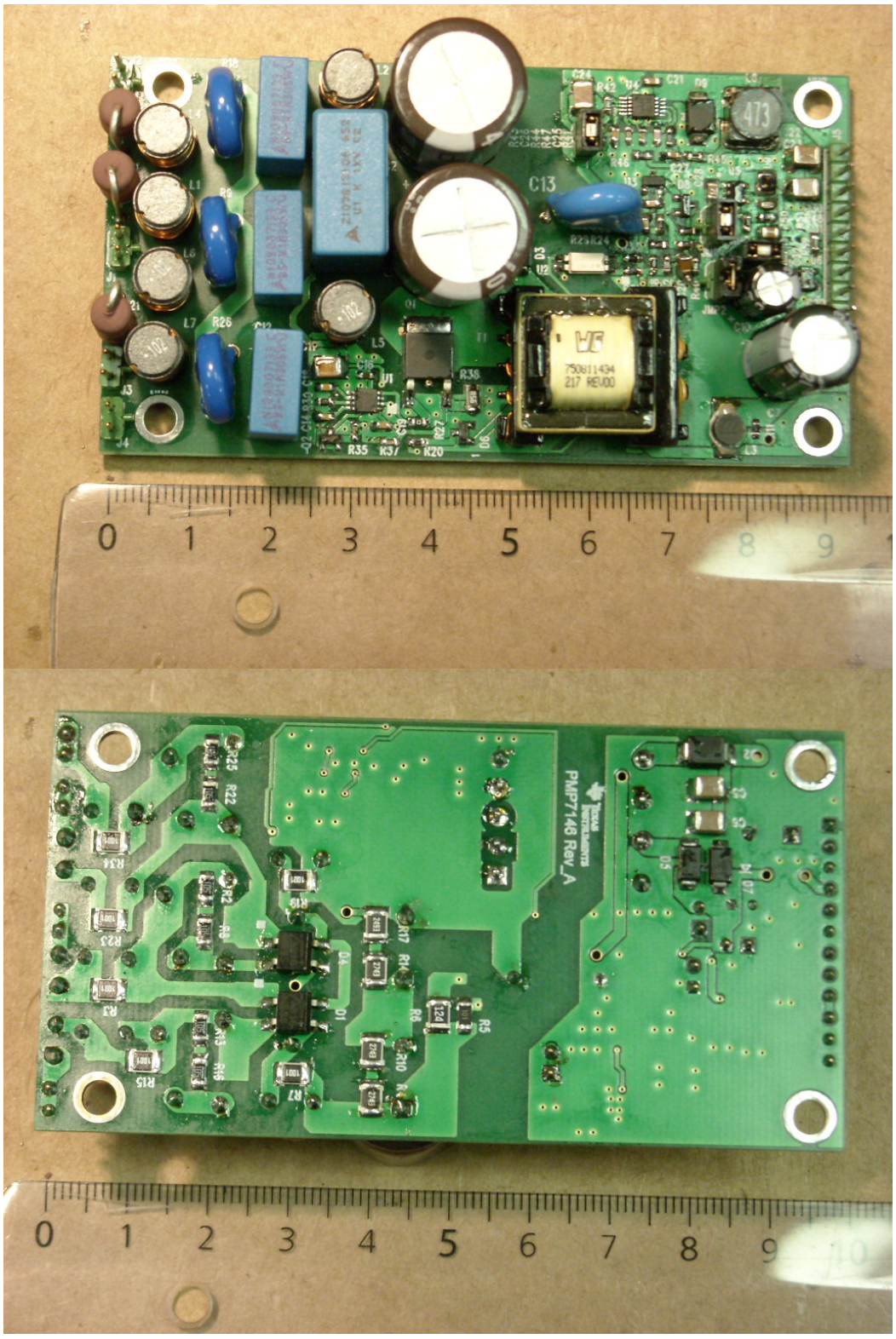
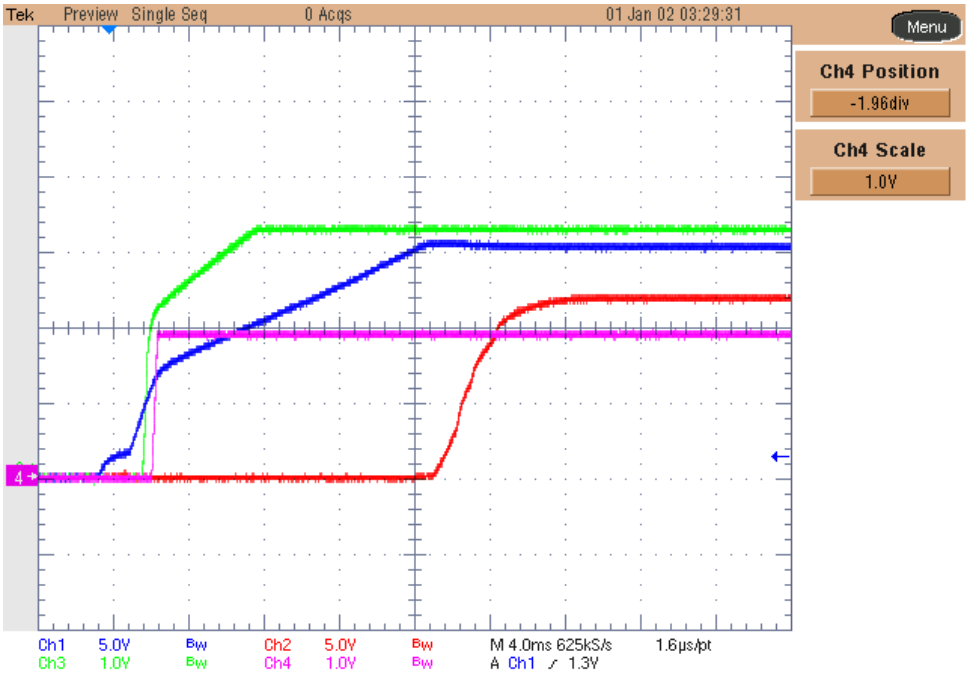
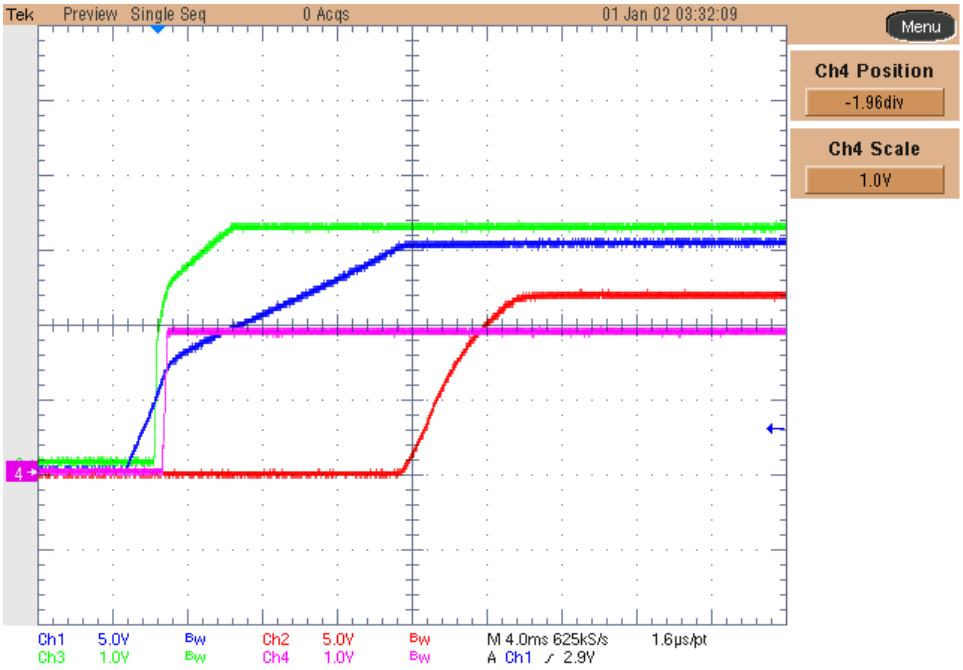
1. Photo of the prototype



2. Startup

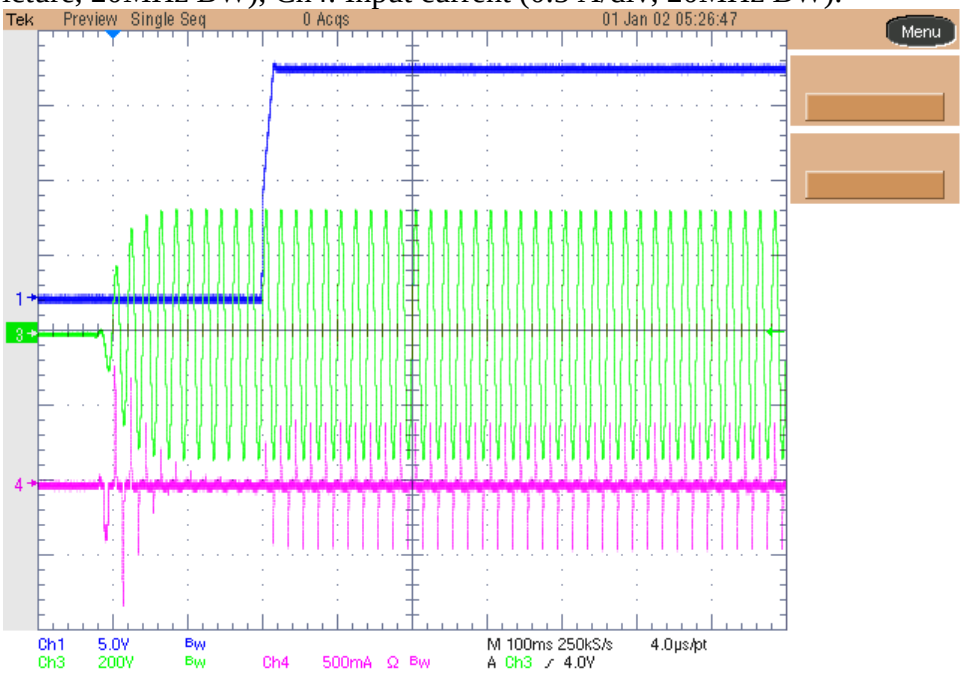
The output voltages at startup are shown in the images below. The input voltage was set to 400Vdc. All outputs were fully loaded (upper picture) and unloaded (lower picture).
Ch1: 16V5 (5 V/div, 4ms/div, 20MHz BW). Ch2: 12V (5 V/div, 20MHz BW)
Ch3: 3.3V (1 V/div, 20MHz BW), Ch4: 1.9V (1 V/div, 20MHz BW).

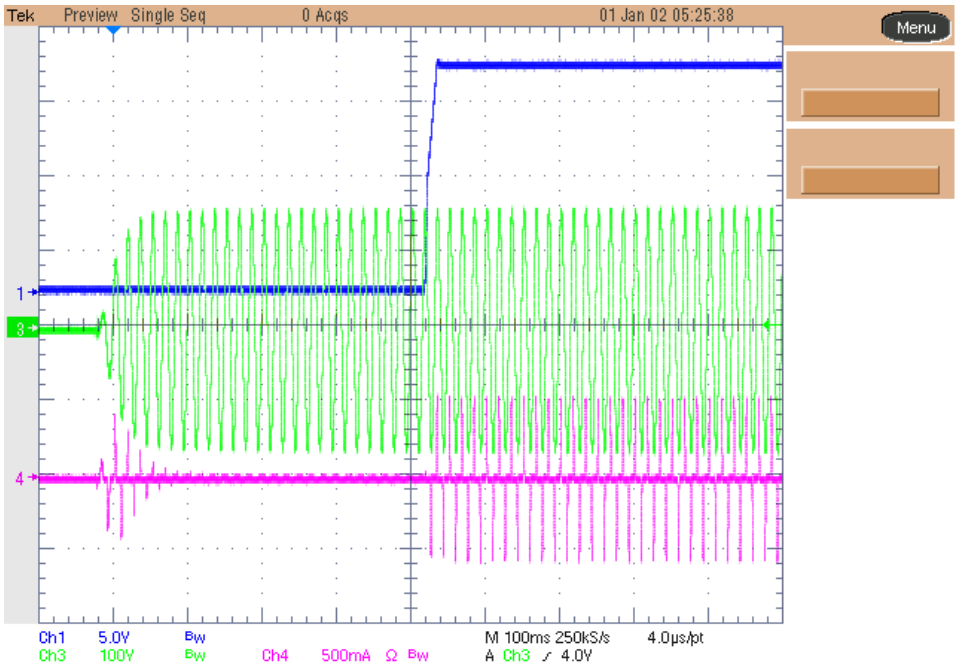




3. Startup: Vin, Iin, 16V5 (before the change described on point 7)

The start up behavior of the input current and 16V5 Flyback output voltage ramp up is shown in the images below. In the upper picture the input voltage was set to 230Vac, 50Hz and the load fully loaded, while the lower picture shows the behavior at 115Vac, 60Hz input , full load.
Ch1: 16V5 (5 V/div, 100ms/div, 20MHz BW), Ch3: Input AC voltage (200 V/div, 100 V/div for the lower picture, 20MHz BW), Ch4: Input current (0.5 A/div, 20MHz BW).

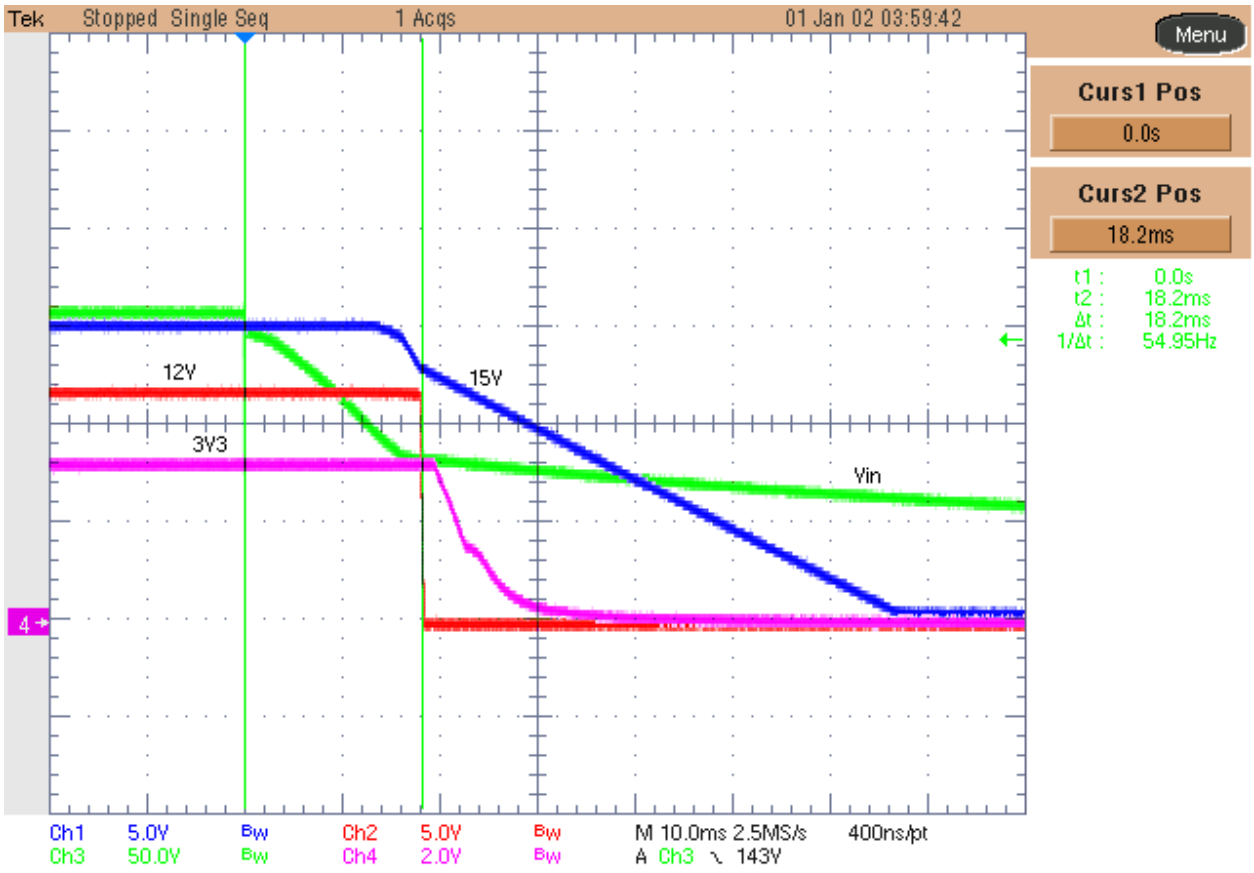




4. Shut down

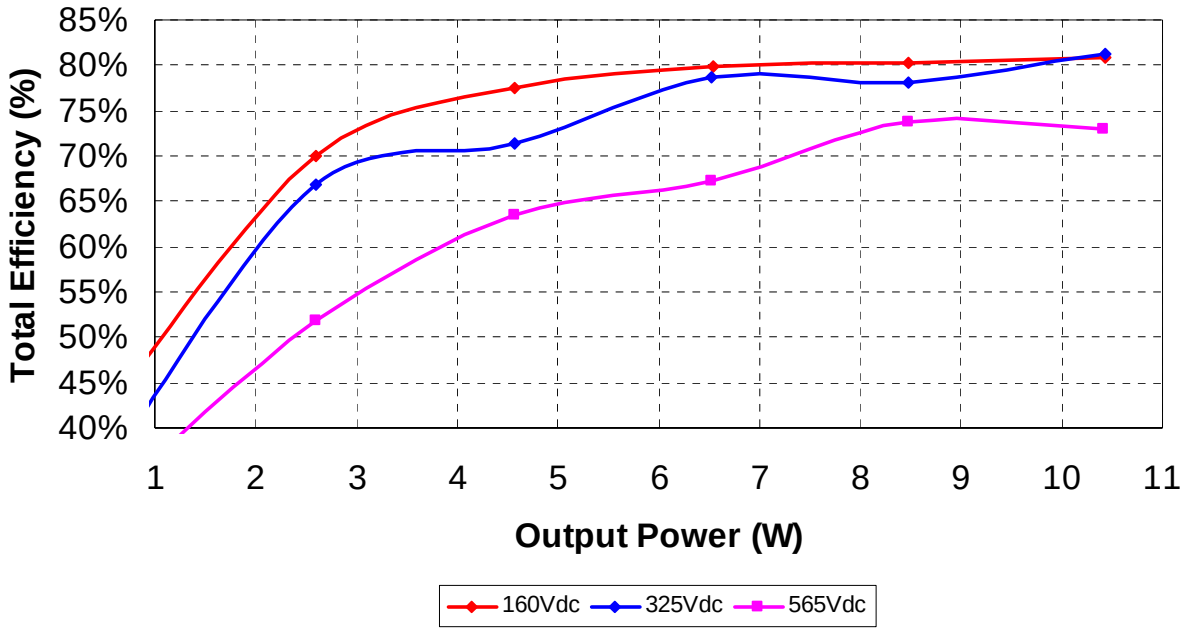
The output voltages during a shut down condition are shown in the image below. The input voltage was set to 160Vdc, which is the 115Vac peak voltage. All outputs were fully loaded. The converter loses regulation after 18.2 milliseconds, useful to provide some hold-up feature.

Ch1: 16V5 (5 V/div, 4ms/div, 20MHz BW). Ch2: 12V (5 V/div, 20MHz BW)
Ch3: Vin (50 V/div, 20MHz BW), Ch4: 3.3V (2 V/div, 20MHz BW).



5. Efficiency: original design

The efficiency data is shown in the tables and graph below. A DC source was set to 160Vdc, 325Vdc and 565Vdc (rectified 115V, 230V and 400V RMS voltages). The output load was increased for all outputs at the same time.



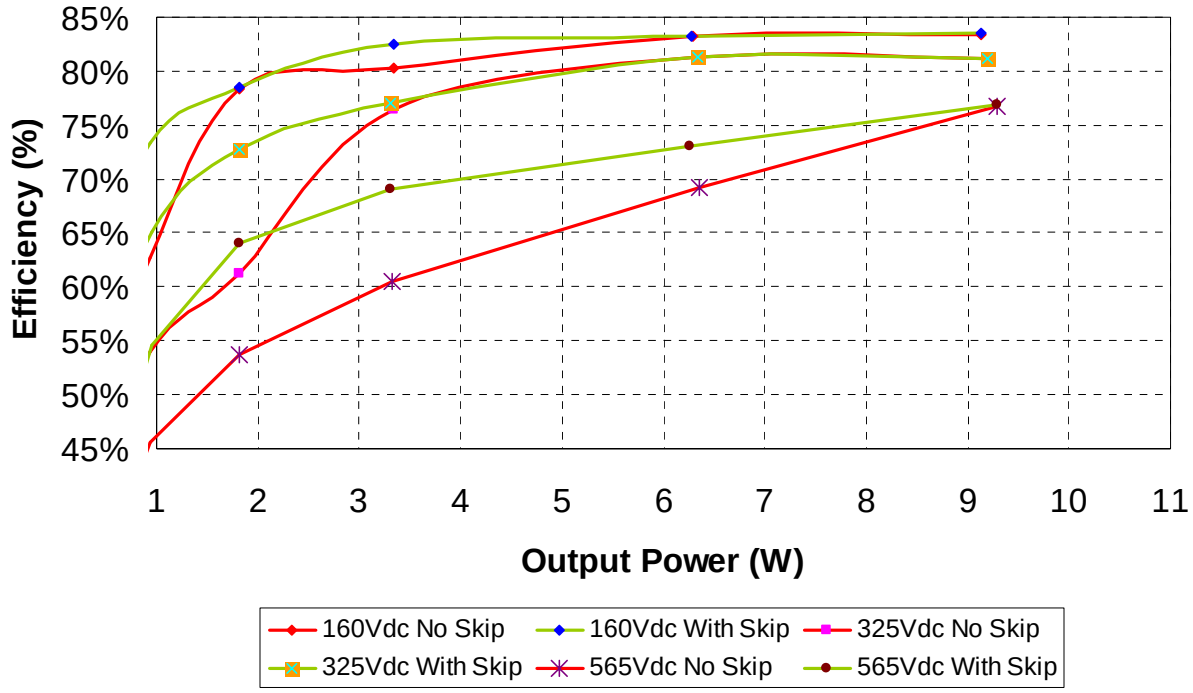
Vin (V)	Iin (mA)	16V5 (V)	I16V5 (mA)	V12 (V)	I12 (mA)	3V3 (V)	I3v3 (mA)	1V9 (V)	I1v9 (mA)	Pout (W)	Pin (W)	Ploss (W)	Eff (%)
160	1.81	15.47	0	11.96	0	3.294	0.00	1.912	0.00	0.00	0.29	0.29	0.0
160	3.66	16.15	0	11.96	0	3.289	24.73	1.907	48.90	0.17	0.59	0.41	0.30
160	5.93	16.47	0	11.96	0	3.287	49.80	1.905	97.69	0.35	0.95	0.60	0.37
160	8.82	16.98	0	11.96	0	3.283	99.48	1.905	146.54	0.61	1.41	0.81	0.43
160	23.19	15.71	50.0	11.96	101.0	3.283	99.48	1.903	146.38	2.60	3.71	1.11	0.70
160	36.80	15.57	100.1	11.94	200.9	3.282	99.45	1.903	146.38	4.56	5.89	1.33	0.77
160	51.1	15.47	150.8	11.95	300.9	3.282	99.45	1.903	146.38	6.53	8.18	1.64	0.80
160	66.0	15.38	200.6	11.93	400.9	3.281	99.42	1.902	146.31	8.47	10.56	2.09	0.80
160	80.5	15.31	250.8	11.94	500.8	3.281	99.42	1.901	146.23	10.42	12.88	2.46	0.81

Vin (V)	Iin (mA)	16V5 (V)	I16V5 (mA)	V12 (V)	I12 (mA)	3V3 (V)	I3v3 (mA)	1V9 (V)	I1v9 (mA)	Pout (W)	Pin (W)	Ploss (W)	Eff (%)
325	0.98	15.50	0	11.96	0	3.294	0.00	1.911	0.00	0.00	0.32	0.32	0.0
325	2.17	16.47	0	11.96	0	3.291	24.74	1.907	48.90	0.17	0.71	0.53	0.25
325	3.32	16.78	0	11.96	0	3.287	49.80	1.905	97.69	0.35	1.08	0.73	0.32
325	5.03	17.11	0	11.96	0	3.283	99.48	1.904	146.46	0.61	1.63	1.03	0.37
325	11.99	15.73	50.2	11.95	100.9	3.283	99.48	1.904	146.46	2.60	3.90	1.30	0.67
325	19.69	15.60	100.4	11.94	200.9	3.282	99.45	1.903	146.38	4.57	6.40	1.83	0.71
325	25.5	15.51	150.1	11.94	300.9	3.282	99.45	1.901	146.23	6.53	8.30	1.77	0.79
325	33.4	15.42	200.2	11.93	400.8	3.281	99.42	1.902	146.31	8.47	10.86	2.39	0.78
325	39.5	15.33	251.0	11.93	500.8	3.281	99.42	1.901	146.23	10.43	12.83	2.40	0.81

Vin (V)	Iin (mA)	16V5 (V)	I16V5 (mA)	V12 (V)	I12 (mA)	3V3 (V)	I3v3 (mA)	1V9 (V)	I1v9 (mA)	Pout (W)	Pin (W)	Ploss (W)	Eff (%)
565	0.97	15.38	0	11.96	0	3.295	0.00	1.910	0.00	0.00	0.55	0.55	0.0
565	1.68	16.64	0	11.96	0	3.289	24.73	1.906	48.87	0.17	0.95	0.77	0.18
565	2.36	17.14	0	11.96	0	3.287	49.80	1.905	97.69	0.35	1.33	0.98	0.26
565	3.31	17.67	0	11.96	0	3.282	99.45	1.904	146.46	0.61	1.87	1.26	0.32
565	8.86	15.71	50.2	11.95	100.9	3.283	99.48	1.903	146.38	2.60	5.01	2.41	0.52
565	12.74	15.56	100.3	11.93	201.0	3.282	99.45	1.902	146.31	4.56	7.20	2.63	0.63
565	17.18	15.51	150.2	11.92	301.0	3.281	99.42	1.902	146.31	6.52	9.71	3.18	0.67
565	20.36	15.44	201.0	11.90	400.8	3.281	99.42	1.901	146.23	8.48	11.50	3.03	0.74
565	25.25	15.39	251.0	11.89	500.7	3.280	99.39	1.900	146.15	10.42	14.27	3.85	0.73

6. Efficiency: Flyback converter only (16V5 out), original design

The efficiency of the Flyback converter alone (the jumpers JMP1,2,3 where removed) is shown in the tables and graph below. The DC source was set to the same values as above. The green curves show the efficiency values when the converter was running with the skip-cycle mode activated (R35 removed), while for the red curves the skip-cycle was OFF and the converter working into burst mode at light loads. It is clear the boost on efficiency at light load.



Without Skip-Cycle									
Vin (V)	Iin (mA)	16V5 (V)	I16V5 (mA)	V5 (V)	I5 (mA)	Pout (W)	Pin (W)	Ploss (W)	Eff (%)
160	3.79	16.21	0.0	5.009	50.1	0.25	0.61	0.36	0.41
160	4.61	16.02	5.7	5.044	50.4	0.35	0.74	0.39	0.47
160	9.41	15.68	43.6	5.097	51.0	0.94	1.51	0.56	0.63
160	14.53	15.55	100.2	5.126	51.3	1.82	2.32	0.50	0.78
160	26.02	15.37	200.1	5.156	51.6	3.34	4.16	0.82	0.80
160	47.20	15.03	400.0	5.215	52.2	6.28	7.55	1.27	0.83
160	68.50	14.71	602.4	5.269	52.7	9.14	10.96	1.82	0.83

With Skip-Cycle									
Vin (V)	Iin (mA)	16V5 (V)	I16V5 (mA)	V5 (V)	I5 (mA)	Pout (W)	Pin (W)	Ploss (W)	Eff (%)
160	2.96	17.04	0.0	4.860	48.6	0.24	0.47	0.24	0.50
160	3.68	16.43	5.7	4.969	49.7	0.34	0.59	0.25	0.58
160	8.04	15.75	43.5	5.087	50.9	0.94	1.29	0.34	0.73
160	14.41	15.43	100.2	5.147	51.5	1.81	2.31	0.49	0.79
160	25.27	15.32	200.1	5.166	51.7	3.33	4.04	0.71	0.82
160	47.20	15.02	400.0	5.217	52.2	6.28	7.55	1.27	0.83
160	68.40	14.70	602.4	5.272	52.7	9.13	10.94	1.81	0.83

Without Skip-Cycle									
Vin (V)	Iin (mA)	16V5 (V)	I16V5 (mA)	V5 (V)	I5 (mA)	Pout (W)	Pin (W)	Ploss (W)	Eff (%)
325	2.31	16.59	0.0	4.942	49.4	0.24	0.75	0.51	0.33
325	2.73	16.17	5.7	5.016	50.2	0.34	0.89	0.54	0.39
325	5.38	15.69	43.6	5.097	51.0	0.94	1.75	0.80	0.54
325	9.16	15.56	100.2	5.125	51.3	1.82	2.98	1.16	0.61
325	13.46	15.39	200.1	5.154	51.5	3.35	4.37	1.03	0.76
325	24.01	15.19	400.0	5.187	51.9	6.35	7.80	1.46	0.81
325	34.89	14.83	602.4	5.250	52.5	9.21	11.34	2.13	0.81

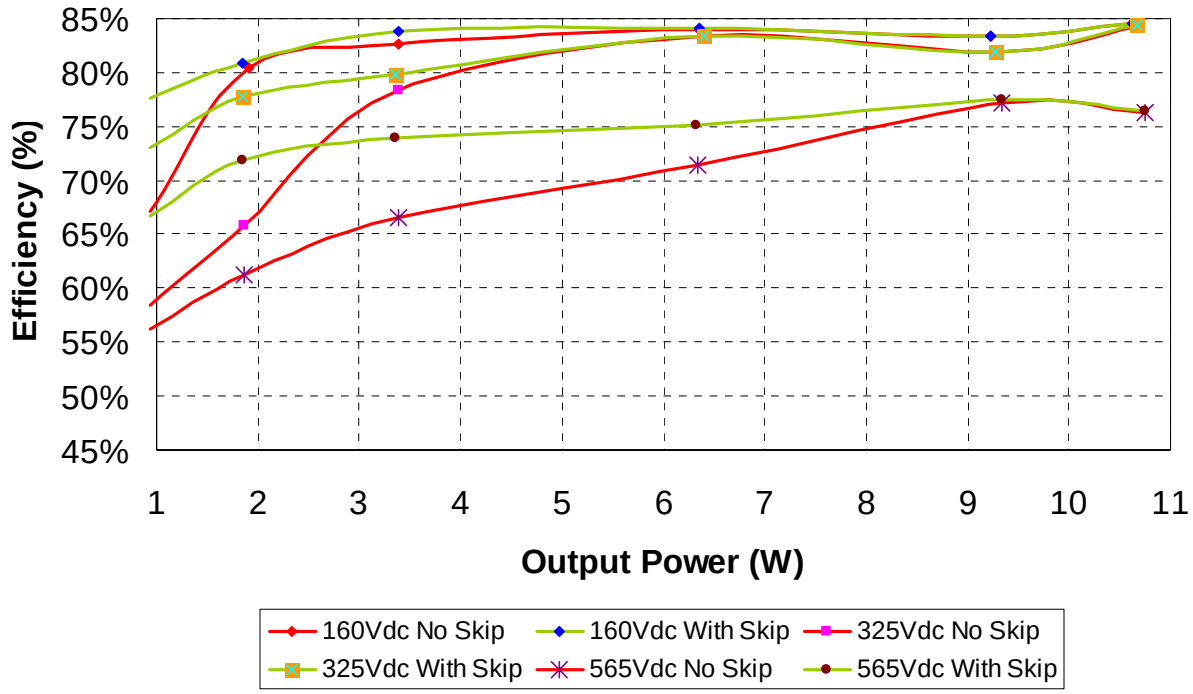
With Skip-Cycle									
Vin (V)	Iin (mA)	16V5 (V)	I16V5 (mA)	V5 (V)	I5 (mA)	Pout (W)	Pin (W)	Ploss (W)	Eff (%)
325	1.84	17.22	0.0	4.828	48.3	0.23	0.60	0.36	0.39
325	2.21	16.54	5.7	4.950	49.5	0.34	0.72	0.38	0.47
325	4.47	15.77	43.6	5.083	50.8	0.95	1.45	0.51	0.65
325	7.67	15.44	100.2	5.147	51.5	1.81	2.49	0.68	0.73
325	13.21	15.19	200.1	5.192	51.9	3.31	4.29	0.98	0.77
325	23.99	15.18	400.0	5.189	51.9	6.34	7.80	1.46	0.81
325	34.86	14.81	602.4	5.253	52.5	9.20	11.33	2.13	0.81

Without Skip-Cycle									
Vin (V)	Iin (mA)	16V5 (V)	I16V5 (mA)	V5 (V)	I5 (mA)	Pout (W)	Pin (W)	Ploss (W)	Eff (%)
565	1.72	16.90	0.0	4.886	48.9	0.24	0.97	0.73	0.25
565	1.99	16.33	5.7	4.988	49.9	0.34	1.12	0.78	0.30
565	3.67	15.72	43.6	5.092	50.9	0.94	2.07	1.13	0.46
565	5.97	15.46	100.2	5.142	51.4	1.81	3.37	1.56	0.54
565	9.74	15.31	200.1	5.167	51.7	3.33	5.50	2.17	0.61
565	16.26	15.22	400.0	5.181	51.8	6.36	9.19	2.83	0.69
565	21.42	14.97	602.4	5.224	52.2	9.29	12.10	2.81	0.77

With Skip-Cycle									
Vin (V)	Iin (mA)	16V5 (V)	I16V5 (mA)	V5 (V)	I5 (mA)	Pout (W)	Pin (W)	Ploss (W)	Eff (%)
565	1.50	17.40	0.0	4.797	48.0	0.23	0.85	0.62	0.27
565	1.71	16.66	5.7	4.930	49.3	0.34	0.97	0.63	0.35
565	3.06	15.80	43.5	5.077	50.8	0.95	1.73	0.78	0.55
565	5.01	15.43	100.2	5.150	51.5	1.81	2.83	1.02	0.64
565	8.47	15.15	200.1	5.199	52.0	3.30	4.79	1.48	0.69
565	15.16	14.96	400.0	5.229	52.3	6.26	8.57	2.31	0.73
565	21.37	14.96	602.4	5.227	52.3	9.29	12.07	2.79	0.77

7. Efficiency: Flyback converter only (16V5 out), modified design

The efficiency of the Flyback converter alone (the jumpers JMP1,2,3 where removed) has been measured again by removing R2, R8, R13, R16, R22, R25, selecting for R4 and R10 1MOhm and for R17 887KOhm, and replacing the clamp network R5, C4, R6 with two SMAJ58A TVS in series. The efficiency has been measured again and below is shown the results, with and without (respectively green and red curves) the skip-cycle activated. There is a great improvement on light load and no-load loss reduction.



Without Skip-Cycle									
Vin (V)	Iin (mA)	16V5 (V)	I16V5 (mA)	V5 (V)	I5 (mA)	Pout (W)	Pin (W)	Ploss (W)	Eff (%)
160	0.922	15.16	0.0	5.222	0.0	0.00	0.15	0.147	0.00
160	8.74	15.75	43.0	5.112	51.1	0.94	1.40	0.46	0.67
160	14.79	15.61	105.0	5.136	51.4	1.90	2.37	0.46	0.80
160	25.64	15.45	202.1	5.164	51.6	3.39	4.10	0.71	0.83
160	47.30	15.14	401.9	5.217	52.2	6.36	7.57	1.21	0.84
160	69.10	14.87	601.8	5.263	52.6	9.23	11.06	1.83	0.83
160	78.50	14.75	701.6	5.284	52.8	10.63	12.56	1.93	0.85

With Skip-Cycle									
Vin (V)	Iin (mA)	16V5 (V)	I16V5 (mA)	V5 (V)	I5 (mA)	Pout (W)	Pin (W)	Ploss (W)	Eff (%)
160	0.63	15.40	0.0	5.179	0.0	0.00	0.10	0.101	0.00
160	7.56	15.79	42.9	5.107	51.1	0.94	1.21	0.27	0.78
160	14.30	15.50	102.3	5.157	51.6	1.85	2.29	0.44	0.81
160	25.24	15.41	202.1	5.174	51.7	3.38	4.04	0.66	0.84
160	47.20	15.13	401.9	5.220	52.2	6.35	7.55	1.20	0.84
160	69.10	14.87	601.8	5.266	52.7	9.23	11.06	1.83	0.83
160	78.50	14.75	701.6	5.286	52.9	10.63	12.56	1.93	0.85

Without Skip-Cycle									
Vin (V)	Iin (mA)	16V5 (V)	I16V5 (mA)	V5 (V)	I5 (mA)	Pout (W)	Pin (W)	Ploss (W)	Eff (%)
325	0.503	15.37	0.0	5.184	0.0	0.00	0.16	0.163	0.00
325	4.94	15.77	42.9	5.110	51.1	0.94	1.61	0.67	0.58
325	8.69	15.56	102.3	5.147	51.5	1.86	2.82	0.97	0.66
325	13.32	15.45	202.1	5.164	51.6	3.39	4.33	0.94	0.78
325	23.62	15.24	401.9	5.199	52.0	6.40	7.68	1.28	0.83
325	34.85	14.96	601.8	5.247	52.5	9.28	11.33	2.05	0.82
325	38.94	14.81	701.6	5.272	52.7	10.67	12.66	1.99	0.84

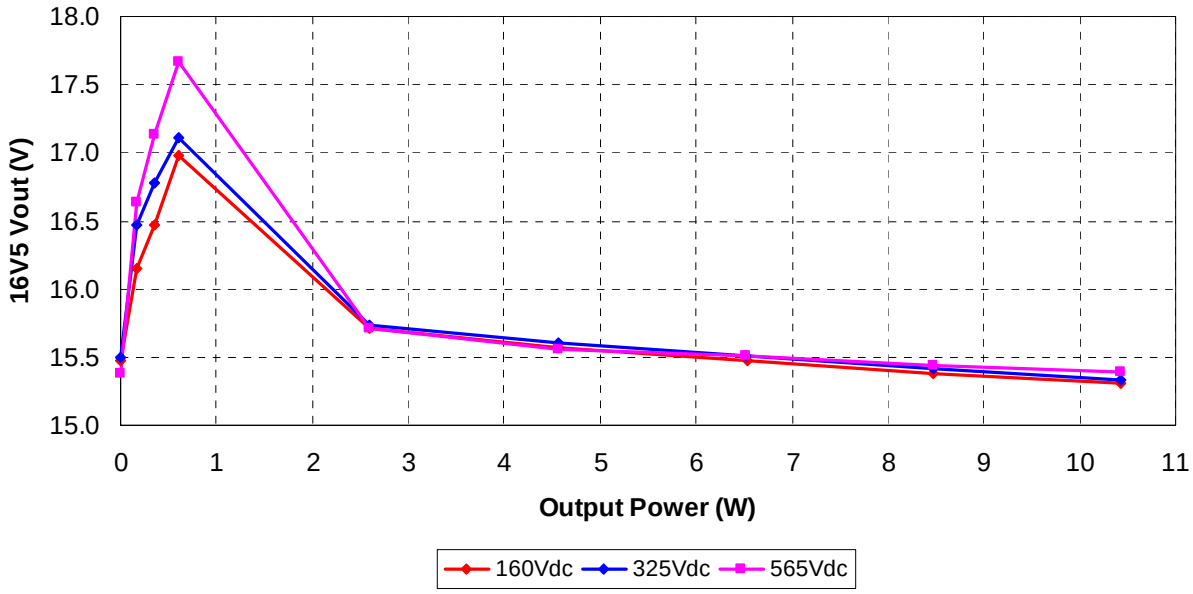
With Skip-Cycle									
Vin (V)	Iin (mA)	16V5 (V)	I16V5 (mA)	V5 (V)	I5 (mA)	Pout (W)	Pin (W)	Ploss (W)	Eff (%)
325	0.3829	15.42	0.0	5.174	0.0	0.00	0.12	0.124	0.00
325	3.95	15.79	42.9	5.106	51.1	0.94	1.28	0.35	0.73
325	7.33	15.51	102.3	5.157	51.6	1.85	2.38	0.53	0.78
325	12.94	15.27	202.1	5.198	52.0	3.36	4.21	0.85	0.80
325	23.61	15.24	401.9	5.201	52.0	6.40	7.67	1.28	0.83
325	34.83	14.96	601.8	5.249	52.5	9.28	11.32	2.04	0.82
325	38.92	14.82	701.6	5.274	52.7	10.68	12.65	1.97	0.84

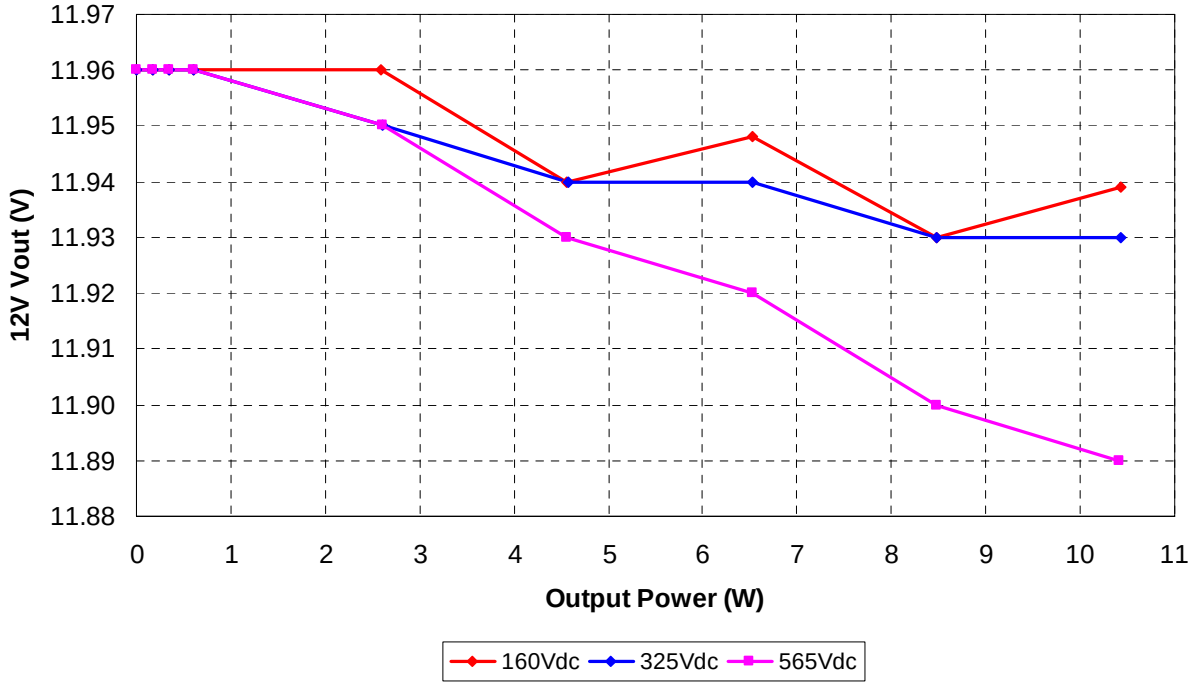
Without Skip-Cycle									
Vin (V)	Iin (mA)	16V5 (V)	I16V5 (mA)	V5 (V)	I5 (mA)	Pout (W)	Pin (W)	Ploss (W)	Eff (%)
565	0.387	15.34	0.0	5.189	0.0	0.00	0.22	0.22	0.00
565	2.95	15.78	42.9	5.108	51.1	0.94	1.67	0.73	0.56
565	5.37	15.56	102.3	5.147	51.5	1.86	3.03	1.18	0.61
565	9.02	15.45	202.1	5.166	51.7	3.39	5.10	1.71	0.67
565	15.69	15.08	401.9	5.229	52.3	6.33	8.86	2.53	0.71
565	21.40	15.06	601.8	5.229	52.3	9.34	12.09	2.75	0.77
565	24.91	14.92	701.6	5.253	52.5	10.74	14.07	3.33	0.76

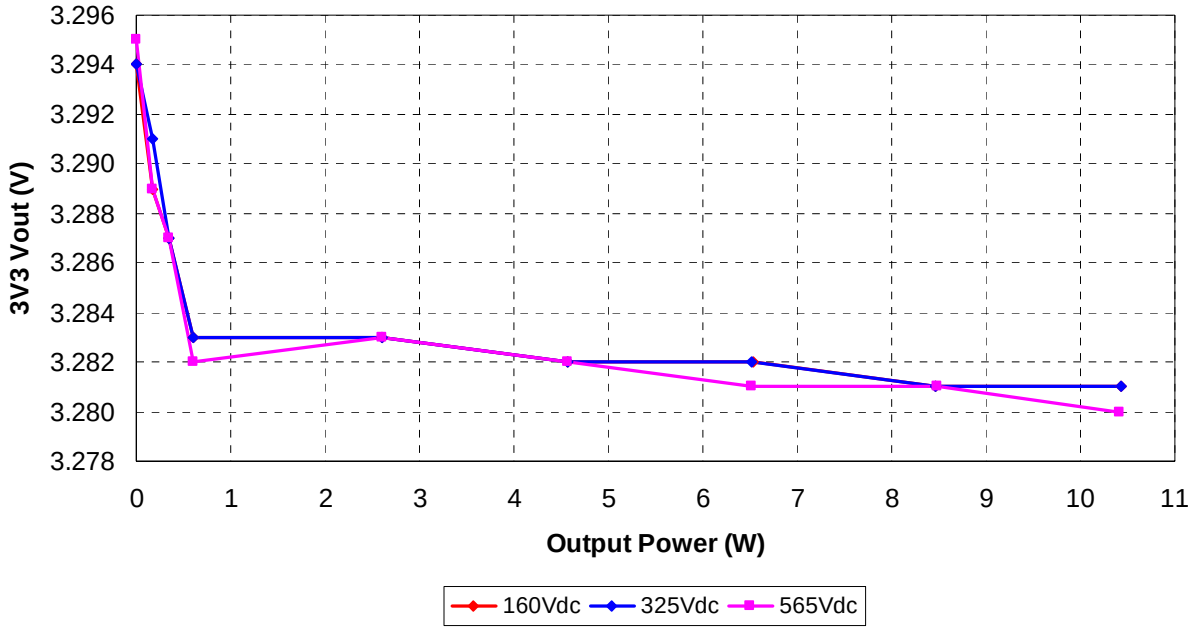
With Skip-Cycle									
Vin (V)	Iin (mA)	16V5 (V)	I16V5 (mA)	V5 (V)	I5 (mA)	Pout (W)	Pin (W)	Ploss (W)	Eff (%)
565	0.3242	15.39	0.0	5.181	0.0	0.00	0.18	0.18	0.00
565	2.49	15.83	42.9	5.099	51.0	0.94	1.41	0.47	0.67
565	4.56	15.51	102.3	5.157	51.6	1.85	2.58	0.72	0.72
565	8.03	15.26	202.1	5.201	52.0	3.35	4.54	1.18	0.74
565	14.89	15.05	401.9	5.235	52.4	6.32	8.41	2.09	0.75
565	21.34	15.06	601.8	5.232	52.3	9.34	12.06	2.72	0.77
565	24.89	14.92	701.6	5.256	52.6	10.74	14.06	3.32	0.76

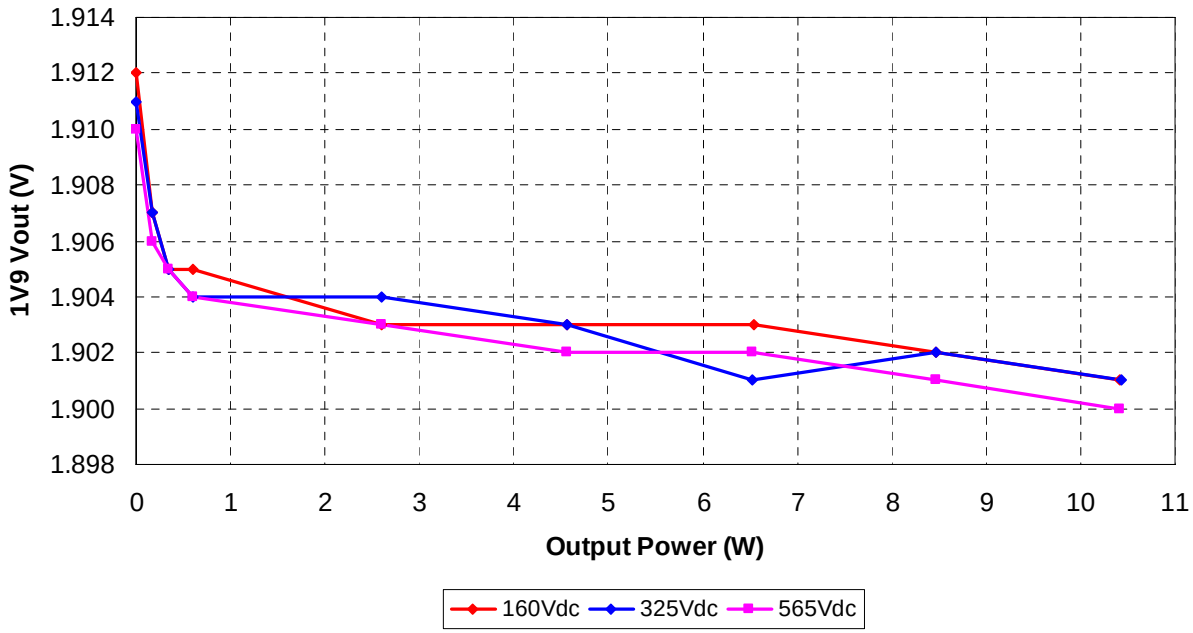
8. Line and Load Regulation

The output voltages variations as function of load change and input voltage change is shown below. For the first four points the 16V5 output was unloaded, then increased by 50mA per step, while the 3V3 and the 1V9 were kept at constant load. The load on the 12V was varied also by 100mA per step.







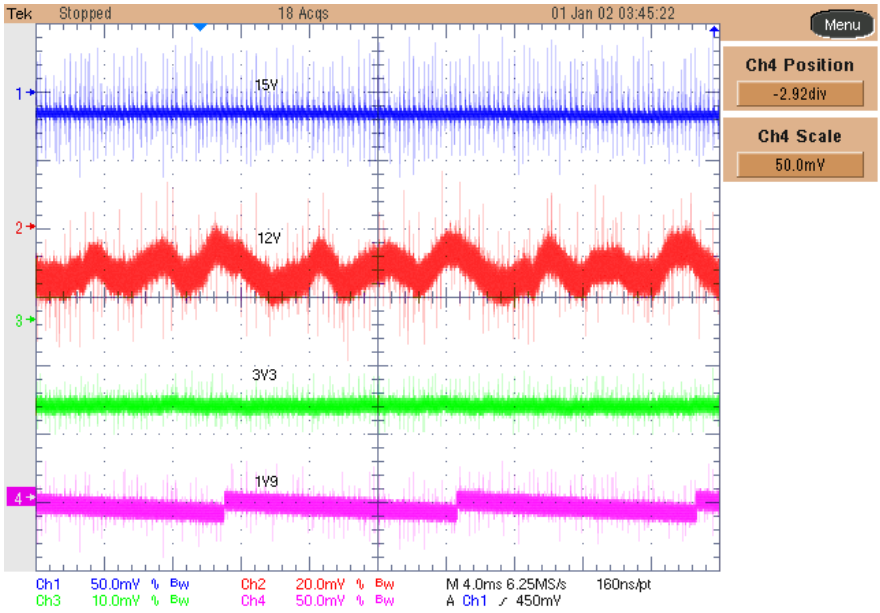


A minimum load of 20mA must be always present on the 3.3V output, or 100mW load to any other output, in order to get the 13.5V minimum on the 16V5 output.

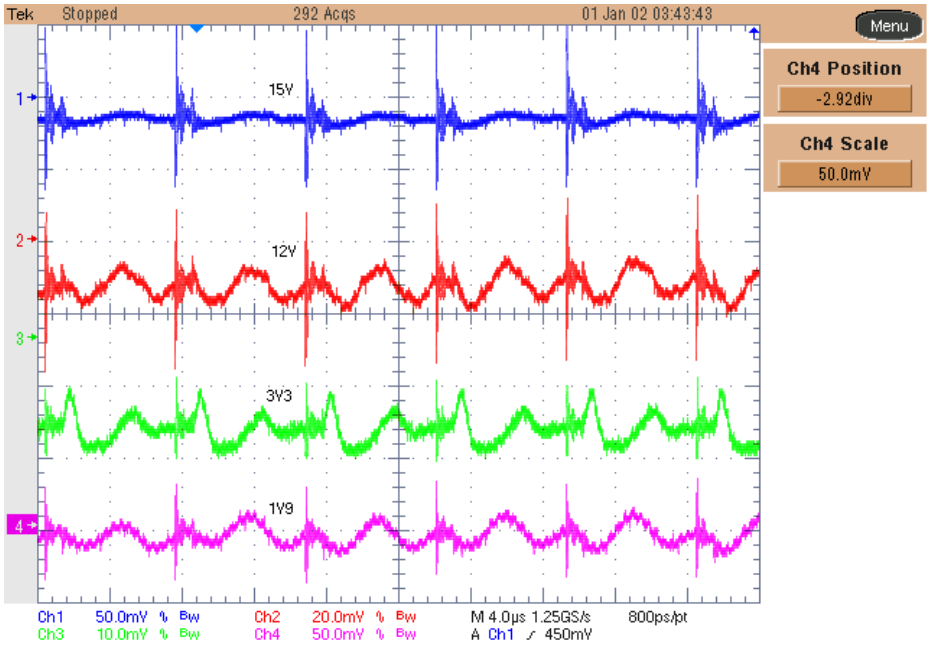
9. Output Ripple Voltages

The output ripple voltage for the four outputs is shown in the plots below. The input was set to 400Vdc.

No load conditions: AC coupling and 20MHz BWL for all channels, 4msec/div.
Ch1: 16V5 (50mV/div), Ch2: 12V (20mV/div),
Ch3: 3V3 (10mV/div), Ch4: 1V9 (50mV/div)

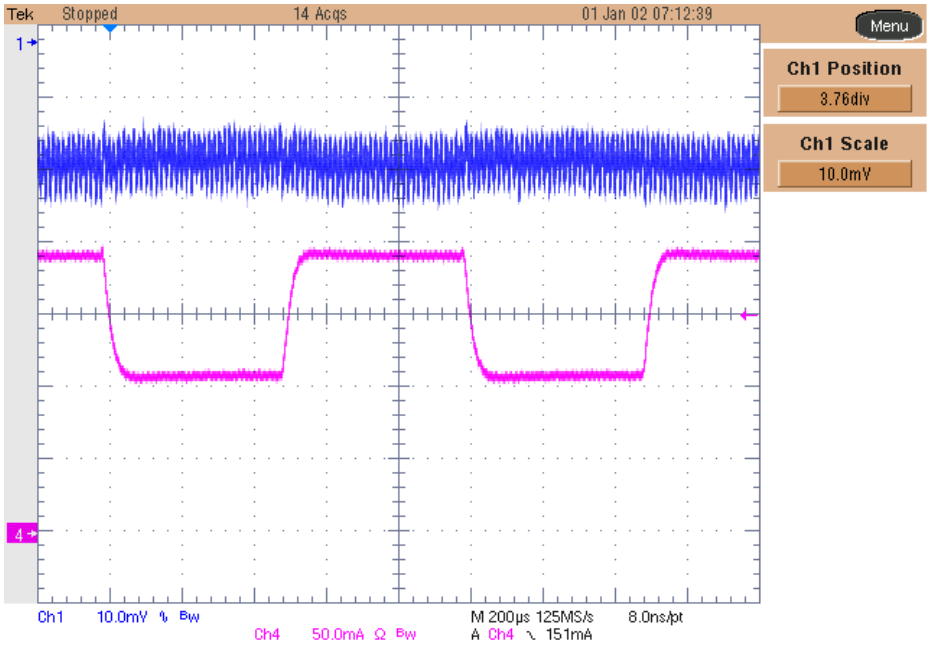


Full load conditions: AC coupling and 20MHz BWL for all channels, 4usec/div.

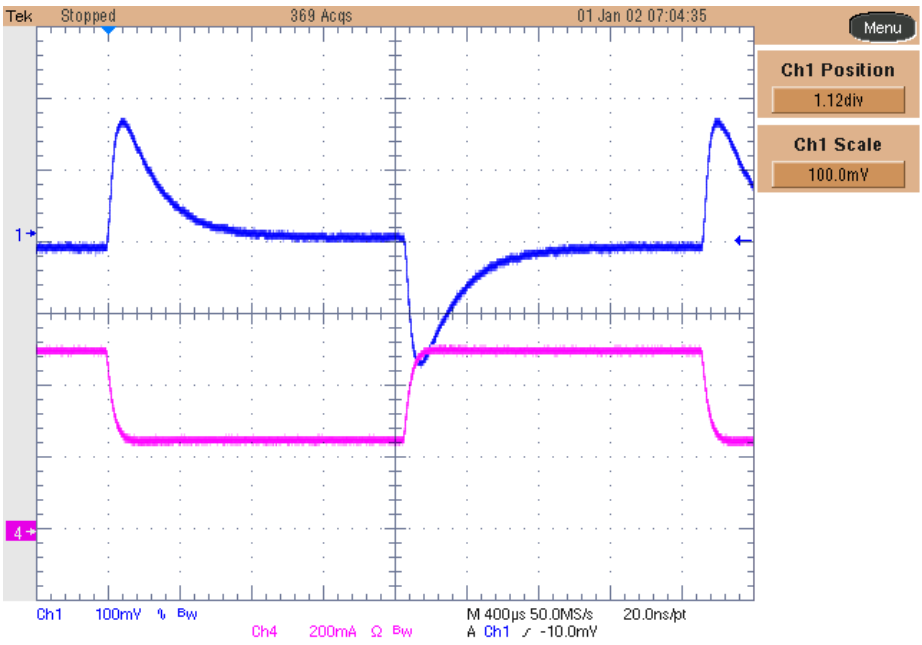


10. Load Transient on 1V9 and 12V outputs

The images below show the response of the 1V9 and 12V outputs due to a 50% to 100% load transient. The input voltage was set to 325Vdc.
Channel 1: 1V9 output voltage (10mV/div, 200us/div, ac coupled, 20MHz BWL)
Channel 4: 1V9 output current (50mA/div, dc coupled, 20MHz BWL)

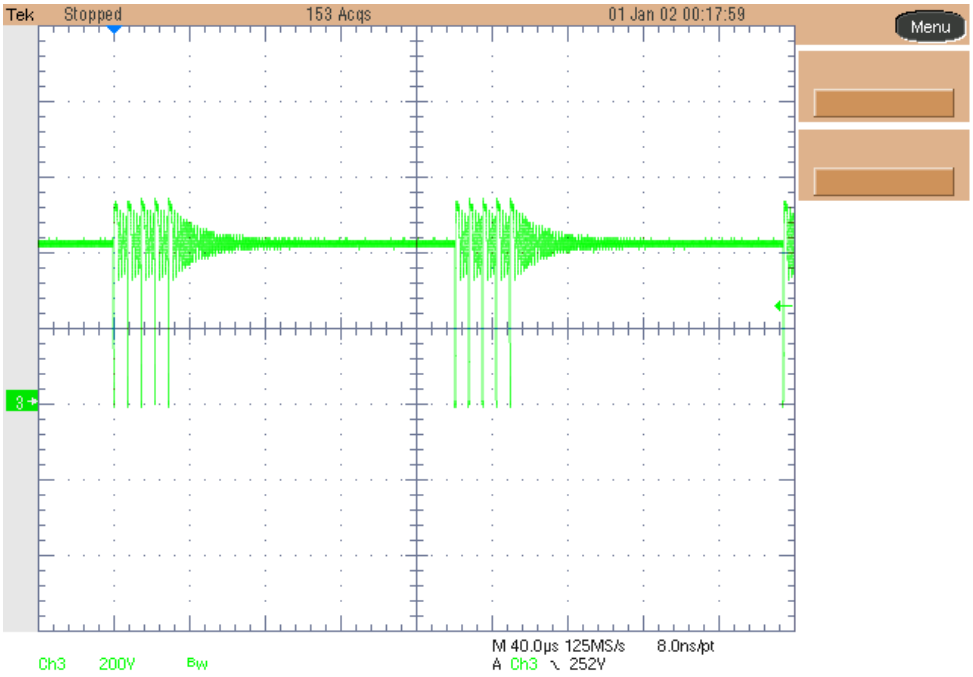


Channel 1: 12V output voltage (100mV/div, 400us/div, ac coupled, 20MHz BWL)
Channel 4: 12V output current (200mA/div, dc coupled, 20MHz BWL)

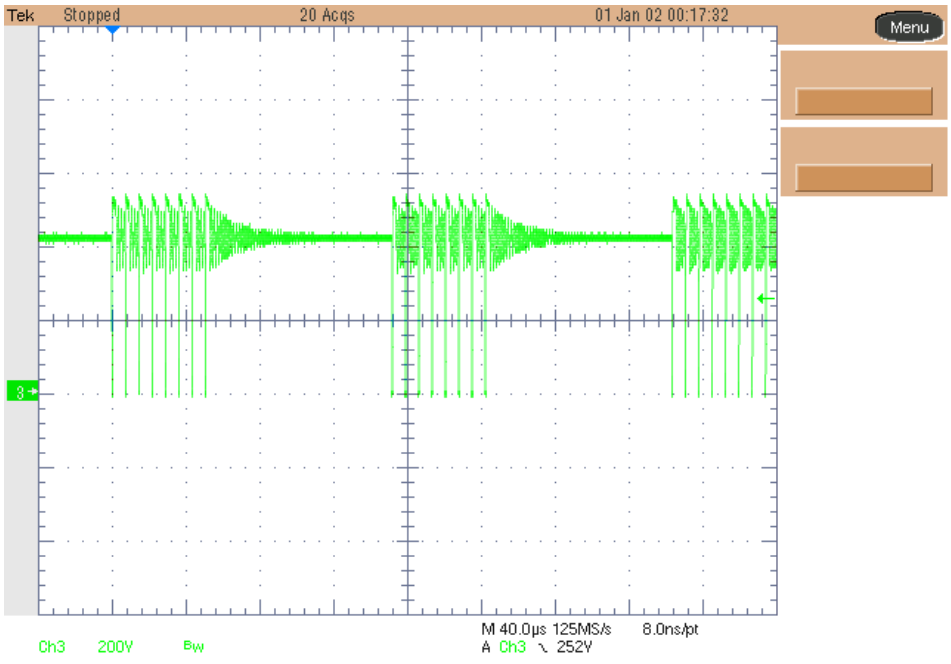


11. Switching waveforms

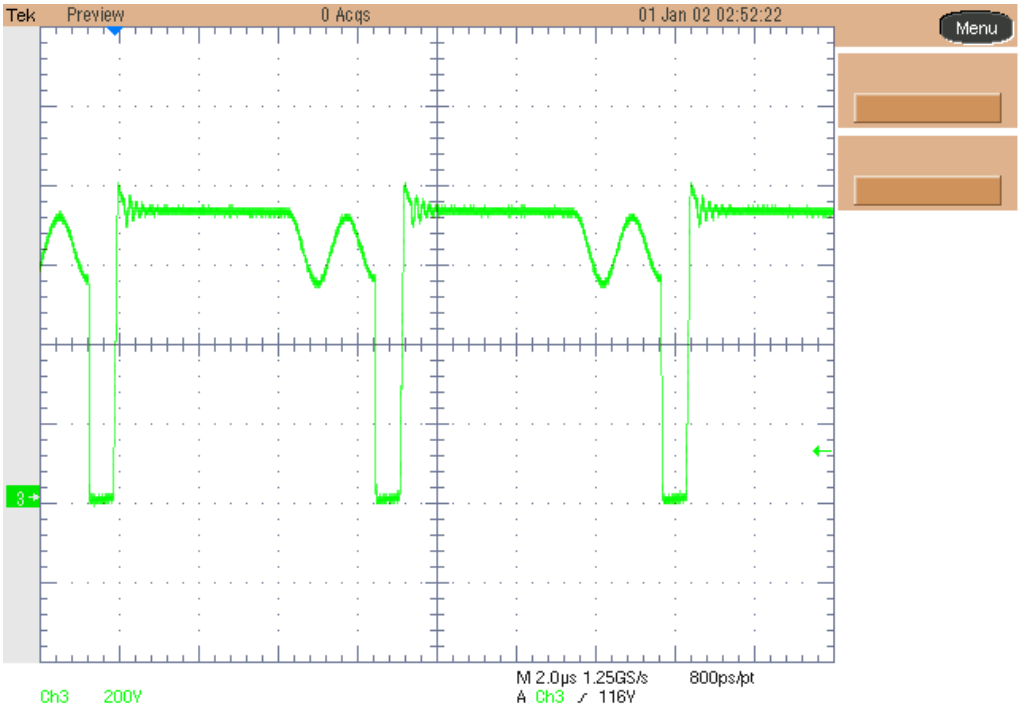
The images below show the switch-node waveforms taken at 420Vdc input and several load conditions.
All outputs unloaded except 3.3V, which was loaded with 50mA.
Channel 3: Vds (Q1) (200V/div, 40usec/div, 20MHz BW).



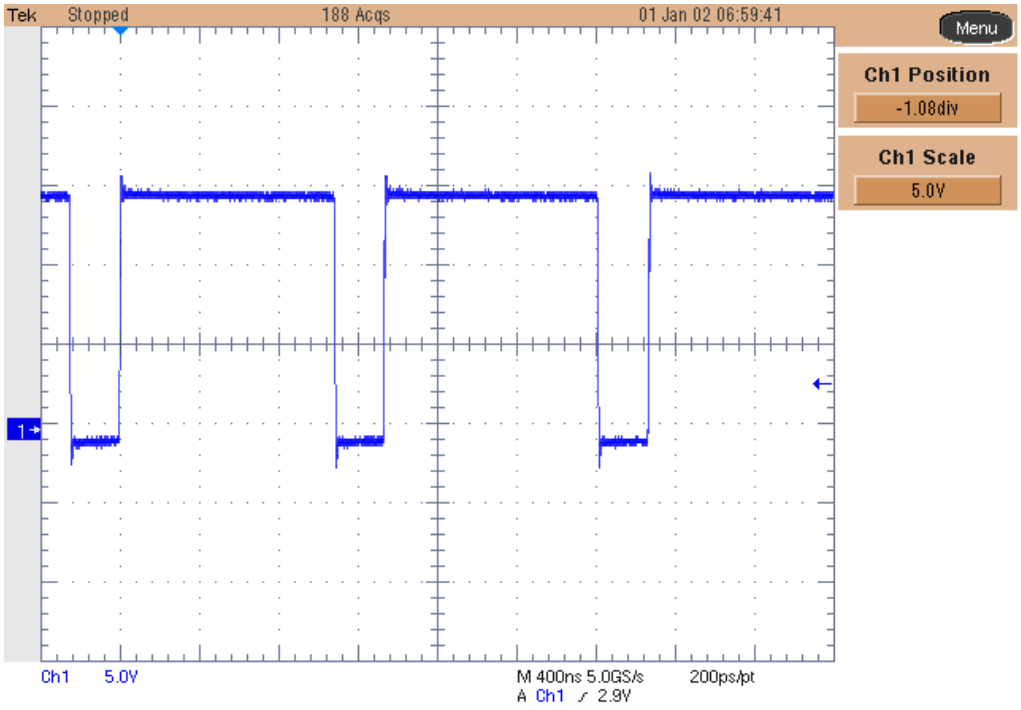
Load conditions: 16V5 and 12V unloaded, 3.3V @ 50mA and 1V9 at 150mA.
Channel 3: Vds (Q1) (200V/div, 40usec/div, 20MHz BW).



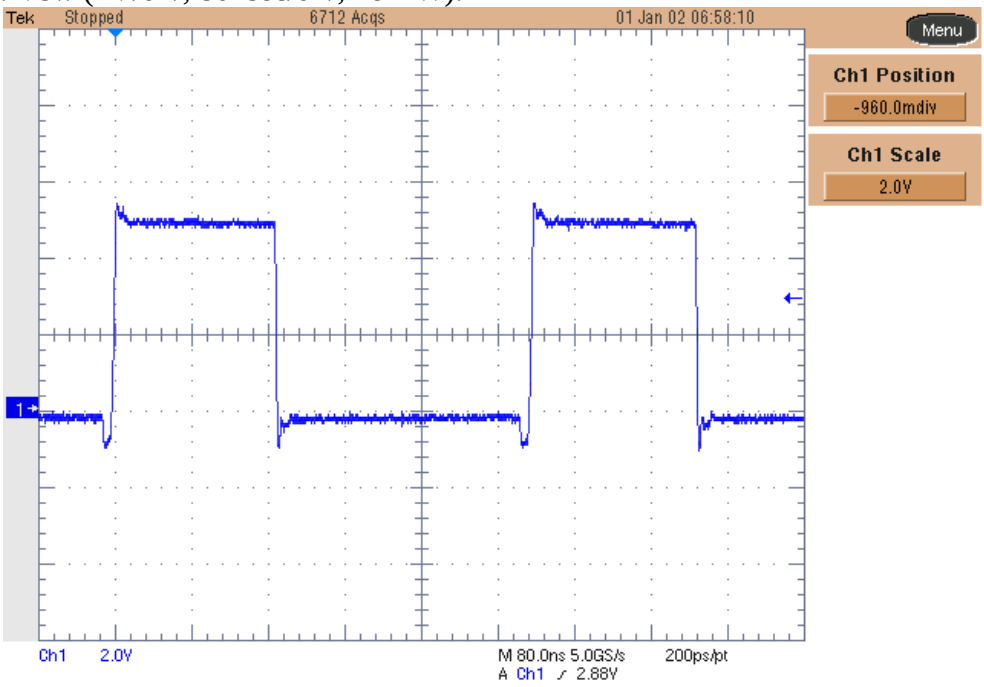
Load conditions: all outputs fully loaded, Vin = 630Vdc
Channel 3: Vds (Q1) (200V/div, 2usec/div, no BW).



12V output, U4 PH node: 15V input, 500mA load
Channel 1: Vph (5V/div, 400nsec/div, no BW).

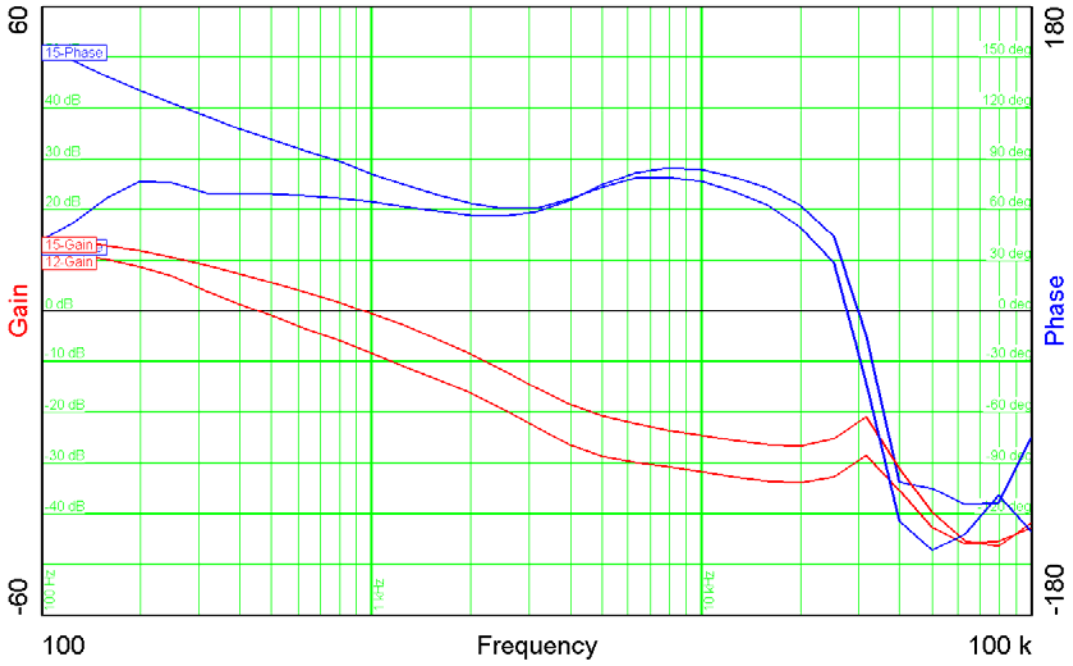


1V9 output, U5 SW node: 5V input, 150mA load
Channel 1: Vsw (2V/div, 80nsec/div, no BW).

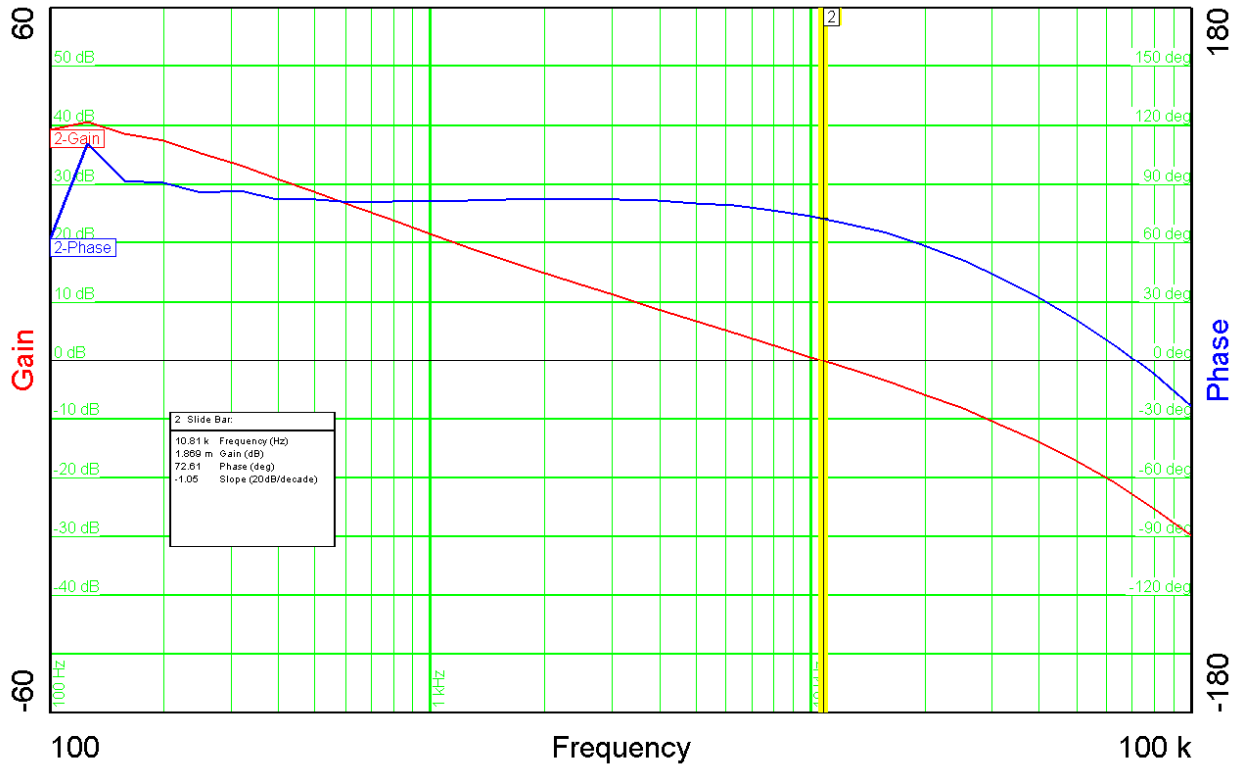


12. Loop Response

The image below shows the loop response of the Flyback converter measured with a 320Vdc input, at 0.2A and 0.5A load. The worst case phase margin was 69 deg., the crossover frequency is 450Hz and1KHz.



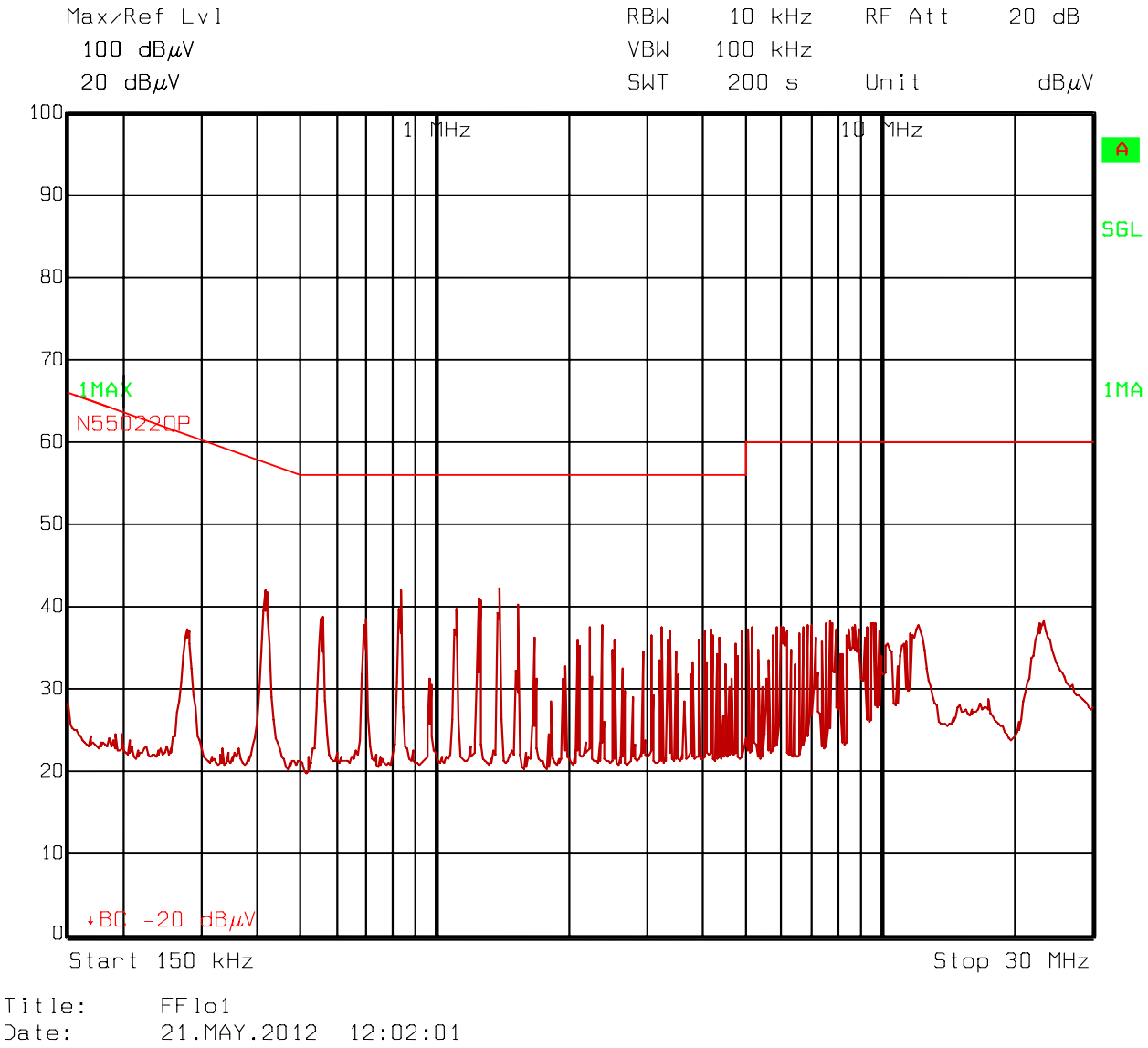
The loop response of the 12V Buck converter has been measured and the result is shown in the graph below. The input voltage was 15V and the load 0.5A. The measured phase margin was 72.6deg. and the crossover frequency 10.8KHz.



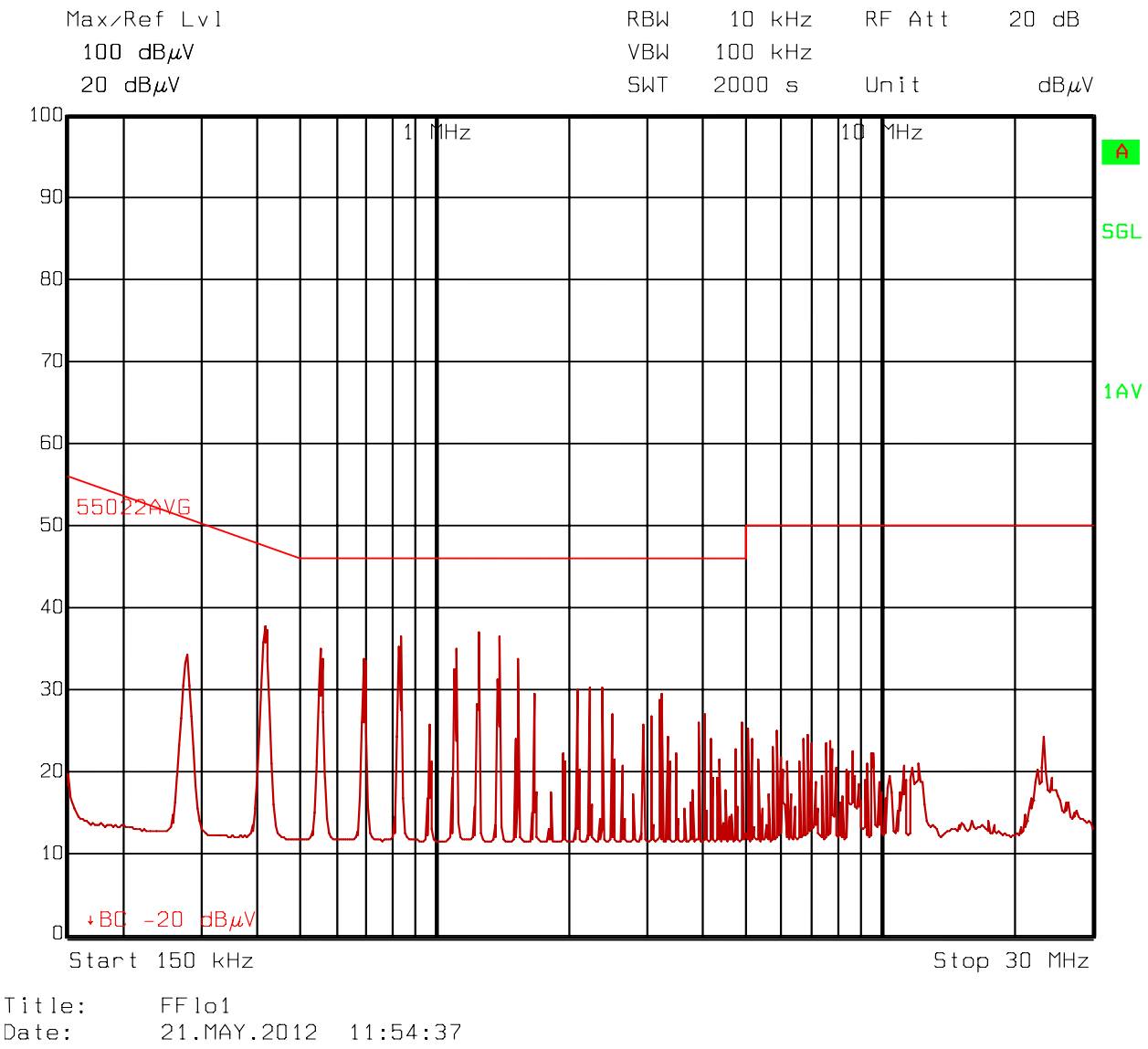
13. EMI measurements

The graphs below show EMI measure taken on the prototype while working with a 230Vac mains and full load (resistors on all loads). A 360W isolation transformer and a Hameg HM6050-2 LISN have been used as AC source. The receiver was a Rohde & Schwarz, 9 KHz…3.5 GHz, set to measure the noise in “quasi-peak” and average mode.

EN55022 Quasi-Peak measurement:



EN55022 Average measurement:



Title: FFlo1
Date: 21.MAY.2012 11:54:37

14. Thermal measurement

The thermal image shown below has been taken when the prototype was supplied with 430Vdc and fully loaded. The board was horizontal on the bench in still air conditions.

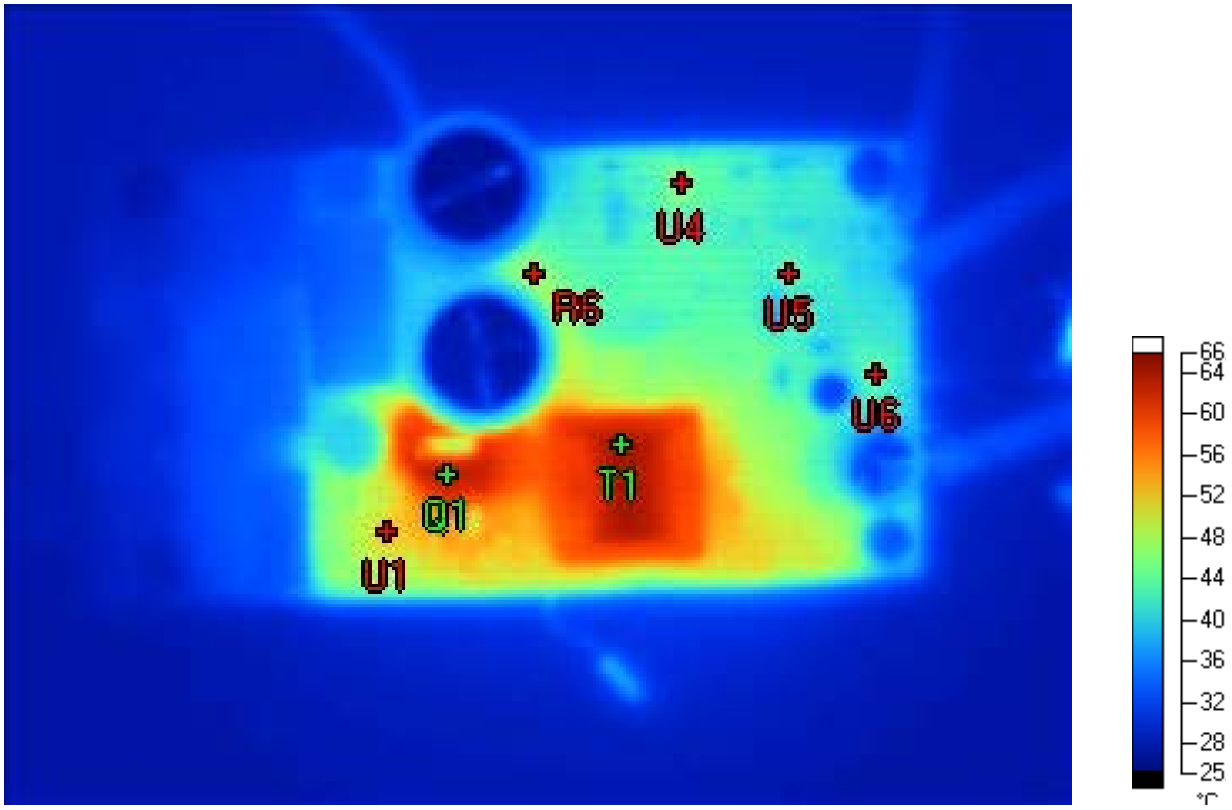


Image Info

Background	25.0 °C
Camera Model	Ti40FT
Image Range	26.0 °C to 64.3 °C
Image Time	5/8/2012 2:06:45 PM
Manufacturer	Fluke
Camera Serial Number	Ti40FT-070263

Markers

Label	Temperature	Emissivity	Background
T1	64.3 °C	0.96	25.0 °C
Q1	63.1 °C	0.96	25.0 °C
U1	52.6 °C	0.96	25.0 °C
U4	46.9 °C	0.96	25.0 °C
U6	43.6 °C	0.96	25.0 °C
U5	43.6 °C	0.96	25.0 °C
R6	46.6 °C	0.96	25.0 °C

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