TOPSwitch® Power Supply for Echelon® PLT-21 Power Line Transceiver

Design Note DN-15

Introduction

A TOPSwitch power supply is ideally suited to power the Echelon PLT-21 power line transceiver control node. *TOPSwitch* requires 50% fewer components compared with a discrete power supply implementation saving both manufacturing cost and valuable printed circuit board space. The wide 85 VAC to 265 VAC mains input range of the *TOPSwitch* allows worldwide operation, from 100 VAC applications in Japan to 230 VAC nodes in Europe. The *TOPSwitch* supply also satisfies EN 50065-1 EMI limits, a requirement for CENELEC-compliant applications.

Echelon's PLT-21 Power Line Transceiver is designed for use in very small enclosures. The transceiver requires both +5 VDC and +12 VDC for normal operation and under worst case conditions consumes 250 mA from +12 VDC and 33 mA from +5 VDC. Given the minimal space available for a power supply in a typical node, the worst case current requirements dictate the use of a very compact, efficient *TOPSwitch* power supply.

The highly efficient *TOPSwitch* supply delivers 4.8 W at 12 V, satisfying the worst case current needs of the PLT-21 transceiver without generating excessive heat - a critical design benefit in the small, sealed enclosures that typify control nodes such as light switches and electric meters. The wide -40 to +85° C ambient operating range of the *TOPSwitch* allows one common power supply design to be used for both indoor and outdoor nodes, minimizing design time and part stocking requirements.

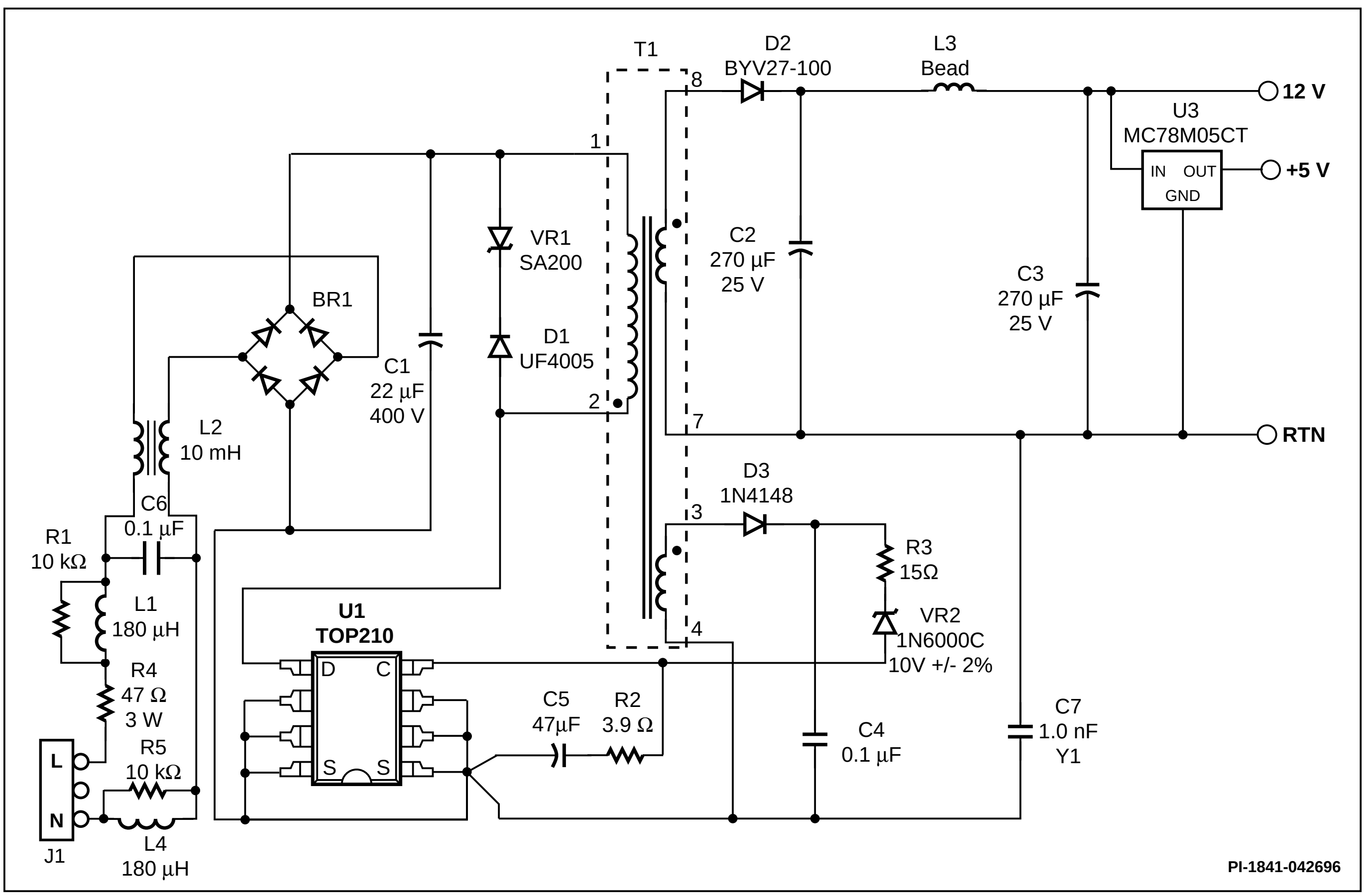

Figure 1. PLT-21 Power Supply Circuit Using TOP210.

Introduction to Echelon Control Networks

A control network is a system of sensors, actuators, displays, and logging devices (referred to as “nodes”) that are linked together to monitor and control electrical devices. LONWORKS® is a control networking technology developed by Echelon Corporation that is flexible enough to be used for virtually any control network application. The microcontrollers at the heart of LONWORKS are called Neuron® Chips. Neuron Chips are manufactured and sold under license by Motorola and Toshiba, providing LONWORKS customers access to the latest semiconductor manufacturing technology and a low-cost, reliable supply of components.

Nodes incorporating Neuron Chips can communicate over virtually any medium. Transceivers are available for power mains, twisted pair, fiber optic, coaxial cable, infrared, and radio frequency signaling. Power mains transceivers from Echelon signal through any AC or DC power mains. Typical nodes using power mains transceivers include light switches, electrical outlets, electric meters, contactors, and temperature sensors. The high volume, small size, and low cost of these nodes dictates that the control electronics and associated power supply be very compact.

Summary of PLT-21 Transceiver Requirements

The PLT-21 transceiver has the following power supply requirements:

- 12 V ± 0.6 V @ 250 mA (maximum)
- 5 V ± 0.25 V @ 33 mA (maximum)
- High Input Impedance at 130 kHz (> 300 Ω)
- -40° C to 85° C operating ambient temperature range (at maximum transmit duty cycle)
- Meets recommended AC line input noise mask
- Meets recommended output noise mask

This *TOPSwitch* power supply is designed to meet requirements for a PLT-21 transceiver compatible power supply, as presented in Echelon’s *PLT-21 Power Line Transceiver User’s Guide*. SELV outputs are provided for use with either an isolated transceiver coupling circuit or a non-isolated transceiver coupling circuit. See the *PLT-21 Power Line Transceiver User’s Guide* for details about the PLT-21 transceiver coupling circuits.

Summary of Design Example Features

This *TOPSwitch* power supply design example has the following key system features when used in conjunction with the PLT-21 transceiver and recommended coupling circuits:

- Low parts count (25) and low cost
- 85 VAC to 265 VAC mains line input, 50/60 Hz
- 250 mA @ 12 V output for PLT-21 transceiver
- 150 mA @ 5 V output for PLT-21 transceiver, Neuron 3120® Chip or Neuron 3150® Chip, PROM, and application electronics
- Safety-isolated Extra Low Voltage (SELV) power supply outputs
- High efficiency for enclosed applications
- Supports both safety-isolated and non-isolated PLT-21 transceiver coupling circuits
- Unconstrained PLT-21 transceiver transmit duty cycle and packet length
- -40° C to +85° C ambient temperature operation
- Meets both CENELEC EN 50065-1 and FCC Part 15 conducted emission requirements

This *TOPSwitch* power supply design demonstrates compliance with the European standard for power line communication conducted emissions, EN 50065-1. The European standard is significantly more stringent than the requirements imposed by the FCC and Industry Canada in North America.

A schematic and parts list is provided along with the following measured performance data: regulation, transient response and efficiency.

General Description of Power Supply Operation

The dual-output power supply shown in Figure 1 meets the power requirements of the PLT-21 transceiver. The power supply has additional output power capability to support the demands of application specific circuits. Approximately 117 mA is available at the 5 V output for powering node electronics in addition to the PLT-21 transceiver. The constant frequency flyback switching power supply uses the TOP210 *TOPSwitch* integrated circuit. 5 V is derived from the 12 V output using a monolithic linear regulator which is the most cost effective method of producing the low-noise 5 V output. The transformer uses a small, low-cost EE187-size ferrite core. Manufacturers and part numbers for the components used are shown in Table 1.

TOPSwitch performs all bias, pulse width modulation, high-voltage switching, and circuit protection functions. The low power dissipation of the TOP210 reduces power loss and increases efficiency which eliminates the need for a heat sink. The 100 kHz constant operating frequency of the power supply is outside the range of PLT-21 transceiver communications frequency, eliminating the need for additional filtering.

AC input voltage is rectified and filtered by BR1 and C1 to create a high-voltage DC bus ranging from 100 to 375 VDC. The primary of T1 is connected between the high-voltage bus and the *TOPSwitch* Drain pin. T1 has typical primary inductance of 3.7mH and can operate in both the continuous and discontinuous modes. D1 and VR1 clamp leading voltage spikes caused by leakage inductance when *TOPSwitch* turns off. The VR1 voltage rating of 200 V is selected to clamp the Drain voltage spike approximately 65 V above the reflected output voltage at maximum output current.

The power secondary is rectified and filtered by D2 and C2 to typically 12 VDC. L3 and C3 provide additional filtering to reduce high frequency ripple voltage to acceptable levels for the PLT-21 transceiver.

The bias winding is rectified and filtered by D3 and C4. Bias current flows through R3 and VR2 into the *TOPSwitch* Control pin when the output voltage is regulated. C5 filters high-frequency currents, sets the auto-restart interval, and provides control loop frequency compensation. Note that C5 is connected to the Source pins of *TOPSwitch* with a Kelvin connection to reduce the effect of Source current switching noise. R2, the equivalent series resistance (ESR) of C5, the *TOPSwitch* Control pin dynamic impedance Z_C, along with C5 create a pole-zero pair for control loop compensation.

This is a primary regulated flyback converter. The output voltage is determined by the turns ratio between the output winding and bias winding and the voltage drops of rectifiers D2 and D3. Regulation is achieved when the bias voltage rises sufficiently above the Zener diode (VR2) voltage plus the *TOPSwitch* Control pin voltage, approximately 15.8 VDC. R3 and the dynamic impedance of VR2 control the DC feedback gain.

The power supply is short circuit protected. When an overload occurs, the transformer primary current increases. An internal peak-detecting cycle-by-cycle current limit reduces duty cycle to limit *TOPSwitch* peak current. The reduction in duty cycle decreases the output voltage. As the output voltage reduces further, the bias winding will also decrease due to the coupling between the windings. As the bias winding voltage drops below 15.8V, *TOPSwitch* will enter the shutdown auto-restart mode. The shutdown auto-restart mode cycles the power supply on and off at typically 1.2 Hz with the *TOPSwitch* enabled approximately 5% of the time. When the load returns to normal, the output voltage will also return. *TOPSwitch* power supplies have lower cost EMI filters due to inherently lower conducted emissions. Controlled turn-on reduces common-mode EMI by limiting *TOPSwitch* Drain voltage dv/dt each time *TOPSwitch* turns on. Common-mode conducted emissions are reduced with Y1-capacitor C7 and common-mode inductor L2. Differential-mode conducted emissions are reduced by the leakage inductance of L2 and X2-capacitor C6.

L1 and L4 isolate the PLT-21 transceiver from X2-capacitor C6 insuring that a high input impedance will be seen at the AC mains. L1 and L4 have been carefully chosen to prevent saturation at the peak of the AC mains waveform which lowers the effective input impedance. R1 and R5 damp the resonance due to stray capacitance of L1 and L4 respectively. R4 prevents L1, L4 and C6 from resonating with the PLT-21 transceiver coupling circuit which degrades communication performance. Note that R4 is specified as a wire wound 3 W resistor for high reliability under surge voltage conditions commonly found on AC power mains.

TOPSwitch has an internal over-temperature shutdown that can (with proper thermal design) protect all components in the power supply.

Component Listing

Reference	Value	Part Number	Manufacturer
BR1	600 V, 1A	DFO6M	General Instrument
		S1VB60	Shindengen
C1	22 µF, ±20%, 400 V	UVX2G220MHA	Nichicon
C2, C3	270 µF, ±20%, 0.09 Ω max. ESR, 25 V	ECA1EFQ271	Panasonic
C4	0.1 µF, 20%, 50 V	K104M20Z5UFVBWN	Philips
C5	47 µF, ±20%, 10 V, 1 Ω to 2 Ω ESR	ECEA1CGE470	Panasonic
C6	0.1 µF, ±20%, 250 VAC X2-SAFETY	F1772-410-20	Roderstein
C7	1000 pF, ±20%, 250 VAC Y1-SAFETY	DE1110E102MACT4K-KD	Murata
D1	UF4005, 600 V, ≤ 75 ns	UF4005	General Instrument
D2	BYV27-100, 100 V, ≤ 25 ns	BYV27-100	Philips
D3	1N4148, 75 V, ≤ 25 ns	1N4148	National Semiconductor
VR1	200 V, 1 W, ≥ 105 W peak TVS	SA200	Motorola
VR2	10 V, ±2%, Izt=5 mA	1N6000C	Motorola
L1, L4	180 µH, ±10%, Imax ≥ .25 A	LAL05T180K	Taiyo Yuden
L2	Common Mode Filter 10 mH, I_{DC}>0.25 A	XF0073-0002	XFMRS Inc.
L3	Bead, 88 Ω min at 10 MHz	2773007112	Fair-Rite
R1, R5	10 kΩ, ±5%, 1/4 W	5043EM10001J	Philips
R2	3.9 Ω, ±5%, 1/8 W	5063JD3R900J	Philips
R3	15 Ω, ±5%, 1/8 W	5063JD15R00J	Philips
R4	47 Ω, ±5%, 3 W, wire wound	FA2583	RCD
T1	3.7 mH ±10%	Flyback Power Transformer	Custom
U1	TOP210, 700 V *TOPSwitch*	TOP210PFI	Power Integrations
U3	5 V, ±5%, Linear Regulator	MC78M05BT	Motorola

Table 1. Parts List for Flyback Power Supply Shown in Figure 1.

Transformer Documentation

Transformer Winding Sequence:

1) Wind 126 turns #37AWG magnet wire, wind two layers (63 turns/layer) starting on pin 2, finishing on Pin 1. One layer of tape between winding layers to insulate winding layers and reduce capacitance as shown in figure 2.
2) Two layers of tape to secure windings.
3) Wind 12 turns of #24AWG triple insulated wire, start on pin 8 finish on pin 7. Wind uniformly across entire width of the bobbin.
4) Two layers of tape to secure windings.
5) Wind 14 turns of #28AWG magnet wire, start on pin 3 and finish on pin 4. Wind uniformly across entire width of the bobbin.
6) Three layers of tape to secure windings.
7) Insert cores in bobbin. Wrap the “Belly Band” foil shield (1 turn) around the bobbin/core assembly. Physical contact between the foil shield and the ferrite core is required to insure a low Ohmic contact to the core for adequate shielding performance. The start and finish of the foil should overlap to provide adequate shielding function. Solder start and finish together and connect shield wire to pin 4. Secure cores together with tape or spring clip.
8) Measure primary inductance from pin 1 to pin 2 with all other windings open. The inductance shall be 3.7 mH ± 10%. Primary leakage inductance with pins 7 and 8 shorted together shall be less than 3% of primary magnetizing inductance.

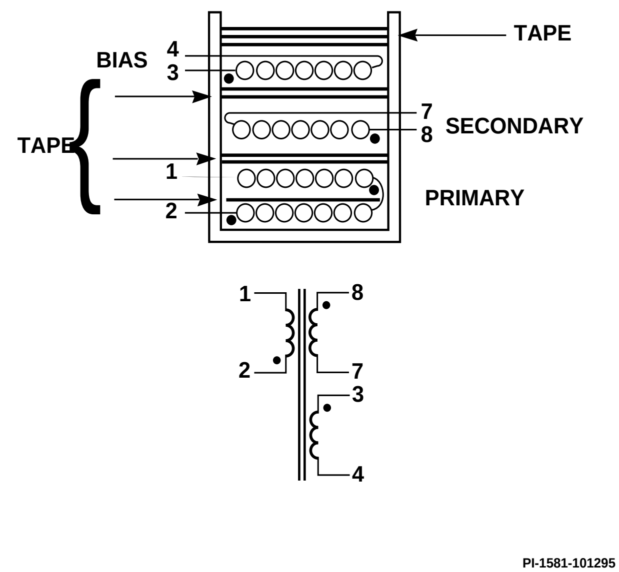

Figure 2. T1 Transformer Construction and Schematic.

Material	Manufacturer
#28 AWG and #37AWG Magnet Wire	Phelps Dodge Heavy Nyleze
#24 AWG Triple Insulated Wire	Rubadue Wire Co. Part# TIC24A01F592-3 Teflon
	Furukawa Electric Co. America, Inc. Solderable Polyester Part# TEX-E Wire, Order by Description
Tape	Polyester Film (3M #1298) 0.35" wide
Foil	Copper 0.002" thick x 0.35" wide
Bobbin: Horizontal	TDK BE-19-118CPH Tokin EB19-P1108-F
Core	TDK PC40EE19/16-Z (Gapped A_L=234 nH/T^2) Siemens B66379-G-X127 Tokin FEE19/16/5 2500B

Table 2. Material List for Transformer. (Refer to AN-18 for Manufacturer's Addresses, Telephone and Fax Numbers)

Performance Data

The measured circuit performance data shown in Figures 3 to 9 confirms that this power supply design meets the requirements of the Echelon PLT-21 transceiver. To operate the PLT-21, the 12 V output should be within ±0.6 V (refer to Echelon's PLT-21 Power Transceiver User's Guide).

Load Regulation

The amount of change in the DC output voltage for a given change in the output current is referred to as load regulation (Figure 3). The 12 V output stays within ± 5% for a 25% to 100% load range. Data was taken at 115 VAC and 230 VAC input voltage to show the combined effects of line and load regulation.

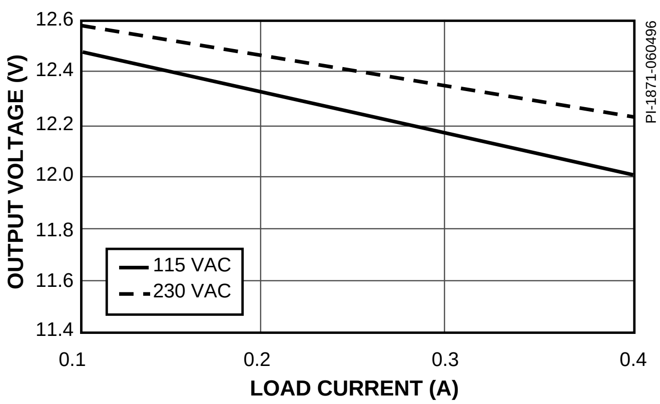

Figure 3. Load Regulation for 12 V Output.

Line Regulation

The amount of change in the DC output voltage for a given change in the AC input voltage is called line regulation (Figure 4). The maximum change in output voltage is within ±3.5 % for 85 to 265 VAC input voltage range.

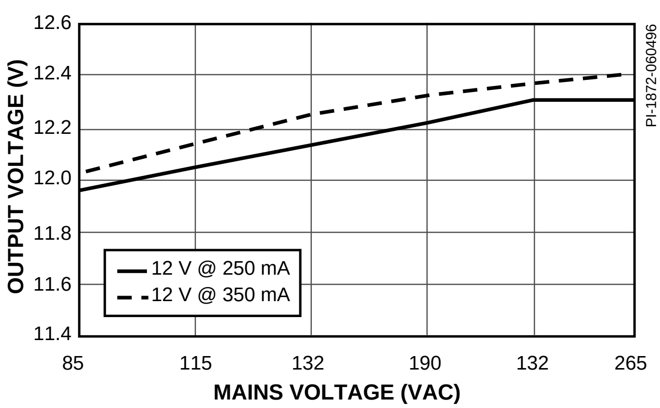

Figure 4. Line Regulation for 12 V Ouput.

Transient Response

The output voltage must stay within the specified regulation range of 12 V ± 0.6 V when the transceiver is changing from receive to transmit and back to receive again. The specified maximum load transient step is 250 mA. The transient response shown in Figure 5 is for an increase in the 12 V load from no load to 250 mA. The 5 V load is 100 mA. The response with 115 VAC and 230 VAC inputs are shown. The 230 VAC response shows less change than 115 VAC as the gain of the switching power stage is higher at 230 VAC. The recovery waveform indicates a stable well controlled power supply that easily meets the Echelon requirements.

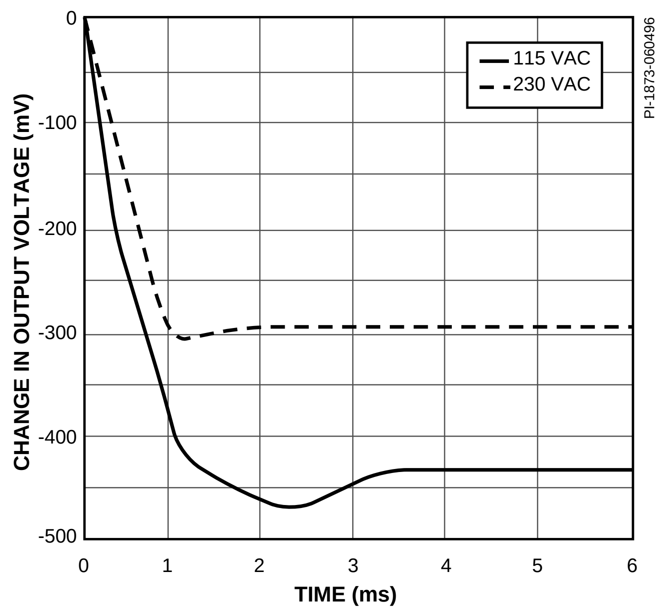

Figure 5. Output Voltage Response with Load Current Switching Transient.

Efficiency vs. Mains Voltage

Figure 6 shows efficiency data for the 12 V switching power supply output. Full-power efficiency is 75% (typical) with a 12 V load of 350 mA.

The effect of the 5 V linear regulator on the overall system efficiency is shown in Figure 7. The full-power system efficiency is 67% with 12 V load of 250 mA and 5 V load of 50 mA. Note that every milliamp of 5 V current passing through the 5 V linear regulator presents a milliamp of load on the 12 V output.

Efficiency vs. Load

The change in efficiency with load current is shown in Figure 8 for input voltages of 115 VAC and 230 VAC. Data is shown for 12 V current only as the effects of the linear regulator efficiency are easily calculated.

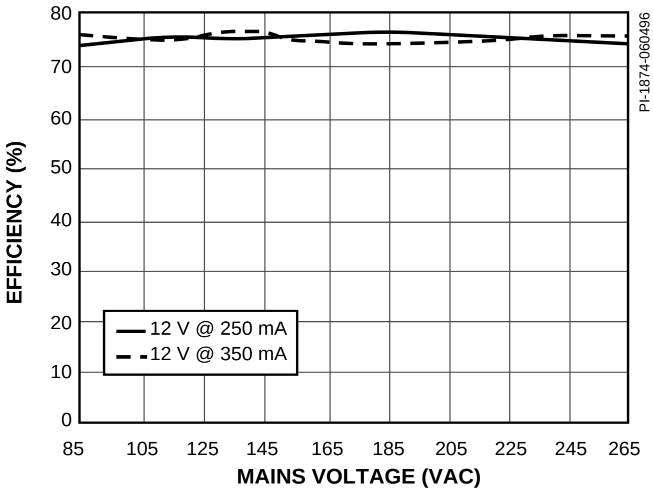

Figure 6. Efficiency vs. AC Mains Voltage.

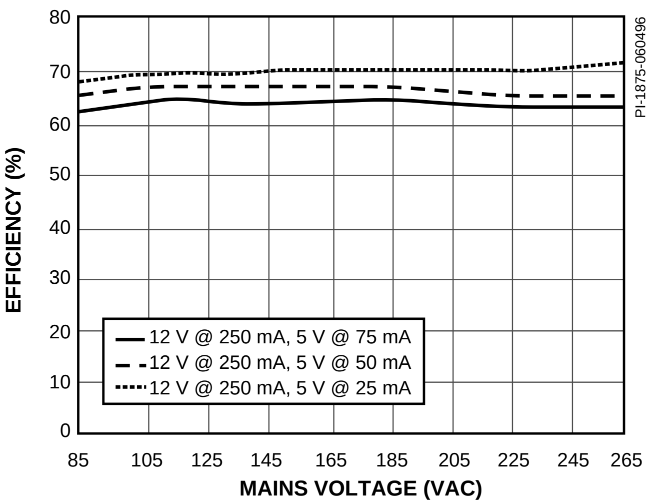

Figure 7. Efficiency with Linear Regulator vs. AC Mains Voltage.

Temperature Protection

System thermal protection can be accomplished by taking advantage of the internal thermal shutdown within the TOP210. By thermally designing the TOP210 as the hottest component in the power supply (Refer to DN-13, Table 3 for power dissipating components), the TOP210 will shutdown and protect other components from failing when ambient reaches an over temperature condition. Unlike other *TOPSwitches*, the TOP210 thermal protection is non latching. After an over temperature shutdown, the TOP210 will restart as the TOP210 temperature drops 30°C (typical thermal shutdown hysteresis).

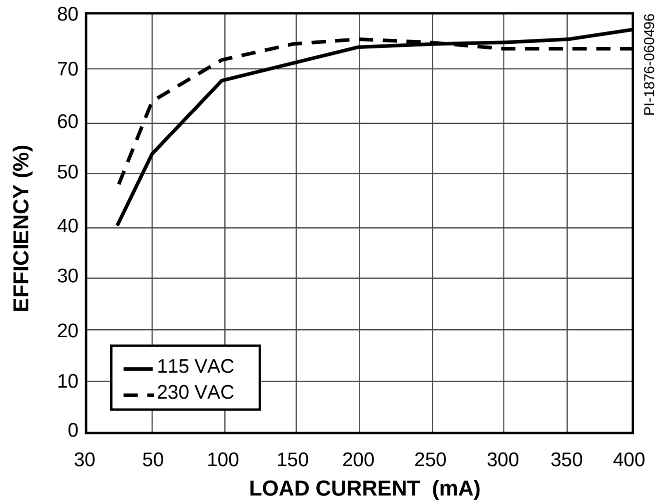

Figure 8. Efficiency vs. Load Current.

AC Mains Noise Measurements

Switching power supply input noise (Conducted Emissions) for the PLT-21 is required to meet the levels of CENELEC EN 50065-1 or FCC Section 15.107. Refer to DN-13 for the these curves or in the "PLT-21 Power Line Transceiver User's Guide". This *TOPSwitch* based supply is designed to meet both curves for Line and Neutral measurements.

AC Mains Connection Schematic

The schematic in Figure 9 illustrates the connection of the power supply relative to the PLT-21 transceiver, the transceiver coupling circuit, the fuse (F1) and the transient suppression element (MOV1).

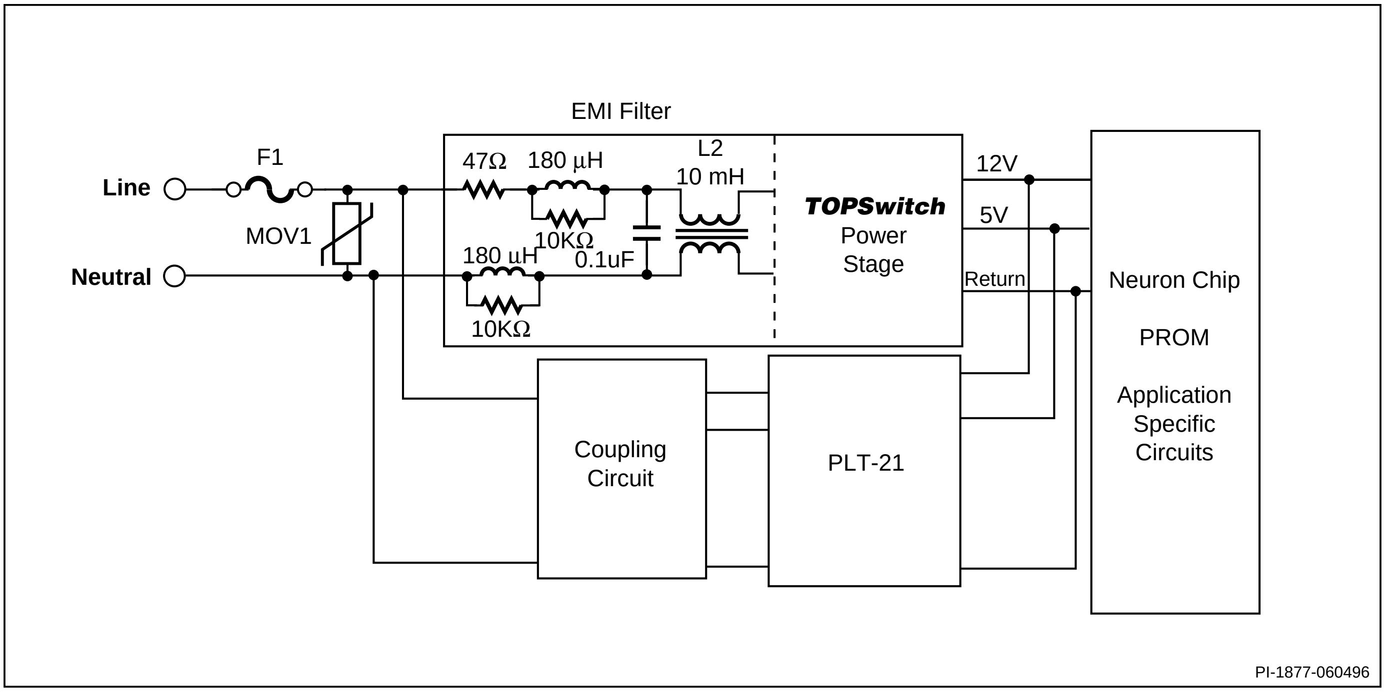

Figure 9. AC Mains System Connection Schematic.

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