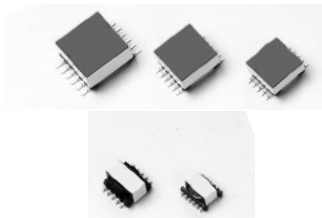


Using the Versa-Pac as a forward converter transformer



Overview

The Versa-Pac range of transformers is one of the many products offered from Eaton. Versa-Pac is available in five sizes and is suitable for a maximum switching frequency of 500 kHz and power levels up to 30 W, for single ended topologies, or 60 W for bipolar applications.

The VP series was designed, primarily, for low voltage applications typically 3.3 V, 5 V and 12 V. With the addition of the VPH products to the range the Versa-Pac can now be used for 24 V, 48 V and, at higher frequencies, even 120 V applications.

Each transformer has six identical windings that can be configured in series and parallel to produce the required transformer design, the isolation between these windings is 500 Vdc. Full product data is available on our website: www.eaton.com/electronics

Single ended forward converter design procedure

In order to design a forward converter transformer using the Versa-Pac the following information is required:

- nominal, minimum and maximum input voltages ($V_{in(nom)}$, $V_{in(min)}$ & $V_{in(max)}$)
- output voltage (V_o),
- output current (I_o)
- switching frequency (F_s)

For the purpose of our example let's take the following values:
 $V_o = 3.3\text{ V}$, $I_o = 5\text{ A}$, $V_{in(min)} = 40\text{ V}$, $V_{in(nom)} = 48\text{ V}$, $V_{in(max)} = 56\text{ V}$ and $F_s = 250\text{ kHz}$.

Using the information in Figure 1 for Unipolar (Flyback) Power vs. Frequency from the data sheet select the required Versa-Pac size by reading off your required output power and operating frequency. At 250 kHz and 16.5 W this gives a VP5 size.

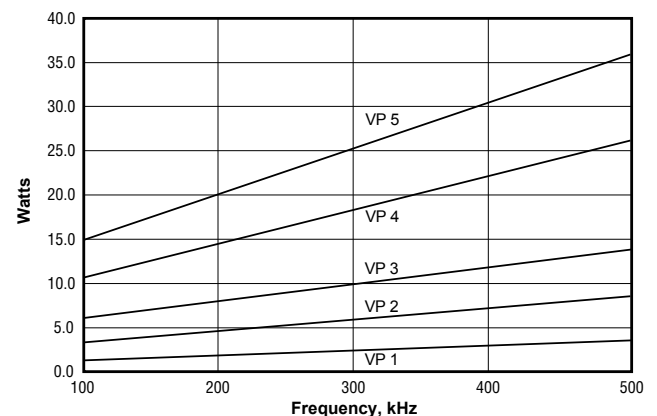


Figure 1. Unipolar (Flyback) Power vs Frequency graph

Single ended forward converter design procedure

Although the data used in the Power vs. Frequency curve was derived using a flyback topology, as a guide to Versa-Pac size requirements, it still holds true for unipolar forward converters.

Calculate the turns ratio for a duty cycle (D) of 0.25 using the equation;

$$V_o/V_{in(nom)} = D \times N_{sec}/N_{pri} \quad (1)$$

Where N_{sec} is the number of secondary windings and N_{pri} is the number of primary windings, N_{pri}/N_{sec} is the turns ratio which must be rounded to the nearest achievable value (i.e. 0.5, 0.667, 1, 1.5, 2, 3 etc).

$$3.3/48 = N_{sec}/N_{pri} \times (0.25)$$

$$N_{pri}/N_{sec} = (48 \times 0.25)/3.3 = 3.6$$

Rounding down, $N_{pri}/N_{sec} = 3$

$V_{in(nom)}$ and 0.25 duty cycle are used only as a starting point, it is possible that using $V_{in(min)}$ with lower or high duty cycles you may achieve a more suitable turns ratio. Note: Maximum duty cycle for most unipolar forward converters is 0.5.

Calculate the maximum duty cycle for $V_{in(min)}$ using equation 1 and the calculated turns ratio rounded up or down to the nearest achievable value.

$$3.3/40 = 1/3 \times (D)$$

$$(3.3 \times 3)/40 = D$$

$$D(max) = 0.2475$$

Calculate the primary volt-seconds product using the following equation:

$$\text{Primary } V_s = D(max) \times T_s \times V_{in(min)} \quad (2)$$

$$\text{Where } T_s = 1/F_s$$

This value should be less than the rated primary Volt- μ sec, if the primary uses one winding the rated Volt- μ sec is the same as Volt- μ sec(Base). If the primary is two windings in series then the rating is then 2 x Volt- μ sec(Base) and for 3 series windings 3 x Volt- μ sec(Base) etc. If the Volt- μ sec rating can not be achieved using the selected Versa-Pac size then you will need to select a larger size or increase the switching frequency.

$$\text{Primary } V_s = 0.2475 \times 1/250 \times 103 \times 40 = 39.6 \mu\text{Vsec}$$

The VP5 has a Volt- μ sec(Base) of 65.6 μ Vsec, multiplying this by 3 gives a rating of 196.8 μ Vsec. So the VP5 easily meets the volt-seconds requirements.

If the required volt-seconds rating can't be achieved you can reduce the required rating by increasing the switching frequency. Alternatively you can recalculate the turns ratio using $V_{in(min)}$ as this may increase the number of series primary windings.

Starting with the highest inductance value for the selected VP, calculating the rms primary currents we can determine if the selected Versa-Pac meets the specified requirements. In order to calculate the rms primary current you first need to calculate the peak current.

$$I_{pri(peak)} = N_{sec}/N_{pri} \times (I_o + \Delta I_o/2) + I_{mag(peak)} \quad (3)$$

Where:

$$I_{mag(peak)} = (V_{in(min)} \times T_s \times D(max))/L_{pri} \quad (4)$$

Primary rms current:

$$I_{pri(rms)} = (D(max) \times (I_{pri(peak)} - I_{mag(peak)}))^2)^{0.5} \quad (5)$$

Where:

$$I_{pri(peak)} = (I_{pri(peak)} + (I_{pri(peak)} - I_{mag(peak)}))/2 \quad (6)$$

Assuming ΔI_o is set to 10% of I_o max, which is achieved by selection of the correct output inductor value. Using a VP5-1200, the L (base) is 76.8 μ H therefore:

$$I_{mag(peak)} = (40 \times 1/250 \times 103 \times 0.248)/$$

$$3^2 \times 76.8 \times 10^{-6} = 0.0574 \text{ A}$$

$$I_{pri(peak)} = 1/3 \times (5 + (0.5/2) + 0.0574) = 1.81 \text{ A}$$

$$I_{pri(peak)} = (1.81 + (1.81 - 0.0574))/2 = 1.78 \text{ A}$$

$$I_{pri(rms)} = (0.248 \times 1.78^2)^{0.5} = 0.89 \text{ A}$$

The rms current rating, $I_{rms(base)}$, for the VP5-1200 is 2.08A

Finally, calculate the maximum rms secondary current,

$$I_{sec(rms)} = (D(max) \times (I_o + I_{sec(peak)}/2))^2)^{0.5} \quad (7)$$

Where, referring to equation 3:

$$I_{sec(peak)} = I_{pri(peak)} \times N_{pri}/N_{sec} \quad (8)$$

$$I_{sec(peak)} = 1.81 \times 3 = 5.43 \text{ A}$$

$$I_{sec(rms)} = (0.248 \times ((5 + 5.43)/2))^2)^{0.5} = 2.6 \text{ A}$$

The rms current rating, $I_{rms(base)}$, for the VP5-1200 is 2.08A. In order to achieve the required rms current rating at least two parallel windings must be used to make up the secondary. For improved efficiency it would be normal practice to use both the spare windings and have a secondary made up of three parallel windings.

Transformer Reset

In a practical single ended forward converter design you need to consider how transformer reset is going to be achieved. During the switch 'ON' period current proportional to the output current plus the magnetizing current flow in the primary winding, the magnetizing current must be reset to zero during the switch 'OFF' period in order to prevent converter failure. This can be achieved in a number of ways, Figure 2 shows a method that uses an auxiliary primary winding connected in anti-phase to the main primary. This additional winding acts in flyback mode during the switch 'OFF' period recovering the magnetizing energy in to the supply rail.

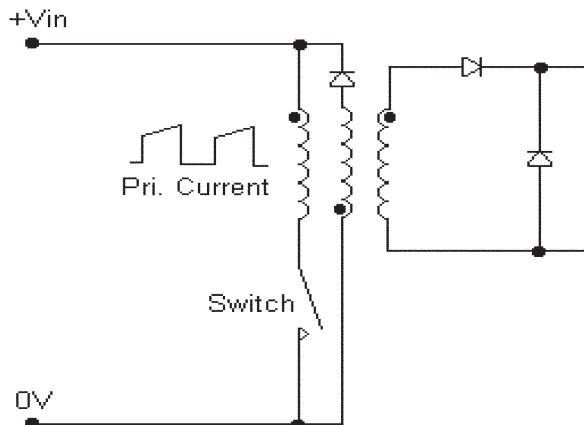


Figure 2. Transformer reset using auxiliary primary winding

For Versa-Pac designs this method limits the converter maximum duty cycle to 50% and also reduces the number of possible configurations, as only 5 windings will be available. Figure 3 shows a simple way of resetting the transformer using an resistor-capacitor-diode (RCD) network which allows all 6 windings to be used when configuring the transformer.

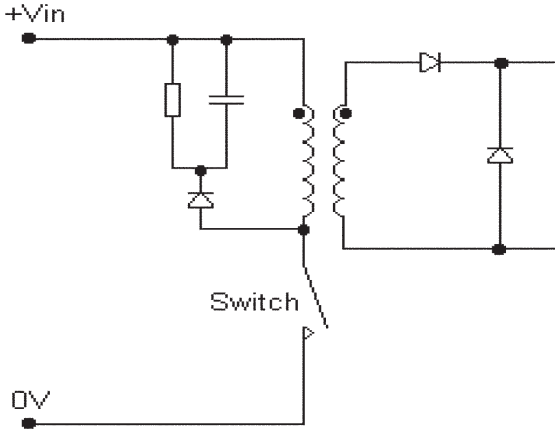


Figure 3. Transformer reset using RCD network

Using an RCD reset network has a number of advantages, it reduces the voltage stress on the switch, it limits turn off voltage spike and permits operation at greater than 50% duty cycle.

Figure 4 shows a reset method for a dual switch topology, this method allows the primary winding to operate in flyback mode with the current flowing through the two recovery diodes. This technique is similar to that shown in Figure 2, the advantages of this topology include reduced voltage rating requirement for the switches and no requirement for an auxiliary primary winding.

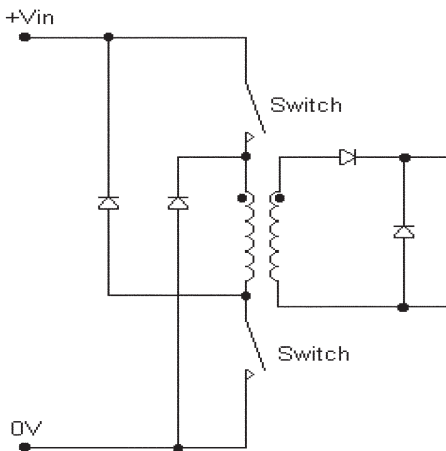


Figure 4. Transformer reset using dual switch topology

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