Practical comparisons of DC/DC control-modes to solve end equipment challenges

Product Training

APP/BSR/CCP

Training Summary

Practical comparisons of DC/DC control-modes summary:

Certain end-equipment, like communications, server, industrial, and personal electronics have design challenges solved by the DC/DC converter's control-mode. This session will compare and contrast 3 different devices using 3 different control modes under the same design criteria to see how each control mode solves particular size, efficiency, external component, ripple and transient response design challenges.

What you'll learn:

- Learn the basics of step-down DC/DC control modes as it pertains to design challenges for many different end equipment
- Understand how the control mode affects performance of the point of load power supply with an apples-to-apples comparison
- See 3 different devices with 3 different control modes respond to the same design criteria – to help show which one is the better device for specific design challenges.
- See how output filters are designed

URL link to complimentary training – Control Mode Theory Summary

Training level: Intermediate

Course Details:

- Audience: Analog, Systems, Power

Specific Parts Discussed:

- TPS54824, TPS54A20, TPS56C215

TI Designs

- PMP11438 - Three Different Buck Converter Circuits to Convert 12V to 1.2V at >6A Load
- PMP15008 - Tiny, Low Profile 10 A Point-of-load Voltage Regulator Reference Design
- PMP15018 - Power Reference Design With Dual VOUT of 1.2V@10A and 1V@10A

Other Trainings

- Fixed Freq Control vs COT Control
- Survey of Control Topologies

Agenda

- Market challenges
- Overview of control methods and parts used in comparison
- Bounding the 3 designs: V_{IN}, I_{OUT} , V_{OUT} and V_{OUT} tolerance during transient
- Inductor & capacitor selection
- Loop response and transient comparison
- Output ripple and jitter
- Efficiency comparison
- Thermal comparison
- Solution size
- Considering cost
- Summary

Market Challenges

Telecom / Datacom / Industrial power needs

- **Telecom/Datacom**
  - Increasing PCB density requires **small solution size** with high power density
  - **High efficiency** allows increased card density and higher product performance
  - **Fixed frequency operation** helps to reduce unwanted noise in the system
- **Servers / SSD**
  - Increasing PCB density requires **small solution size** with high power density
  - **High efficiency** allows increased card density and higher product performance
  - High **light load** efficiency is needed
  - **Cost is key**
- **Industrial**
  - Increasing PCB density requires **small solution size** with high power density
  - **High efficiency** allows increased card density and higher product performance
  - **Fixed frequency operation** helps to reduce unwanted noise in the Medical and Test & Measurement systems
  - **Cost** is key in majority of Industrial applications outside Medical and Test & Measurement

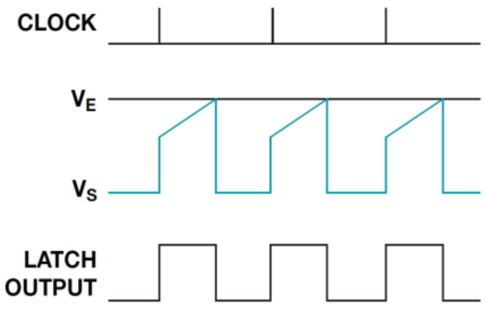






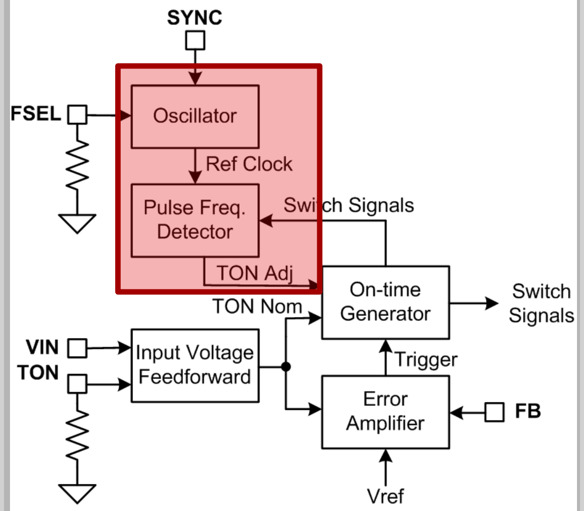
Control, Converters and Topology

Current Mode



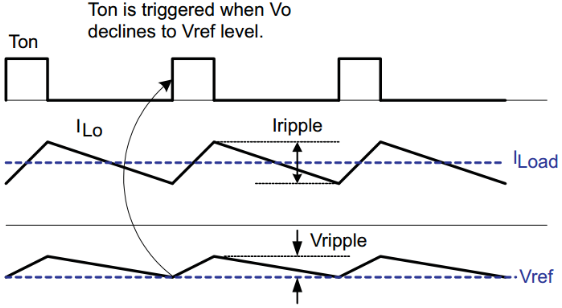
- Used in **TPS54824**
- On time **initiated by clock** signal
- Scaled inductor current compared to control voltage to **modulate pulse width**
- **Fixed frequency** under all conditions

COT with SYNC



- Used in **TPS54A20**
- **Phase lock loop** (PLL) added to constant on-time (COT) controller
- PLL **slowly adjusts** on-time
- Fixed frequency in **steady state**
- **Non-linear, fast** transient response

D-CAP3™



- Used in **TPS56C215**
- Advanced constant on-time (COT) control where a on-time **adapts with voltage** conditions
- A new high side on-pulse is **triggered** when falling feedback voltage equals the reference voltage
- Supports all **ceramic output caps** with internal ramp circuit
- Improved **voltage set-point accuracy**

TPS54824

Overview

- V_{IN} 4.5 – 17V
- I_{OUT} 8A
- f_{SW}: 200kHz to 1.6MHz
- Control Mode: **Current Mode**

Advantages

- Low jitter fixed frequency operation
- Control loop is tunable adding flexibility for filter components
- Small signal model can be modeled for CM based control

Disadvantages

- Solution size
- Requires external compensation

Applications

- **Communications and Industrial** applications where many signal chain devices are used.
- The switching frequency is **predictable** and programmable with **low jitter** which helps improve noise performance.

TPS54A20

Overview

- V_{IN} 8 – 14V
- I_{OUT} 10A
- f_{SW} : 2 – 5MHz per phase
- Control Mode: **COT with Sync**

Advantages

- Smallest solution size
- Fast transient response
- Low profile
- No external compensation required

Disadvantages

- Limited V_{OUT} range: 0.5 – 2.0V
- Limited V_{IN} range: 8 – 14V
- Small signal model for COT based control can nor be modeled

Applications

- Ideal for non-portable applications needing **small size** with a **fast transient response.**
- **High frequency** enables a very small design, but where highest efficiency is not needed.

TPS56C215

Overview

- V_{IN}: 4.5 – 17V
- I_{OUT}: 12A
- f_{SW} : 400kHz, 800kHz and 1.2MHz
- Control Mode: **D-CAP3™**

Advantages

- No external compensation required
- Fast transient response
- Light load efficiency (Eco Mode™)

Disadvantages

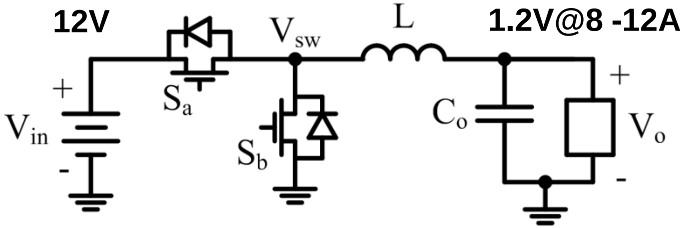
- Solution size
- Frequency Jitter
- Small signal model for COT based control can nor be modeled

Applications

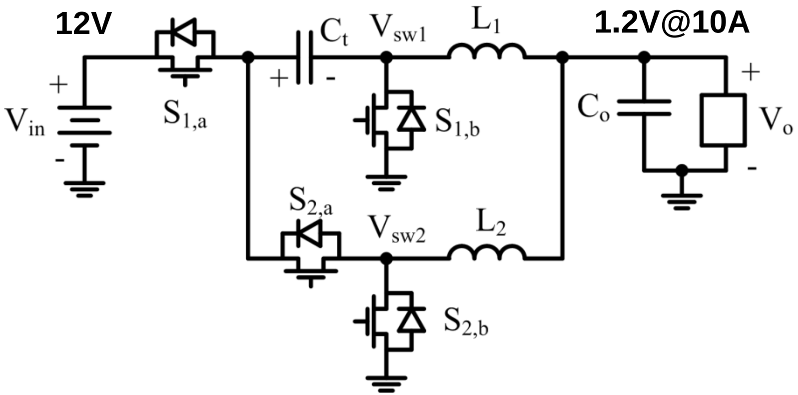
- Ideal for applications, like **enterprise**, where there are fewer noise-sensitive analog components
- Powering low voltage processors that need **high accuracy** and present **fast load transients**.

Step Down Converter Topologies

Buck Converter: **TPS54824, TPS56C215**



Series Capacitor Buck Converter: **TPS54A20**



Buck Converter

- **Two** MOSFET switches (single phase)
- One output inductor

Series Capacitor Buck Converter

- **Four** MOSFET switches (two phase)
- Two output inductors
- One series capacitor
- **Reduced switching loss** enables efficient high frequency operation

Bounding the 3 designs

Design Specifications

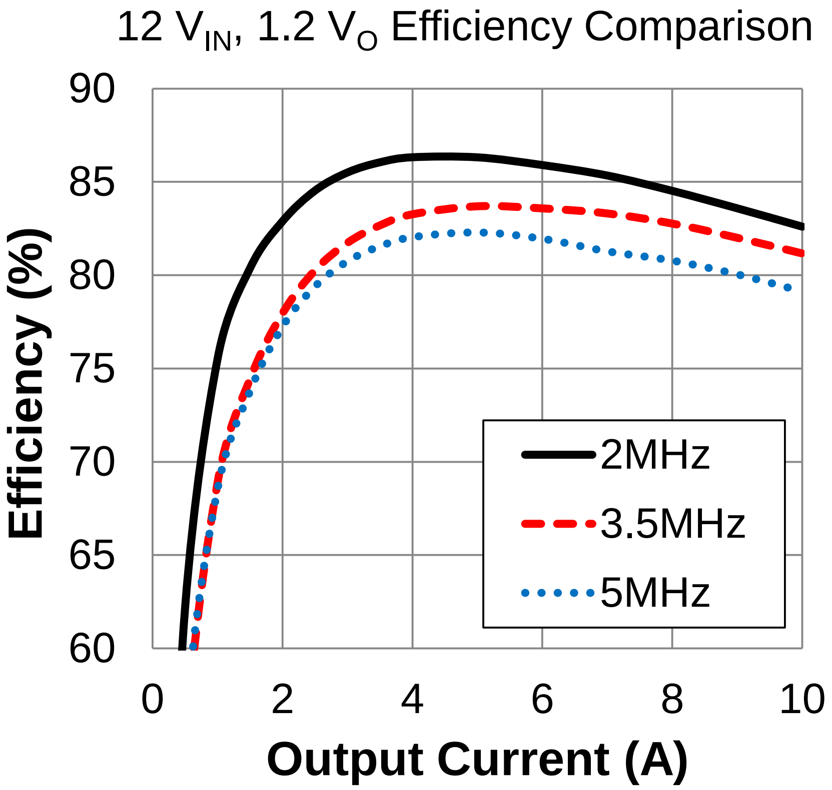
Parameter		Conditions	Min	Typ	Max	Unit
V_{OUT}	Output voltage	±5% of typical	1.14	1.2	1.26	V
I_{OUT}	Output current		0		8	A
V_{IN}	Input voltage	±10% of typical	10.8	12	13.2	V
ΔV_{OUT}	Transient response	2 to 6A load step @ 1A/us			36	mV

Other aspects to consider:

- Overall converter **size**
- Power **(heat)** dissipation
- Solution **cost**

Inductor & Capacitor Selections

Choosing the Switching Frequency



- Higher frequency operation **reduces overall solution size**
  - Lower inductance required
  - Fewer decoupling capacitors
- Tradeoff: **efficiency decreases** with increased switching frequency
- Minimum on-time consideration

Minimum On-time Considerations

- For FCCM, min on-time at min load is the corner case to consider.
- Equation to estimate maximum fsw:

$$f_{SW} \leq \frac{1}{t_{ON,min}} \times \frac{V_O}{V_{I,max}}$$

Part Number	Typical Minimum on-time (ns)	Maximum f_{SW} (kHz)
TPS54824	95	957
TPS54A20	14	12,987
TPS56C215	54	1,683

- Must consider part to part, temperature and load variation in min on-time.
- TPS54824 recommended max to use for calculation considering all conditions is 150 ns, max fsw for this application is **606 kHz**.

TPS54824 curve for temperature and load variation.

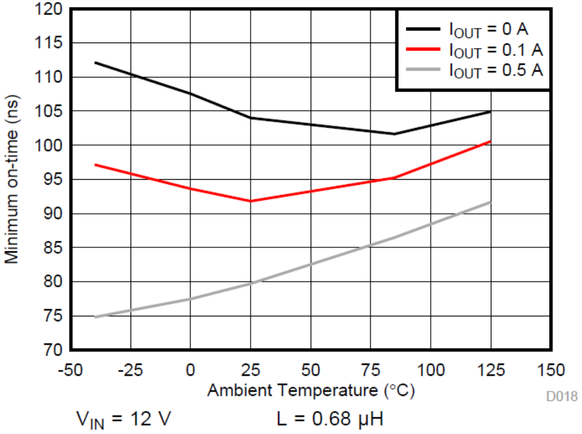


Figure 18. Minimum on-time vs Ambient Temperature

Inductor Value Selection

- Inductance equation for traditional Buck Converter (TPS54824/TPS56C215)

$$L = \left(\frac{V_{IN,MAX} - V_O}{K \times I_O}\right)\left(\frac{V_O}{V_{IN,MAX} \times f_{SW}}\right)$$

- Inductance equation for Series Cap Buck Converter (TPS54A20)

$$L = \left(\frac{V_{IN,MAX} - 2V_O}{K \times {}^{I_O}\!/_{2}}\right)\left(\frac{V_O}{V_{IN,MAX} \times f_{SW}}\right)$$

  - $K = \Delta I_L / I_O$, where I_O is full load current
  - K is usually between 0.1 and 0.4

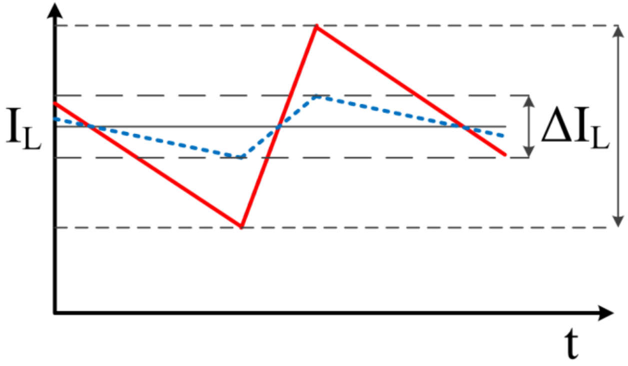
Part Number	$V_{IN,Max}$ (V)	V_O (V)	I_O (A)	F_{SW} (MHz)	K	L (µH)	L Chosen (µH)
TPS54824	13.2	1.2	8	0.5	0.3	0.909	1.00
TPS54A20	13.2	1.2	10	2/phase	0.4	0.245	0.22 (x 2)
TPS56C215	13.2	1.2	8	1.2	0.3	0.379	0.47

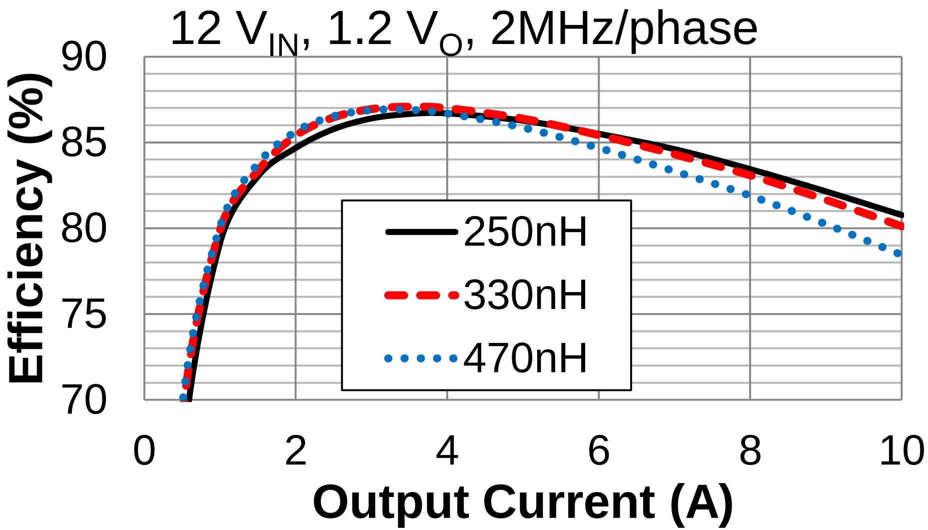
Inductance Impact on Efficiency

- Inductance equation for TPS54A20 (series cap buck)

$$L = \left(\frac{V_{IN,MAX} - 2V_O}{K \times {I_O}/{2}}\right)\left(\frac{V_O}{V_{IN,MAX} \times f_{SW}}\right)$$

  - K = ΔIL/IO, where IO is full load current
  - K is usually between 0.1 and 0.4

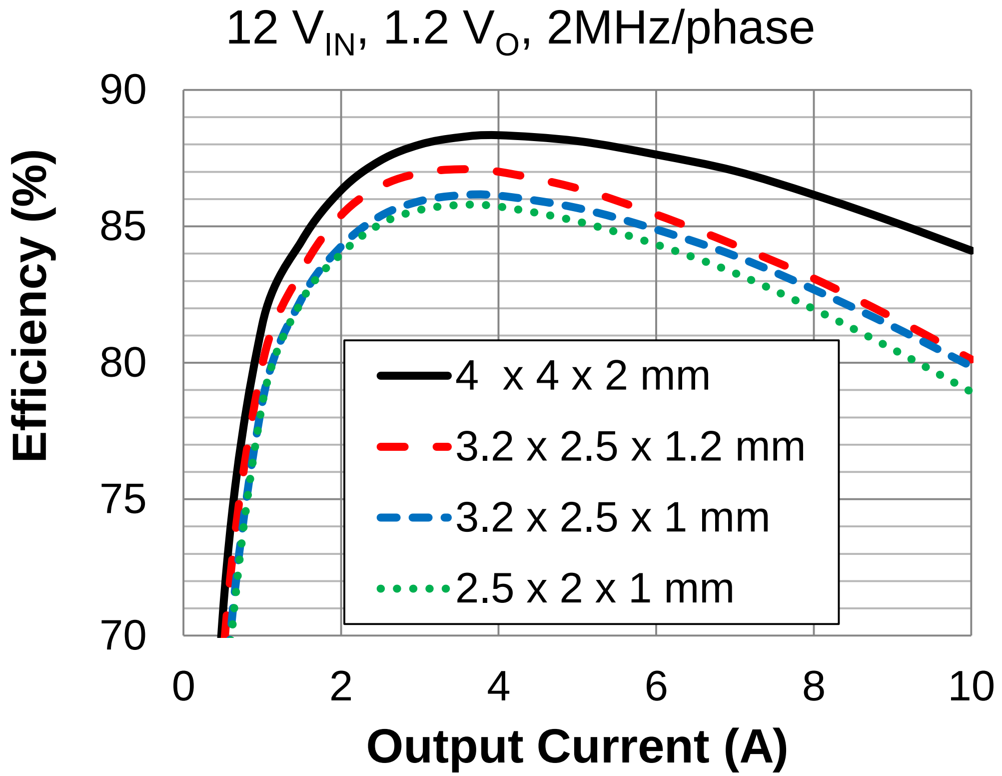




- Higher inductance tends to increase **peak efficiency**
- Lower inductance has higher **full load efficiency** and **better transient response**

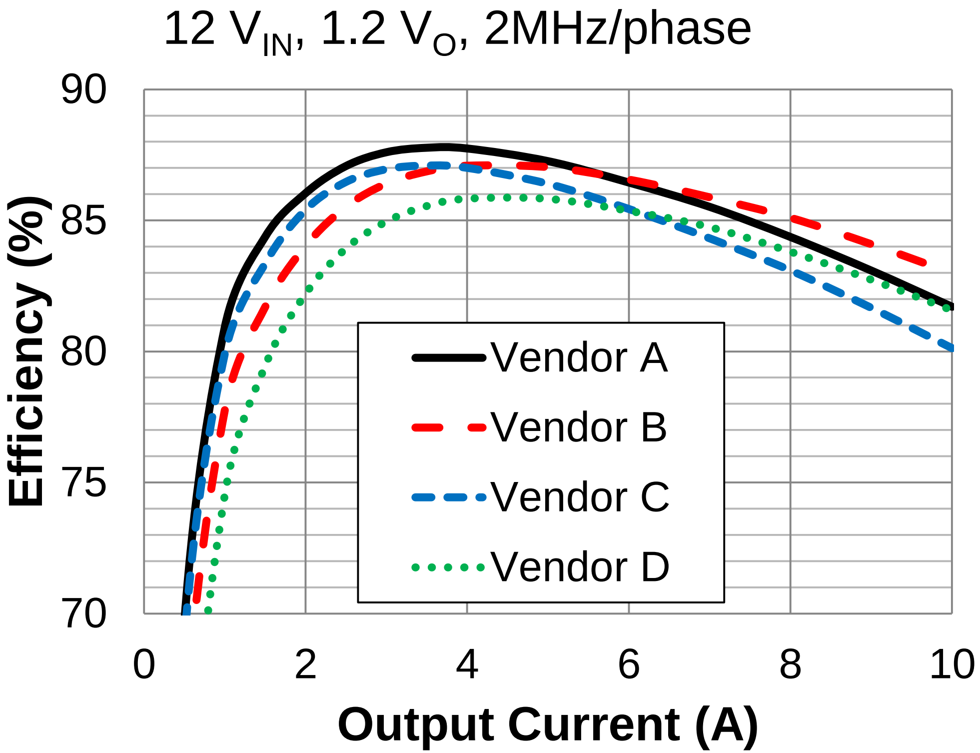
Inductor Size – TPS54A20

- **Larger inductors tend to result in higher efficiency**
  - Thicker wire
  - Lower winding resistance
  - Benefit seen in mid to high load current range
- **Measured results for**
  - Same inductance
  - Same vendor
  - Same core material



Inductor Vendor – TPS54A20

- **Finding the right inductor vendor matters**
  - Various core material, construction, etc.
  - Should not judge an inductor by DC resistance alone
- **Measured results for**
  - Same inductance
  - Same size
- If possible, **experimentally test inductors**



Output Capacitor Selection – TPS54A20

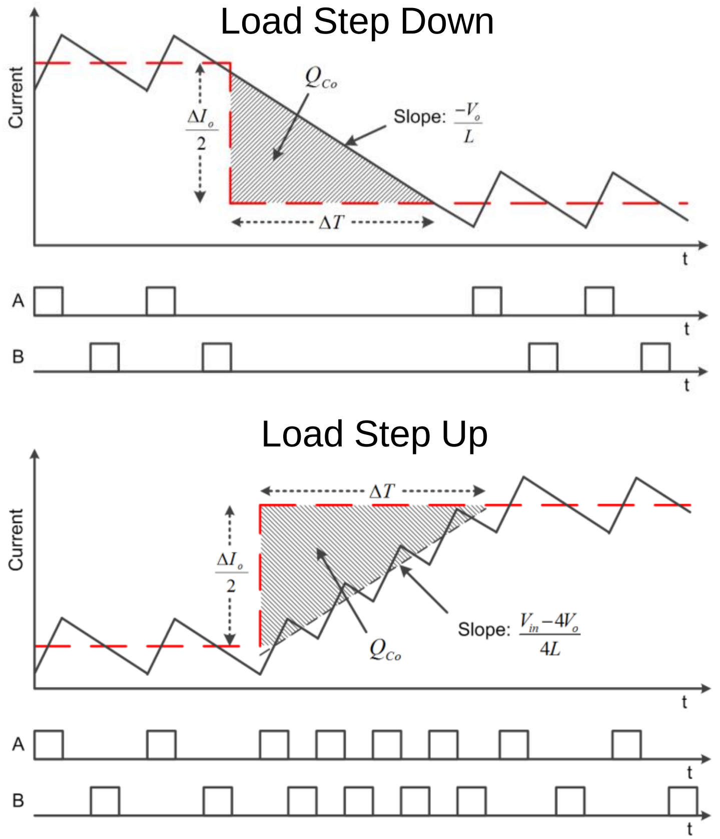
- **Load step down:**
  - Ex: $\Delta I_{o,max}$ = 5A, L = 330nH, Vo = 1.2V, $\Delta V_{o,max}$ = 25mV, $V_{IN,min}$ = 10.8V

$$C_o \geq \frac{(\Delta I_{o,max})^2 L}{4V_o \Delta V_{o,max}} = 66\mu F$$

- **Load step up:**

$$C_o \geq \frac{2L(\Delta I_{o,max})^2}{(V_{IN,min} - 4V_o)\Delta V_{o,max}} = 106\mu F$$

- Select largest value and take variation in to account→ TPS54A20: 47 µF + 100 µF



Output Capacitor Selection – TPS56C215

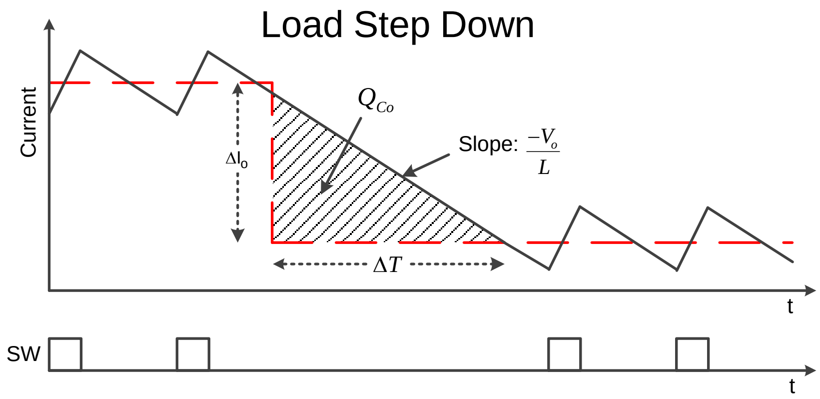
- Ex: $\Delta I_{o,max}$ = 4A, $\Delta V_{o,max}$ = 0.025V, $V_{IN,min}$ = 10.8V, Vo = 1.2V, L = 470nH, f_{SW} = 1.2MHz, $t_{OFF,min}$ = 0.31us
- **Load step down:**

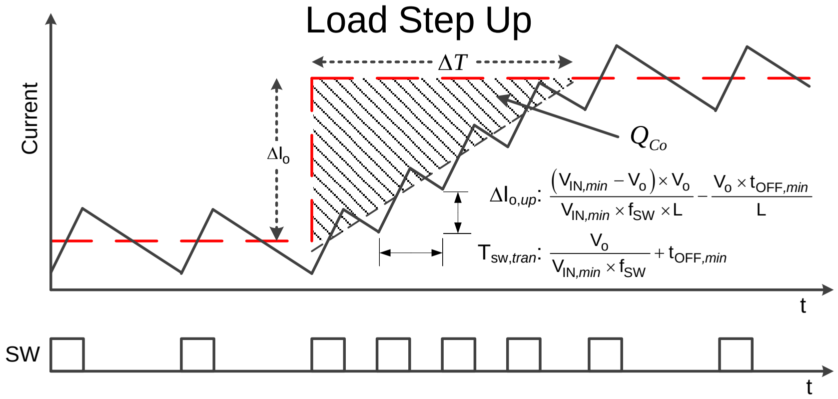
$$C_o \geq \frac{(\Delta I_{o,max})^2 \times L}{2 \times V_o \times \Delta V_{o,max}} = 125\ \mu F$$

- **Load step up:**

$$C_o \geq \frac{L \times (\Delta I_{o,max})^2 \times \left(\frac{V_o}{V_{IN,min} \times f_{SW}} + t_{OFF,min}\right)}{2 \times \Delta V_{o,max} \times V_o \times \left(\frac{V_{IN,min} - V_o}{V_{IN,min} \times f_{SW}} - t_{OFF,min}\right)} = 117\mu F$$

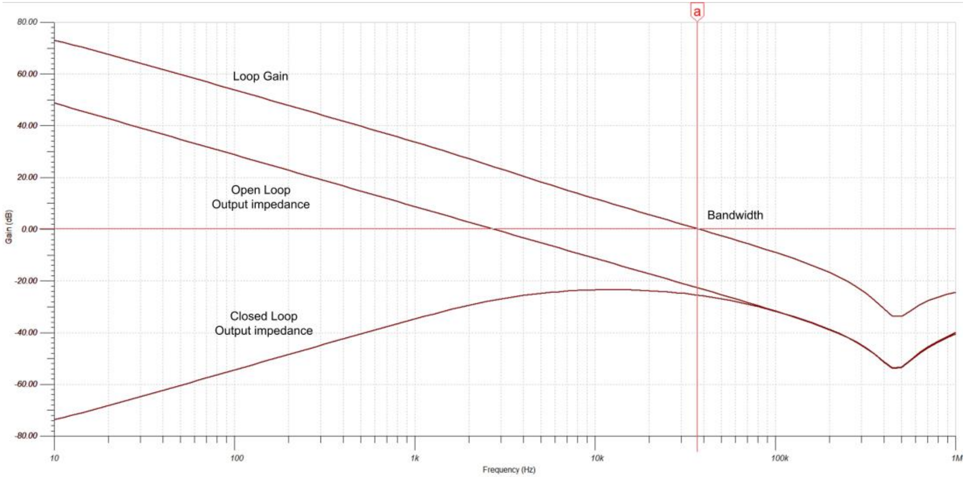
- Select largest value and take DC Bias variation into account → TPS56C215: 47 µF x 4pcs





Output Capacitor Selection – TPS54824

- Peak CMC typically has lower loop bandwidth than COT based converters
  - Higher closed loop output impedance
  - Slower transient response



- Reasonable estimation of loop bandwidth is **fsw/10**.
- Ex: $\Delta I_{o,max}$ = 4 A, $\Delta V_{o,max}$ = 36 mV, f_{CO} = fsw/10 = 50 kHz

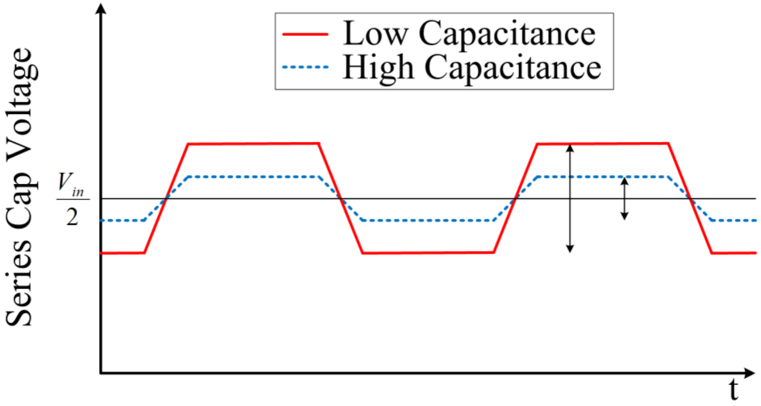
$$C_o \geq \frac{\Delta I_{o,max}}{2 \times \pi \times f_{CO} \times \Delta V_{o,max}} = 354\mu F$$

- Required capacitance varies with **load step slew rate**. Lower slew rate requires less output capacitance.
- **PSPICE transient simulation** is a great tool to find more accurate capacitance before testing a real circuit.

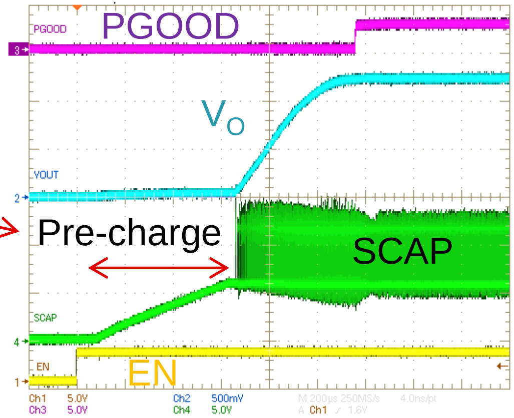
Series Capacitor Selection – TPS54A20

- Select the cap value to keep **voltage ripple <8%** at full load, lowest V_{IN}
  - Ex: 10 A load, 2 MHz, 10.8 V_{IN}, 1.2 V_O

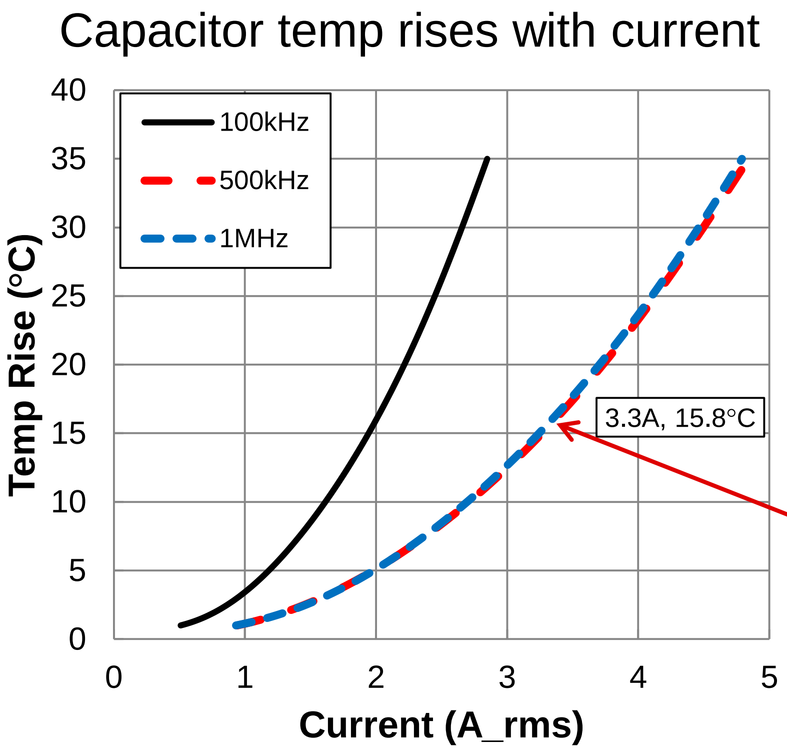
$$C = \frac{DT\left(\frac{i_{out}}{2}\right)}{0.08\left(\frac{V_{in}}{2}\right)} = \frac{\left(\frac{2\times 1.2V}{10.8V}\right)\frac{1}{2MHz}\left(\frac{10A}{2}\right)}{0.08\left(\frac{10.8V}{2}\right)} = 1.29\mu F$$



- Tradeoff: **Startup delay** to pre-charge the series cap
  - 10 mA pre-charge current into 1 µF cap → 625 µs to pre-charge to 6 V ($V_{IN,typ}/2$)



Series Capacitor Self Heating – TPS54A20



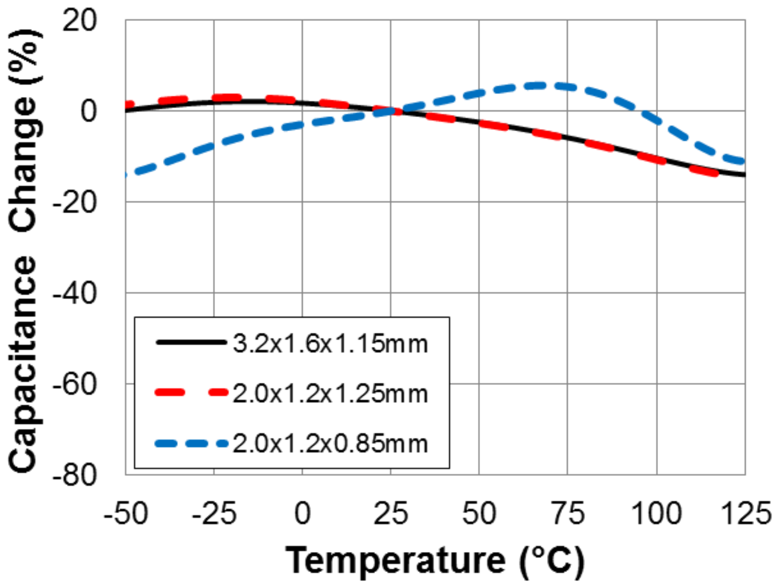
- **Ensure series cap temperature stays within limits**
  - Calculate RMS current
  - Check datasheet/online tools
- **Ex: 10.8$V_{IN,MIN}$, 1.2V_O, $I_{L,RMS}$ = 5.02A**

$$I_{SCAP,RMS} = \sqrt{2\left(\frac{2V_O}{V_{IN,MIN}}\right)I_{L,RMS}^2} = 3.34A$$

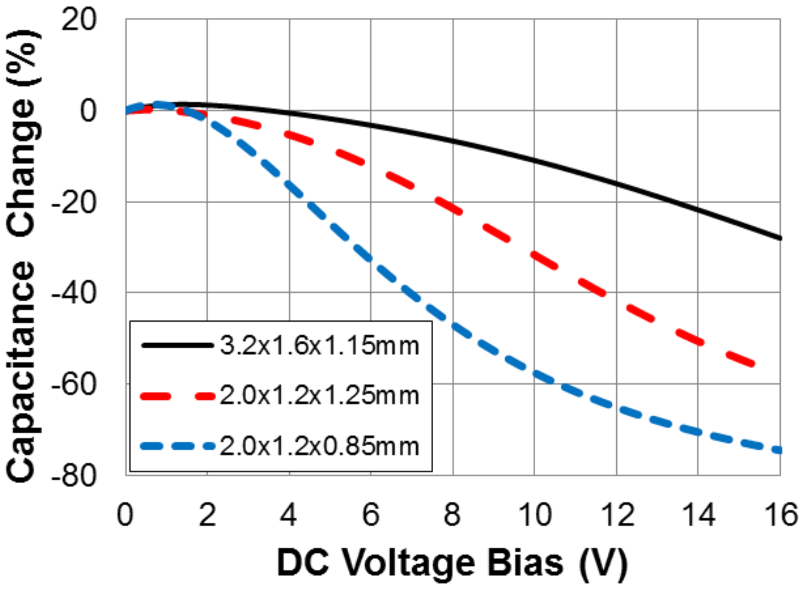
  - 2.2µF cap, 1206 (3.2 x 1.6 x 1.15mm)
  - Result: **15.8°C temp rise**
- **Same approach applies to input caps and output caps**

DC Voltage and Temp Impact on Capacitance

- **Capacitance varies with temperature**



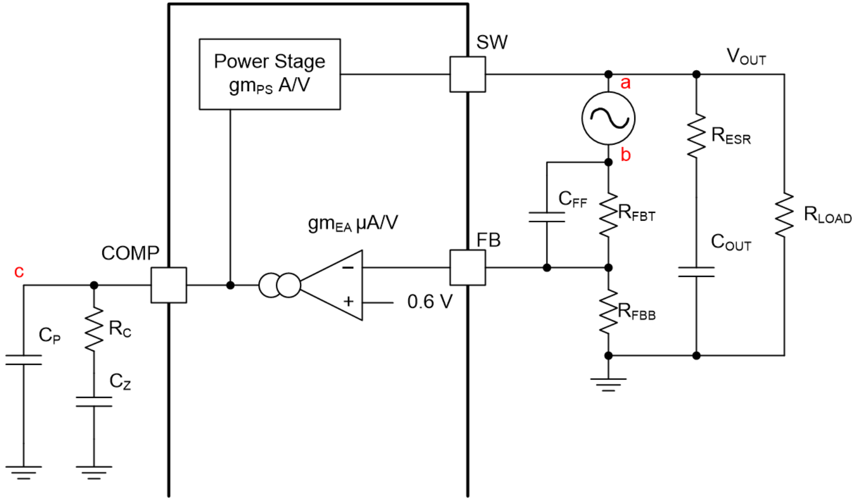
- **Capacitance decreases with DC voltage**



Select a capacitor taking capacitance variation into account.

TPS54824 Compensation Calculations

- Simplified equations in datasheet ignoring slope compensation. Stable design but conservative loop bandwidth.
- Start by selecting target loop bandwidth. Use smallest of the two calculated values.



$$f_{CO} = \sqrt{f_{P,mod} \times f_{Z,mod}} = 42.6\text{kHz}$$

$$f_{CO} = \sqrt{f_{P,mod} \times \frac{f_{SW}}{2}} = 27.5\text{kHz}$$

- Calculate compensation using DC bias de-rated C_{OUT} of ~352 µF.

$$R_C = \frac{2 \times \pi \times f_{CO} \times C_{OUT}}{gm_{PS}} \times \frac{V_{OUT}}{V_{REF} \times gm_{EA}} = 6.98\text{k}\Omega$$

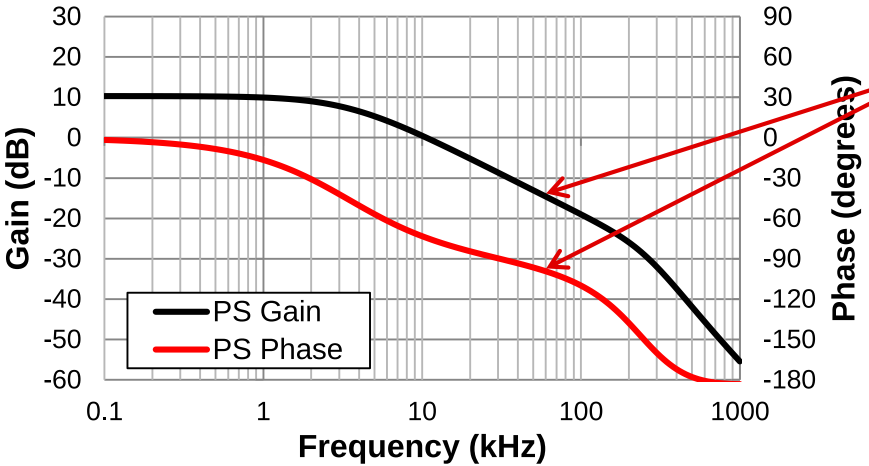
$$C_Z = \frac{1}{2 \times \pi \times \frac{f_{CO}}{10} \times R_C} = 8200\text{pF}$$

$$C_P = \frac{1}{2 \times \pi \times \frac{f_{SW}}{2} \times R_C} = 82\text{pF}$$

$$C_{FF} = \frac{1}{3 \times \pi \times f_{CO} \times R_{FBT}} = 680\text{pF}$$

TPS54824 More Optimized Compensation

- TINA or PSPICE average model to simulate power stage gain and phase.
- Calculate new R_C based on power stage gain at new target f_{CO} of 60 kHz.

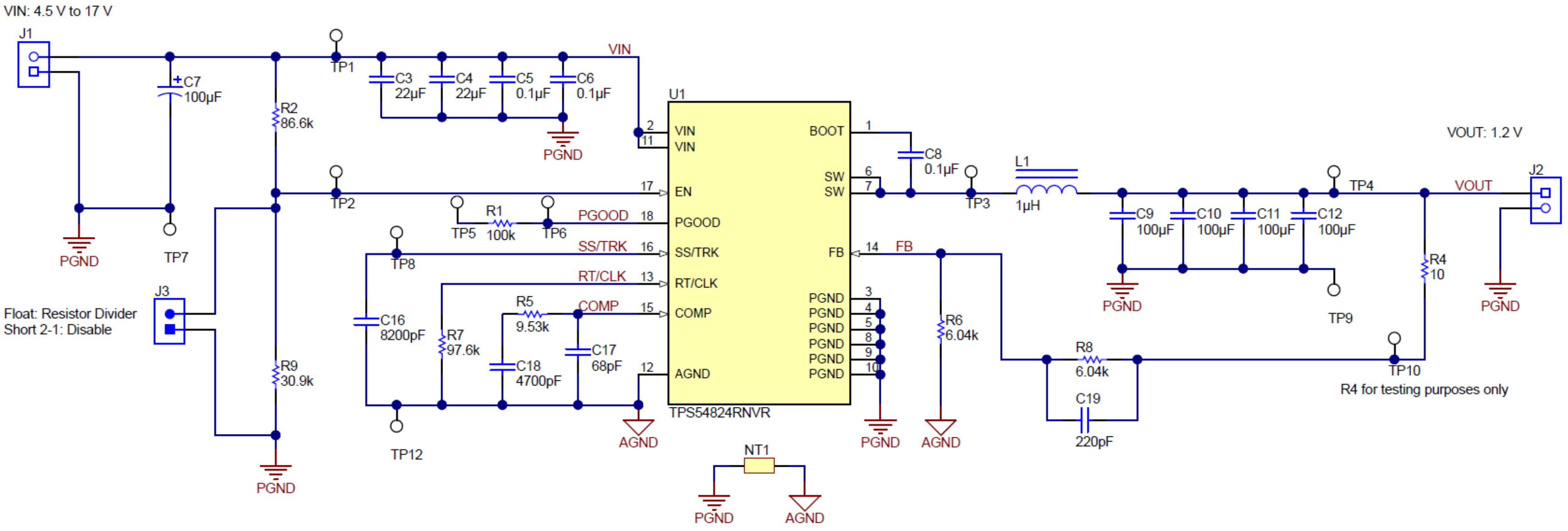


f_{CO} selected where phase is -100 degrees
Gain at 60 kHz f_{CO} is -14.6 dB

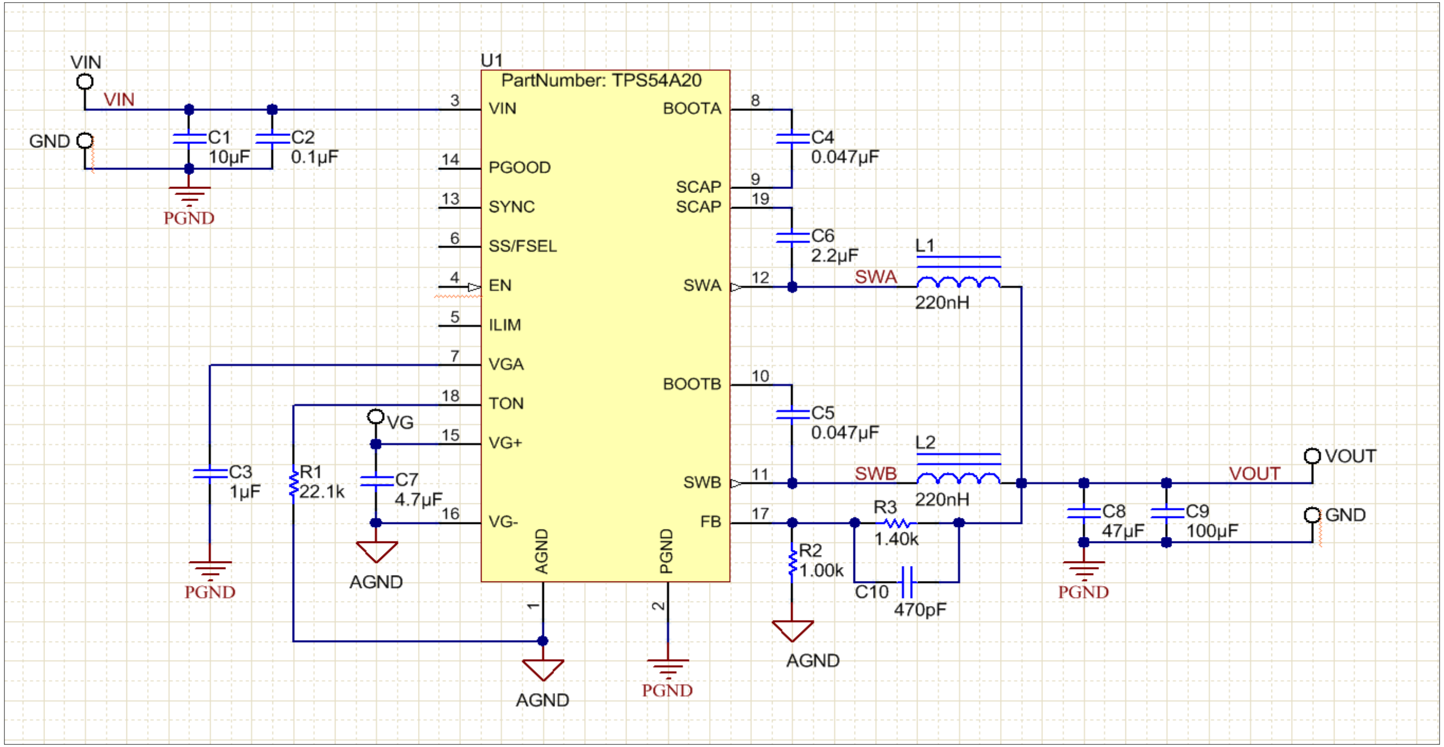
$$R_C = \frac{1}{10^{\frac{A_{PS,f_{CO}}}{20}}} \times \frac{V_{OUT}}{V_{REF} \times gm_{EA}} = 9.53\text{k}\Omega$$

- New compensation values are 9.53 kΩ, Cc = 4.7 nF, Cp = 68 pF, Cff = 220 pF.

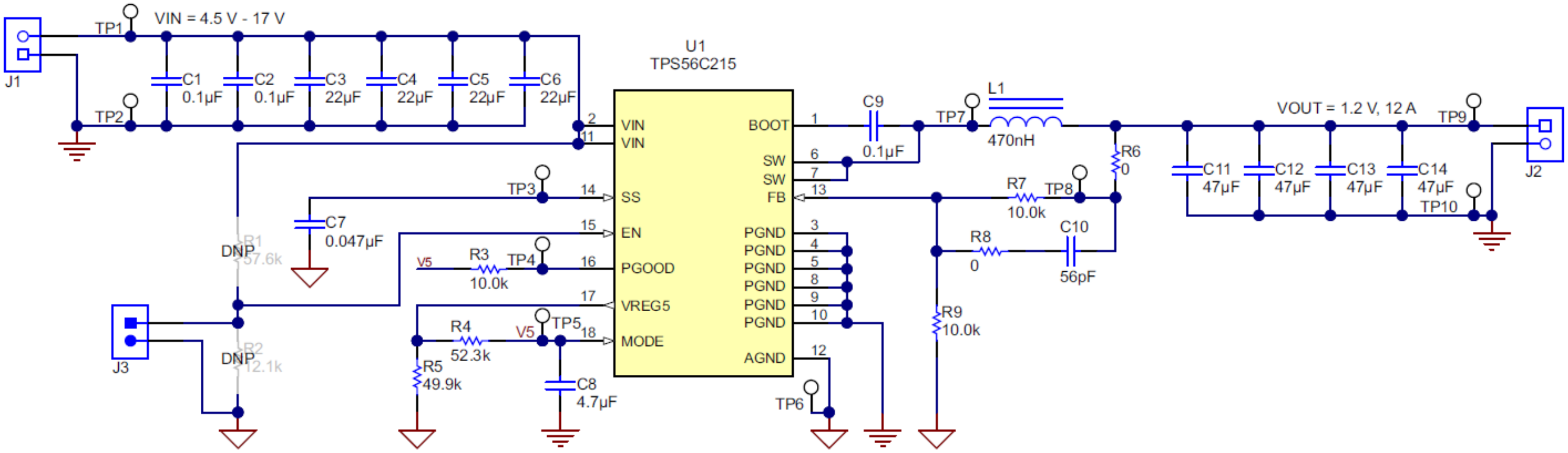
TPS54824 Schematic



TPS54A20 Schematic



TPS56C215 Schematic



*Could use 2 x 100uF output capacitors

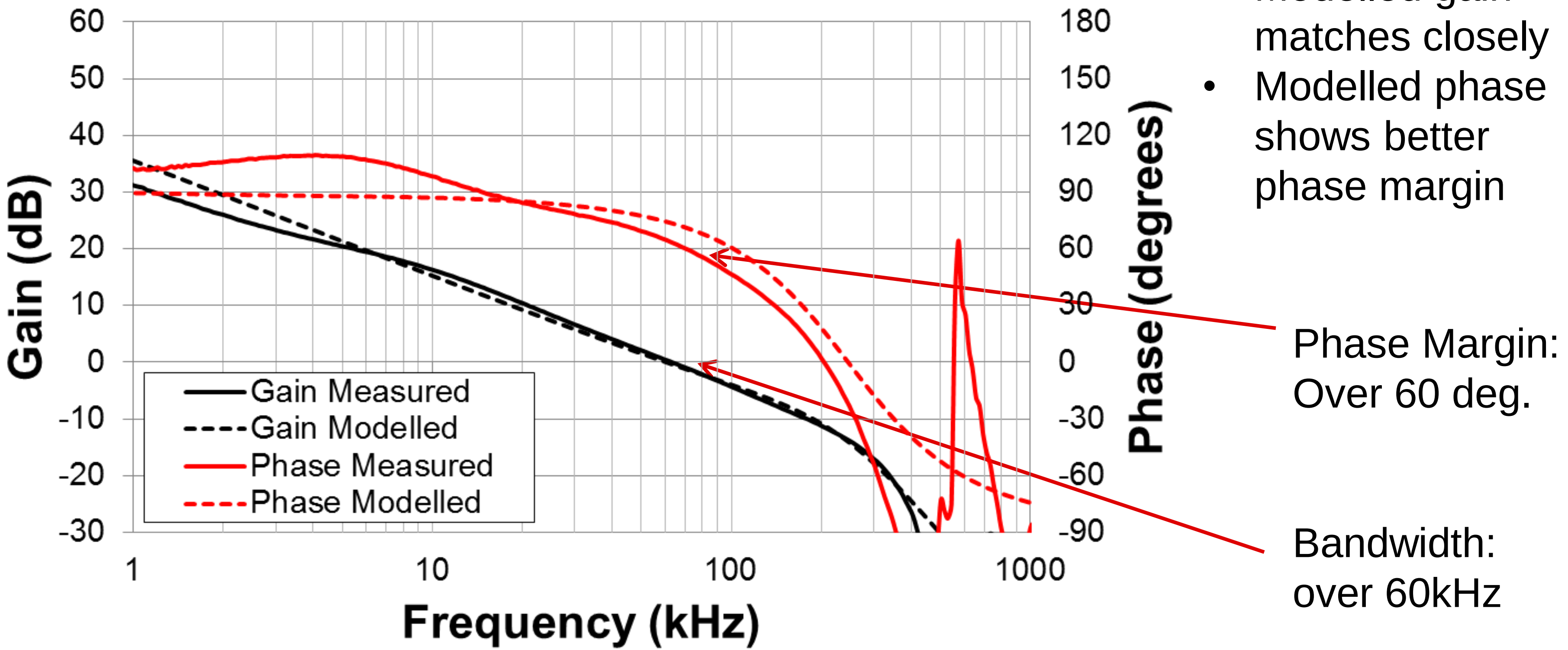
Solution Comparisons

Part Number	Control	F_{SW}	R_{DSON}	Minimum ON Time	Inductor	C_{OUT}
TPS54824	Peak CMC	500kHz	14.1-mΩ HS 6.1-mΩ LS	95ns	1µH, 11A, 10 mΩ	4 x 100µF 6.3V X5R 1210
TPS54A20	Sync COT	2MHz per phase	~14-mΩ HS* ~4-mΩ LS*	14ns	2 x 220 nH, 7.6 A, 9mΩ	47µF & 100 µF 4V X5R 0805
TPS56C215	DCAP3	1.2MHz	13.5-mΩ HS 4.5-mΩ LS	54ns	470 nH, 17.5 A, 4mΩ	4 x 47µF 6.3V X5R 0805

*Estimated RDSON due to 2 phase configuration

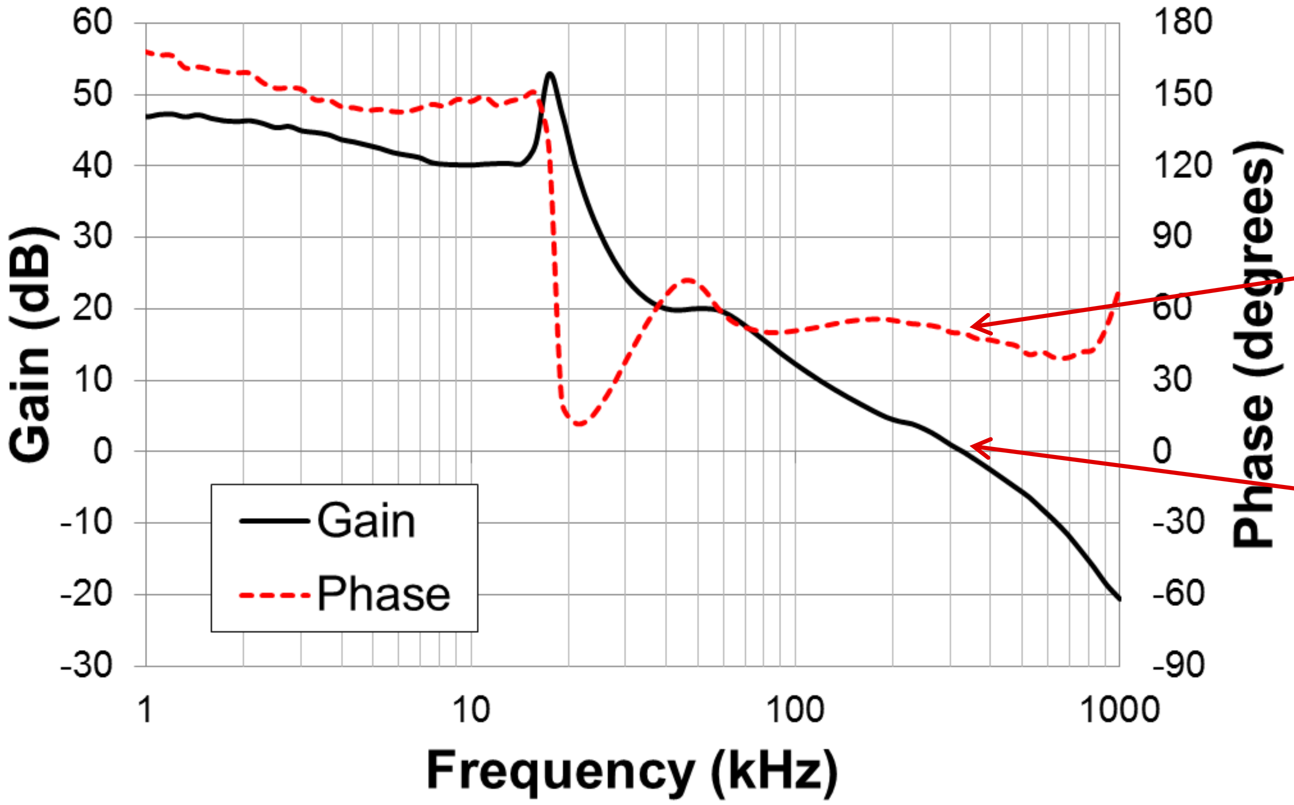
Loop Response and Transient Comparisons

TPS54824 Measured Loop Response (CCM)



- Modelled gain matches closely
- Modelled phase shows better phase margin

TPS54A20 Measured Loop Response (CCM)

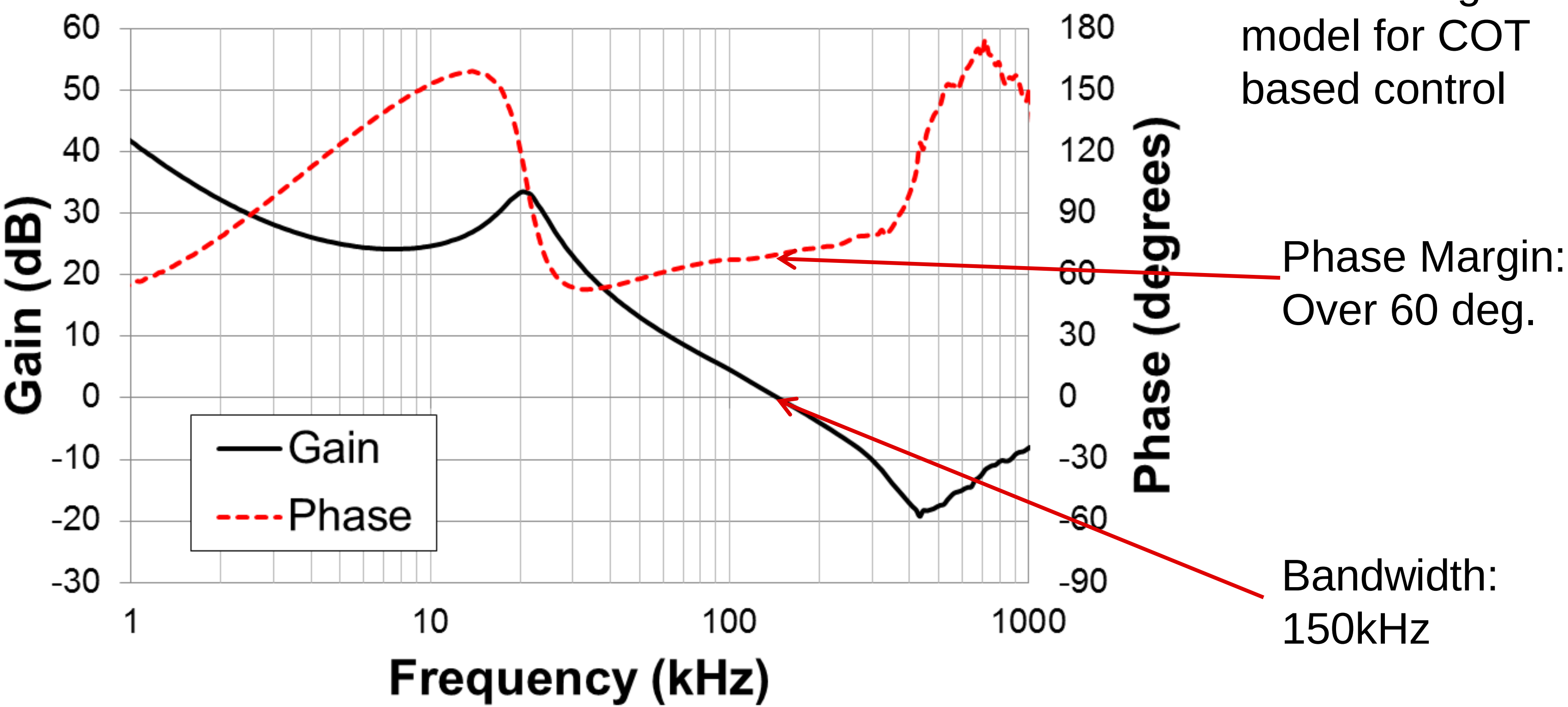


- No small signal model for COT based control

Phase Margin: Over 50 deg.

Bandwidth: over 300kHz

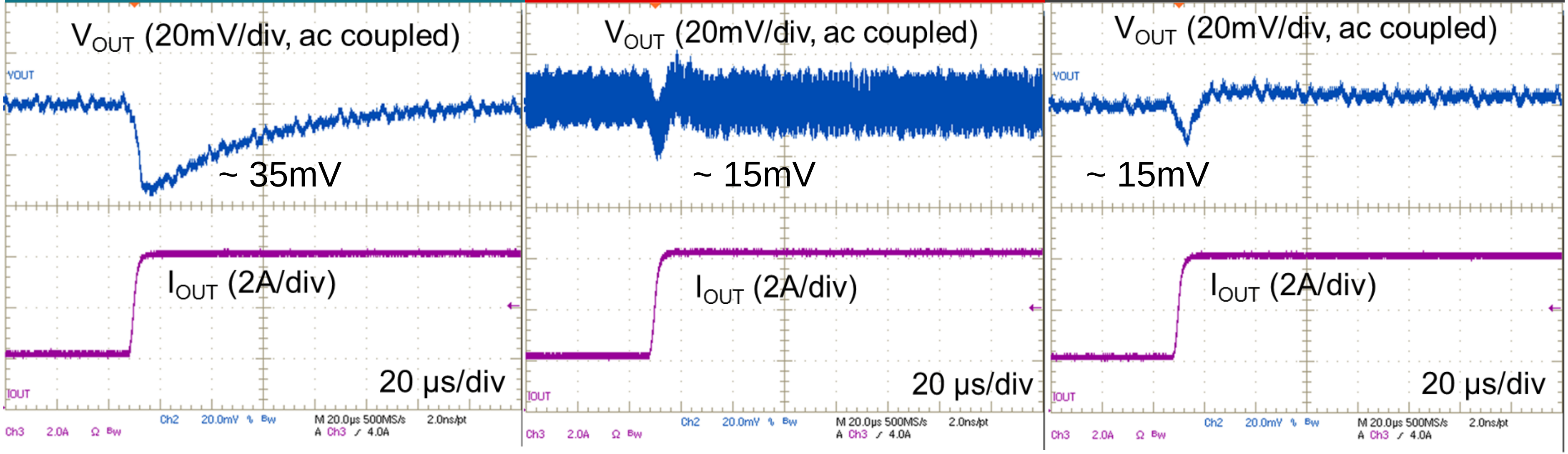
TPS56C215 Measured Loop Response (CCM)



- No small signal model for COT based control

Load Step Comparison (2 A to 6 A step at 1 A/µs)

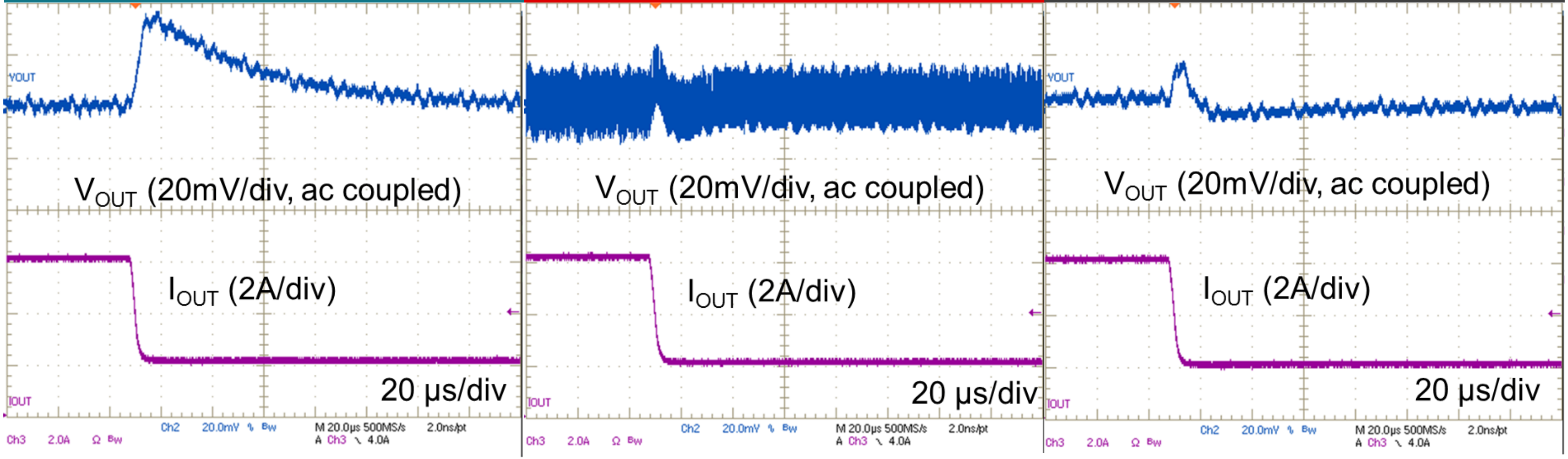
TPS54824	TPS54A20	TPS56C215



- TPS54824: **Largest undershoot** and settling time due to CM control
- TPS54A20 and TPS56C215: **Minimal undershoot** due to fast transient response of COT control

Load Step Comparison (6 A to 2 A step at 1 A/µs)

TPS54824	TPS54A20	TPS56C215

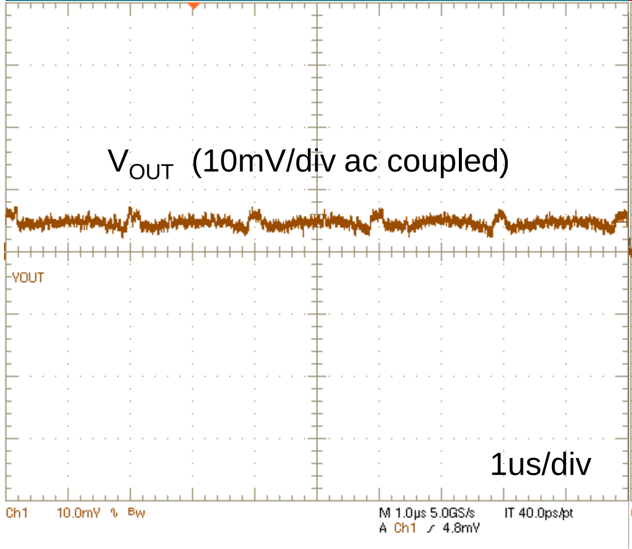


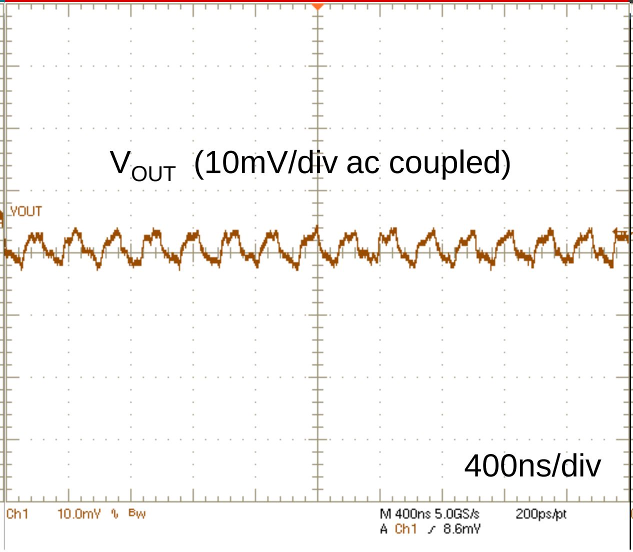
- TPS54824: **Largest overshoot** and settling time due to CM control
- TPS54A20 and TPS56C215: **Minimal overshoot** due to fast transient response of COT control

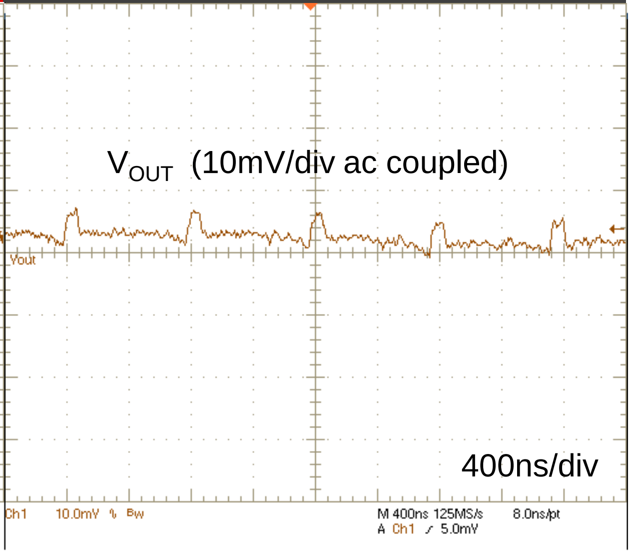
Output Ripple and Jitter

V_{OUT} Ripple – I_{OUT} = 0 A

TPS54824	TPS54A20	TPS56C215



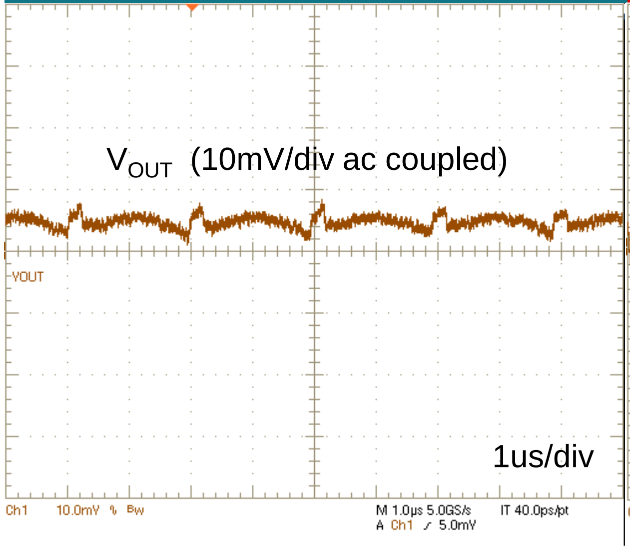


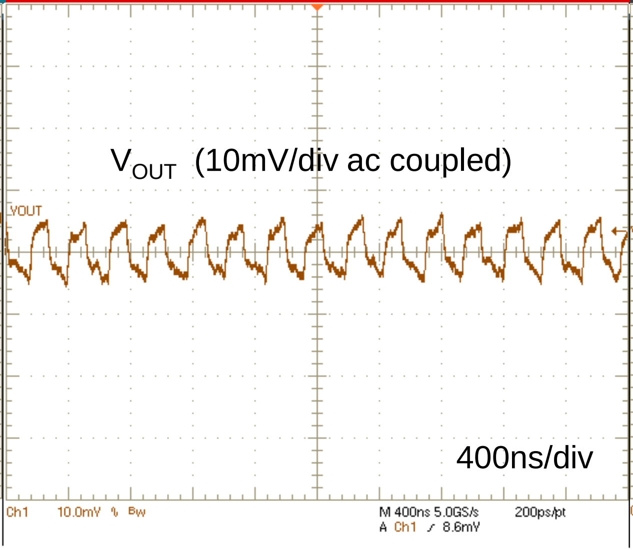


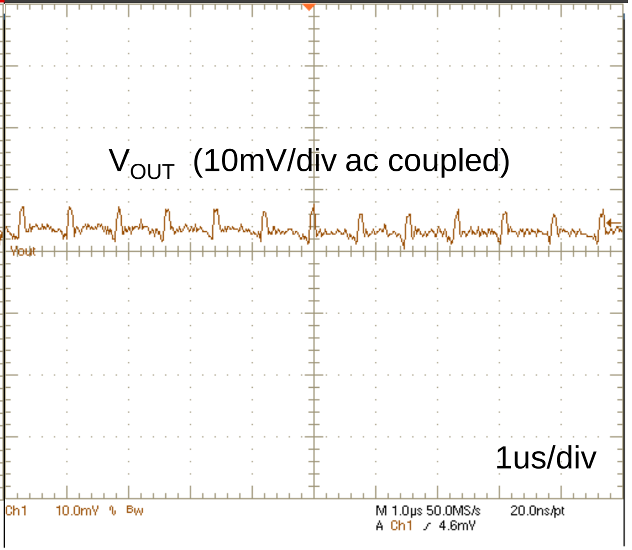
- All three designs have <10mV output voltage ripple

V_{OUT} Ripple – I_{OUT} Full Load

TPS54824	TPS54A20	TPS56C215

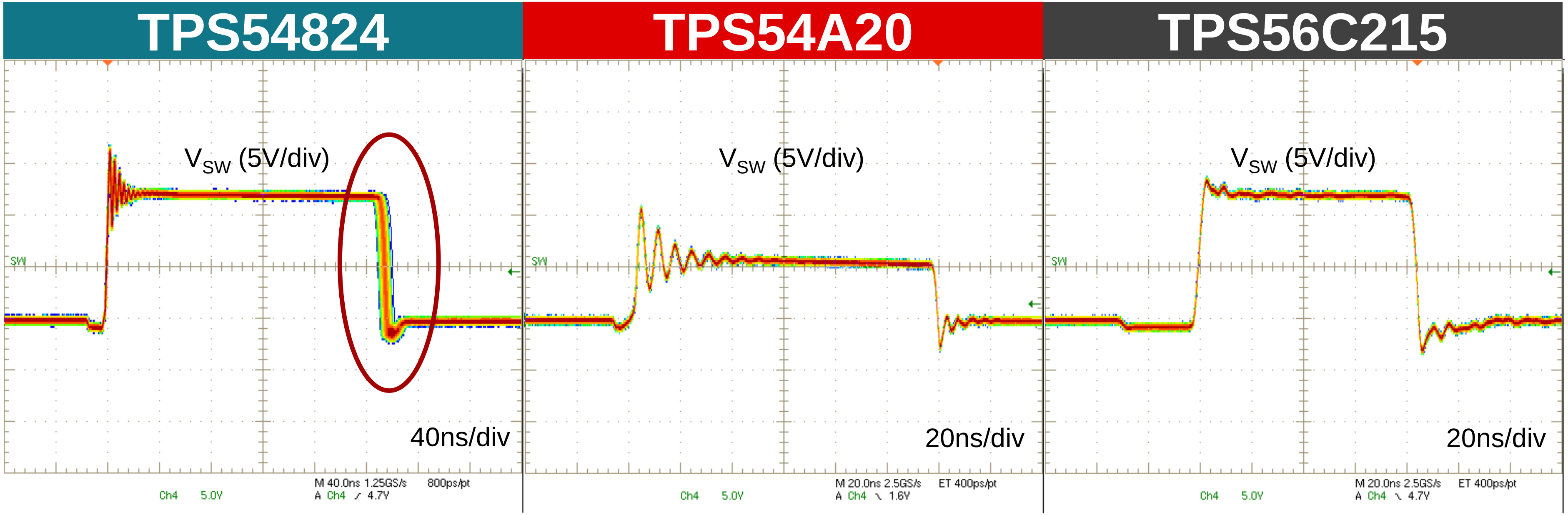






- All three designs have <10mV output voltage ripple
- Steady-state output ripple is slightly increased at full load

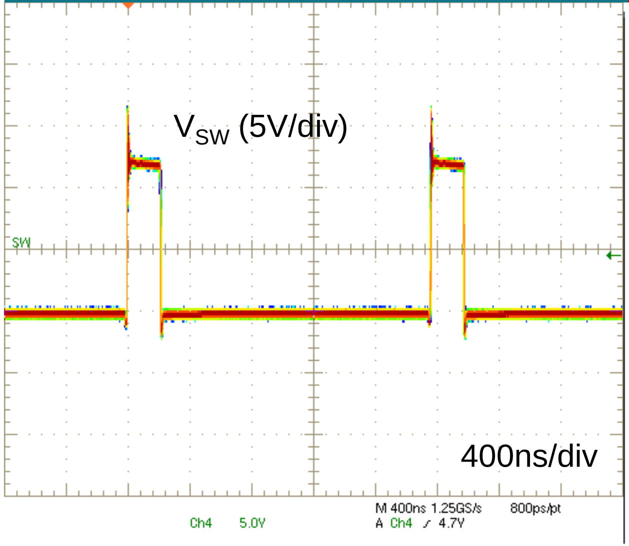
On-Time Jitter Comparison

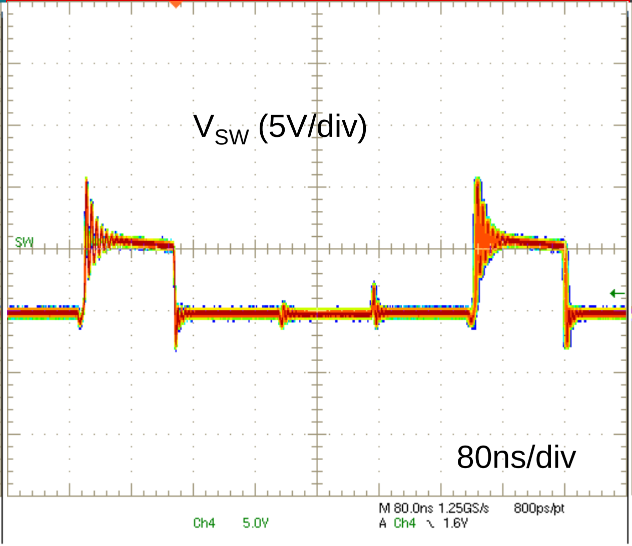


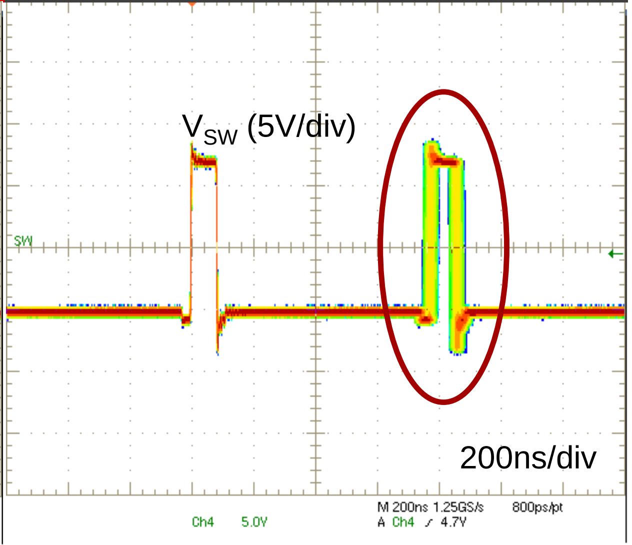
- TPS54824: **Small on-time jitter** due to on-time modulation
- TPS54A20 and TPS56C215: **No on-time jitter** due to constant on-time control
- TPS54A20: **Lower V_{SW}** due to series cap buck topology

Frequency Jitter Comparison

TPS54824	TPS54A20	TPS56C215



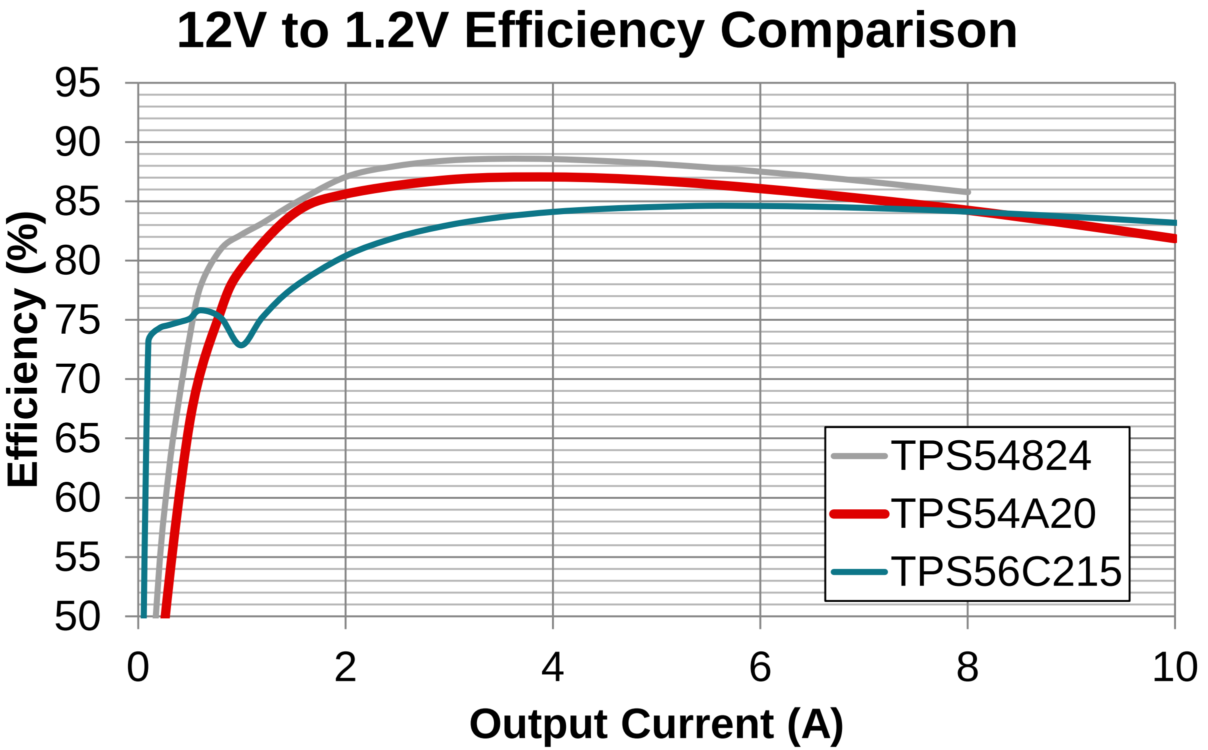




- TPS54824: **No frequency jitter** due to fixed frequency current mode control
- TPS54A20: **Very low frequency jitter** due to **synchronizable** COT control
- TPS56C215: **Frequency jitter** due to DCAP3 (COT control)
- PCB layout can affect Jitter

Efficiency Comparison

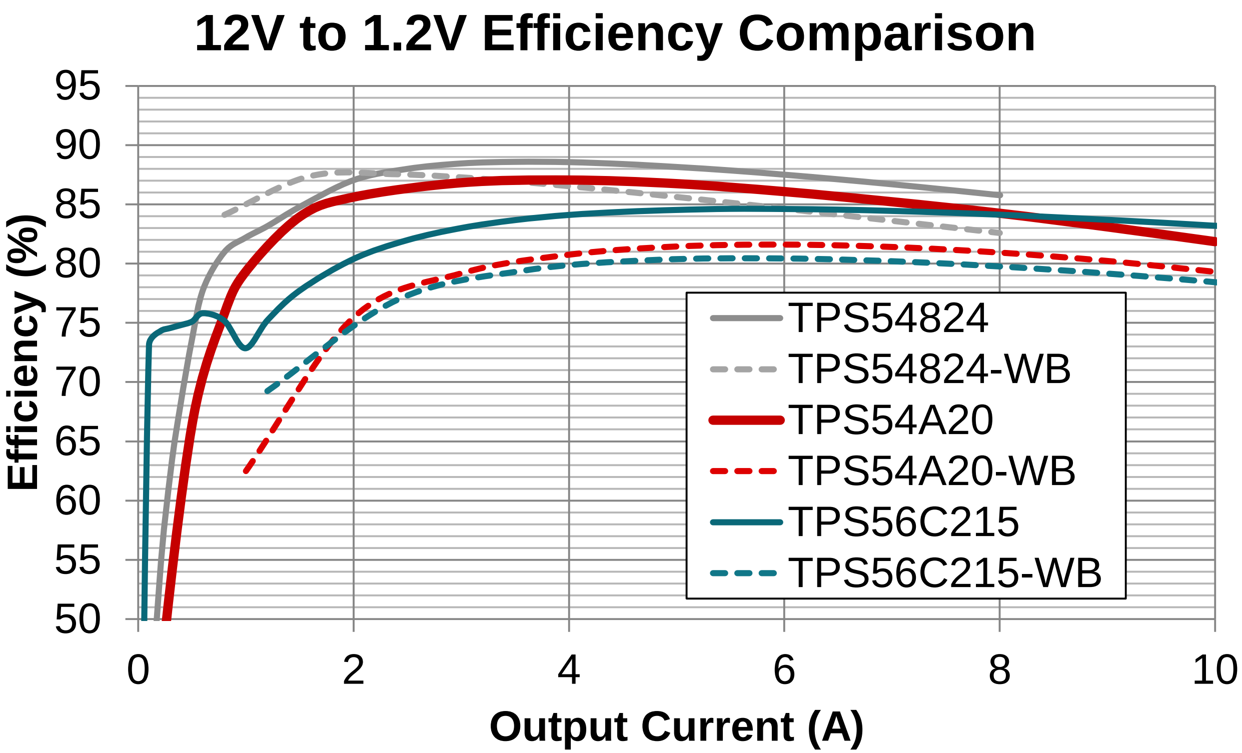
Measured Efficiency



- **TPS54824** (500 kHz) is the **highest** efficiency solution
- **TPS56C215** (1.2MHz) has best **light load** efficiency due to **Eco Mode™**
- **TPS54A20** (2MHz/phase) very **close** to TPS54824 efficiency at **4X FSW**

Note:
TPS54A20 & TPS56C215 external 5V bias

Measured Efficiency vs WEBENCH Simulation



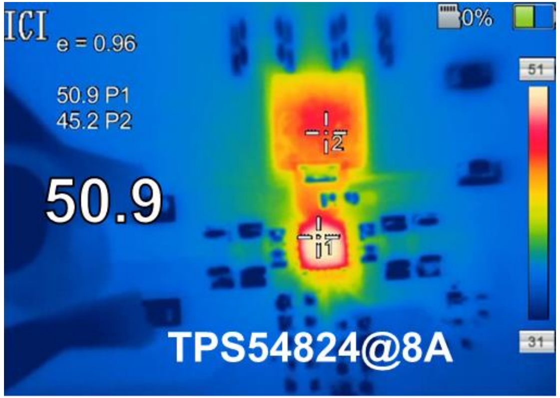
- WEBENCH efficiency estimates are **lower** than measured data.
- **External Bias** is not simulated in WEBENCH.
- **Inductor core loss** is not simulated in WEBENCH.

Thermal Comparison

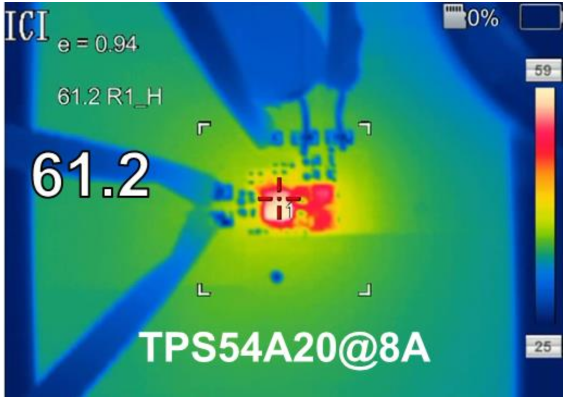
Thermal Comparison

Observations

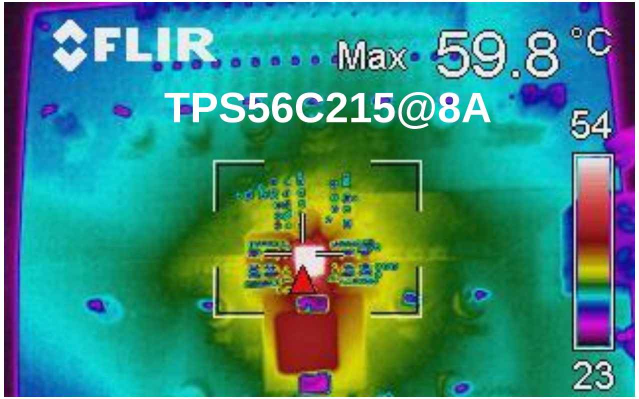
- In all 3 designs, the IC is the thermal hot spot
- TPS54A20’s small inductors are not a thermal bottleneck
- All designs have less than 40ºC temp rise



IC: 3.5x3.5mm, θ_{JA} = 34°C/W



IC: 3.5x4mm, θ_{JA} = 25°C/W



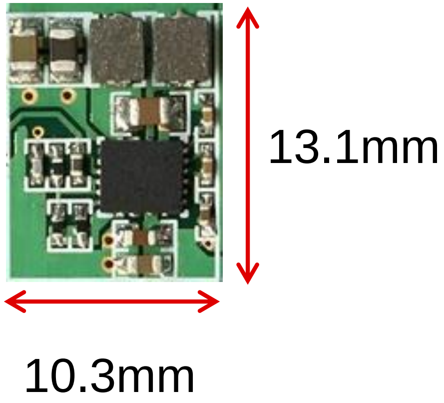
IC: 3.5x3.5mm, θ_{JA} = 29.5°C/W

Solution Size

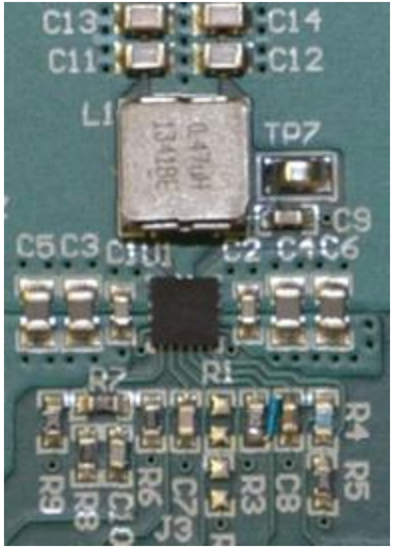
Solution Size Comparison

TPS54824 ~382 mm^2

TPS54A20 ~136 mm^2



TPS56C215 ~382 mm^2



- TPS54824 – **Largest** solution size and **highest efficiency**.
- TPS54A20 – **Smallest** solution size and **lowest profile** with 1.25 mm height vs 3.0 mm.
- TPS56C215 – **Lowest cost solution**. Could reduce size by using a smaller inductor.

Considering Cost

TPS54824 BOM Analysis

	Part Number	Description	Footprint	QTY	1k Price	Total Cost
IC	TPS54824RNVR	4.5-V to 17-V Input, 8-A Synchronous Step-Down DC/DC Converter	3.5x3.5mm	1	$2.0000	$2.0000
Inductor	IHLP2525CZER1R0M01	Inductor, Shielded Molded, 1µH, 11A, 10 mOhm	6.95x2.8x6.6mm	1	$1.0500	$1.0500
Output Caps	GRM32ER60J107ME20L	CAP, CERM, 100 µF, 6.3 V, +/- 20%, X5R, 1210	1210	4	$0.1800	$0.7200
Input Caps	GRM32ER61E226KE15L	CAP, CERM, 22 µF, 25 V, +/- 10%, X5R, 1210	1210	2	$0.1631	$0.3262
	GRM188R71E822KA01D	CAP, CERM, 8200 pF, 25 V, +/- 10%, X7R, 0603	0603	1	$0.0203	$0.0203
	GRM1885C1H270JA01D	CAP, CERM, 27 pF, 50 V, +/- 5%, C0G/NP0, 0603	0603	1	$0.0155	$0.0155
	GRM188R71E222KA01D	CAP, CERM, 2200 pF, 25 V, +/- 10%, X7R, 0603	0603	1	$0.0130	$0.0130
	885012006057	CAP, CERM, 100 pF, 50 V, +/- 5%, C0G/NP0, 0603	0603	1	$0.0365	$0.0365
	06033C104KAT2A	CAP, CERM, 0.1uF, 25V, +/-10%, X7R, 0603	0603	3	$0.0053	$0.0158
	CRCW0603100KJNEA	RES, 100 k, 5%, 0.1 W, 0603	0603	1	$0.0041	$0.0041
	CRCW060386K6FKEA	RES, 86.6 k, 1%, 0.1 W, 0603	0603	1	$0.0041	$0.0041
	CRCW060310R0JNEA	RES, 10, 5%, 0.1 W, 0603	0603	1	$0.0041	$0.0041
	CRCW06039K53FKEA	RES, 9.53 k, 1%, 0.1 W, 0603	0603	1	$0.0041	$0.0041
	CRCW06036K04FKEA	RES, 6.04 k, 1%, 0.1 W, 0603	0603	1	$0.0041	$0.0041
	CRCW060369K8FKEA	RES, 69.8 k, 1%, 0.1 W, 0603	0603	1	$0.0041	$0.0041
	CRCW060312K1FKEA	RES, 12.1 k, 1%, 0.1 W, 0603	0603	1	$0.0041	$0.0041
	CRCW060330K9FKEA	RES, 30.9 k, 1%, 0.1 W, 0603	0603	1	$0.0041	$0.0041
			Total Cost			**$4.23**

TPS54A20 BOM Analysis

	Part Number	Description	Footprint	QTY	1k Price	Total Cost
IC	TPS54A20	8V to 14V, 10A, up to 10MHz Synchronous Step-Down Converter	3.5x4mm	1	$3.25	$3.25
Inductors	HMLW32251B-R22MS-79	Inductor, Powdered Iron, 220 nH, 7.6 A, 0.009 ohm, SMD	3.2x2.5x1.2mm	2	$0.2240	$0.4480
Output Caps	GRM21BR60J476ME15L	47µF ±20% 6.3V Ceramic Capacitor X5R 0805	0805	1	$0.1278	$0.1278
	GRM21BR60G107ME15L	CAP, CERM, 100 µF, 4 V, +/- 20%, X5R, 0805	805	1	$0.4305	$0.4305
Series Cap	GRM21BR71A225MA01L	CAP, CERM, 2.2 µF, 10 V, +/- 20%, X7R, 0805	0805	1	$0.0459	$0.0459
Input Caps	C1608X5R1E106M080AC	CAP, CERM, 10 µF, 25 V, +/- 20%, X5R, 0603	0603	1	$0.3010	$0.3010
	GRM188R61E104KA01D	CAP, CERM, 0.1 µF, 25 V, +/- 10%, X5R, 0603	0603	1	$0.0090	$0.0090
	GRM155R61E105KA12D	CAP, CERM, 1 µF, 25 V, +/- 10%, X5R, 0402	0402	1	$0.0177	$0.0177
	GRM155R71A473KA01D	CAP, CERM, 0.047 µF, 10 V, +/- 10%, X7R, 0402	0402	2	$0.0061	$0.0122
	GRM155R61A475M	CAP, CERM, 4.7 µF, 10 V, +/- 20%, X5R, 0402	0402	1	$0.0948	$0.0948
	C1005C0G1H471J	CAP, CERM, 470 pF, 50 V, +/- 5%, C0G/NP0, 0402	0402	1	$0.0108	$0.0108
	CRCW040222K1FKED	RES, 22.1 k, 1%, 0.063 W, 0402	0402	1	$0.0058	$0.0058
	CRCW04021K00FKED	RES, 1.00 k, 1%, 0.063 W, 0402	0402	1	$0.0058	$0.0058
	CRCW04021K40FKED	RES, 1.40 k, 1%, 0.063 W, 0402	0402	1	$0.0058	$0.0058
	CRCW040247K0FKED	RES, 47k, 1%, 0.063 W, 0402	402	1	$0.0058	$0.0058
	CRCW040280K6FKED	RES, 80.6k, 1%, 0.063 W, 0402	402	1	$0.0058	$0.0058
	CRCW040212K4FKED	RES, 12.4k, 1%, 0.063 W, 0403	402	1	$0.0058	$0.0058
			Total Cost			**$4.78**

TPS56C215 BOM Analysis

	Part Number	Description	Footprint	QTY	1k Price	Total Cost
IC	TPS56C215RNNR	4.5V to 17V Input, 12A Synchronous Step-Down Converter,	RUW0015A	1	$1.90	$1.90
Inductor	IHLP2525CZERR47M01	Inductor, Shielded Drum Core, Powdered Iron, 470 nH, 17.5 A, 0.004 ohm	IHLP-2525CZ	1	$1.06	$1.06
Output Caps	GRM21BR61E226ME44L	22µF ±20% 25V Ceramic Capacitor X5R 0805	0805	4	$0.1162	$0.46
Input Caps	GRM21BR60J476ME15L	47µF ±20% 6.3V Ceramic Capacitor X5R 0805	0805	4	$0.1278	$0.5111
	GRM188R71E104KA01D	CAP, CERM, 0.1 µF, 25 V, +/- 10%, X7R, 0603	0603	3	$0.0049	$0.0146
	GRM188R71H473KA61D	CAP, CERM, 0.047 µF, 50 V, +/- 10%, X7R, 0603	0603	1	$0.0147	$0.0147
	GRM188R61A475ME15	CAP, CERM, 4.7 µF, 10 V, +/- 20%, X5R, 0603	0603	1	$0.0303	$0.0303
	GRM1885C1H560JA01D	CAP, CERM, 56 pF, 50 V, +/- 5%, C0G/NP0, 0603	0603	1	$0.0155	$0.0155
	CRCW060310K0FKEA	RES, 10.0 k, 1%, 0.1 W, 0603	0603	3	$0.0055	$0.0166
	CRCW060352K3FKEA	RES, 52.3 k, 1%, 0.1 W, 0604	0603	1	$0.0055	$0.0055
	CRCW060349K9FKEA	RES, 49.9 k, 1%, 0.1 W, 0605	0603	1	$0.0055	$0.0055
	MCR03EZPJ000	RES, 0, 5%, 0.1 W, 0603	0603	2	$0.0024	$0.0047
	CRCW060357K6FKEA	RES, 57.6 k, 1%, 0.1 W, 0603	0603	1	$0.0055	$0.0055
	CRCW060312K1FKEA	RES, 12.1 k, 1%, 0.1 W, 0603	0603	1	$0.0055	$0.0055
			Total Cost			**$4.05**

BOM Analysis

Part Number	Inductors	Caps	Resistors	IC	Total
TPS54824	$1.05	$1.15	$0.03	$2.00	$4.23
TPS54A20	$0.45	$1.05	$0.03	$3.25	$4.78
TPS56C215	$1.06	$1.05	$0.04	$1.90	$4.05

IC cost is not the only factor to consider!! (Note all pricing is 1K Resale)

- Make sure to evaluate the **total solution cost**!!
- **Capacitors & inductors** can greatly affect the solution cost
  - Capacitors cost will vary with package chosen
    - Caps selected for TPS54A20 were more expensive per piece due to smaller package size
  - Inductor cost will vary depending on size and construction

Summary

TPS54824	TPS54A20	TPS56C215
• Highest **efficiency** • Lowest **temperature** rise • No frequency **jitter** • **3X solution size**	• Smallest solution **size** • Lowest **profile** (height) • Highest **bandwidth**	• Lowest **cost** solution • Fast **transient** response • High **light load efficiency** • **3X solution size**

Part Number	Efficiency @2A/6A/8A	Solution Size (mm^2)	BW (kHz)	Transient (mV)	Ripple @Full Load (mV)	On-Time Jitter	FREQ Jitter	IC Thermal @8A	Solution Cost
TPS54824	87/87.5/86	382	60	35	5	very little	no	50.9°C	$4.23
TPS54A20	85.5/86/84.5	136	300	15	10	no	very little	61.2°C	$4.78
TPS56C215	80.5/84.5/84	382	150	15	5	no	yes	59.8°C	$4.05