

Board connection

On your workbench you'll find:

- 1 Power supply (2 sections or more)
- 1 Premounted board;
- 1 Rheostat
- 1 Assembly with 3 fixed resistors
- 3 red/black cables;
- 2 Scope probes
- 1 Hook-BNC coax cable for synchronizing the scope.

Board description (as a reference, orient the board to have connector B4 up left). Board left side contains the control circuitry, used for all the topologies. It has to be powered through connector B4.

On the right part, the top section is a Buck converter, the middle section is a Boost converter and the bottom one is a Buck-Boost converter. Connectors B1 IN, B2 IN, and B3 IN are power inputs for Buck, Boost and Buck-Boost respectively, see figure 1.

One section of your power supply is used to power the control part and connected to connector B4. Respect the color code (RED positive, BLACK negative). The second section is used as power source of the converter (V_{in}). Connect the second power supply section to B1 IN, B2 IN or B3 in according the converter you are working on. Connect the rheostat to the converter you are using (B1 OUT, B2 OUT or B3 Out). If your rheostat is less than $100\ \Omega$, connect in series to the variable resistance a fixed resistor in order to get $100\ \Omega$ or more as a maximum load resistance.

Set initially both power supply sections to 0V. Remember that Boost and Buck-Boost converters shouldn't work open loop without a load!

Jumper CONTROL sends to one of the three converters the PWM signal generated by the single controller on board. Set the jumper for the converter you are working with (J1 for Buck, J2 for Boost, J3 for Buck-Boost).

Potentiometer close to the top left corner, near B4 connector, allows you to change the duty cycle (in open loop conditions) or to change the reference voltage V_{ref} (closed loop).

For open loop operations, using a short piece of wire, place a short circuit instead of C_c on socket Z1

Set to maximum the current limit control of the power supply section connected to the converter, while the other section (control) must be close to the minimum. Keep the voltage setting of both sections to 0.

Turn on the power supply, and slowly increase to 15V the control section. Absorbed current should be minuscule, and a red LED on the board should be ON.

Check on TP4 (close to the control IC) if you get narrow pulses at about 50 kHz: this shows that the control part is oscillating. Ground connection of TP4 is on the far side from the IC, signal is on the near side. If you are not sure which side is ground, watch under the board!

Synchronize your scope with this signal, using the hook-bnc coax cable, connecting it to the scope external trig and choosing external synchronization. This external synchronization from the control IC makes your life easier ☺. **KEEP THIS SETTING FOR ALL YOUR MEASURES!**

Turn off the power supply and move the to pertinent section for the experiment.

EXPERIENCES ON BUCK (Open Loop)

Buck converter has been designed with these specs:

- $V_{in} = 15V - 25V$;
- $V_{out} = 10V$;
- $f_s = 50 \text{ kHz}$.

Load resistance can drive the converter both in CCM and DCM. It consists of an external variable resistance (100Ω max)

Connect the input power to the buck section (B1 IN), the load to B1 OUT, check that CONTROL jumper is in J1 position, and that you have a short on socket Z1, position Cc.

Power supply for control section should already have been set to 15V and connected to B4. Set the rheostat about midway (50Ω), and the duty cycle potentiometer around midway (50%).

Connect a voltmeter to the output (TP1 or across the rheostat) and gradually increase the converter input voltage from 0 to 25V. Observe the output voltage with the HP voltmeter, and adjust duty cycle to keep output voltage at 10V

For the next steps you have to measure duty cycle and load resistance, and to check if the converter is in CCM or DCM.

Duty cycle can be measured on cathode of D1 (point A1 on schematics, Figure 2). Cathode is on the diode band side. Cathode voltage waveform indicates also if the converter is in CCM (2 level voltage) or DCM (3 level voltage, with possible ringing).

Load resistance can be measured directly with the HP multimeter: turn off the systema, *disconnect the load* and measure its resistance, or you can measure the rheostat voltage and current.

1. Relationship between D and M.

For this experiment you have to apply 3 different input voltages (15V, 20V, 25V) and 4 different loads (100Ω, 60Ω, 25Ω and 10Ω). Adjust the duty cycle to keep the output voltage (measured on TP1) at 10V. Measure the required duty cycle and compare it with the lossless case. Pay attention to the mode (CCM and DCM and use the right equation to find the ideal duty cycle). For DCM you have to invert the equation M(D) we found in class.

Change the load with constant input voltage, and observe the output voltage variations. In CCM output voltage is fairly stable with load changes, whereas in DCM output voltage is sensitive to the output load.

| | | Nominal Vin=15V | | | | V nominal Vin=20V | | | | V nominal Vin=25V | | | |
|---------------|--------------|-----------------|-----------------|------------|-----------------|-------------------|-----------------|------------|-----------------|-------------------|-----------------|------------|-----------------|
| | | Actual Vin= | | | | Actual Vin= | | | | Actual Vin= | | | |
| Nominal Rload | Actual Rload | D calculated | $\frac{c}{c_m}$ | D measured | $\frac{c}{c_m}$ | D calculated | $\frac{c}{c_m}$ | D measured | $\frac{c}{c_m}$ | D calculated | $\frac{c}{c_m}$ | D measured | $\frac{c}{c_m}$ |
| 100Ω | Ω | | | | | | | | | | | | |
| 60Ω | Ω | | | | | | | | | | | | |
| 25Ω | Ω | | | | | | | | | | | | |
| 10Ω | Ω | | | | | | | | | | | | |

2. Determine the converter efficiency. Using the multimeters, measure input voltage and current, and output voltage and load resistance at least in three different conditions:

$$\eta = P_{out} / P_{in}$$

3. Observe the voltage at A1 (you can use the diode cathode or the inductance lead) and the output voltage ripple. Output voltage ripple is taken from TP1, set the scope in AC, 50 mV/div. Remove the probe cap and connect the probe directly to TP1 (no ground wire).

4. With the current probe, observe the currents through:

- Inductor L1 (clamp the long inductor wires);
- Capacitors C3 e C4 (clamp wires IC3 e IC4);
- Diode D1 (clamp the diode);
- Mosfet MF 1 (clamp wire IM 1);

There are only a few current probes, 1 active and 2 passive. Passive probes show only the AC component (they are transformers!) active probes show also the DC component.

1. Design a snubber to damp the ringing in DCM. Insert a small (few nF) capacitor between A1 and GND, and measure the new ringing frequency. Find the values of Rsn and Csn (explained during the lab), mount them on R6 and C9, and check that ringing is damped out.

EXPERIMENTS ON BOOST (Open Loop)

Boost converter has been designed with these specs:

- $V_{in} = 10V - 20V$;
- $V_{out} = 25V$;
- $f_s = 50 \text{ kHz}$.

Load is given by a fixed 100Ω resistor mounted on the board in series to the external 100Ω rheostat. Using this load boost can work both in CCM and DCM. DO NOT measure the output voltage on the rheostat, because part of the load is on the board. Use instead TP2.

Connect the input power to the boost section (B2 IN), the external load to B2 OUT, check that CONTROL jumper is in J2 position, and that you have a short on socket Z1, position Cc.

Power supply for control section should already have been set to 15V and connected to B4. Set the rheostat about midway (50Ω), and the duty cycle potentiometer around midway (50%).

Connect a voltmeter to the output (TP2 only) and gradually increase the converter input voltage from 0 to 15V. Observe the output voltage with the HP voltmeter, and adjust duty cycle to keep output voltage at 25V

For the next steps you have to measure duty cycle and load resistance, and to check if the converter is in CCM or DCM.

Duty cycle can be measured on jumper CONTROL J2 (remember that for the boost, duty cycle potentiometer works backwards: when you read 0% it is actually 100% and viceversa). Anode voltage (point B1, fig, 2) also indicates if the converter is in CCM (2 level voltage) or DCM (3 level voltage, with possible ringing). During Ton voltage is about 0V.

Load resistance can be calculated from output voltage (TP2) and output current, or measuring the rheostat and the on board load resistance. BE CAREFULL! NEVER DISCONNECT the load, if the converter is working. FIRST turn it off, THEN disconnect the load.

1. Design a snubber to damp the ringing in DCM.
Measure the ringing frequency. Insert a small (few nF) capacitor between B1 and GND, and measure the new ringing frequency. Find the values of R_{sn} and C_{sn} (explained in a previous lab), mount them on R9 and C10, and check that ringing is damped out.

2. Relationship between D and M.

Using the appropriate relationship between M and D, find the ideal (lossless) M and compare it with the actual conversion ratio. Apply 3 different input voltages (10V, 15V, 20V) and 4 different loads (200Ω, 150Ω, 100Ω). Adjust the duty cycle to keep the output voltage (measured on TP2) at 25V. Measure the required duty cycle and compare it with the lossless case. Pay attention to the mode (CCM and DCM and use the right equation to find the ideal duty cycle). For DCM you have to invert the equation M(D) we found in class.

Change the load with constant input voltage, and observe the output voltage variations. In CCM output voltage is fairly stable with load changes, whereas in DCM output voltage is sensitive to the output load.

| | | Nominal Vin=10V | | | | V nominal Vin=15V | | | | V nominal Vin=20V | | | |
|---------------|--------------|-----------------|-------|------------|-------|-------------------|-------|------------|-------|-------------------|------------|-------|--|
| | | ActualVin= | | | | Actual Vin= | | | | ActualVin= | | | |
| Nominal Rload | Actual Rload | D calculated | c c m | D measured | c c m | D calculated | c c m | D measured | c c m | D calculated | D measured | c c m | |
| 200Ω | Ω | | | | | | | | | | | | |
| 150Ω | Ω | | | | | | | | | | | | |
| 100Ω | Ω | | | | | | | | | | | | |

3. Determine the converter efficiency. Using the multimeters, measure input voltage and current, and output voltage and load resistance at least in these conditions: Load 100Ω, Vin=10V, 15V and 20V:

$$\eta = P_{out} / P_{in}$$

4. Observe the voltage at B1 (you can use the diode anode or the inductance lead: it's a magnet wire, so be sure to reach the copper) and the output voltage ripple. Output voltage ripple is taken from TP2, set the scope in AC, 50 mV/div. Remove the probe cap and connect the probe directly to TP2 (no ground wire).

5. With the current probe, observe the currents through:

- Inductor L2 (clamp the long inductor wires);
- Capacitors C5 e C6 (clamp wires IC5 e IC6);
- Diode D2 (clamp the diode);
- Mosfet MF 2 (clamp wire IM 2);

There are only a few current probes, 1 active and 2 passive. Passive probes show only the AC component (they are transformers!), active probes show also the DC component.

EXPERIMENTS ON BUCK-BOOST (Open Loop)

Buck-Boost converter has been designed with these specs:

- $V_{in} = 10V - 25 V$;
- $V_{out} = -15V$;
- $f_s = 50 \text{ kHz}$

Load is given by an external 100Ω rheostat. Using this load, buck boost can work both in CCM and DCM.

Connect the input power to the boost section (B3 IN), the external load to B3 OUT, check that CONTROL jumper is in J3 position, and that you have a short on socket Z1, position Cc.

Power supply for control section should already have been set to 15V and connected to B4. Set the rheostat about midway (50Ω), and the duty cycle potentiometer around midway (50%).

CAUTION! When you measure the output voltage with a scope, connect the scope ground reference (alligator clip) to the RED output wire!
CAUTION! DON'T DISCONNECT THE LOAD!

Connect a voltmeter to the output (TP3 or across the rheostat) and gradually increase the converter input voltage from 0 to 15V. Observe the output voltage with the HP voltmeter, and adjust duty cycle to keep output voltage at -15V.

For the next steps you have to measure duty cycle and load resistance, and to check if the converter is in CCM or DCM.

Duty cycle can be measured on cathode of diode D3 (point C1 on schematics) This same point also indicates if the converter is in CCM (2 level voltage) or DCM (3 level voltage, with possible ringing).

Load resistance can be calculated from output voltage and output current, or measuring directly the rheostat resistance. BE CAREFULL! NEVER DISCONNECT the load, if the converter is working. FIRST turn it off, THEN disconnect the load and measure it.

1. Design a snubber to damp the ringing in DCM.
Measure the ringing frequency. Insert a small (few nF) capacitor between C1 and GND, and measure the new ringing frequency. Find the values of R_{sn} and C_{sn} (explained in a previous lab), mount them on R14 and C11, and check that ringing is damped out.

2. Relationship between D and M.

Using the appropriate relationship between M and D, find the ideal (lossless) M and compare it with the actual conversion ratio. Apply 3 different input voltages (10V, 15V, 25V) and 3 different loads (100Ω, 60Ω, 20Ω). Adjust the duty cycle to keep the output voltage at -15V. Measure the required duty cycle and compare it with the lossless case. Pay attention to the mode (CCM and DCM and use the right equation to find the ideal duty cycle). For DCM you have to invert the equation M(D) we found in class.

Change the load with constant input voltage, and observe the output voltage variations. In CCM output voltage is fairly stable with load changes, whereas in DCM output voltage is sensitive to the output load.

| | | Nominal Vin=10V | | | | V nominal Vin=15V | | | | V nominal Vin=25V | | | |
|---------------|--------------|-----------------|---------------|------------|---------------|-------------------|---------------|------------|---------------|-------------------|------------|---------------|--|
| | | ActualVin= | | | | Actual Vin= | | | | ActualVin= | | | |
| Nominal Rload | Actual Rload | D calculated | $\frac{D}{M}$ | D measured | $\frac{D}{M}$ | D calculated | $\frac{D}{M}$ | D measured | $\frac{D}{M}$ | D calculated | D measured | $\frac{D}{M}$ | |
| 100Ω | Ω | | | | | | | | | | | | |
| 60Ω | Ω | | | | | | | | | | | | |
| 20Ω | Ω | | | | | | | | | | | | |

3. Determine the converter efficiency. Using the multimeters, measure input voltage and current, and output voltage and load resistance in these conditions: Load 20Ω, output voltage -15V and Vin=10V, 15V and 25V:

$$\eta = P_{out} / P_{in}$$

4. Observe the voltage at C1 (you can use the diode cathode or the inductance lead: it can be a magnet wire, so be sure to reach the copper) and the output voltage ripple. Output voltage ripple is taken from TP3, set the scope in AC, 50 mV/div. Remove the probe cap and connect the probe directly to TP3 (no ground wire).

5. With the current probe, observe the currents through:

- Inductor L3 (clamp the long inductor wires);
- Capacitors C7 e C8 (clamp wires IC7 e IC8);
- Diode D3 (clamp the diode);
- Mosfet MF3 (clamp wire IM3);

There are only a few current probes, 1 active and 2 passive. Passive probes show only the AC component (they are transformers!), active probes show also the DC component.

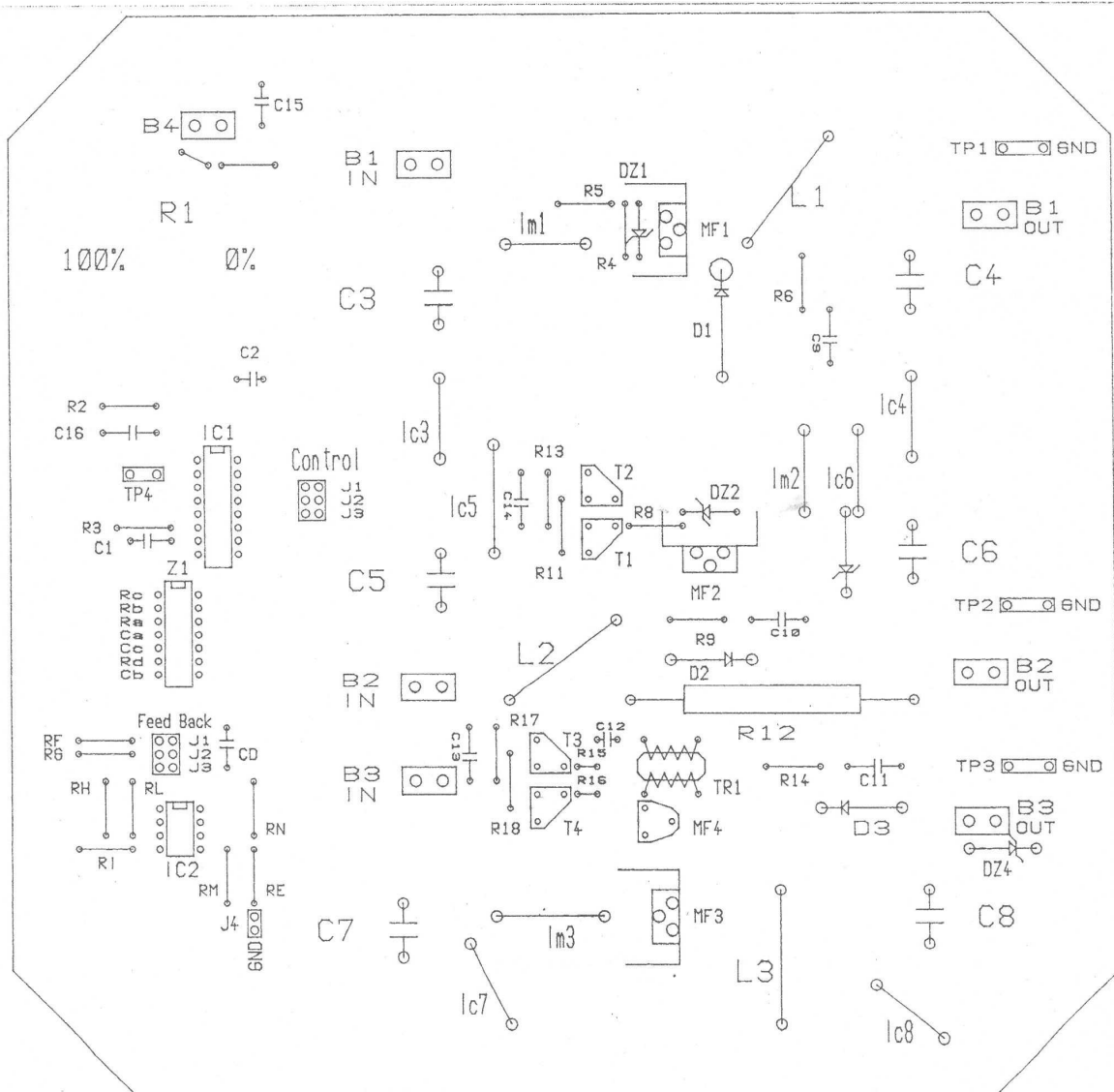
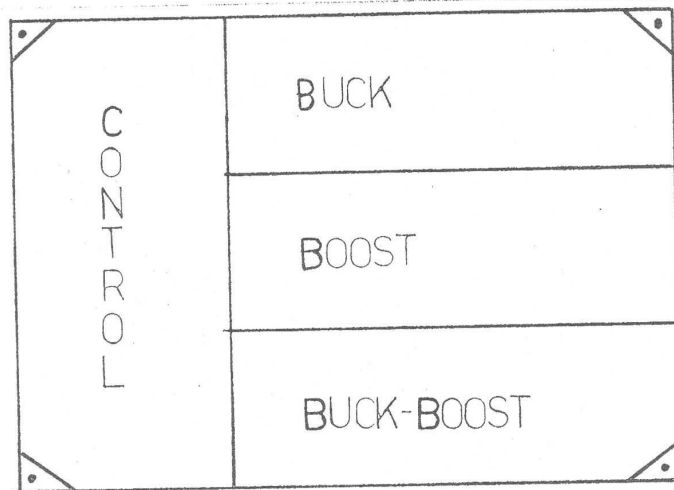


Figure 1: Board layout

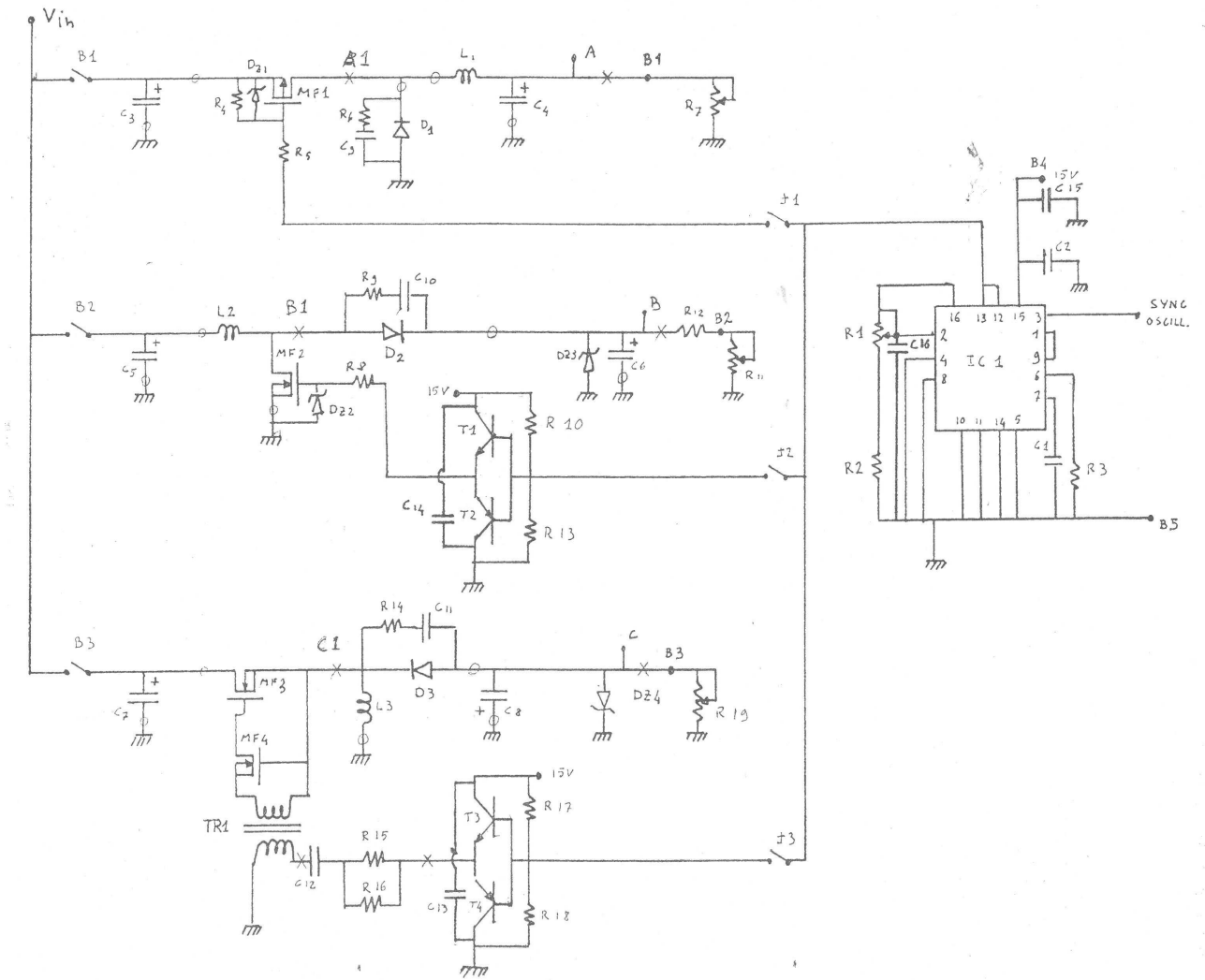


Figure 2 – Power section schematics

Component list

Resistors ($\frac{1}{4}$ W unless otherwise indicated)

| | | |
|------------------------|----------------------------|---------------------------|
| R1: 2.2k Ω pot. | R7: 100 Ω rheostat | R13: 3.3 Ω |
| R2: 680 Ω | R8: 22 Ω | R14: 680 Ω |
| R3: 2.2 k Ω | R9: 680 Ω | R15: 100 Ω |
| R4: 330 Ω | R10: 390 Ω | R16: 180 Ω |
| R5: 150 Ω | R11: 100 Ω rheostat | R17: 390 Ω |
| R6: 680 Ω | R12: 100 Ω 10W | R18: 3.3k Ω |
| | | R19 100 Ω rheostat |

Capacitors

| | | |
|---------------------------|---------------------------|------------------|
| C1: 10 nF pol. | C7: 1000 μ F elt 100V | C13: 100 nF pol. |
| C2: 100 nF pol. | C8: 1000 μ F elt 100V | C14: 100 nF pol. |
| C3: 1000 μ F elt 100V | C9: 3.3 nF pol. | C15: 100 nF pol. |
| C4: 1000 μ F elt 100V | C10: 3.9 nF pol. | C16: 100 nF pol. |
| C5: 1000 μ F elt 100V | C11: 3.3 nF pol. | |
| C6: 1000 μ F elt 100V | C12: 100 nF pol. | |

Mosfets and bjts

| | | |
|--------------|------------|-----------|
| MF1 IRF 9532 | MF4 BS 170 | T3 2N2218 |
| MF2 IRF 530 | T1 2N2218 | T4 2N2904 |
| MF3 IRF 530 | T2 2N2904 | |

Inductors and transformer

| | | |
|----------------|----------------|-----------------------------|
| L1 220 μ H | L3 220 μ H | Red core Np= 6 turns Ns = 8 |
| L2 160 μ H | TR1 red core | turn |

Diodes

| | | |
|---------------|------------------|---------------|
| Dz1 zener 12V | Dz3 zener 47V 2W | D2 BYV 28-150 |
| Dz2 zener 15V | Dz4 zener 47V 2W | D3 BYV 28-150 |
| | D1 IR 31 D6 | |

Integrated circuits

| | |
|------------|-----------|
| IC1 U3524A | IC2 TL082 |
|------------|-----------|

Connectors

| | | |
|-------------------|-------------|------------------------|
| B1 bipolar. Male | J2 jumper | J2FB jumper |
| B2 bipolar. Male | J3 jumper | J3FB jumper |
| B3 bipolar. Male | J4 jumper | Z1 socket for discrete |
| B4 bipolar. Male. | J5 jumper | components |
| J1 jumper | J1FB jumper | |