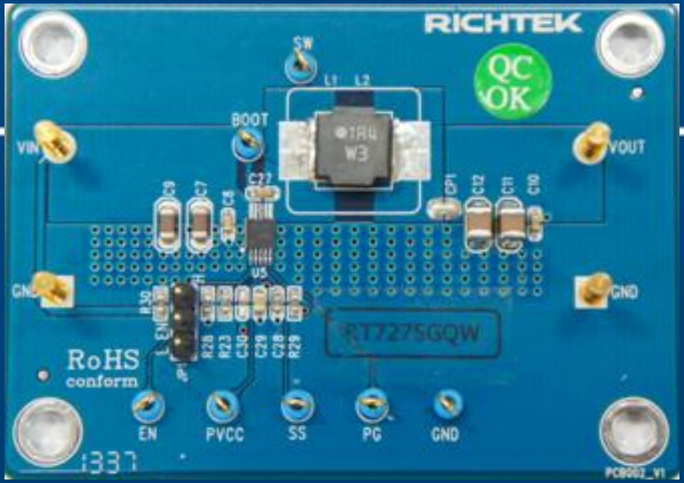
Richtek Advanced Constant On Time Buck converters:

Richtek ACOT™ RT7275GQW EVM kit



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FAE Richtek Europe
August 2014

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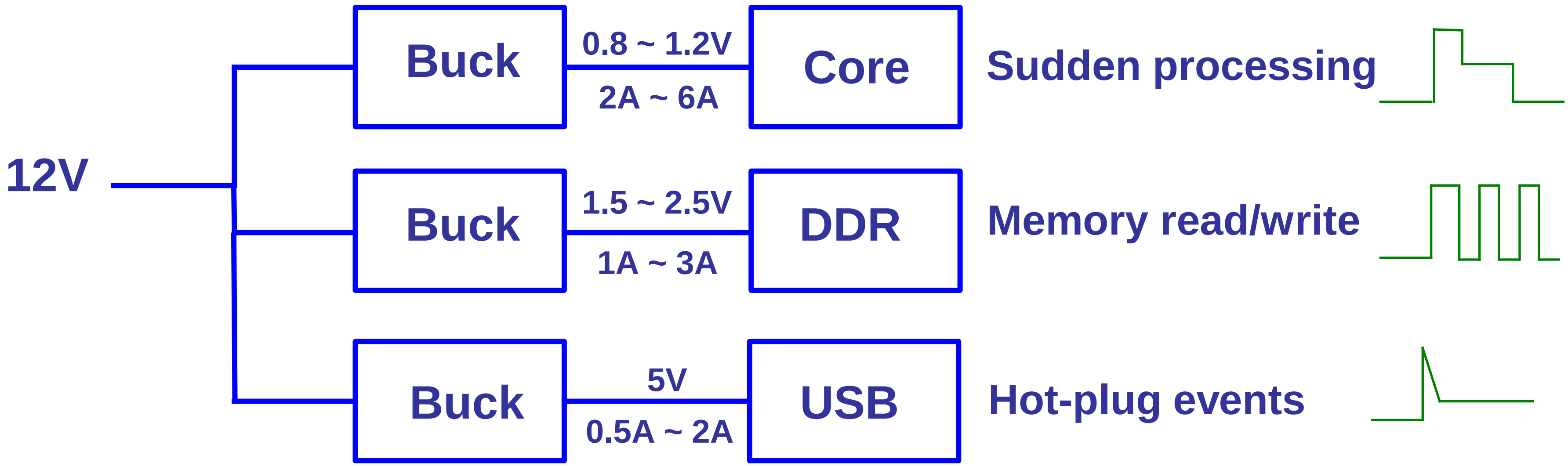
Content

- Challenges with high load transient applications
- Current Mode buck converter versus ACOT
- ACOT design considerations
- RT7275GQW EVM kit parameters
- ACOT Frequently Asked Questions (FAQ)
- ACOT design tools & application notes

Challenges in powering High Transient Loads

FPGA, DSP and SoC applications can exhibit fast changing loads:

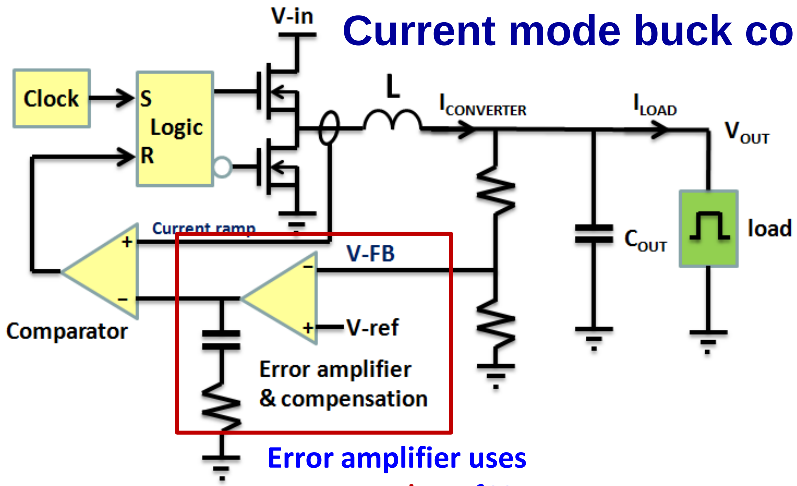
Dynamic load condition:



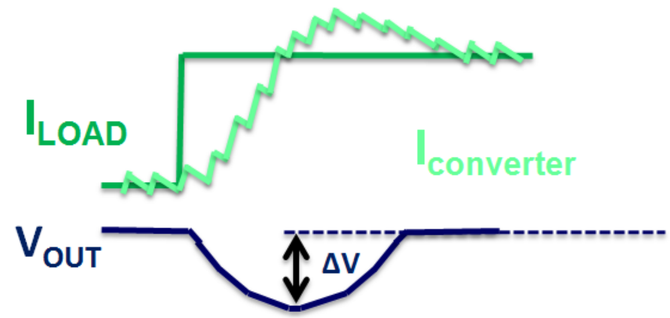
→Output Voltage Sag under transient load should not affect normal operation

Current mode vs. ACOT buck converter reaction speed

Current mode buck converter



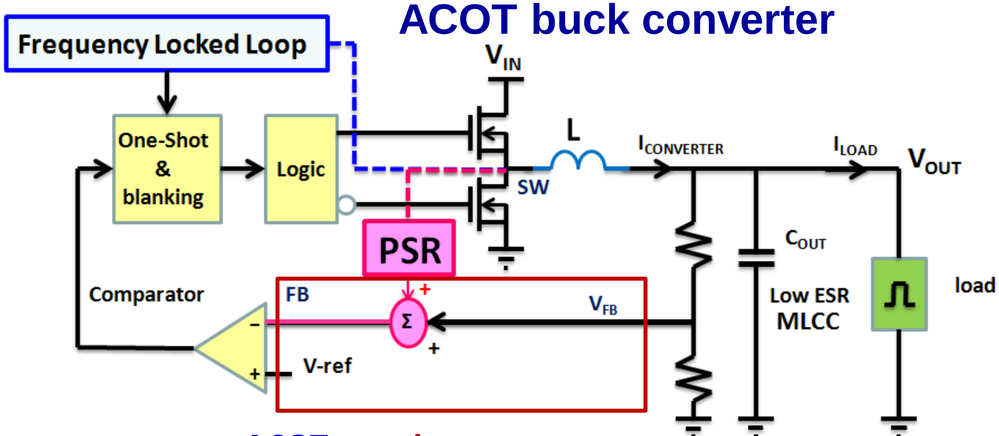
Error amplifier uses average value of V_{OUT}



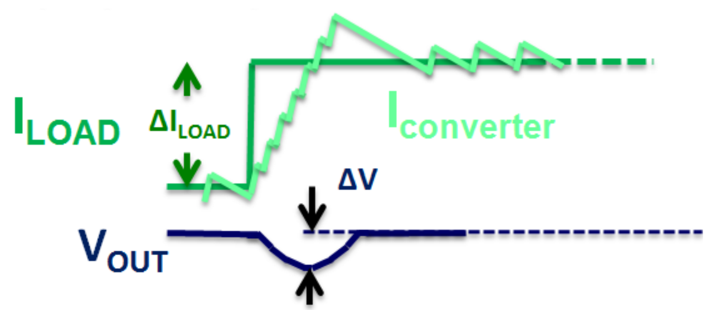
Current mode buck takes several switch cycles to react on load transient.

Needs larger C_{OUT} for small ΔV

ACOT buck converter



ACOT uses instantaneous value of V_{OUT}



ACOT reaction speed is almost instantly.

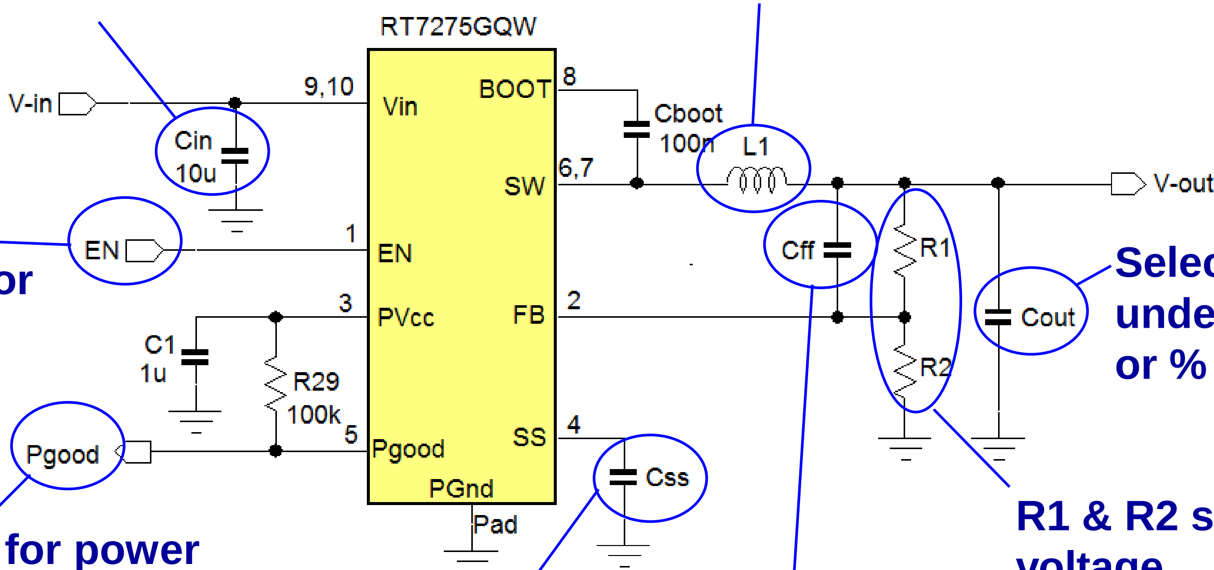
C_{OUT} can be smaller for same ΔV

Design considerations for ACOT Buck converters

Add low ESR C_{IN} for input rail filtering and check C_{IN} RMS current rating

Select L-value for 20 ~ 50% current ripple

EN for power sequence or connect to V_{IN} for auto-start.



Select C_{OUT} for % sag under load transient or % output ripple

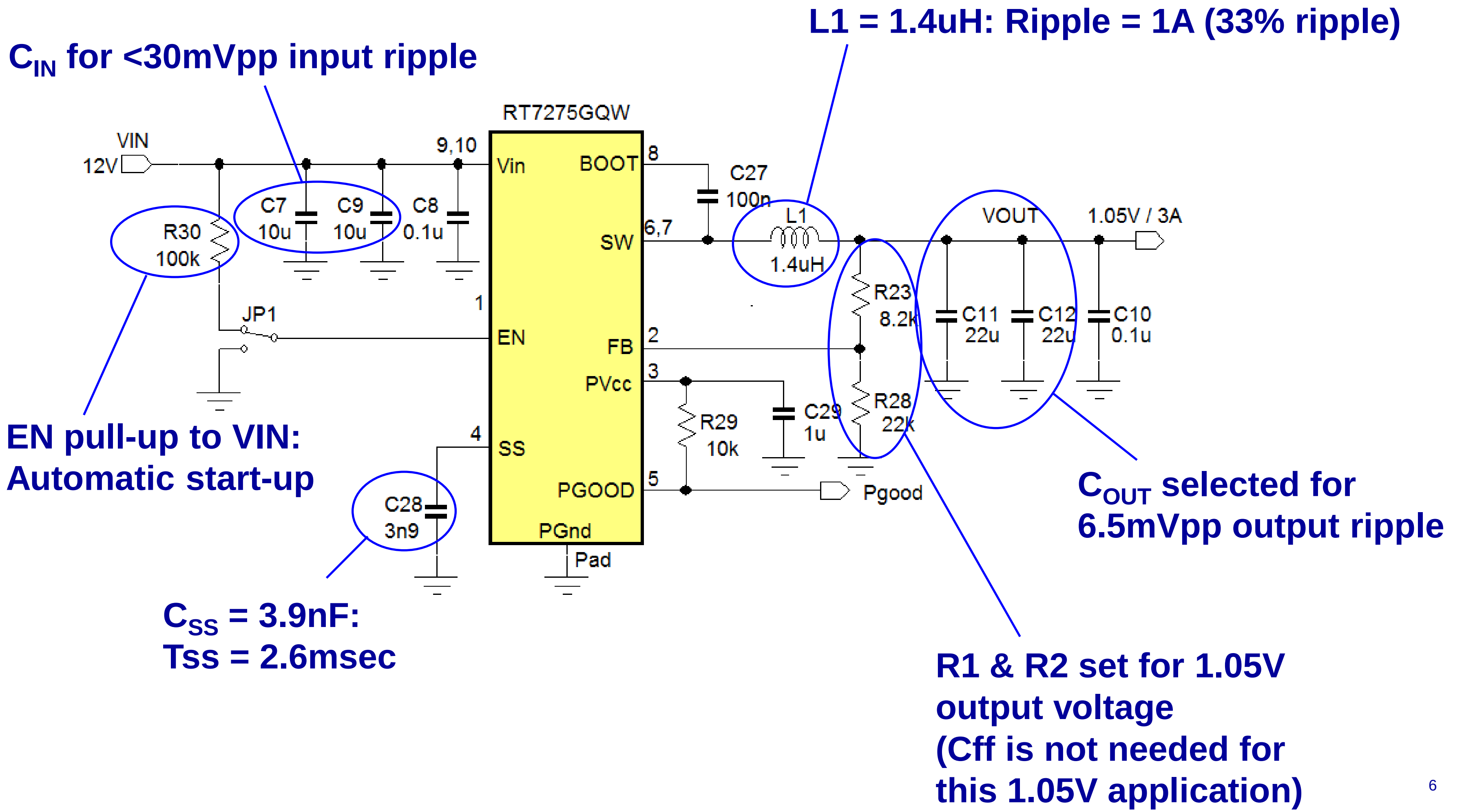
Pgood for power sequence or SoC enable

C_{SS} sets soft-start time

R1 & R2 set output voltage

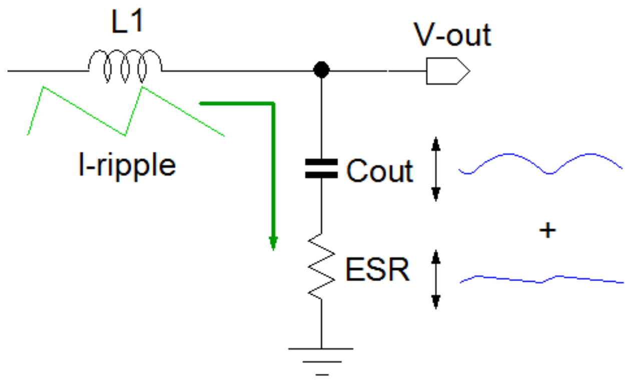
Add some Cff for extra damping (high V_{OUT} and high C_{OUT} applications)

RT7275GQW EVM KIT:

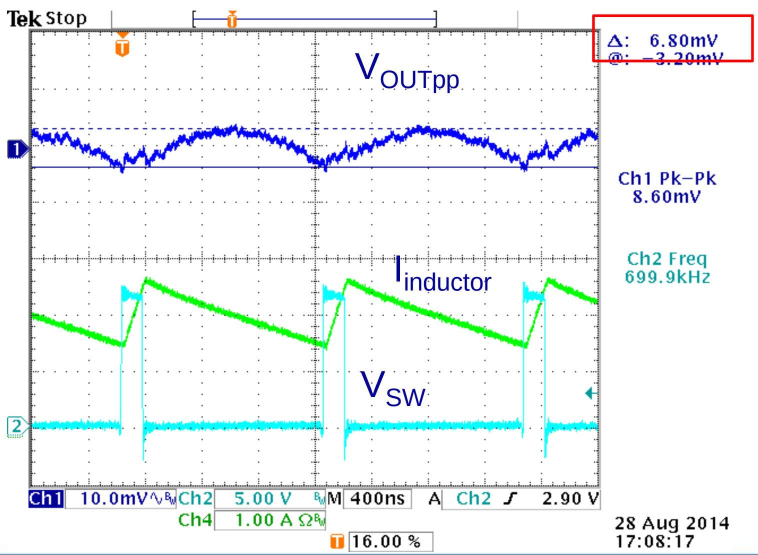


ACOT FAQ: Calculate and measure output ripple

How does output ripple happen?



EVM measurement result



Calculation method:

$$V_{RIPPLE} = V_{RIPPLE(ESR)} + V_{RIPPLE(C)}$$

$$V_{RIPPLE(ESR)} = \Delta I_L \times R_{ESR}$$

$$V_{RIPPLE(C)} = \frac{\Delta I_L}{8 \times C_{OUT} \times f_{SW}}$$

In the RT7275GQW 1.05V evaluation board:

$$V_{RIPPLE(ESR)} = 1A \times 2.5m\Omega = 2.5mV$$

$$V_{RIPPLE(C)} = \frac{1A}{8 \times 44\mu F \times 0.7MHz} = 4mV$$

$$V_{RIPPLE} = 2.5mV + 4mV = 6.5mV$$

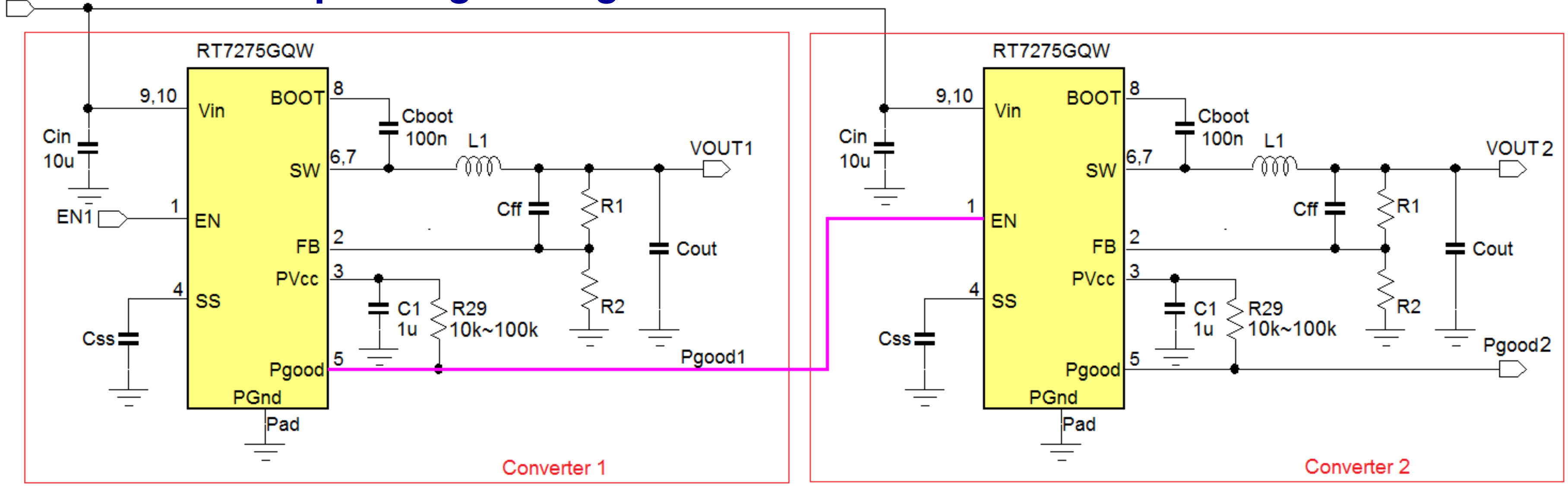
V_{RIPPLE} measured: 6.8mVpp

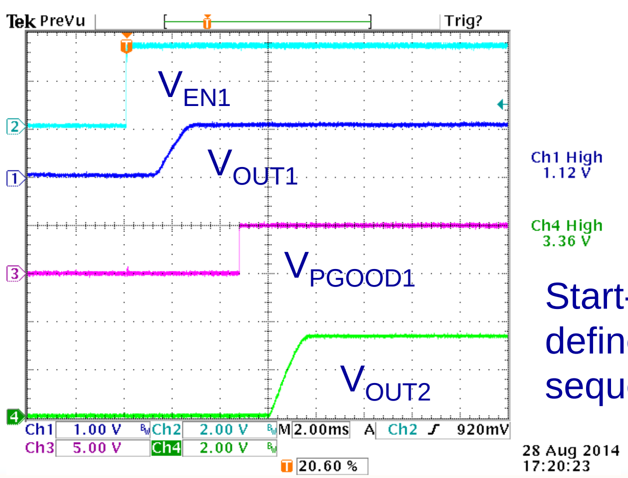
Measurement setup:

Use short probe leads to minimize inductor stray field noise pick-up

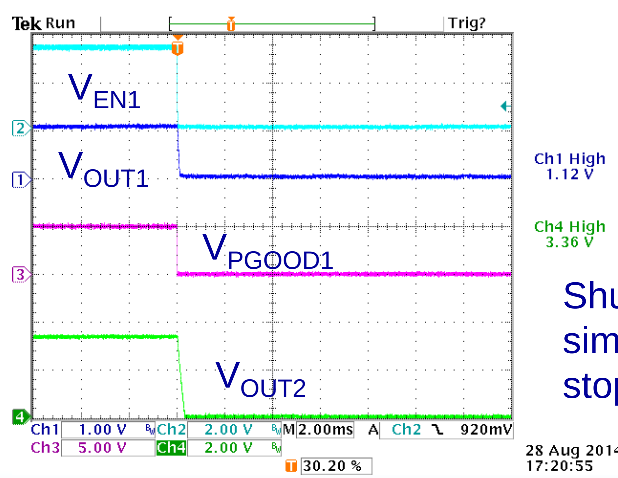
ACOT FAQ: How to make power sequence

Use power good signal of converter 1 to enable converter 2





Start-up with defined power sequence

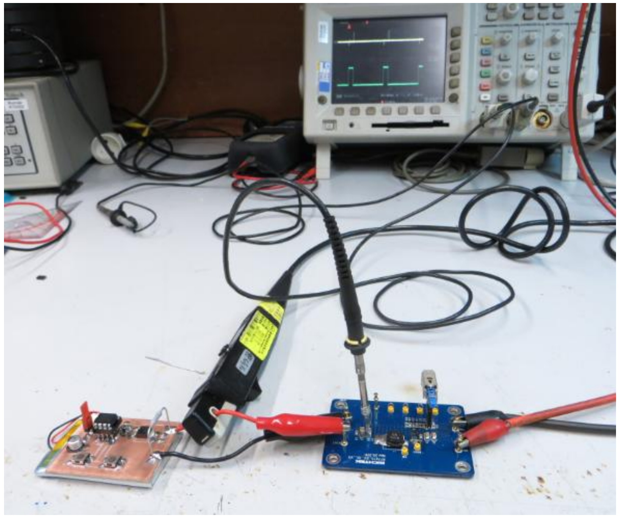


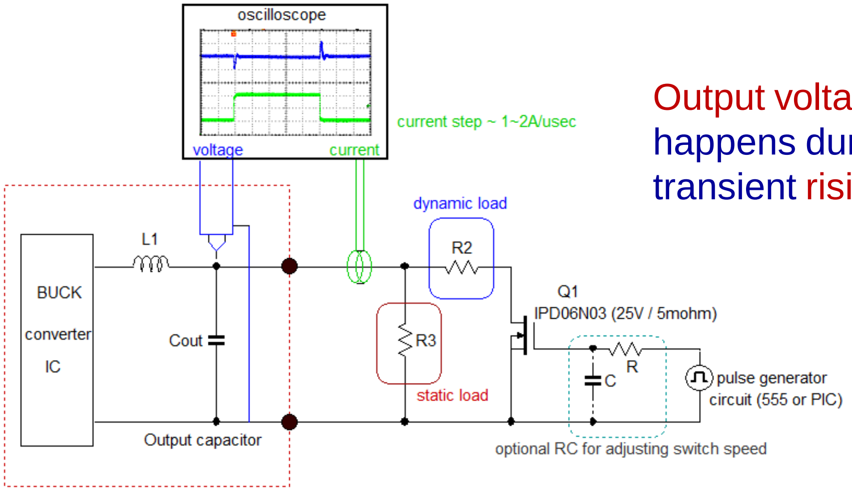
Shut-down will simultaneously stop all converters

ACOT FAQ: Calculate and measure output sag during load transient

Measurement method:
Apply a fast step load 1~2A/µsec at converter output, using dynamic load or MOSFET switch (or use a power resistor briefly touching the load)

Measurement setup:





Output voltage sag happens during load transient rising edge

Calculation method:

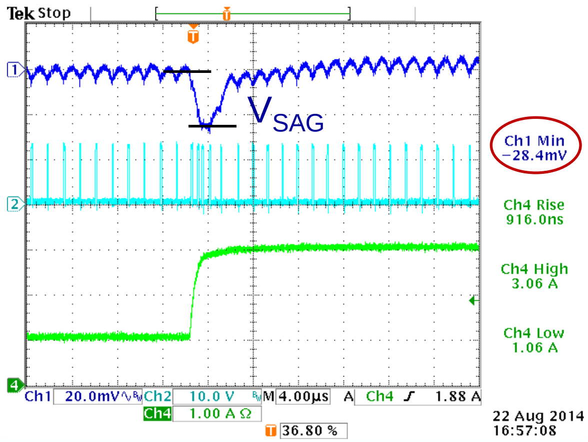
$$V_{SAG}=\frac{L\times(\Delta I_{OUT})^2}{2\times C_{OUT}\times(V_{IN}\times D_{MAX}-V_{OUT})}$$

$$t_{ON}=\frac{V_{OUT}}{V_{IN}\times f_{SW}} \text{ and } D_{MAX}=\frac{t_{ON}}{t_{ON}+t_{OFF(MIN)}}$$

In RT7275GQW 1.05V demo board and 2A fast load step:

$$V_{SAG}=\frac{1.4\mu H\cdot 2A^2}{2\cdot 22\mu F\cdot(12\cdot 0.35-1.05)}=40mV$$

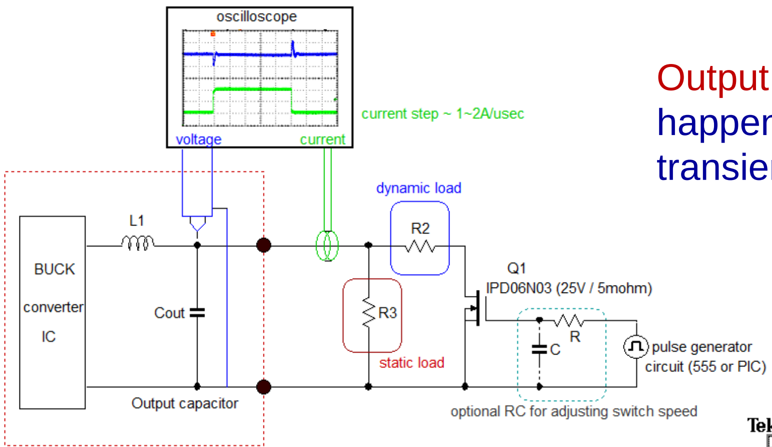
Measurement result:



(measured V_{SAG} is lower than calculated due to rise time of load step)

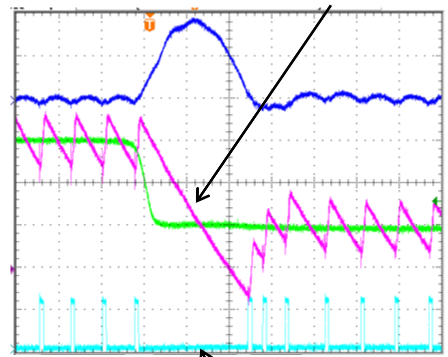
ACOT FAQ: Calculate and measure output soar during load transient

Measurement method:
Apply a fast step load 1~2A/μsec at converter output, using dynamic load or MOSFET switch (or use a power resistor briefly touching the load)



Output voltage soar happens during load transient falling edge

The inductor current drops slower than load current, thereby charging the output capacitor



Converter in 0% duty-cycle to maximize output discharge

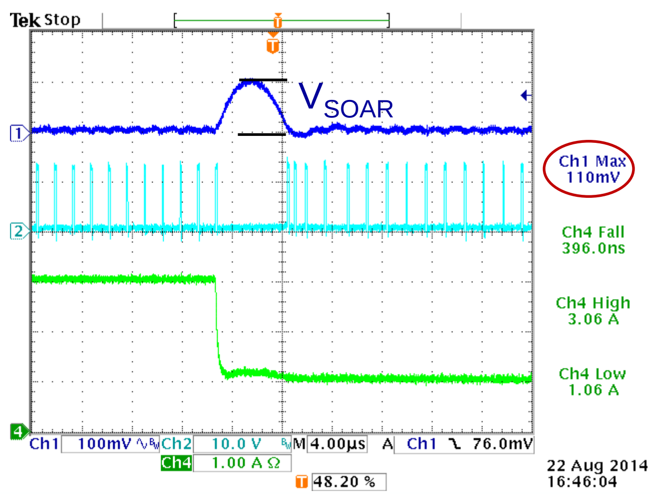
Calculation method:

$$V_{SOAR} = \frac{L \times (\Delta I_{OUT})^2}{2 \times C_{OUT} \times V_{OUT}}$$

In 1.05V demo board and 2A fast load step:

$$V_{SOAR} = \frac{1.4\mu H \cdot 2A^2}{2 \cdot 22\mu F \cdot 1.05V} = 121mV$$

Measurement result:

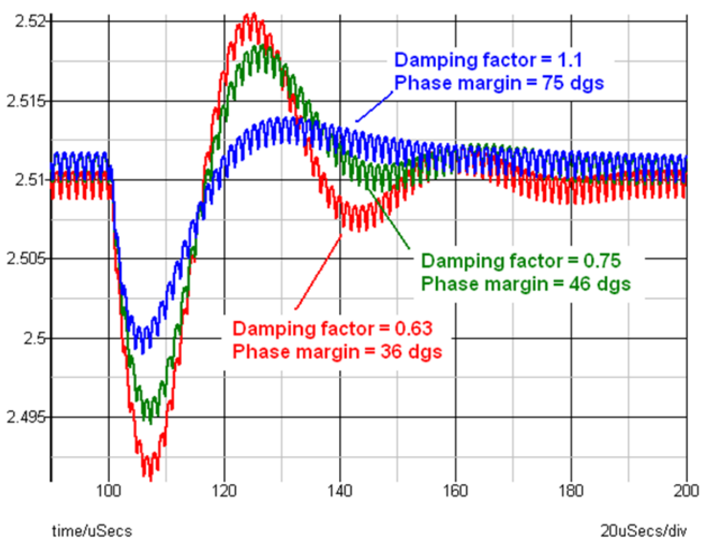


Measured V_{SOAR} is lower than calculated due to fall time of load step

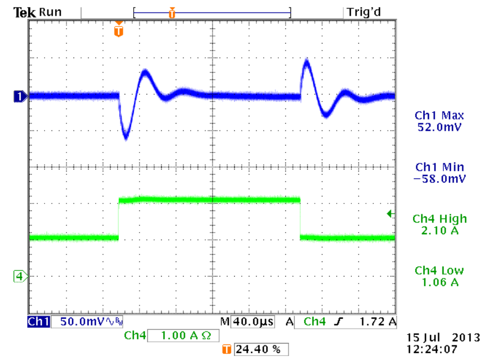
(soar pulse may have different amplitude depending on timing of load step relative to the last switching on-time**)**

ACOT FAQ: How to check converter stability

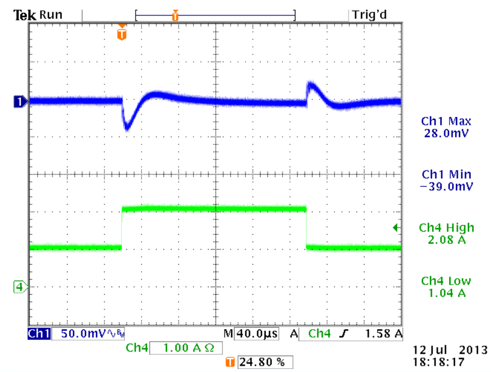
ACOT uses a non-linear constant ON time control system, and traditional open loop gain-phase stability analysis methods are not suitable to be used with ACOT converters. *Closed loop* analysis is valid for ACOT and can be used for mathematical calculations. For practical stability measurements, it is recommended to use **fast step loads** to measure the converter damping. Sufficiently damped response **will not show any ringing**, and corresponds to a stable control loop.



Relation between step load response ringing, damping and phase margin

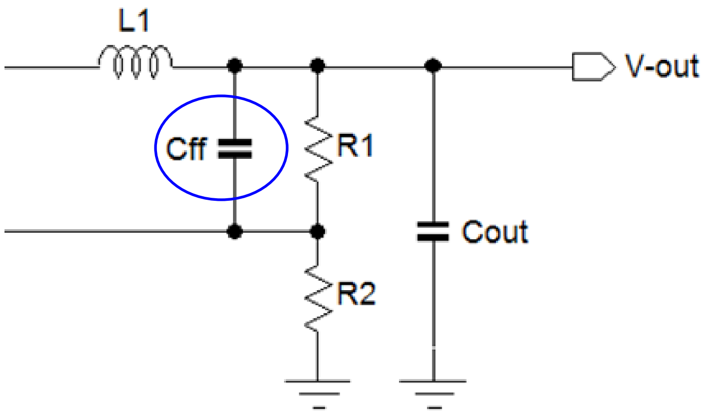


Step load measurement showing under-damped response (Cff needs to be added or increased in value)



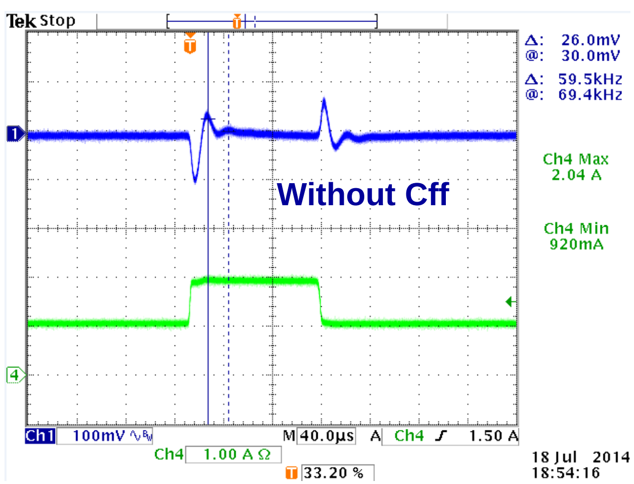
Step load measurement showing well-damped response

ACOT FAQ: How to tune Cff



The feed-forward capacitor plays a role in the damping of the ACOT control loop, especially at high duty-cycle applications like 12V → 5V. For low duty-cycle applications like 12V → 1V it is normally not needed. The value of Cff for a specific ACOT converter depends on duty-cycle, C_{OUT} value, inductor value and R1 value.

Practical method to find Cff value:



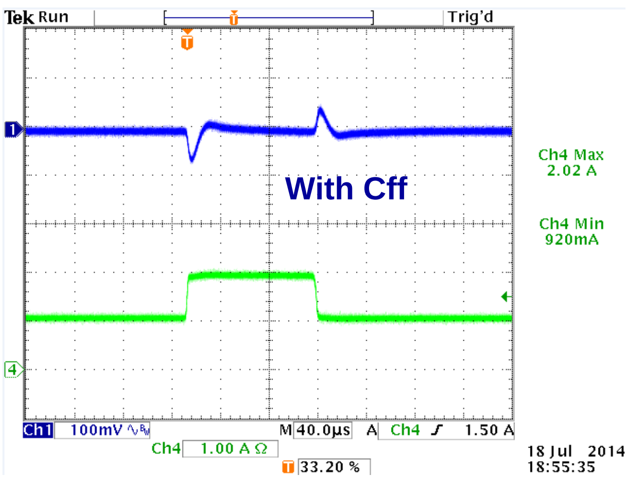
1. Apply a step load and if it shows ringing, measure the ringing frequency
In this 12V → 5V example: f_{RING}=59.5kHz

2. Calculate Cff by the formula:

$$C_{FF} = \frac{1}{2\pi \cdot R1 \cdot f_{RING} \cdot 0.8}$$

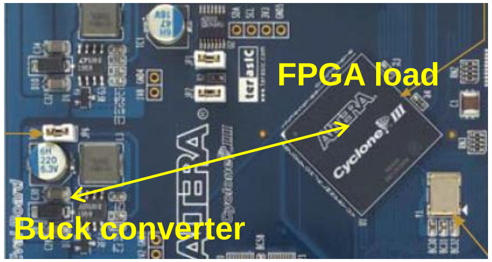
In this example: (R1 = 120k)

$$\frac{1}{2\pi \cdot 120k \cdot 59.5k \cdot 0.8} = 27.9pF$$

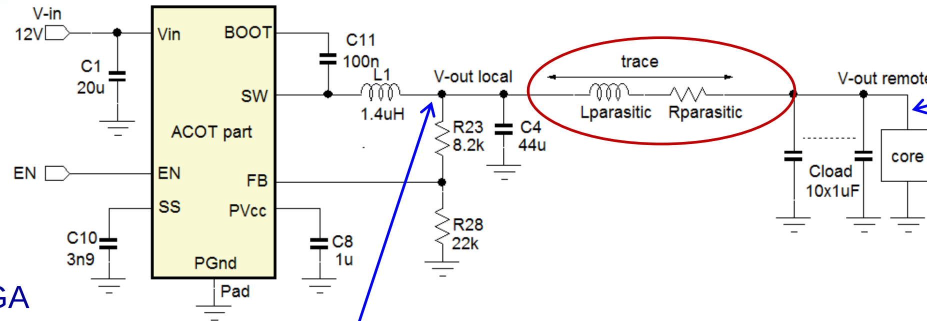


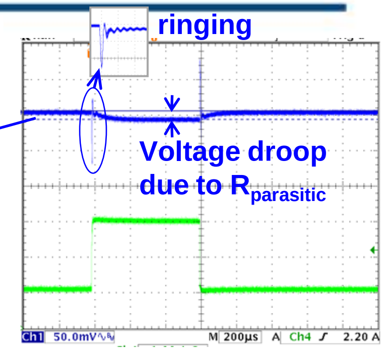
After adding Cff = 27pF: well-damped step response

ACOT FAQ: ACOT converter with remote sense



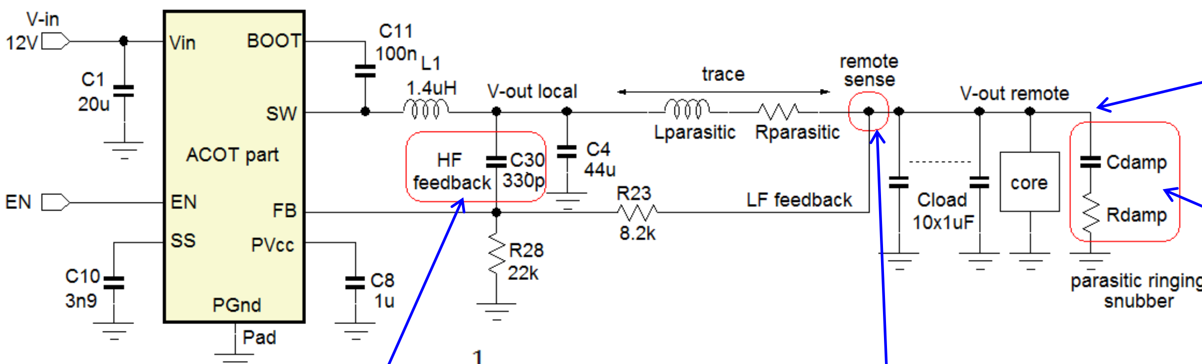
Distance between converter and FPGA

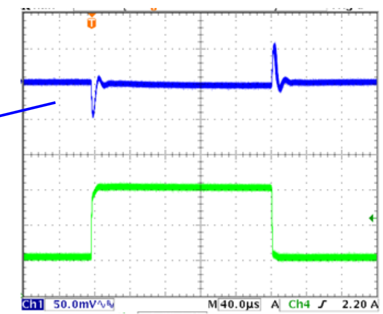




Converter regulates V_{OUT} local

Solution: Use remote sense





$$\frac{1}{2\pi f \cdot C30} \ll R23 \;\; (f \approx 300kHz)$$

Use capacitor from V_{OUT} local to feedback to avoid instability due to $L_{PARASITIC}$ & C_{OUT} phase delay

Feedback resistor connection at remote load side

Add RC snubber at load side to damp the ringing that can happen due to $L_{PARASITIC}$ and C_{LOAD}

$$R_{SNUBBER} = \sqrt{\frac{L_{PARASITIC}}{C_{LOAD}}} \approx \sqrt{\frac{30nH}{10\mu F}} = 55m\Omega$$

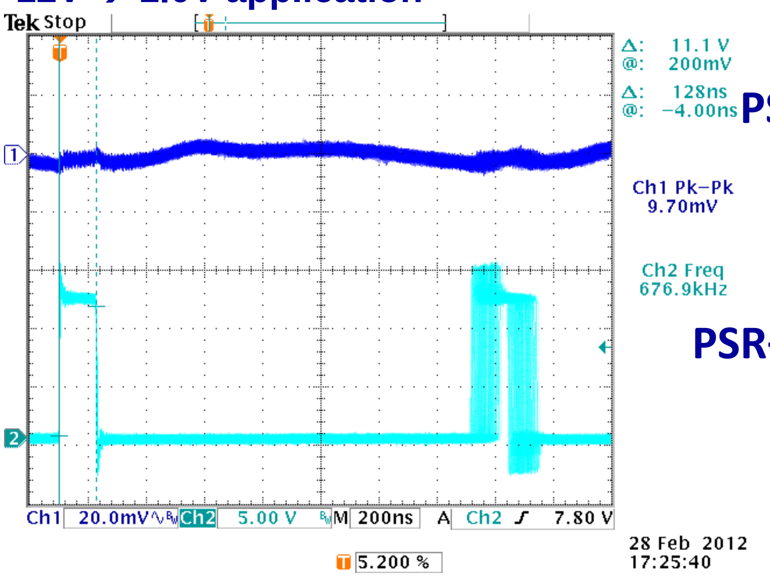
$$C_{SNUBBER} > \frac{2\pi\sqrt{L_{PARASITIC} \cdot C_{LOAD}}}{R_{SNUBBER}} \approx \frac{2\pi\sqrt{30nH \cdot 10\mu F}}{55m\Omega} = 62\mu F$$

(you can use OSCON capacitor as snubber)

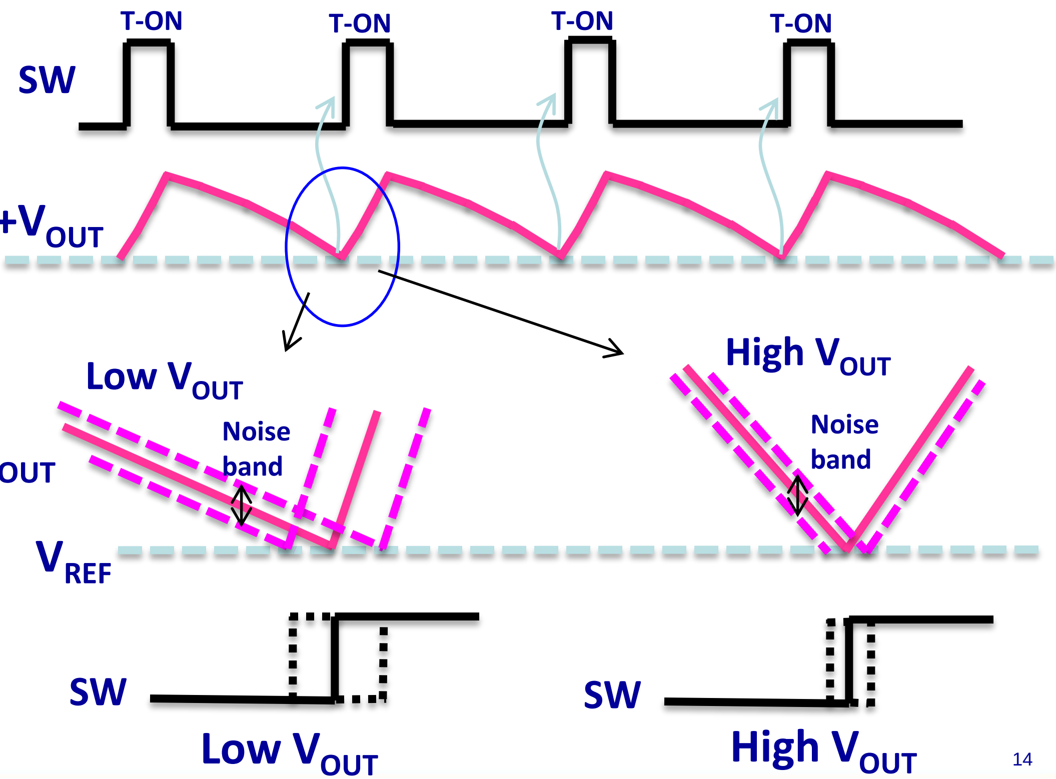
ACOT FAQ: Why do switch waveforms show frequency jitter?

ACOT uses a (pseudo) fixed T_{ON}, and controls T_{OFF} to regulate the output voltage. This means that load transients will always result in frequency changes in the switch waveform. At steady load conditions, the duty-cycle will be constant, and the frequency locked loop will slowly control T_{ON} for operation near the nominal frequency. However, there will always be some frequency jitter visible in the switch waveform due to noise in the feedback signal. At low V_{OUT} applications, frequency jitter will be more than at high V_{OUT} applications.

V_{OUT} and switching waveform for a 12V → 1.0V application

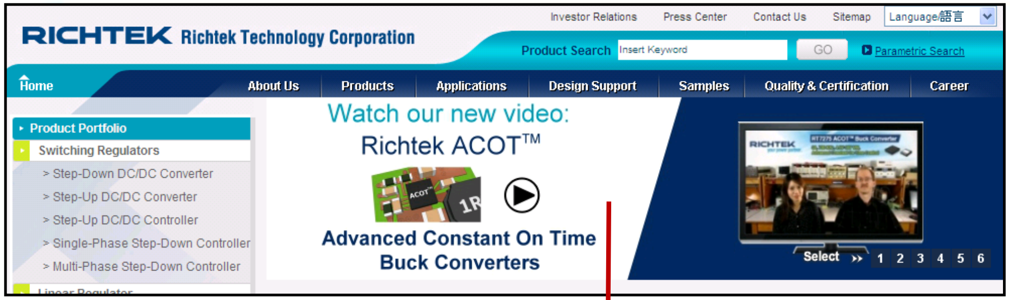


Switching waveform shows ~ 7% jitter

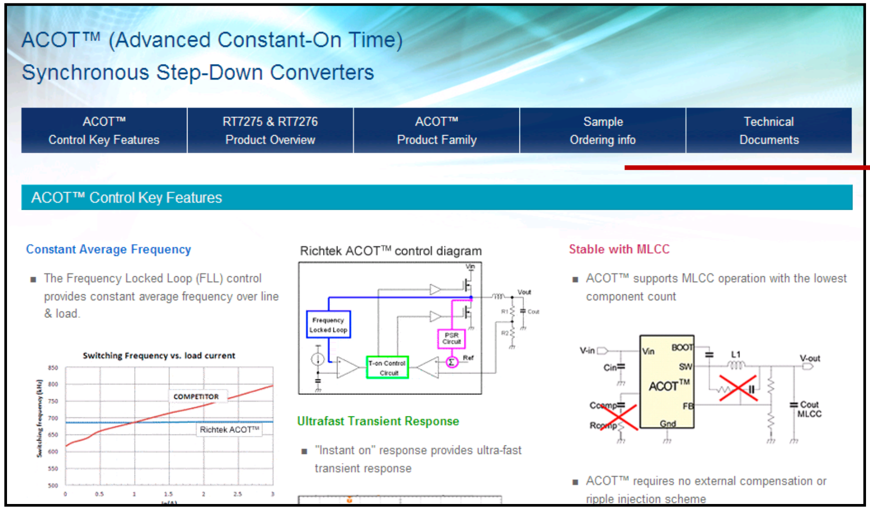


- ACOT^{TM} Design tools & Application notes

Richtek Website ACOT™ Landing Pages



Click ACOT banner or search for "ACOT"



ACOT Landing page with more info on specific products

Application notes, design tools and tutorial videos

Richtek Website Product Pages

Application notes and tools can be found under "Documents and Tools" tab

RT7275/RT7276

3A, 18V, 700kHz ACOT™ Synchronous Step-Down Converter

Datasheet

Overview | Documents & Tools | Ordering Information

Datasheets

Title	Description	Size	Last Updated
DS7275_76-00.pdf	Datasheets for RT7275/RT7276	359 KB	2014 Jul

Application Notes

Download	Title	Last Updated
	ACOT™ Stability Testing	2013-11-07

Design Tool

Type	Title
	Richtek Designer™ Web Simulation Tool

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