DN0046
Design note

Power over ethernet - PD converter with 24 V 2.5 A output, synchronous flyback

***Design notes** describe tested circuit designs from ST labs which provide optimized solutions for specific applications.*
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Main components	
PM8804TR	PWM peak current mode controller for PoE
750311783	Power Transformers
BSC500N20NS3GATMA1	Primary MOSFET
STL40N10F7	Secondary MOSFET
SRK1000	Adaptive synchronous rectification controller
FOD817AS	Optocoupler
TS2431-AILT	Adjustable Shunt Voltage Reference

Specification

- Input voltage range 36 V to 54 V
- Output voltage 24 V ±5%
- Switching frequency 250 KHz
- Max. Output current 2.5 A
- PWM operation current mode controller
- Max. Output power 60 W
- DC-DC Efficiency above 90%
- Peak to peak output ripple at full load 160 mV
- Transient response ΔV pk-pk 100% to 50% load step 1.4 V

Circuit description

This Design Notes describes a Flyback circuit for PoE applications, delivering 24 V @2.5 A.

A prototype with these characteristics has been based on modifying an existing demo board, the STEVAL-POE002V1; this demo board integrates a front-end part to interface the Ethernet input and a 40 W converter delivering 5 V @8 A). Only the DC-DC converter part has been used to do the trials (to the right of the red line in the below figure) after modifying the circuitry according to the new design specification.

The DC-DC converter stage is based on the fixed frequency Flyback topology controlled by the PM8804 and uses a secondary synchronous rectification managed by SRK1000.

Figure 1. Steval-poe002v1 evaluation board

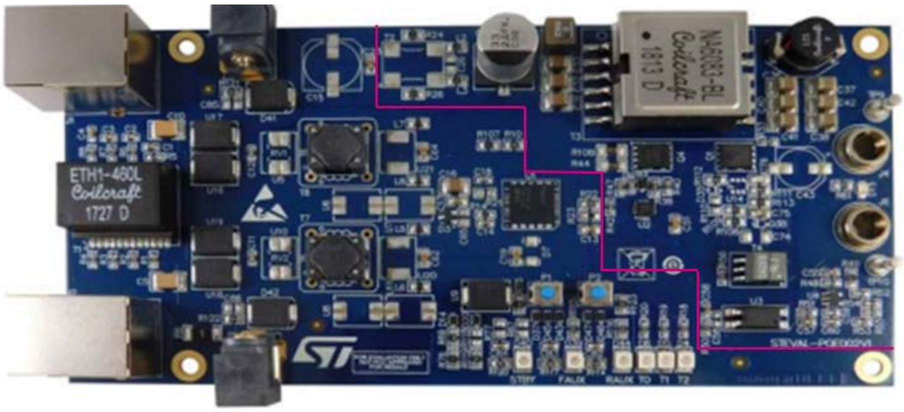


Figure 2. Circuit diagram

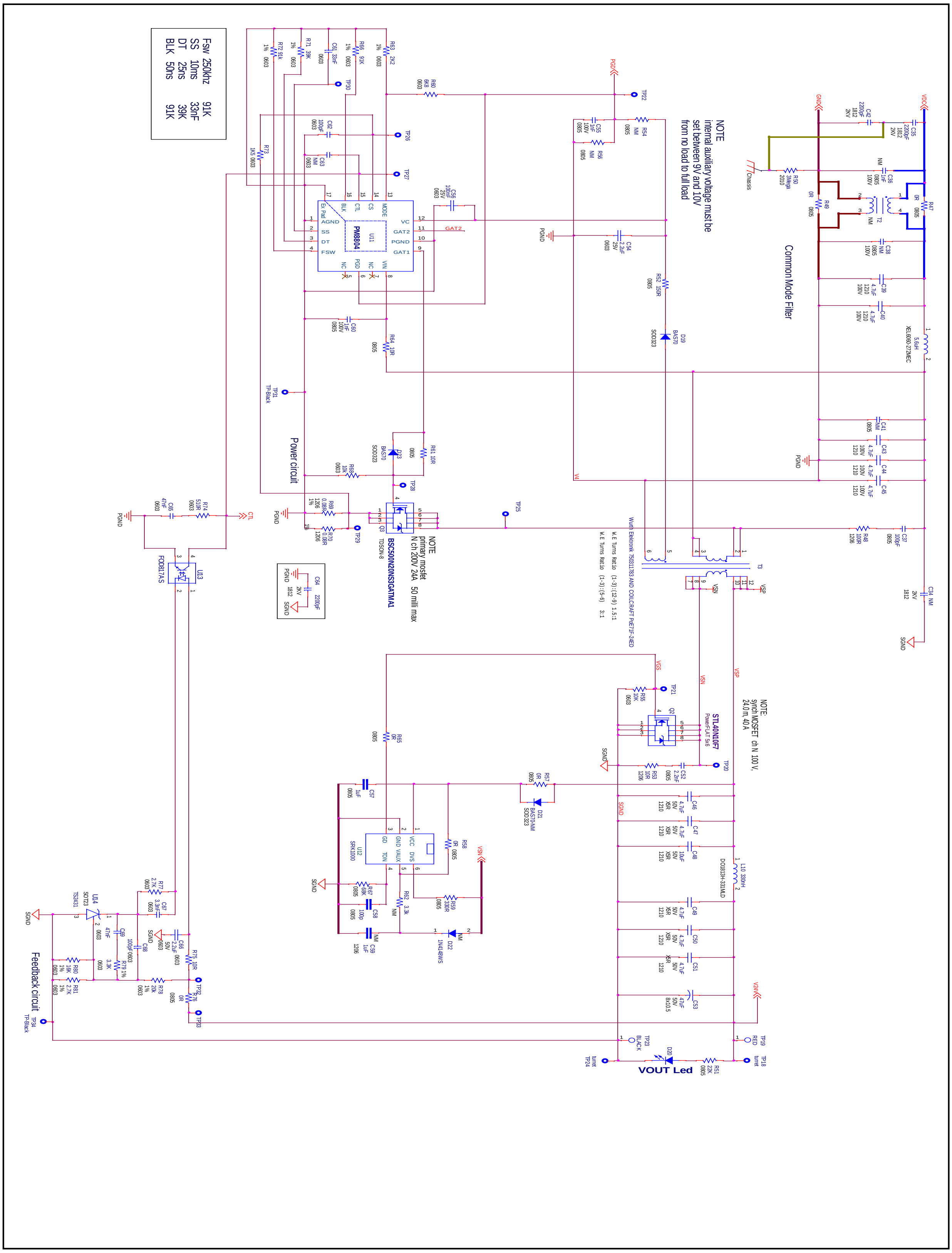


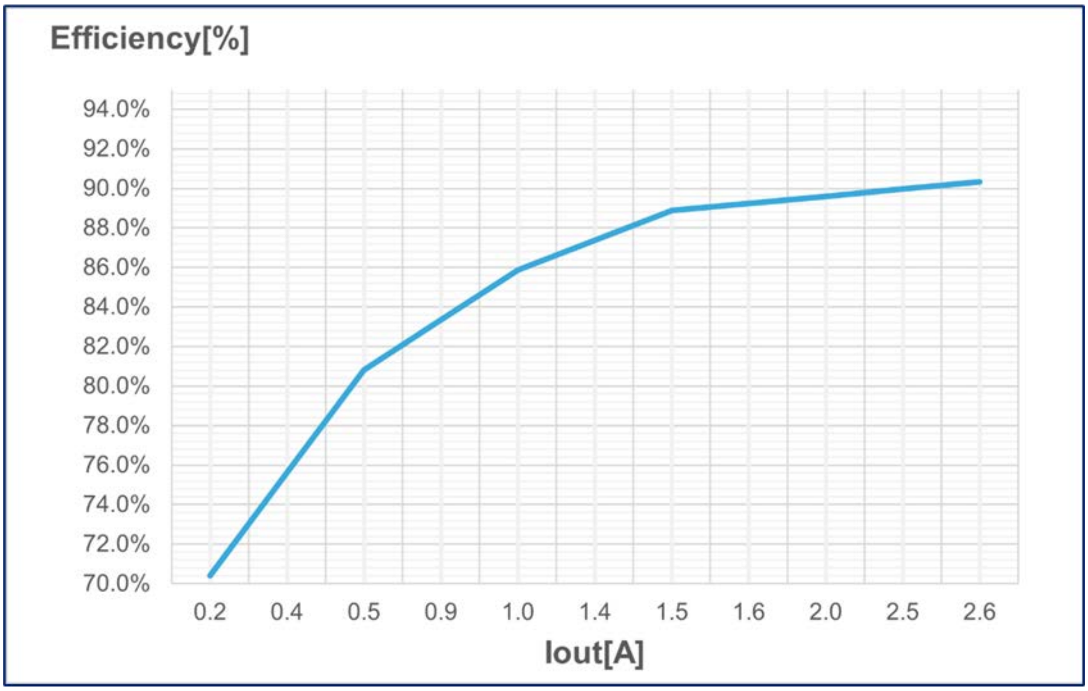
Table 1. Bill of materials

Item	Q. ty	Ref.	Part/Value	Description	Manufacturer	Order code
1	1	C34	10nF, 1812, 2KV	Capacitor	NM	NM
2	3	C35, C42	2200pF, 1812, 2KV	Capacitor	TDK	C4532X7R3D222K130KA
3	1	C36, C38	1nF, 0805, 100V	Capacitor	NM	NM
4	1	C37	100pF, 0806, 50V	Capacitor	Walsin	0805N101J500CT
5	4	C40, C43, C44, C45	4.7uF, 1210, 100V	Capacitor	TDK	C3225X7S2A475K200AB
6	1	C41	4.7uF, 1210, 100V	Capacitor	NM	NM
7	5	C46, C47, C49, C50, C51	4.7uF, 1210, 50V	Capacitor	Taiyo Yuden	UMK325BJ475KN-T
8	1	C48	10uF, 1210, 50V	Capacitor	Taiyo Yuden	UMK325BJ106KM-P
9	1	C52	2.2nF, 0805, 100V, x7R	Capacitor	Wurth Elektronik	885382207005
10	1	C53	47uF, 8x10mm, 50V	Capacitor	Nichicon	UCX1H470MCS1GS
11	1	C54	2.2uF, 0603, 25V	Capacitor	Kemet	C0603C104M5RACTU
12	1	C55	1nF, 0805, 100V	Capacitor	Walsin	0805B102J101CT
13	1	C56	100nF, 0603, 25V	Capacitor	Walsin	0603B104M250CT
14	1	C57	1uF, 0805, 50V	Capacitor	Murata	GRM21BR71H105KA12L
15	1	C58	100pF, 0805, 50V	Capacitor	Walsin	0805N101J500CT
16	1	C59	1uF, 1206, 50V	Capacitor	NM	NM
17	1	C60	1nF, 0805, 100V	Capacitor	Walsin	0805N102J101CT
18	1	C61	33nF, 0603, 50V	Capacitor	Walsin	0603B334K500CT
19	1	C62	100pF, 0603, 50V	Capacitor	Walsin	0201N101J500CT
20	1	C63	100pF, 0603, 50V	Capacitor	NM	NM
21	1	C64	2200pF, 1812, 2kV	Capacitor	TDK	C4532X7R3D222K130KA
22	2	C65, C69	47nF, 0603, 50V	Capacitor	TDK	C1608X7R1H473K080AA
23	1	C66	2.2uF, 0603, 50V	Capacitor	Yageo	CC0603KRX5R9BB225
24	1	C67	3.3nF, 0603, 50V	Capacitor	Wurth Elektronik	885012206086
25	1	C68	100pF, 0603, 50V	Capacitor	TDK	C1608NP01H101J080AA
26	2	C70, C71	100nF, 0603, 50V	Capacitor	NM	NM
27	1	C72	1uF, 0603, 50V	Capacitor	NM	NM
28	2	D19, D23	BAS70-SOD-323	Diode	STMicroelectronics	BAS70JFILM
29	1	D20	VOUT SMD_0805	Led Diode	Kingbright	APT2012SGC
30	3	D21, D24, D25	BAS70-SOD-323	Diode	NM	NM
31	1	D22	1N4148WS, SOD-323	Diode	NM	NM
32	1	L9	5.6uH, 7.2A	Inductor	COILCRAFT	XAL5050-562MEB
33	1	L10	330nH, 7A	Inductor	COILCRAFT	DO1813H-331MLD
34	1	Q2	100V, 10A, 24mΩ, PowerFLAT-5x6-8	Power MOSFET	STMicroelectronics	STL40N10F7
35	1	Q3	200V, 24A, 50mΩ, TDSON-8	Power MOSFET	Infineon	BSC500N20NS3GATMA1

36	1	Q4	40V, 0.2A, SOT23	BJT	NM	NM
37	1	T2	WURTH_WE-SL5	Common choke	NM	NM
38	1	T3	24V, 2.5A, 20uH	Power Transformers	Wurth Elektronik	750311783
39	1	U11	16QFN_3X3X0.75_0.5	Controller	STMicroelectronics	PM8804TR
40	1	U12	SRK1000 SOT-23-6LEAD	Controller	STMicroelectronics	SRK1000
41	1	U13	FOD817AS	Optocoupler	ON Semiconductor	FOD817AS
42	1	U14	TS431AILT, SOT-23-5LEAD	Voltage, Reference	STMicroelectronics	TS2431-AILT
43	2	R47, R49	0R, 0805, 5%	Resistor	Yageo	RC0805JR-070RL
44	1	R48	100R, 1206, 1%	Resistor	Yageo	RC1206FR-07100RL
45	1	R50	3MΩ, 2010, 5%	Resistor	Panasonic	ERJ-12ZYJ305U
46	1	R51	22KΩ, 0805, 1%, 100 PPM / C	Resistor	Any	Any
47	1	R52	150Ω, 0603, 1%, 100 PPM / C	Resistor	TE Connectivity	CRG0603F150R
48	2	R53, R64	10, 0805, 1%, 200 PPM / C	Resistor	Yageo	RC0805FR-0710RL
49	2	R54, R56	10Ω, 0805	Resistor	NM	NM
50	2	R55, R68,	10KΩ, 0603,1%, 100 PPM / C	Resistor	Yageo	RC0603FR-0710KL
51	2	R86, R87	10KΩ, 0603,1%, 100 PPM / C	Resistor	NM	NM
52	4	R57, R58, R65, R76	0Ω, 0805, 5%	Resistor	Yageo	RC0805JR-070RL
53	2	R82, R83	0Ω, 0805, 5%	Resistor	NM	NM
54	1	R59	330Ω, 0805, 1%, 100 PPM / C	Resistor	Yageo	RC0805FR-07330RL
55	1	R60	6.8KΩ, 0603, 1%, 100 PPM / C	Resistor	Yageo	RC0603FR-076K8L
56	3	R61, R64, R75	10Ω, 0603, 1%, 200 PPM / C	Resistor	Yageo	RC0603FR-0710RL
57	1	R85	10Ω, 0603, 1%, 200 PPM / C	Resistor	NM	NM
58	2	R64, R72	91kΩ, 0603, 1%, 100 PPM / C	Resistor	Yageo	RC0603FR-0791KL
59	1	R67	68KΩ, 0805, 1%, 100 PPM / C	Resistor	Any	Any
60	2	R69, R70	80mΩ, 1206, 1%, 600 PPM / C	Resistor	Any	Any
61	1	R71	39KΩ, 0603, 1%, 100 PPM / C	Resistor	Any	Any
62	1	R73	1.5KΩ, 0603, 1%, 100 PPM / C	Resistor	Yageo	RC0603FR-071K5L
63	1	R74	510Ω, 0603, 1%, 100 PPM / C	Resistor	Any	Any
64	2	R77, R81	2.7kΩ, 0603, 1%, 100 PPM / C	Resistor	Any	Any
65	1	R78	20kΩ, 0603, 1%, 100 PPM / C	Resistor	Vishay	CRCW060320K0FKEA
66	1	R79	3.3kΩ, 0603, 1%, 100 PPM / C	Resistor	Yageo	RC0603FR-073K3L
67	1	R80	16kΩ, 0603, 1%, 100 PPM / C	Resistor	Any	Any
68	1	R84	1kΩ, 0603, 1%, 100 PPM / C	Resistor	NM	NM
69	1	R88	100Ω, 0805, 1%, 100 PPM / C	Resistor	NM	NM

Measurement results

Figure 3. DC-DC Efficiency measurement: VIN(V:C38) 48 V; Iout (TP18-TP24): 0.2 A-2.5 A



In Figure 3 the efficiency measurement is performed, applying different values of current (0.2A-2.5A) in the (TP18-TP24); It's noted an efficiency value greater of 90% to max. load.

Figure 4. Output voltage ripple: Vin(C:38) = 48 V, Iout = no load

Ch1: Vout (TP18-TP24); Ch3: Iout (TP18-TP24)

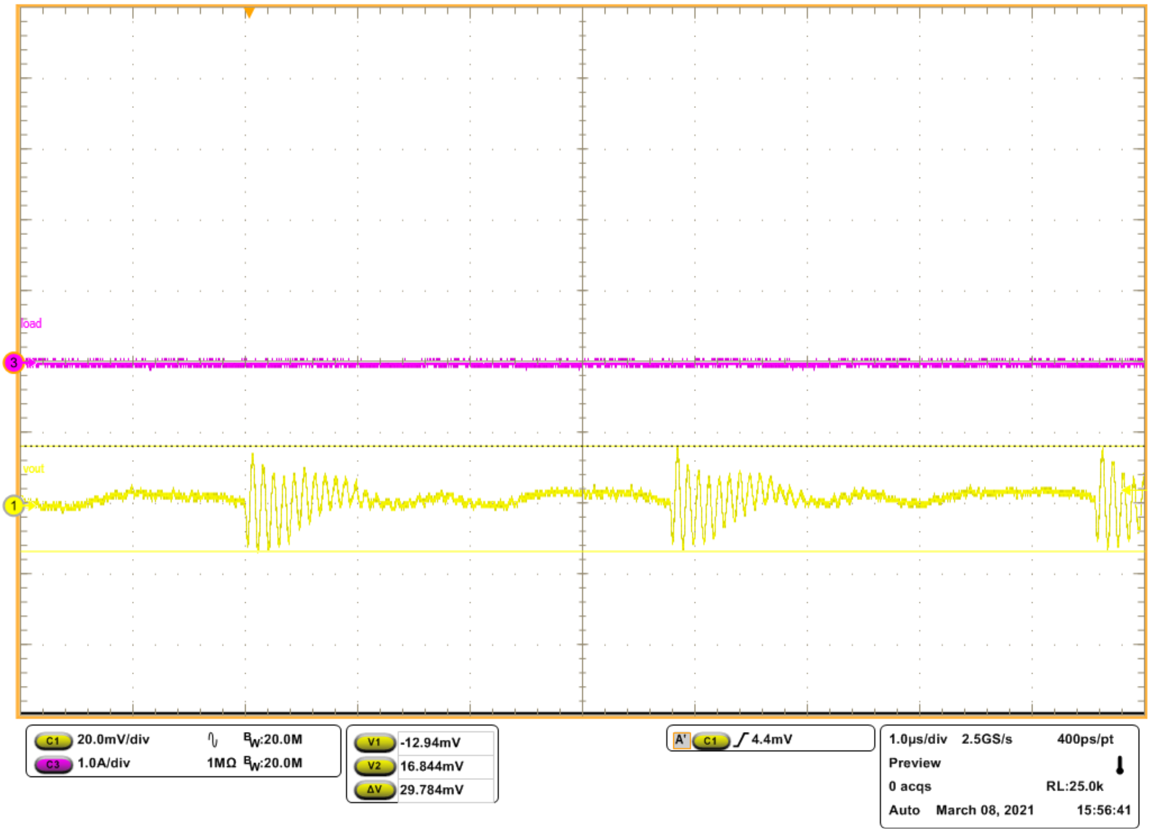


Figure 5. Output voltage ripple: Vin(C:38) = 48 V, Iout (TP18-TP24) = 2.5 A

Ch1: Vout (TP18-TP24); Ch3: Iout (TP18-TP24

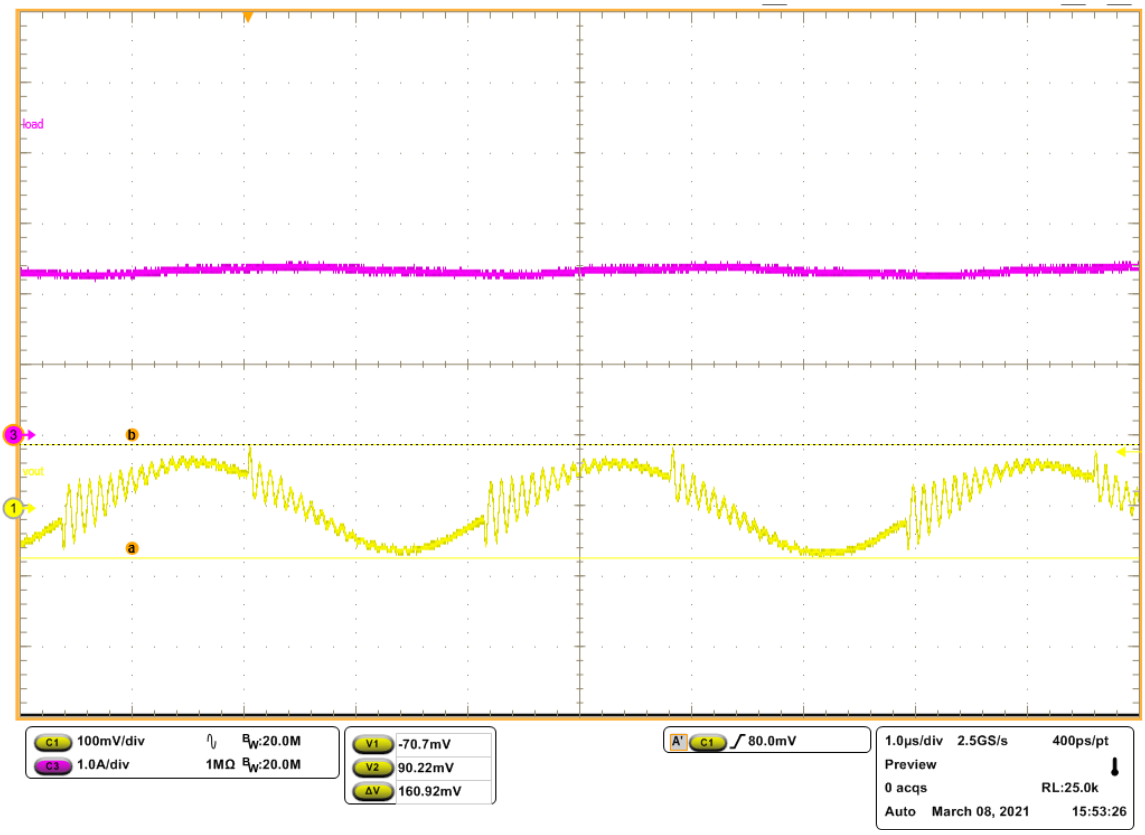


Figure 6. Input voltage ripple: Vin(C:38) = 48 V, Iout (TP18-TP24) = no load

Ch1: after Input filter(V:C43); Ch2: Vgs1(V: R68)
Ch3: Iout (TP18-TP24); Ch4: before Input filter(V:C40)

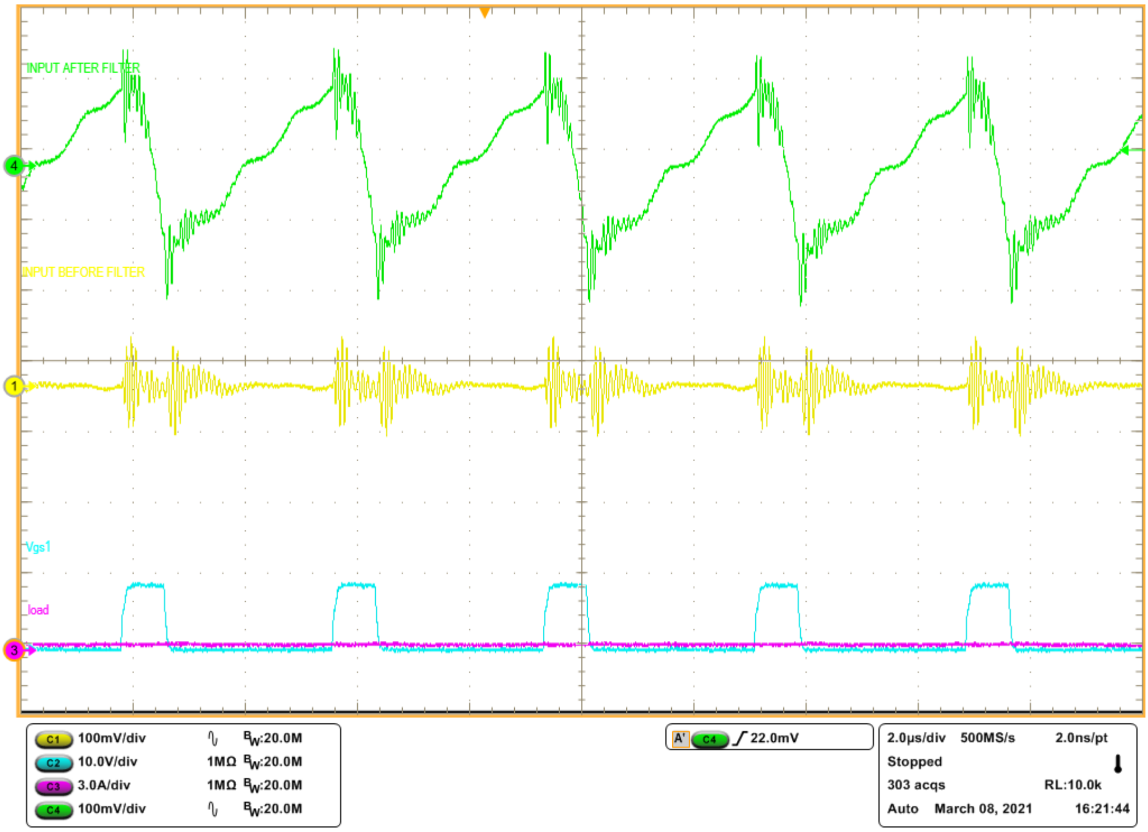


Figure 7. Input voltage ripple: Vin (C:38) = 48 V, Iout (TP18-TP24) = 2.5 A

Ch1: after Input filter(V:C43); Ch2: Vgs1(V: R68)
Ch3: Iout (TP18-TP24); Ch4: before Input filter(V:C40)

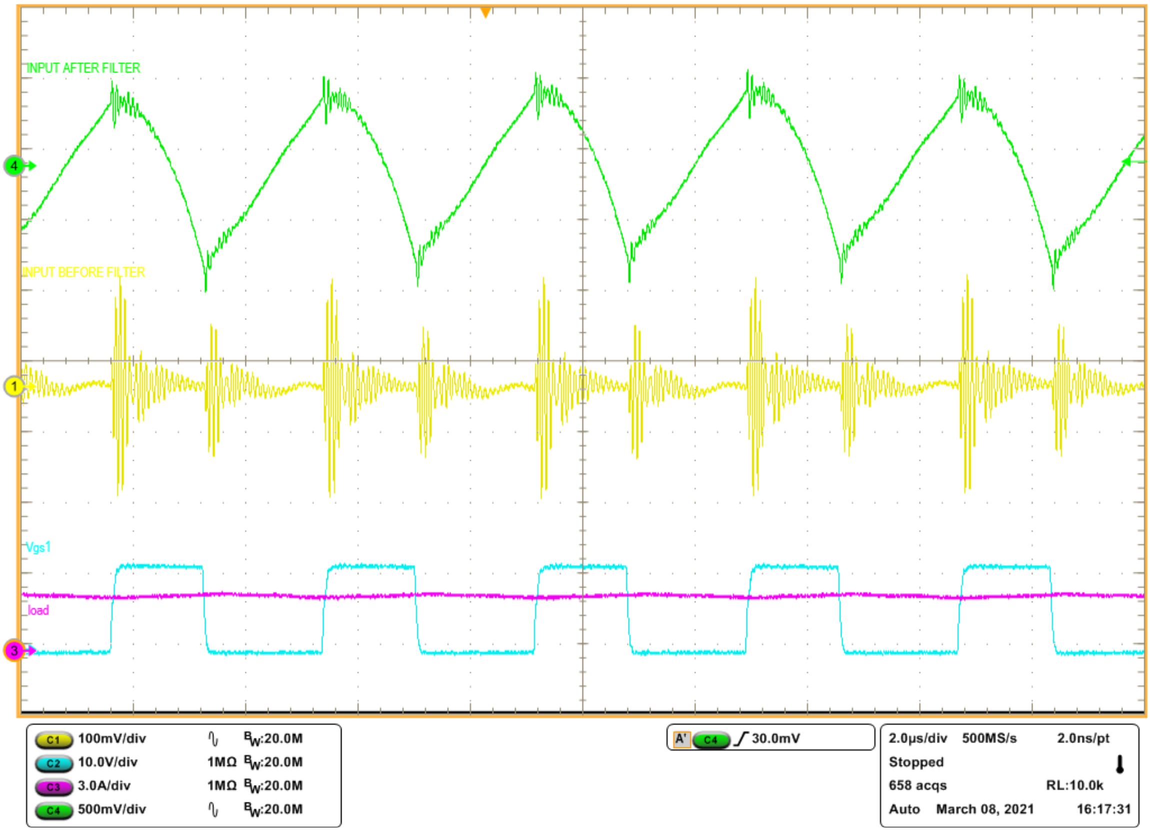


Figure 8. Startup; Vin (C:38) = 48 V, Iout (TP18-TP24) = no load

Ch1: Vout (TP18-TP24); Ch2: Vgs1(V: R68)
Ch4: SS (V: C61)

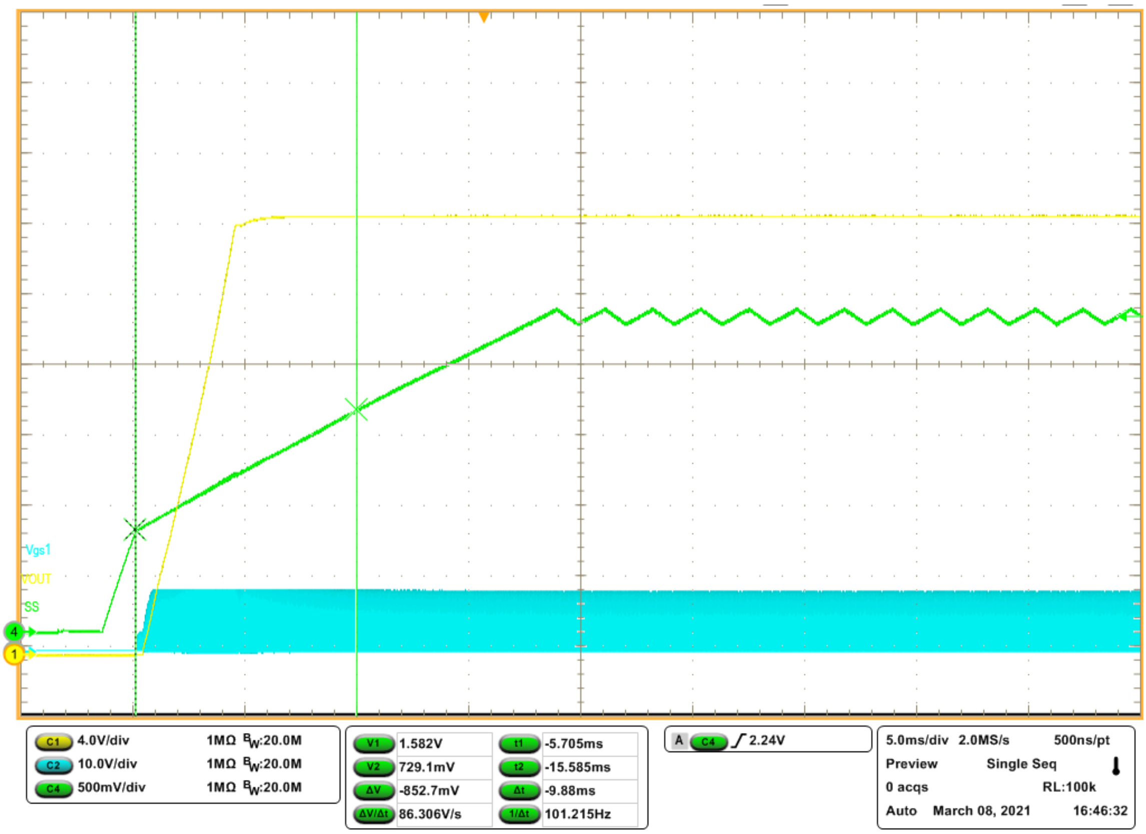
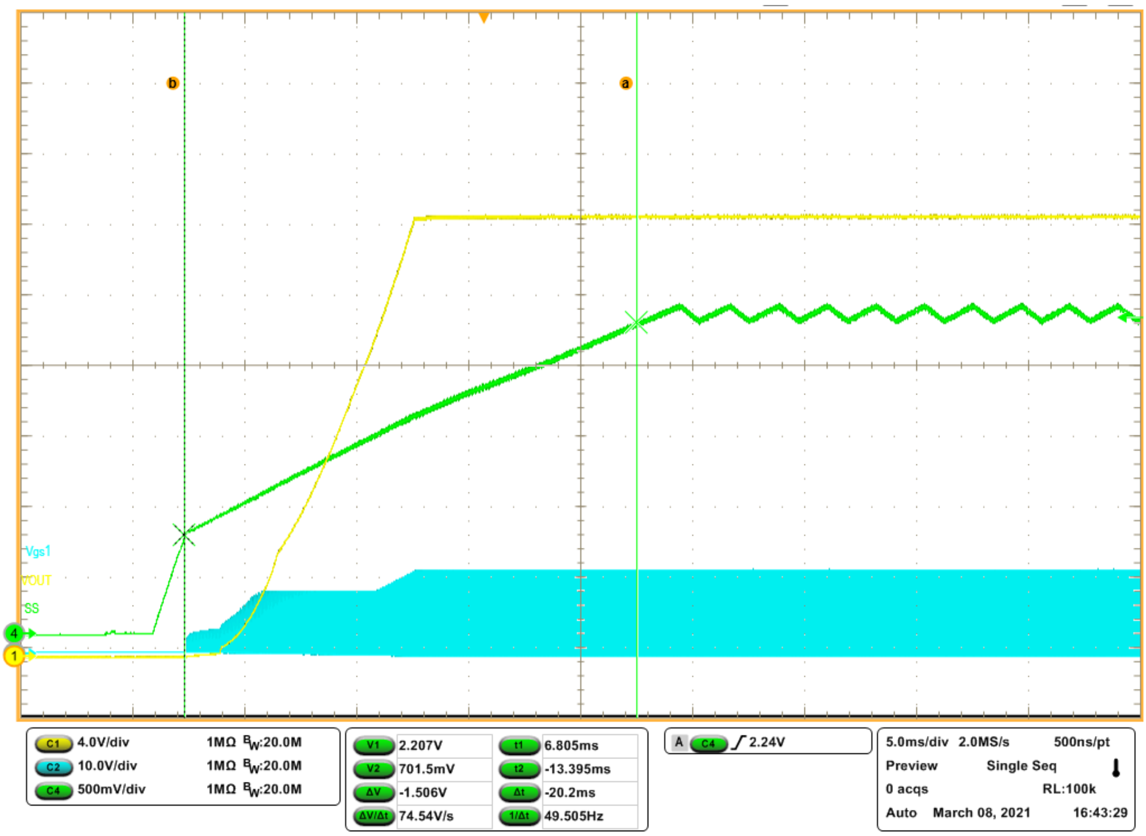


Figure 9. Startup; Vin (C:38) = 48 V, Iout (TP18-TP24) = 2.5 A

Ch1: Vout (TP18-TP24); Ch2: Vgs1(V: R68)
Ch4: SS (V: C61)



In Figure 9 we can see the soft-start (SS) feature that allows the output voltage to ramp up in a safe and controlled way; in this phase the voltage gate (Vgs1) is kept to 8 V, thanks to an internal HV regulator. After the start-up phase, the SS voltage level is actively maintained at 2.3 V by an internal control circuitry, and the Vgs1 rises.

Figure 10. Power-off, Vin (C:38) = 48 V, Iout (TP18-TP24) = no load

Ch1: Vin (V:C36); Ch2: Vgs1(V: R68)
Ch3: Vout (TP18-TP24); Ch4: SS (V: C61)

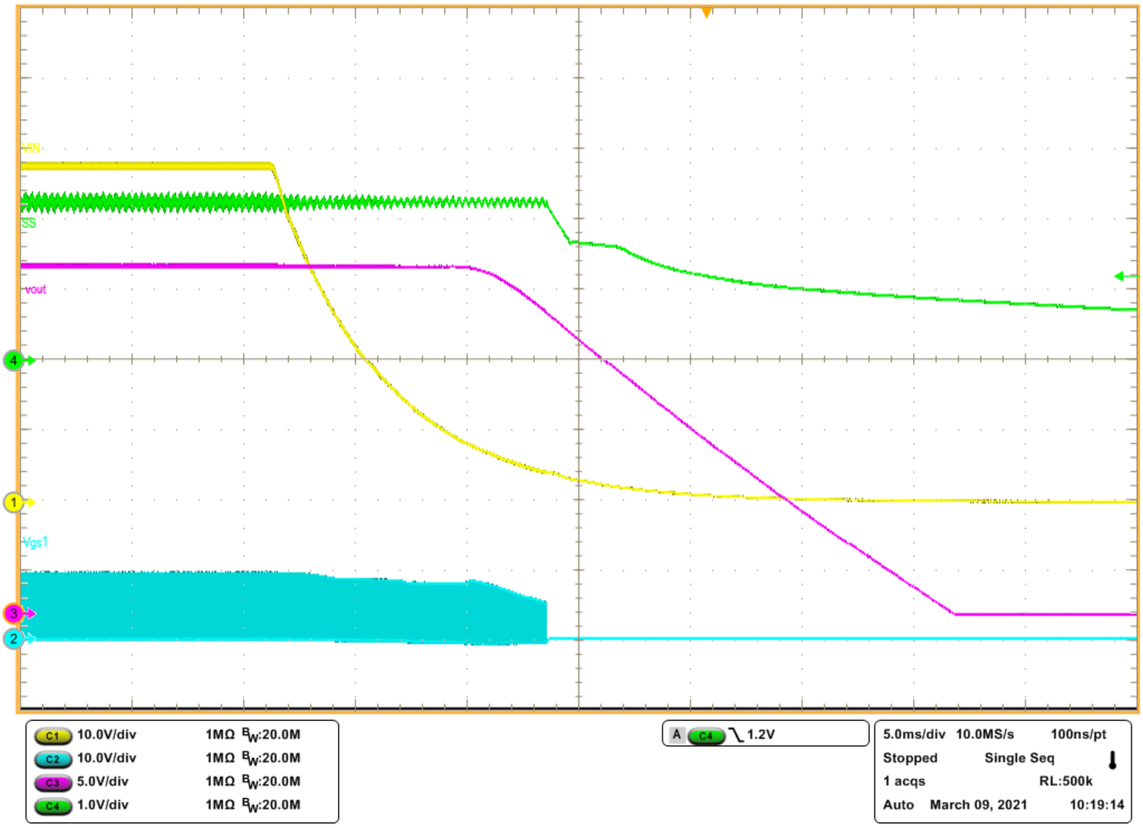
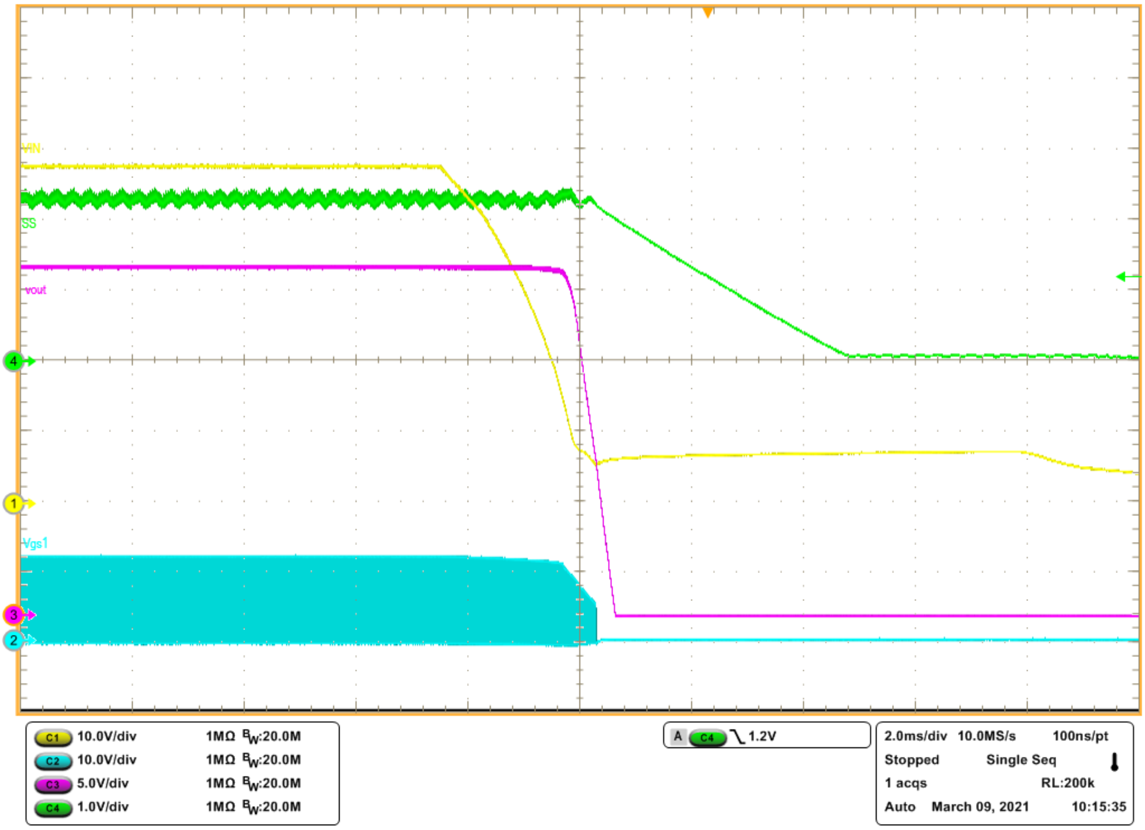


Figure 11. Power-off, Vin (C:38) = 48 V, Iout (TP18-TP24) = 2.5 A

Ch1: Vin (V:C36); Ch2: Vgs1(V: R68)
Ch3: Vout (TP18-TP24); Ch4: SS (V: C61)



In case of power-off, shown in Figure 11, the device features a soft-stop procedure; it reduces the stress and the overvoltages on the power MOSFET. In the soft-stop phase the output voltage decreases.

Figure 12. Load transient: Vin (C:38) = 48 V, Iout (TP18-TP24) = 1.25A to 2.5 A

Ch1: Vout (TP18-TP24); Ch3: Iout (TP18-TP24)

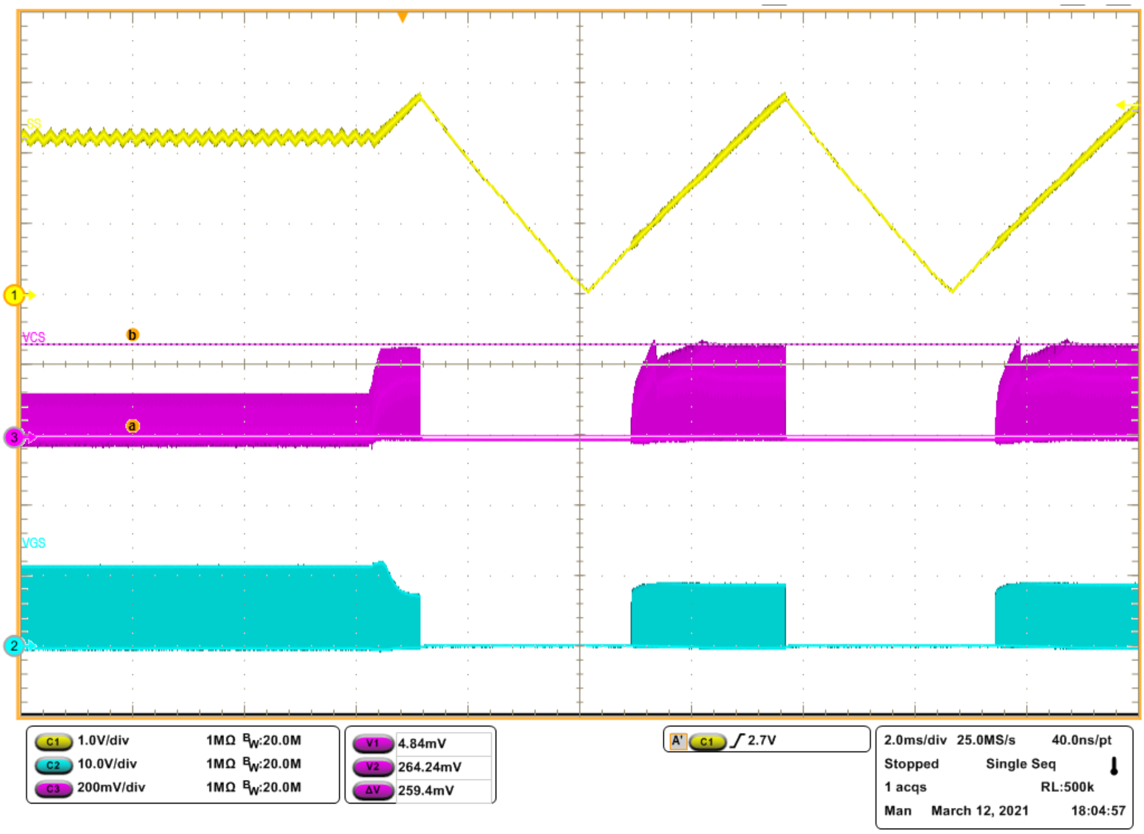
In Figure 12, you can see the load transient; the test was performed through an electronic load, applying 1.25 A to 2.5 A currents with slew-rate of 2.5 A/µs. The output voltage is measured between (TP18-TP24).

Figure 13. Primary/Secondary steady-state: Vin (C:38) = 48 V, Iout (TP18-TP24) = 2.5 A

Ch1: VDS2 (Q2); Ch2: VGS1 (V: R68)
Ch3: VDS1 (Q3); Ch4: VGS2 (V: R55)

Figure 14. Overload protection 1st level. Vin (C:38) = 48 V, Iout (TP18-TP24) = 3 A

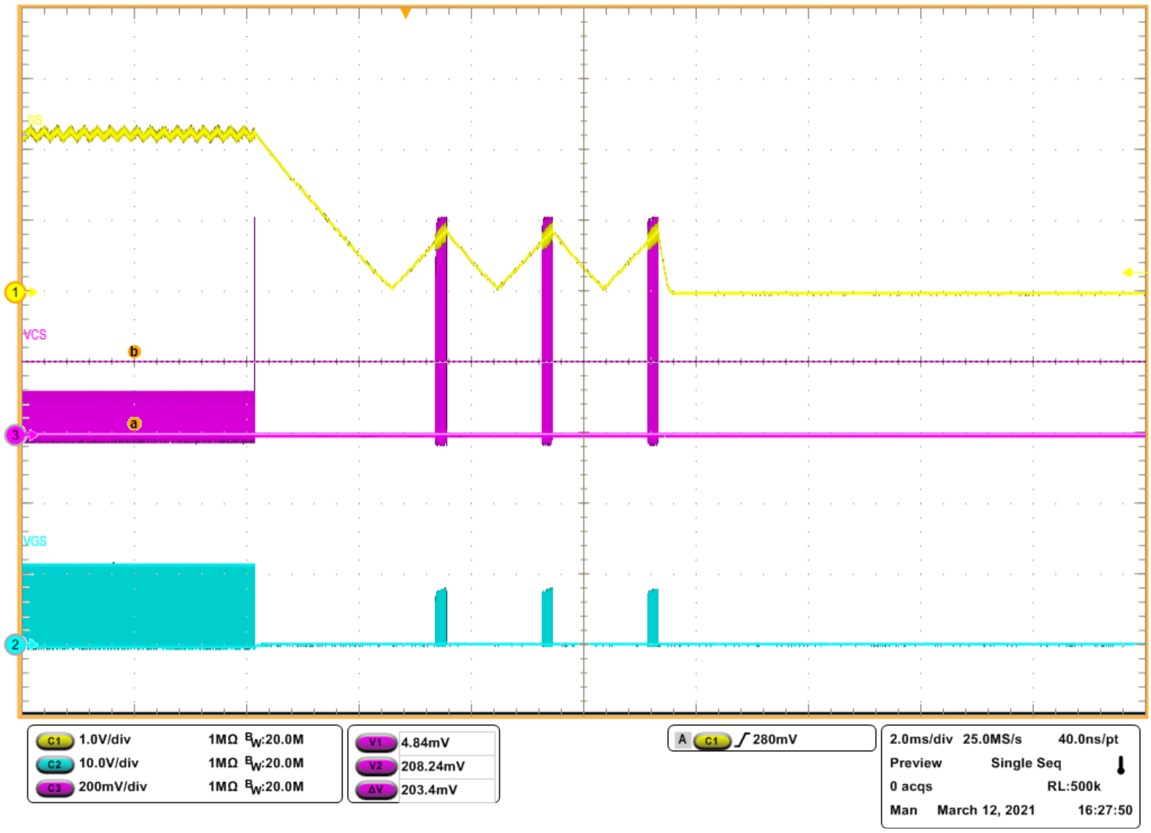
Ch1: SS (V: C61); Ch2: VGS (V: R68)
Ch3: VCS (V: R69)



The lower level of 250 mV is used to perform a cycle-by-cycle current limit, terminating the PWM pulse. The voltage on SS (V: C61) rises whenever, during a PWM cycle, an overcurrent event occurs, while it decreases to the default voltage (2.3 V) if it does not. In Figure14, the OCP 1st level is enabled when VCS (V: R69) is about 259 mV, as expected. The test was performed applying a load output (TP18-TP24) of about 3.

Figure 15. Overload protection 2nd level. Vin (C:38) = 48 V

Ch1: SS (V: C61); Ch2: VGS (V: R68)
Ch3: VCS (V: R69)



In Figure 15 the behavior of the device when the Vcs voltage is higher than 350 mV is shown; In particular the control logic tries 4 cycles of fast hiccup before definitively shutting down the PWM controller, just as shown in the image. The test was performed applying a short on output (TP18-TP24).

Figure 16.Overvoltage protection. Vin (C:38) = 48 V, Vout (TP18-TP24) = 2.5 A

Ch1: VC (V:C54); Ch2: CTL(V:C63)
Ch3: Vout (TP18-TP24);

In Figure16, we can see the overvoltage condition which occurs when circuitry detects a feedback fault condition on the output voltage by sensing the VC voltage; in particular when the VC exceeds the OV rising threshold (15 V), the PWM controller is stopped, the soft-start capacitor discharged, then a new startup is attempted. In case of persistent overvoltage, the control logic tries 4 cycles of fast hiccup before definitively shutting down the PWM controller. The test was performed removing R78.

Figure 17. Closed loop: Vin (C:38) = 48 V, Iout (TP18-TP24); = 2.5 A

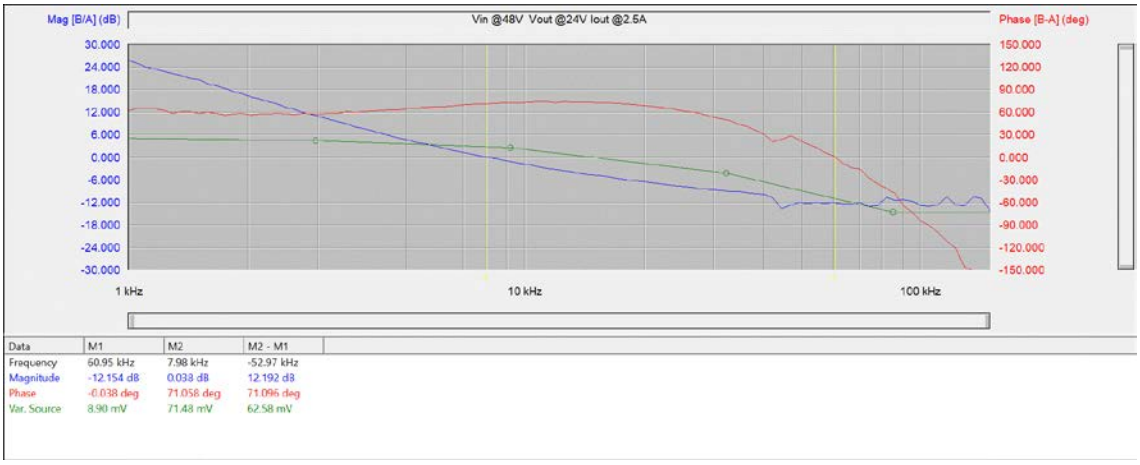
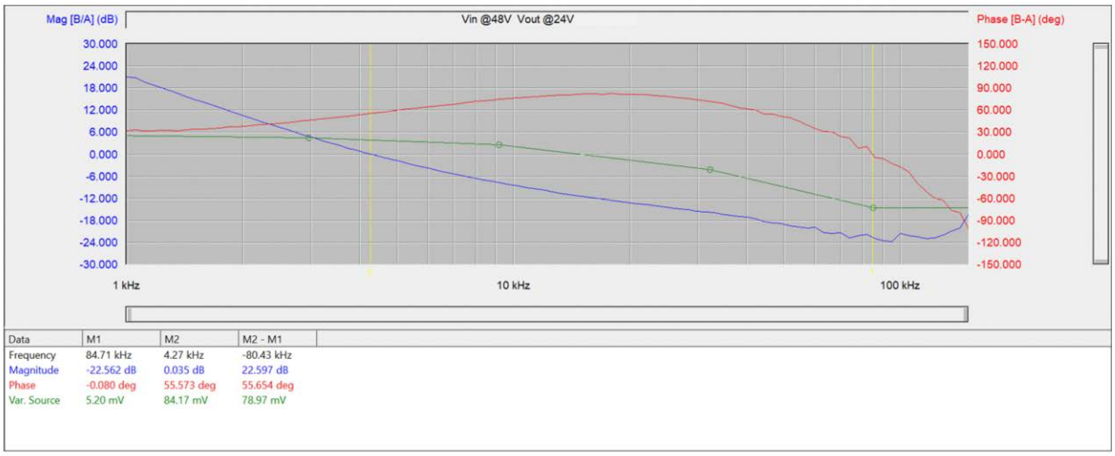


Figure 18. Closed loop: Vin (C:38) = 48 V, Iout (TP18-TP24); = 0.2 A



In figures 17 and 18, the closed loop measure performed through AP 300 instrument is seen. As you can see from the images, the phase margin is higher than the minimum acceptable value of 45 degrees, and 10 dB for gain margin. The set-up for tests was done replacing R76 with a resistor of 33 Ω and applying on it an injected voltage of about 5 mV and two probes for frequency analyzer.

Support material

Related design support material
Steval-poe002v1 evaluation board
Documentation
Datasheet PM8804, PWM peak current mode controller for PoE and telecom systems
Datasheet SRK1000, Adaptive synchronous rectification controller
Application note, AN5174, Power over Ethernet - PD converter with 5 V 8 A output, synchronous Flyback, IEEE802.3bt standard compliant

Revision history

Date	Version	Changes
02-Mar-2022	1	Initial release.