DC to DC Converters Using *TOPSwitch*® for Telecom and Cablecom Applications

Design Note DN-16

POWER INTEGRATIONS, INC.

Description

The *TOPSwitch* product family provides a cost effective and reliable solution for DC to DC converter applications. The TOP100-TOP104 series of products can be used for input voltages as low as 16VDC and as high as 200VDC in a flyback topology. The 350V breakdown voltage minimizes primary clamping requirements in low voltage applications, reducing cost and simplifying the design. The high level of system integration reduces component count and board space while boosting power density. Because *TOPSwitch* is very easy to use, design time to production is greatly reduced. Compared to discrete PWM and converter modules, the *TOPSwitch* solution reduces total cost, component count, size, and weight while also increasing system reliability.

Output power ranges for each *TOPSwitch* as a function of DC input voltage are shown in the table below. For each minimum input voltage value shown, an output power range is given for each *TOPSwitch* for an expected converter efficiency of approximately 80% with losses split evenly between *TOPSwitch* and the rest of the circuitry. The transformer should be designed for the indicated reflected voltage V_{OR} and will have maximum duty cycle D_{MAX} approaching 64%. Refer to Application Note AN-17 for more information on reflected voltage and transformer design.

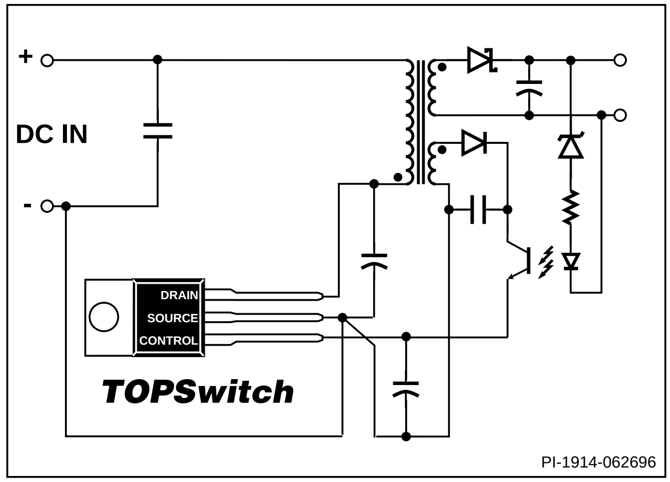


Figure 1. Typical Application.

Typical Application Circuits

Circuits for three different DC to DC applications are shown using the TOP104. The flyback converter shown in Figure 2 operates directly from the -48 VDC telecom input voltage and delivers up to 15 Watts at a highly accurate +3.3 VDC output voltage. A multiple output flyback converter suitable for Cablecom applications is shown in Figure 6. This converter also delivers a total power of 15 Watts while operating from

TOPSwitch OUTPUT POWER RANGE vs. INPUT VOLTAGE						
MINIMUM INPUT VOLTAGE	REFLECTED VOLTAGE V_{OR}	FLYBACK CONVERTER OUTPUT POWER RANGE (80% EFFICIENCY)				
		TOP100	TOP101	TOP102	TOP103	TOP104
18 VDC	30 V	0-0.9 W	0.8-1.6 W	1.2-2.3 W	1.5-2.9 W	1.7-3.4 W
24 VDC	40 V	0-1.6 W	1.3-2.7 W	1.9-3.8 W	2.5-5.0 W	2.8-5.7 W
36 VDC	60 V	0-3.7 W	3.3-6.5 W	4.6-9.2 W	6.0-12 W	7.0-14 W
48 VDC	80 V	0-6.8 W	6.0-12 W	8.5-17 W	11-22 W	12-25 W
60 VDC	*100 V	0-10 W	9.0-18 W	12-25 W	16-33 W	19-38 W
72 VDC	*120 V	0-14 W	12-25 W	17-35 W	23-46 W	26-52 W
90 VDC	*150 V	0-21 W	18-37 W	26-52 W	33-67 W	39-78 W

**Some Cablecom Applications require derating of output power due to input withstand voltage requirement. Refer to Cablecom example circuit section.*

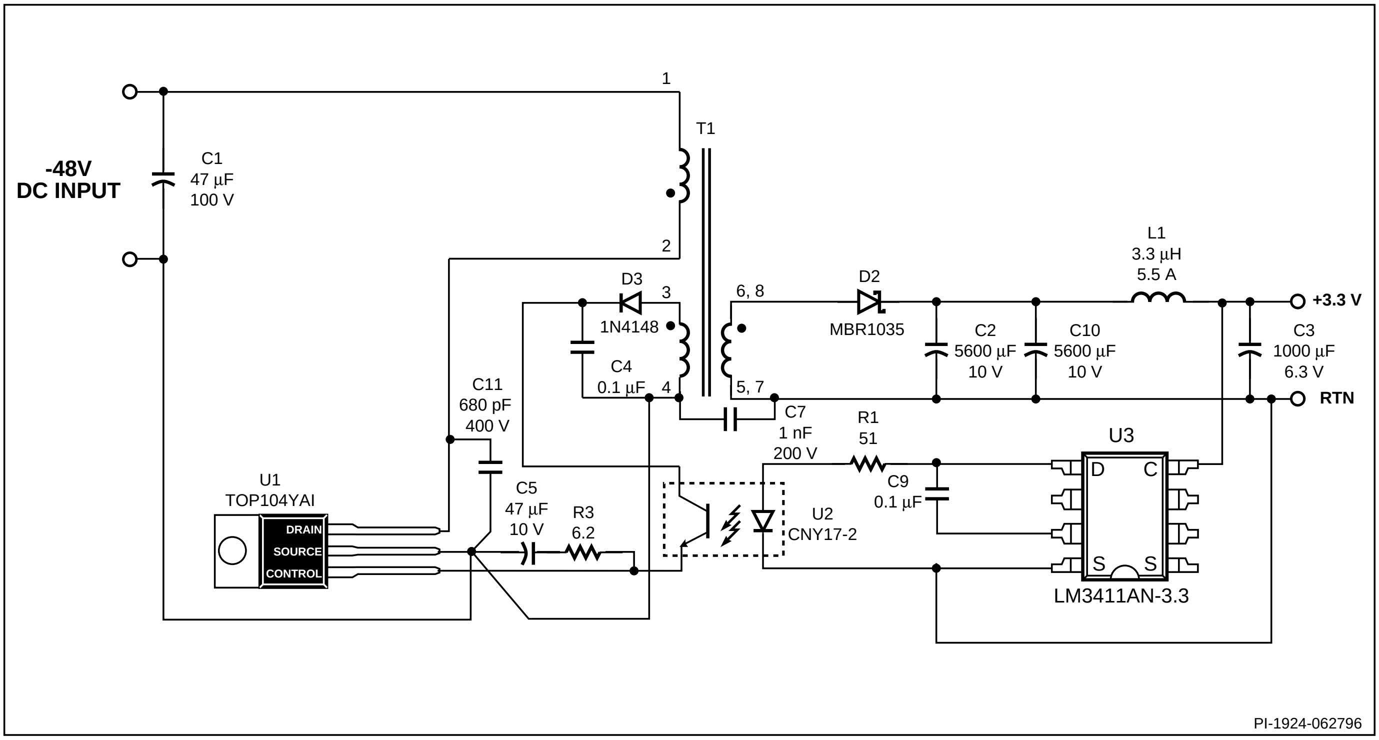


Figure 2. Simple, Low Cost 3.3V, 15W DC to DC Converter Using the TOP104.

rectified quasi-square wave input voltage ranging from 36 VAC to 90 VAC, typical of a ferro-resonant transformer. The 5V output is tightly regulated and the ±15 VDC outputs are regulated via the transformer secondary turns ratios. Figure 10 shows a ring generator bias flyback converter that operates from the -48 VDC telecom input voltage. This is a primary regulated converter that delivers up to 16 Watts of power at -55 VDC output voltage.

-48V Telecom Converter

Figure 2 shows an isolated flyback DC to DC converter using the TOP104 that operates from -36VDC to -70VDC and delivers 15W of power. Output voltage is accurately regulated from the secondary by using an LM3411-3.3 (U3) which is a precision regulator/driver.

DC voltage is applied to the primary winding of T1 as shown in Figure 2. The other side of the transformer primary is driven by the integrated high voltage MOSFET within the TOP104. The switching frequency of the TOP104 is 100KHz, set by the internal oscillator. With a breakdown voltage of 350V, the clamp circuit to limit the *TOPSwitch* Drain voltage becomes very simple. C11 limits the leading-edge voltage spike caused by the transformer leakage inductance. Note that the effectiveness of C11 to limit the Drain voltage spike is directly related to the value of the transformer leakage inductance. If the leakage inductance is greater than the values specified in Table 1, a clamp circuit consisting of a Zener diode and ultrafast diode must be used (refer to AN-14).

The 3.3V secondary winding is rectified and filtered by D2, C2, C3, C10 and L1 to create the 3.3 V output voltage. The LM3411 directly senses the output voltage V_O and regulates the output voltage by controlling the optocoupler U2 LED current. C9 rolls off the high frequency gain of the LM3411 for stable operation. R1 limits the optocoupler LED current and determines the loop gain. The bias winding voltage is rectified and filtered by D3 and C4 to generate an approximate 11 V bias voltage to supply the transistor-side of the optocoupler. Optocoupler transistor current is driven into *TOPSwitch* Control pin to determine the duty cycle. U3 together with U2 adjusts the current into the control pin to vary the duty cycle and maintain the output voltage of 3.3V. R3 and C5 tailor the frequency response of the power supply.

Table 1 (at the end of this Design Note) shows electrical specifications and construction details for flyback Transformer T1.

Performance Data

Load regulation is the amount of change in DC output voltage for a given change in output current. Data is taken at nominal input voltage of -48VDC. Output voltage is measured at the power supply output connector. Figure 3 shows that the 3.3V output voltage stays within ± 0.4% from 0% load to 100% load.

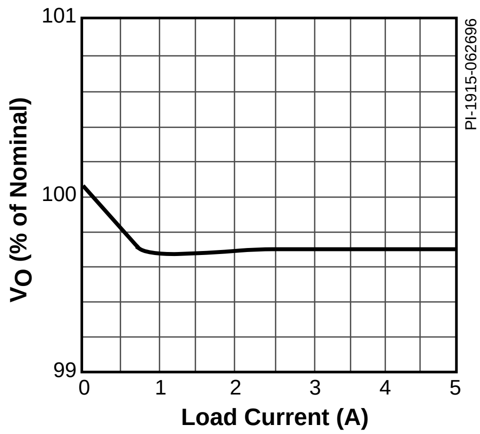


Figure 3. Load Regulation.

Line regulation is the amount of change in the DC output voltage for a given change in the DC input voltage. Data for line regulation, shown in Figure 4, is taken at the maximum load condition. Figure 4 shows that the 3.3V output stays within 0.6% from -36VDC input to -70VDC input.

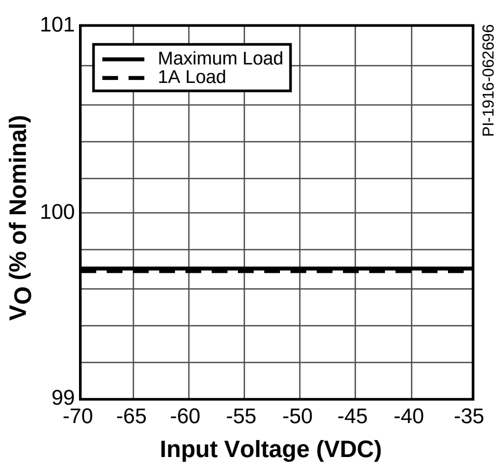


Figure 4. Line Regulation.

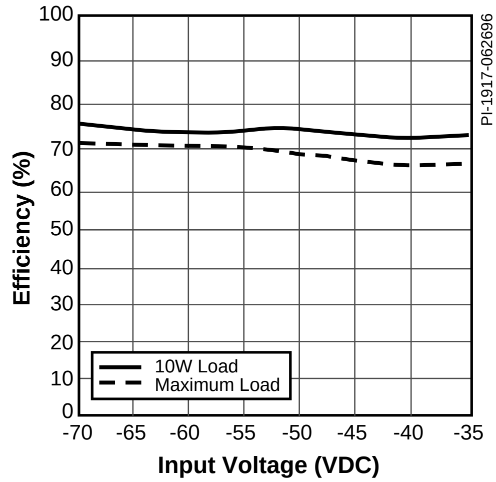


Figure 5. Efficiency vs. Input Voltage.

Efficiency is the ratio of output power to input power. Figure 5 shows curves for efficiencies at two load conditions as a function of input voltage. Worst case efficiency occurs at -36VDC input and maximum load current. At this condition, the output diode average current is approximately 4.6 A. Most of the power dissipation loss is due to D3 (3W to 4W). To improve the overall efficiency, a lower V_F (0.3V) Schottky diode may be used for D2 (Motorola, MBR2515L or equivalent).

Multiple Output Cablecom Power Supply

Figure 6 shows a multiple output flyback DC to DC converter using the TOP104. This isolated power supply operates from rectified quasi-square wave input voltage of 36 VAC to 90 VAC and delivers a total power of 15W. 5VDC output voltage V_O is accurately regulated from the secondary by using a TL431 (U3) which is a precision shunt regulator. ±15VDC output voltages are derived from the turns ratio of transformer T1 (between the 15V windings and the +5V winding) which take into account the voltage drops of rectifiers D2, D4, and D5.

The 5V secondary winding is rectified and filtered by D2, C2, C3, and L1 to create the 5 V output voltage. The TL431 directly senses the output voltage, via resistor divider R4 and R5, and regulates the 5V output voltage by controlling the optocoupler U2 LED current. C9 rolls off the high frequency gain of the TL431 for stable operation. R1 limits the optocoupler LED current and determines the loop gain. The +15V output winding is rectified and filtered by D4, C12, C13, and L4, and the -15V output winding is rectified and filtered by D5, C14, C15, and L5. The bias winding voltage is rectified and filtered by D3 and C4 to generate an approximate 12 V bias voltage to supply the transistor side of the optocoupler. Optocoupler transistor current is driven into the *TOPSwitch* Control pin to determine the duty cycle. U3 together with U2 adjusts the current into the control pin to vary the duty cycle and maintain an output voltage of 5V. R3 and C5 tailor the frequency response of the power supply.

In cable distribution, the power supply may have to withstand input voltage as high as 187 VAC (quasi-square wave) which will require a Zener diode drain clamp circuit consisting of VR1 and D1. This clamp circuit will limit the leading-edge voltage spike caused by transformer leakage inductance to a safe value below *TOPSwitch* breakdown rating. Transformer reflected voltage V_{OR} will also have to be reduced to approximately 60V which limits maximum duty cycle D_{MAX} to a lower value and decreases converter output power capability by 20% to 35% compared to the values shown in the table at the beginning of this Design Note. Refer to Application Note AN-17 for more information on reflected voltage and transformer design.

Table 2 (at the end of this Design Note) shows electrical specifications and construction details for flyback Transformer T1.

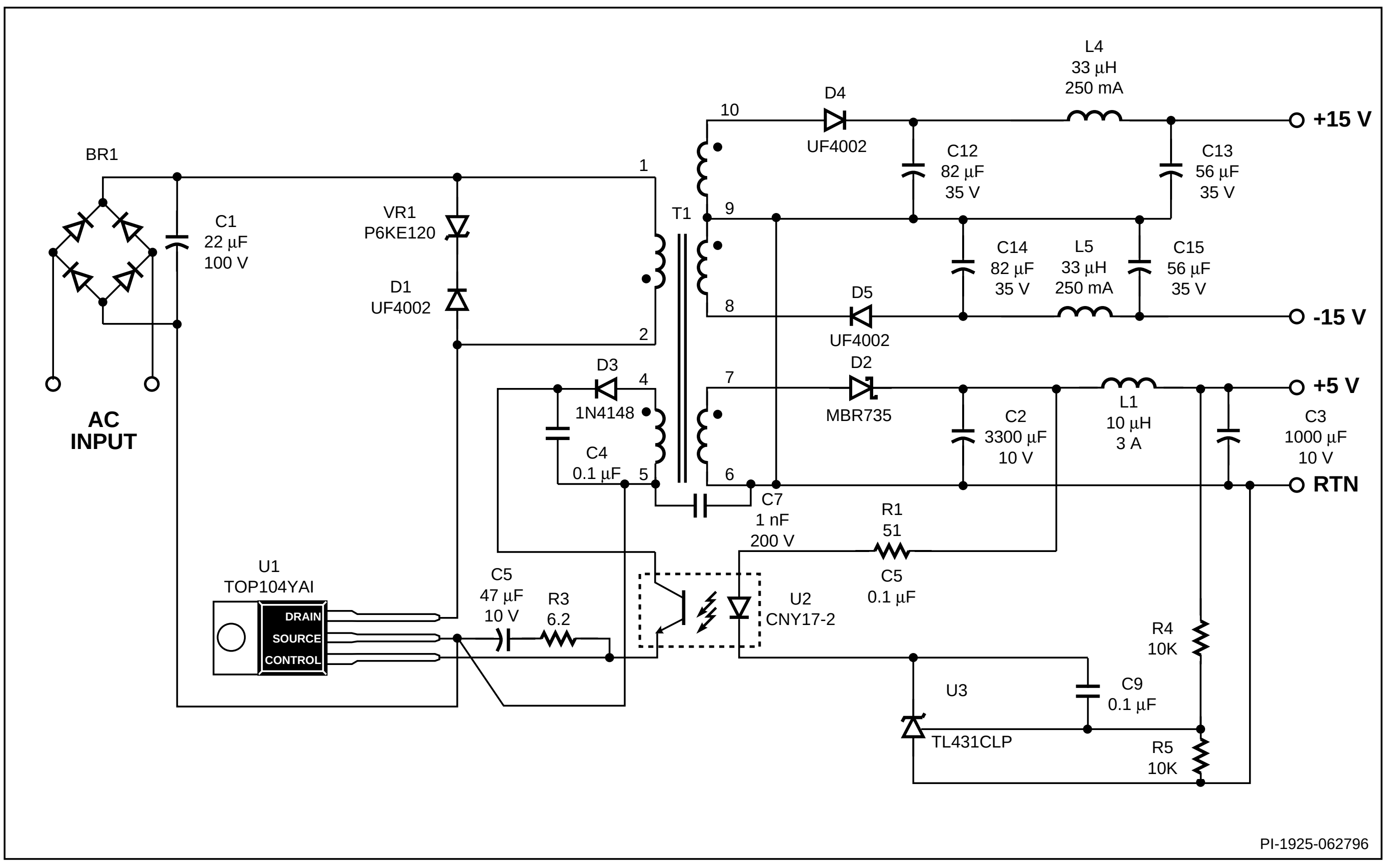


Figure 6. Multiple Output 5V, ±15V, 15 Watt DC to DC Converter Using the TOP104 Operating from Rectified 36 VAC to 90 VAC Quasi -Square Wave Input Voltage.

Performance Data

Data for load regulation is taken at nominal input voltage of 48VDC. Load for the 5V output is varied from 0.25A to 2A while the load for the 15V is maintained at 0.17A. Figure 7 shows that the 5V output voltage stays within 0.4% from 0.25A to 2A load. Load cross regulation is the amount of change in the ±15V output voltages for a given change in 5V output current. Figure 7 also show that the cross regulation is 8.1% for the +15V output and 7.9% for the -15V output.

Data for line regulation, shown in Figure 8, is taken at maximum load condition. Figure 8 shows that the 5V output stays within 0.4%, the +15V is within 8.3%, and the -15V is within 8.1% from 36 VAC to 90 VAC quasi-square wave input voltage.

Figure 9 shows curves for efficiencies at three load conditions as a function of input voltage. Worst case efficiency of 74% occurs at 36 VAC quasi-square wave input voltage and maximum load current.

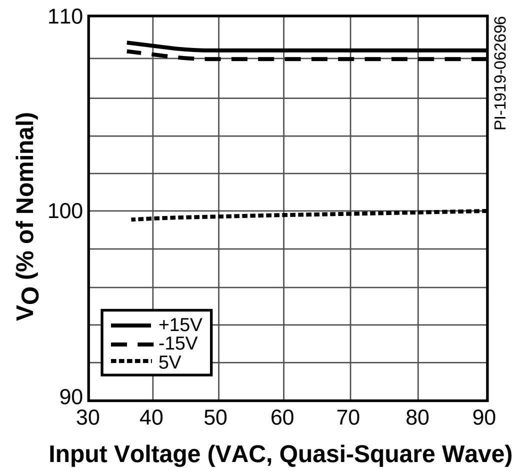


Figure 8. Line Regulation at 15W Load

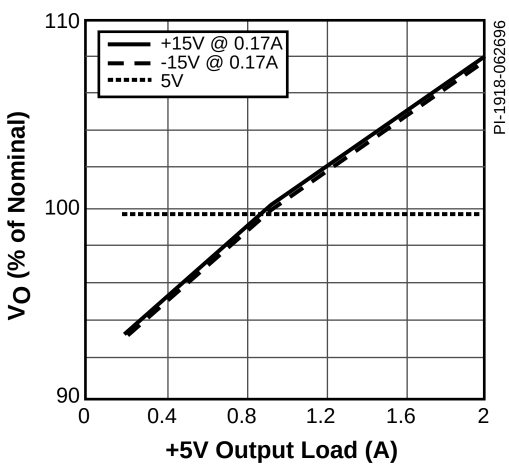


Figure 7. Load Regulation at 48 VDC Input as 5 V Load Varies.

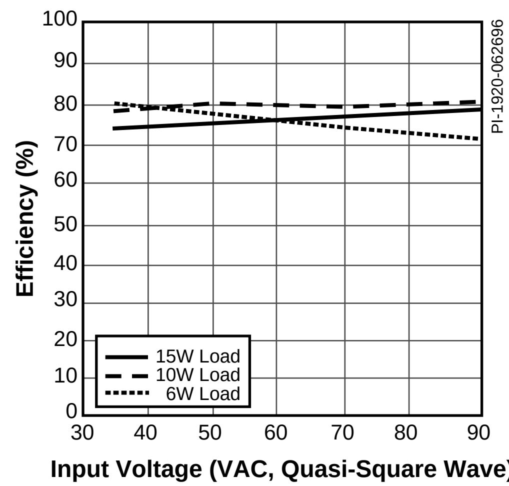


Figure 9. Efficiency Curves vs. Input Voltage

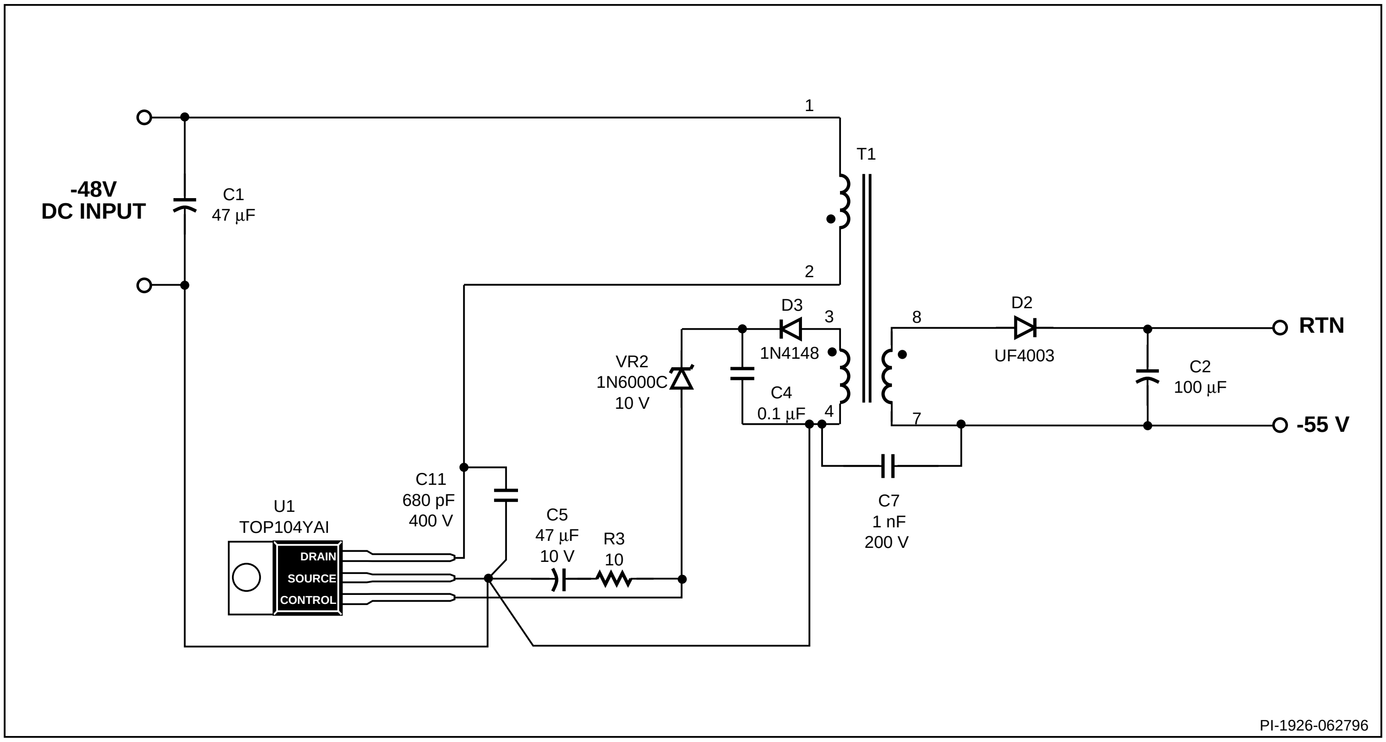


Figure 10. Ring Generator Bias Voltage DC to DC Converter Using the TOP104.

Telecom Ring Generator Bias Circuit

Figure 10 shows the TOP104 used for a ring generator bias application. This is also an isolated flyback DC to DC converter that operates from -36VDC to -60VDC and delivers up to 16W of power at an output voltage of -55 VDC. With a breakdown voltage of 350V, the clamp circuit to limit the *TOPSwitch* Drain voltage becomes very simple. C11 limits the leading-edge voltage spike caused by the transformer leakage inductance. Note that the effectiveness of C11 to limit the Drain voltage spike is directly related to the value of the transformer leakage inductance. If the leakage inductance is greater than the values specified in Table 3, a clamp circuit consisting of a Zener diode and ultrafast diode must be used (refer to AN-14). Primary side regulation is used to control the output voltage. Output voltage is indirectly regulated via the primary bias winding. The output voltage is determined by the *TOPSwitch* Control pin voltage V_C (typically 5.8V), Zener voltage V_{VR2}, the voltage drops of rectifiers D2 and D3, and the turns ratio between the output winding and bias winding of T1.

The output winding is rectified and filtered by D2 and C2 to create -55 VDC. The bias winding voltage is rectified and filtered by D3 and C4 to create a bias winding voltage of 15.8V (the sum of V_{VR2} and V_C). C5 is the filter for the Control pin. C5 and R3 compensate the control loop of the power supply.

Table 3 (at the end of this Design Note) shows electrical specifications and construction details for flyback Transformer T1.

Performance Data

Load regulation data is taken at nominal input voltage of -48VDC. Output voltage is measured at the power supply output connector. Figure 11 shows that the output voltage stays within ± 2.5% of the nominal value from 10% load to 100% load.

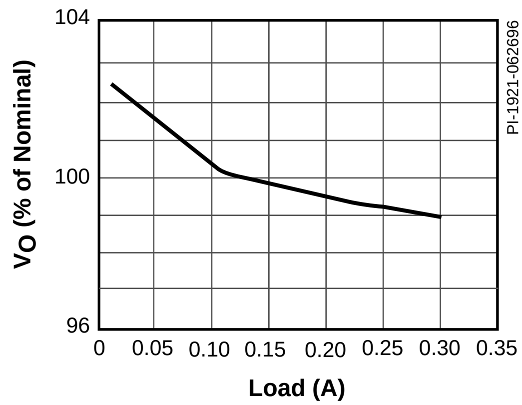


Figure 11. Load Regulation at -48 VDC Input.

Data for line regulation, shown in Figure 12, is taken at maximum load. Figure 12 shows that the output voltage stays within 2% of the nominal value from -36VDC input to -60VDC input.

Figure 13 shows curves for efficiencies for three load conditions as a function of input voltage. Worst case efficiency occurs at -36VDC input and maximum load current. Data shows that efficiency measurements are greater than 82%.

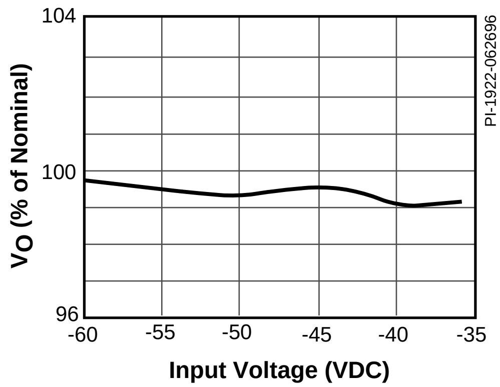


Figure 12. Line Regulation at Maximum Load

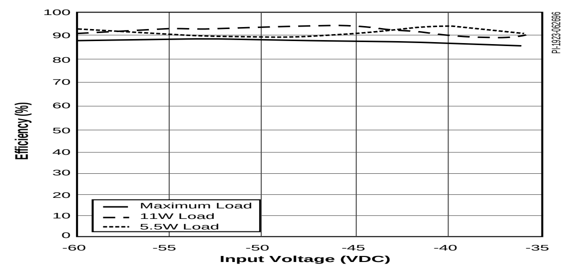
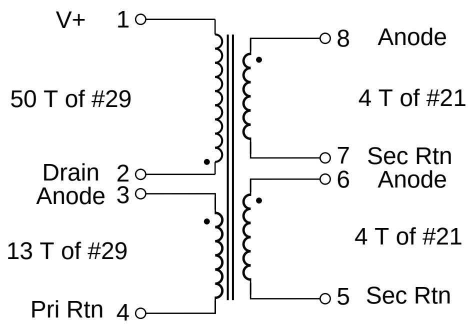


Figure 13. Efficiency vs. Input Voltage

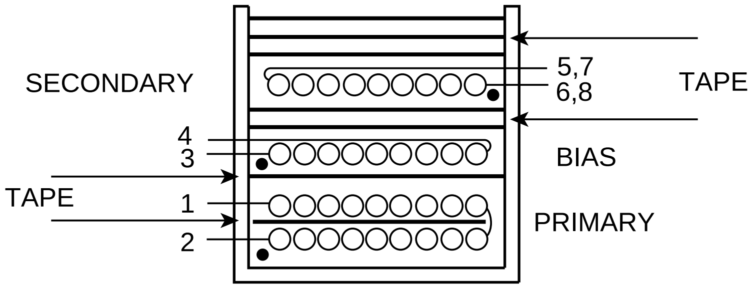


MATERIAL	
Item	**Description**
1	Core: EE19, PC40EE19-Z,TDK Gapped for A_L of 72 nH/T^2
2	Bobbin: BE-19-118CPH TDK
3	Magnet Wire: #29 AWG Heavy Nyleze
4	Magnet Wire: #21 AWG Heavy Nyleze
5	Tape: 3M 1298 Polyester Film (white) 0.38 inches wide by 2.2 mils thick
6	Varnish

ELECTRICAL SPECIFICATIONS		
Electrical Strength	60 Hz, 1 minute, from pins 1-4 to pins 7-8	500 VAC
Creepage	Between pins 1-4 and pins 5-8	1.5 mm (min)
Primary Inductance	All windings open	180µH
Resonant Frequency	All windings open	1 MHz (min)
Primary Leakage Inductance	Pins 5-8 shorted	5 µH

PI-1908-062596

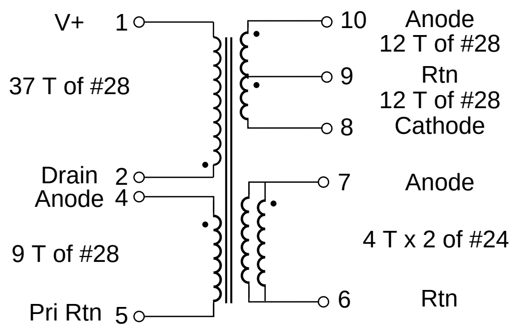
Table 1. Telecom 3.3 V Output Transformer



WINDING INSTRUCTIONS	
Two-Layer Primary	Start at pin 2. Wind 25 turns of #29 (item 3) from left to right. Wind in a single layer. Apply 1 layer of tape, item 5, for basic insulation. Wind remaining 25 turns in the next layer from right to left. Finish on pin 1.
Basic Insulation	1 layer of tape (item 5) for basic insulation.
Bias Winding	Start at pin 3. Wind 13 turns #29 (item 3) from left to right. Wind uniformly, in a single layer, across entire width of bobbin. Finish on pin 4.
Basic Insulation	2 layers of tape (item 5) for basic insulation.
Secondary Winding	Start at pins 6 and 8. Bifilar wind 4 turns of #21 (item 4) from left to right. Wind uniformly, in a single layer, across entire width of bobbin. Finish on pins 5 and 7, respectively.
Outer Insulation	3 layer of tape (item 5) for insulation.
Final Assembly	Assemble and secure core halves. Impregnate uniformly with varnish (item 6).

PI-1911-062596

Table 1. Telecom 3.3 V Output Transformer (Continued)

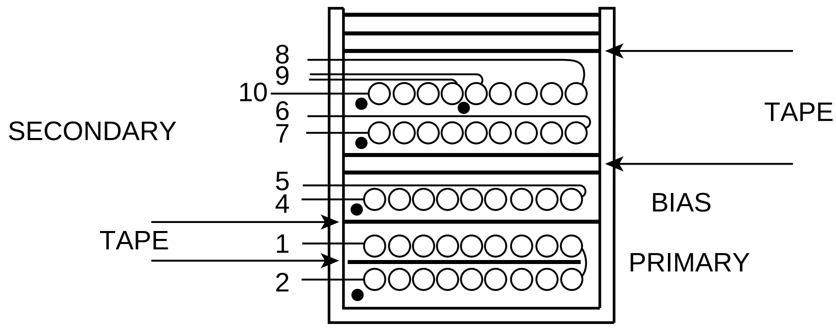


MATERIAL	
Item	**Description**
1	Core: EE19, PC40EE19/27/5-Z,TDK Gapped for A_L of 89 nH/T^2
2	Bobbin: YW118, EL19, 10 Pin (YIH HWA Enterprises)
3	Magnet Wire: #28 AWG Heavy Nyleze
4	Magnet Wire: #24 AWG Heavy Nyleze
5	Tape: 3M 1298 Polyester Film (white) 0.85 inches wide by 2.2 mils thick
6	Varnish

ELECTRICAL SPECIFICATIONS		
Electrical Strength	60 Hz, 1 minute, from pins 1-5 to pins 6-10	500 VAC
Creepage	Between pins 1-5 and pins 6-10	1.5 mm (min)
Primary Inductance	All windings open	125 µH
Resonant Frequency	All windings open	1 MHz (min)
Primary Leakage Inductance	Pins 6-10 shorted	5 µH

PI-1909 -062596

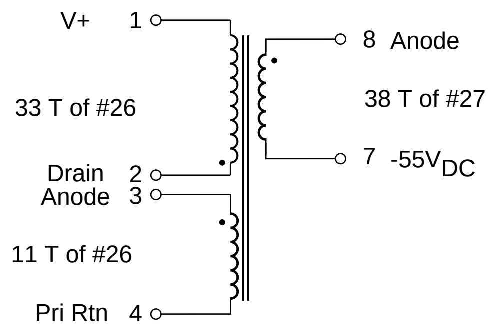
Table 2. Multi Output Transformer



WINDING INSTRUCTIONS	
Two-Layer Primary	Start at pin 2. Wind 19 turns of #28 (item 3) from left to right. Wind in a single layer. Apply 1 layer of tape, item 5, for basic insulation. Wind remaining 18 turns in the next layer from right to left. Finish on pin 1.
Basic Insulation	1 layer of tape (item 5) for basic insulation.
Bias Winding	Start at pin 4. Wind 9 turns #28 (item 3) from left to right. Wind uniformly, in a single layer, across entire width of bobbin. Finish on pin 5.
Basic Insulation	2 layers of tape (item 5) for basic insulation.
Bifilar 5V Winding	Start at pin 7. Wind bifilar 4T (item 4) from left to right. Wind uniformly, in a single layer, across entire width of bobbin. Finish on pin 6.
Bifilar ±15V Winding	Start at pins 10 and 9. Wind bifilar 12T (item 3) from left to right. Wind uniformly, in a single layer, across entire width of bobbin. Finish on pins 9 and 8, respectively.
Outer Insulation	3 layers of tape (item 5) for insulation.
Final Assembly	Assemble and secure core halves. Impregnate uniformly with varnish (item 6).

PI-1912-062596

Table 2. Multi Output Transformer (Continued)

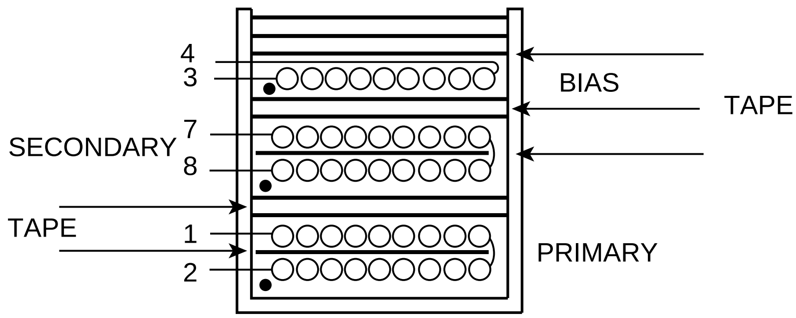


MATERIAL	
Item	**Description**
1	Core: EE22, PC40EE22-Z,TDK Gapped for A_L of 170 nH/T^2
2	Bobbin: BE-22-118CP TDK
3	Magnet Wire: #26 AWG Heavy Nyleze
4	Magnet Wire: #27 AWG Heavy Nyleze
5	Tape: 3M 1298 Polyester Film (white) 0.38 inches wide by 2.2 mils thick
6	Varnish

ELECTRICAL SPECIFICATIONS		
Electrical Strength	60 Hz, 1 minute, from pins 1-4 to pins 7-8	500 VAC
Creepage	Between pins 1-4 and pins 7-8	1.5 mm (min)
Primary Inductance	All windings open	180 µH
Resonant Frequency	All windings open	1 MHz (min)
Primary Leakage Inductance	Pins 7-8 shorted	5 µH

PI-1910-062596

Table 3. Ring Generator Bias Transformer



WINDING INSTRUCTIONS	
Double Primary Layer	Start at pin 2. Wind 17 turns of #26 (item 3) from left to right. Wind in a single layer. Apply 1 layer of tape, item 5, for basic insulation. Wind remaining 16 turns in the next layer from right to left. Finish on pin 1.
Basic Insulation	2 layers of tape (item 5) for basic insulation.
Double Secondary Layer	Start at pin 8. Wind 19 turns #27 (item 4) from left to right. Wind in a single layer. Apply 1 layer of tape (item 5) for basic insulation. Wind remaining 19 turns in the next layer from right to left. Finish on pin 7.
Basic Insulation	2 layers of tape (item 5) for basic insulation.
Bias Winding	Start at pin 3. Wind 11 turns of #26 (item 3) from left to right. Wind uniformly, in a single layer, across entire width of bobbin. Finish on pin 4.
Outer Insulation	3 layers of tape (item 5) for insulation.
Final Assembly	Assemble and secure core halves. Impregnate uniformly with varnish (item 6).

PI-1913 -062596

Table 3. Ring Generator Bias Transformer (Continued)

NOTES

NOTES

WORLD HEADQUARTERS
Power Integrations, Inc.
477 N. Mathilda Avenue
Sunnyvale, CA 94086
USA
Main: 408•523•9200
Customer Service:
Phone: 408•523•9265
Fax: 408•523•9365

AMERICAS
For Your Nearest Sales/Rep Office
Please Contact Customer Service
Phone: 408•523•9265
Fax: 408•523•9365

EUROPE & AFRICA
Power Integrations (Europe) Ltd.
Mountbatten House
Fairacres
Windsor SL4 4LE
United Kingdom
Phone: 44•(0)•1753•622•208
Fax: 44•(0)•1753•622•209

JAPAN
Power Integrations, Inc.
Keihin-Tatemono 1st Bldg.
12-20 Shin-Yokohama 2-Chome.Kohoku-ku
Yokohama-shi, Kanagawa 222
Japan
Phone: 81•(0)•45•471•1021
Fax: 81•(0)•45•471•3717

ASIA & OCEANIA
For Your Nearest Sales/Rep Office
Please Contact Customer Service
Phone: 408•523•9265
Fax: 408•523•9365

APPLICATIONS HOTLINE
World Wide 408•523•9260

APPLICATIONS FAX
Americas 408•523•9361
Europe/Africa 44•(0)•1753•622•209
Japan 81•(0)•45•471•3717
Asia/Oceania 408•523•9364