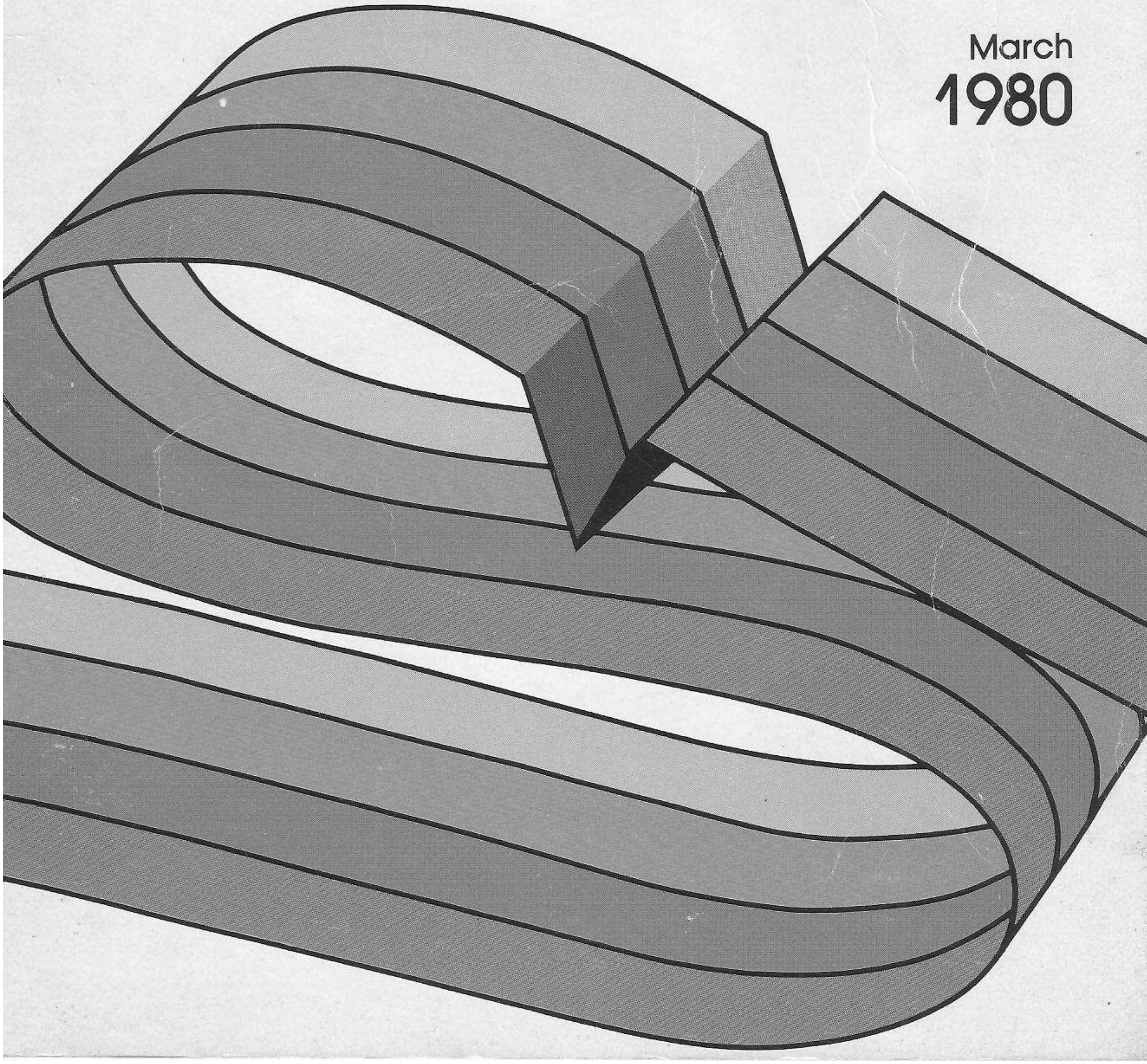
Siliconix

VMOS Power FETs

Applications Handbook

Design Catalog

March 1980



Design Aid DA80-1

A Low Cost Regulator for Microprocessor Applications

Build a 100 KHz Multiple Output Switching Regulator

David Mele
Michael Herrick

INTRODUCTION

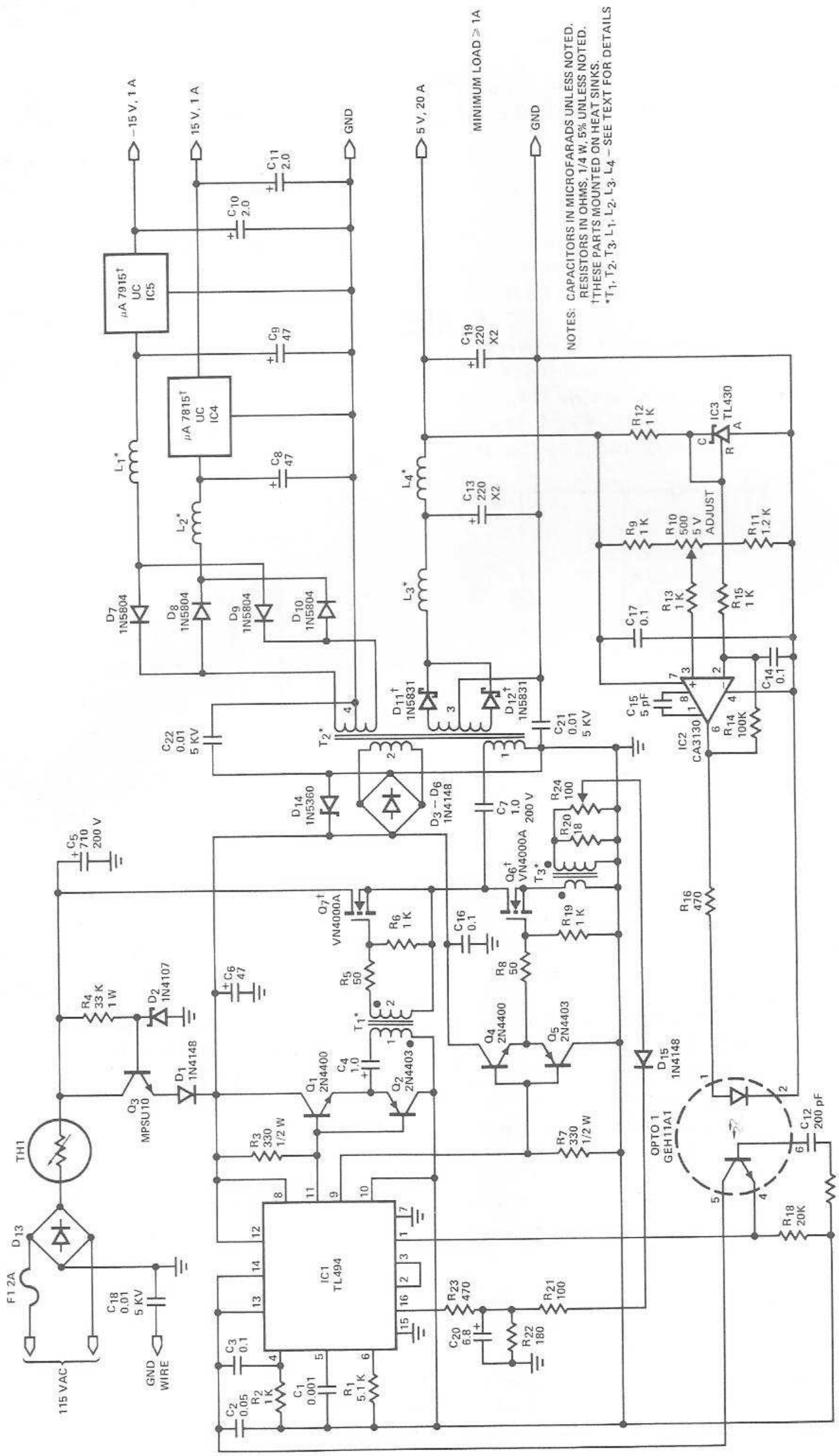
Commercial switching power supplies typically operate at frequencies from 20 KHz to 40 KHz and achieve efficiencies as high as 70% to 75% at a reasonable size and weight. These same efficiencies or better can be realized by increasing the operating frequency to 100 KHz and above when using VMOS Power FETs as the power switching transistors. At these higher frequencies much smaller reactive components are necessary thus decreasing the cost, size and weight of the power supply while maintaining the same output power. The main factor limiting the operating frequency of conventional switching supplies is the inherently slow switching times of the power bipolar transistors due mainly to minority carrier storage time. VMOS Power FETs are majority carrier devices and therefore do not have storage time. The VN4000A series of 400 volt VMOS Power FETs have maximum switching times of 100 ns thus enabling efficient switching rates up to 500 KHz and above.

This higher operating frequency results in a reduction of the size and cost of ferrites and capacitors needed for the same power transfer and filtering capability. Since VMOS is a voltage controlled device, drive circuits are much simpler and consume less power than high current bipolar drives. VMOS' rectangular safe-operating area means that maximum rated voltage and current can be controlled simultaneously with no fear of second breakdown. Snubbers add extra cost and dissipate excess power in bipolar designs – none are needed to protect VMOS Power FETs. Catch diodes are required for totem-pole switch configurations such as full-bridge and half-bridge power supplies to catch high voltage inductive spikes. These diodes must be added externally to bipolar designs at extra cost, but they are already built into VMOS Power FETs.

Their rugged safe-operating area, built-in catch diodes and simpler drive circuits make designing with VMOS Power FETs simple and economical.

Power Supply Overview

The power supply presented here uses two VN4000A 400 volt VMOS Power FETs in a half-bridge power switch configuration (Figure 1). Outputs available are +5 volts at 20 amperes and ±15 volts (or ±12 volts) at 1 ampere each. Since linear three terminal regulators are used for the low current outputs, either ±12 or ±15 volts can be made available with a simple change in the transformer secondary windings (see Construction Details). A TL494 switching regulator IC provides pulse width modulation control and drive signals for the power supply. The upper VMOS Power FET (Q_7) in the power switch stage is driven by a simple transformer drive circuit. The lower VMOS (Q_6), since it's ground referenced, is directly driven from the control IC.



100 KHz, 150 Watt Half-Bridge Switching Power Supply
Figure 1

For initial start-up, a linear regulator (Q_3, R_4 and D_2 in Figure 1) supplies about 14 volts from the full-wave rectified line voltage for all the drive and control circuitry. Once the power supply starts up, the voltage from a separate secondary winding (#2) is rectified and filtered and used to supply all power to the control IC and drive circuitry. When this supply reaches full voltage (about 18 volts) diode D_1 is reverse biased thus automatically turning-off the less efficient linear regulator used for start-up. A minimum current of one ampere must be drawn from the +5 V output to assure turning off the linear start-up regulator. If less current is drawn from this output, the control circuitry will be powered by the linear regulator and excess power will be dissipated in Q_3.

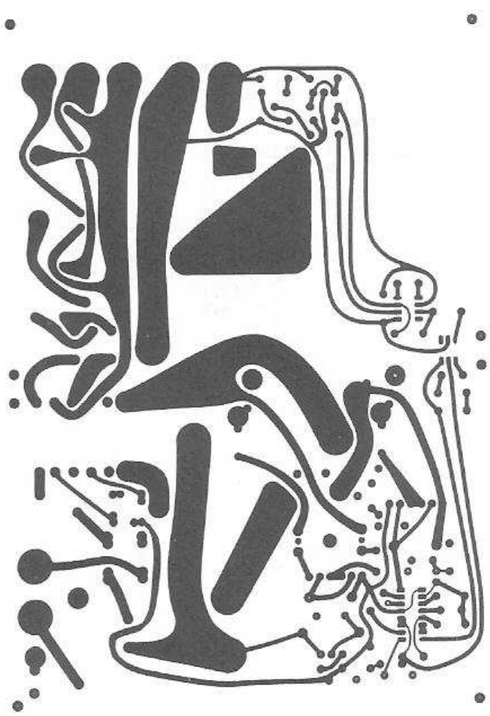
All outputs are isolated from the AC power line. The 5 volt output was chosen to be the main regulated output controlled by the pulse width modulator. Feedback from this output is optically isolated from the line side of the power supply. The complete supply is over-current protected by sensing the primary current in the lower VMOS Power FET (Q_6) and using this signal to shut down the supply.

CONSTRUCTION DETAILS

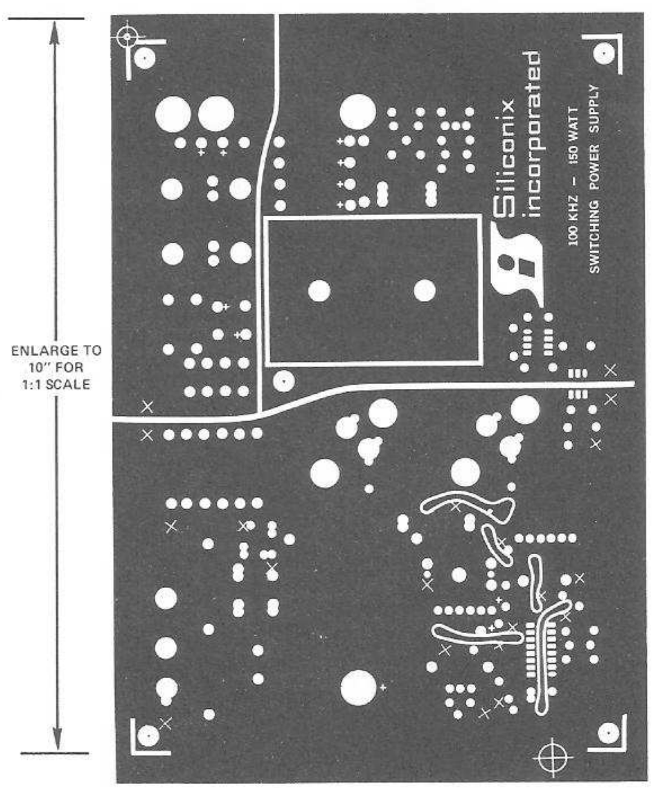
Careful circuit board layout is very important for the proper operation of high power, high frequency switching regulators. Single point grounding is absolutely necessary to prevent ground loops from rendering the circuit totally unstable or inoperable. Ground planes are also required to lessen the effects of electromagnetic interference on the circuit. Presented here is a circuit board layout which is known to operate correctly and reliably. Use of this layout will make the construction of this power supply much simpler and will speed your evaluation of the VN4000 series of high-voltage VMOS Power FETs.

Circuit Board

The circuit board layout (Figure 2) uses double sided construction. Most of the traces are on the bottom side of the board while the top side is used as a ground plane. Three ground planes are used – one for the input and control circuitry, one for the ±15 volt outputs and one for the +5 volt output. If a common ground is desired for all DC outputs, both output ground planes may be connected together.



Circuit Board (Bottom Side)
Figure 2a



Circuit Board (Top Side)
Figure 2b

For copies of 1:1 scale for circuit board, write to Siliconix c/o the author.

Plated-through holes are not necessary for making the circuit board, but they would be useful. If plating-through is not used, all of the components connecting to top traces or the ground plane must be soldered on top of the board in addition to any soldering necessary on the bottom. There are a few connections from one side of the circuit board to the other side that do not have components mounted in them. If plating-through is not used, a short piece of wire must be soldered in these holes to both sides of the board. All solder points on the top side are indicated by an 'X'. Table I shows the recommended drill sizes to be used for drilling the circuit board.

TABLE I. RECOMMENDED DRILL SIZES

The following drill sizes should be used on the circuit board:

#66	IC1-IC3, 1/4 W resistors, disc capacitors, opto-isolator, Q_1-Q_5, D_1-D_6, C_6, C_{13}
#60	T_1 bobbin leads, 1/2 W resistors, C_8, C_9, T_3 secondary
#57	1 W resistors, T_2 bobbin leads, D_7-D_{10}, C_7
#54	R_{10}, IC4, IC5, L_1–L_4, R_{24}, T_3 primary
#44	TO-3 lead sockets, line cord
#23	IC4, IC5, TO-3 screw-mount holes, 5 V CT
3/16"	D_{11}, D_{12}
1/4"	C_5
5/16"	Banana jacks

Transformers

Three transformers are used in this power supply: 1) VMOS drive transformer, 2) power transformer and 3) current sense transformer. The winding details explained here should be closely followed, especially for the power transformer T_2.

T_1 – VMOS Drive Transformer

Using the correct bobbin and pot core (see parts list), wind the following:

Primary (1) – 20 turns of #24 enamel wire

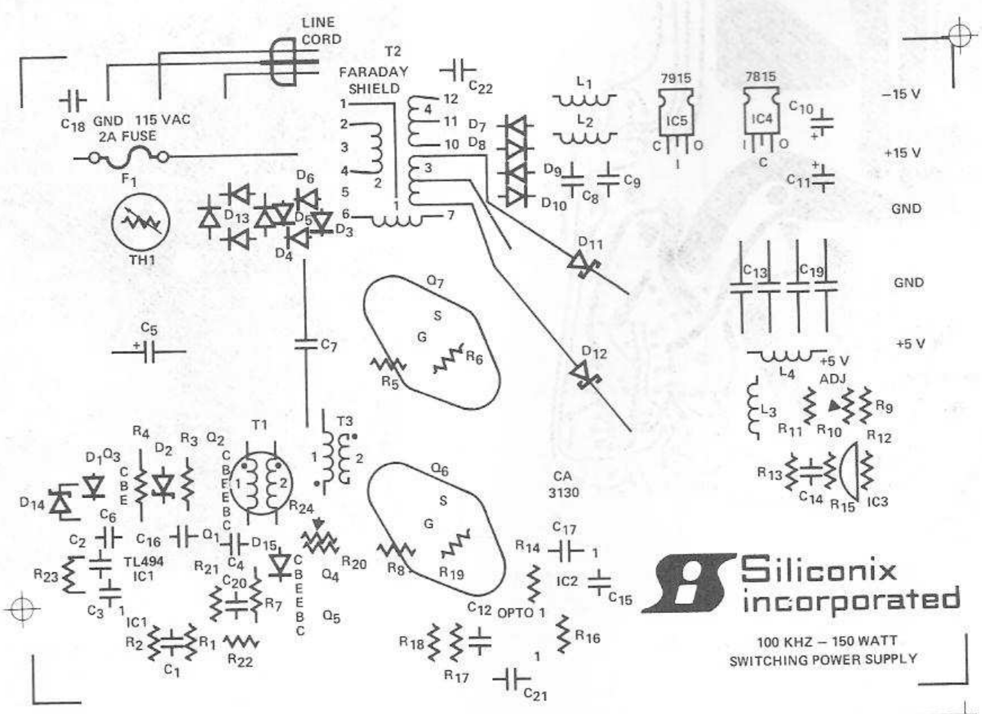
Secondary (2) – 30 turns of #24 enamel wire

Make all connections to the bobbin according to the parts placement diagram (Figure 3).

T_2 – Power Transformer

Using the appropriate bobbin, wind the following (pin 1 of the bobbin has a notch for identification):

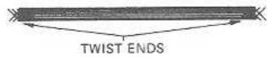
Primary (1) – The primary is made up of a type of litz wire using several strands of regular enamel wire (refer to Figure 4). Cut 8 strands of #28 enamel wire (about 6 feet long) and place them together in parallel. Twist the ends only together (not the whole length), but do not solder. Fold this twisted bundle of wires in half and wind 8 turns of this doubled over bundle onto the bobbin. Cut the folded over end of the bundle so that there are now 4 ends coming out of the bobbin. Twist the ends of each newly cut bundle. Next, connect one of the beginning bundles (D) to the end of the other (B). This effectively connects the bundles in series, wound in the same direction, to form a single 16 turn primary. The purpose of winding in this manner is to equalize the flux across the transformer core. There should now be two ends of the wire free and two ends connected to each other. Connect the free ends to the bobbin as shown in Figure 3. Make sure all windings are wound tight and neat – do not waste any space. Now put a layer of transformer tape to cover the primary.



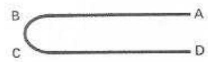
Parts Location Diagram

Figure 3

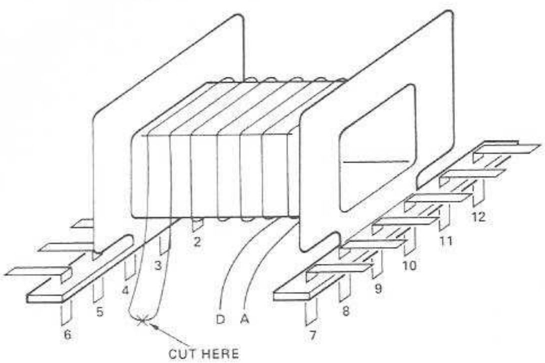
Step 1 – Parallel 8 strands #28 wire



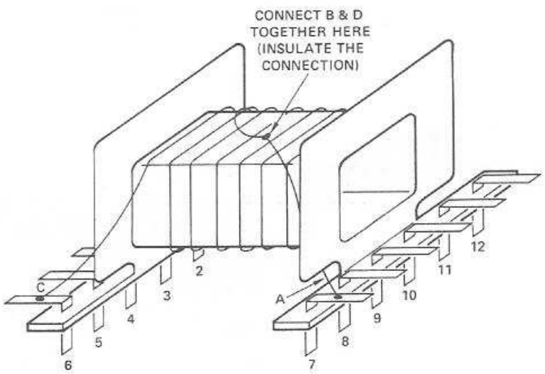
Step 2 – Fold in half



Step 3 – Wind on bobbin



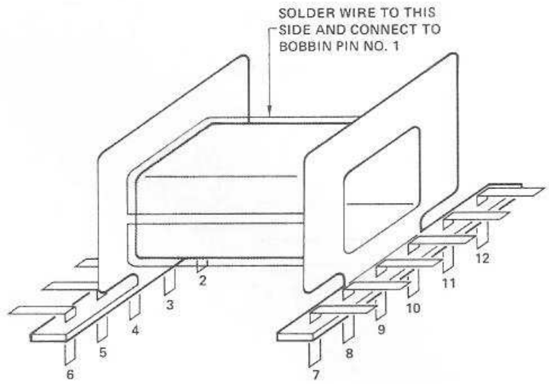
Step 4 – Connect C and A to pins 6 and 7



Primary Power Transformer
Figure 4

Secondary (2) – Start-up Winding: Wind 4 1/2 turns of #24 enamel wire (about 20 inches long) evenly on top of the primary winding. Connect the ends as shown in Figure 3. Put a single layer of transformer tape over the start-up winding.

Faraday Shield – This is a shield used to minimize radiated electromagnetic interference (EMI). Cut a piece of 5/8 inch copper tape about 3 inches long and wrap this around the existing windings (refer to Figure 5). Do not make a complete loop – leave about 1/4 inch between the ends so that they can't touch. Solder a small stranded wire (#20) onto the shield and connect it to the bobbin as shown in Figure 3. Put a layer of transformer tape over the Faraday shield.



Faraday Shield
Figure 5

Secondary (4) – ±15 volt secondary. Make another litz wire similar to the primary but this time parallel 6 strands of #28 enamel wire about 40 inches long (refer to Figure 6). Twist the ends together and double the bundle over itself. Wind 5 turns of this doubled over bundle neatly on the bobbin (4 1/2 turns for ±12 V outputs). Cut the double end and connect B and D together and connect to bobbin pin #11. Connect the two free ends of the bundle to the other bobbin pins. Put a layer of transformer tape over these windings.

Secondary (3) – 5 volt secondary: Make up some insulated copper tape by placing transformer tape on one side of a 10 inch long piece of 5/8 inch wide, 2 mil copper tape (refer to Figure 7). Make two of these insulated tapes. Make sure the transformer tape is slightly wider than the copper tape so that the windings don't short to each other. Wind both of these insulated tapes at once (like bifilar tape) for two turns. Connect the beginning of one tape (A) to the end of the other tape (D) – this is the 5 volt center tap. Connect three #18 stranded wires (or #18 ribbon cable) in parallel to each of the free copper tape ends and to the center tap. Spread out the stranded wires flat when soldering to the copper tape – this makes a much neater and less bulky connection. Connect the ends of these paralleled wires to the output rectifiers and P.C. boards as shown in Figure 3. Wrap a final layer of transformer tape to hold everything together.

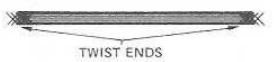
T_3 – Current Sense Transformer

Place the windings directly on the toroid:

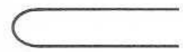
Secondary (2) – Wind the secondary first. Wind 7 turns of #20 enamel wire (about 10 inches long) onto one side of the toroid (Figure 2).

Primary (1) – Form the primary by soldering 2 strands of #16 enamel wire to the circuit board connections (Figure 3). Run these strands through the center of the toroid. This forms one turn primary. Solder the secondary into the board as shown (Figure 8).

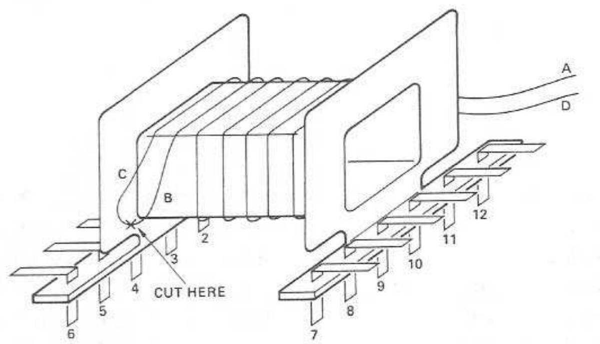
Step 1 – Parallel 6 strands #28 wire



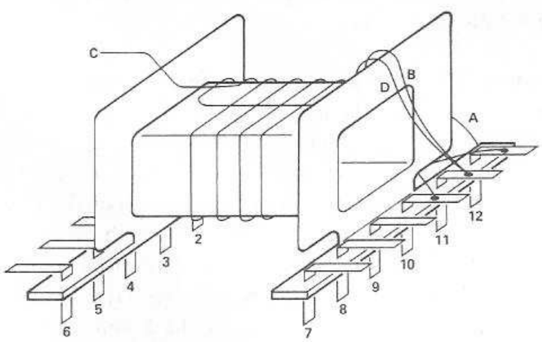
Step 2 – Fold in half



Step 3 – Wind on bobbin

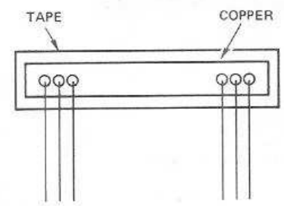


Step 4 – Connect the free ends to bobbin pins #10, 12. Connect doubled over end to pin 11.

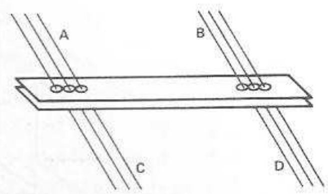


±15 V Secondary
Figure 6

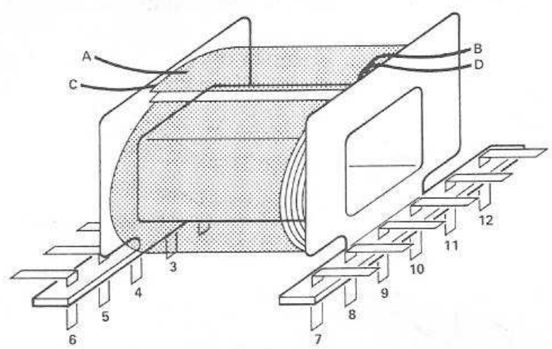
Step 1 – Make two insulated copper straps



Step 2 – Place one strap on top of the other with leads on opposite sides.



Step 3 – Wrap two turns of this double copper tape onto the bobbin. Connect A to D and solder this center tap into the circuit board. Connect the other free ends, B and C, to diodes D_{11} and D_{12}.



5 V Secondary
Figure 7

Output Inductors

L_1 and L_2 are identical. Wind one turn of #18 enamel wire through each core and solder to the circuit board.

L_3 is also one turn, but use three strands of #18 in parallel.

L_4 is an air core inductor. Close wind 10 turns of #16 wire on a 5/16 inch diameter form.

Heat Sinks

Mount the TO-3 heat sinks off the board with 1/4 inch spacers (to make space for R_5, R_6, R_8 and R_{19}). No insulating washers are needed, but heat sink compound should be used.

Mount IC4 and IC5 onto their heat sinks with thermal compound. IC5 should be insulated from the heat sink. Use metal screws for mounting IC4 and IC5. Cut off the center lead of each regulator and insert the other two pins into the circuit board.

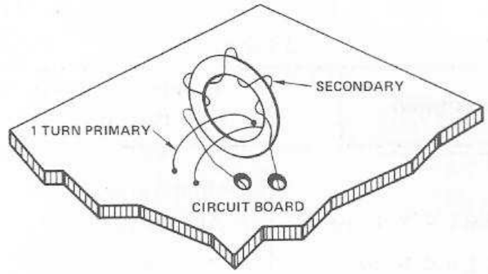
Schottky rectifiers D_{11} and D_{12} mount directly on the heat sink with thermal compound. Use star washers for a good electrical connection when bolting rectifiers D_{11} and D_{12} to the board.

Miscellaneous

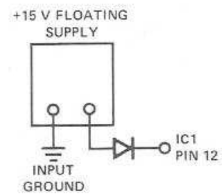
Use star washers on both sides of the board when mounting C_5. IC sockets may be used for IC1, IC2 and Opto 1.

ALWAYS use an isolation transformer when connecting an oscilloscope to look at waveforms on the primary side of the power supply.

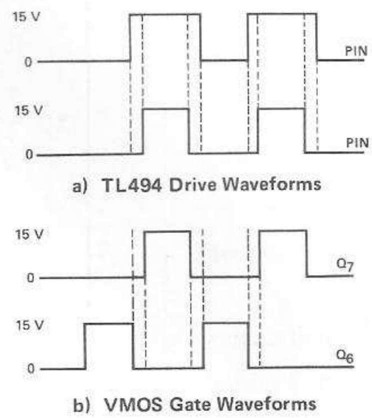
Do not mount Q_3 until after the initial test procedures.



Current Sense Transformer
Figure 8



Power-Up Connection
Figure 9



Drive Circuit Waveforms
Figure 10

Power-Up Procedures

Even though this is a proven circuit board, the control circuitry should be checked separately before powering up the complete supply. To do this, connect an isolated +12 volt supply through a diode between pin 12 of IC1 and ground (Figure 9). Use an oscilloscope to check the drive signals at pins 9 and 11 of IC1. These signals should be in-phase, quasi-square waves at a frequency of 100 KHz (Figure 10a). When these signals check OK, look at the gate waveforms of the VMOS Power FETs. These waveforms should be out of phase (Figure 10b). Q_7's waveform may have some overshoot. With Q_3 still out of the circuit board, connect a variac or a high voltage DC power supply to the AC input. Slowly increase this power supply voltage (the control circuitry is still running with the floating 12 V supply) while monitoring the output voltage. When the 5 volt output gets somewhere between 4.5 volts and 6.5 volts the supply should begin regulating and further increases in the input voltage will not change the output. No significant current should be flowing from the high voltage supply at this time. Check the ±15 volt outputs for the correct voltage.

While monitoring the supply voltage on pin 12 of IC1 (using a floating voltmeter) connect a load to the 5 volt output to draw about 1 ampere. The supply voltage on pin 12 should increase to about 15-20 volts if the power supply winding #2 on T_2 is working correctly. If everything works correctly so far, disconnect all power supplies and install Q_3 in the circuit board. Using a variac or DC power supply and a floating voltmeter (or an isolation transformer and a non-floating meter), increase the input voltage to the line cord to about 20 VDC or 40 VRMS while monitoring the supply voltage on pin 12 of IC1. This voltage should level off around 10-12 volts. Connect a minimum load to the power supply (5 Ω, 5 W) and increase the line voltage to full voltage. IC1's supply voltage should increase to about 15-20 volts.

The power supply is now ready for use. Adjust the output voltage to 5 volts using R_{10}. Adjust the current limit R_{24} with the ±15 volts fully loaded and the +5 volt output delivering about 25 amperes. A minimum current of about 5 amperes must be drawn from the 5 volt output for the ±15 volt outputs to be able to deliver 1 ampere each.

The power supply may now be plugged in directly to the power line for operation. The only requirement necessary is to have a minimum load of about 1 ampere at all times on the +5 volt output.

Power Supply Features and Specifications

5 Volt Output

- 20 Amperes output current
- 0.2% line regulation (±20% line variation)
- 0.4% load regulation (no load to full load)
- < 100 mVp-p ripple and noise at full load
- Output over-current protection
- ≤ 0.5 ms transient response time (no load to full load)
- Over-current protected

15 Volt Outputs

- 1 Ampere output current each
- 0.2% line regulation
- 1.0% load regulation
- < 10 mV ripple
- Short circuit current limiting

VN4000A Features

- 400 volt BV_{DSS}
- < 1 ohm on-resistance
- < 100 ns switching times
- Rugged safe-operating area
- No secondary breakdown

PARTS LIST

Part #	Quantity	Description	Recommended Mfg. & Part Number
Resistors			
R_1	1	5.1 KΩ ±5% 1/4 W Resistor	Allen Bradley
$R_2, R_6, R_9, R_{12}, R_{13}, R_{15}, R_{19}$	7	1 KΩ ±5% 1/4 W Resistor	
R_3, R_7	2	330 Ω ±10% 1/2 W	
R_4	1	33 K ±10% 1 W	
R_5, R_8	2	50 Ω ±5% 1/4 W	
R_{10}	1	500 Ω ±10% Trimpot	
R_{11}	1	1.2 KΩ ±5% 1/4 W	
R_{14}, R_{17}	2	100 KΩ ±5% 1/4 W	
R_{16}, R_{23}	2	470 Ω ±5% 1/4 W	
R_{18}	1	20 KΩ ±5% 1/4 W	
R_{20}	1	18 Ω ±10% 1 W	
R_{21}	1	100 Ω ±5% 1/4 W	
R_{22}	1	180 Ω ±5% 1/4 W	
R_{24}	1	100 Ω ±10% Trimpot	
Capacitors			
C_1	1	0.001 μF Ceramic Disc	
C_2	1	0.05 μF Ceramic Disc	
$C_3, C_{14}, C_{16}, C_{17}$	4	0.1 μF, 25 V Ceramic Disc	
C_4	1	1.0 μF, 25 V Electrolytic	
C_5	1	710 μF, 200 V Electrolytic (32D)	Sprague
C_6, C_8, C_9	3	47 μF, 25 V Electrolytic	
C_7	1	1.0 μF, 400 V TRW-35	TRW
C_{10}, C_{11}	2	2 μF, 25 V Tantalum	
C_{12}	1	200 pF Mica	
C_{13}, C_{19}	4	220 μF, 10 V Tantalum	Mallory 227K010P1G
C_{15}	1	5 pF Mica or Ceramic	
C_{18}, C_{21}, C_{22}	3	0.01 μF, 5 KV Ceramic	
C_{19}	1	10 μF Electrolytic	
C_{20}	1	6.8 μF Electrolytic	
Integrated Circuits			
IC1	1	TL494 PWM IC	Texas Instruments
IC2	1	CA3130 Op-Amp	RCA
IC3	1	TL430 Voltage Reference	Texas Instruments

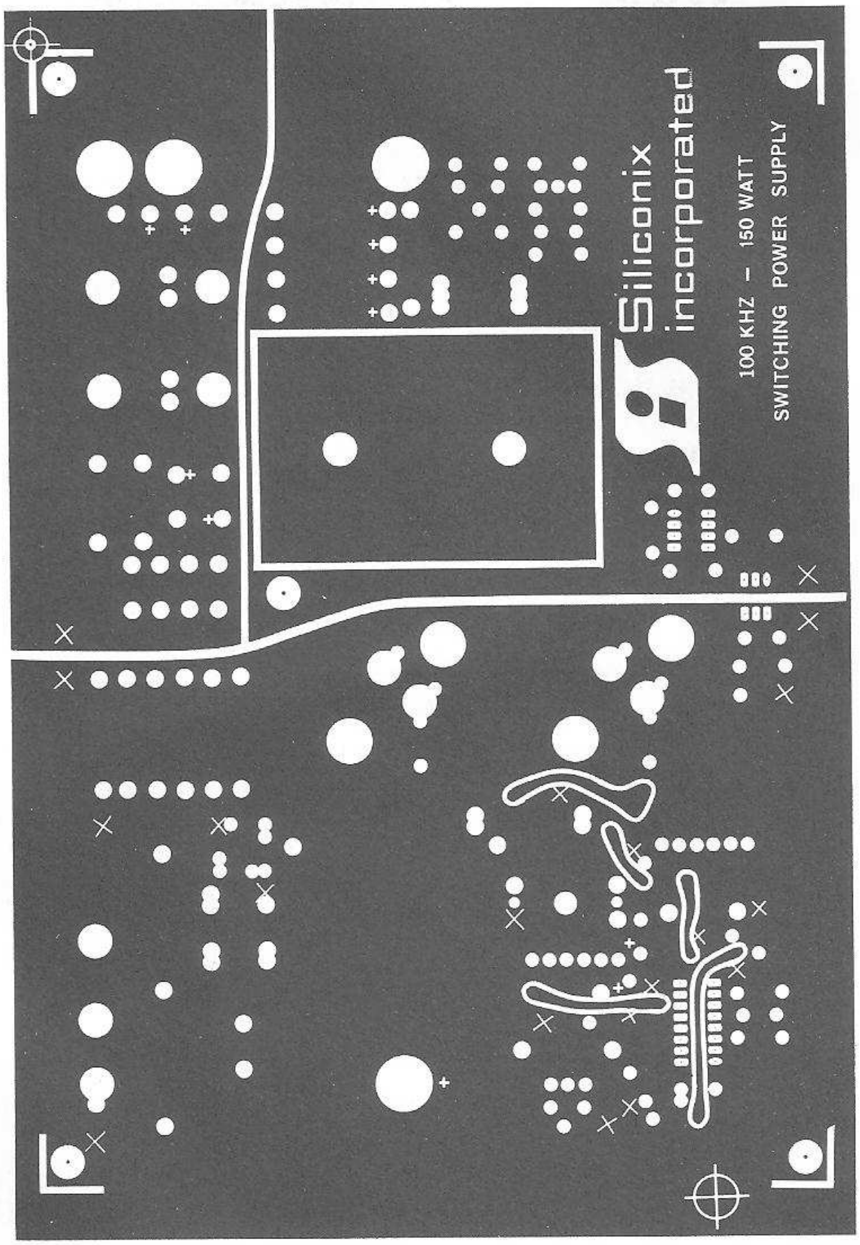
PARTS LIST (CONTINUED)

Part #	Quantity	Description	Recommended Mfg.
Integrated Circuits (continued)			
IC4	1	μA7815UC +15 V Regulator (μA7812UC +12 V)	Fairchild
IC5	1	μA7915UC −15 V Regulator (μA7912 −12 V)	Fairchild
Diodes/Rectifiers			
$D_1, D_3–D_6, D_{14}, D_{15}$	6	1N4148 Diode	Motorola
D_2	1	1N4107 Zener	Motorola
$D_7–D_{10}$	4	1N5804 Fast Recovery	Unitrode
D_{11}, D_{12}	2	1N5831 Schottky	Unitrode
D_{13}	4	1N5406 Rectifier	Motorola
D_{14}	1	1N5360 Zener	Motorola
Ferrites & Accessories			
T_1	1	F1146-1-06 Pot Core	Indiana General
T_1 Bobbin	1	B475-1	Indiana General
T_2	1	IR8030-1	Indiana General
T_2 Bobbin	1	B680-1	Indiana General
T_3	1	BBR7727-1 Toroid	Indiana General
L_1, L_2	2	F1146-1-TC9	Indiana General
L_3	1	F2037-1-TC9	Indiana General
Transistors			
Q_1, Q_4	2	2N4400	Motorola
Q_2, Q_5	2	2N4403	Motorola
Q_3	1	MPSU10	Motorola
Q_6, Q_7	2	VN4000A VMOS Power FET	Siliconix
Miscellaneous			
Opto 1	1	H11A1 Opto-Isolator	G.E.
TH_1	1	2D754 Thermistor	Midwest Components, Inc.
F_1	1	2 A Fast Blow Fuse	Buss
TO-3 Heat Sink	2	LAT03B5CB	IERC
TO-220 Heat Sink	2	LAD66A4CB	IERC
TO-3 P.C. Sockets	4	LSG-3DG2-1	Augat
D_{11}, D_{12} Heat Sink	1	E240-001	IERC
Output Banana Jacks	5		
3-Wire Line Cord	1		
Fuse Block for F_1	1		

Circuit Board (Bottom Side)

Scale 2:1

Circuit Board (Top Side)



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