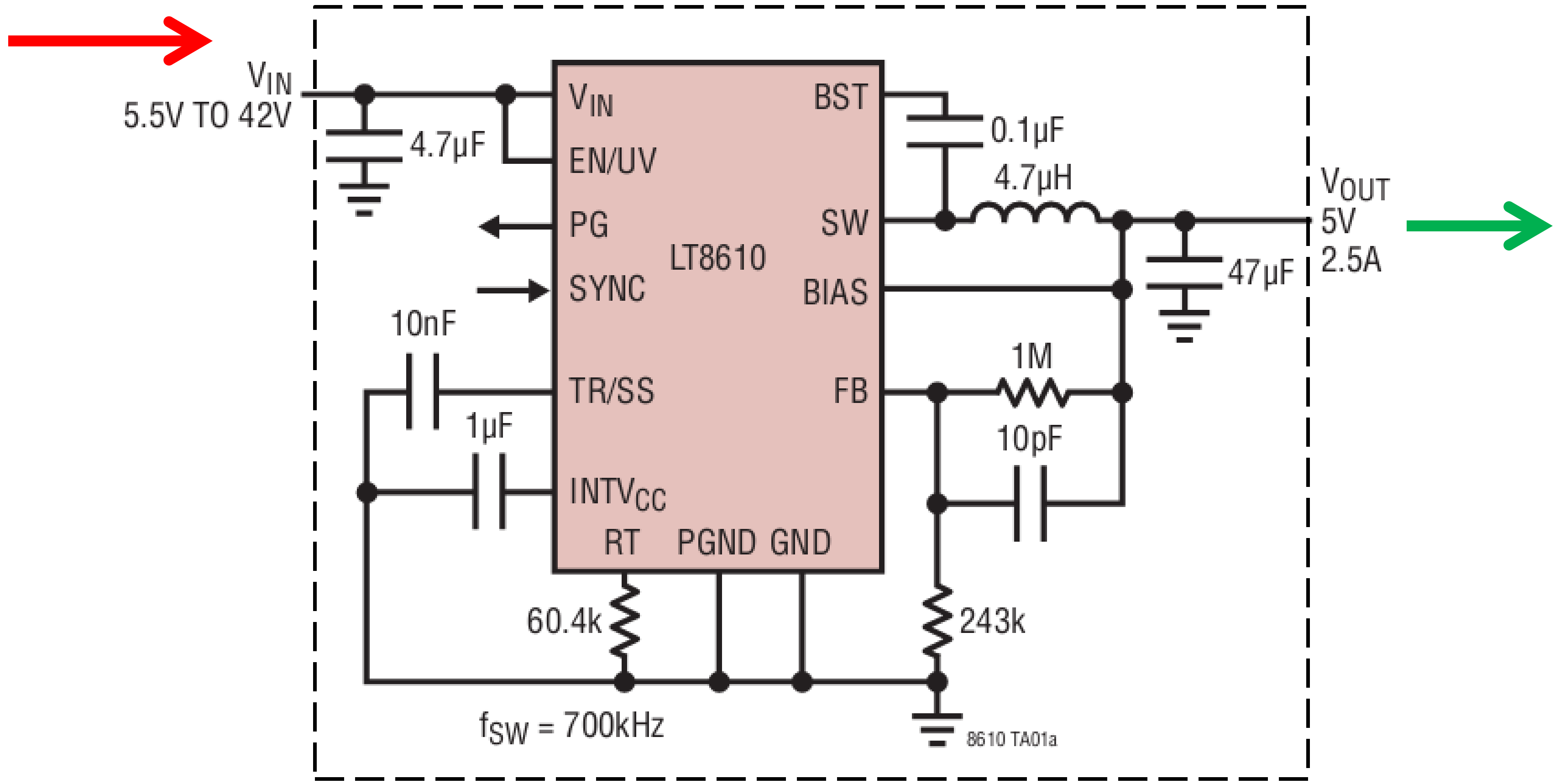
LT8614 – Silent Switcher™

- 42V, 4A Sync buck
- Low EMI
- Max Output = 4A
- Ultra-Fast $T_{ON(MIN)}$=25ns
- 88/40mΩ $R_{DS(ON)}$ Switches
- 18-Lead QFN 3x4

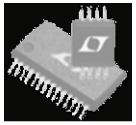


LT8614 – Silent Switcher

LT8610: A Synchronous Buck Regulator



LT8614 – Silent Switcher



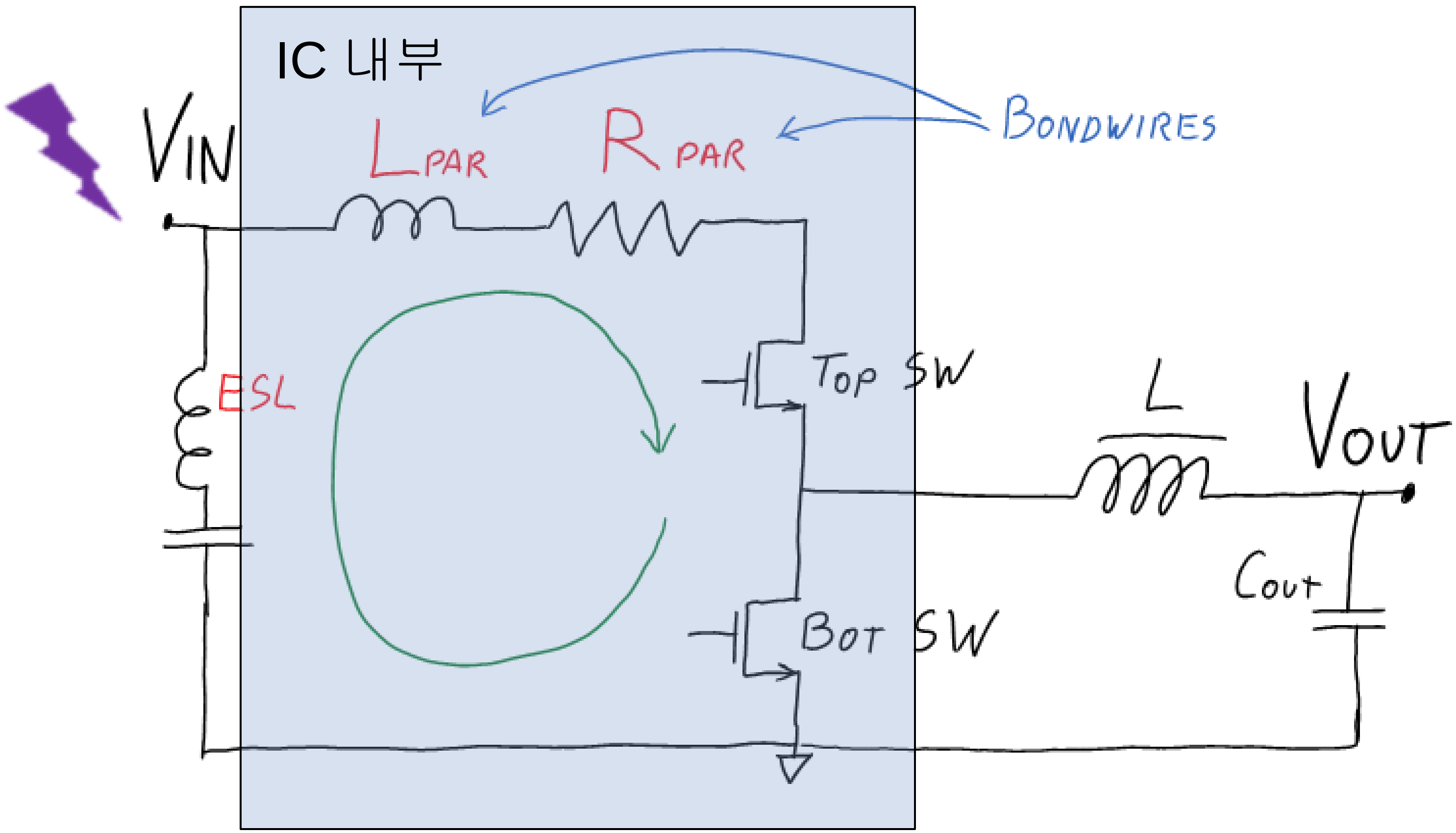
Customer Needs vs. LT8610

1. Lower EMI with simple PCB
2. Higher efficiency (at >2MHz)
3. Smaller Footprint
4. ????

Fundamental Limitations

1. C_{VIN} parasitic L
2. Bond-wire parasitic L+R

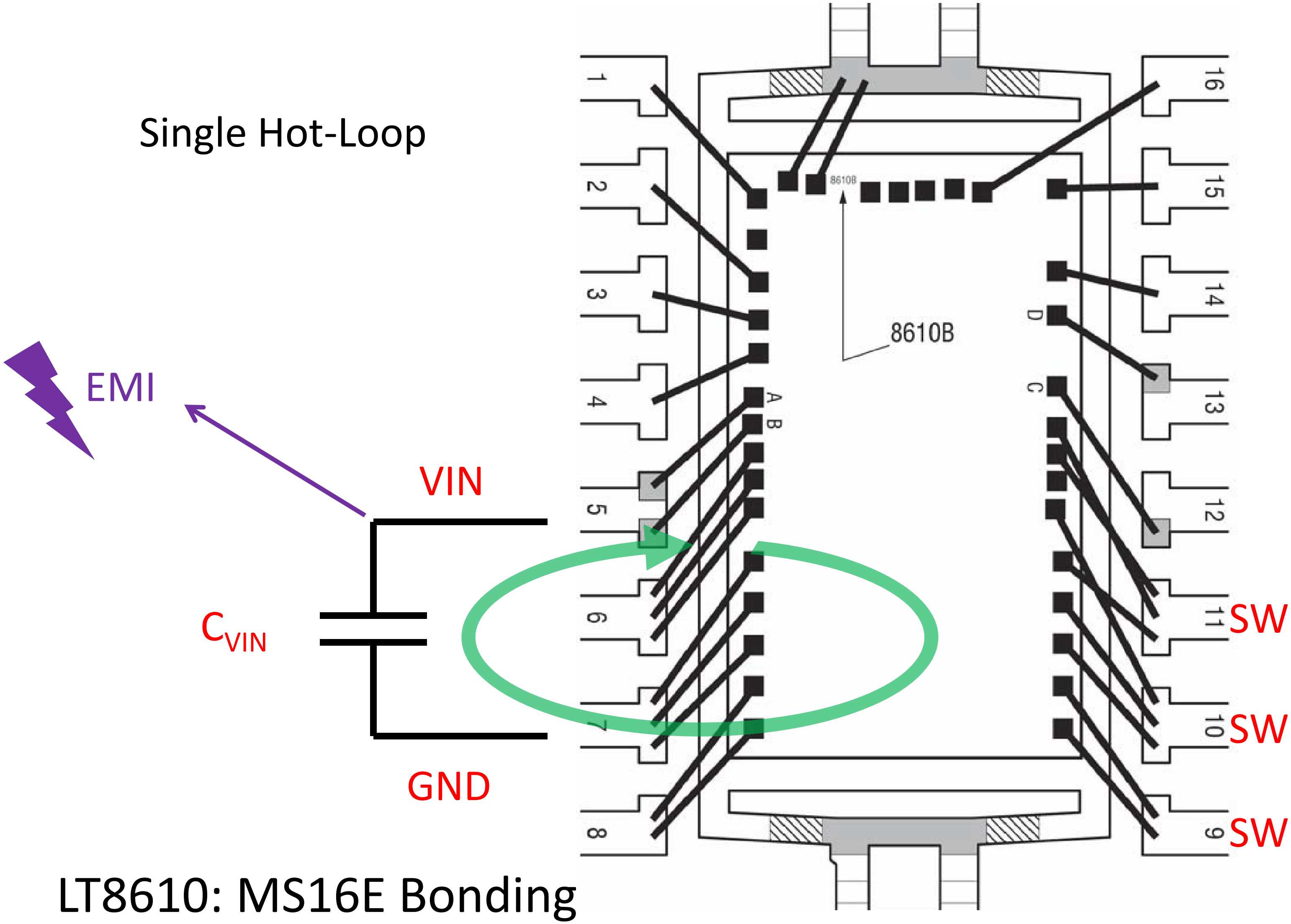
LT8614 – Silent Switcher



Synchronous Buck : Parasitic L+R

LT8614 – Silent Switcher

Single Hot-Loop

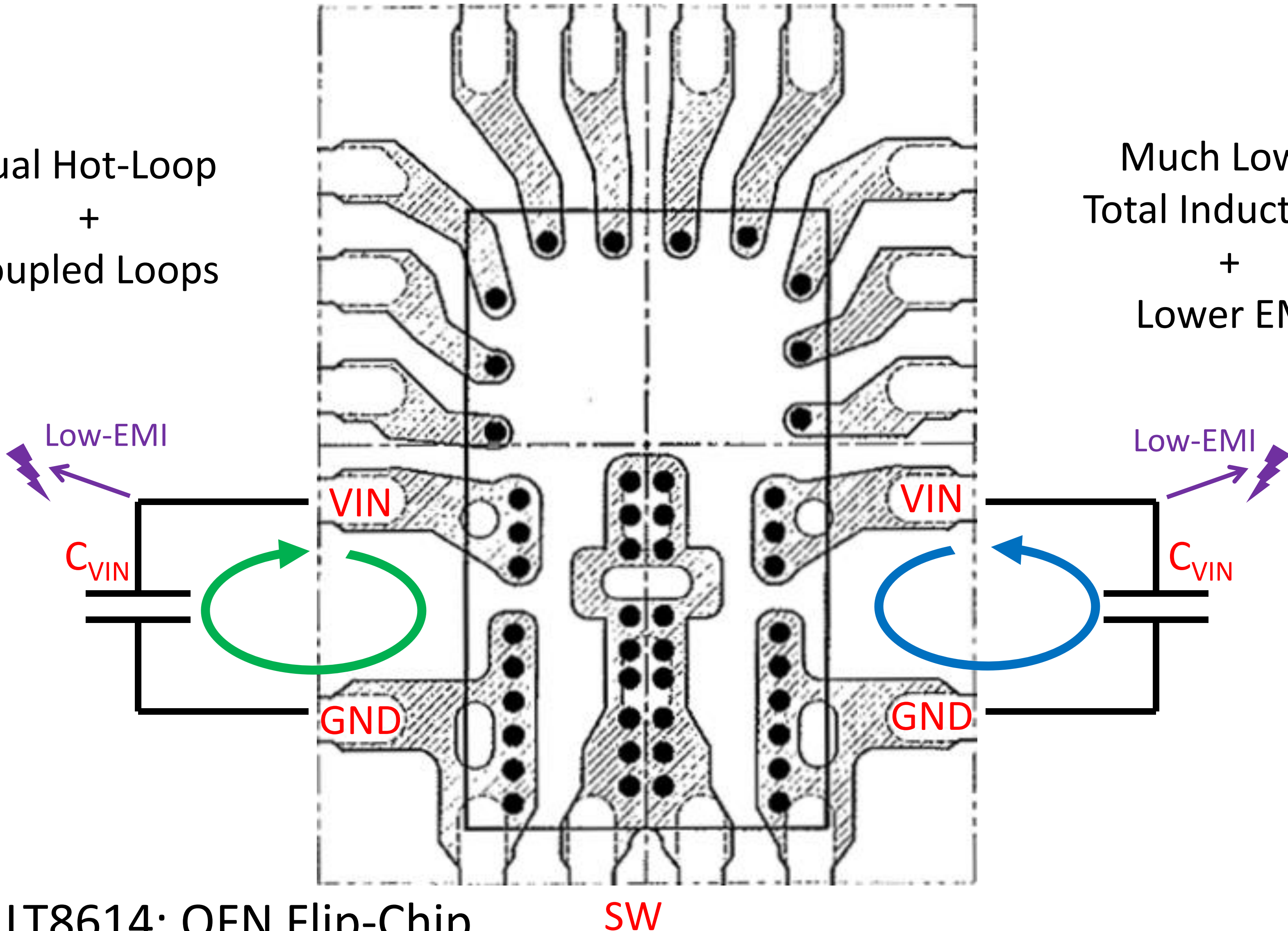


LT8610: MS16E Bonding

LT8614 – Silent Switcher

Dual Hot-Loop
+
Coupled Loops

Much Lower
Total Inductance
+
Lower EMI

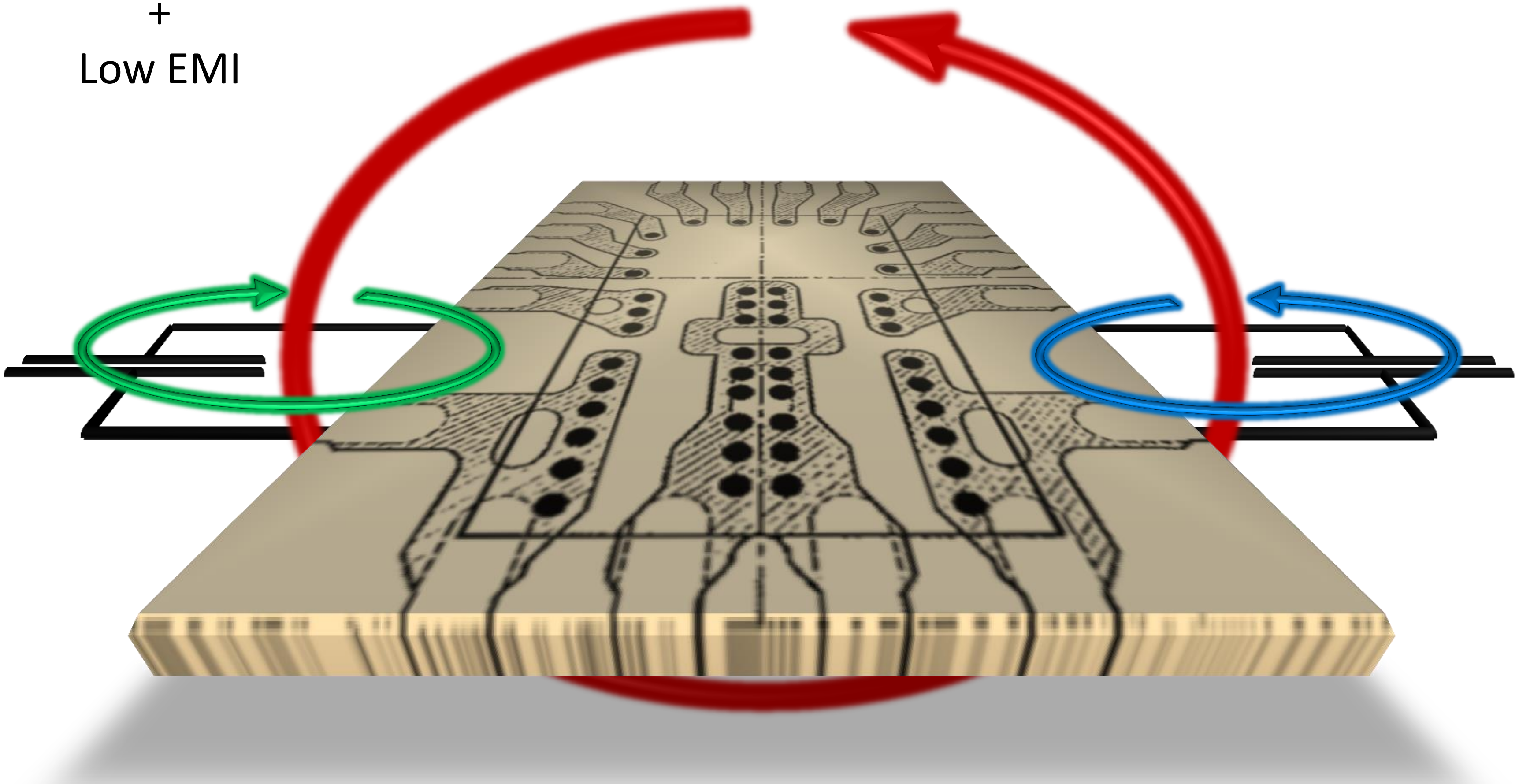


LT8614: QFN Flip-Chip

LT8614 – Silent Switcher

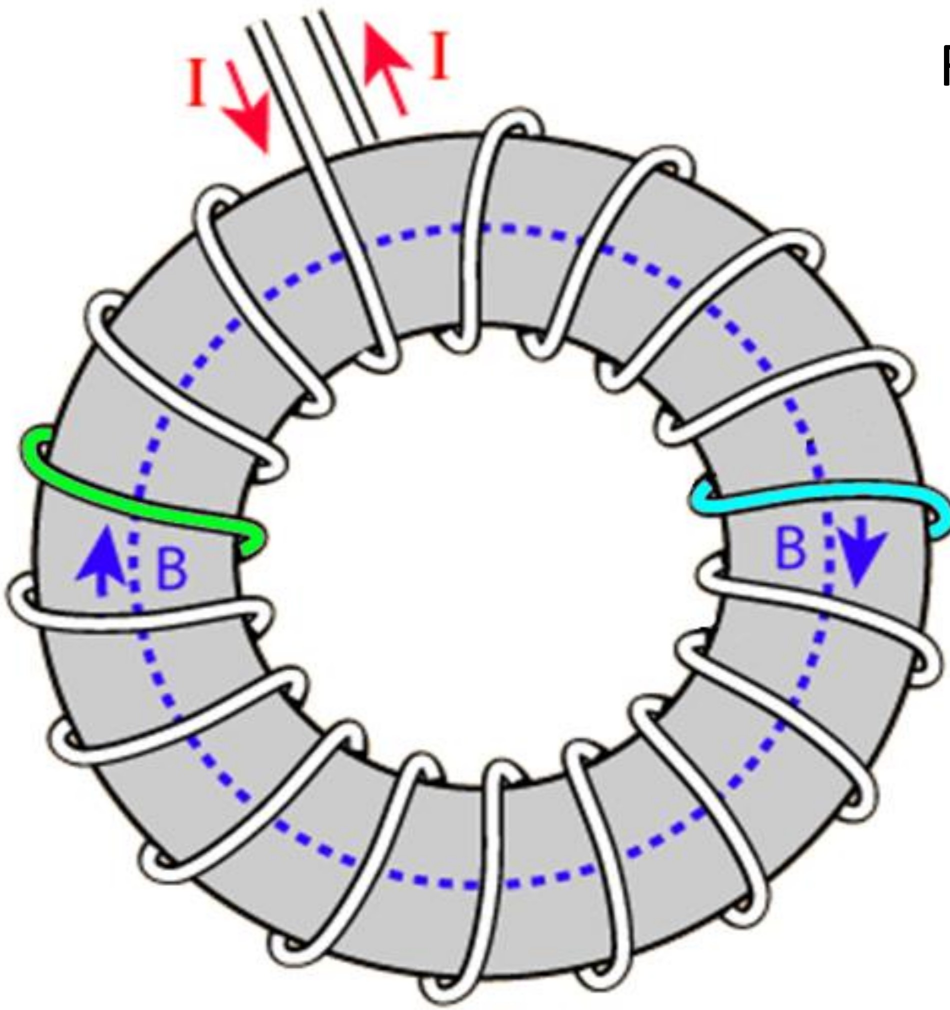
Coupled Hot Loops

Confined
Magnetic Field
+
Low EMI

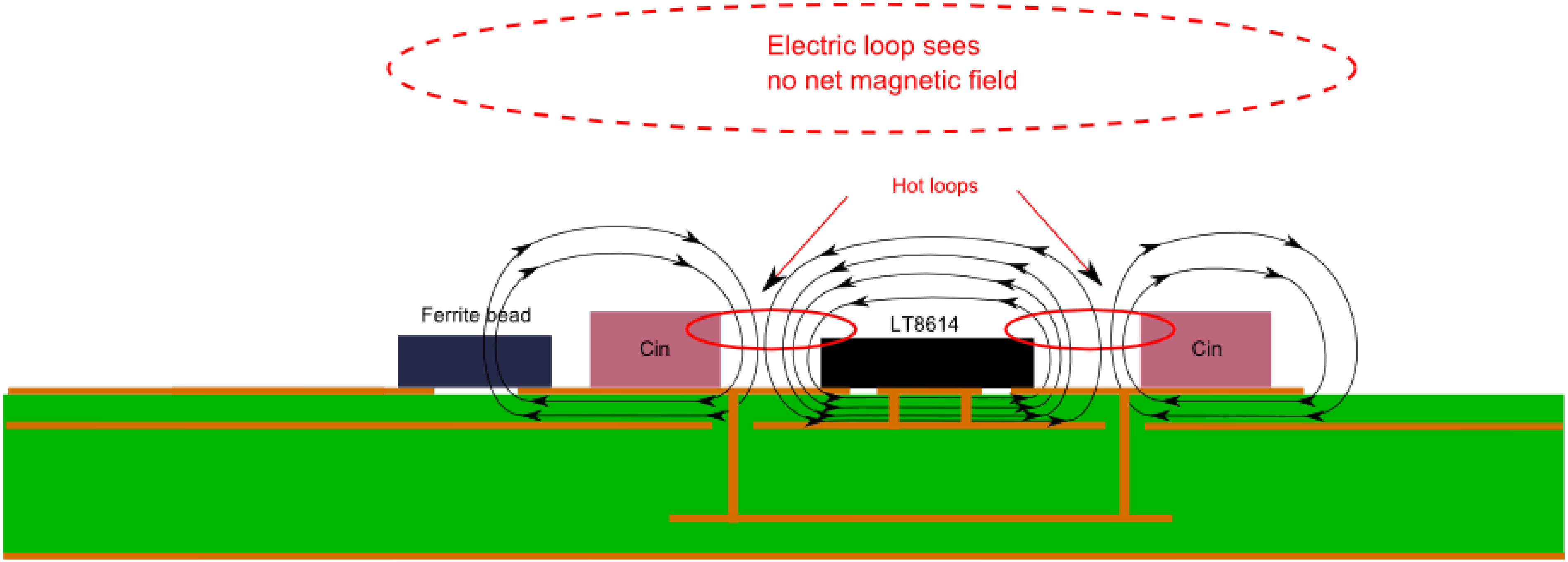


LT8614 – Silent Switcher

Field in a Toroid

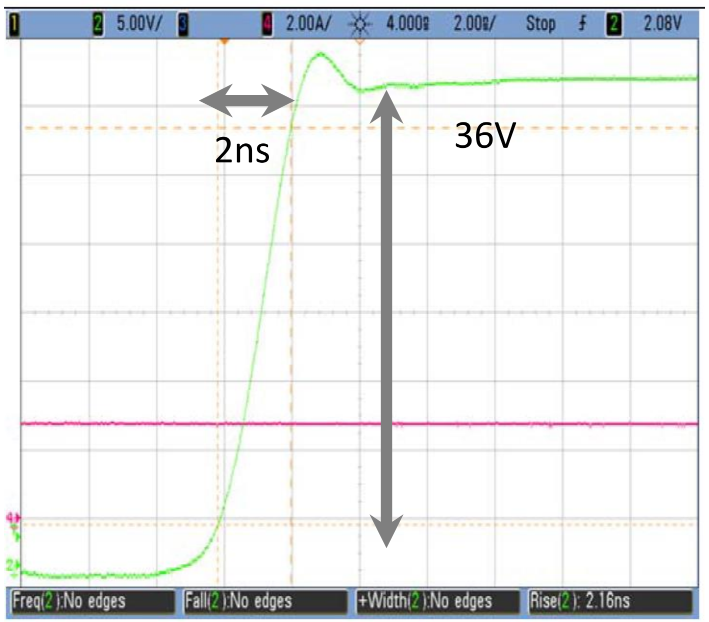


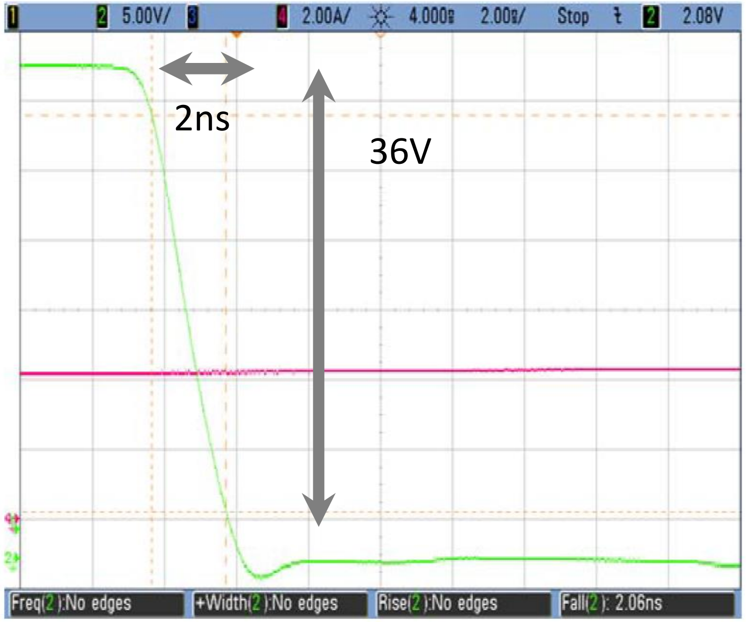
LT8614 – Silent Switcher



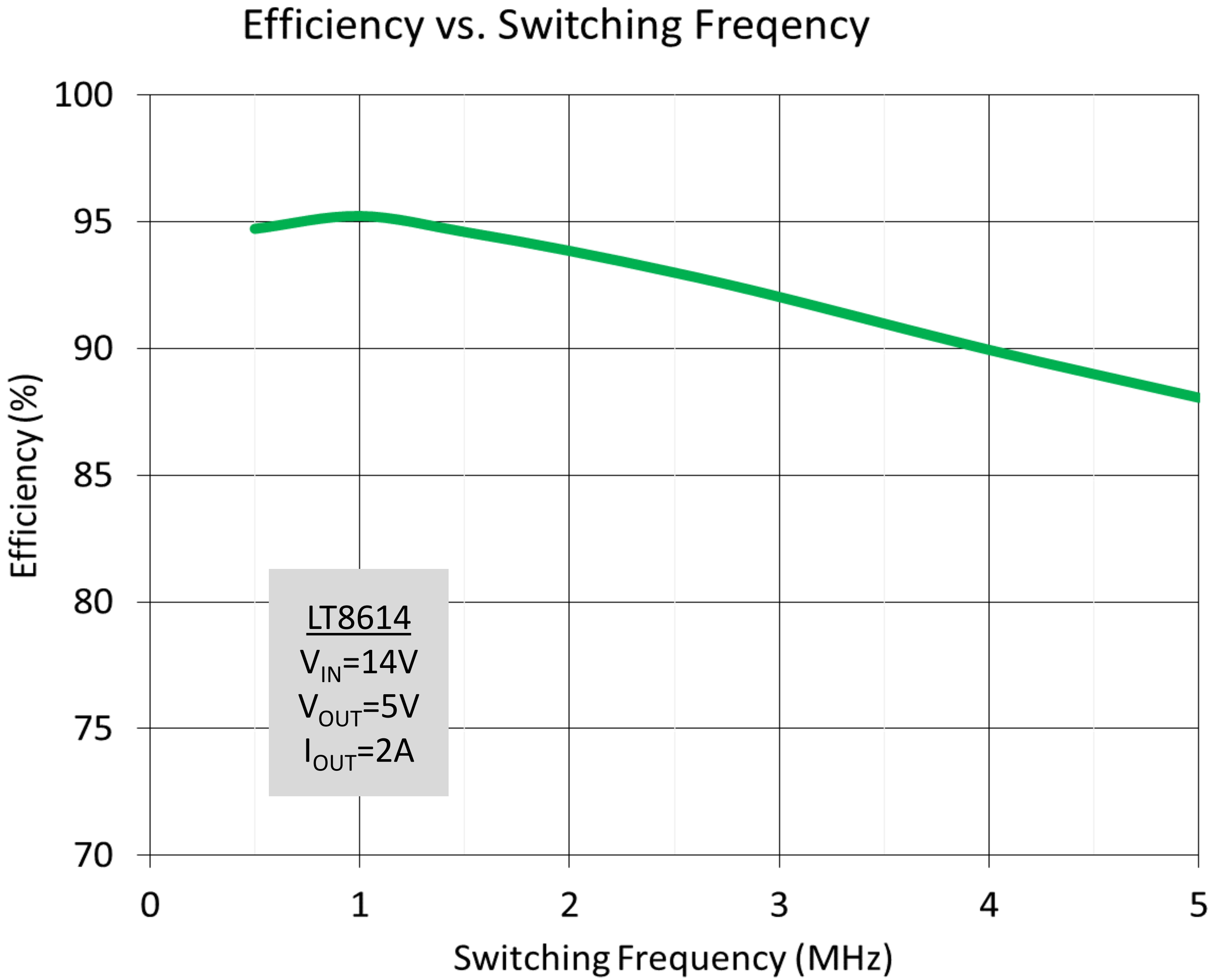
How does it work

LT8614 – Silent Switcher

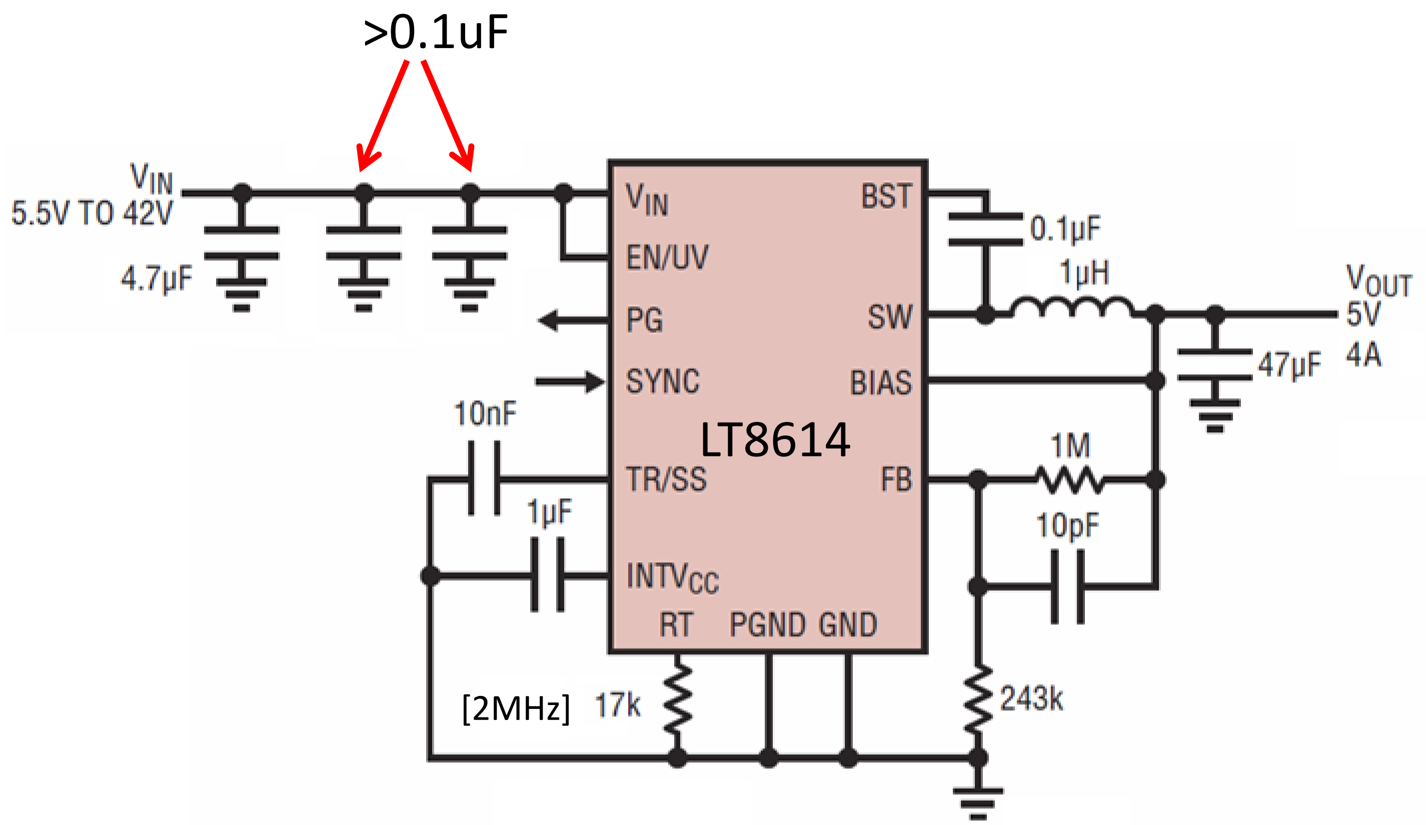




LT8614 – Silent Switcher

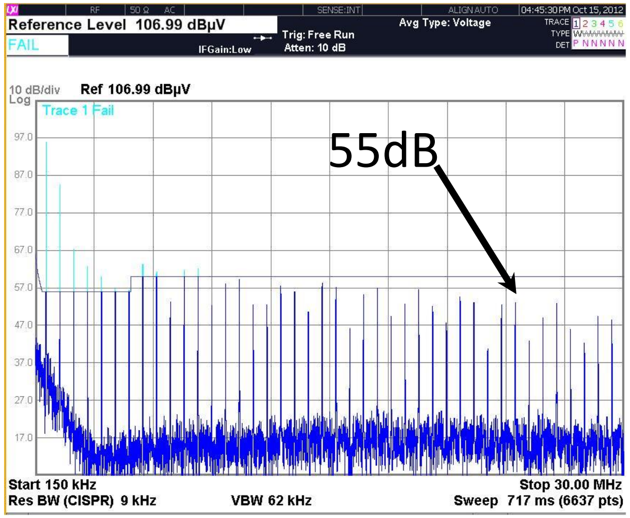


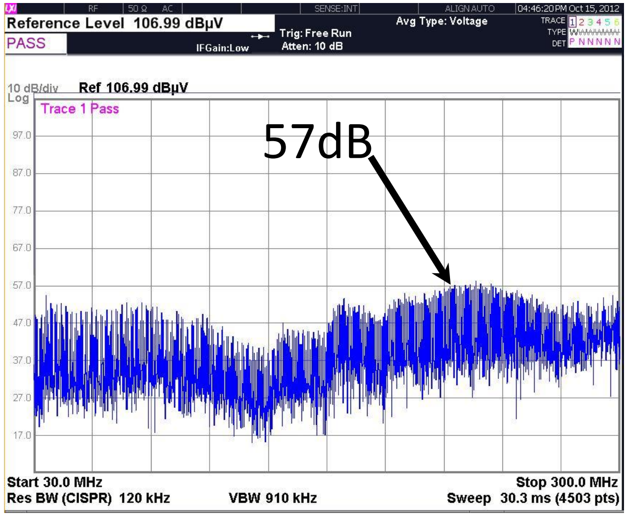
LT8614 – Silent Switcher



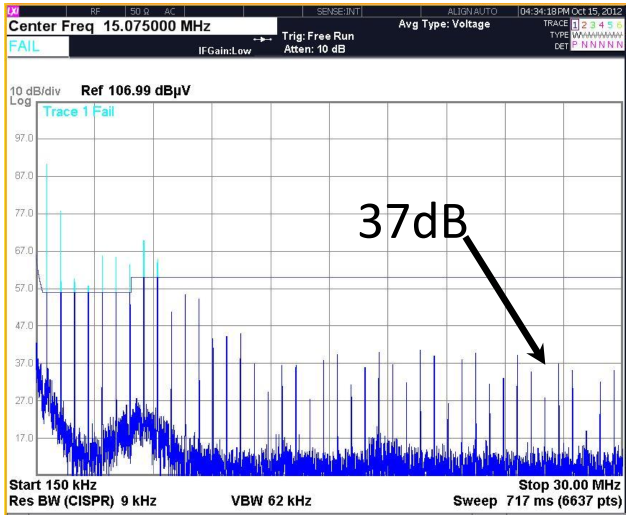
LT8614 Typical App

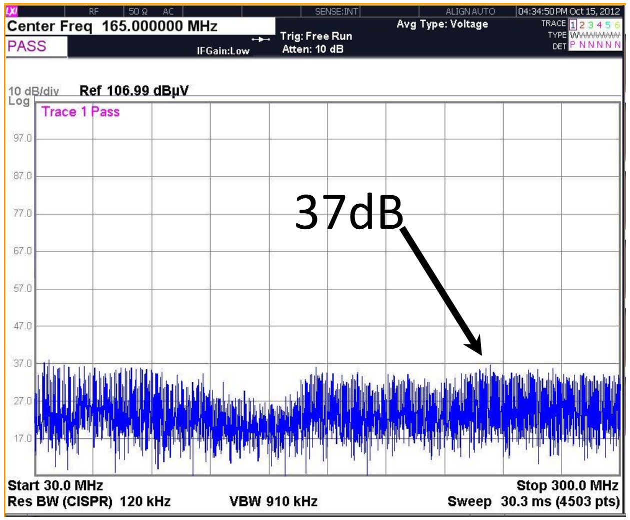
LT8614 EMI Performance





LT8610: 12V to 3.3V, 2A





LT8614: 12V to 3.3V, 2A

감사합니다.