TOPSwitch®-FX Flyback Quick Selection Curves

Application Note AN-26

POWER
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Introduction

This application note is for engineers starting a flyback power supply design with *TOPSwitch-FX*. It offers a quick method to select the proper *TOPSwitch-FX* device from parameters that are usually not available until much later in the design process. The *TOPSwitch-FX* Flyback Quick Selection Curves provide the essential design guidance to estimate requirements before even starting to build a prototype.

Curves estimating the efficiency of the Power Supply and the corresponding dissipation for the *TOPSwitch-FX* devices are provided. They form a powerful tool for estimating cost and project requirements before even committing to or starting development. This application note is similar to AN-21 'Quick Selection Curves' for the *TOPSwitch-II* family.

Overview of Quick Selection Curves

The *TOPSwitch-FX* Quick Selection Curves (Figures 1-4) show the expected power supply efficiency and expected *TOPSwitch-FX* dissipation for typical applications. Power supplies with either a 5 V or a 12 V output, operating with either Universal input (85 - 265 VAC) or Single 230 VAC input voltage (195 - 265 VAC) are described.

The solid lines in the Quick Selection Curves give a typical efficiency figure for a given load, depending upon the *TOPSwitch-FX* device used. Each solid line efficiency curve extends to the maximum power capability of the device. The superimposed dashed lines are contours of constant *TOPSwitch-FX* device dissipation and the intersections these dashed lines make with the solid lines provide the corresponding dissipation at different loads. The dissipation at intermediate points can be found by interpolation or extrapolation.

Selection Curve Assumptions

The Selection Curves are based on specific design assumptions which are now detailed.

- The switching frequency is 130 kHz in all cases.
- Universal input (85 - 265 VAC) curves in Figures 1 and 2 assume a worst-case input line condition of 85 VAC and an average voltage across the bulk capacitor of 105 VDC (peak of 120 V and trough of 90 V).
- The single 230 VAC input (195 - 265 VAC) curves in Figures 3 and 4 assume a worst case of 195 VAC and an average voltage across the bulk capacitor of over 250 VDC (peak of 275 V and trough of 230 V).
- For Universal input the input bulk capacitor is sized at 3 µF/W. For the single voltage input case the input bulk capacitor is similarly 1 µF/W.

QUICK START

1) Determine which graph (Figures. 1, 2, 3 or 4) is closest to your application.
   Example: Use Figure 1 for Universal input, 12 V output.
2) Find your power requirement on the X- axis.
3) Move vertically from your power requirement until you intersect with a *TOPSwitch-FX* curve (solid line).
4) Read the associated efficiency on the Y- axis.
5) Determine if this is the appropriate efficiency for your application. If not, continue to the next *TOPSwitch-FX* curve.
6) Read *TOPSwitch-FX* power dissipation from the dashed contours to determine heatsink requirements.
7) Start the design. Use the *TOPSwitch-FX* Transformer Design Spreadsheet.

Note: See 'Selection Curve Assumptions' for limits of use.

- Table 1 gives the values of primary inductance used for generating these curves.
- A V_{OR} (reflected voltage) of 135 V is assumed for all the curves. This is the output voltage reflected by the turns ratio to the primary side.
- In all cases a 200 V Zener clamp is used to clamp the transformer leakage inductance spike.
- All curves assume a Schottky output diode. The 5 V output curves use a 45 V Schottky diode with a forward drop of 0.4 V. The 12 V output curves use a 60 V Schottky diode with a forward voltage drop of 0.54 V.

Besides the design criteria above, typical power supply component parameters used in generating the data for the Quick Selection Curves are provided in Tables 1 and 2. The efficiency curves are valid only when using the component values shown in Tables 1 and 2. Changes to these parameters may give different results.

Selecting the Right *TOPSwitch-FX*

This section explains how to select the correct *TOPSwitch-FX* from the curves (Figures 1-4). The procedure uses the curves to estimate efficiency of the power supply and the corresponding dissipation in the *TOPSwitch-FX*. Start with the output power of the application on the X-axis. Move vertically to the intersection with the first *TOPSwitch-FX* curve encountered and then read the efficiency directly from the Y-axis. From the same intersection point on the *TOPSwitch-FX* curve, interpolate the *TOPSwitch-FX* power dissipation from the constant power dissipation contours. Some output powers can be delivered by more than one *TOPSwitch-FX* device. When moving vertically from the X-axis, the first curve encountered will be the smallest, lowest cost *TOPSwitch-FX* device, while the last curve encountered will be the largest, most efficient *TOPSwitch-FX* device suitable for the desired output power. Thermal requirements and packaging of the proposed power supply may call out for a more efficient device rather than the smallest or lowest-cost possibility.

Example 1: 30 W Universal Application

Consider a 5 V, 30 W power supply with Universal input range. From the curves in Figure 2, we can see that the TOP234 can deliver 30 W (X-axis) with an estimated Efficiency (Y-axis) of about 69.5%. The projected *TOPSwitch-FX* dissipation is approximately 3.3 W. The thermal environment and the available heatsinking must be evaluated to confirm the choice of device in this application.

Example 2: 13 W Adapter Application

Consider a 13 W, 12 V supply with Universal input range. From Figure 1 we see that a TOP232 and TOP233 could be used. TOP232 with an efficiency of 76% and a device dissipation

TYPICAL COMPONENT PARAMETERS FOR UNIVERSAL INPUT (85-265 VAC) POWER SUPPLY (Figures 1 and 2)

		12 V OUTPUT (Figure 1)			5 V OUTPUT (Figure 2)		
PARAMETER	**UNITS**	**TOP232**	**TOP233**	**TOP234**	**TOP232**	**TOP233**	**TOP234**
Maximum Transformer Primary Inductance	µH	3050	1550	1050	2930	1500	960
Transformer Leakage Inductance	µH	46	16	11	44	22	14
Secondary Trace Inductance	nH	30	30	30	20	20	20
Transformer Resonant Frequency (secondary open)	kHz	750	800	850	750	800	850
Transformer Primary AC Resistance	mΩ	2400	1200	800	2000	1060	700
Transformer Secondary AC Resistance	mΩ	30	15	10	12	6	4
Output Capacitor Equivalent Series Resistance @100kHz	mΩ	24	18	15	18	9	6
Output Inductor DC Resistance	mΩ	32	25	20	6	4.5	3.5
Common Mode Inductor DC Resistance (both legs)	mΩ	370	333	300	370	333	300
Core Loss	mW	100	200	250	100	200	250

Table 1. Typical component parameters for a TOPSwitch-FX flyback power supply with a Universal input voltage (85-265 VAC).

TYPICAL COMPONENT PARAMETERS FOR SINGLE VOLTAGE INPUT (230 VAC ±15%) POWER SUPPLY (Figures 3 and 4)

		12 V OUTPUT (Figure 3)			5 V OUTPUT (Figure 4)		
PARAMETER	**UNITS**	**TOP232**	**TOP233**	**TOP234**	**TOP232**	**TOP233**	**TOP234**
Maximum Transformer Primary Inductance	μH	3500	1600	1150	3090	1550	1100
Transformer Leakage Inductance	μH	53	16	12	46	23	16
Secondary Trace Inductance	nH	30	30	30	20	20	20
Transformer Resonant Frequency (secondary open)	kHz	750	800	850	750	800	850
Transformer Primary AC Resistance	mΩ	5600	2800	1840	4600	2400	1600
Transformer Secondary AC Resistance	mΩ	30	15	10	12	6	4
Output Capacitor Equivalent Series Resistance @100kHz	mΩ	24	18	15	18	9	6
Output Inductor DC Resistance	mΩ	32	25	20	6	4.5	3.5
Common Mode Inductor DC Resistance (both legs)	mΩ	370	333	300	370	333	300
Core Loss	mW	100	200	250	100	200	250

Table 2. Typical component parameters for a TOPSwitch-FX flyback power supply with a single input 230 VAC ±15%.

(P_D) of 1.5 W or a TOP233 with an efficiency of 82.5% and a device dissipation of 0.75 W.

This is an adapter design in an enclosed plastic box, so the maximum power available from the supply is limited by thermal considerations. The worst-case external ambient temperature (T_{A_EXT}) is 50 °C with an estimated temperature rise of of 25 °C inside the plastic box, giving an internal ambient (T_{A_INT}) of 75 °C. Assuming a *TOPSwitch-FX* in DIP-8 (P-package), from the datasheet we obtain the thermal impedance from junction-to-case (θ_{JC}) 5 °C/W. The *TOPSwitch-FX* is connected to a PC-board heatsink of thermal impedance case-to-air (θ_{CA}) of 28 °C/W. This gives an overall thermal impedance from junction-to-air (θ_{JA}) of 28 + 5 = 33 °C/W.

$$T_J = T_{A\_INT} + (\theta_{JA} \times P_D)$$

$$T_{J\_TOP232} = T_{A\_INT} + (\theta_{JA} \times P_{D\_TOP232})$$

$$T_{J\_TOP232} = 75 + (33 \times 1.5) = 124.5\ {}^{\circ}C$$

$$T_{J\_TOP233} = T_{A\_INT} + (\theta_{JA} \times P_{D\_TOP233})$$

$$T_{J\_TOP233} = 75 + (33 \times 0.75) = 99.75\ {}^{\circ}C$$

We can therefore see that a TOP233 with a junction temperature of less than 100 °C is the correct device for this application.

Other Key Considerations

We have seen how to use the information provided by the *TOPSwitch-FX* Quick Selection Curves. However, there are other key factors to consider when completing the power supply design. These can produce results that differ from the predictions of the Quick Selection Curves.

Factors Which can Lower the Performance

- An electrolytic capacitor can have an actual (measured) capacitance 20% less than its nominal specified value. Also, its capacitance can fall an additional 20% as it ages. This can significantly decrease the available capacitance per watt and adversely affect both the power capability and device dissipation. The designer should choose the capacitor value to accommodate this derating.

- In production, the primary inductance of the Transformer will have a significant tolerance. Inductances higher than those in Tables 1 and 2 would cause the power supply to operate beyond recommended design guidelines (K_{RP} too low). Values of primary inductance significantly lower than those in Tables 1 and 2 would lead to higher peak and RMS drain currents in the *TOPSwitch-FX* MOSFET. This causes an increase in device dissipation and also causes the device to reach current limit at less than the maximum load.

- The Quick Selection Curves assume that the AC Input voltage waveform is a pure sine wave. If the input voltage waveform is distorted, the resultant peak voltage on the input bulk capacitor may be much lower than anticipated. This causes the *TOPSwitch-FX* device to reach current limit or duty cycle limit at loads less than the maximum possible load. Therefore, in locations where significant line distortion is expected, the designer should provide a suitable design margin. This can be accomplished by derating maximum output power or increasing the input capacitance.

- Some wattmeters give erroneous readings when the current has a high crest factor. Take efficiency measurements with an appropriate instrument. Several electronic wattmeters are designed for this purpose. The Voltech PM100 is an example.

- Minimum line frequency is important. A low line frequency requires larger carryover periods for the input bulk capacitor, causing higher voltage ripple across it. If the line frequency is expected to be lower than 50 Hz, the input capacitor should be sized appropriately.

- The *TOPSwitch-FX* processes (switches) an amount of power that is almost equal to the input power. This is approximately the output power divided by the efficiency of the power supply. Therefore, anything that lowers the efficiency of the power supply will increase the power processed by the *TOPSwitch-FX,* increasing device dissipation, and reduceing its power capability. If the solid line efficiency curves cannot be achieved under these conditions, the dashed line dissipation curves are likewise no longer valid.

- The choice of V_{OR} can affect the efficiency greatly. Too high a V_{OR} will significantly increase dissipation in the Zener clamp and the output section. It could also destroy the *TOPSwitch-FX* due to excessive reset voltage applied across DRAIN to SOURCE. Too low a V_{OR} may cause excessively continuous operation (beyond the recommended design guidelines).

- For low voltage outputs, the secondary currents and their associated losses can become significant. Close attention must be paid to the Equivalent Series Resistance (ESR) of the output capacitor in particular. The values in Tables 1 and 2 for the 5 V Quick Selection Curves (Figures 2 and 4) use a capacitor with very low ESR.

- Energy stored in the leakage inductance is dumped into the Zener clamp when the *TOPSwitch-FX* turns off. Therefore, the efficiency will fall significantly if the leakage inductance is too high.

- This leakage has two components, both of which need to be considered.

  The first is the leakage of the transformer. This is commonly measured from the transformer primary with the pins of the secondary windings shorted. Values of 1-1.5% of the transformer primary inductance were used for these curves (see Tables 1 and 2). If designers measure leakage beyond this level, then they can either accept the resulting lower power supply efficiency or revise the transformer design/ construction to reduce the leakage inductance.

  The second component of the effective leakage is the inductance of the secondary traces on the circuit board. This has a great impact on the efficiency of medium to high power converters operating at low line and having low voltage outputs (5 V or 3.3 V for example). A higher V_{OR} further aggravates the problem because of the higher turns ratio. The secondary trace inductance, which could be of the order of only 20-40 nH, is reflected to the primary by the square of the turns ratio and adds to the transformer primary leakage inductance. Hence, it can be a significant part of the total effective leakage inductance. The Zener clamp has to dissipate as much energy as if all the leakage were concentrated on the primary side.

To measure the in-circuit effective leakage inductance, the transformer must be first soldered onto the actual printed circuit board. Then, rather than shorting the secondary pins directly at the transformer, the short is created by soldering a thick short jumper across the output diode and another one across the pins of the output capacitor. The inductance across the pins of the primary winding then provides the total in-circuit effective leakage inductance. The secondary side PCB trace inductance can be easily estimated as shown in Example 3. As with other parameters, designs having significantly different parameter values than those of Tables 1 and 2 will not give the same performance.

Example 3: Effect of Leakage Inductance

A Universal input TOP234 based power supply delivering 40 W with a 5 V output has been designed with a V_{OR} of 135 V. A measurement of leakage by shorting the secondary pins of the transformer directly gives a leakage measurement of 14 µH which conforms to the values in Table 1. The in-circuit measurement technique described above gives 26.5 µH. The turns ratio is:

$$\frac{N_P}{N_S} = \frac{V_{OR}}{(V_O + V_D)} = \frac{135}{5.4} = 25$$

So the estimated secondary trace inductance is:

$$L_{TRACE} = \frac{26.5\mu H - 14\mu H}{25^2} = 20nH$$

A secondary trace inductance of 20 nH is consistent with the values of Tables 1 and 2.

Factors Which can Improve Performance

For more advanced designers, there are ways to improve the performance indicated by the Quick Selection curves. Some of these are now mentioned briefly.

- The recommended capacitance per watt is based on the optimum cost to performance ratio. Better performance can certainly be obtained in terms of efficiency, *TOPSwitch-FX* dissipation and life expectancy of the input bulk capacitor, by using a higher capacitance per watt than recommended.

- If the intended application is for low line only (provided no voltage doubler is being used at the input of the power supply), the clamp voltage and V_{OR} may be raised by a calculated amount. This will enhance the overall efficiency and lower the device dissipation at the expense of higher secondary peak currents.

  It should be mentioned that increasing the V_{OR} causes an increase in the duty cycle and a corresponding reduction in the RMS currents and heating in the *TOPSwitch-FX* device, provided the overall efficiency is not adversely affected. A high V_{OR} also decreases the reverse voltage stress on the output diodes.

- There are two separate limits on the maximum power that can be obtained from a *TOPSwitch-FX*. The first is set by device operational parameters such as maximum duty cycle and current limit, etc. The second is thermal power limitation determined by device temperature (design guidelines recommend a minimum junction temperature of 100 °C).

  The *TOPSwitch-FX* curves are shown for non-thermally limited designs (i.e. those limited purely by device parameters). The primary inductance (Tables 1 and 2) was chosen for the maximum power capability of the device. If the output power of the design is less than the maximum power capability of the device, due to thermal limitations, the inductance should be increased accordingly. For adapter designs, it is possible to reduce device dissipation by reducing the K_{RP}.

- Since the Quick Selection Curves are for a *TOPSwitch-FX* junction temperature of 100 °C, better performance is possible if the *TOPSwitch-FX* runs cooler. Improved heatsinking will help achieve higher efficiency and power.

Conclusions

This application note has presented a simple method by which a designer can quickly select *TOPSwitch-FX* device for typical applications. For best results the design should conform to the component parameters in Tables 1 and 2. Adherence to the selection curve assumptions will allow the designer to achieve the efficiencies indicated by the solid line curves in Figures 1 through 4. Thermal requirements can be estimated from the dashed curves. Other key considerations are presented to allow the designer to achieve the best performance from *TOPSwitch-FX*.

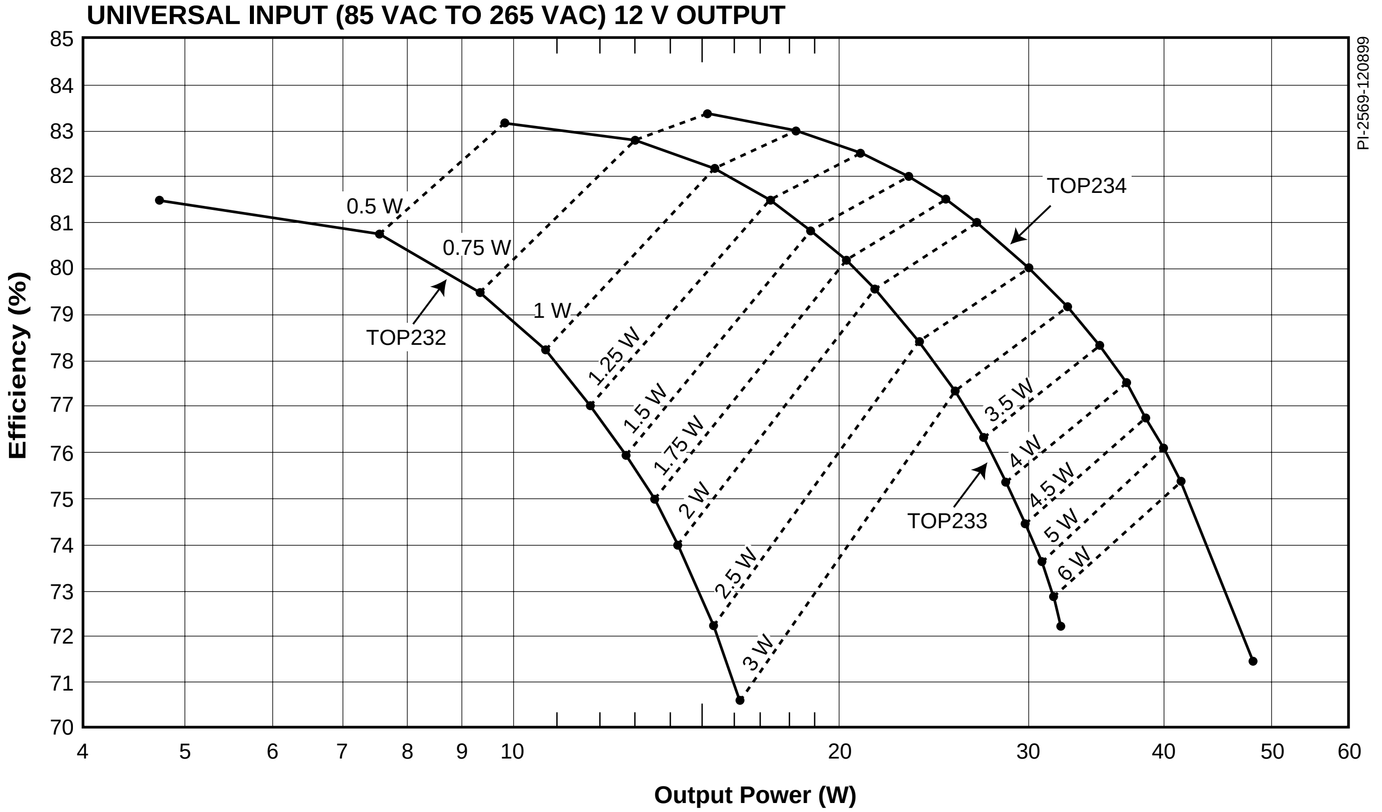

Figure 1. Efficiency vs. Output Power with Contours of Constant TOPSwitch-FX Power Loss for Universal Input and 12 V Output.

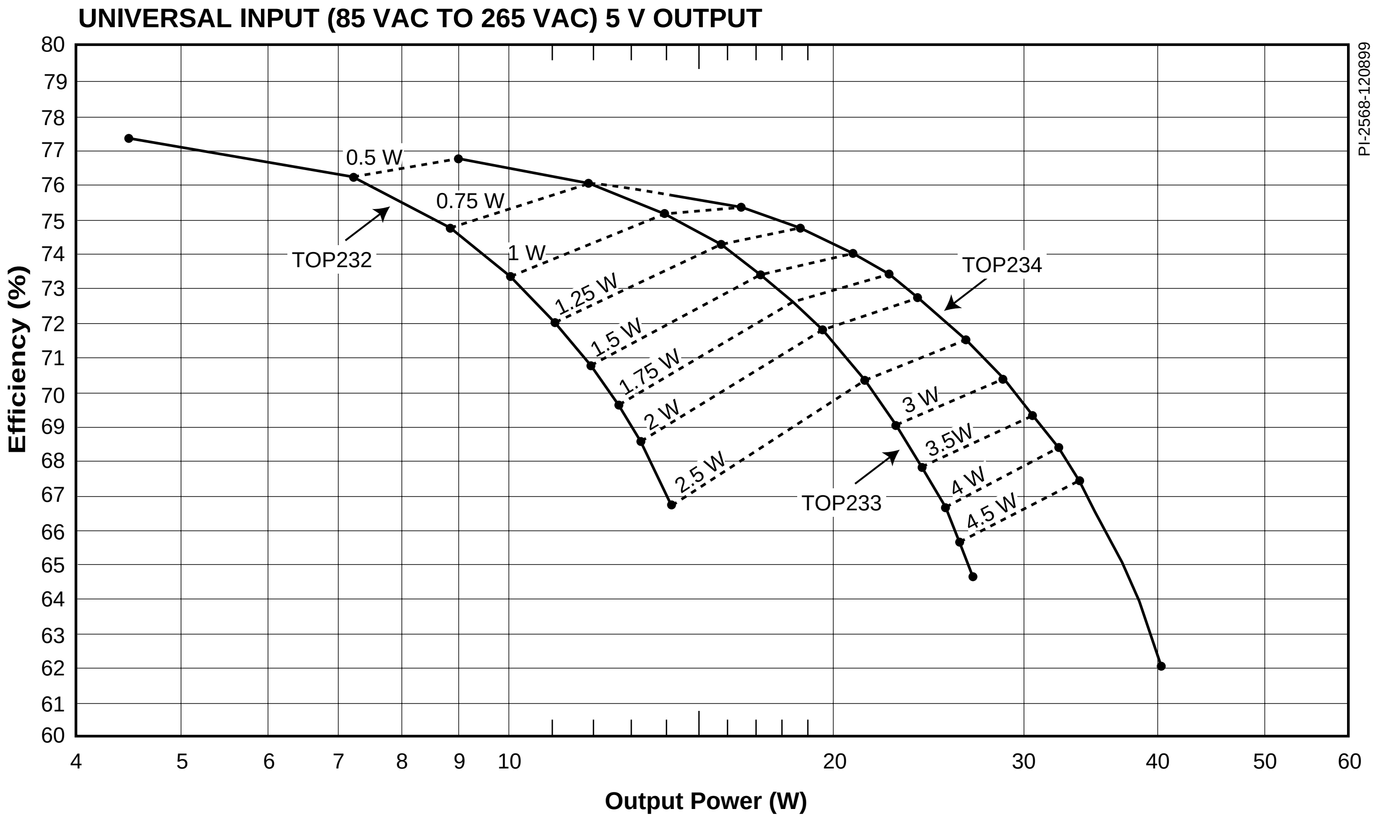

Figure 2. Efficiency vs. Output Power with Contours of Constant TOPSwitch-FX Power Loss for Universal Input and 5 V Output.

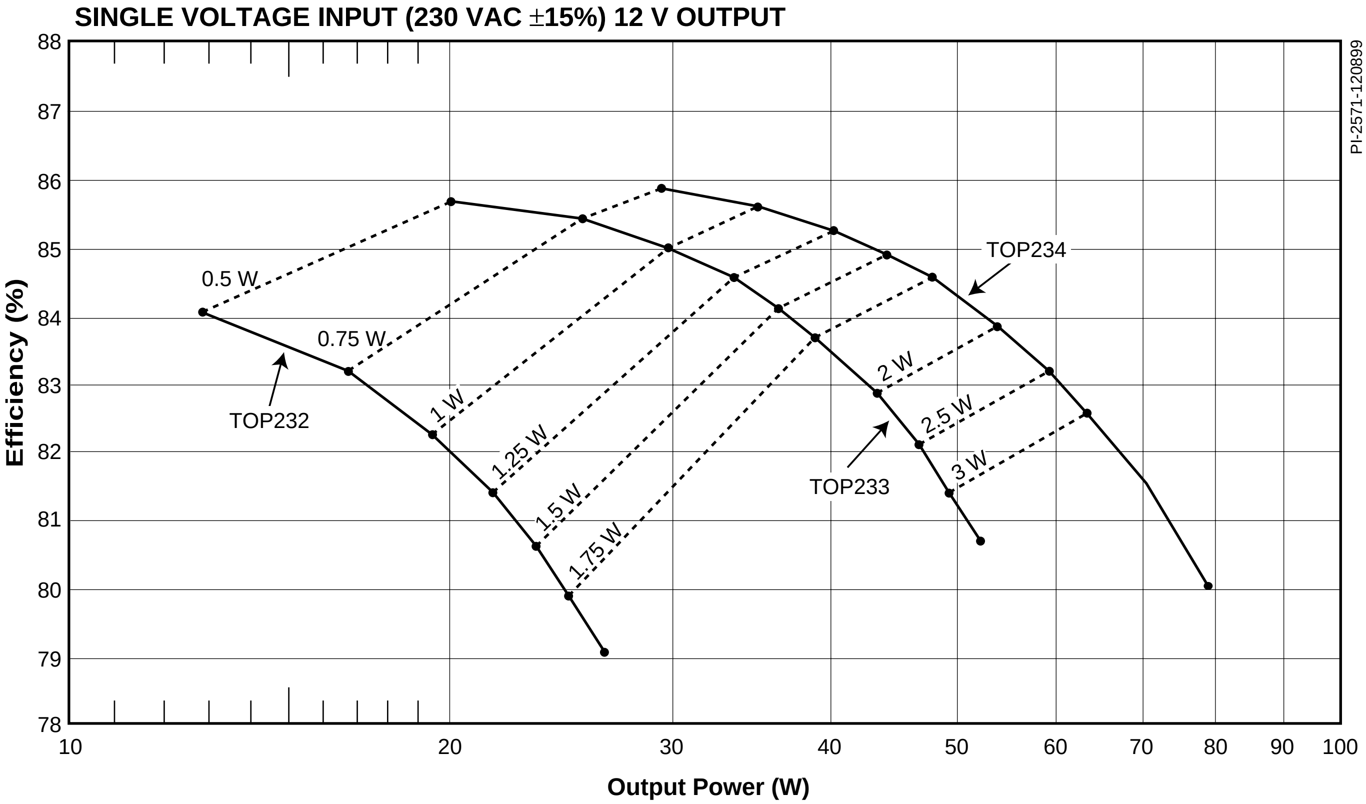

Figure 3. Efficiency vs. Output Power with Contours of Constant TOPSwitch-FX Power Loss for Single Voltage Application and 12 V Output.

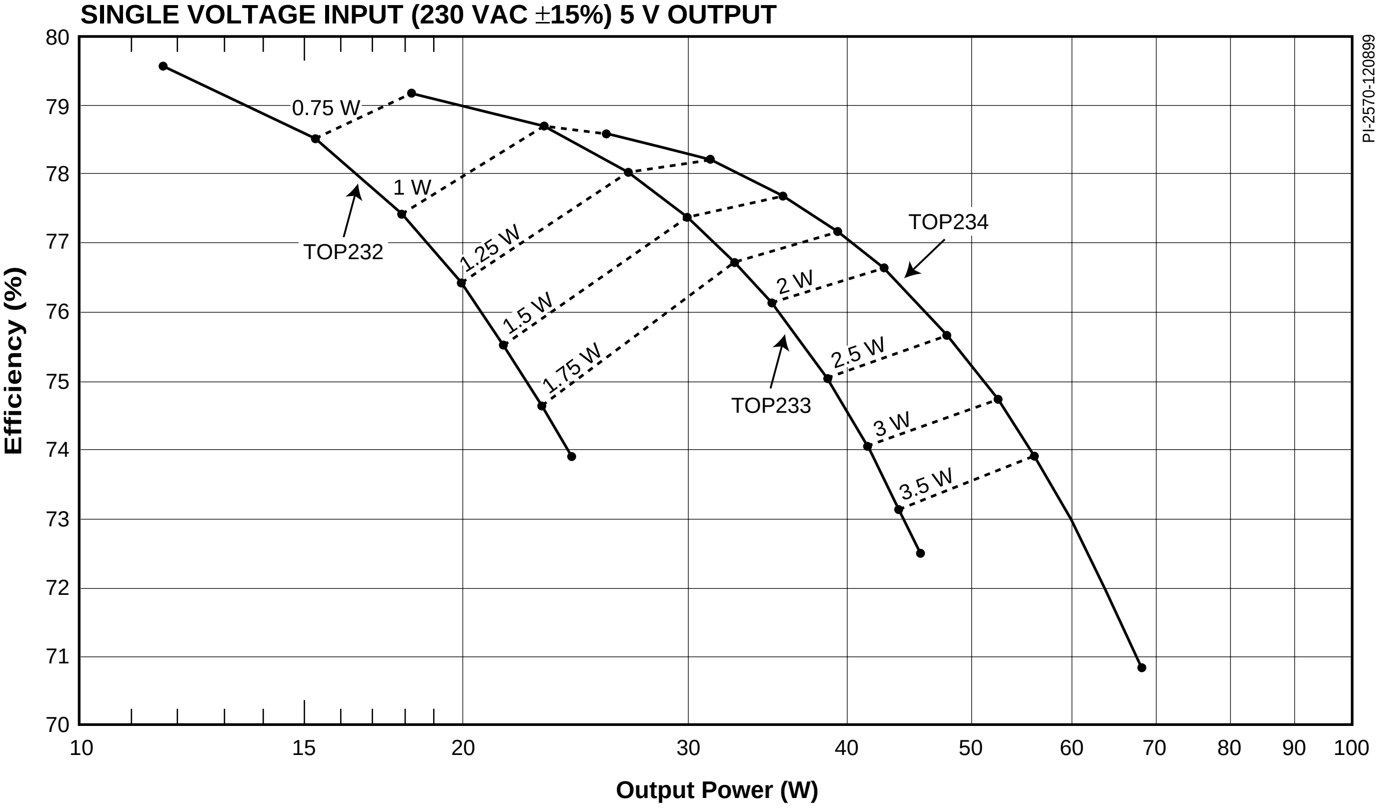

Figure 4. Efficiency vs. Output Power with Contours of Constant TOPSwitch-FX Power Loss for Single Voltage Application and 5 V Output.

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WORLD HEADQUARTERS
AMERICAS
Power Integrations, Inc.
5245 Hellyer Avenue
San Jose, CA 95138 USA
Main: +1 408-414-9200
Customer Service:
Phone: +1 408-414-9665
Fax: +1 408-414-9765
e-mail: usasales@powerint.com

EUROPE & AFRICA
Power Integrations (Europe) Ltd.
Centennial Court
Easthampstead Road
Bracknell
Berkshire, RG12 1YQ
United Kingdom
Phone: +44-1344-462-300
Fax: +44-1344-311-732
e-mail: eurosales@powerint.com

TAIWAN
Power Integrations
International Holdings, Inc.
17F-3, No. 510
Chung Hsiao E. Rd.,
Sec. 5,
Taipei, Taiwan 110, R.O.C.
Phone: +886-2-2727-1221
Fax: +886-2-2727-1223
e-mail: taiwansales@powerint.com

CHINA
Power Integrations
International Holdings, Inc.
Rm# 1705, Bao Hua Bldg.
1016 Hua Qiang Bei Lu
Shenzhen, Guangdong 518031
China
Phone: +86-755-367-5143
Fax: +86-755-377-9610
e-mail: chinasales@powerint.com

KOREA
Power Integrations
International Holdings, Inc.
Rm# 402, Handuk Building
649-4 Yeoksam-Dong,
Kangnam-Gu,
Seoul, Korea
Phone: +82-2-568-7520
Fax: +82-2-568-7474
e-mail: koreasales@powerint.com

JAPAN
Power Integrations, K.K.
Keihin-Tatemono 1st Bldg.
12-20 Shin-Yokohama 2-Chome
Kohoku-ku, Yokohama-shi
Kanagawa 222-0033, Japan
Phone: +81-45-471-1021
Fax: +81-45-471-3717
e-mail: japansales@powerint.com

INDIA (Technical Support)
Innovatech
#1, 8th Main Road
Vasanthnagar
Bangalore, India 560052
Phone: +91-80-226-6023
Fax: +91-80-228-9727
e-mail: indiasales@powerint.com

APPLICATIONS HOTLINE
World Wide +1-408-414-9660

APPLICATIONS FAX
World Wide +1-408-414-9760