A low cost, high efficiency adapter for modems using CamSemi's resonant discontinuous forward converter (RDFC) topology and advanced controller IC

RDFC Controller IC product number: C2472PX2 (SOT23-6)

This report describes a low cost, high efficiency, offline adapter demonstrator (reference AD-2078) for ADSL modems, routers and similar products. It operates from a 230 Vac nominal line input and provides a single isolated 12 V output that can deliver 12 W continuous output power.

Figure 1: AD-2078 Adapter Demonstrator for Modems

For further information about the RDFC topology and to obtain the C2472PX2 datasheet (reference DS-1423), visit www.camsemi.com.

Contents

1 SPECIFICATION

Description	Symbol	Min	Typ	Max	Units	Comments
Line input voltage	V_{IN}	195	230	265	Vac	
Line frequency	F_L	47	50	53	Hz	
Output voltage	V_{OUT}	12.2	12.57	12.8	V	V_{IN} = 230Vac, 50 Hz; I_{OUT} = 1 A. Measured at the output connector. Nominally a 12 V output but positioned slightly higher to compensate for voltage drops in external output leads, and to compensate for poor quality mains supplies.
No-load output voltage	V_{OUT}		16.25	16.5	V	V_{IN} = 265 Vac, 53 Hz. (High line frequency slightly increases output voltage.)
Output voltage variation with load	V_{OUT}	12.2		13.8	V	V_{IN} = 230 Vac, 50 Hz; I_{OUT} = 1 A to 0.05 A. See Figure 10.
Output voltage variation with input voltage and frequency	V_{OUT}	10.2		14.8	V	V_{IN} = 195 Vac, 47 Hz V_{IN} = 265 Vac, 53 Hz I_{OUT} = 1 A. See Figure 10.
Rated continuous output current	I_{OUT}			1	A	
Peak output current	I_{OUTPK}	1.2			A	Thermally and electrically limited.
Output ripple voltage - line frequency	$V_{RIPPLEFL}$		0.365	1.2	V	
Output ripple voltage - switching frequency	$V_{RIPPLEF}$		160	200	mV	
Rated continuous output power	P_{OUT}	0		12	W	Thermally and electrically limited.
Conversion efficiency	η	77.8	86.1		%	Energy Star EPS V2.0 limit is 77.8%.
No-load consumption	$P_{NO\text{-}LOAD}$		0.211	0.3	W	Energy Star EPS V2.0 limit is 0.3 W.

Table 1: Key Parameters

2 CIRCUIT SCHEMATIC

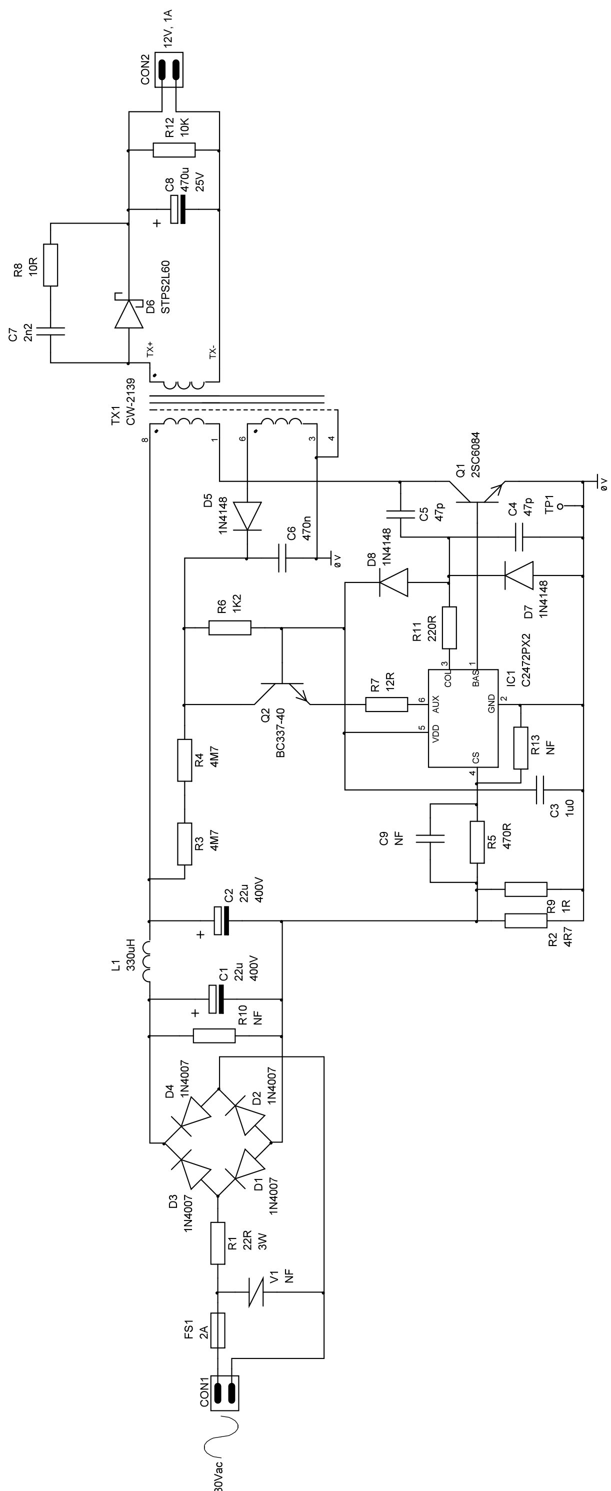

Figure 2: Application Schematic

3 BILL OF MATERIALS

Qty	Value	Ref	Description	Mfr	Mfr Number
1	47 pF	C4	CAP 0805 47 pF NPO 100 V 5% 125 C	AVX	08051A470JAT2A
1	2.2 nF	C7	CAP 0805 2.2 nF X7R 50 V 10% 125 C	AVX	08055C222KAT2A
1	470 nF	C6	CAP 0805 470 nF X7R 16 V 10% 125 C	AVX	0805YC474KAT2A
1	1 uF	C3	CAP 0805 1 uF X7R 25 V 10% 125 C	AVX	08053C105KAZ2A
1	NF	C9	CAP 0805 NOT FITTED	NONE	NOT FITTED
2	22 uF	C1	CAP ALEL TH 22 uF 400 V -40-105 C	Luxon	ESM226M400S1A5L200
	22 uF	C2		Luxon	ESM226M400S1A5L200
1	470 uF	C8	CAP ALEL TH 470 uF 25 V 20% -55-105 C	PANASONIC	EEUFC1E471
1	47 pF	C5	CAP CER TH 47 pF 2 kV	MURATA	DEA1X3D470JA2B
2	2 WAY	CON1	CON TERM BLOCK 2-WAY 415 V/16 A -40 TO +105 C	IMO	20.501M/2
	2 WAY	CON2		IMO	20.501M/2
1	TEST POINT	TP1	CON PCB TERMINAL BLACK PTH TEST POINT TH 35THOU	VERO	20-2137
4	1N4007	D1	DIODE EPI AXIAL 1N4007 1000 V 1 A	MULTICOMP	1N4007
	1N4007	D2		MULTICOMP	1N4007
	1N4007	D3		MULTICOMP	1N4007
	1N4007	D4		MULTICOMP	1N4007
3	1N4148	D5	DIODE EPI 1N4148 75 V 0.2 A 4 ns	PHILIPS	1N4148
	1N4148	D7		PHILIPS	1N4148
	1N4148	D8		PHILIPS	1N4148
1	STPS2L60	D6	DIODE SCHOTTKY AXIAL STPS2L60 60 V 2 A	STMICROELECTRONICS	STPS2L60
1	2 A	FS1	FUSE QUICK BLOW TR5 2 A 250 VAC	WICKMANN	19370K 2A
1	C2472PX2	IC1	IC CAMSEMI C2472PX2 FCC SOT23-6	CamSemi	C2472PX2
1	12R	R7	RES 0805 12R 1% 0W1	MULTICOMP	MC 0.1W 0805 1% 12R
1	220R	R11	RES 0805 220R 1% 0W1	MULTICOMP	MC 0.1W 0805 1% 220R
1	470R	R5	RES 0805 470R 1% 0W1	MULTICOMP	MC 0.1W 0805 1% 470R
1	10K	R12	RES 0805 10K 1% 0W1	MULTICOMP	MC 0.1W 0805 1% 10K
1	1K2	R6	RES 0805 1K2 1% 0W1	MULTICOMP	MC 0.1W 0805 1% 1K2
1	NF	R13	RES GEN PURPOSE 0805 NOT FITTED	RES 0805 NOT FITTED	RES 0805 NOT FITTED
1	NF	R10	RES TH 0W25 NOT FITTED	RES TH 0W25 NOT FITTED	RES TH 0W25 NOT FITTED
1	1R	R9	RES 1206 1R 1% 0W25	PHYCOMP	232272461008
1	10R	R8	RES 1206 10R 1% 0W25 -55-125C	PHYCOMP	232272461009
2	4M7	R3	RES 1206 4M7 1% 0W25	PHYCOMP	232272464705
	4M7	R4		PHYCOMP	232272464705
1	4R7	R2	RES 1206 4R7 1% 0W25 -55-125C	PHYCOMP	232272464708
1	22R	R1	RES TH 22R 5% 3 W	WELWYN	WA84-22RJI
1	DWG-2138-02	PCB1			
1	NF	V1	VARISTOR NOT FITTED	NOT FITTED	VAR NOT FITTED
1	CW-2139	TX1		CAMSEMI	CW-2139
1	330 uH	L1	WOUND IND TH RAD 330 uH 380 mA 10%	C&D TECHNOLOGIES	22R334C
1	2SC6084	Q1	XSTR NPN 2SC6084 TO220	SANYO	2SC6084
1	BC337-40	Q2	XSTR NPN BC337-40 TO92 45 V 800 mA	ON SEMICONDUCTOR	BC337-40ZL1G

Table 2: Application Bill Of Materials

4 TRANSFORMER DETAILS

4.1 Overview

The transformer uses a low cost E16 core and bobbin. The secondary winding uses triple insulated wire to provide safety isolation. Safe creepage and clearance distances are achieved by using flying leads for the secondary.

4.2 Materials

Item	Type	Material Description	Approved Part Number
1	Core	Pair EE16 TDK PC40EE16-Z (gapped 25 µm in each limb)	TDK PC40EE16-Z
2	Bobbin	ULV94V-0 EE16 8-PIN	HIMEDA EE-16 (8P)
3	Tape	Class B (130°C), polyester film, 9 mm wide	3M 56 Tape, 9 mm.
4	ECW	Grade 2, Class B, enamelled copper Wire. 0.112 mm, 0.14 mm, 0.16 mm	
5	Wire	Triple insulated wire. TEX-E 0.3 mm diameter	Furukawa TEX-E 0.3 mm
6	Gap shim	0.001 inch or 25 µm polyester	

Table 3: Transformer Materials List

4.3 Testing

Winding	Pin Connections	Inductance (mH)	Conditions / Connections
W2 (primary)	1 to 8	30 to 42	0.5 V, 10 kHz
W2 (primary) leakage	1 to 8	0.36 to 0.47	0.5 V, 10 kHz W4 (secondary) shorted

Table 4: Inductance

Test	Connection 1	Connection 2	Voltage (Vac rms)	Frequency (Hz)	Duration (s)
Primary to secondary	All pins	Flying leads	3750	50	10
Core to secondary	Core	Flying leads	3750	50	10

Table 5: Voltage Isolation

5 PCB LAYOUT

The PCB is 80 mm long, 32 mm wide. The following images are not to scale.

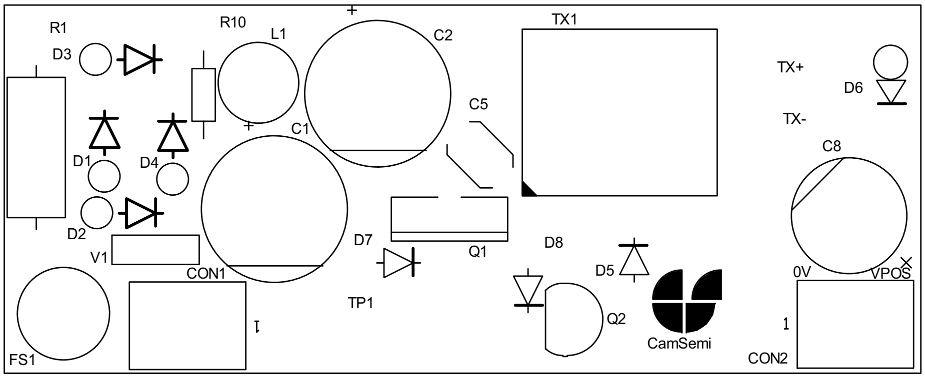

Figure 3: PCB Layout - Top Silk Screen

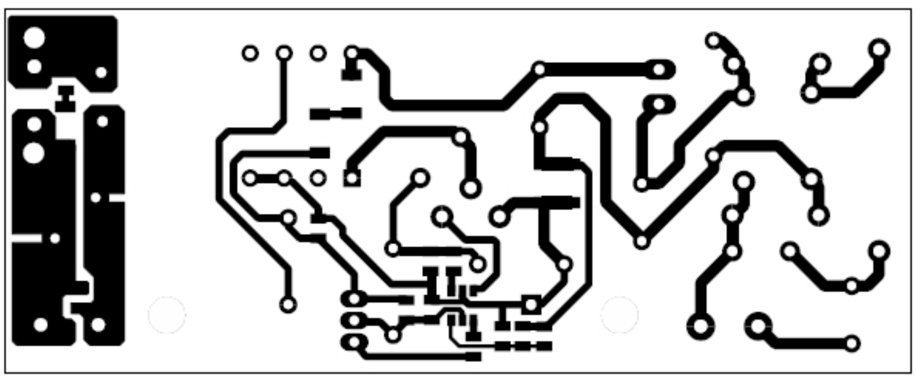

Figure 4: PCB Layout - Bottom Copper

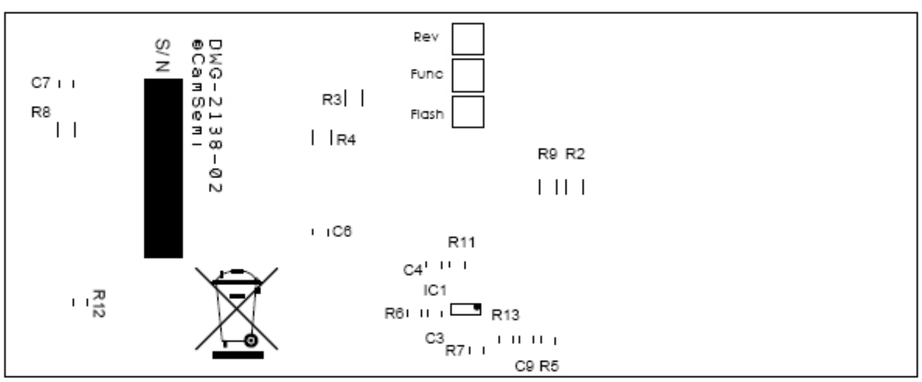

Figure 5: PCB Layout - Bottom Silk Screen

6 PERFORMANCE MEASUREMENTS

All measurements were made with the PCB mounted horizontally in free air at an ambient temperature of approximately 22°C.

6.1 Safety

Offline power supply prototypes may exhibit safety hazards including, but not limited to, electric shock, high temperatures, fire and smoke. Indeed, some standard procedures deliberately take the unit under test to the point of destruction. Prototypes should be tested and worked on only by competent and suitably trained personnel. The following general advice is offered but cannot take account of risks associated with any particular prototype or test set up. If you are in any doubt as to the safety of any unit or test procedure, please consult a competent adviser before proceeding.

- Before operating the unit:
  - Ensure that the documentation matches the unit to be tested and familiarise yourself with both. If there is a discrepancy or any doubt do not proceed with testing but contact your CamSemi representative for assistance;
  - Prototypes are often modified in the course of development. Check the unit to be tested for design or build errors before connecting it to the supply. Only proceed if you are satisfied that the unit is as intended and in a suitable condition for the testing to be performed;
  - Ensure general safety of the test set-up. For example, minimise the risk of inadvertent contact with the unit under test and injury from material which may be ejected from it in the event of a "catastrophic" failure;
- While operating the unit:
  - Do not connect the unit direct to the mains utility. Use a suitable isolated supply for the type of unit and the tests to be performed;
  - Remember that insulation between high voltage and low voltage parts of a prototype may not provide full safety isolation;
  - Regard all parts of the unit as potentially LIVE and HAZARDOUS;
- After disconnecting the supply:
  - Hazardous voltages will persist for some time after the supply is disconnected due to charge stored in capacitors. If necessary, capacitors can be safely and quickly discharged using a suitable resistor.
  - Allow the unit to cool before handling it.

6.2 Efficiency

In accordance with the Energy Star method, efficiency was measured at 25, 50, 75 and 100 % of rated load current. The numerical average of the four measurements is typically 86.1%.

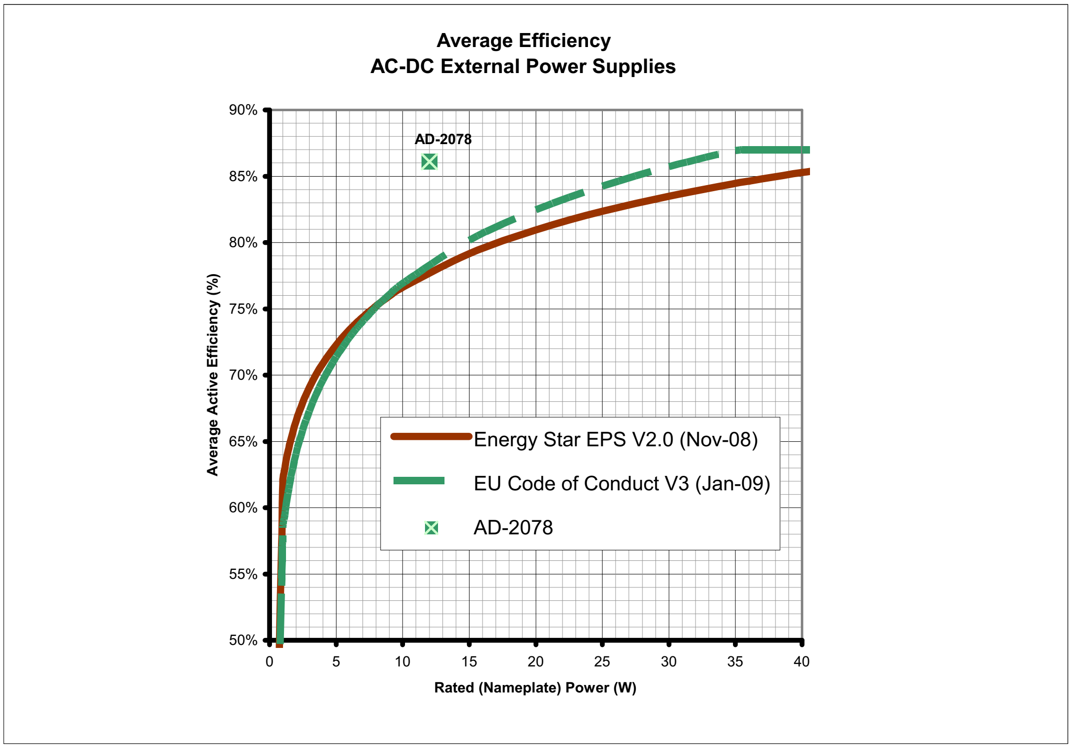

Figure 6: Comparison of AD-2078 Average Efficiency with Existing and Proposed Regulations

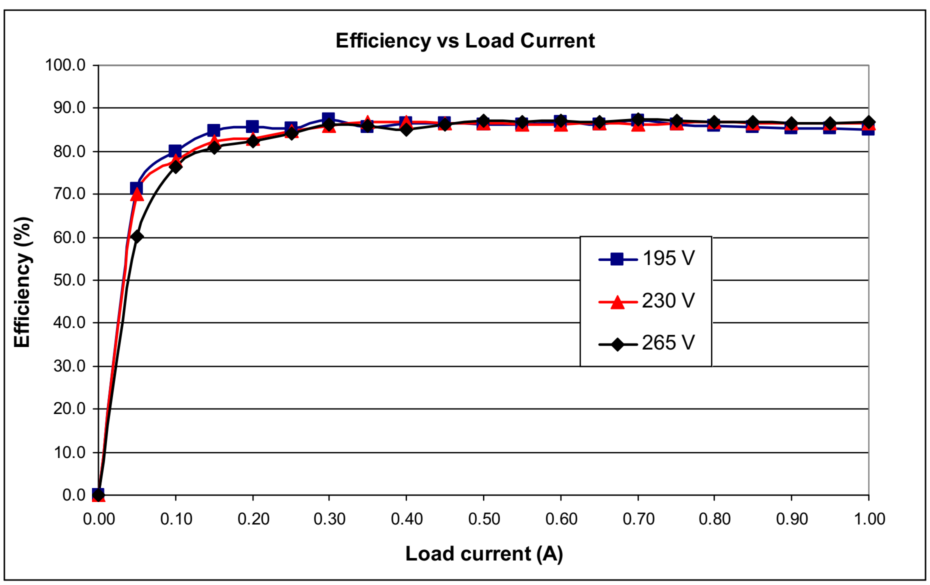

Figure 7: Efficiency as a Function of Load Current and Input Voltage (at 50 Hz)

6.3 No-Load Power Consumption

Typical no-load power consumption is 211 mW, with input of 230 V.

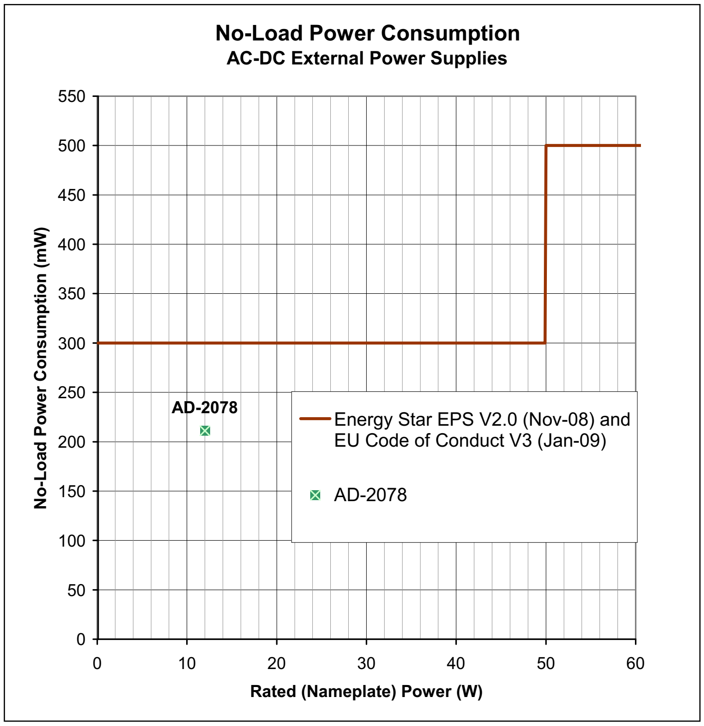

Figure 8: Comparison of AD-2078 No-load Power Consumption with Existing and Proposed Regulations

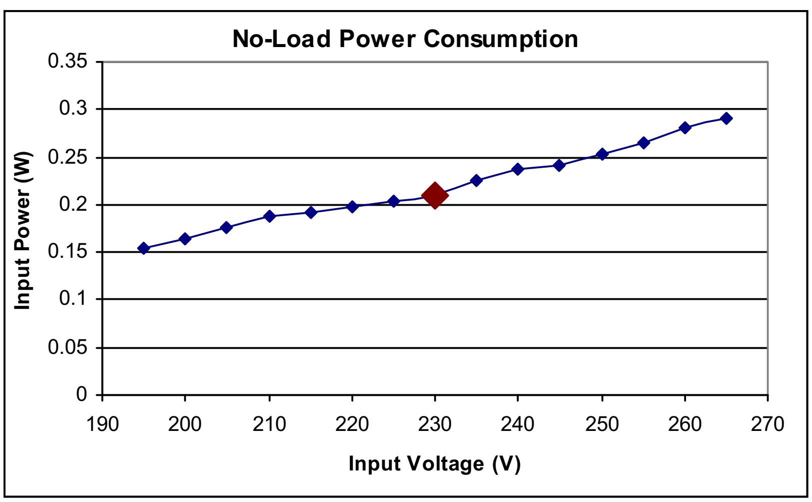

Figure 9: No-Load Power Consumption as Function of Input Voltage

6.4 Line and Load Regulation

Note: Line frequency has a small effect on output voltage such that higher frequency increases output voltage. In these tests, the AC power was from a high quality, sinusoidal, source.

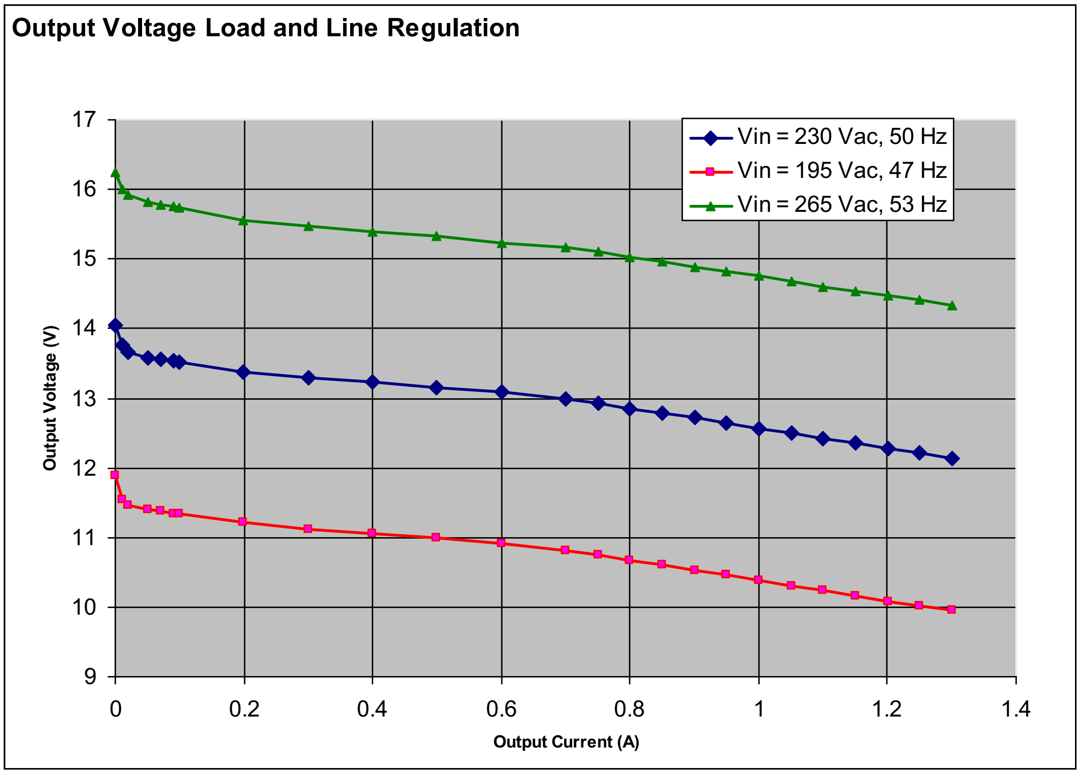

Figure 10: Output Voltage Load and Line Regulation

7 OPERATIONAL WAVEFORMS

7.1 Bipolar Switching Transistor Waveforms

7.1.1 Typical Operation

Figure 11 shows the collector-emitter voltage of the switching transistor and the voltage across emitter current sense resistors, R2 and R9 in parallel. Figure 12 shows the envelope of the same waveforms over several mains cycles.

Conditions: Input voltage = 230 V; load = 1 A.

CH2 (upper trace) = collector emitter voltage. CH3 = voltage across R2 and R9.

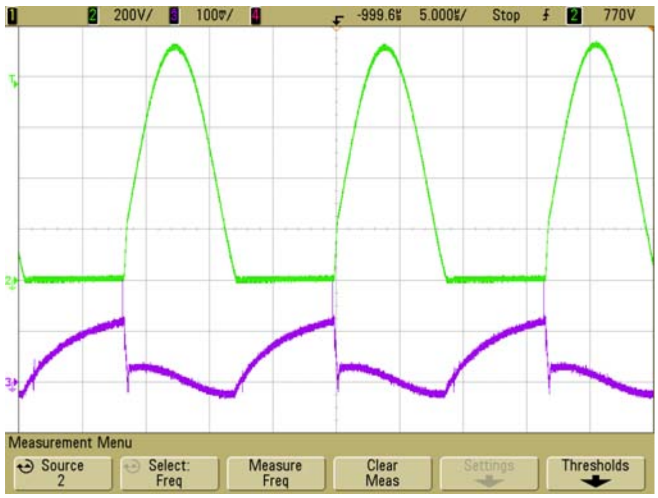

Figure 11: Typical Switching Transistor Voltage and Current, 5 µs/div

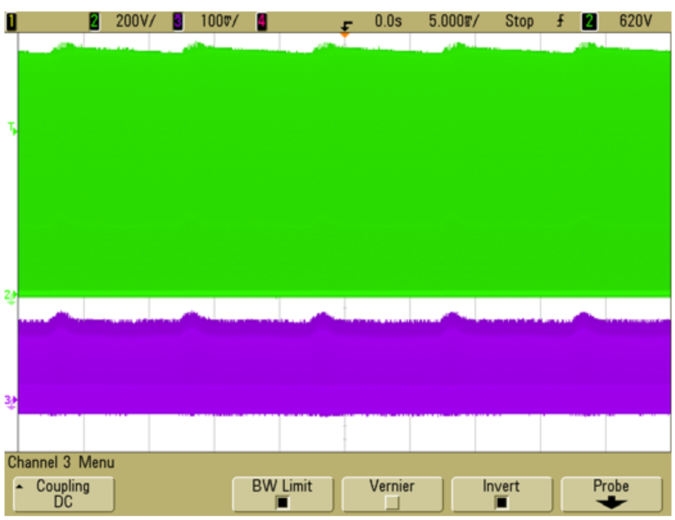

Figure 12: Typical Switching Transistor Voltage and Current, 5 ms/div

7.1.2 Start-up Behaviour Without Additional Load Capacitance

Figure 13 and Figure 14 show the collector-emitter voltage and emitter current during start-up.

Conditions: Input voltage = 265 V; load = 1 A, constant current electronic load

CH2 (upper trace) = collector emitter voltage. CH3 = voltage across R2 and R9.

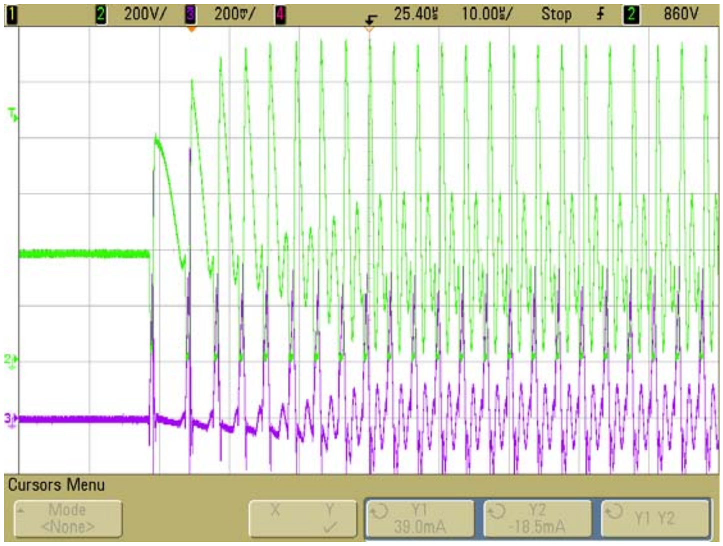

Figure 13: Start-up Switching Transistor Voltage and Current, 10 μs/div

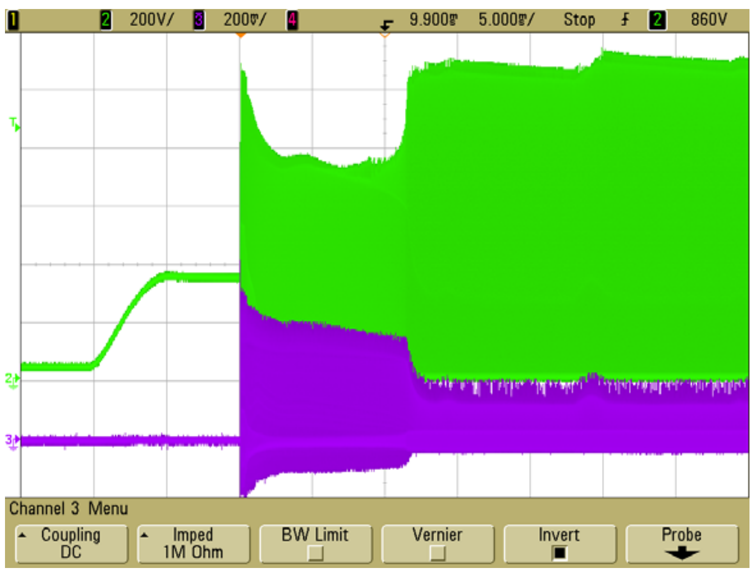

Figure 14: Start-up Switching Transistor Voltage and Current, 5 ms/div

Note: peak collector voltage is about 1150 V and it is not higher during start-up than during normal running.

7.1.3 Start-up Behaviour With Additional 1000 µF Load Capacitance

Figure 15 and Figure 16 show the collector-emitter voltage and emitter current during start-up, with additional capacitive load.

Conditions: Input voltage = 265 V; load = 1 A, constant current electronic load plus 1000 µF electrolytic capacitor.

CH2 (upper trace) = collector emitter voltage. CH3 = voltage across R2 and R9.

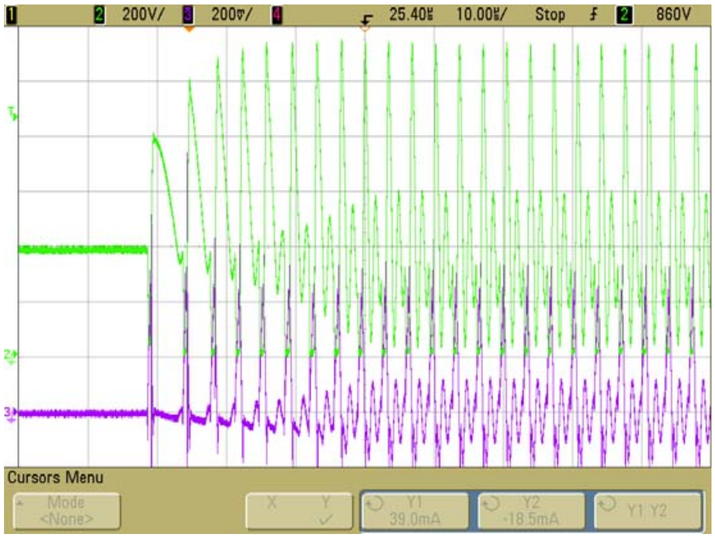

Figure 15: Start-up Switching Transistor Voltage and Current, 1000 µF load, 10 µs/div

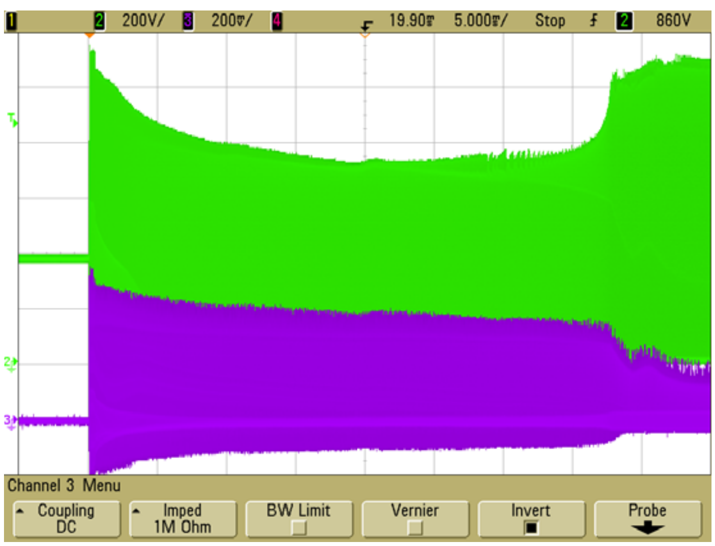

Figure 16: Start-up Switching Transistor Voltage and Current, 1000 µF load, 5 ms/div

Note: peak collector voltage is about 1150 V and it is not higher during start-up than during normal running.

7.2 Output Ripple

Conditions: Input voltage = 230 V; load current = 1 A

7.2.1 Output Ripple - Line Frequency

365 mV at 100 Hz.

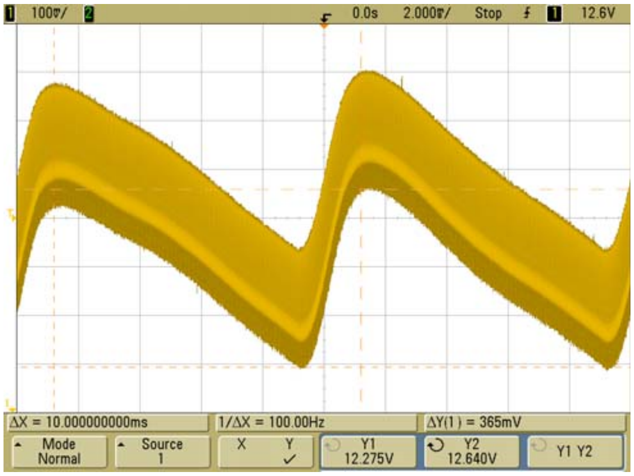

Figure 17: 100 Hz Output Voltage Ripple

7.2.2 Output Ripple - Switching Frequency

160 mV at switching frequency (57 kHz).

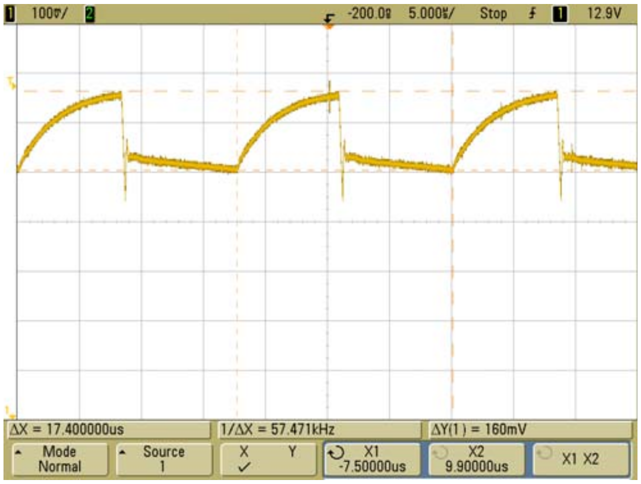

Figure 18: Switching Frequency Output Voltage Ripple

7.3 Transient Load Response

Conditions: Input voltage = 230 V; load switched between zero and 1 A (constant current electronic load).

Output voltage deviation = 1.7 V. No undershoot or overshoot.

CH3 = output current at 1 A/div. CH4 = output voltage.

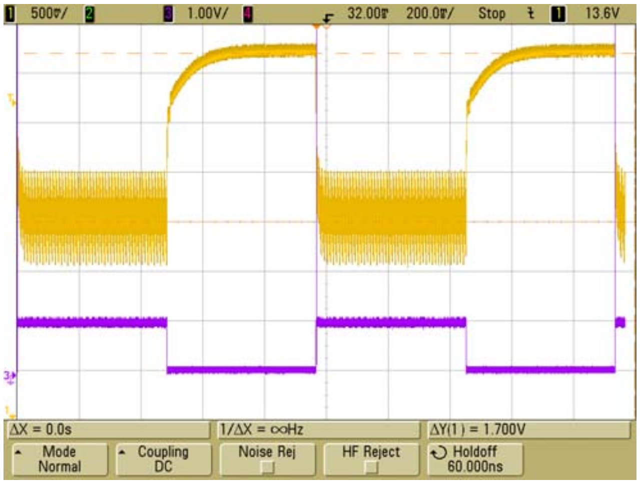

Figure 19: Transient Load Response

7.4 Output Short-Circuit Recovery

Conditions: Input voltage = 230 V

The PSU was loaded with a constant current electronic load of 1 A. The PSU output was shorted, during which time the PSU periodically issued bursts of current designed to pull up the voltage on capacitive loads without continuously stressing the PSU. After the short was removed (around the midpoint of the plot), the output was established at the next burst.

CH3 = output voltage. CH4 = output current.

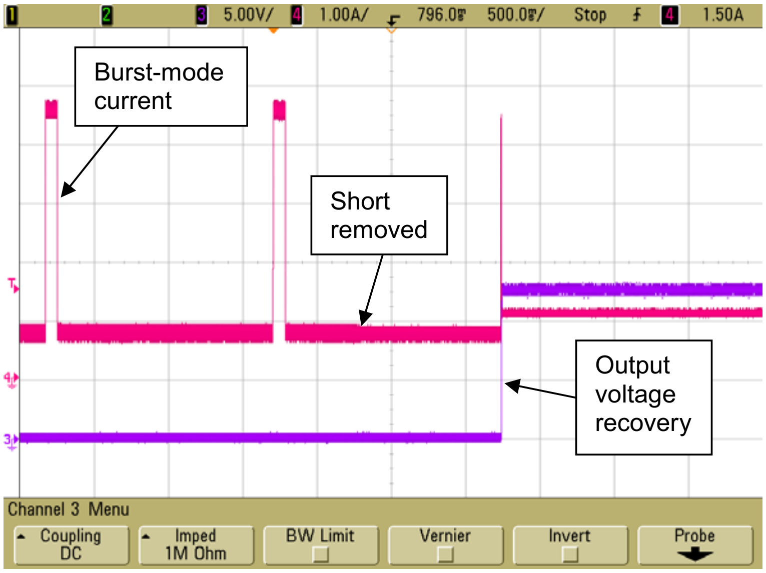

Figure 20: Output Short-Circuit Recovery

8 ELECTROMAGNETIC COMPATIBILITY (EMC)

8.1 Conducted Emissions

Figure 21 and Figure 22 show typical conducted emissions of AD-2078. The upper trace in each plot is the quasi-peak measurement; the lower trace in each plot is the average measurement. Measurements were made with 230 Vac input and full load output (1 A), with the output negative rail connected to earth to give worst-case conditions. Quasi-peak emissions are at least 6 dB lower than EN55022 limits.

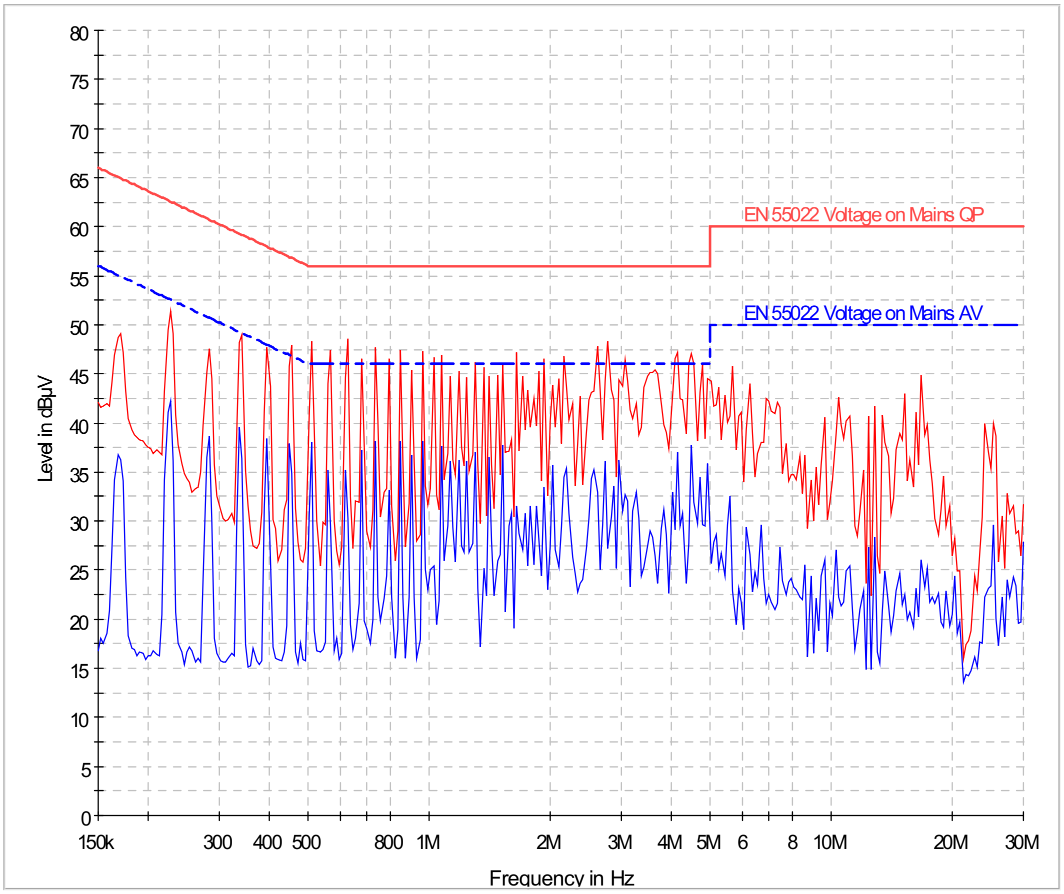

Figure 21: Neutral Line Conducted Emissions

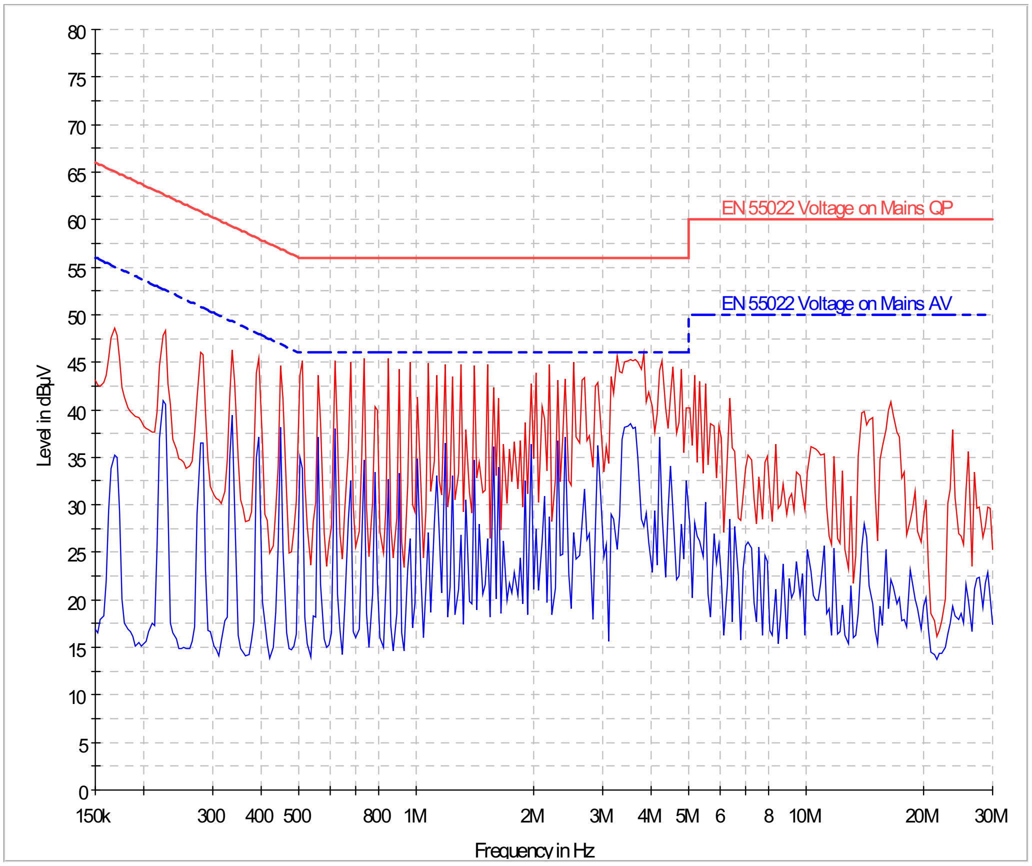

Figure 22: Live Line Conducted Emissions

8.2 Transient Surge Immunity

AD-2078 passes the requirements of EN 61000-4-5: Surge on AC power supply (1ph), Class 3

Conditions: Input voltage = 230 V; load = 1 A. The negative output was connected to Protective Earth (PE).

A Combination Wave Generator (CWG) was used to impose the following surge voltages:-

In accordance with IEC 60-1: open-circuit voltage, 1.2 µs front time, 50 µs to half value; short-circuit current, 8 µs front time, 20 µs to half value.

CWG on AC (1 ph): 1000 V Live to Neutral, 2000 V Live to PE and Neutral to PE.

Five pulses, positive and negative, every 20 s, at 0º, 90º, 180º, 270º. Total 120 pulses.

APPLICATION DESIGN REPORT STATUS

Application design information and specifications provided in this Application Design Report (e.g., circuit schematics, board layouts and custom wound component drawings) have not been fully developed for production and have not been subjected to safety or EMC approvals testing. Hence, design information contained herein should not be used for production without further development, verification, validation, approvals and certification appropriate for the intended application.

This Application Design Report contains information relating to use of an IC product whose specification is subject to change without notice. Therefore, please always refer to the most current version of this document and the relevant IC product datasheet, available at www.camsemi.com.

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