

# The Techno-Whizzy 1, Part I

*Build a direct digital synthesis (DDS) radio.*

by John Welch N9JZW

I've grown tired of the same old designs being rehashed over and over again. I wanted something new, something state-of-the-art, but my wallet balked at paying over \$2,000 for a new rig. Nobody offered a cheap Direct Digital Synthesized (DDS) radio but, folks, it is not only possible to design one, it is both fun and easy.

No, it doesn't have *all* the bells and whistles yet. What it does offer is a chance to build a DDS radio of your own, for a lot less than buying a whole new rig. It's modular, so as I (or you) design new boards they can be added to the basic unit without throwing out all your work. I call it the TW-1, for Techno-Whizzy, model 1.

The TW-1 is a modular multiband CW QRP transmitter, using a new Direct Digital Synthesis (DDS) chip from Qualcomm (1055 Sorrento Valley Rd., San Diego CA 92121; Tel: (619) 597-5005). It has 11 diode-programmable channels and one dip switch variable frequency channel, and it puts out 2 watts from 1 MHz through 21.5 MHz (that's 160 meters, 80 meters, 40 meters, 30 meters, 20 meters, 17 meters and 15 meters, FULL COVERAGE, plus many MARS and CAP bands to boot). With some modifications to the amplifier stage it can even cover the 1750 meter Experimenters Band. I'm planning to eventually add a receiver board, a linear amp, a doubler to get full HF coverage, a digital signal processor to handle SSB and a digital frequency display with keypad input.

Instead of a VFO, the heart of this transmitter is the new Q2220 DDS chip from Qualcomm. It runs at 55 MHz clock input, and has a 24-bit phase accumulator. In English, this means that the minimum frequency change is  $55,000,000 / 2^{24}$  (two raised to the 24th power), or just about 3 hertz. Above 1/8th the clock frequency, the quality of the output signal falls off, but tight filtering can remove the harmonics. Between 1/3 and 1/2 the clock frequency is the maximum output frequency you'll get without a *lot* of fancy filters. I've designed the TW-1 to run at any frequency from 3 hertz to over 21 MHz in 3 Hz steps while maintaining a decent sine wave output to the amplifier. With the additional filtering after the amplifier, it's FCC legal—the spurious emissions are all more than 30 dB down as measured on a spectrum analyzer.

## How It Works

The frequency is set using pull-up resistors and diodes. The input to the Q2220 chip is binary (don't panic—I'll explain this later), with 1's being a 5-volt input and 0's being

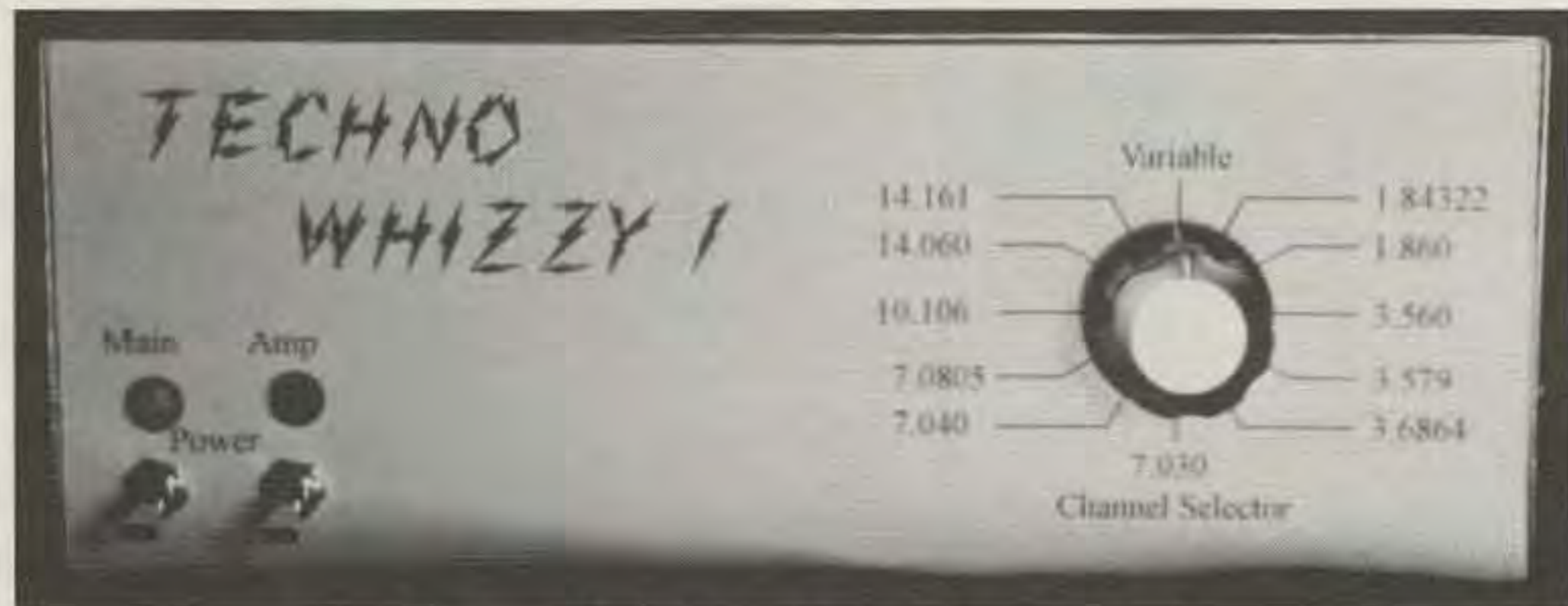


Photo A. The Techno-Whizzy 1 DDS transmitter.

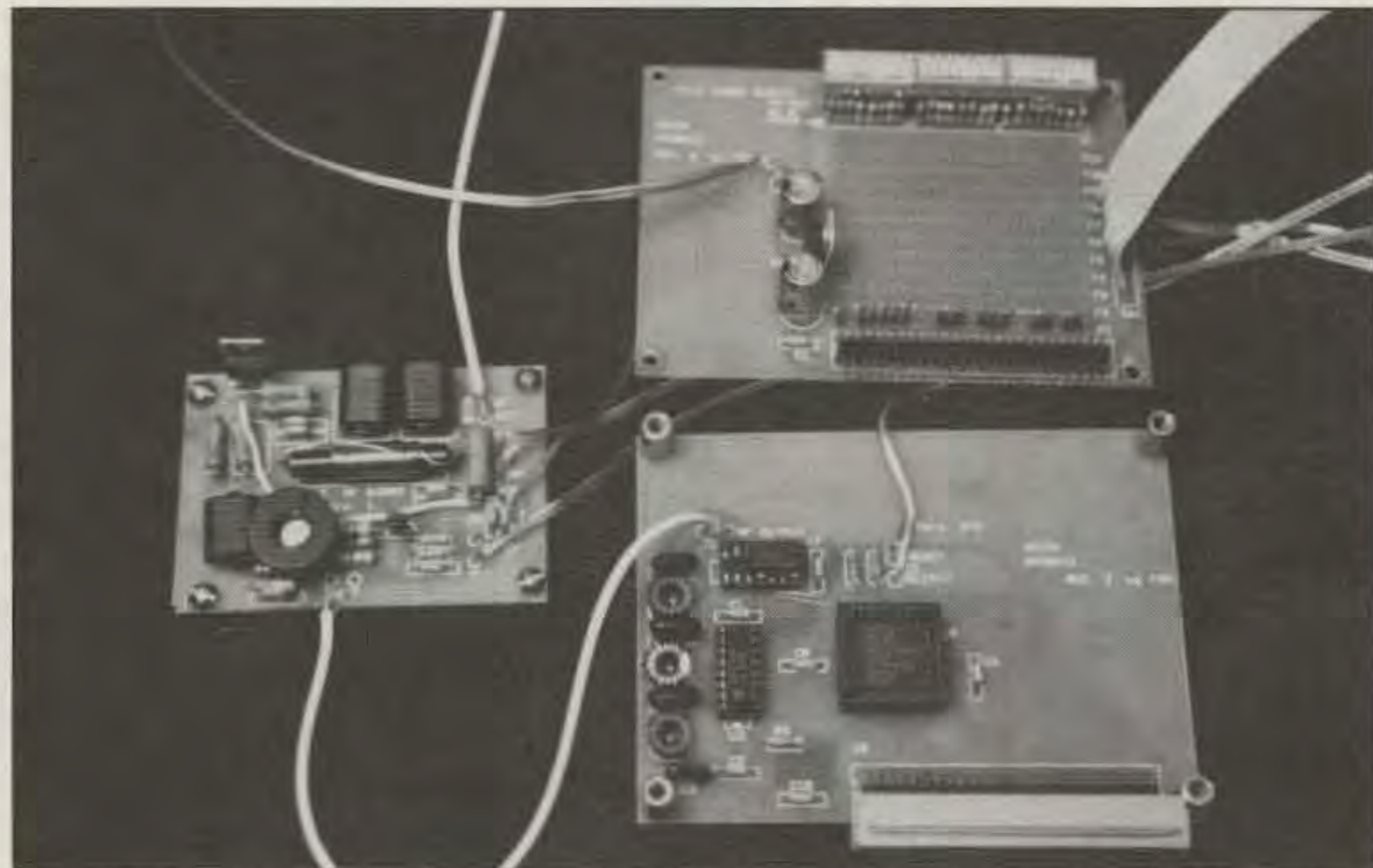


Photo B. The TW-1 DDS transmitter consists of three separate PC boards. The RF amplifier is shown on the left, the diode matrix for frequency selection is shown at the upper right and the DDS synthesizer board at the lower right.

grounded inputs. There is a line of pull-up resistors, one for each input line, and a place to install pull-down diodes. When you select a channel, it grounds the cathode end of that row of diodes, pulling those lines low.

The Q2220 reads the input lines from the frequency selection board 55 million times a second (once per clock cycle), and adds that value to its current value in the phase accumulator. (If the result is larger than  $2^{24}$ , it subtracts  $2^{24}$  from it to keep the phase angle between 0 and  $2^{24}$ ). This number, expressed as a percent of  $2^{24}$ , tells the DDS how far around a circle it currently is. It then calculates the sine at that position, and outputs the sine's value to the Digital-to-Analog Converter (DAC).

The DAC then takes this value and translates it into a voltage between DC and 1 volt. At this point, the signal doesn't look like a

sine wave—it looks like a staircase with up to 256 steps built on a sine wave. To remove the "staircase," the signal is passed through a seven-pole low-pass filter that cleans it up. The now-clean sine wave (at 2 milliwatts) is sent to a low-level class A linear RF amplifier.

If the key is on, power is applied to the class A driver amplifier, which then amplifies the signal to 80 milliwatts and passes it to the final amp. The final runs class A also, for maximum linearity (after all, if you've gone through all the trouble of making a clean sine wave, why mess it up with a non-linear amp?). The final outputs 2 watts into a 50-ohm load (either a dummy load or your antenna).

Switching to another frequency is easy; just turn the channel knob. The DDS chip reads the new value, and starts all over from

there. It takes six clock cycles for this change to be seen at the driver stage, which is about 120 ns—so fast it's effectively instantaneous. There are no adjustments to tweak, no guessing where you are—just *click* and you're there. That's the joy of a digital rig!

### How to Set the Frequency

Okay, now for the hard part—math! With the simple setup this rig has, you do have to do some pencil work. It's not hard, and you can even cheat two ways—I've included a table of several standard QRP frequencies and there's BASIC source code for a program to compute the frequency if you have a computer.

Keep in mind that there is a difference between repeatability and absolute accuracy. This rig is repeatable—a channel is always on the same frequency it was last time. It can also be accurate, but you'll have to measure the output frequency of your particular oscillator. Mine was 55.001 MHz or so at room temperature. If you want accuracy, use your exact oscillator frequency instead of 55 million in the following calculations. Note: The table was designed using 55 million—it'll be close to the correct frequency and repeatable, but not absolutely accurate.

Remember earlier where I said the DDS has a 24-bit phase accumulator, and runs at 55 MHz? The size of a step, then, is 55 million divided by  $2^{24}$ . To get the radio on your desired frequency, divide your frequency by that step (55000000/16777216, or 3.2782555). Convert this number to binary—use a scientific calculator, computer or a

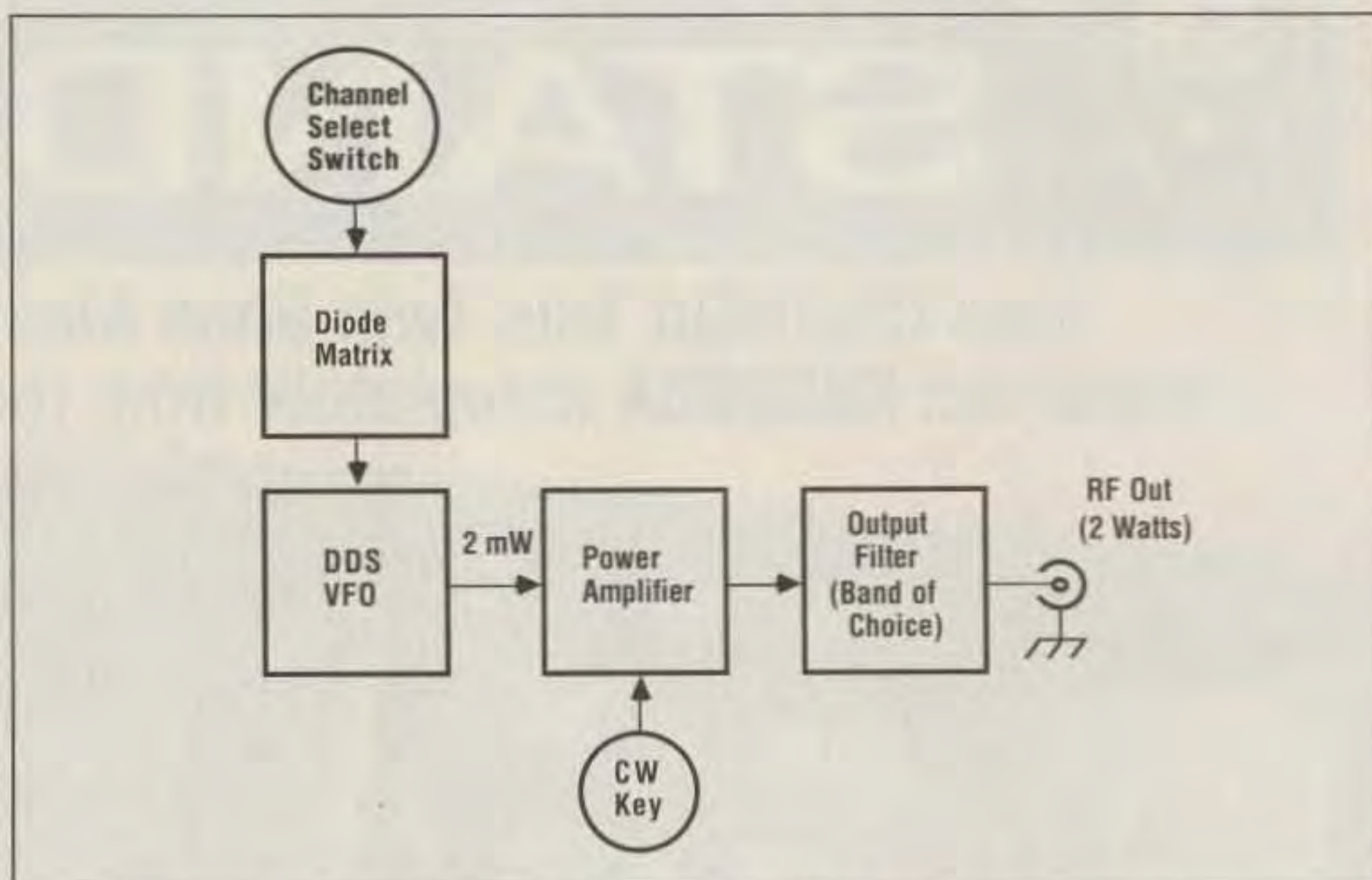


Figure 1. Block diagram of the TW-1 DDS transmitter circuit.

13-year-old computer nut for this. The number must have 23 digits—if you're short a few, put 0's at the *LEFT* side until you have 23 digits.

Pick an unused switch position and find the line of holes for that channel (they're numbered starting from F1 at the ribbon cable back to F11 near the resistor packs). Counting from left (nearest the power supply) to right, at every place you had a 0 put in a diode (1N914s will work fine) with the cathode (the banded end) in the air and the anode through the hole. Leave any spot that had a 1 empty. Run a wire tying all the cath-

odes together, and run that wire into the hole nearest the silk-screened "F???" label for that channel. When you switch the channel selector to that channel, the diodes conduct, pulling those lines to ground. The lines without diodes remain at 5 volts.

For example: If you want to set the TW-1 to 7,040 kHz on channel 1, take  $7040000/3.2782555 = 2147483$ . Converting this to binary gives you 010 0000 1100 0100 1001 0110. You would put a diode in holes 1,3,4,5,6,7,10,11,12,14,15,17,18,20 and 23. (See Figure 6 for details). If you wanted this frequency on the DIP switch channel (chan-

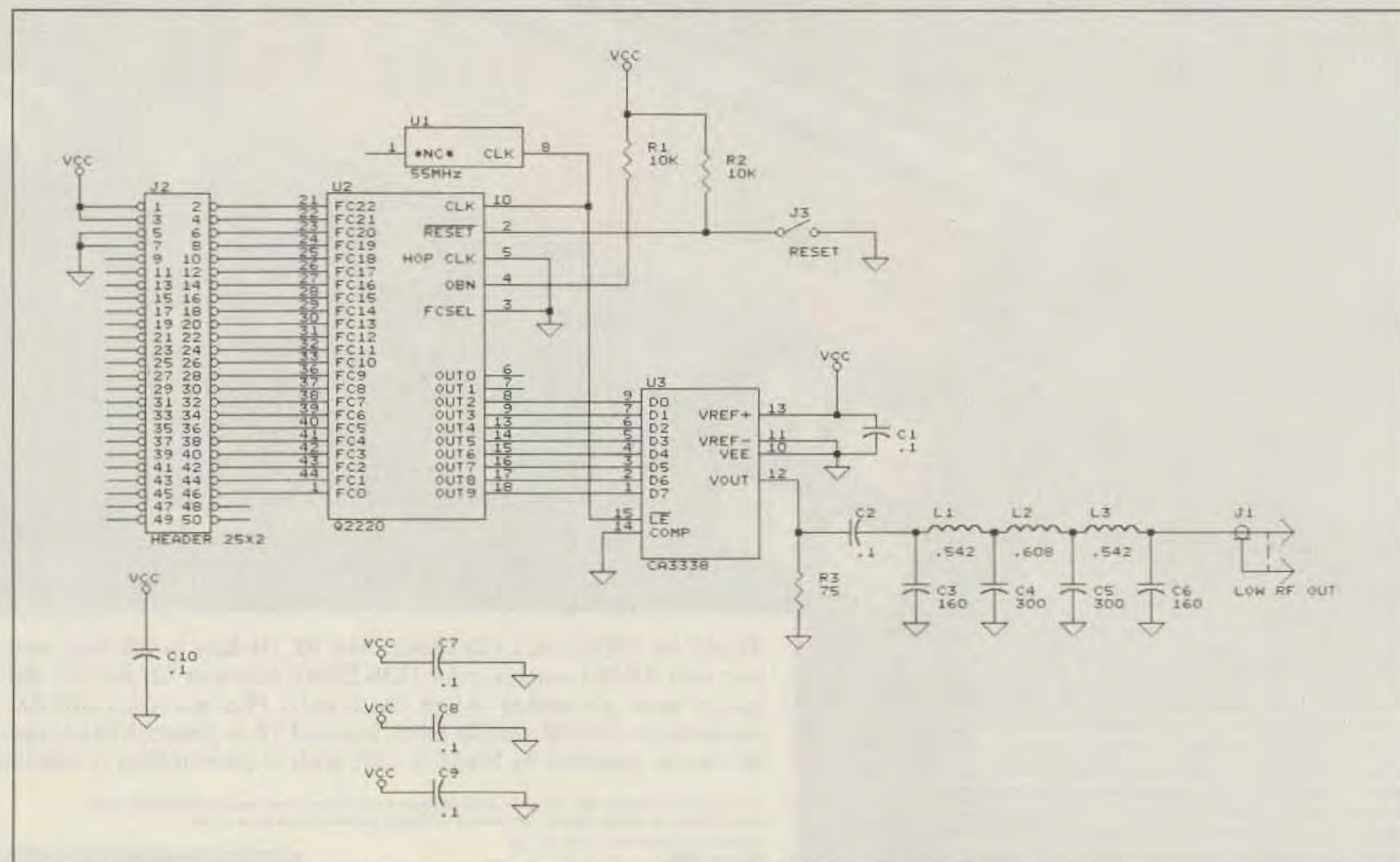


Figure 2. Schematic diagram of the DDS VFO board.

nel 12), for any digit that was a 0 turn the switch ON. This will pull those lines to ground when you select channel 12.

Doing 7030 kHz gives 2144433, or 010 0000 0110 1000 0110 0001 in binary. 10.106 MHz gives 010 1111 0000 1001 1111 0001 in binary. For other values, see the chart on p. 18 showing some common QRP frequencies. If you don't like the math and need a different frequency, I've written a program you can use (see the program listing on p. 18).

### Construction

Take a tip from me—use a fine-tipped low-wattage soldering iron for these boards. The pins sometimes have traces running between them, so keep a keen eye out for solder bridges and cold solder joints. When you're done soldering, nip off the leads close to the boards. This keeps things looking neat and will prevent accidental shorts when you assemble the boards into a chassis.

Build the power supply and frequency selector board first. Install the DIP switches and their diodes first, with the banded ends of the diodes tied together to the hole near the DIP switches. Set the DIP switch (channel 12) to 7,040 kHz (see above). Attach the

12-position channel switch to a short length of ribbon cable, with the common connection on the red wire. Run this cable to the 13 holes at the right side of the board, with the red wire at the top. Bend one set of pins on the resistor packs horizontal (or use individual resistors—I did), and put the resistor packs on the board with the horizontal set of leads in the holes and the other set in the air. Run a bare wire from the JUMPER hole across the pins in the air, soldering to each pin. Install the 50-pin header, being careful of shorts. Make sure you have the 7805 and the electrolytic caps in correctly. Check all connections for shorts and bad solder joints. When you're satisfied with your work, apply 12 volts to the power supply. You should have 5 volts at the jumper; if not, check your wiring.

At the holes marked FF (for Frequency, Future), you should read 5 volts on holes 2,8,9,13,16,19,21 and 22. Holes 1,3,4,5,6,7,10,11,12,14,15,17,18,20 and 23 should be at ground (0.7 volts or less). Remove power from the board and it's functional!

Next, build the DDS board. Install U1, the clock oscillator, first. The mounting is designed to allow either a 14-pin-sized oscillator or an 8-pin-sized oscillator. Pin 1 is the same for either, but the 8-pin-sized oscillator

is shorter and only reaches to the first set of holes. A 14-pin-sized device covers the middle set of holes, and installs in the second set of holes. If you want to socket this chip, use a 14-pin socket but remove the unused pins. Also, install the jumper wire from U1 to U2 now.

Install the socket for the DDS chip (U2) next. Make sure the socket matches the outline, with pin 1 facing up and the angled corner in the upper left. Install U3, the DAC, and the 50-pin header. These parts all have wires between pins, so be very careful when soldering them.

I socketed U3, and ran into phase jitter problems that were cured by adding two extra bypass caps soldered directly to the pins on U3. I added a 1.0  $\mu$ F cap between pins 16 and 14, and another between pins 13 and 11. For best results, these should be tacked in either on the chip or under the board, but keep the leads as short as possible for good bypassing.

Install the filter next. L1 and L3 are 12 turns on a T37-2 (red) core and L2 is 14 turns on a T37-6 (yellow) core. For those who are new to this, a "turn" is any time the wire goes through the hole. (A bobby-pin on a core would be one turn.) Once you have these wound, spread the turns out to cover

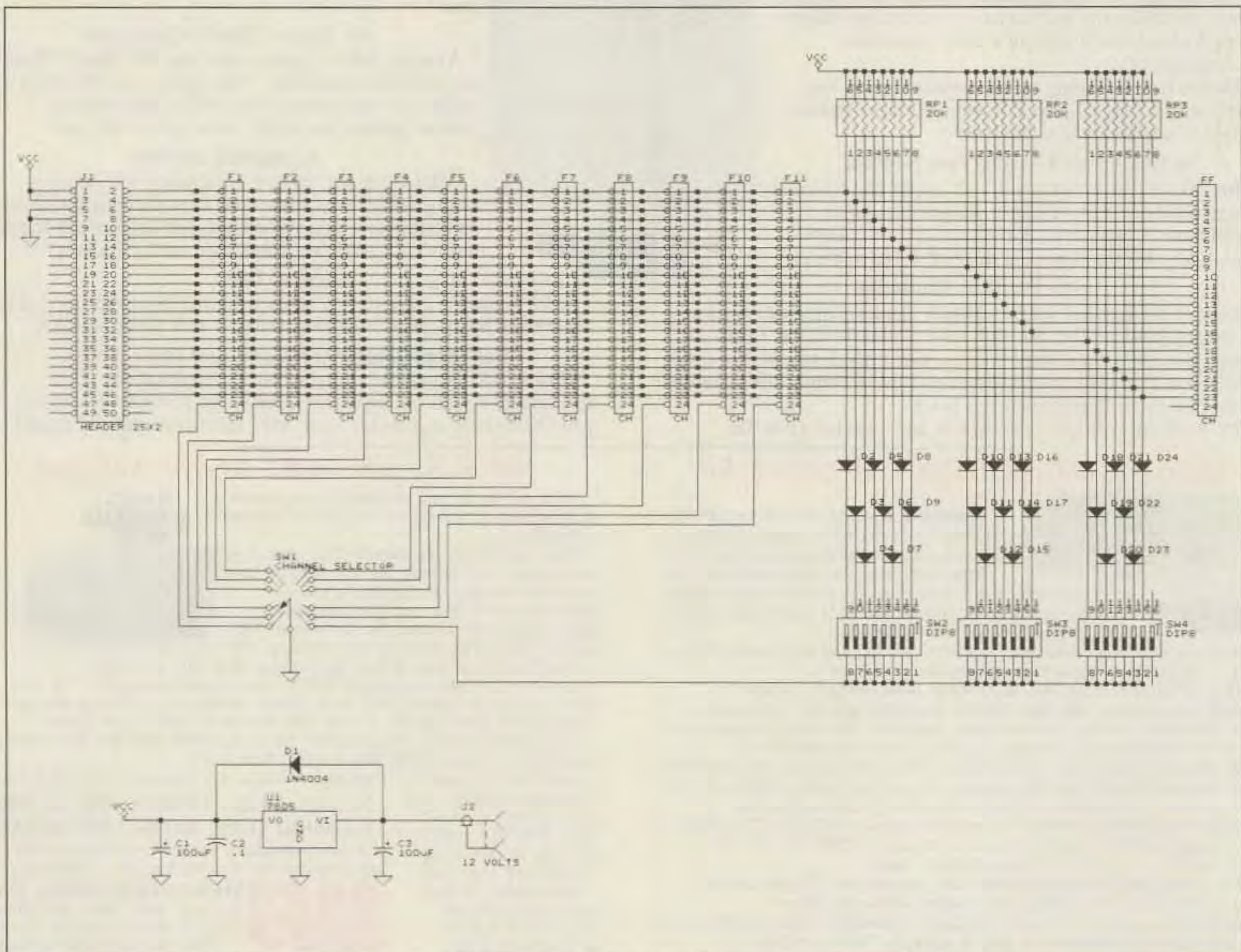


Figure 3. Schematic diagram of the diode matrix frequency selection board and power supply.

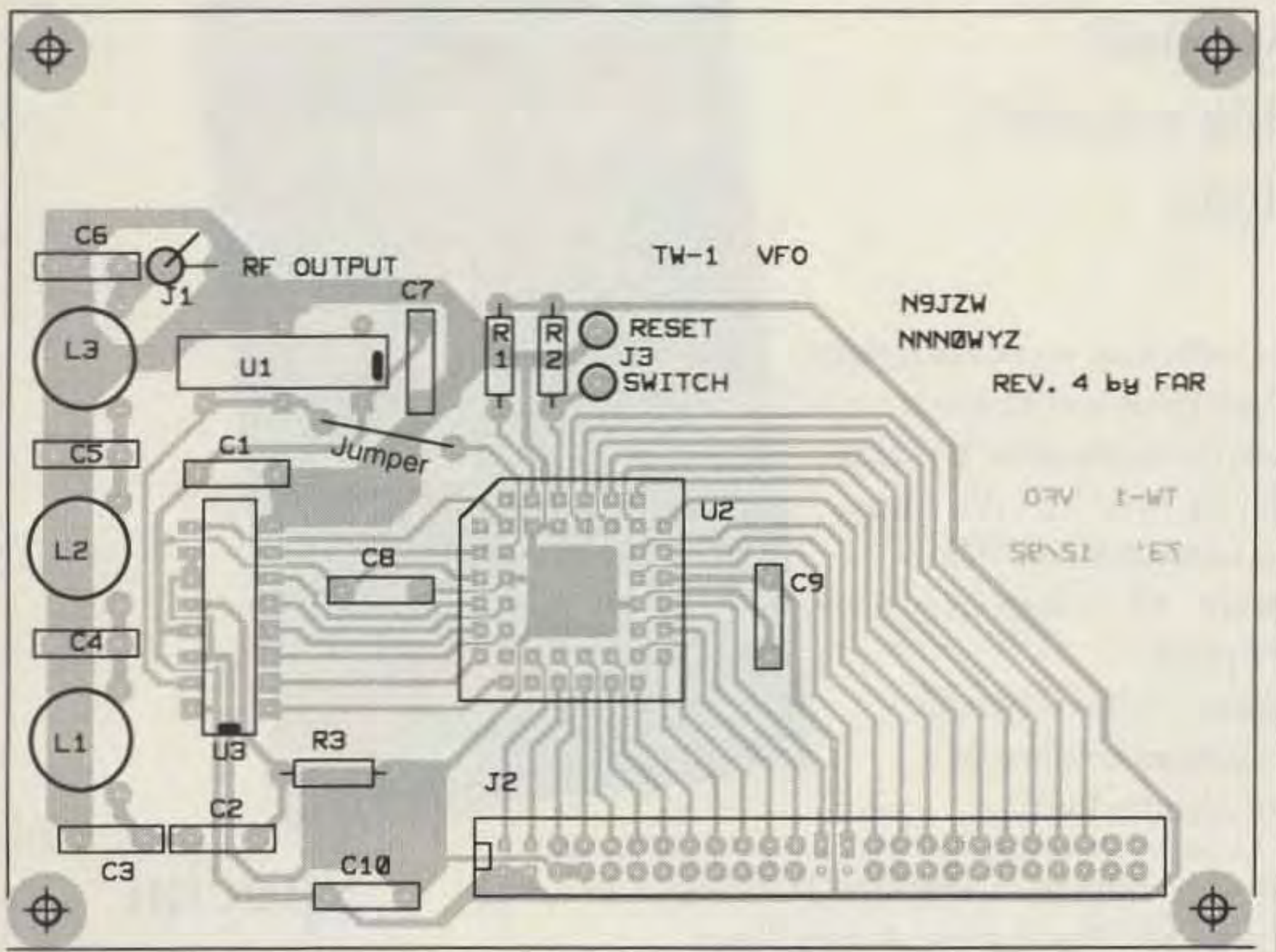
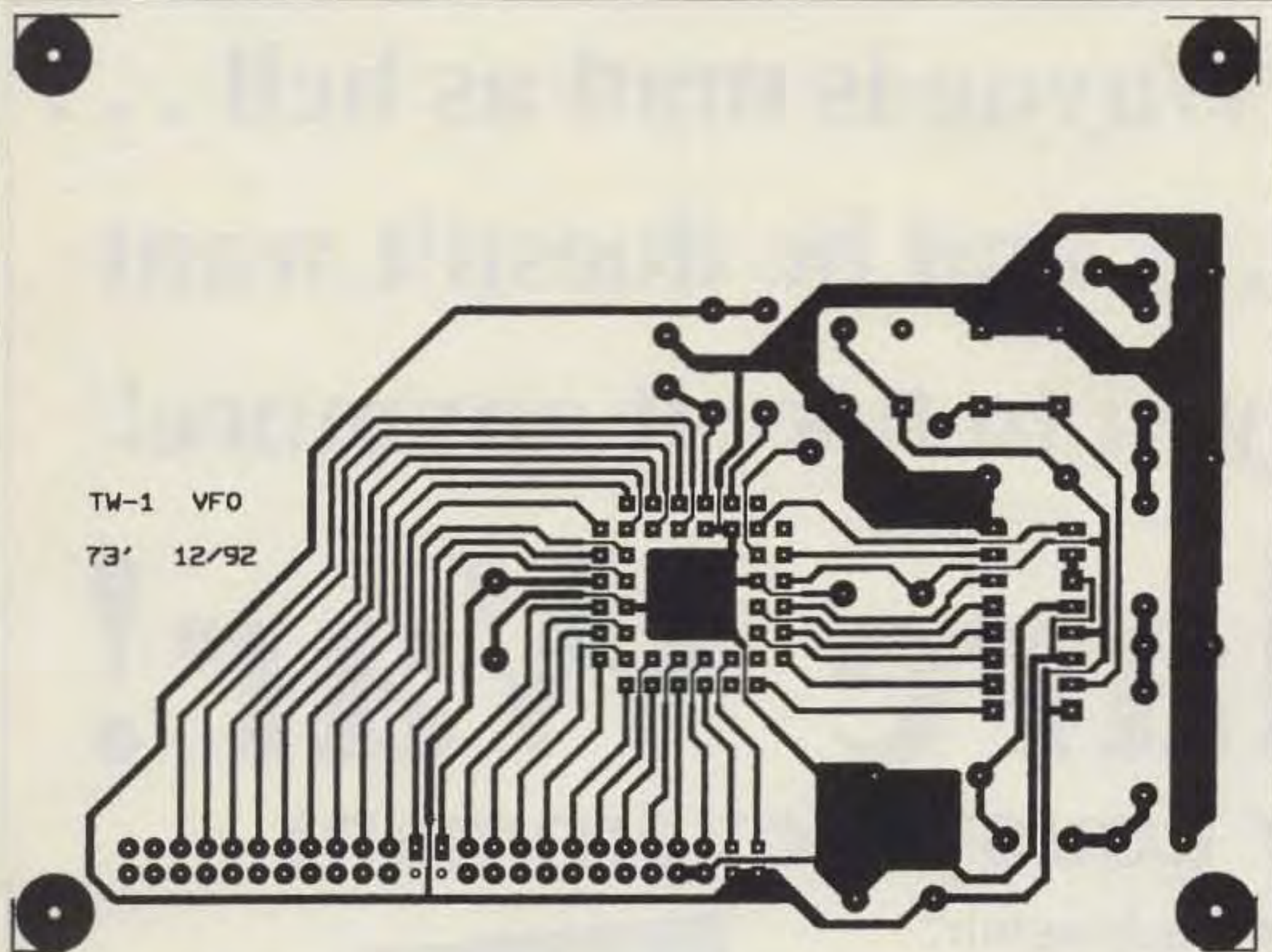


Figure 4. (a). PC board foil pattern for the DDS VFO board. (b). Parts placement.

three-quarters of the core, then cover the cores in plastic model cement. Make sure you remember which core is which!

Install the remaining resistors and capacitors in their proper places. Solder a short (5" or so) length of RG174 coax cable to J1, with the center connected to the trace going to L3 and the braid connected to ground (the other hole). Solder another short hunk of two-conductor wire to J3, and put an SPST Normally Open momentary switch at the other end. This is the RESET switch, which resets the DDS chip. You'll probably never use this, so it can go on the back of the case.

Attach the DDS board under the power sup-

ply board, leaving a small gap. Mounting holes have been provided at each corner for this. Make the ribbon cable to connect the first board with the DDS board. Pin 1 is on the left side, and should be the red stripe on the cable.

Check all work carefully, because we're going to give it a trial run now. With the DIP switches set to 7,040 kHz as above, connect the two boards with the ribbon cable. Set the channel switch to 12. Connect power to the power supply board. You should get 5 volts at pin 1 of U1. The input lines on the 50-pin header should be the same as they were when you tested the power supply board. Remove power—we're ready for a live test!

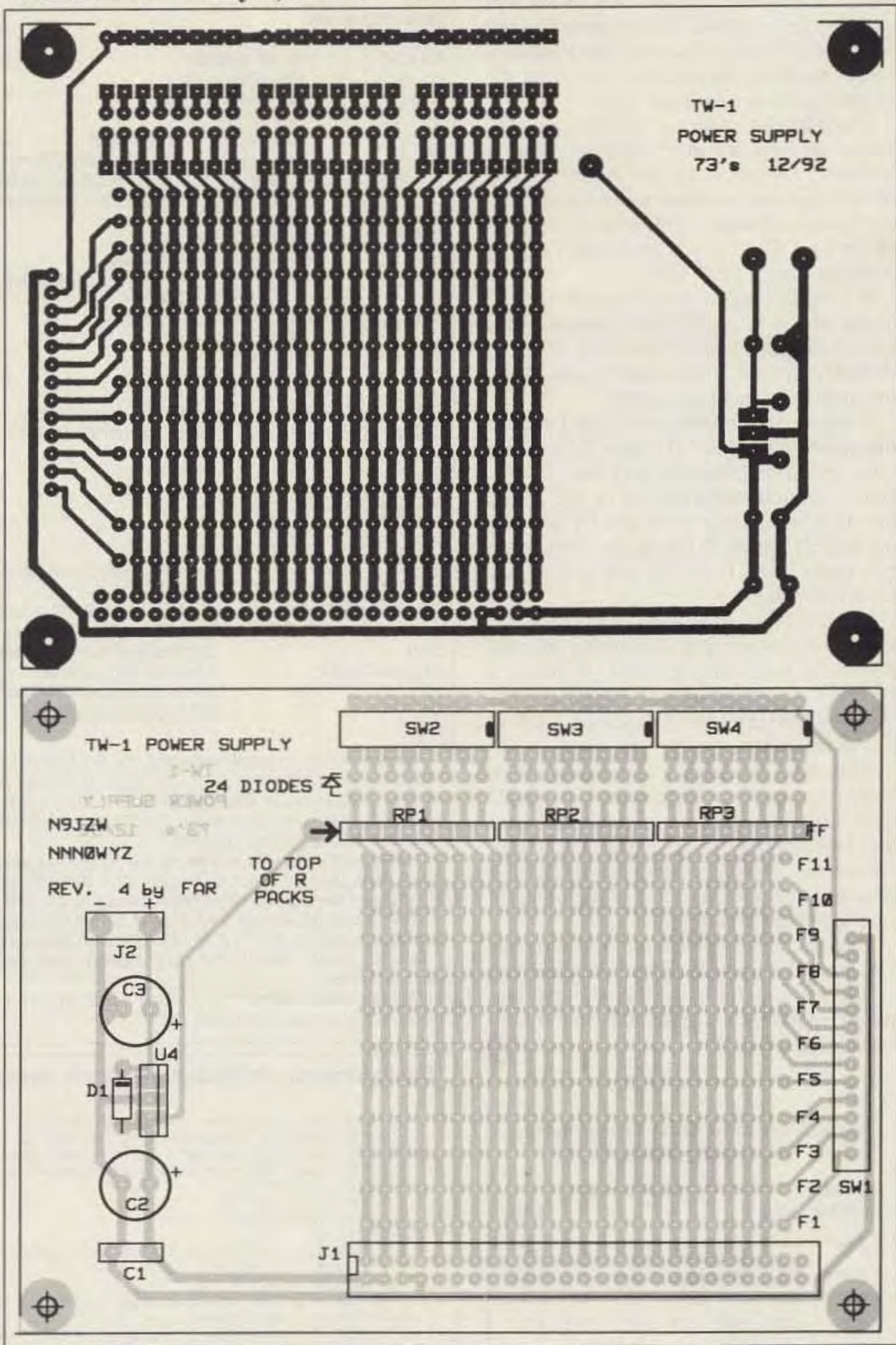


Figure 5. (a). PC board pattern for the diode matrix frequency selection board. (b). Parts placement.

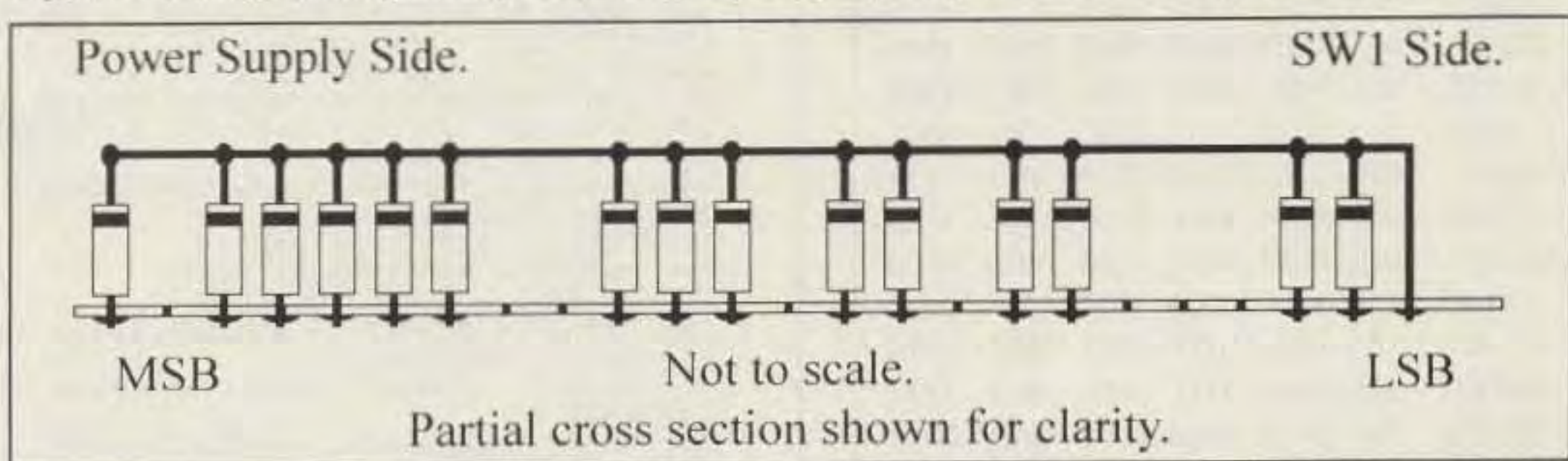


Figure 6. An example of diode array programming for frequency selection. A frequency of 7.040 MHz is shown. The view is from the front side of the frequency select/power supply board.

*Continued on page 18*

Install the chips in the sockets. Be especially careful installing U2! Removing this chip requires a special tool to prevent damage, so make sure it faces up! You should be able to read the chip number if you have the 50-pin header at your lower right.

Temporarily solder a 51-ohm resistor across the free end of the RG174. Hook a frequency counter to the hot end of the 51-ohm output resistor. Once again, apply power. You should have 7,040 kHz coming out of the unit. If so, congratulations! You've just built a basic DDS VFO!

If it didn't work, check for power on pin 1 of the ribbon cable. If there's power, check for +5 on pins 4 and 16—2,6,8,10,12,14 should be ground. If these aren't right, check the ribbon cable and connectors.

If there's power to the VFO board, look at the inputs to the DAC (U3 pins 2-9). These pins should be changing very fast. If they aren't, re-check the soldering on U2, check for clock signals out of U1 and try pressing the RESET switch. If the signals work while you press RESET, you've got a Normally Closed switch.

If the inputs to the DAC are changing, look for output. If there's no output, the chip may be in backwards or dead. If there's a signal at the output of U3, all that's left is the filter and the cable. Check these, and repair as necessary.

Now that you have a functional VFO, hook up a scope to the output. You should have a 0.7-0.8-volt peak-to-peak sine wave that looks pretty clean. Unplug the power, remove the 51-ohm resistor from the RG174 coax and you now have a very useful signal source and test generator.

Next month in Part II, we will turn this low-level (2 milliwatt) signal into something a little more useful by adding a 2-watt amplifier which should make this into a very capable QRP rig.

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### Some Common QRP Frequencies for the TW-1

Frequency (MHz)	Set TW-1 diode array to:					
	MSB					LSB
1.810	000	1000	0101	1100	1011	1011
1.84322	000	1000	1001	0100	0101	0000
1.860	000	1000	1010	1000	0100	1111
1.900	000	1000	1101	0111	1111	1001
3.54025	001	0000	0111	1010	0101	1111
3.560	001	0000	1001	0001	1111	0111
3.579	001	0000	1010	1000	1001	1011
3.6864	001	0001	0010	1000	1001	0100
7.030	010	0000	1011	1000	1011	0001
7.040	010	0000	1100	0100	1001	1100
7.0805	010	0000	1111	0100	1101	1110
7.110	010	0001	0001	1000	0000	0100
10.106	010	1111	0000	1001	1111	0001
14.060	100	0001	0111	0001	0101	0010
14.161	100	0001	1110	1001	1011	1100
18.074	101	0100	0010	0000	0101	0010
21.060	101	0010	0000	0101	0101	0100

Put diodes, banded end up, wherever there is a 0 (zero).

### Parts List

#### DDS VFO Board

C1,C2,C7,C8,	
C9,C10	0.1 µF ceramic
C3,C6	160 pF silver mica
C4,C5	300 pF silver mica
J1	Low RF out
J2	50 pin-header (25 pins by 2) Digi-Key# 923876-R-ND
J3	Reset switch, SPST (Normally ON) momentary
L1,L3	0.542 µH, 12 turns #26 enameled wire on T37-2 toroid
L2	0.608 µH, 14 turns #26 enameled wire on T37-6 toroid
R1,R2	10k ohm, 1/4 watt
R3	75 ohm, 1/4 watt
U1	55 MHz oscillator module Digi-Key# SE1109
U2	Q2220 DDS by Qualcomm (See note below)
U3	CA3338AE DAC by Harris Digi-Key# CA3338AE
1	44-pin PLCC socket for U2 Digi-Key# A417-ND
1	If needed
1	If needed
1	1 µF ceramic between pins 16 & 14 of U3
1	1 µF ceramic between pins 11 & 13 of U3
1	Ribbon cable connector Digi-Key# ASC50T-ND

#### Diode Matrix Frequency Selection & Power Supply

C1,C3	100 µF 25-volt electrolytic
C2	0.1 µF
D1	1N4004
D2,D3,D4,D5,D6,	1N914
D7,D8,D9, D10,D11,D12,	
D13,D14,D15, D16,D17,	
D18,D19,D20, D21,D22,D23,D24	
J1	50-pin header (25 pins by 2) Digi-Key# 923876-R-ND
J2	12 volts in
RP1,RP2,RP3	20k ohm, 1/4-watt R-packs or 20k, 1/4 watt individual resistors Digi-Key# 761-3-R20K
SW1	Channel selector 1P12T rotary switch Digi-Key# EG1952-ND or GH5601-ND
SW2,SW3,SW4	8-position DIP switches Digi-Key# A5208-ND
1	50-pin ribbon cable connector Digi-Key# ASC50T-ND
U1	7805 voltage regulator
Misc.	1N914 for setting channels

A complete kit of parts (including the PC boards) is available from Elkronics-NE, Rt. 1 Box 789, Hancock NH 03449, Tel: (603) 525-4001. Prices as follows: *DDS VFO module* — \$99; *Diode Matrix module* — \$49; *Power Amplifier module* — \$49; *Output Filter module* (specify band)— \$10. A complete package of all modules — \$199. The Qualcomm Q2220 DDS chip can be ordered separately for \$39. All prices include postage/handling.

Etched and drilled PC boards for this project are also available separately from FAR Circuits, 18N640 Field Court, Dundee IL 60118. Pricing: *DDS VFO PC board* — \$8; *Diode Matrix* — \$8; *Power Amplifier* — \$6; *Output Filter board* — \$3. Please add \$1.50 per order for shipping.

The Q2220 (as well as data sheets) is also available directly from Qualcomm, 10555 Sorrento Valley Rd., San Diego CA 92121; (619) 597-5005, for \$49, but they have a \$150 minimum order.

The CA3338A, the 55 MHz clock oscillator and most of the small parts are available from Digi-Key; (800) 344-4539.

Toroids are available from Amidon Associates or KA7QJY Components (Danny Stevig), Box 3893, Logan UT 84323; Tel: (801) 563-5173.

### Basic Program to Determine Diode Array Placement for a Given Frequency.

```

10 REM tw1-freq.bas by n9jzw nnn0wyz 9-24-92
20 REM program computes the layout of the binary array of diodes for
30 REM setting the tw-1 to a given frequency
40 REM load the hex-to-binary conversion table
50 DIM binary$(16)
60 FOR x = 1 TO 16
70 READ binary$(x)
80 NEXT x
100 REM set the clock speed and number of bits of phase accumulator
110 clock = 55000000
120 phase = 24
130 REM set the maximum step rate
140 fstep = 2 * phase
150 REM compute max frequency (MHz) that still has 3 steps per cycle
160 max = (.4 * clock) / 1000000
170 PRINT "Maximum frequency is"; max; "and minimum frequency is .0001"
180 INPUT "Enter the frequency in MHz (eg 7.040 = 7040KHz) -->"; freq
190 IF freq < .0001 GOTO 170
200 IF freq > max GOTO 170
210 REM compute the frequency setting in decimal
220 setting = (freq * 1000000) / (clock / fstep)
230 REM now in binary...
240 diode$ = "000000000000000000000000"
250 temp$ = HEX$(setting)
260 FOR x = 1 TO LEN(temp$)
270 temp1$ = MID$(temp$, x, 1)
280 IF temp1$ < "A" THEN 300
290 temp1$ = STR$(10 + ASC(temp1$) - ASC("A"))
300 temp = VAL(temp1$)
310 diode$ = diode$ + binary$(temp + 1)
320 NEXT x
330 PRINT "Put diodes, banded end UP, in the positions which have 0s:"
340 PRINT RIGHT$(diode$, phase - 1)
9000 DATA "0000","0001","0010","0011","0100","0101","0110","0111"
9010 DATA "1000","1001","1010","1011","1100","1101","1110","1111"
9999 END

```