SMPS WITH L4990 FOR MULTISYNC MONITORS

by CW Park & G. Gattavari

This paper can be used as design guide of a flyback converter for monitors power supply. The high performance PWM controller L4990 is being used to meet new spec requirements for monitors power supply. The basic requirements of a monitor power supply are listed below:

- high output power range up to 120W, with universal mains voltage

- synchronisation up to 100kHz

- power management

- over voltage and over load protections

- easy design, simple, with lower components count

The L4990 is a current mode controller developed to implement single-ended topologies, off-line flyback and forward, and DC- DC converters at fix frequency, up to 1MHz.

This device includes some additional features as programmable soft start, sync in/out, disable (to be used for overvoltage and overcurrent detection), maximum duty cycle control and hiccup overcurrent protection.

Due to the integration of the listed functions , very often used in monitors power supplies, the component count is dramatically reduced .

The L4990 allows to design high performance power supplies for high end monitors, as 17" and 21" and also low cost power supplies for low end monitors, as 14" and 15".
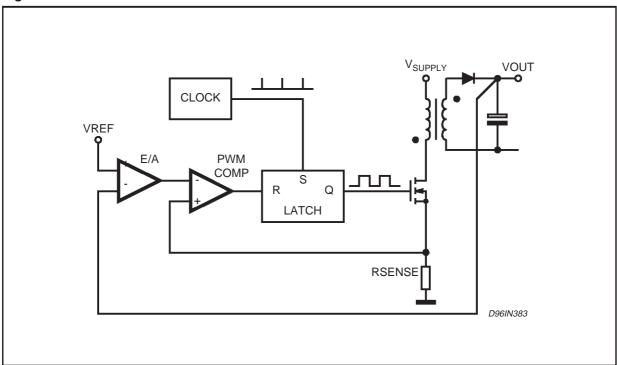
BASIC CIRCUITS AND OPERATION
1. CURRENT MODE CONTROL

The L4990 is based on a current mode architecture.

Fig. 1 shows the current mode control circuit in a typical flyback converter.

A clock signal initiates the power pulse at a frequency fixed by the oscillator. The output of the error amplifier and the primary current are compared at the inputs of the PWM comparator that generates the PWM signal.

Figure 1: Current mode control

D96IN383

2. START- UP CIRCUITRY AND AUXILIARY SUPPLY

Fig. 2 shows a couple of circuit solutions on how to wake-up the device at mains turn-on.

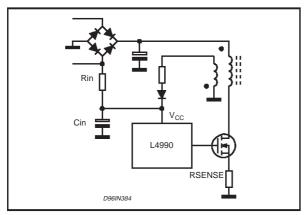**Figure 2a:** Low cost start-up.
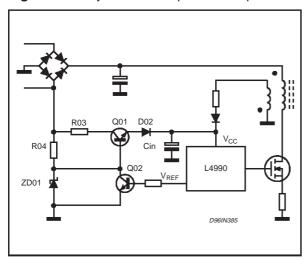

Figure 2b: Very low consumption start-up.

Fig2-a is well suited to applications with fixed mains, 110 or 220Vac; it's the cheapest and largely used system to start-up an IC with hysteretic turn-on.

Fig2-b is suggested for quick start-up and for autoranging applications keeping constant the wake-up time, having low consumption after device turn-on.

ZD01 is fixing the emitter voltage of Q1 that has to be higher than the turn-on threshold max. value.

When the device turns-on, the auxiliary supply will keep the voltage across Cin at a typ. value of 13V while V_{REF} rising from 0 to it's nominal value of 5V will saturate Q2 turning-off Q1.

At this point the current consumption from the mains it's only due to R4, typically above 400kΩ for 220VAC mains.

3. OSCILLATOR AND SYNCHRONISATION FUNCTIONS (PINS 2,1,4,15).

Fig. 3 shows oscillator and sync circuits.

The oscillator frequency is given by the following formula:

$$f \approx \frac{1.44}{R_t \cdot C_t}$$
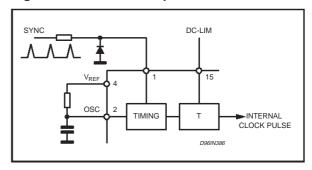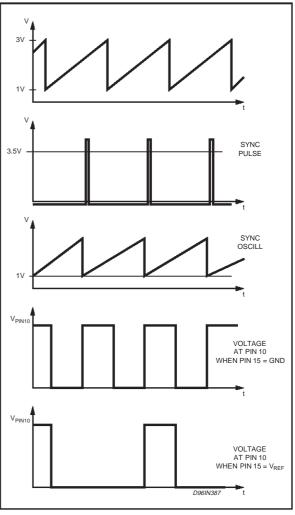
Figure 3: Oscillator with synchronisation.

Figure 4: Oscillator and sync waveforms.

The oscillator can be synchronised by a voltage pulse sent to pin1.

When the voltage at pin 1 reaches 3,5V max., Ct is discharged and a clock pulse is generated.

Fig. 4 shows the correspondent voltage waveforms.

According to Fig 4, when pin 15 is connected to Vref, the internal latch divide by two the oscillator frequency, and the switching frequency of the power section became the half (and the max. duty cycle is limited to 50%).

This possibility conveniently reduces the switching losses; in particular we suggest to ground pin15 from 31 to 48KHz, and pin15 to Vref when operating from 56 to 100KHz, as summarised below:

31KHz to 48KHz: pin 15 to gnd, same frequency as sync input.

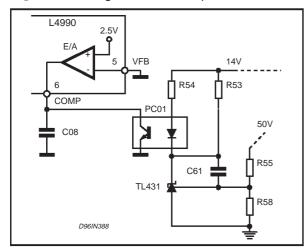56KHz to 100KHz: pin 15 to Vref, half of sync frequency.

4. ERROR AMPLIFIER (PIN 5, PIN 6)

Using a feedback with optocoupler, as in monitor applications, there are available two solutions:

a) by controlling the output of the error amplifier directly with the optotransistor;

b) using the on-board error amplifier;

For this application we choose solution a), reducing the component count, as shown in Fig 5.

Figure 5: Voltage feedback loop.
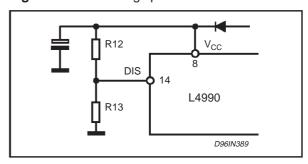

D96IN388

5. OVER VOLTAGE PROTECTION (PIN 14)

At pin 14 is present a disable function. When the voltage at this pin is higher than 2.5V, the device is latched, and the device current consumption is lower than 300µA. This pin is typically used to monitor the rectified mains or the auxiliary supply, or overcurrents too.

In the current application this function is used to

Figure 6: Over voltage protection.

D96IN389

monitor the auxiliary supply through R12 and R13.

After a disable function intervention, to reset the IC, the V_{CC} pin has to be forced below the UVLO threshold (10V), or the user has to disconnect the mains.

6. CURRENT SENSE AND OVERLOAD PROTECTION (PIN 13, 7)

The current sense function is implemented at pin13, detecting the voltage drop on the sensing resistor R10.
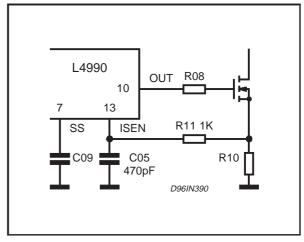
The threshold voltage at pin13 is of 1V, while in normal operation is lower. When the voltage at this pin reaches 1,2V, a fault condition is detected.

The power MOS is immediately turned-off, and the fault signal is internally latched.

A fault reset delay is implemented by discharging the external Soft -Start (SS) timing capacitor before resetting the fault latch and initiating a new soft start cycle.

In case of continuous fault condition, the SS capacitor is charged at 5V before being discharged again, to that on the power elements, power MOS and secondary diodes, the power dissipation is kept under safety limits.

Figure 7: Current sensing.

D96IN390

DESIGN OF FLYBACK CONVERTER FOR MONITOR APPLICATIONS

1. BASIC REQUIREMENTS OF A 15" MONITOR APPLICATION

- Switching frequency
  - standby or off mode : 25kHz
  - free running mode   : 28kHz
  - normal mode   : 31kHz to 64kHz
- Mains voltage range : 85V to 264V AC
- Operating in
  - discontinuous mode at 31kHz
  - continuous and discontinuous mixed mode at higher than 31kHz.
- Nominal output power : 80W
- Output voltage and power
  - V1 for H-Def   : 50V, 50W
  - V2 for Video Amp   : 80V, 12W
  - V3, -V4 for V-Def   : 14V, 12V 10W
  - V5 for heater   : 6.3V, 4W

1-1. Transformer Calculation

- duty cycle ,dc : 50% max. at minimum mains and nominal output power condition.
- efficiency η : 0.85
- Vi min   : 100V DC
- period T   : 32μs
- Vdss of Mos-Fet   : 600V

The peak drain voltage of power Mos-Fet is given by:

$$V_{dsspeak} = V_{inmax} + V_R + V_{spike},$$

where V_R is the secondary to primary reflected voltage.
Considering a 15% of safety margin on V_{dss}, V_{dssmax} results in $600V \cdot 0.85 = 510V$;
$V_{inmax} = 264 \cdot \sqrt{2} \cong 370V$, and considering a $V_{spike} = 50V$,
$V_R = V_{dssmax} - V_{inmax} - V_{spike} = 510 - 370 - 50 = 90V$
The primary inductance is given by the formula:

$$L_P = \frac{(V_{imin} \cdot T \cdot dc)^2}{2 \cdot P_O \cdot T} \cdot \eta = \frac{(100 \cdot 32 \cdot 0.5)^2}{2 \cdot 80 \cdot 32} \cdot$$
$$\cdot \, 0.85 = 425 \mu H$$

and the primary current is given by:

$$I_P = \frac{V_{imin} \cdot T \cdot dc}{L_P} = \frac{100 \cdot 32 \cdot 0.5}{425} = 3.76A$$

The transformer turn ratio between primary and

secondary is:

$$N = \frac{N_{s1}}{N_P} = \frac{V_{o1} + V_{Df}}{V_R} = \frac{50 + 1}{90} = 0.567$$

A popular ferrite core as the EER424215 with 1mm air gap has been chosen.

$$A_L \cong 0.28 \, \mu H/Np^2.$$

The primary turns are so calculated:

$$N_P = \sqrt{\frac{L_P}{A_L}} = \sqrt{\frac{425}{0.28}} = 39T$$

Ns1= Np · 0.567 = 22 T
The voltage per turn, V_T, is:

$$V_T = \frac{V_{o1} + 1}{N_{s1}} = \frac{50 + 1}{22} \cong 2.32V.$$

Taking 13 to 14V from Nd auxiliary winding for L4990 auto-supply, the Nd turns are calculated below:

$$Nd = \frac{13 + V_{Df}}{V_T} = \frac{13 + 1}{2.32} \cong 6 \, T.$$

In the following table is represented the final spec of the transformer, in which all the turns windings have been adjusted a bit to optimise each output voltage:

Winding	Pin	Turns
Np	1 to3	40
Nd	8 to 7	6
Ns1 (50V)	15 to 16	21
Ns2 (80V)	15 to 17	33
Ns3 (14V)	11 to 12	7
Ns4 (-12V)	10 to 11	6
Ns5 (6.3V)	13 to 14	4

1-2. V_{dss} voltage clamp circuit

Fig 8 shows the V_{dss} voltage clamp network.
The secondary reflected voltage and the voltage spike due to the leakage inductance, are charging C10 through D05; R18, connected in parallel, is discharging C10.
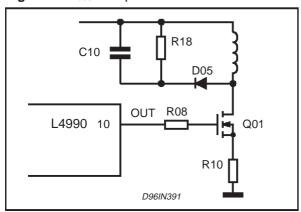The power dissipation on R18 is given by :

$$P_{R18} = \frac{V_{C10}^2}{R18} = \frac{100^2}{22000} = 0.45W$$

When all the outputs are open, at no load, this

power consumption is operating as a dummy load and all the output voltages remain at its nominal value.

Figure 8: V_{dss} clamp circuit.

D96IN391

1-3. Over- voltage protection

The turn-on threshold voltage of the device is 17V max.. So, the OVP intervention is fixed by the formula:

$$V_{OVP} = \frac{R12 + R13}{R13} \cdot V14 = \frac{R12 + R13}{R13} \cdot 2.5V$$

When R12=33KΩ and R13=5.1KΩ, the OVP intervention starts at 18.7V.

If Vo1 winding is strictly coupled with the auxiliary winding, OVP intervention happen at 69V of Vo1, 38% above the nominal value.

Adjustments can be done by changing the R12 and R13 values, or Nd turns or by recalculating the Volt/turns.

The V_{SUPPLY}, device supply voltage provided by the power transformer after turn-on , in normal conditions, is:

$$V_{SUPPLY} = \frac{V_{o1} + V_D}{N_{s1}} \cdot N_D - V_D = \frac{50 + 1}{21} \cdot 6 - 1 = 13.6\ V$$

1-4. Decoupling capacitor on Vcc supply line and start up

C04, capacitor in parallel to the supply voltage of the device, is charged by the external start-up circuit, up to the turn-on threshold.

It has to be large enough (we chose 470μF) to hold the device supply voltage, in open load conditions.

During load transients, from nominal to no load, the output V_{o1} has some overvoltages and L4990 turns-off the power transistor until Vo1 recovers it's nominal value.

If C04 is not big enough, the supply voltage can cross the turn-off threshold, turning-off the device.

The turn-on initialisation restarts, and an un-wanted intermittence operation will be established.

In particular, for autoranging applications and when a high start-up capacitor value is required, it is recommended the use of a quick start-up, as shown in fig2-b, in order to keep almost constant the start-up time on all the operating mains range.

1-5. Current sense

When the voltage at I_{SEN} (pin 13) reaches 1V, the current limiting function is activated.

The peak voltage at I_{SEN} input has been calculated to be 0.85V at nominal output power (for some margin for load transients) and min. switching frequency (31kHz).

Rs, current sense resistor, is calculated here below:

$$R_s = \frac{0.85V}{I_P} = \frac{0.85V}{3.76A} \cong 0.22\Omega$$

The max. primary peak current I_{LIMIT} is :

$$I_{LIMIT} = \frac{1V}{0.85V} \cdot 3.76A = 4.42A$$

The max. output power $P_{o\ LIMIT}$, at 31kHz, is :

$$P_{oLIMIT} = P_o \cdot \left(\frac{I_{LIMIT}}{I_p}\right)^2 = 80 \cdot \left(\frac{4.42}{3.76}\right)^2 = 110W$$

The available output power is higher at higher switching frequency.

1-6. Voltage feedback loop

For a good secondary regulation is requested the use of an optocoupler and a secondary voltage reference with an error amplifier too.

The output source current of the error amplifier, pin 6, is 1.3mA typical.

The sink current capability of PC01 has to be higher, at least 3 mA.

The secondary to primary feedback is stabilising the Vo1 output, by sensing it before the LC filter to avoid possible instabilities.

C61 is introducing a pole in the origin, and the series of C59 and R56 is effective to suppress high frequency parasitic oscillations.

1-7. Power management

a) Normal mode
   The control input of Q72 and Q74 are both high. So, Q71, Q73 and Q75 are in satura-tion. The Horiz. and vertical processors work

with a supply voltage of 14V and -12V.

b) Suspend mode

The control input of Q74 is low and high for Q72.

So, Q73 and Q75 are off.

H/V deflection is stopped, MCU and heater are working.

c) Off mode

All control inputs are low, and Q71, Q73 and Q75 are off. There is no supply for heater and H/V processors. The power consumption of this mode depends on the load current of the 80V output. The total input power consumption, in this mode, is 2.0W at the following conditions:

AC 220V input, 80V output open, 50V output 0.25W dummy, MCU current 20mA from unswitched 14V output.

The power consumption is 1.3W increased by degaussing coil circuit consumption. It is possible to keep at less than 4W the total power consumption if power losses due to the leakage current on the 80V output is less than 0.5W.

1-8. Oscillator and synchronisation

The device oscillator frequency is set at 25KHz.

The synchronisation is obtained by the flyback pulse from FBT via R17and a zener diode for voltage clamping.

1-9. Circuit diagram

Fig.9 shows the complete schematic diagram for a 15" monitor application, and Figg. 10 a and b show the relative PCB layout. Fig. 11 shows the transformer specification.
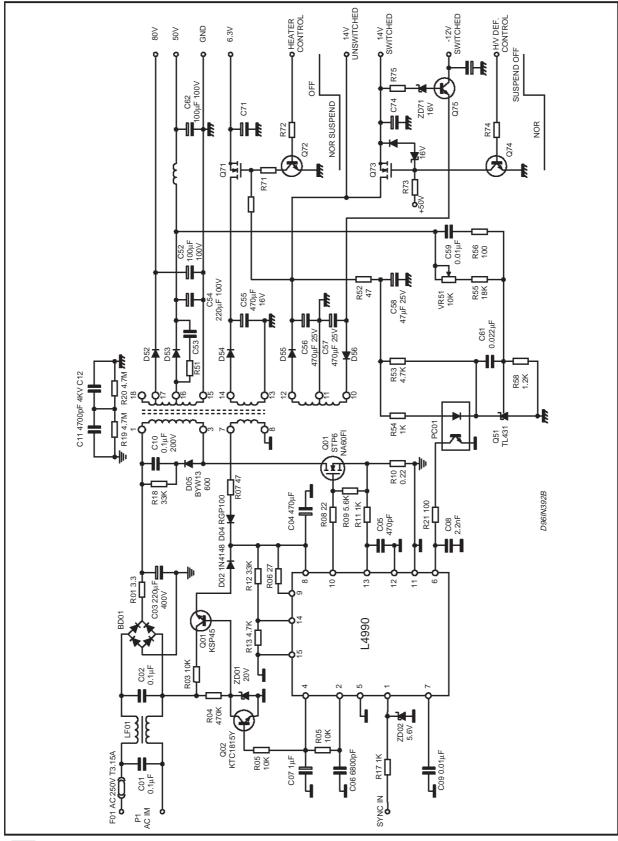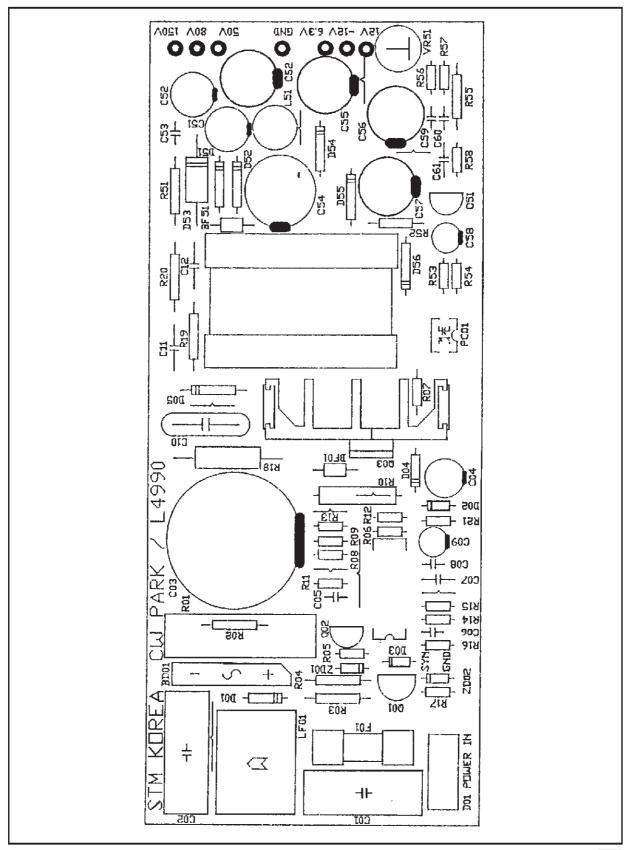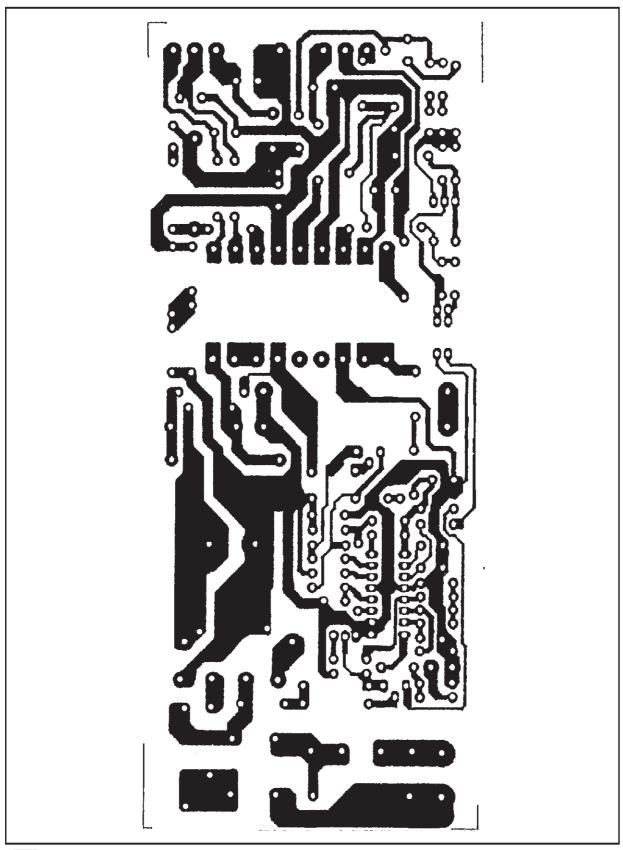
Figure 9: Complete PS. schematic diagram for 15" monitor.

Figure 10a: Printed Circuit Board Layout.(Overlay) (Dimensions: 182mm x 77.5mm).

Figure 10b: Printed Circuit Board Layout. (Bottom Layer) (Dimensions 182mm x 77.5mm).

**TRANSFORMER SPECIFICATION FOR 15"
MULTISYNC MONITOR**

Transformer specification
CORE: EER424215
BOBBIN: VERT. 18 PIN
TOP BARRIER: 3mm
BOTTOM BARRIER: 6mm
Lp (1 - 4): 425µH

Winding specification

W/D	WIRE (mm)	S - F	TURNS	METHOD	TAPE	Ts
Ns4	0.5	10 - 11	6	SOLENOID	0.05 * 10	1
Ns5	0.5	11 - 12	7	SOLENOID AFTER Ns3	0.05 * 15	1
Ns6	0.5	13 - 14	4	SPACE AFTER Ns4	0.05 * 26	3
Nd	0.3	7 - 8	6	SPACE 1 LAYER	0.05 * 26	3
Np1/2	0.16 * 12	1 - 2	20	SOLENOID	0.05 * 26	3
Ns1	0.16 * 12	15 - 16	21	SOLENOID	0.05 * 26	3
Np1/2	0.16 * 12	2 - 4	20	SOLENOID	0.05 * 26	3
Ns2	0.3	16 - 17	12	SOLENOID	0.05 * 15	1
Ns3	0.3	17 - 18	29	SOLENOID AFTER Ns2	0.05 * 26	3

2. MEASUREMENT DATA
2-1. Efficiency at 70W, nominal output power

Mains Voltage	at 31KHz	at 64KHz
90Vac	86.8W	86.1W
	80.6%	81.3%
110Vac	84.1W	83.8W
	83.2%	83.5%
220Vac	80.3W	79.8W
	87.1%	87.7%
270Vac	80.0W	80.5W
	87.4%	86.9%

where in W is indicated the input power consumption at a load of 70W, and in % is indicated the system efficiency.

2-2. Power consumption when in off mode

Conditions : 50V - 5mA, 14V - 20mA and all remaining outputs open.

Mains Voltage :	90Vac	110Vac	220Vac	270Vac
Power consum.:	1.7W	1.7W	2.0W	2.2W

3. MAIN CHARACTERISTICS OF A 17" MONITOR APPLICATION

- Switching frequency :
  - stand-by or off mode : 25KHz
  - free-running mode : 28KHz
  - normal mode : 31KHz to 82KHz
- Nominal output power : 90W
- Output voltage and power
  - V1 for H-Def : 200V, 65W
  - V2 for Video Amp : 80V, 10W
  - V3, -V4 for V-Def : +14V, -12V 10W
  - V5 for Heater : 6.3V, 5W

3-1. Transformer calculation

- duty cycle, dc : 50% max. at min. mains voltage and nominal load
- efficiency : 85%
- Vimin : 100V DC
- period T : 32µs
- Vdss of Mos-Fet : 600V

The peak drain voltage of the power Mos-Fet is given by :

$$V_{dp} = Vimax + V_R + Vspike$$

The maximum value of V_R has to be equal or lower than Vimin to avoid negative Vdss generated by ringing when the transformer has no energy.

Higher V_R is chosen, higher Vdss is required for power Mos-Fet;
but high V_R means also Vr, reverse voltage, for the secondary rectifier of the 200V output.

The peak reverse voltage of secondary diode is :

$$Vr = \frac{Vimax \cdot V_{out}}{V_R} + Vout + Vspike$$

where Vspike is the voltage spike on the secondary winding.

Considering $V_R = 100V$ and Vspike = 150V, the Vr of the diode located on the 200V output results in :

$$Vr = \frac{370V \cdot 200V}{100V} + 200V + 150V = 1090V$$

This reverse voltage, greater than 1000V, is effectively too high for a fast recovery rectifier diode.

Fig 11 shows a method to reduce the required reverse voltage.

Using this simple system to generate the 200V
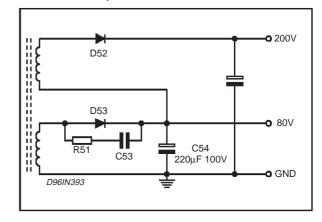
output, the Vr is not anymore critical.

At this point we can review also the V_R value, choosing less than 100V.

Considering $V_R = 95V$ and $V_{dp} = 515V$, the new value of Vspike is:

$$Vspike = 515V - 100V - 370V = 45V$$

Now, to limit again Vspike less than 45V, it is very important to reduce the transformer leakage inductance.

Figure 11: Rectifier circuits for 200V and 80V outputs.

The primary transformer inductance is:

$$Lp = \frac{(V_{imin} \cdot T \cdot dc)^2}{2 \cdot P_O \cdot T} \cdot \eta = \frac{(100 \cdot 32 \cdot 0.5)^2}{2 \cdot 90 \cdot 32} \cdot$$
$$\cdot 0.85 \cong 380\mu H$$

and the primary current becomes:

$$Ip = \frac{V_{imin} \cdot T \cdot dc}{Lp} = \frac{100 \cdot 32 \cdot 0.5}{380} = 4.2A$$

The turn ratio between primary and secondary winding is:

$$N = \frac{N_{s1} + N_{s2}}{N_p} = \frac{V_{o1} + 2 \cdot V_{Df}}{V_R} = \frac{200 + 2}{95} = 2.12$$

We chose the ferrite core EER424215 with 1.0 mm air gap.

$$A_L \approx 0.28 \, \mu H/Np^2$$

$$N_P = \sqrt{\frac{L_p}{A_L}} = \sqrt{\frac{380}{0.28}} = 37 \ T$$

$$Ns1 + Ns2 = Np \cdot 2.12 = 79\ T$$

$$Ns1 = \frac{(120+1) \cdot 79}{200+2} = 47\ T$$

Ns2 = 79 - 47 = 32 T
The volt/turn VT is:

$$V_T = \frac{V_{o1}+2}{N_{s1}} = \frac{200+2}{79} = 2.56\ V$$

Considering 13 to 14V the auxiliary winding to supply the L4990, the number of turns is calculated as follows:

$$N_d = \frac{13 + V_{Df}}{V_T} = \frac{14}{2.56} = 6\ T$$

The following paragraph shows the detailed transformer windings spec and fig. 12 shows the schematic diagram of the complete power supply.

TRANSFORMER SPECIFICATION FOR 17" MULTISYNC MONITOR
Transformer specification
CORE: EER424215
BOBBIN: VERT. 18 PIN
TOP BARRIER: 3mm
BOTTOM BARRIER: 6mm

Winding specification

W/D	WIRE (mm)	S - F	TURNS	METHOD	TAPE	Ts
Ns4	0.5	10 - 11	5	SOLENOID	0.05 * 10	1
Ns5	0.5	11 - 12	6	SOLENOID AFTER Ns3	0.05 * 15	1
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Nd	0.3	7 - 8	6	SPACE 1 LAYER	0.05 * 26	3
Np1/2	0.16 * 12	1 - 2	20	SOLENOID	0.05 * 26	3
Ns1	0.45	15 - 16	32	SOLENOID	0.05 * 26	3
Ns2	0.45	17 - 18	47	SOLENOID	0.05 * 15	1
Np1/2	0.16 * 12	2 - 4	17	SOLENOID	0.05 * 26	3

3. MEASUREMENT DATA
3-1. Efficiency at 90W, nominal output power

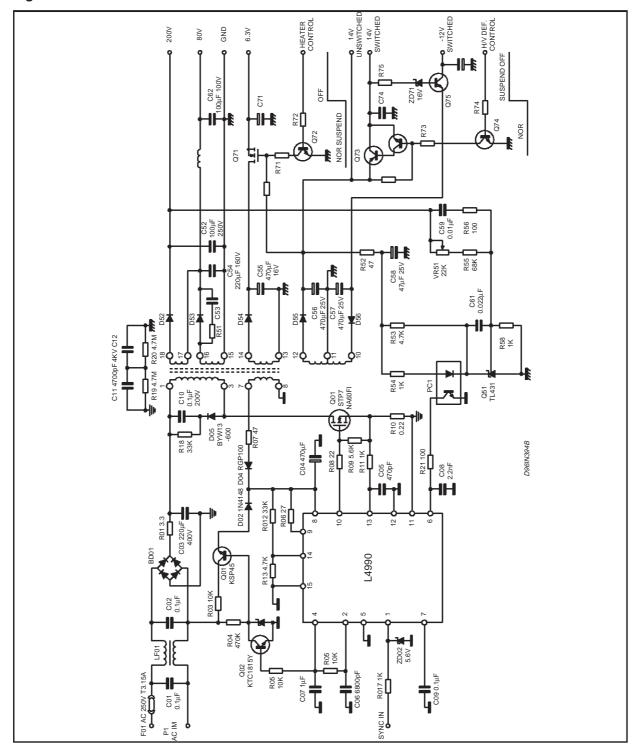| Mains Voltage	at 31KHz	at 82KHz
90Vac	112.7W	117.8W
	79.9%	76.4%
110Vac	108W	112.5W
	83.3%	80.0%
220Vac	102W	108.1W
	88.2%	83.3%
270Vac	102.1W	108.5W
	88.1%	82.9%

3-2. Power consumption when in off mode
Conditions : 0.5W on ±12V and all remaining outputs open.

Mains Voltage :	90Vac	110Vac	220Vac	270Vac
Power consum.:	1.8W	1.8W	2.6W	3.3W

Figure 12: SMPS for 17" monitor.

SUMMARY

A practical flyback SMPS for 15" and 17" multi-sync monitors has been analysed, incorporating all the requested features for a correct functionality in normal operating conditions and stand-by mode.

By using the L4990 the component count is minimised, reducing the overall system cost and complexity.