A 400W FLYBACK CONVERTER

Bengt Assow
Ericsson Components AB
S-164 81 Stockholm
Sweden

There is a great choice in converter topologies when designing a new power supply. A simple flyback, an easy forward, a difficult half bridge with low ripple in the output, a Ćuk converter with difficult transformers and capacitors, combination converters with some unique properties or resonance converters. By far the simplest is the flyback converter and followed by the forward converter. Today resonance converters are very complicated, but within 10 to 15 years it is possible that the semiconductor integration and integration of magnetic components will make this converter type preferable.

But we have to make power supplies now. The possibility to make a simple and compact power converter is best with the flyback topology. This is not the common way to procede, so therefore, I must start by changing all reference books!

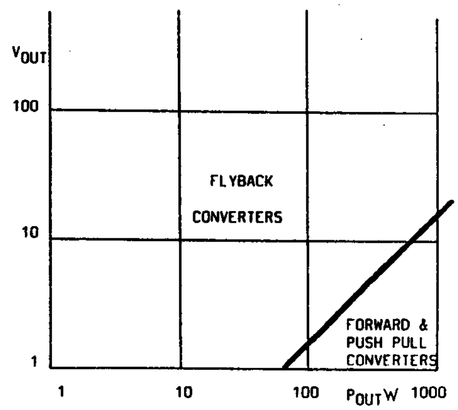

FIG. 2 FROM NOW ON

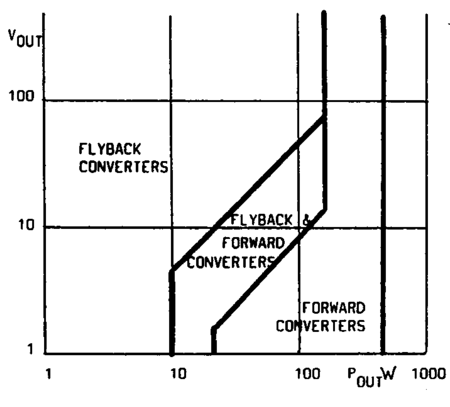

FIG. 1 ACCORDING TO THE BOOK

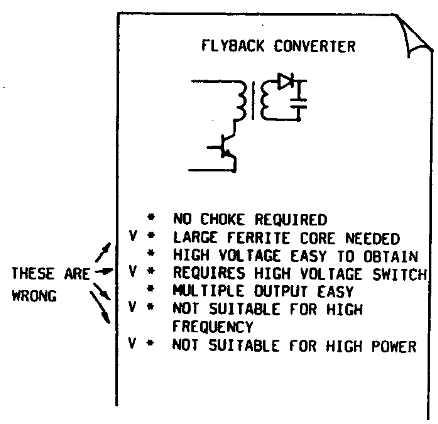

FIG.3 PLEASE TAKE AWAY THE SENTENCES MARKED WITH "V" IN YOUR BOOK ABOUT CONVERTER TOPOLOGIES AT HOME.

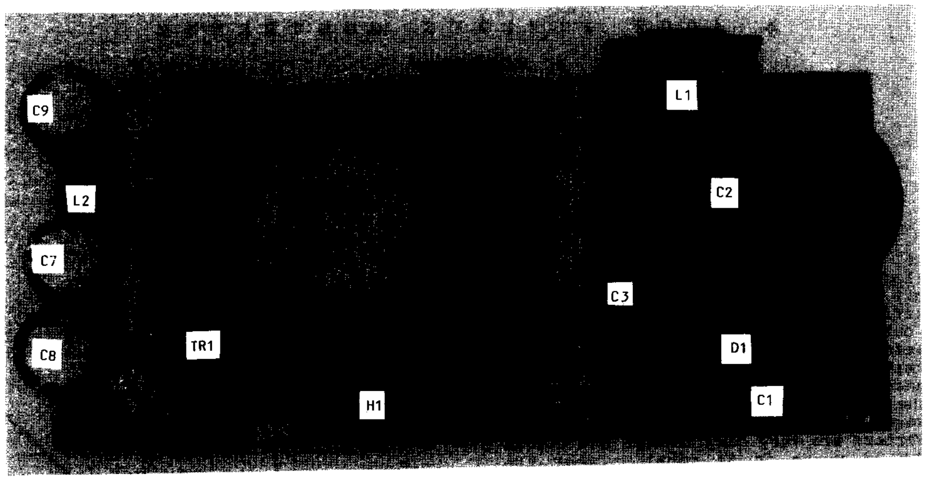

FIG. 5 THE 400W FLYBACK AC/DC CONVERTER WITH POWER DENSITY OF 20W/INCH^3 (PART OF HEATSINK NOT INCLUDED)

SCALE 1:1

A 400W flyback

An experimental 400W converter has been made. The intended use was to charge a 48V battery as cheaply, reliably and compactly as possible. Existing half bridge converters tend to be expensive and difficult to design. Because I have worked with flyback topology for several years and have very good experience with these kinds of converters, I choose this topology.

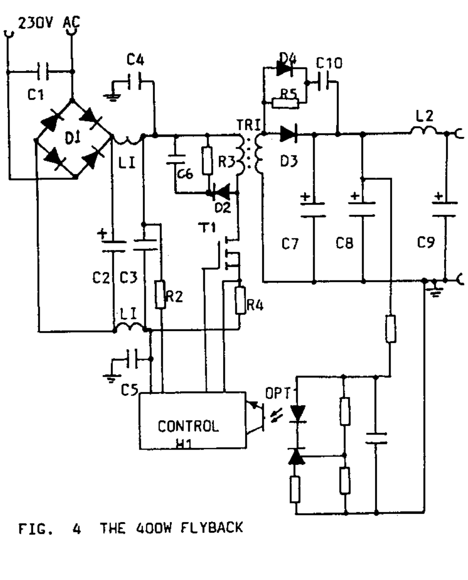

FIG. 4 THE 400W FLYBACK

As the competition in the converter area is W/inch^3, my goal was to get as high power density as possible on a complete AC/DC 400W 230V AC to 54V DC converter. With high W/inch^3, it is necessary to have as few components and as high an efficiency as possible. With few components, reliability is high.

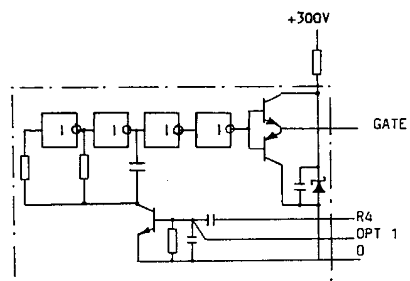

FIG. 6 CONTROL CIRCUIT

Figure 4 shows the circuit diagram and figure 5 shows the complete converter. The AC voltage is rectified by the bridge D1 and filtered by the electrolytic capacitor C2.

The transistor T1 is controlled by a pulse width modulated control circuit H1. This control circuit is built with discrete transistors and a 4069 on a thick film circuit. The reason for this, is to get current consumption as low as possible. Every mA will lower the efficiency by 0,08%. At 80 kHz using a 0,4 ohm 500V FET , the necessary current is only 8 mA from the rectified mains. That means an efficiency loss of 0,65%. It is possible to lower this with an additional winding in the transformer and about 10 extra components . Figure 6 shows the control circuit used in this converter. As the designer is allowed to use his own or any other control circuit, it will not be further described here.

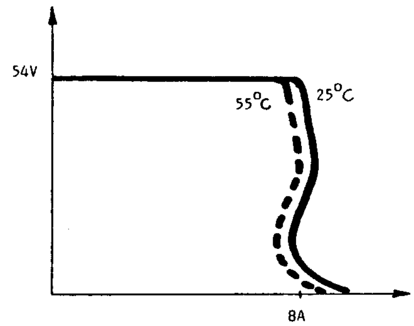

FIG. 7 CURRENT LIMIT

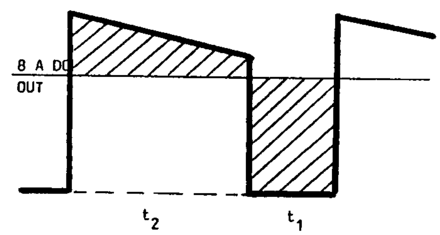

FIG. 9 RIPPLE CURRENT IN OUTPUT CAPACITORS

The control circuit senses the current through the switching transistor T1 across the resistor R4. At current limit (fig. 7) the voltage drop across the resistor R4 is 1V, that means a power loss of 0,3%.

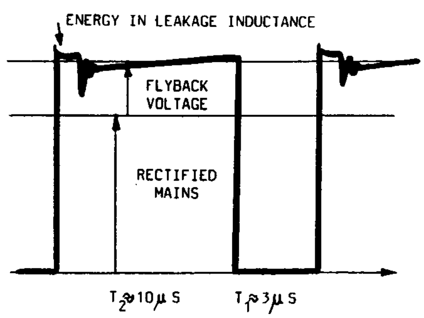

FIG. 8 VOLTAGE ACROSS THE TRANSISTOR SWITCH

Figure 8 shows the voltage waveform across the switching transistor T1. The transistor charges the choke/transformer TR1 during t_1 and during t_2 the choke/transformer is discharges through the secondary diode D3: Capacitor C3 is partly discharged when the transistor is conducting and charged when diode D3 is conducting. Therefore, the voltage increases across T1 during its off time.

The energy stored in the leakage inductance in TR1 is taken care off in the snubber network D2, R3 and C6.

Output capacitors C7 and C8 deliver energy when D3 is not conducting. Therefore the capacitors must handle some ripple current. In this case with the choosen pulse width, the ripple current is about 5 A_{RMS} at 8A DC output current (fig. 9).

The output filter L2/C9 takes the high frequency ripple down from 0,1 V_{RMS} to $10mV_{RMS}$.

The snubber across D3 decreases noise and ringing across the diode, and even takes care of some leakage inductance in the transformer.

Isolation is maintained between input and output by an opto coupler in the voltage feed-back. The control circuit in the output circuit is an adjustable zener diode connected to the LED in the optocoupler.

Diode D3 forward loss	7 W
Diode D3 switching loss	1 W
Conductors on printed board	0,6W
Transformer winding	4 W
Ferrite	3,0W
R4	1,2W
Input Common mode choke	1 W
Output choke	0,2W
Primary snubber	0,8W
Control Circuit	2,5W
Sek snubber	0,7W
Transistor loss	9 W
Output capacitors	0,5W
Sek control circuit	0,2W
Efficiency measured between C2 and C9	92,6%
Total efficiency	91 %

Fig. 10 POWER LOSSES (54V, 400W on output)

This is simple enough, but what makes this flyback better than others? As I have not studied a bad flyback very careful before, I can only guess that the following design criteria would make the difference.

1. Choosing pulse ratio to optimize switching transistor/diode.

2. Low leakage inductance in the transformer and a way of taking care of the energy stored in it.

3. Choosing turns ratio in the transformer to get a low leakage inductance and low output ripple.

4. Choosing the airgap and number of turns depending on transformer and output voltage (a 5V supply should run more in continuous mode than a 48V supply).

5. Always having one "high frequency" secondary winding (tightly coupled to the primary) and one "low frequency winding" for the main part of the current.

6. Tune the leakage inductance to maximum efficiency. Too low leakage inductance may cause losses in the transistor switch if the secondary diode is slow.

RFI NOISE

To make a compact AC/DC converter, there is no place for complicated noise filtering. In the 400W flyback, the filtering is by a small common mode 1,6A 22mH choke placed after the electrolytic capacitor C2. There is therefore, smooth DC current through the filter and the RMS current is less than 1,5A. Two Y capacitors are connected across C3 to earth. The rest of the noise filtering is made by making:

1. Small current loops

2. High voltage switching frequencies confined to small areas as the PCB.

3. Neutral transformer with regard to noise.

4. Good, clean earthing

The noise in the D1 rectifing bridge is taken care of by the X-capacitor C1. If the bridge rectifier has a fast recovery time, this capacitor is not necessary.

Conclusions:

It is possible to make a very compact high power, switch mode power supply in flyback technique using standard components with no sacrifice in performance and working at 80 kHz. Unfortunately one needs a lot of experience with this technique to get this far. Theoretical calculations to design the transformer does not work very well, as too many parameters are interdependent.

Ref. Intelec 87 page 2-5 "Smaller more efficient power supplies but how".