PMP8639RevA2 Test Results

Topology: Inverting Cuk, 36Vin/-36Vout
Device: LM5022

1 Startup

The startup waveform is shown in the Figure 1. The input voltage was set at 36V, with 1A load at the output. Power supply was switched on.

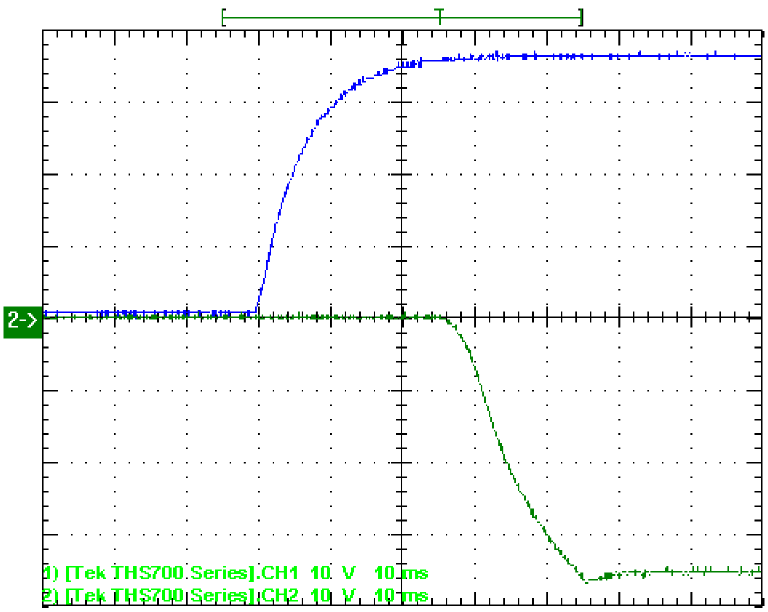


Figure 1

Ch1=> input voltage 10V/div

Ch2=> output voltage 10V/div

10ms/div

20MHz bw

2 Shutdown

The shutdown waveform is shown in the Figure 2. The input voltage was set at 36V, with 1A load on the output. The power supply was switched off (short).

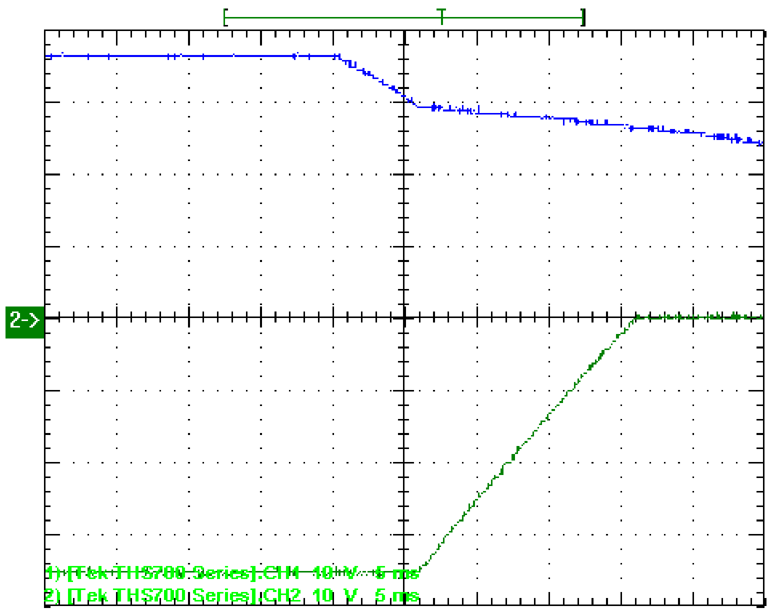


Figure 2

Ch1=> input voltage
10V/div

Ch2=> output voltage
10V/div

5ms/div

20MHz bw

3 Efficiency

The efficiency is shown in the Figure 3 below. The input voltage was set to 36V.

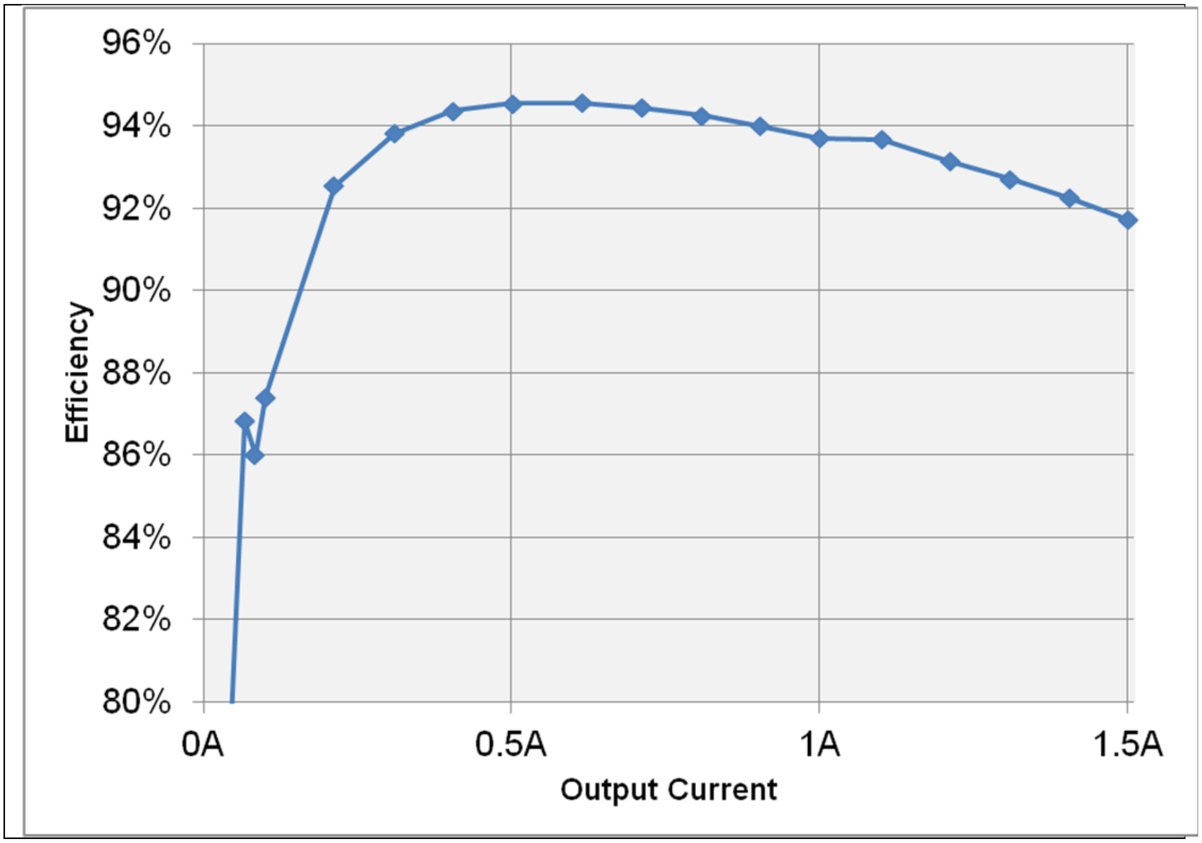


Figure 3

4 Load Regulation

The load regulation of the output is shown in the Figure 4 below. The input voltage was set to 36V.

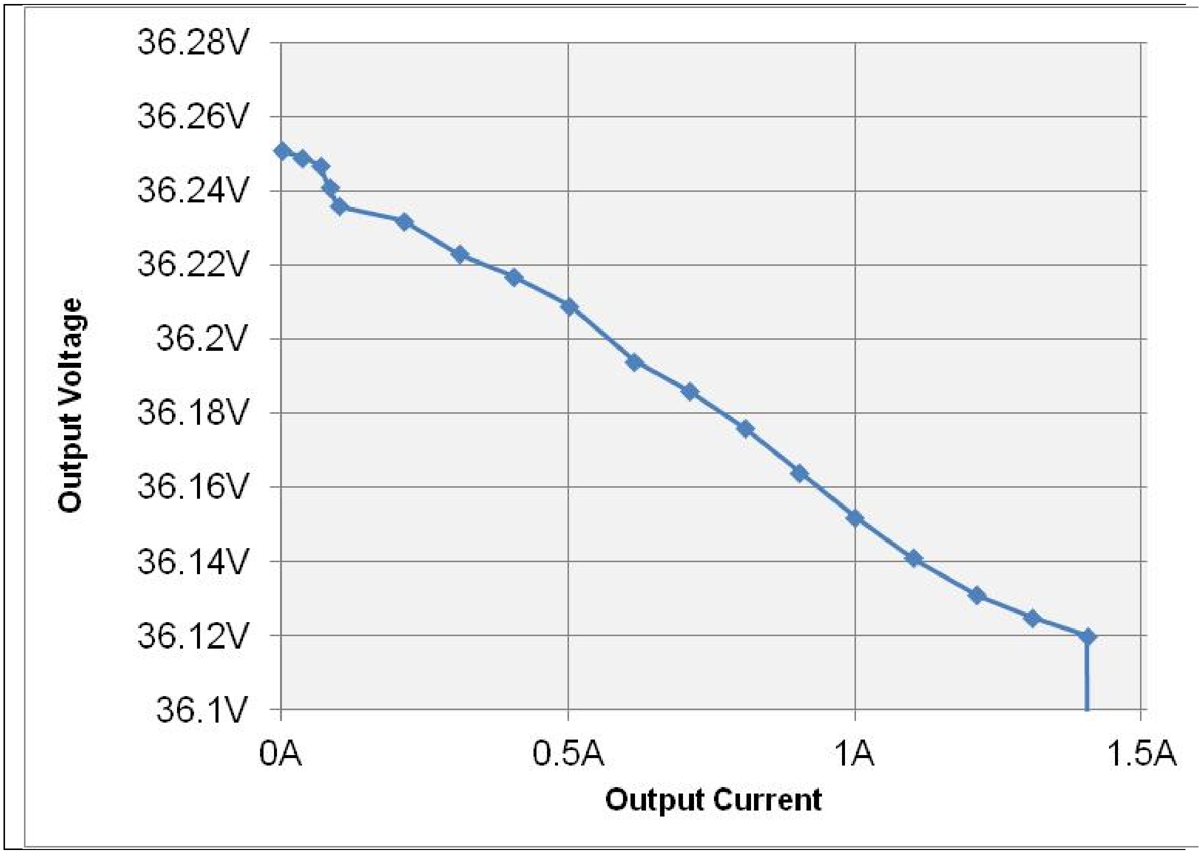


Figure 4

5 Ripple Voltage

The output ripple voltage is shown in Figure 5. The image was taken with 1A load and 36V input.

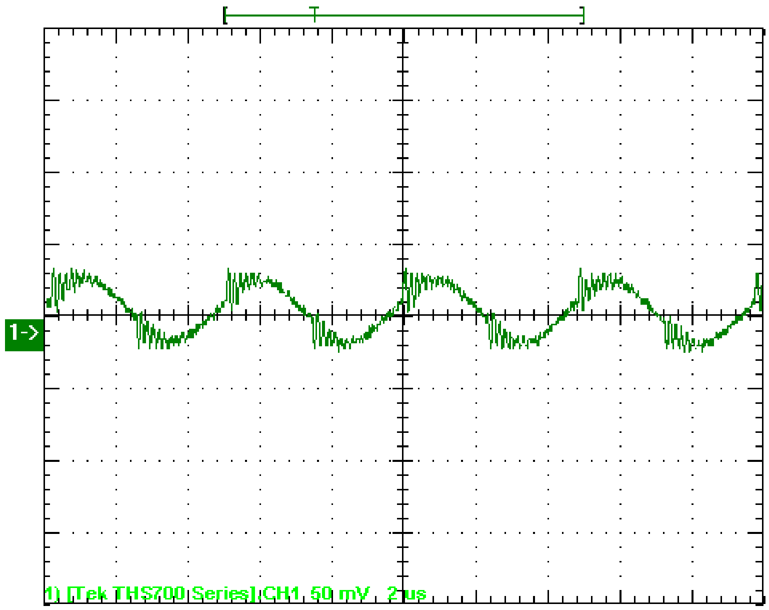


Figure 5

Ch1 => output voltage @ 41Vin
50mV/div

AC coupled

20MHz bw

2µs/div

The input ripple voltage is shown in Figure 6. The image was taken with 1A load 36V at the input.

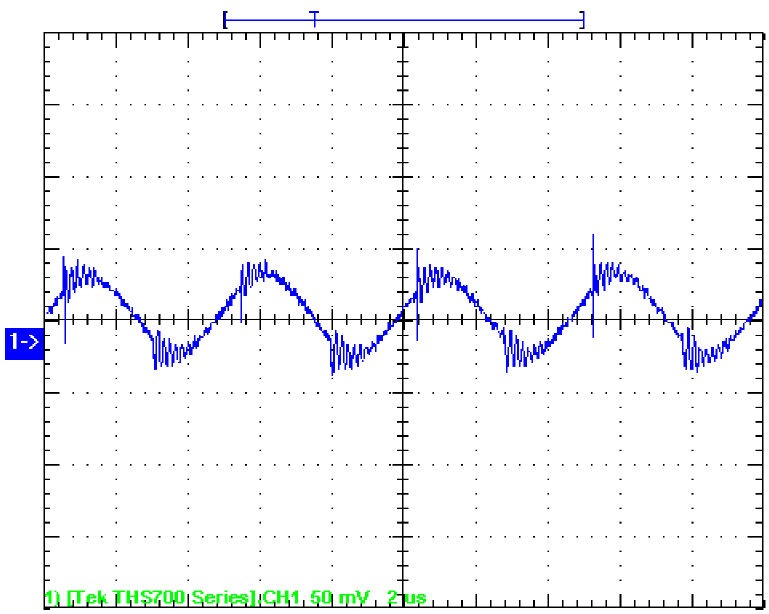


Figure 6

Ch1 => input voltage
50mV/div

20MHz bandwidth setting

AC coupled

2µs/div

6 Control Loop Frequency Response

Figure 7 and Figure 17 show the loop response with 1A load and 36V input with different compensation types

6.1 Type 2 compensation FINAL = 71.2kOhm

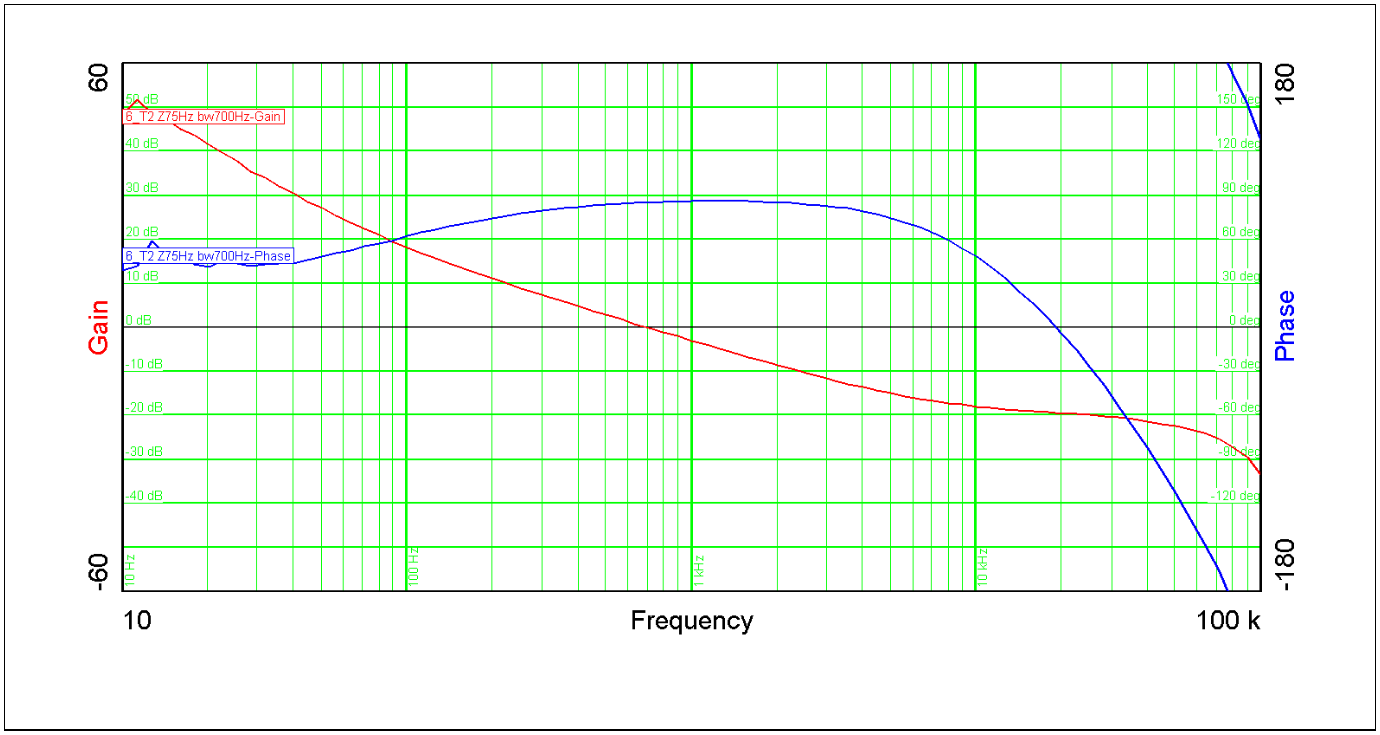


Figure 7

Table 1 summarizes the results from Figure 7

Input Voltage	36V
Bandwidth (Hz)	698
Phasemargin	85°
slope (20dB/decade)	-0.996
gain margin (dB)	-19.5
slope (20dB/decade)	-0.234
freq (kHz)	19

Table 1

Here: R14 71.5k, C17 33nF, C18 100pF

7 Load Transients

The Figure 8 shows the response to load transients. The load is switching from 0.5A to 1A, 50% nominal load step. The input voltage was set to 36V:

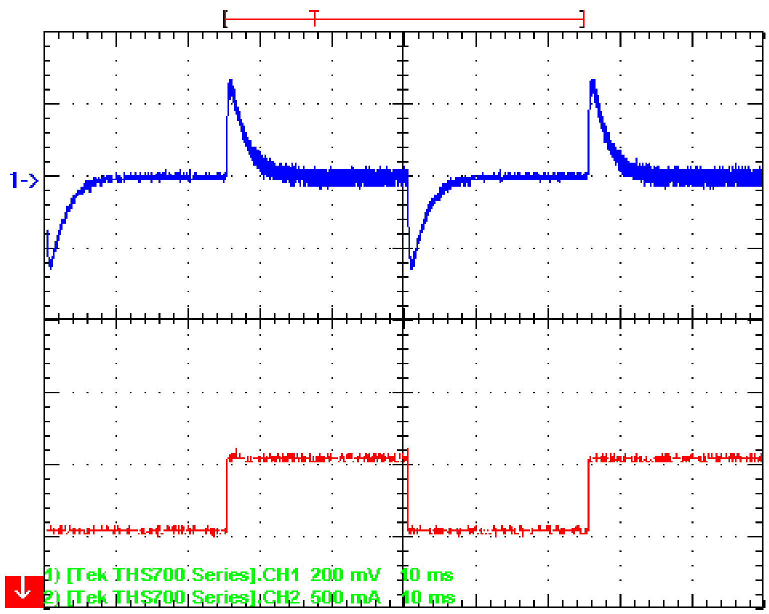


Figure 8

Ch1 => output voltage 200mV/div

20MHz bandwidth setting

Ch2 => output current 500mA/div

10ms/div

The Figure 9 shows the response to load transients. The load is switching from 0.14A to 1.4A. The input voltage was set to 36V.

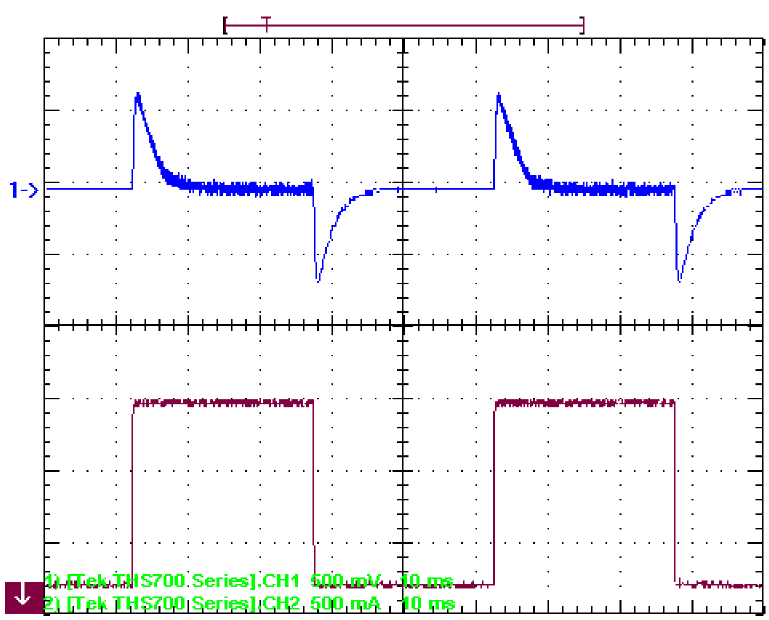


Figure 9

Ch1 => output voltage 500mV/div

20MHz bandwidth setting

Ch2 => output current 500mA/div

10ms/div

8 Miscellaneous Waveforms

The **drain-source** voltage on Q2 results in the waveform shown in Figure 10. Input voltage was set to 36V and output current to 1A.

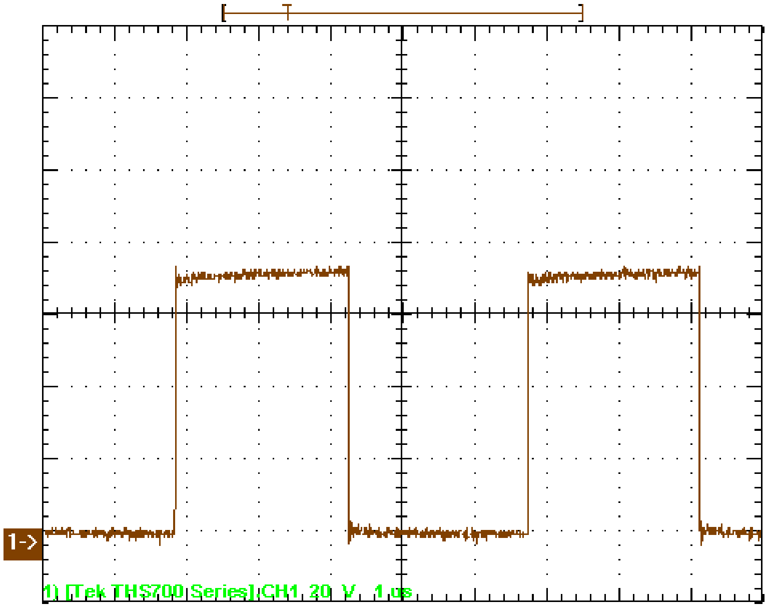
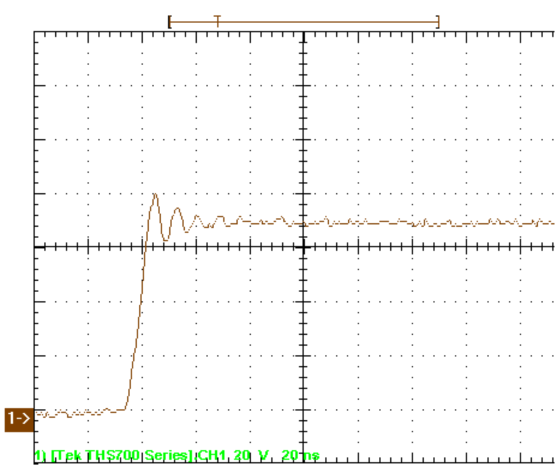
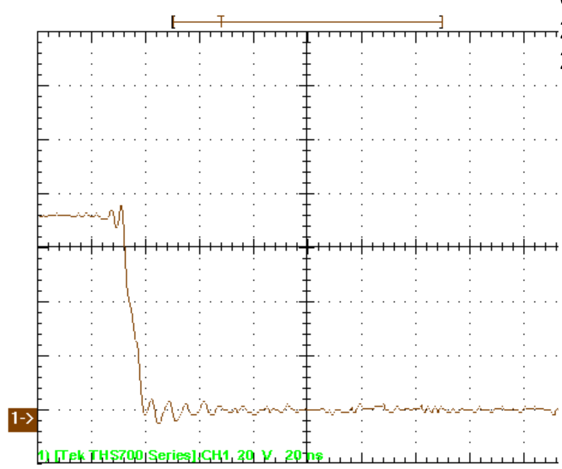
	Ch1 => 20V/div 1µs/div full bandwidth
 	Ch1 => 20V/div 20ns/div

Figure 10

PMP8639RevA2 Test Results

The **gate-source** voltage on Q1 results in the waveform shown in Figure 11. Input voltage was set to 36V and output current to 1A.

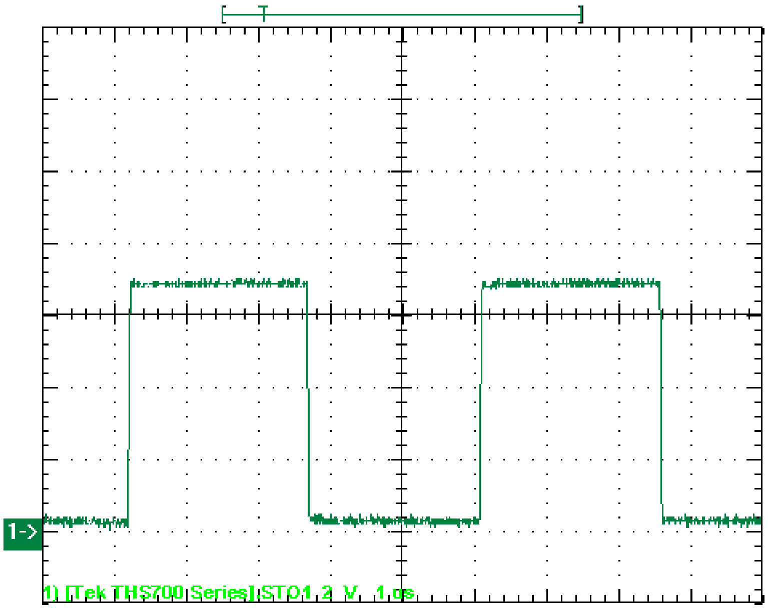
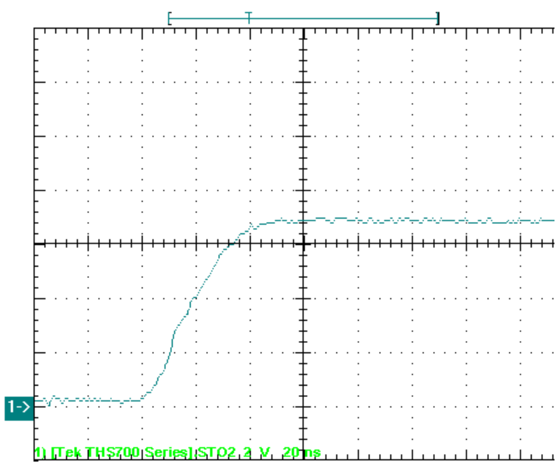
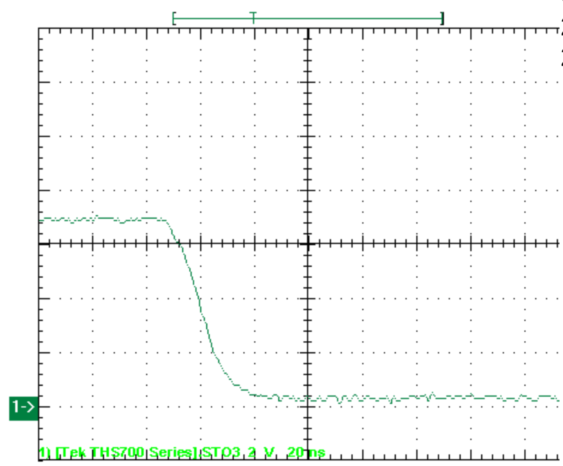
	Ch1 => 2V/div 1µs/div 20MHz bandwidth
 	Ch1 => 2V/div 20ns/div

Figure 11

The voltage at D3 results in the waveform shown in Figure 12. Input voltage was set to 36V and output current to 1A.

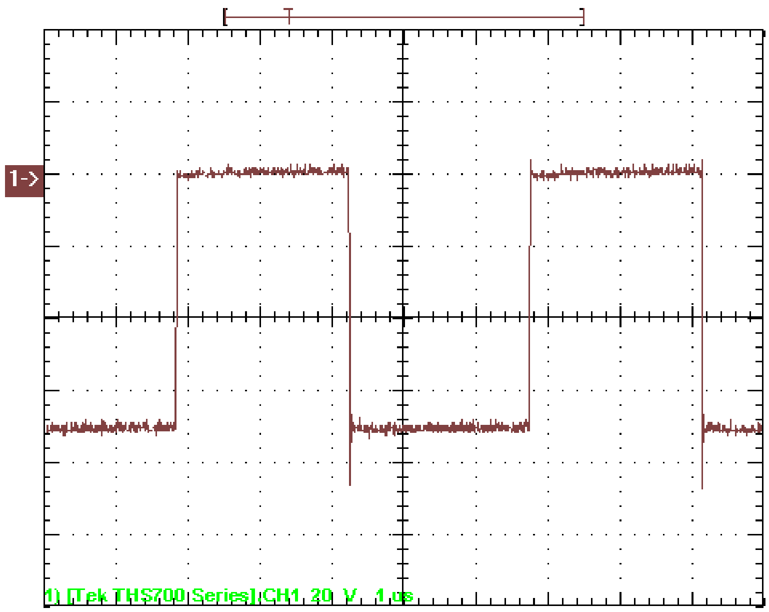
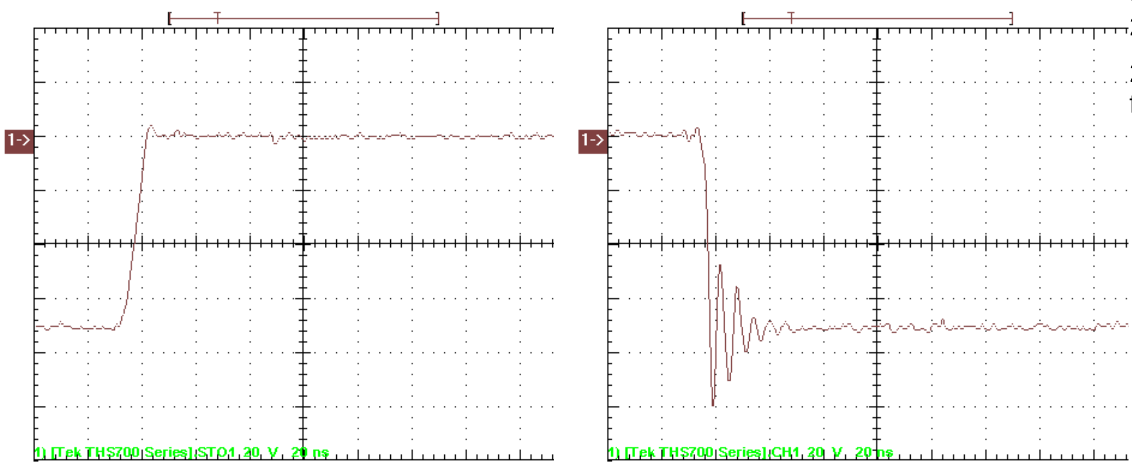
	Ch1 => 20V/div 1µs/div full bandwidth
	Ch1 => 20V/div 20ns/div full bandwidth

Figure 12

Figure 13 shows the waveform between the two switchnodes (C10, C11, C12, C13, C24, C25)

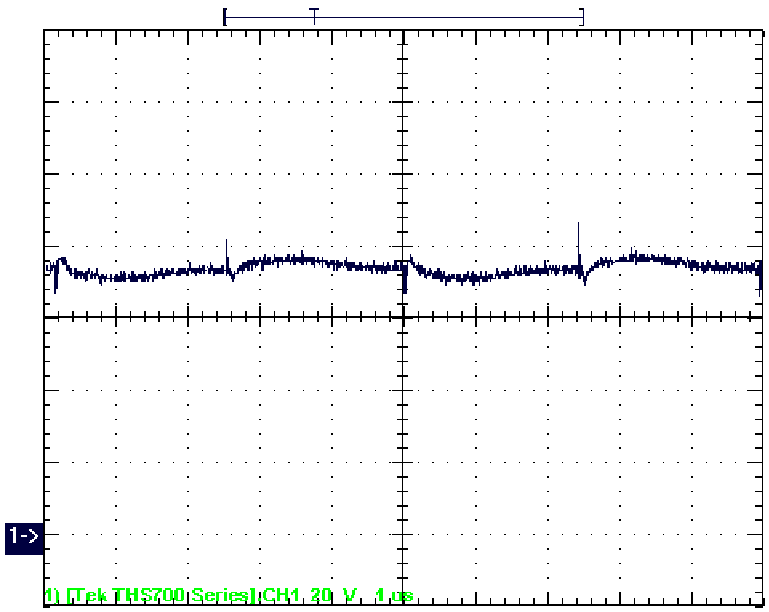


Figure 13

Ch1 =>
20V/div

1µs/div
full bandwidth

9 Thermal Image

Figure 14 shows the IR-Image input voltage was set to 36V with 0.5A output current.

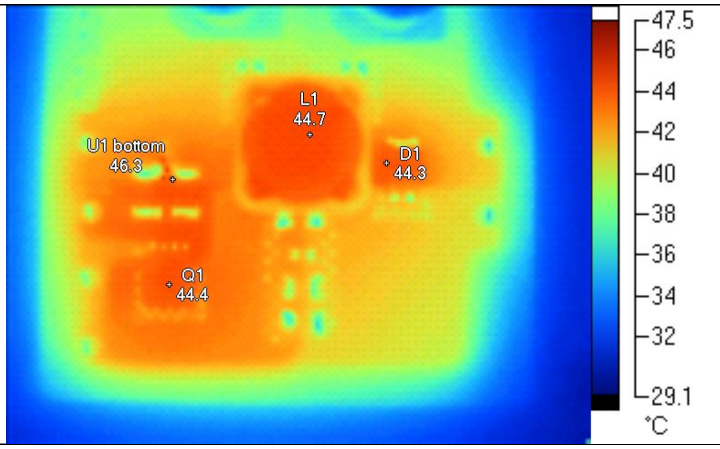


Figure 14

Name	Temperature
U1 bottom	46.3°C
D1	44.3°C
Q1	44.4°C
L1	44.7°C

Table 2

Figure 15 shows the IR-Image input voltage was set to 36V with 1A output current.

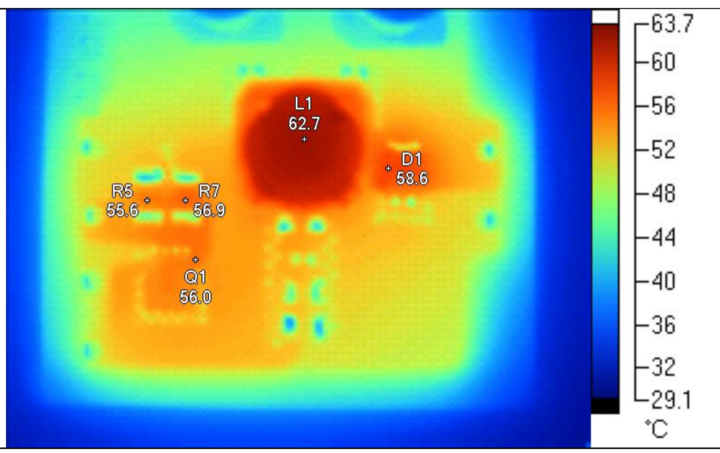


Figure 15

Name	Temperature
L1	62.7°C
D1	58.6°C
Q1	56.0°C
R7	56.9°C
R5	55.6°C

Table 3

Figure 16 shows the IR-Image input voltage was set to 36V with 1.4A output current.

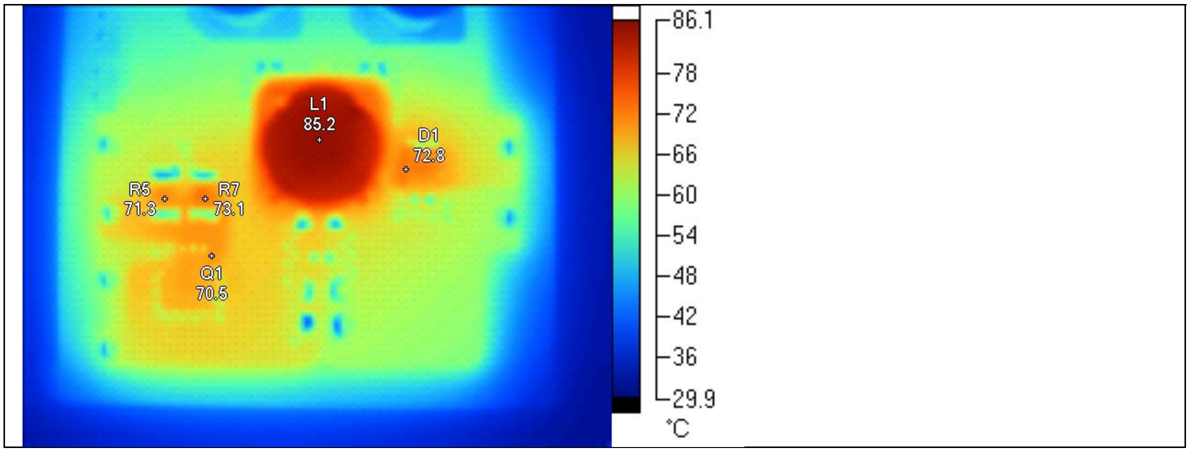


Figure 16

Name	Temperature
L1	85.2°C
D1	72.8°C
Q1	70.5°C
R7	73.1°C
R5	71.3°C

Table 4

For 1.5A continuous load there is rework on the dual inductor needed; semiconductors and controller still OK

10 Loop Appendix

10.1 Type 3 Compensation

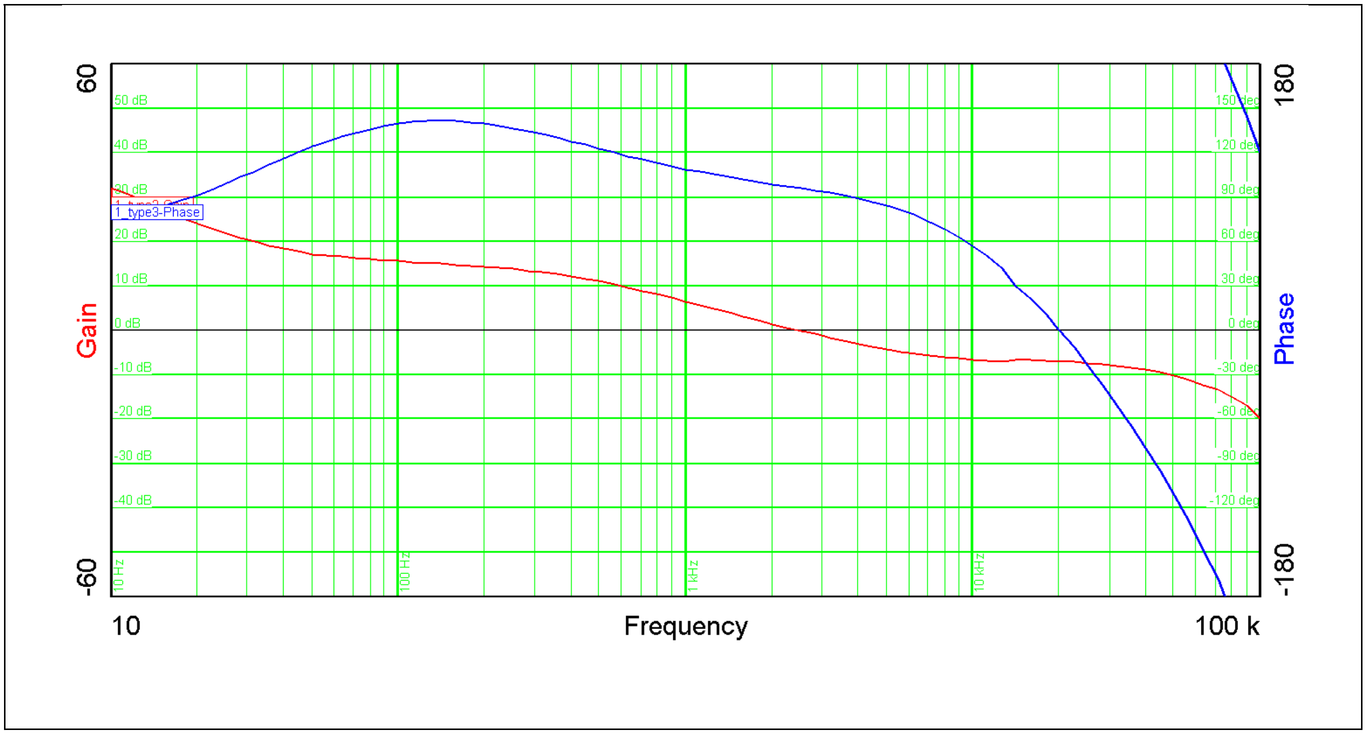


Figure 17

Table 5 summarizes the results from Figure 17,

Input Voltage	36V
Bandwidth (kHz)	2.45
Phasemargin	96°
slope (20dB/decade)	-0.81
gain margin (dB)	-7.1
slope (20dB/decade)	-0.125
Freq (kHz)	20

Table 5

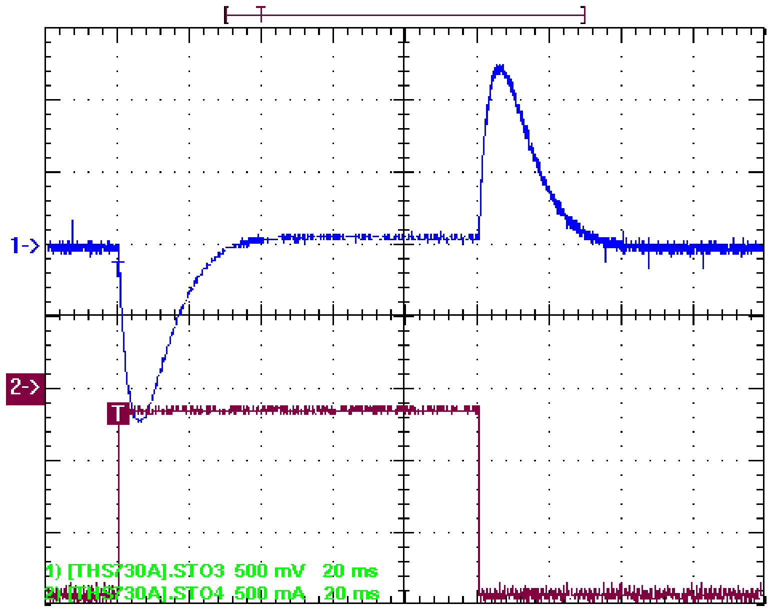
	Ch1 => output voltage **500mV**/div 20MHz bandwidth setting Ch2 => output current 500mA/div **20ms/div**

Figure 18

R14 20k, C17 330nF, C18 330pF,
R2 10k, C1 68nF

Type 3 compensation:

On a first glance highest bandwidth w/ 2.45kHz, but a very low, flat DC gain – results in transient response **du 1.25V** by di 90% (140mA to 1.4A)

10.2 Type 2 Compensation Z25Hz P25kHz

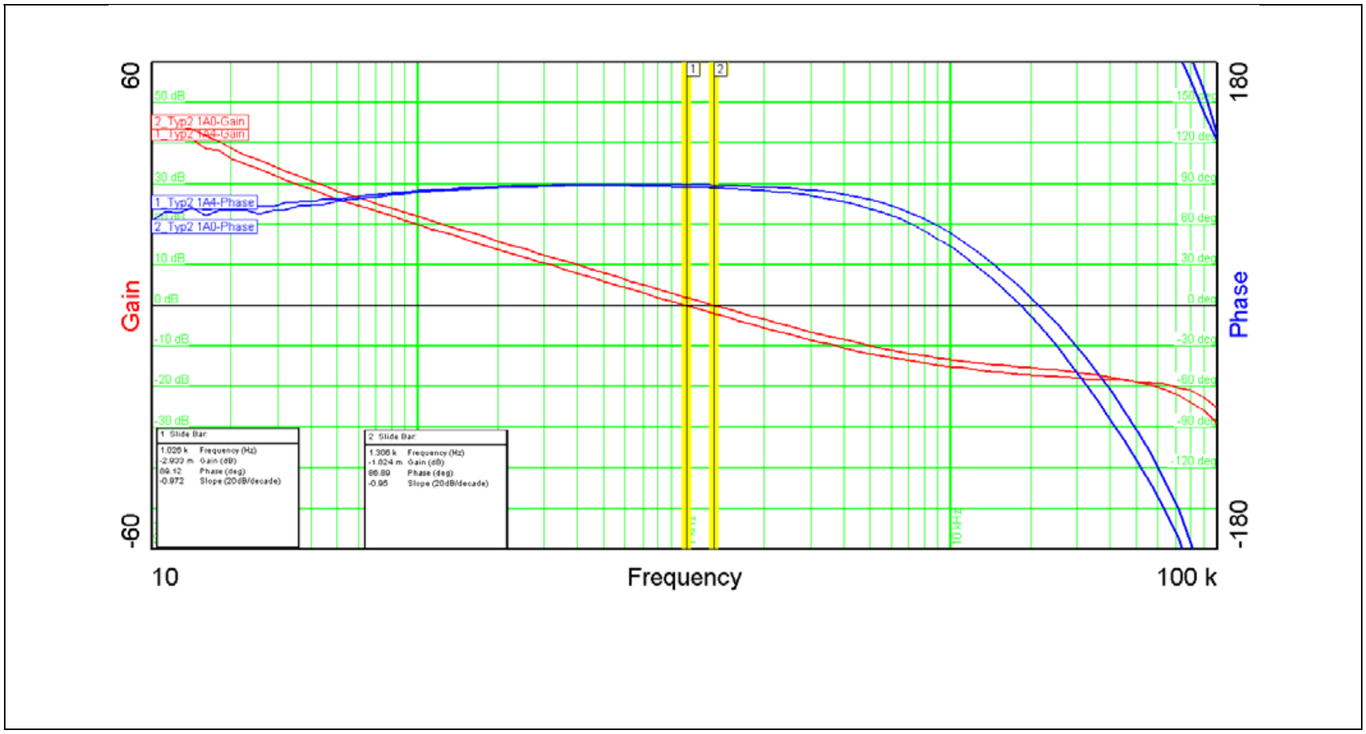
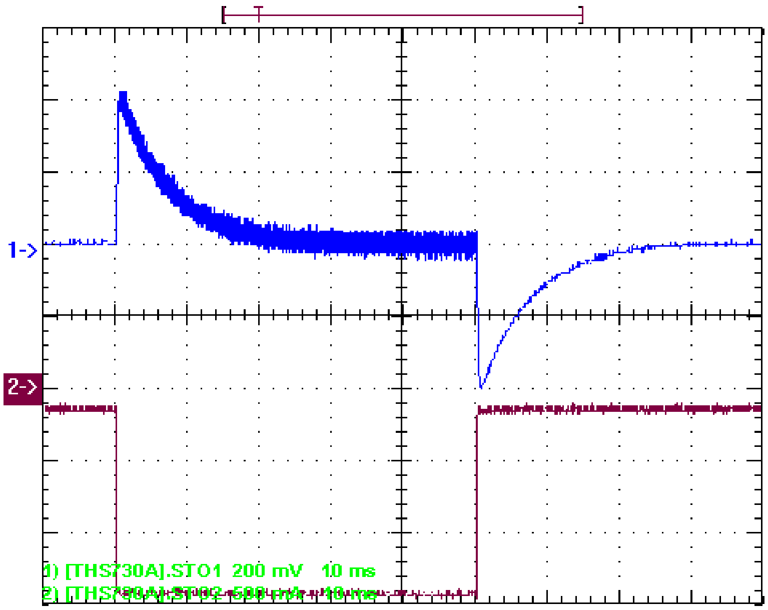


Figure 19

Table 6 summarizes the results from Figure 19,

Output Current	1A	1.4A
Bandwidth (kHz)	1.3	1
Phasemargin	87°	89
slope (20dB/decade)	-0.95	-0.97
gain margin (dB)	-15.2	-17.3
slope (20dB/decade)	-0.28	0.187
Freq (kHz)	18.3	21.5

Table 6



Ch1 => output voltage **200mV**/div

20MHz bandwidth setting

Ch2 => output current 500mA/div
10ms/div

Figure 20

R14 133k, C17 56nF, C18 56pF

Type 2 compensation:

Less than half the bandwidth of type 3, but improved DC gain – results in transient response **du 400mV** by di 90% (140mA to 1.4A).

Means only one third derivation than the type 3 compensation !

BUT: due to the high gain at the error amplifier R14 133kOhm = 28.5db (!) signal to noise ratio decreases, results in **gate jitter** and modulating subharmonics to Vout.

Next step: increasing the ZERO and reducing the gain.

10.3 Type 2 Compensation Z250Hz P25kHz

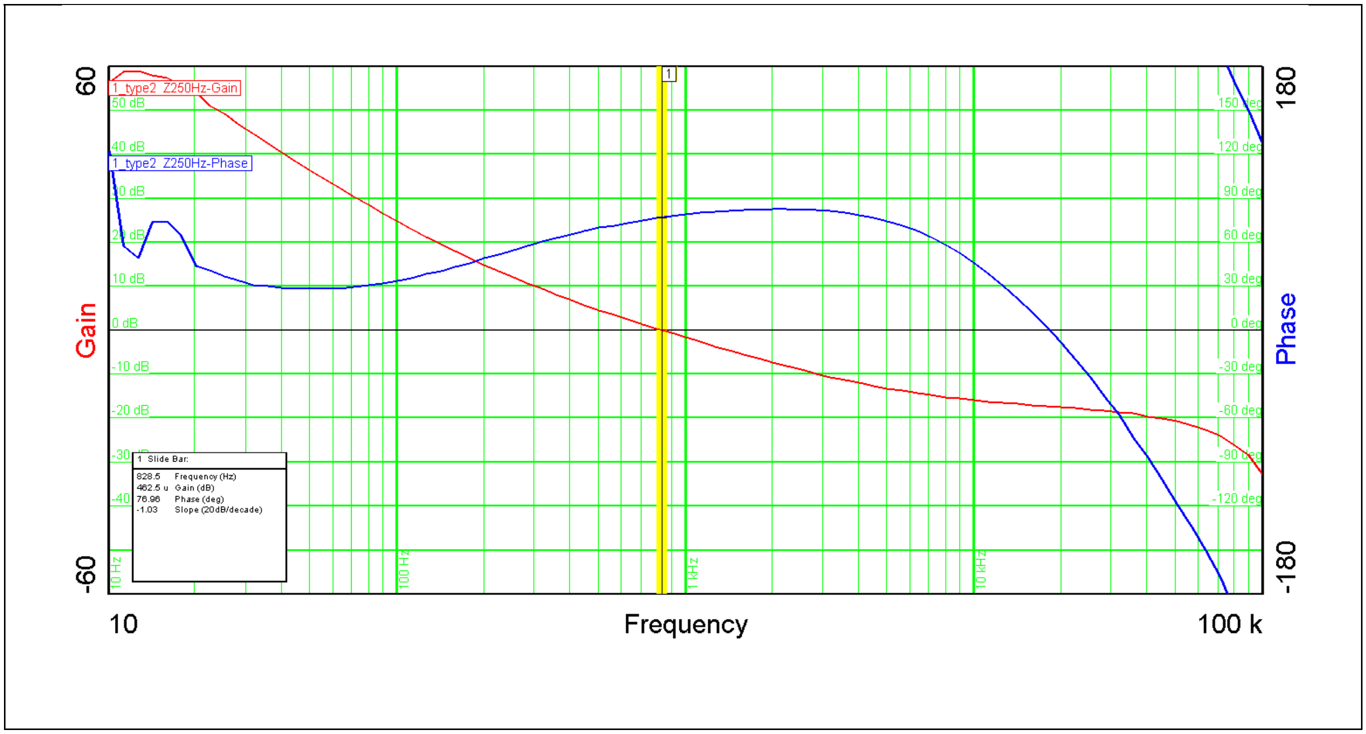
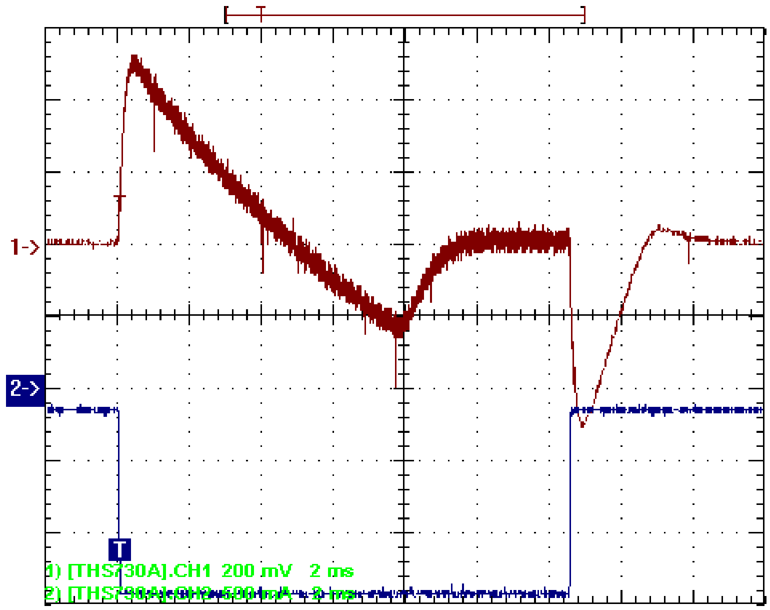


Figure 21

Table 7 summarizes the results from Figure 21

Bandwidth (Hz)	828
Phasemargin	77°
slope (20dB/decade)	-1
gain margin (dB)	-17.3
slope (20dB/decade)	-0.25
Freq (kHz)	18.4

Table 7



Ch1 => output voltage **200mV**/div

20MHz bandwidth setting

Ch2 => output current 500mA/div
2ms/div

Figure 22

R14 80.6k, C17 10nF, C18 100pF

Tried to improve the DC gain further by increasing the ZERO from 25Hz to 250Hz;
Though bandwidth is well below 1kHz AOL of the error amplifier is hurt, too much gain.
The amplifier is clipping, see transient response, curve 1, above !
Furthermore the phase drops to 30 degs around 50Hz.

Next step: reducing the ZERO from 250Hz to 75Hz, adjusting the gain.

10.4 Type 2 Compensation Z75Hz P25kHz bw 1kHz

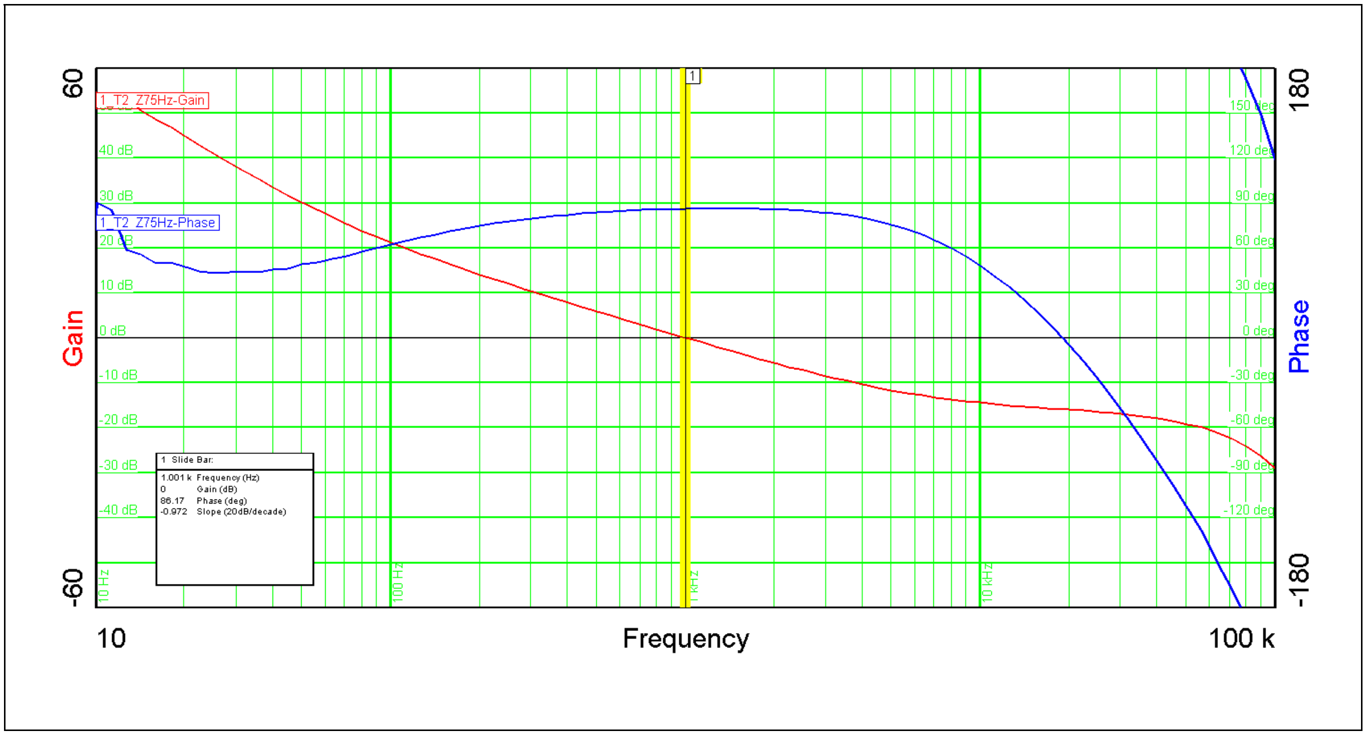
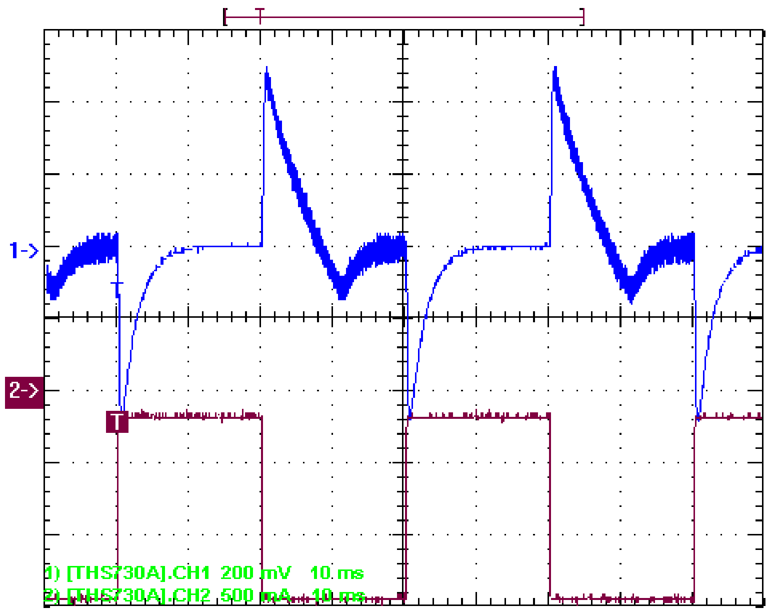


Figure 23

Table 8 summarizes the results from Figure 23

Bandwidth (kHz)	1
Phasemargin	86°
slope (20dB/decade)	-0.97
gain margin (dB)	-15.9
slope (20dB/decade)	-0.174
Freq (kHz)	19

Table 8



Ch1 => output voltage **200mV**/div

20MHz bandwidth setting

Ch2 => output current 500mA/div
10ms/div

Figure 24

R14 100k, C17 33nF, C18 100pF

Reduced the Zero from 250Hz to 75Hz, set bandwidth to 1kHz – amplifier still clipping !
Reduced the gain a bit, this resulted in the final solution, this best trade off on page 7/8.
Gain was adjusted to prevent amplifier from clipping. The final solution works then w/ reasonable S/N, so no gate jitter. A derivation of 600mV for 90% transient could be achieved, less than half of the type 3 solution. This means 1.7% of the output voltage, the output capacitors could be reduced further to stay still w/in the limits of 3%.

Working properly on the compensation shows that a Cuk is achieving reasonable transient response, final solution page 7/8: **R14 71.5k, C17 33nF, C18 100pF**

11 Inductor Appendix

The circuit of the Cuk-Converter was built up on a PCB from an older Layout (PMP8619 Rev A) for having more board space to use bigger core shapes. Overall system efficiency was tested by using three different coupled inductors (windings ratio 1:1), whose specifications are listed below:

- Coilcraft L = 220 µH, Rdc = 230 mOhm, **smallest geometry** (red trace)
- Hand wired, Würth PQ 2016 Core, bifilar wired, 33 windings, d = 0.4 mm, L = 229 µH, Rdc = 208 mOhm, **medium geometry** (blue trace)
- Hand wired Würth, PQ 2620 Core, bifilar wired, 19 windings, d = 0.8 mm, L = 150 µH, Rdc = 40 mOhm, **largest geometry** (yellow trace)

Result of the efficiency measurement with different load currents between 0.1 A and 1.5 A is that the DC resistance of the inductor has the major impact on the CUK's system efficiency, which is displayed in the graphic below.

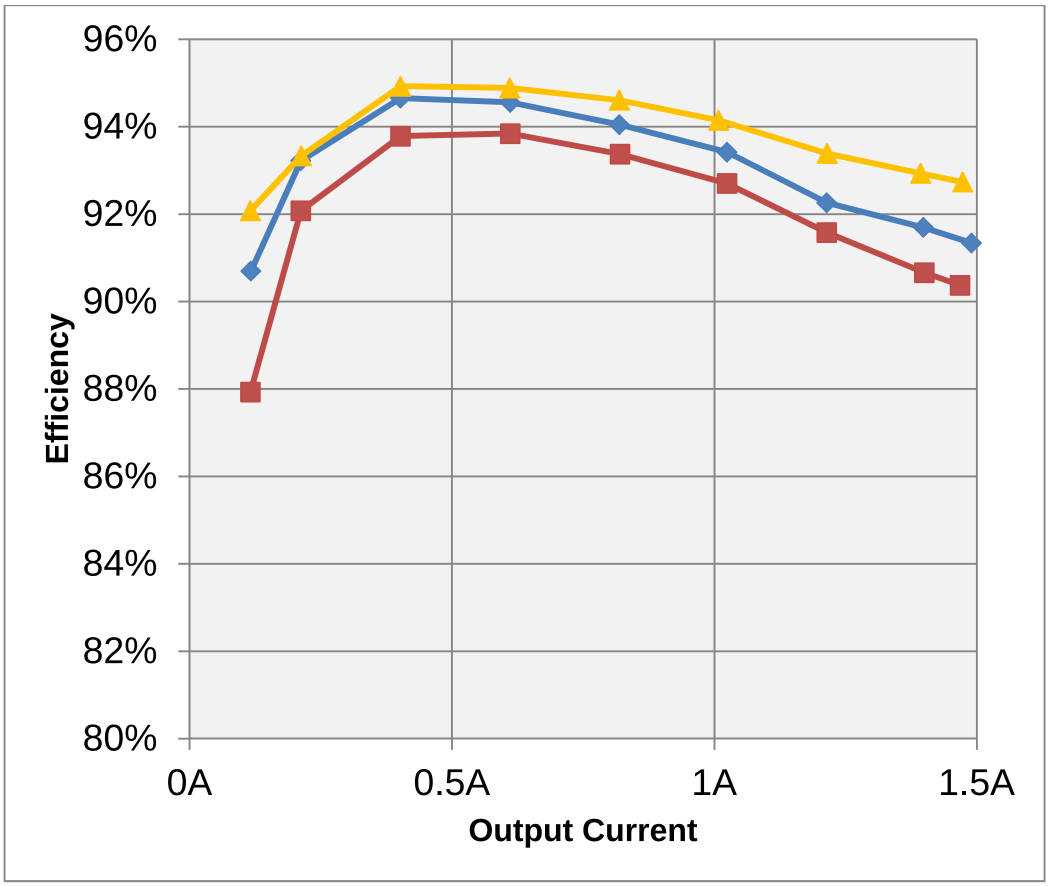


Figure 25: Diagram of the measurement data displayed on page 2

= efficiency increases with lower DC resistance of the inductors

Coilcraft (220µH, R=230mOhm)

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{out} (A)	P_{IN} (W)	P_{OUT} (W)	Eff	P_{LOSS} (W)
36,17	0,134	36,74	0,116	4,84678	4,26184	0,879314	0,58494
36,16	0,234	36,75	0,212	8,46144	7,791	0,920765	0,67044
36,13	0,436	36,75	0,402	15,75268	14,7735	0,93784	0,97918
36,09	0,663	36,75	0,611	23,92767	22,45425	**0,938422pk**	1,47342
36,05	0,895	36,74	0,82	32,26475	30,1268	0,933737	2,13795
36,01	1,127	36,74	1,024	40,58327	37,62176	0,927026	2,96151
35,97	1,354	36,74	1,214	48,70338	44,60236	0,915796	4,10102
35,94	1,579	36,75	1,4	56,74926	51,45	0,90662	5,29926
35,93	1,661	36,74	1,468	59,67973	53,93432	**0,903729**	5,74541

handwired PQ 2016, (210µH, R=200mOhm, d=0,4mm, 33 windings)

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{out} (A)	P_{IN} (W)	P_{OUT} (W)	Eff	P_{LOSS} (W)
36,16	0,131	36,72	0,117	4,73696	4,29624	0,906961	0,44072
36,15	0,231	36,72	0,212	8,35065	7,78464	0,93222	0,56601
36,11	0,432	36,73	0,402	15,59952	14,76546	**0,946533pk**	0,83406
36,07	0,658	36,73	0,611	23,73406	22,44203	0,945562	1,29203
36,02	0,888	36,73	0,819	31,98576	30,08187	0,940477	1,90389
35,98	1,119	36,73	1,024	40,26162	37,61152	0,934178	2,6501
35,96	1,344	36,73	1,214	48,33024	44,59022	0,922615	3,74002
35,92	1,559	36,73	1,398	55,99928	51,34854	0,91695	4,65074
35,9	1,669	36,73	1,49	59,9171	54,7277	**0,91339**	5,1894

handwired PQ 2620(150µH, R=40mOhm, d=0,8mm, 19 windings)

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{out} (A)	P_{IN} (W)	P_{OUT} (W)	Eff	P_{LOSS} (W)
36,17	0,128	36,75	0,116	4,62976	4,263	0,920782	0,36676
36,15	0,232	36,75	0,213	8,3868	7,82775	0,933342	0,55905
36,11	0,431	36,75	0,402	15,56341	14,7735	**0,949246pk**	0,78991
36,07	0,655	36,75	0,61	23,62585	22,4175	0,948855	1,20835
36,03	0,883	36,75	0,819	31,81449	30,09825	0,946055	1,71624
35,99	1,093	36,74	1,008	39,33707	37,03392	0,941451	2,30315
35,95	1,33	36,75	1,215	47,8135	44,65125	0,933863	3,16225
35,91	1,534	36,75	1,393	55,08594	51,19275	0,929325	3,89319
35,9	1,626	36,75	1,473	58,3734	54,13275	**0,927353**	4,24065

The system output voltage ripple is dependent on the load current. It increases with big and decreases with small loads. Furthermore is the ripple bigger with a coil of smaller inductance. With a 1.5A load current the peak-to-peak ripple is approximately 250 mV. Considering that the output voltage is -36 V, this is less than 1% deviation. Pictures of the input and output voltage ripple are shown in the following figures:

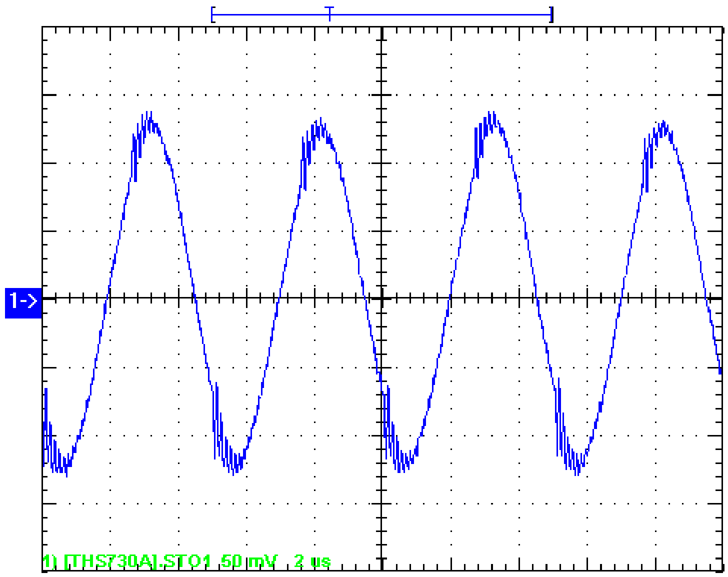


Figure 25: Output Voltage Ripple at 1.5A load current.

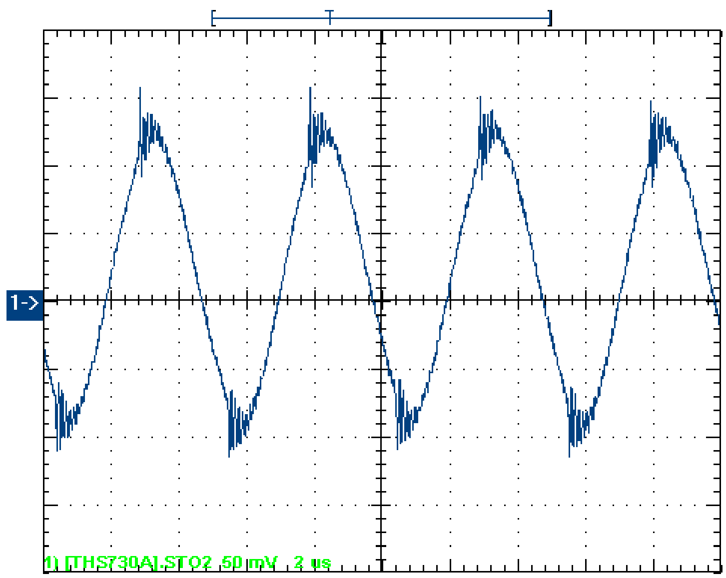


Figure 27: Input Voltage Ripple at 1.5A load current.

The idea of using a transformer with equal DC resistance, but with bigger leakage inductance to reduce the current ripple over the coil and AC capacitor path, did not deliver the desired result of higher system efficiency. The efficiency was even lower than with a good coupled bifilar wired inductor of similar inductance and DC resistance.

In conclusion for this CUK converter the inductor's DC resistance is responsible for the main part of the power dissipation of the transformer.

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