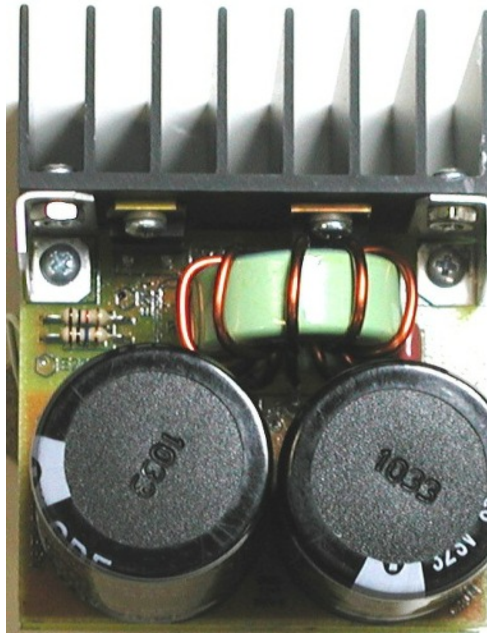
PS-17A-1 DC/DC SMPS Boost Regulator



PS-17A-1 DC/DC SMPS Boost Regulator

The PS-17A-1 is a high efficiency switch mode power supply, providing a regulated output of 30 Amps* at 13.25 VDC from a 12 Volt battery. Operating at a typical efficiency of 90% and effectively down to 10 VDC input, the PS-17A-1 solves the ARS problems of distortion, motor-boating, erratic performance and loss of output power that are common when operating from battery power.

Complete utilization of a battery's capacity (typically 0.8C for AGM) is ensured while the ARS operating voltage is held fixed at 13.25 VDC.

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* Duty cycle limited above 10 ADC.

Disclaimer:

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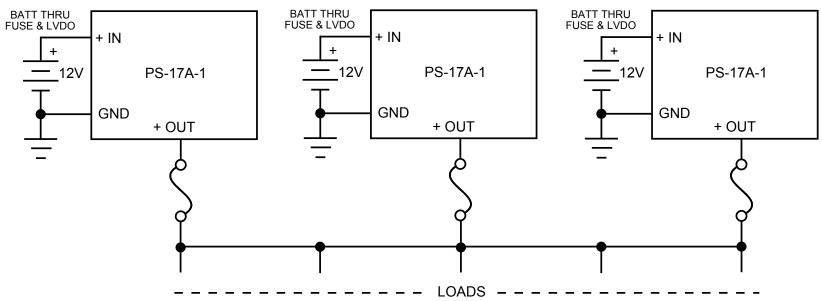
PS-17A-1 DC/DC SMPS Boost Regulator

Applications:

- Used in the AP-10A-1, Portable Power Unit, to provide fixed DC Buss Voltage from AGM battery.
- Ideal to regulate and boost DC Voltage from solar panels, vehicular or other low DC Voltage systems.
- Provide point-of-use regulation in distributed 12 VDC systems (motor homes).
- Provides boost and regulation only for input voltages lower than the output.
- Very low RFI/EMI noise makes the PS-17A-1 ideal for noise sensitive applications.
- Can be paralleled, without external diodes, for redundancy and/or increased output current.



- As shown above, separate batteries are isolated from one another by the PS-17A-1 internal rectifiers. Thus each can be accurately charged and monitored while the outputs are effectively paralleled. Triple redundancy or triple current is provided.
- Above PS-17A-1s can be feed from a single battery source as well. As another option, when fed from a single buss, each output can feed its' own dedicated load providing isolation and regulation from the common buss.
- Other combinations allow custom DC Buss configurations to suit the specific application. Note these applications also apply to the AP-10A-1, ARS Portable Power Unit.

Features:

- 90% typical efficiency for input voltages of 10 to 15 VDC.
- 10 ADC continuous output current, 30 Amp with duty cycle limitations - see Figures 4 and 5.
- Internal PWM current limit protects MOSFET, Input/Output current protection with external fuses.
- Uses readily available distributor stock components.
- Two circuit board design using "½ brick" heat sink.
- Low RFI/EMI from 30 kHz PWM controller.
- Excellent regulation (load and line).
- Low output impedance.
- Good load step response (regulation for changing loads).

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Physical Characteristics:

Size	2.5” x 2.9” x 3.5”
Enclosure	Open Frame
Mounting	Four 4-40 screws and brackets to heat sink.

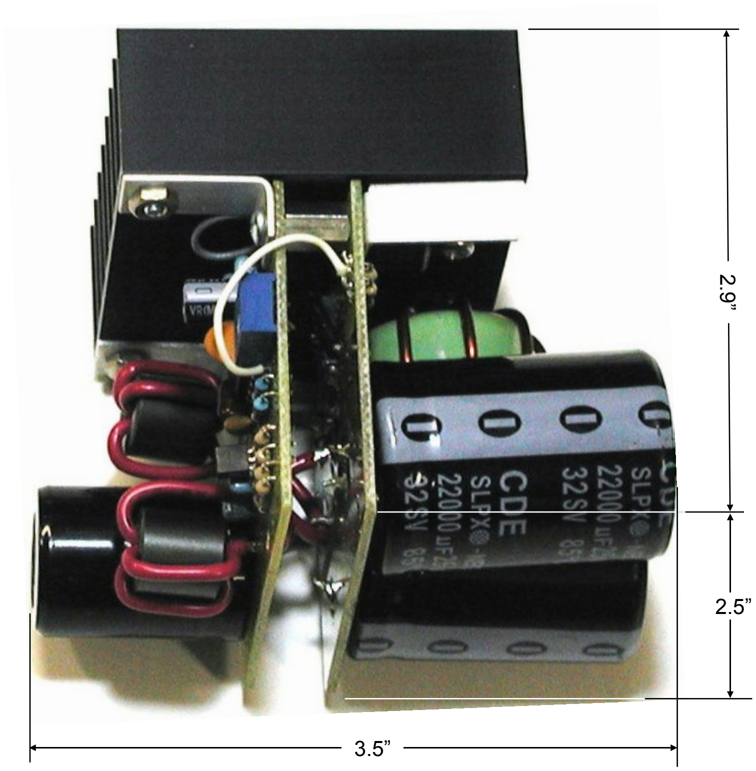


Figure 1. PS-17A-1 Assemblies mounted to ½ brick heat sink. In typical application the heat sink will be on the outside of the enclosure and the two TO220 devices will mount to the heat sink through a cutout.

Electrical Characteristics:

Parameter	Conditions		Value	Notes
Input Voltage	Normal operation		10 to 15 VDC	
	Absolute maximum		18 VDC	
Input Current	V_i = 10.5 VDC, V_o = 13.25 VDC, I_o = 20 ADC		< 30 ADC	3
Temperature	Free air flow around heat sink		0 to +45 °C	
Output Voltage	Adjustment range at +25 °C	V_i = 10.5 to 13.80 VDC, I_o = 0.5 to 30 Amps	12.4 to 13.8 VDC	3
	Temperature coefficient 0 to +45 °C		< 1.5 mV/°C	
	Load Regulation, V_i = 12.5 VDC	Δ I_o = 0 to 10 ADC	< 0.1%	1
	Line Regulation, I_o = 10 ADC	Δ V_i = 10.5 to 13.5 VDC	< 0.1 %	
Power Dissipation	V_i = 10.5 to 13.80 VDC, V_o = 13.25 VDC, I_o = 0.5 to 10 ADC		< 25 Watts	
Under Voltage Lock Out	PWM " Power Good" monitor - protects SMPS only - does not protect Battery from excessive discharge	Turn On	7.8 to 9.0 VDC	
		Turn Off	7.0 to 8.2 VDC	
Over Voltage Shut Down	PWM shuts Off - INPUT POWER STILL PASSES THROUGH TO OUTPUT		15.6 to 17.6 VDC	
Output Ripple	Nominal 30 kHz switching frequency	V_i = 12.50 VDC, V_o = 13.25 VDC, I_o = 10 ADC	< 5 mV_{rms}	2
Output Spikes	Nominal width of 50 ns or less	V_i = 12.50 VDC, V_o = 13.25 VDC, I_o = 10 ADC	± 30 mV peak	
Output Impedance	V_i = 12.50 VDC, V_o = 13.25 VDC, I_o = 5 ADC with 1 A P-P modulating current	10 Hz	0.010 Ω	2
		100 Hz	0.010 Ω	
		1 kHz	0.020 Ω	
		10 kHz	0.030 Ω	
		100 kHz	0.030 Ω	
Output Load Step Response	V_i = 12.5, V_o = 13.25 VDC, Δ I_o = (peak change, recovering in μs)	0.5 to 10.0 ADC	< 500 mV, 50 μs	
		10.0 to 0.5 ADC	< 300 mV, 200 μs	
Current Limit	Internal Current Mode PWM Controller Protects MOSFET	External Input Fuse	30 Amp	
		External Output Fuse	20 Amp	

Notes:
1. Measured at E104 to E105.
2. Measured at output of external filter shown in the schematic.
3. Duty cycle limited above 10 ADC, see Figures 4 and 5.

PS-17A-1 DC/DC SMPS Boost Regulator

Theory of Operation:

The PS-17A-1 is a fixed frequency, PWM (pulse width modulated) boost converter designed to operate from a 12 Volt rechargeable battery. Voltage sensitive loads normally do not consume all of a battery's available charge capacity. As a lead acid battery discharges its' terminal voltage drops, slowly at first but then more rapidly as it approaches the mid 10 Volt range. Electronic loads such as Amateur Radio transceivers often become erratic when the power drops below 12 Volts.

The PS-17A-1 regulates a 12 Volt battery input and boosts it to 13.25 VDC, holding it there as the battery voltage drops to 10 VDC. Typically operating at 90 to 95% efficiency it provides up to 30 Amps, with duty cycle limitations, or 10 ADC @ 100% duty cycle.

A current mode controller, U101, operateing at a fixed frequency turns on Q201, the power switch, every other cycle. This alternate cycle "on time" limits the switch duty cycle to less than 50%. Q201 source current is monitored by the voltage across R203, a low inductance SMT resistor. The controller turns off Q201 when the sensed voltage reaches the feed back voltage from R103, R104 and R105.

Output voltage regulation results from this action and will be maintained for battery voltages down to 10 VDC and for loads up to 30 Amps, as long as the RMS value does not exceed 10 Amps. L201, a distributor stock item, is the energy storage inductor shuttling charge between C202 and C204 through catch diode D201 as the PWM turns Q201 on and off.

U101 contains a precision +5 Volt reference, the output of which is divided internally to +2.5 Volts. The internal error amplifier compares a fraction of the output voltage to this +2.5 Volt reference and outputs a control voltage to the

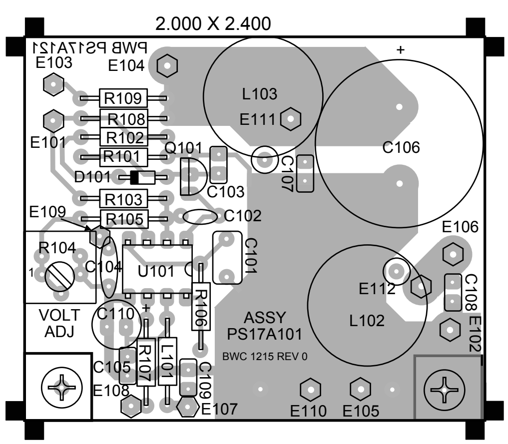


Figure 2. PS-17A-1 component locator for PS17A101 Assembly.

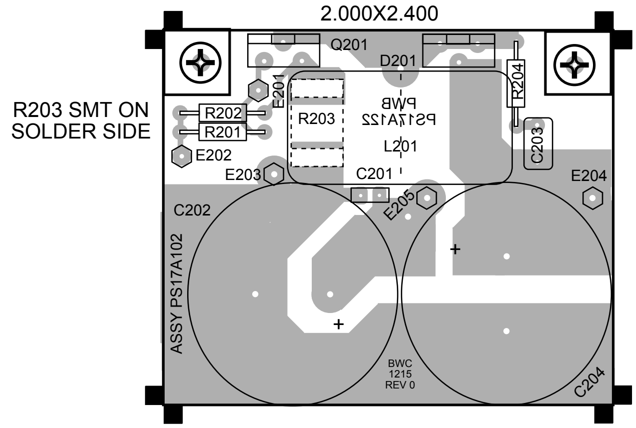


Figure 3. PS-17A-1 component locator for PS17A102 Assembly.

internal current sense amplifier. A linear voltage ramp at U101-3 represents L201's current when Q201 is on. When the ramp rises to the feedback voltage, the PWM latch turns off Q201.

This PWM control regulates the output voltage. When power is first applied or if the output is shorted to ground, the current ramp will not reach the feedback voltage. To ensure the MOSFET is not damaged, due to inductor saturation, an internal current limit causes the PWM latch to turn off Q201.

D101 and Q101 shut down the controller if the output voltage exceeds approximately 16 VDC. This fail safe is only designed to stop a malfunction in the PWM controller from driving the output voltage extremely high. Note, this circuit does not stop the input power from passing through D201 and L201 to the output.

L102, L103, associated capacitors and the external filter, shown on the schematic, reduce switching frequency ripple and switching spike's high frequency energy. Comparatively large components are required due to the 30 kHz switching frequency; however, this also puts most of the energy below HF frequencies, reducing EMI/RFI in ARS applications.

Intermittent Commercial and Amateur Service:

This phrase is still in use today even though it was originally used to describe transmitting vacuum tubes operating beyond their CCS ratings (normally with reduced life, but higher output power). As the term seems to have no standard definition, caution is required anytime it is encountered. Several operational details are required to describe an ICAS that can actually be related to measurable steady-state operation.

As used in this document, ICAS is based on several key factors. First, an intermittent current's peak value and duty cycle are used to calculate its' *rms*, root mean square, value. Secondly, the peak current is limited to the internal device's SOA, safe operating area, i^2R and i^2t restrictions. Thirdly, the thermal time constant of critical components are used to limit the repetition rate - after all when an add specifies 50% duty cycle and no repetition rate, it could be assumed a month on and a month off is fine.

Figure 4. shows allowable duty cycle as output current rises above 10 ADC. This de-rating curve maintains an *rms* current equal to 10.0 ADC by reducing the duty cycle as the peak current increases to 30 Amps.

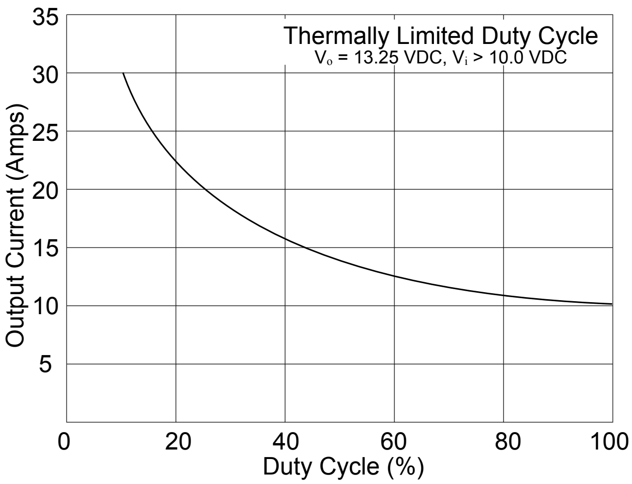


Figure 4. PS-17A-1 Thermally Limited Duty Cycle.

Figure 5. Shows i^2t Limitation on Duty Cycle vs Load Current. Actually, some interpretation of this graph is necessary. The Ordinate, labeled in seconds shows how long the output current can be held at the current plotted on the corresponding abscissa, labeled in Amps. Higher Load Currents can be supplied for less time than lower currents even if meeting the duty cycle limitation. This is the simple cause and effect of how fast a fuse opens under overload conditions. For small over-current a fuse will take seconds or minutes to open; however, for a 200% or more overload it opens quickly. A fuse responds to heating which is related to i^2 and actually has a response curve similar to Figure 5.

Keep in mind the PS-17A-1 is designed to operate a 100 Watt ARS transceiver. For SSB, burst digital, CW and other non-continuous carrier modes the duty cycle limitation is of little or no concern. However, for FM, RTTY and continuous carrier modes the duty cycle limitation must be observed.

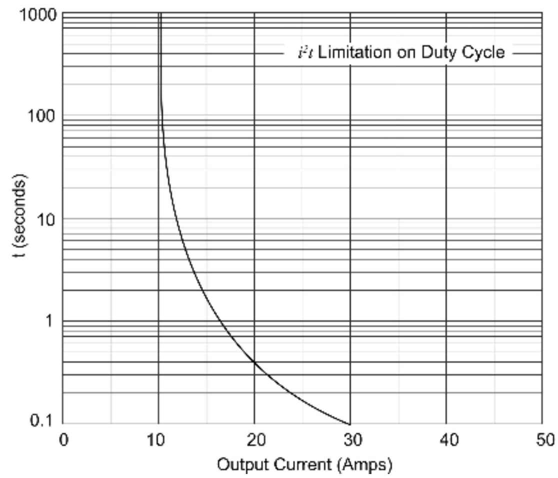


Figure 5. PS-17A-1 i^2t Limitation on Duty Cycle.

Average, *rms*, Peak values.

While the average and *rms* values of voice modulated peak current are difficult to predict accurately, they are quite easy to calculate for rectangular pulse modulation (on/off) operation. A quick review is offered here to help understand the PS-17A-1 performance in non-steady state operation.

Figure 6 depicts a normalized current that is on for 0.25 out of 1.00 units of time (25% duty cycle). The Average current is equal to 0.25 of the Peak current and the *rms* current is equal to 0.50 of the Peak current.

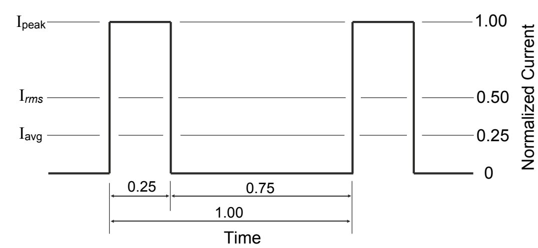


Figure 6. Relationship between Peak, Average and *rms* values of a repetitious on/off current with a 25% duty cycle.

The digital panel meter responds to the Average value as does the battery. Component heating responds to the *rms* value. Note the "Engineering Prototype Measured Data" (page 11) contains thermal measurements for several output currents.

With an output current of 20.0 Amps and 25% duty cycle the PS-17A-1 heat sink temperature is +41.0 ^oC and +43.8 ^oC

at an output current of 10 ADC (100% duty cycle), whereas at 5 ADC the heat sink temperature is +35.5 ^{o}C, showing measured heat sink temperature rise follows the *rms* value of a varying current.

The mathematical expressions for calculating these relationships are;

$$I_{avg} = I_{peak}\left(\frac{t_{on}}{t_{on} + t_{off}}\right) \qquad I_{rms} = I_{peak}\sqrt{\left(\frac{t_{on}}{t_{on} + t_{off}}\right)}$$

and in the general form calculate Average and *rms* values for any on/off function whose peak value is known.

PS-17A-1 DC/DC SMPS Boost Regulator

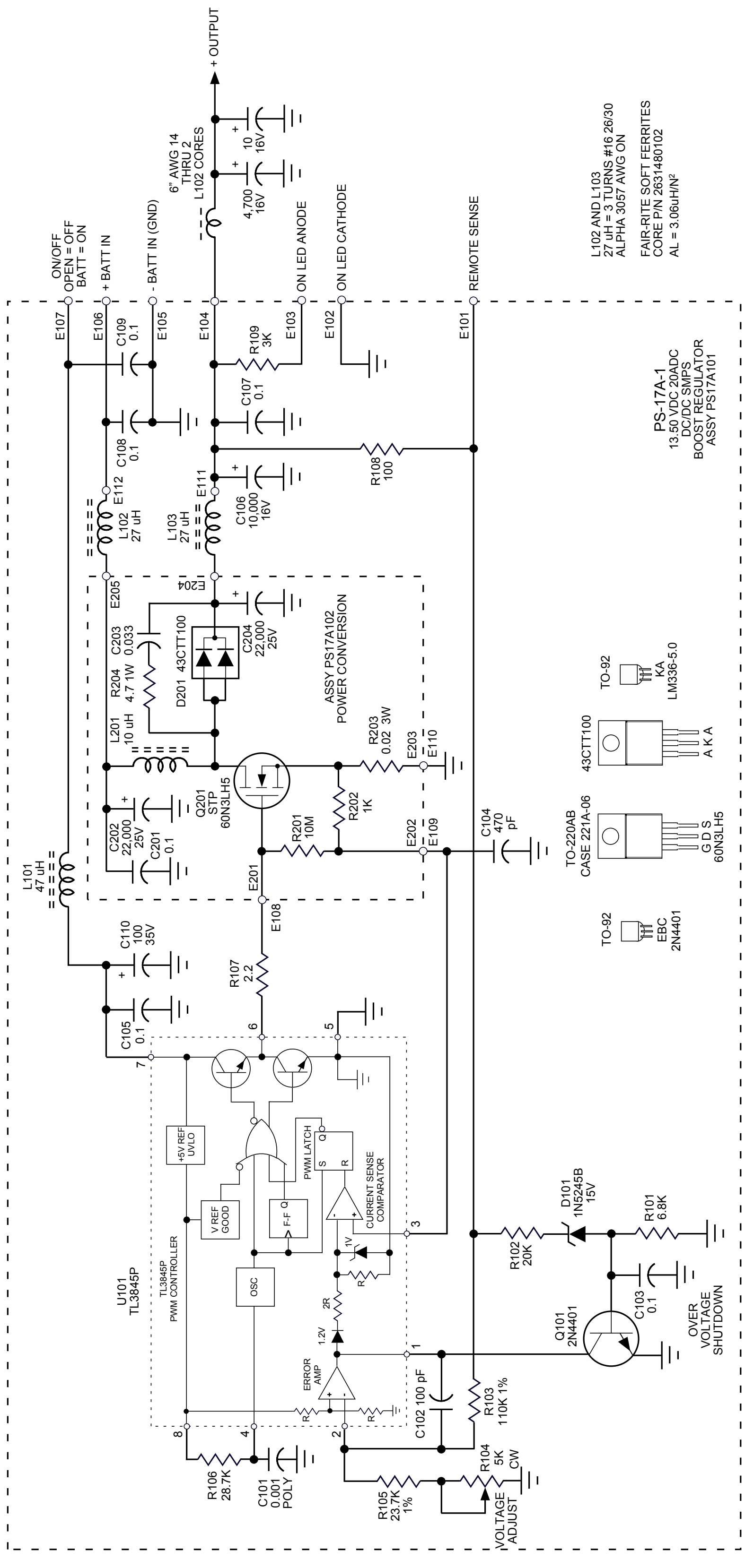


Figure 7. PS-17A-1 Schematic including external EMI filter.

PS-17A-1 Assy PS17A101 List of Material

Qty	Designator	Value/Type	Description	Part Number	Notes[1]
1	C101	0.001 µF, 50 VDC	Poly	140-PM2A102K	
1	C102	100 pF, 50 VDC	NPO Ceramic Disk	140-50S5-101J-RC	
5	C103, 105, 107, 108, 109	0.1 µF, 50 VDC	Dipped MLC Ceramic	581-SR205E104MAR	
1	C104	470 pF, 50 VDC	NPO Disk Ceramic	140-50S5-471J-RC	
1	C106	10,000 µF, 16 VDC	Radial Al Electrolytic	598-SLPX103M016A3P3	
1	C110	100 µF, 16 VDC	Radial Al Electrolytic	647-UVR1C101MDD	
1	D101	1N5245B	15 V, 0.5 W Zener	78-1N5245B	
1	L101	47 µH	Molded Axial	542-78F470-RC	
2	L102, 103	27 µH	Core 2631480102	623-2631480102	5
1	Q101	2N4401	NPN Si Small Signal	512-2N4401TA	
1	R101	6.8 kΩ, 5%, ¼ W	Carbon Film	291-6.8K-RC	
1	R102	20 kΩ, 5%, ¼ W	Carbon Film	291-20K-RC	
1	R103	110 kΩ, 1%, ¼ W	Metal Film	271-110K-RC	
1	R104	5 kΩ, 5%, ¼ W Trimmer	Top Adjust	652-3386P-1-502LF	
1	R105	23.7 kΩ, 1%, ¼ W	Metal Film	271-23.7K-RC	
1	R106	28.7 kΩ, 1%, ¼ W	Metal Film	271-28.7K-RC	
1	R107	2.2 Ω, 5%, ¼ W	Carbon Film	291-2.2-RC	
1	R108	100 Ω, 5%, ¼ W	Carbon Film	271-100-RC	
1	R109	2.7 kΩ, 5%, ¼ W	Carbon Film	271-2.7K-RC	
1	U101	TL3845P	PWM Controller	595-TL3845P	
1		Heat Sink, ½ Brick	Wakefield	567-517-95AB	2
1		Bracket (Right)	0.040" Al	PS17A140R	3
1		Bracket (Left)	0.040" Al	PS17A140L	3
4		4-40 Screw	0.375" Pan Head	87913315	4
4		4-40 Screw	0.25" Pan Head	67413641	4
4		4-40 Nut	0.25" Hex	31F2106	6
4		4-40 Lock Washer	Int Tooth	87920708	4
2		TO-220 Insulator Kit		532-4880SG	

Notes:
1. Supplier is Mouser Electronics (http://www.mouser.com) unless otherwise specified.
2. Two holes drilled and threaded for 4-40 per PS17A141.
3. BWC items shop built - details available at http://www.bwcelectronics.com
4. MSC Industrial Supply Co. (http://www.mscdirect.com)
5. Consists of 3 turns AWG 16 Alpha Wire # 3057 on Fair-Rite Soft Ferrites Core
6. Newark (http://www.newarkinone.com)

PS-17A-1 Assy PS17A102 List of Material

Qty	Designator	Value/Type	Description	Part Number	Supplier[1]
1	C201	0.1 µF, 50 VDC	Dipped MLC Ceramic	581-SR205E104MAR	
2	C202, 204	22,000 µF, 25 VDC	Radial Al Electrolytic	598-SLPX223M025E7P3	
1	C203	0.033 µF, 250 VDC	Poly	667-ECQ-E2333JB	
1	D201	43CTT100	40 Amp, 100 V Schottky	844-43CTT100	
1	L201	10 µH	Hi Current Toroid	542-2301-V-RC	
1	Q201	60N3LH5	N Ch Power FET	511-STP60N3LH5	
1	R201	10 MΩ, 5%, ¼ W	Carbon Film	291-10M-RC	
1	R202	1 kΩ, 5%, ¼ W	Carbon Film	291-1K-RC	
1	R203	0.02 Ω, 1%, 3 W	SMD Foil	660-SL3TTE20L0F	
1	R204	4.7 Ω, 5%, 1W	Carbon	594-5073NW4R700J	
4		4-40 Screw	0.375” Pan Head	87913315	4
4		4-40 Screw	0.25” Pan Head	67413641	4
4		4-40, 0.25” Hex Stand Off	0.375” Threaded	67730200	4
2		Bracket	0.040” Al	PS17A141	3

Engineering Prototype Measured Data:

Parameter	Conditions		Value	Notes
Load Regulation	ΔI_o = 0 to 5.0 ADC	V_i = 12.50 VDC	ΔV_o = 0.5 mV (0.004%)	5
Line Regulation	ΔV_i = 10.50 to 13.50 VDC	I_o = 5.0 ADC	ΔV_o = 13 mV (0.10%)	5
Under Voltage Lock Out	PWM “Power Good” detector - protects SMPS only - does not protect battery from excessive discharge	Disconnects	7.40 VDC	
		Connects	8.25 VDC	
Over voltage Shutdown	Prevents open loop PWM run away		17.46 VDC	
DC BUSS output noise and ripple	Regulated Boost mode at I_o = 10 ADC		2.5 mV_{rms}	1
DC BUSS output spikes	V_i = 12.5 VDC, V_o = 13.25 VDC, I_o = 10 ADC Nominal pulse width 50 ns or less		+20 mV peak -22 mV peak	
Output Load Step Response	V_i = 12.5 VDC, V_o = 13.25 VDC	ΔI_o = 0.5 to 10.0 ADC	-420 mV peak recovering in 75 μs	2
		ΔI_o = 10.0 ADC to 0.5 ADC	+160 mV peak recovering in 75 μs	
Output Impedance	V_o = 13.15 VDC, I_o = 10 ADC	Measured at 100 Hz	0.010 Ω	6
Thermal PS-17A-1 Heat sink	V_i = 12.8 VDC, V_o = 13.20 VDC, I_o = 20 ADC 25% Duty cycle, T_a = +26.7 ^oC	Natural convection cooling with heat sink fins oriented such the fin lengths are vertical.	T_s = +41.0 ^oC	3
Thermal PS-17A-1 Heat sink	V_o = 13.19 VDC, I_o = 5 ADC 100% Duty cycle, T_a = +26.7 ^oC		T_s = +35.5 ^oC	
Thermal PS-17A-1 Heat sink	V_o = 13.19 VDC, I_o = 10 ADC 100% Duty cycle, T_a = +26.7 ^oC		T_s = +43.8 ^oC	
Thermal PS-17A-1 Heat sink	V_o = 13.04 VDC, I_o = 20 ADC 100% Duty cycle, T_a = +26.7 ^oC		T_s = +62.5 ^oC	4

Notes:
1. See Figure 11. Measured at output of external filter.
2. See Figure 13. Measured at output of external filter.
3. See page 6, “Average, *rms*, Peak values”.
4. Operation outside PS-17A-1 capability - one time test for design verification ONLY.
5. Measured at PS-17A-1 output.
6. See Figure 9.

Measured Efficiency (at PS-17A-1 output)

V_i (Volts)	I_i (Amps)	P_i (Watts)	V_o (Volts)	I_o (Amps)	P_o (Watts)	η (%)
10.65	28.5	303.5	13.22	20	264.4	87.1
11.76	17.8	202.3	13.23	14	185.2	91.6
12.30	23.5	289.1	13.22	20	234.4	91.5
13.65	10.1	137.9	13.25	10	132.5	96.1

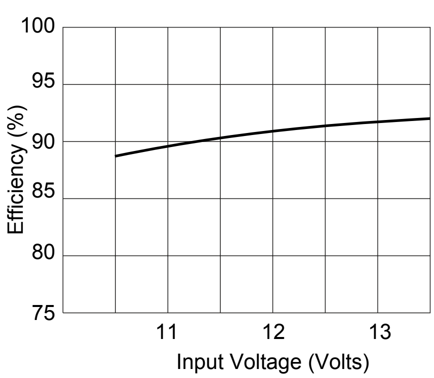


Figure 8. PS-17A-1 Efficiency vs Input Voltage with V_o = 13.22 VDC and I_o = 20.0 ADC.

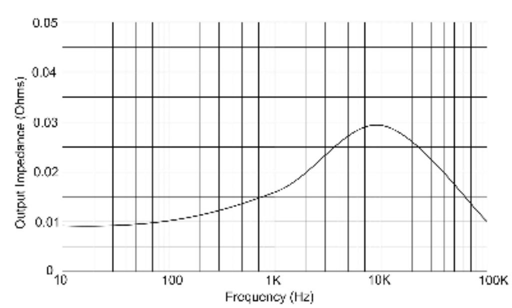
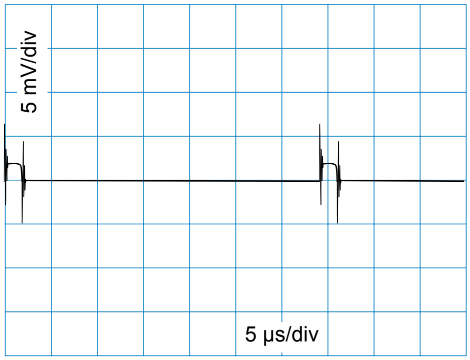


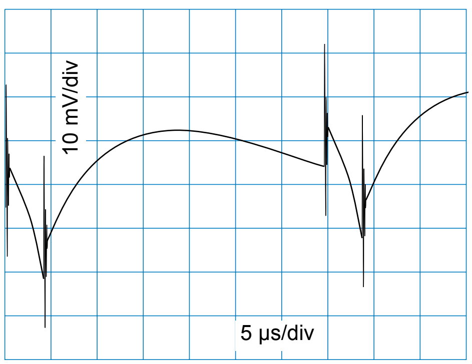
Figure 9. PS-17A-1 Output Impedance. V_i = 12.50 VDC, I_i = 5.50 ADC; V_o = 13.25 VDC, I_o = 5.00 ADC with 1 Amp p-p modulation measured at external filter output.

Engineering Prototype Measured Data:



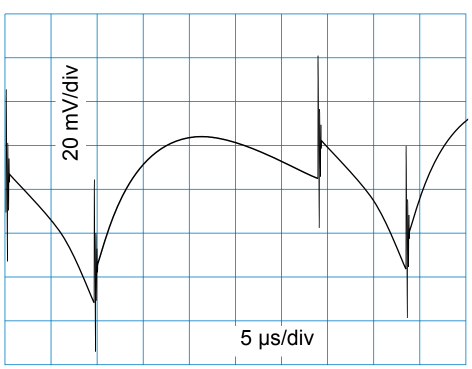
Ripple + Noise = 0.44 mV_{rms} (5 Hz to 2 MHz)

Figure 10. PS-17A-1 Ripple and spikes in "Regulated Boost" mode, 16 VDC charger input, V_o = 13.19 VDC, I_o = 5.00 ADC. Note PWM pulse width = 2.1 µs.



Ripple + Noise = 2.5 mV_{rms} (5 Hz to 2 MHz)

Figure 11. PS-17A-1 Ripple and spikes in "Regulated Boost" mode, 16 VDC charger input, V_o = 13.17 VDC, I_o = 10.00 ADC. Note PWM pulse width = 4.0 µs.



Ripple + Noise = 6.0 mV_{rms} (5 Hz to 2 MHz)

Figure 12. PS-17A-1 Ripple and spikes in "Regulated Boost" mode, 16 VDC charger input, V_o = 13.11 VDC, I_o = 15.00 ADC. Note PWM pulse width = 10.0 µs.

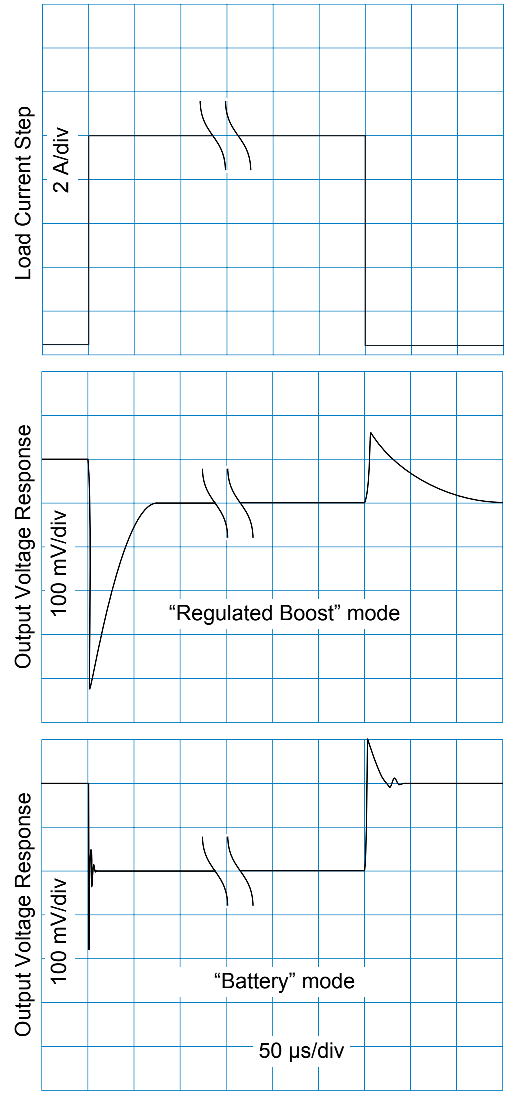


Figure 13. PS-17A-1 Load step response measured at the output connector. Note LCR of power distribution wiring effects this measurement and indeed performance.