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Commercial-Quality Function Generator

How about this addition to the bench?

How many times have you needed a function generator to provide a source of sine or square waves to test your ham equipment or a new circuit idea? More than a couple, at least if you are anything like most experimenters. A good, high-quality, dual-tone sine wave generator is a really needed item also, if you need to check out your SSB transmitter and linear amplifier performance.

Well, here is such an instrument that does those jobs nicely, with the added feature of a frequency counter that is also a nice extra to have. So let us take a look at what is required.

First, we must understand what I was interested in when doing the design phase. The absolute number one

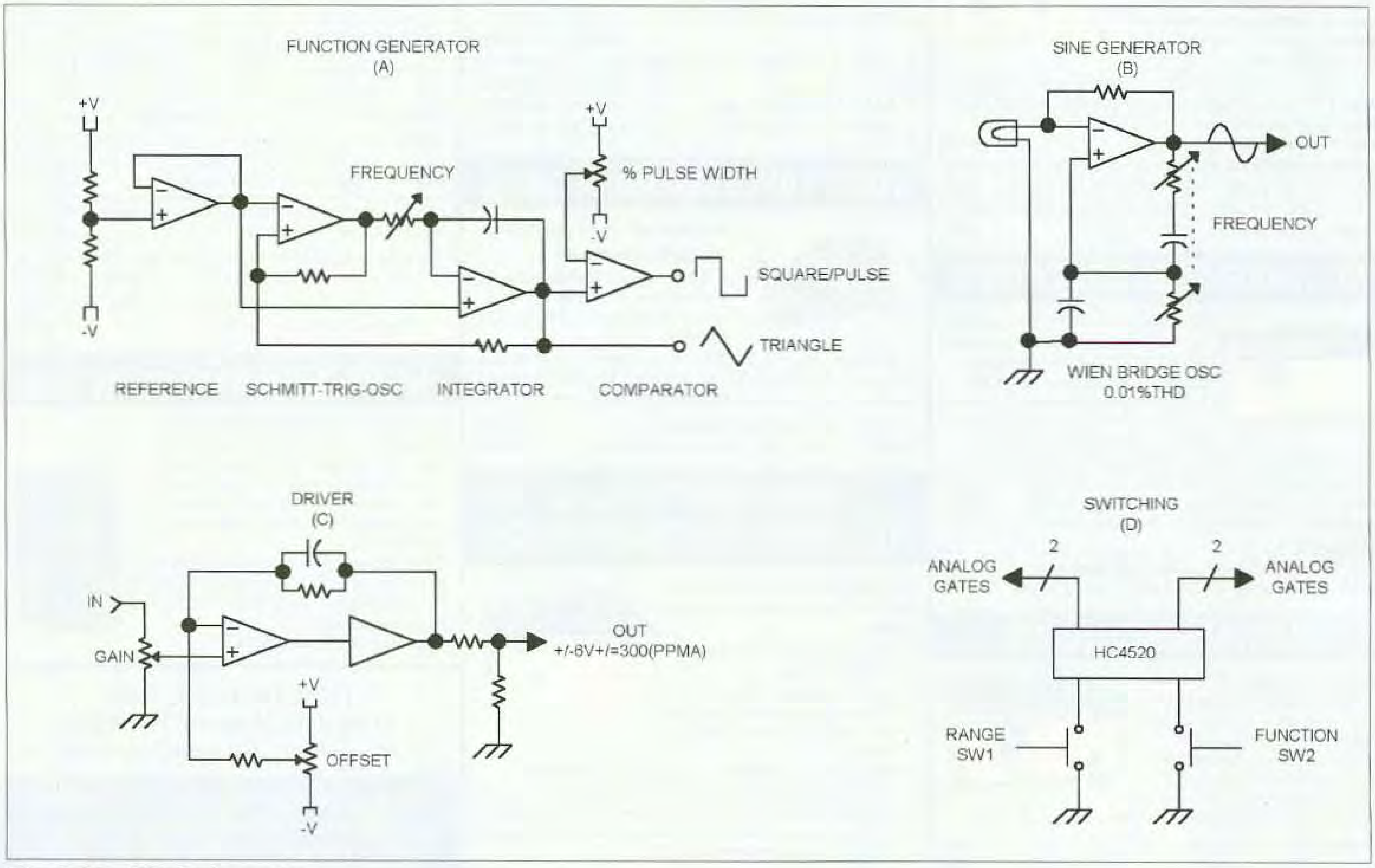
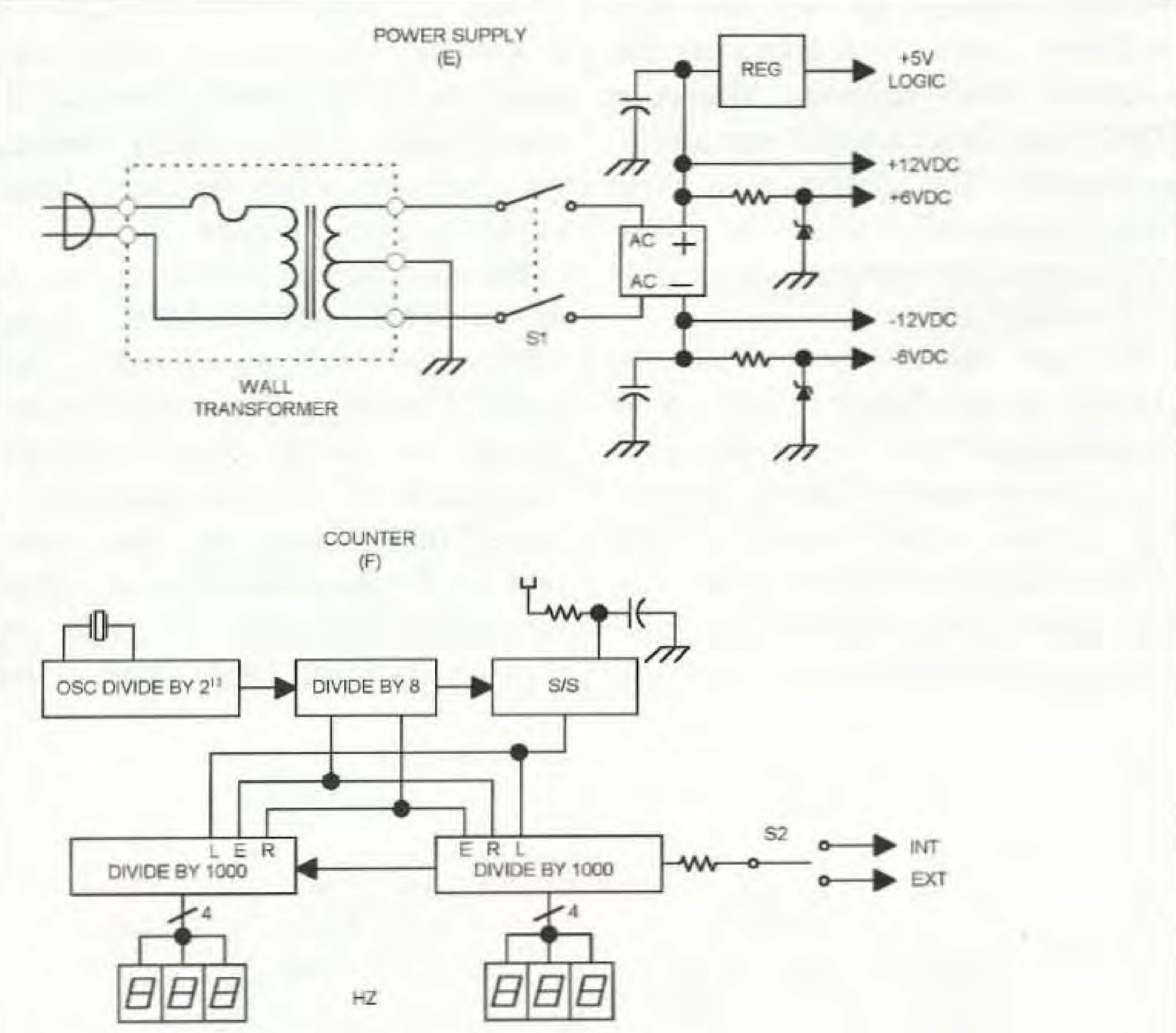


Fig. 1. *Simplified schematics.*



NOTES:
1. RANGE AND FUNCTIONS SELECTED BY ANALOG GATE ICs U7,U8, U13, U14 (NOT SHOWN).

REFERENCES:
1. NATIONAL SEMICONDUCTOR OPAMP DATA BOOK, PAGE 1-465 "FUNCTION GEN."
2. SINEWAVE OSCILLATOR FROM EDN MAGAZINE "INNOVATIVE LINEAR CIRCUITS," PAGE 144.

Fig. 1. Simplified schematics (continued).

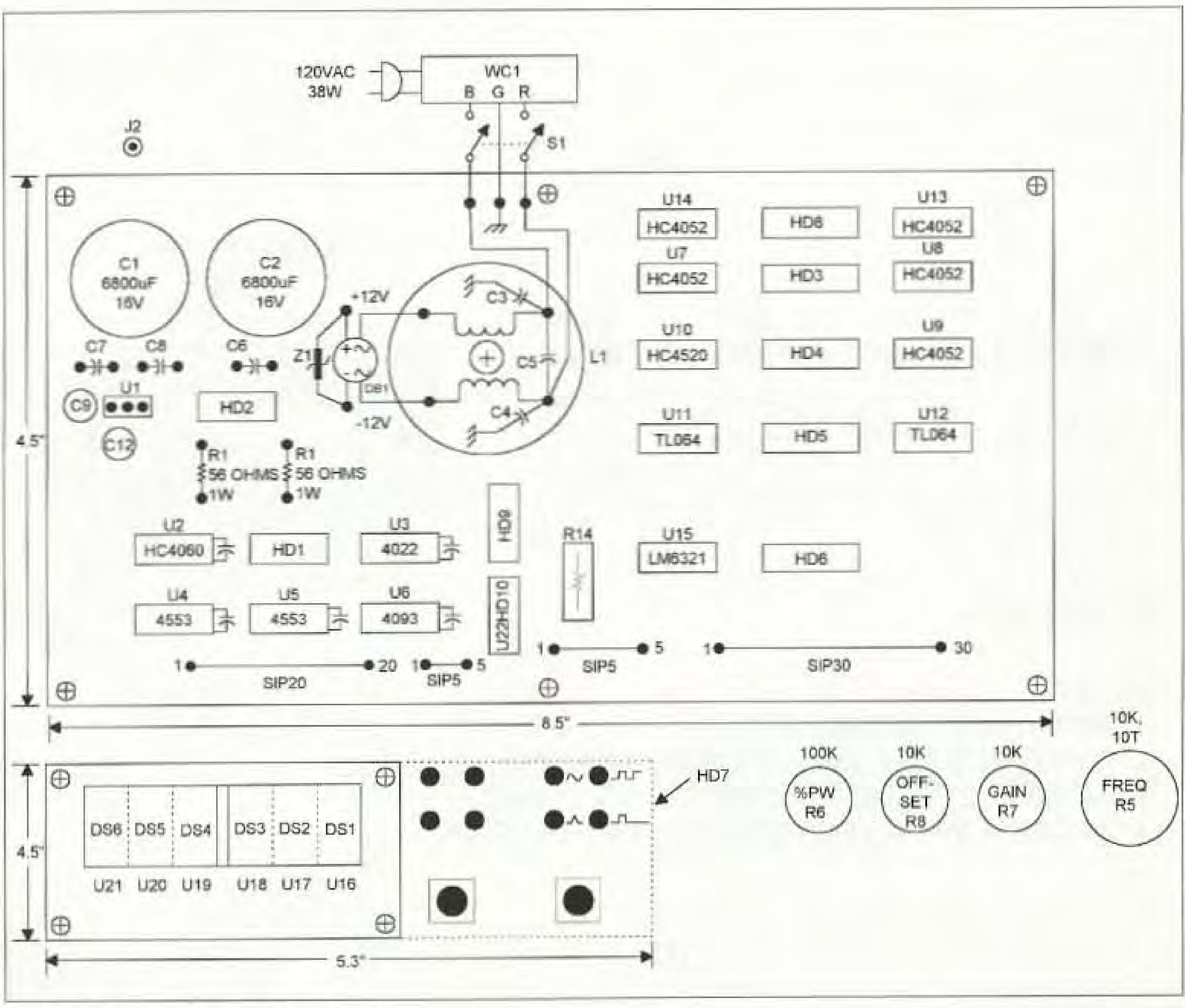


Fig. 2. Component locations.

priority was to get the best sine wave oscillator I could. My requirement was a 0.01% total harmonic distortion (THD) sine wave, which I was able to accomplish. This design is a Wien bridge arrangement with four selectable ranges with continuously variable overlapping bands.

The next absolute was to have an onboard digital counter circuit. It must be inexpensive and reasonably accurate, with an external input for measuring a test circuit frequency. The counter circuit is a watch crystal time base which is divided down to provide a one second window as a counting period. The second one second period is used for the latch and reset functions. The 0.5 Hz is well within the tolerance required to accurately measure the one hertz to one megahertz range of the function generator.

The six stage counter circuit consists of two MC-14553 CMOS digital DIP16 ICs which provide the six decades of counting. The output is multiplexed so as to have a small, inexpensive IC package. These multiplexed BCD outputs are then loaded into the latching and decoding seven segment displays that are made by Hewlett Packard. These displays are

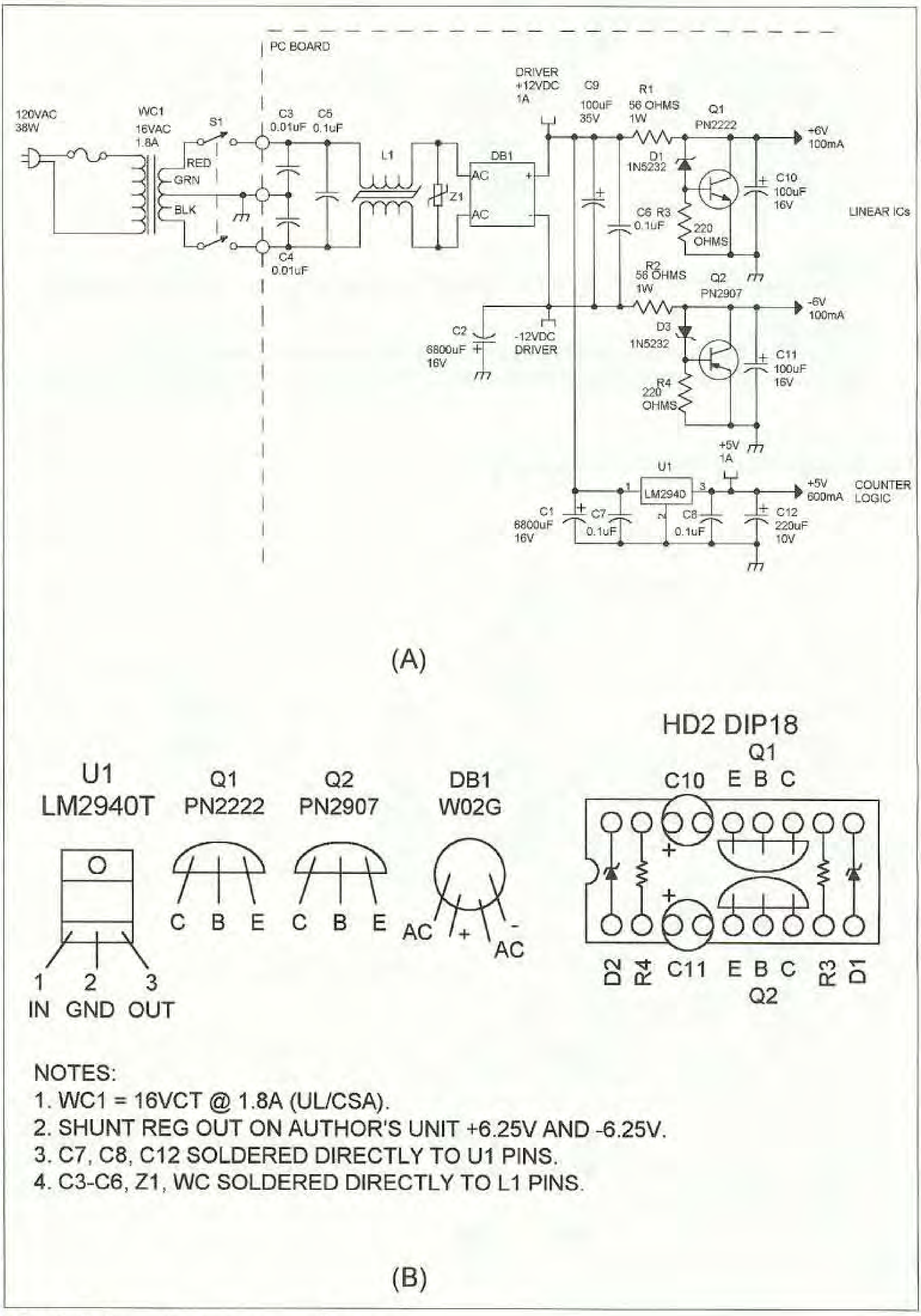


Fig. 3. Schematic, power supply section.

1	ENC	Ten-Tec Enclosure	(TEN-TEC-JW10)	$ 16.00
6	---	0,75"(#4) Stand-Off	(Hosfelt-28-146)	1.50
1	*WC	15VAC-1,8A (CT)Wall Xfmr	(Hosfelt 56-781)	2.95
1	U1	LM2940CT-5 5V-1A Reg IC	(Jameco-107182)	1.29
1	U2	HC4060 CMOS IC DIP	(Mouser-511-M74HC4060)	.64
1	U3	4022 CMOS IC DIP	(Mouser-511-4022)	.66
2	U4,U5	4553 CMOS IC DIP	(Jameco-13709)	5.90
1	U6	4093 CMOS IC DIP	(Jameco-14300)	.29
5	U7-9,13,14	HC4052 CMOS IC DIP	(Mouser-511-M74HC4052)	4.20
1	U10	HC4520 CMOS IC DIP	(Mouser-511-M74HC4520)	.62
3	U11,12,22	TL064ACN Quad OPAmp IC	(Mouser511-TL064ACN)	3.00
1	U15	LM6321 Linear IC	(Digi-Key LM6321N)	5.28
6	U16-U21	HP-5082-7300 7Seg IC	(Jameco-173833)	29.70
1	BZ1	Bezel-- 3,5"--Black	(DigiKey-PRD250B)	2.00
1	BZ2	Bezel-- 3,5"--Red Lens	(DigiKey-PRD250R)	1.60
1	BZ3	Bezel-- 3,5"--Clear Lens	(DigiKey-PRD250W1)	1.60
3	J1,J3,J4	Jack SMA Bulkhead Fem Coax	(Jameco-153285)	7.50
1	J2	Jack (Test Point)	(Any)	.25
1	Q1	PN2222 NPN Tran	(Jameco-178511)	.16
1	Q2	PN2907 PNP Tran	(Jameco-178520)	.16
1	DB1	200V-1,5A Diode Bridge	(Mouser-625-W)2G)	.35
2	D1,D2	1N5232B Zener Diodes	(Jameco-179055)	.14
2	D3,D4	DELETE		---
4	D5-D8	T-1 (3mm) Green LED	(Jameco-34606)	.60
4	D9-D12	T-1 (3mm) Red LED	(Jameco-94529)	.76
8	BZ4-11	3mm LED Bezels (LH-100)	(Jameco-95513)	.96
1	PCB	Perf PC Board 4.5x17"	(Mouser-574-169P44)	10.59
3	B1,2,3	#1240 Lamp T1 Wire Leads	(Hosfelt-25-290)	1.05
1	X1	32768 HZ Watch Crystal TF2	(DigiKey X801)	.30
8	---	DIP16 WW (Mach Pin)Socket	(Hosfelt-21-174)	4.00
9	---	DIP18 WW (Mach Pin)Socket	(Hosfelt-21-180)	4.50
2	---	DIP24(W) WW (MachP)Socket	(Hosfelt-21-184)	.70
8	---	DIP24(S) WW (MachP)Socket	(Hosfelt-21-183)	2.80
2	SIP-1,2	SIP40 WW Header	(Jameco-160881)	.80
1	---	Decal Kit (Radio Shack)	(RS-270-201)	3.00
2	C1,C2	6800MF-16V-Elect-Cap(18x36)	(Jameco-31510)	2.18
4	C3,4,21,22	0,01MF-50V-Mono-Cap	(Mouser-21RX410)	.44
1	C9	100MF-35V Elect Cap (8X11)	(Jameco-93551)	.19
2	C10-C11	100MF-16V Elect Cap (6x5)	(Jameco-94431)	.18
1	C12	220MF-10V Elect Cap	(Digikey 140-MLRL10V220)	.17
6	C13-C17	0,1MF-50V Mono Cap	(Mouser-21RZ310)	.48
21	C5-C8	0,1MF-50V Mono Cap	(Mouser-21RZ310)	1.72
	C23-C37,C50,C52			
2	C19	100PF-50V-NPO-Mono Cap	(Mouser-21RD610)	.10
2	C20,C51	10PF-50V-NPO-Mono Cap	(Mouser-21RD710)	.20
4	C38-C41	0,002MF-50V-5%-Styrene Cap	(Mouser-23PW220)	.96
2	C42,C46	0,001MF-50V-5%-Styrene Cap	(Mouser-23PW210)	.22
1	C18	0,1MF-50V-Mono Cap (Axial)	(Hosfelt-15-407)	.08
2	C43,C47	0,01MF-50V-5%-Styrene Cap	(Mouser-23PW310	.38
2	C44,C48	0,22MF-50V-Elect. Cap	(Mouser-140-L50V,22)	.09
2	C45,C49	4,7MF-16V-Elect Cap	(Mouser-140-L16V4,7)	.09
1	L1	Dual 8,2MH Choke(PE96180)	(Hosfelt-18-129)	.35
1	Z1	11VAC/18VAC Clamp MOV	(Jameco-190449)	.25
2	R1.R2	56-5%-1W-MOF-Resistors	(Mouser-281-56)	.38
2	R3,R4	220-5%-0,25W-CF-Res	(Jameco-30470)	.10
1	**R5A,R5B	10K-10T-Dual POT(Bourns#84A2DB28J15/J15)		---
	Alternate	10K-1T-Dual POT	(Mouser-31VW401)	2.10
	Optional	15:1 Mechanical Dial	(Mouser-5940-16111)	12.00
1	R6	100K-1T-POT	(Mouser-31CN501)	1.02
2	R7,R8	10K-1T-POT	(Mouser-31CN401)	2.04
2	R9,R27	22K-5%-0,25W-CF-Res	(Jameco-30453)	.10
1	R14	10K-15T-T-POT (Bourns-3006)	(Hosfelt-380135)	.85
1	R10	15M-20%-0,25W-CF-Res	(Mouser-291-15M)	.10
3	R15,R16	1K-5%-0,25W-CF-Res	(Jameco-29663)	.15
	R20,R22			
2	R18,R19	47K-5%-0,25W-CF-Res	(Jameco-31149)	.10
1	R12	2200-5%-0,25W-CF-Res	(Jameco-30314)	.05
3	R13,32,33	150-5%-0,25W-CF-Res	(Jameco-30162)	.15
3	R17,24,25	330-5%-0,25W-CF-Res	(Jameco-30867)	.15
1	R21	33-5%-1W-MOF-Res	(DigiKey-P33W-2BK)	.30
3	R22,23,26	10K-5%-0,25W-CF-Res	(Jameco-29911)	.15
2	R28,R31	56K-5%-0,25W-CF-Res	(Mouser-291-56K)	.10
3	R11,29,30	100K-5%-0,25W-CF-Res	(Jameco-29997)	.15
2	R35,R36	1200-5%-0,25W-CF-Res	(Jameco-29735)	.10
1	R35	1800-5%-0,25W-CF-Res	(Jameco-Bulk)	.05
1	R37	560-5%-0,25W-CF-Res	(Jameco-31376)	.05
0	R38	DELETE		
8	R39-R46	CAL Res 5%-0,25W,CF-Res	(Any)	.40
1	---	Knob-0,25"-Black (Large)	(Jameco-138481)	1.25
3	---	Knob-0,25"-Black (Small)	(Jameco-162499)	3.75
1	RN*	100Kx8-2%-DIP16-RNET	(Jameco-108644)	.60
2	SW1,2	PB Switches (KRS-1273-B)	(Jameco-155379)	.80
2	SW1,2	PB Caps (KRS-CAP-B)	(Jameco-155408)	.30
1	S1	DPDT (2-Pos)SubMini Toggle	(Jameco-75977)	1.29
1	S2	SPDT (2-Pos)SubMini Toggle	(Jameco-75969)	1.15
1	S3	SPDT (3-POS)SubMini Toggle	(Jameco-72557)	1.15
1	---	0,25" Rubber Gromet	(Any)	.10
8	---	0,25" Nylon Standoffs #4 screws	(Hosfelt)	
			APPROX. TOTAL:	$ 132.00

NOTE:
(1) ACE Hardware #1003979 Almond Spray Paint (15oz) $3.00
(2) Minwax Polyurethane #33050 Clear Gloss Spray (11oz) $4.00
(3) * WC is GroupWest #57A-15-1800CT (38W) Wall Transformer.
(4)** Author used Bourns 10turn pot because it was available
Tests show Mouser part is O.K.(Optional) 15:1 Dial.
(5) Out/In=6FT Coax with male SMA's (Jameco-159450) $5.75.

Table 1. *Bill of materials.*

high-quality, dot matrix hybrid types which are very compact and high-contrast. They are small enough that three digits can be handled by a standard DIP24 socket. I use the least significant digit's decimal point to show the

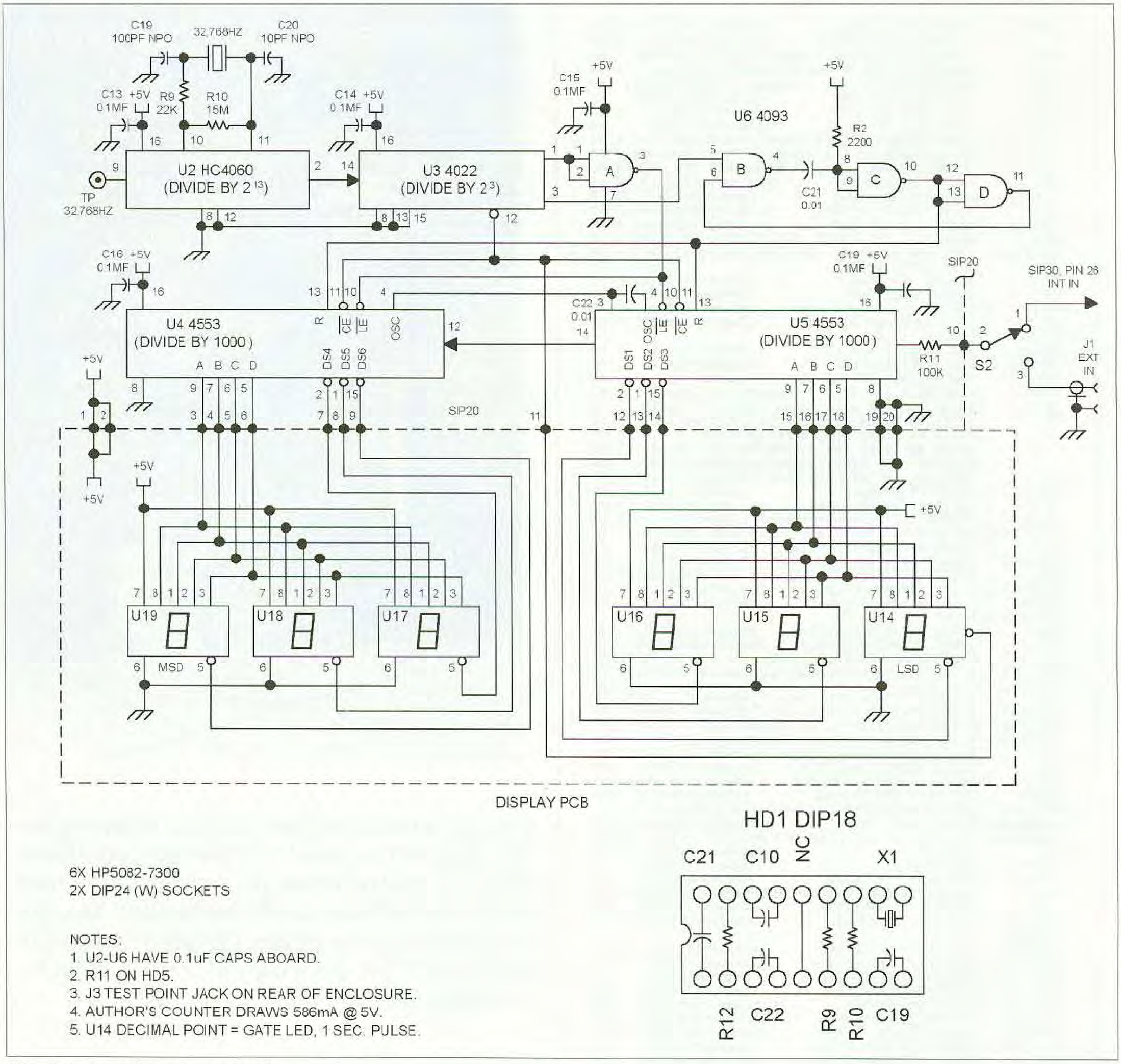


Fig. 4. Schematic, counter section.

Photo A. *The completed function generator with wall converter.*

count gate action. Since upon power-up we do not know what the oscillator time base chain has in it, a couple of seconds is sometimes required to clear and get the first one second count period. The flashing decimal point indicates that everything is working correctly.

The next section of the generator is the triangle, square, and pulse generator. Since we do not normally need an extremely low THD for these functions, a simple quad op amp IC was used to perform these functions. An IC such as the 8038 could have been used but again, something a little better than the 1% specified (THD) was desired. So a voltage reference, Schmitt trigger, integrator, and comparator circuit was designed using a quad JFET op amp IC, TL064A. The circuit also uses a couple of analog gate ICs to do the resistor and capacitor selections. The timing resistor and capacitors are the same ones that are used in the Wien bridge sine wave oscillator. Two additional analog gate ICs were also used to select the LED indicators for range and function. These gates are selected digitally with push-button switches to a dual binary counter IC, U-10.

The multiwave output is then sent out to the gain and offset controls so that amplitude and position relative to ground can be adjusted by the user. The frequency is controlled by the ten-turn dual 10k-ohm pot, R5. The output of the generator is run through a special current mode driver IC. This IC provides 200 mA of continuous drive and is short-circuit and thermal protected. Quite a bargain at under six dollars and in a DIP-8 package!

The power supply circuit was my next concern. The use of a wall converter is most desired so as to keep the high voltage AC out of the enclosure. These wall converters or transformers are UL and CSA approved for safety and are very inexpensive. Ours brings a 15 volt centertapped winding to the PC board and is rated at 1.8 amps. This AC voltage is put through a bridge rectifier to get our POS and NEG 12 VDC at over 1 amp. Note that at 1.8A the voltage would be about 8 VCT, but since we have a maximum of 12 VDC @ 200 mA requirement, we do not level. The two shunt regulator circuits draw another 200 mA to achieve the POS and NEG 6 VDC power for the

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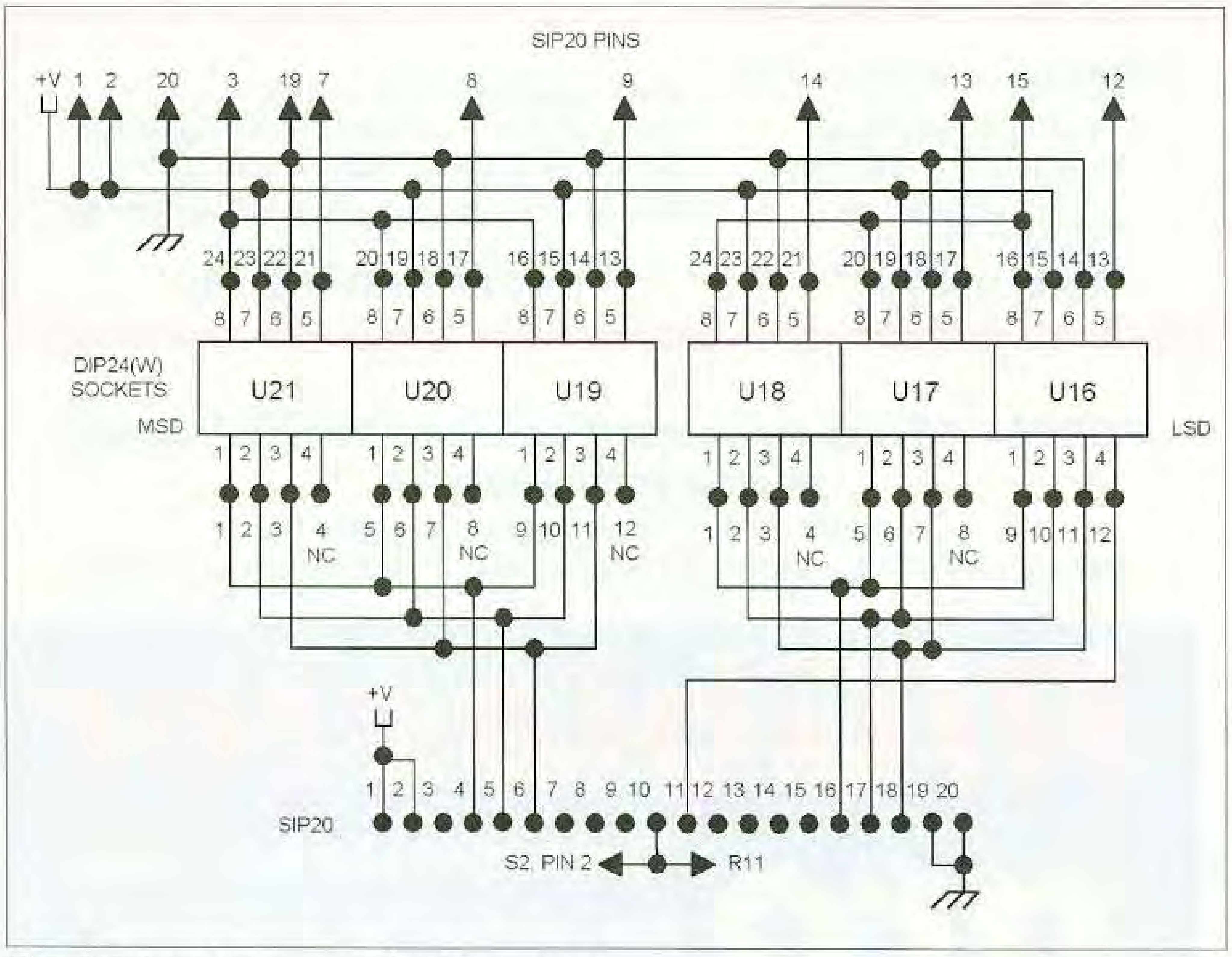

Fig. 5. Schematic, counter display section.

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op amps and CMOS logic components.

Now, the digital logic TTL display hybrids which draw about 100 mA each will need that high-current 5V source. I took the +12VDC line and put the U-1 series voltage regulator IC on it for the 5VDC 600 mA requirement. The regulator IC LM-2940-5 is a low dropout type which can work down to the one half volt differential point, so no problems in our application. The 5 VDC 600 mA display requirement does not throw our bridge rectifier circuit out of balance. The regulator is rated for 1 amp, so 600 mA does not exceed its specification, but do expect a little heat on the TO-220 package running at about four watts. No heat sink is required!

Some folks might ask why the shunt 6V regulators instead of the series ICs? Well, we find that transients, noise and such, will not get through as sometimes happens with series regulators. The use of a dual 8 mH choke L-1 is to eliminate the common mode parts of that power line stuff!

Now, we look at how to put it together. No etched and drilled PC board is available to my knowledge. There does not seem to be an interest in that for this project. I chose to use wire-wrap technology, as always, with this project. The use of machine pin–type wire-wrap sockets to accommodate both ICs and passive components works very well. I also use SIP (single-in-line) wire-wrap binding posts for the termination of wires. These wires go between boards, controls, switches, and the like.

I chose my usual Ten-Tec enclosure and PMI plastic display bezel so that we can get a good professional looking instrument. All of the connectors, switches, and test lines are the sub-mini types. They look and work good, and the cost is very reasonable.

I added an additional two Wien bridge oscillators to provide an SSB test circuit. This is a 700 and 1900 Hz dual tone source. When you put the signals into the microphone jack of an SSB transmitter, you will have the required envelope test to check the rig and linear amplifier for linear operation.

I provided simplified schematic functions in **Fig. 1**. All of the component placements are also shown in **Fig. 2**. All of the header details are in **Fig. 3**. I provided a bill of materials (**Table 1**), the approximate cost, and the sources I found for them. A template is also provided as a guideline for the metalwork necessary on the JW-10 Ten-Tec enclosure. I recommend that a nice coat of enamel spray paint be used after the metal work. The decals make things

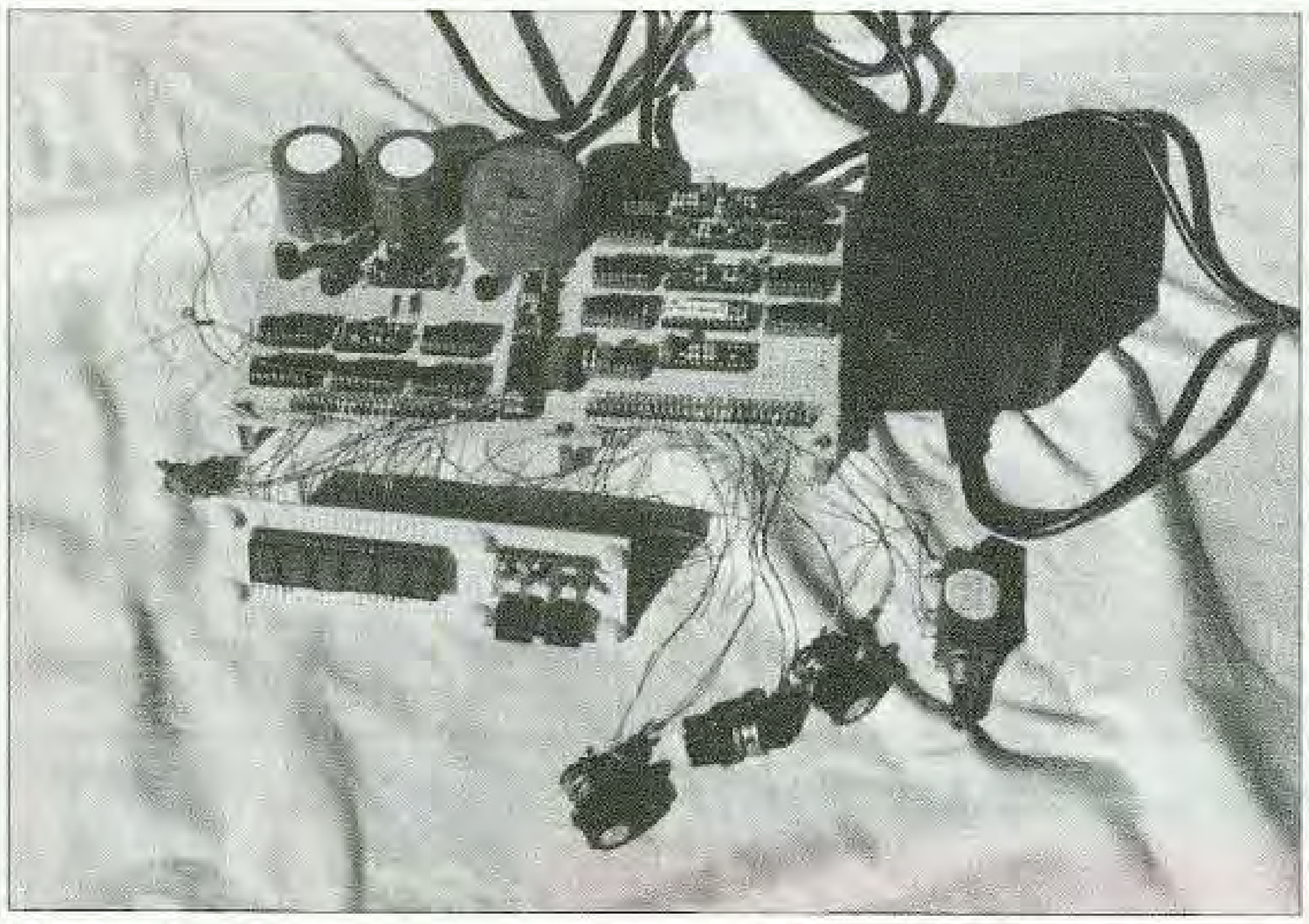

Photo B. *Photo of components on PC board using wire-wrap technology.*

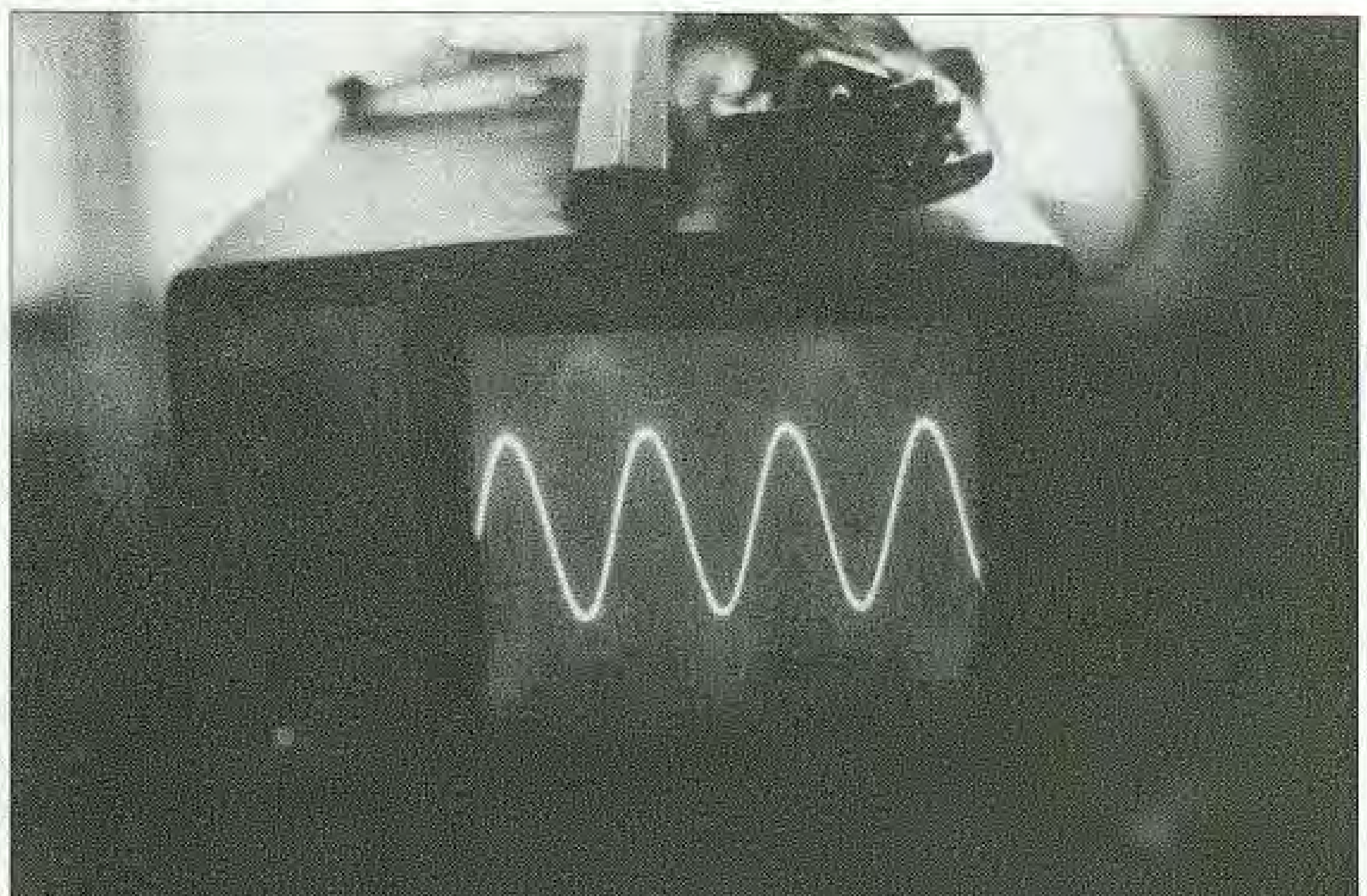

Photo C. *Sine wave.*

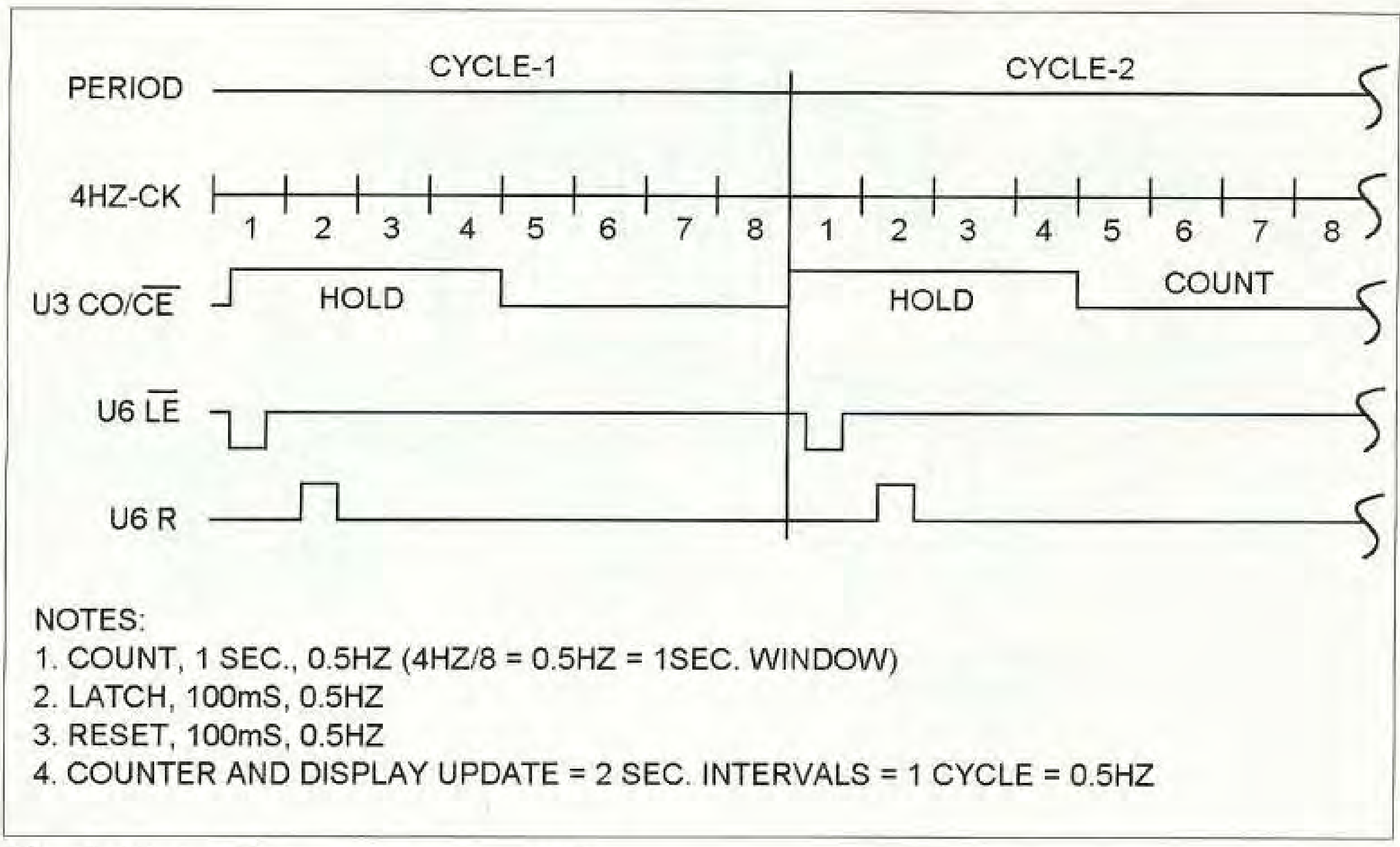

Fig. 6. Timing diagram counter section.

look very professional and can be found at your local Radio Shack or office supply stores. A couple of very light coats of polyurethane gloss will

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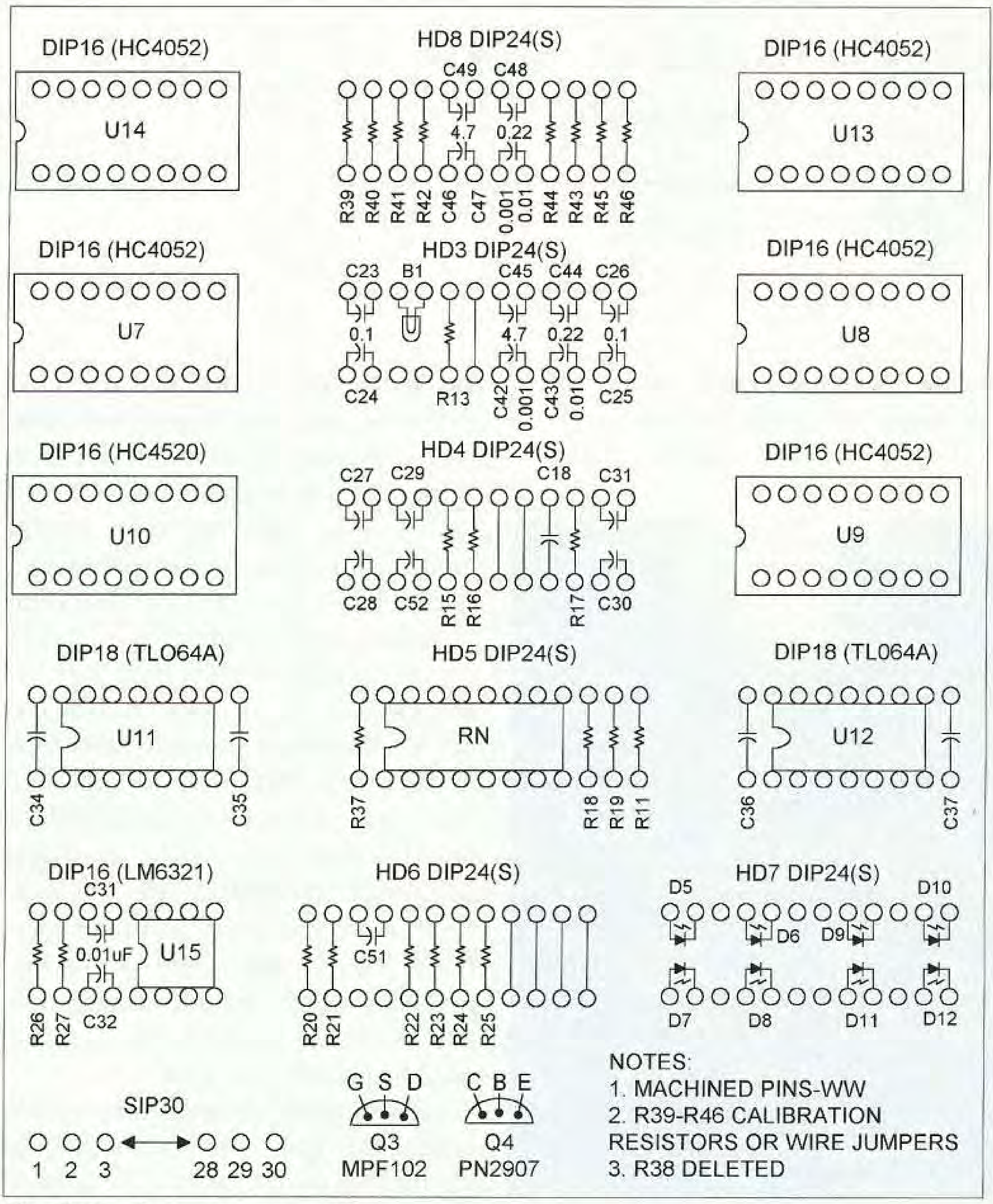

Fig. 7. Header component outline.

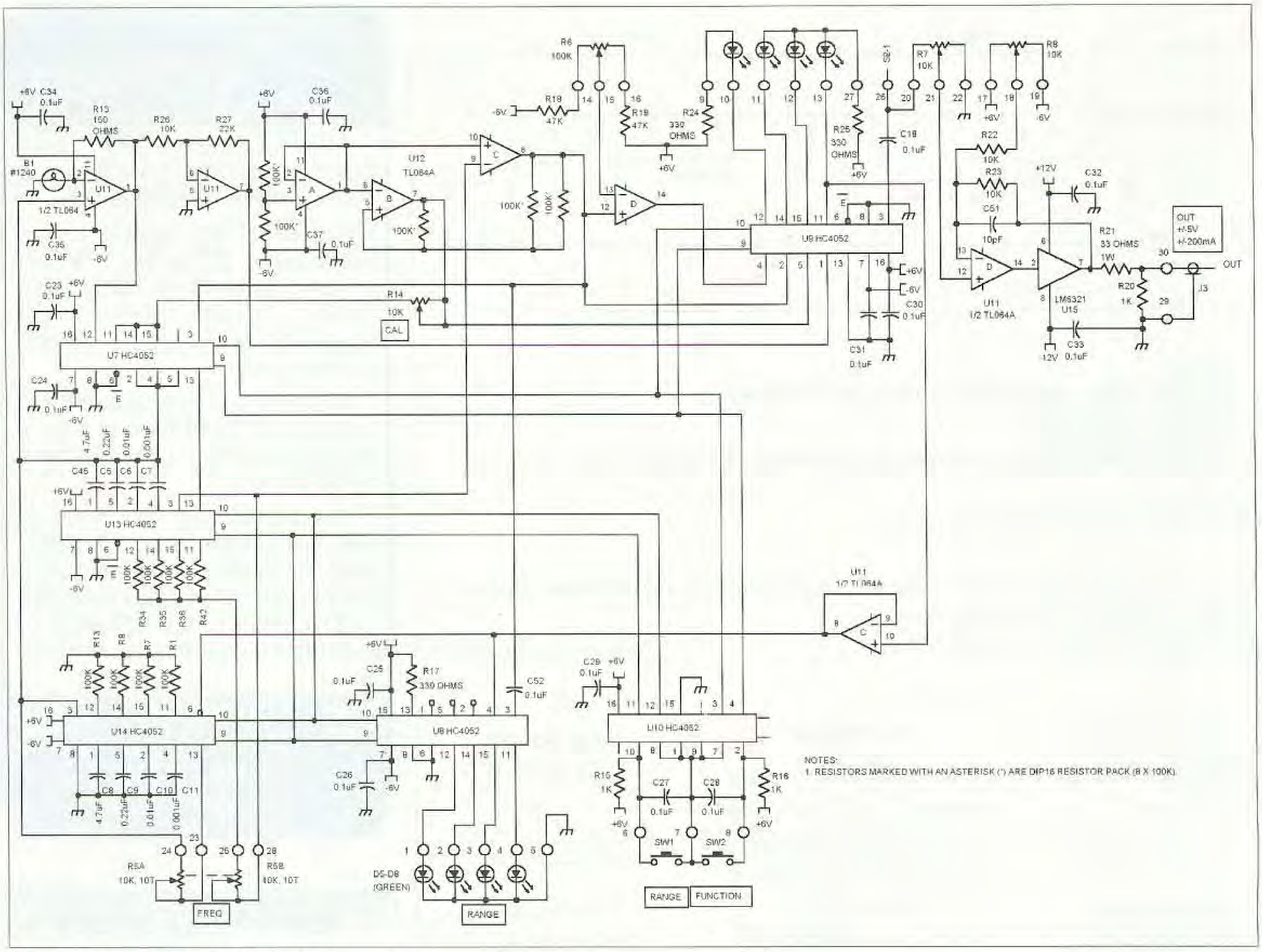

Fig. 8. Schematic, function generator section.

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make it pretty and quite durable, and is definitely well worth the effort.

I have included a couple of photographs to show the extremely low distortion of the wave forms. Note that the fourth range position is for the sine wave only. The triangle (sweep wave), square, and pulse are not usually needed above about 20 kHz. The range can be used, but will have distortion especially on the triangle wave. A note of caution regarding the B1,2,3 #1240 incandescent lamps is that they should not be substituted with any other type if the 0.01% THD is to be expected. This type is the best I found to produce low distortion Wien bridge oscillator sine waves. This 0.01% THD was verified on a laboratory distortion analyzer. Only the zero crossover produced a slight distortion, but still it was below the 0.01% if the TL064A quad op amp IC was used.

I also included an optional time base crystal oscillator output via a jack on the back of the enclosure. The counter probe, in the external position, can be

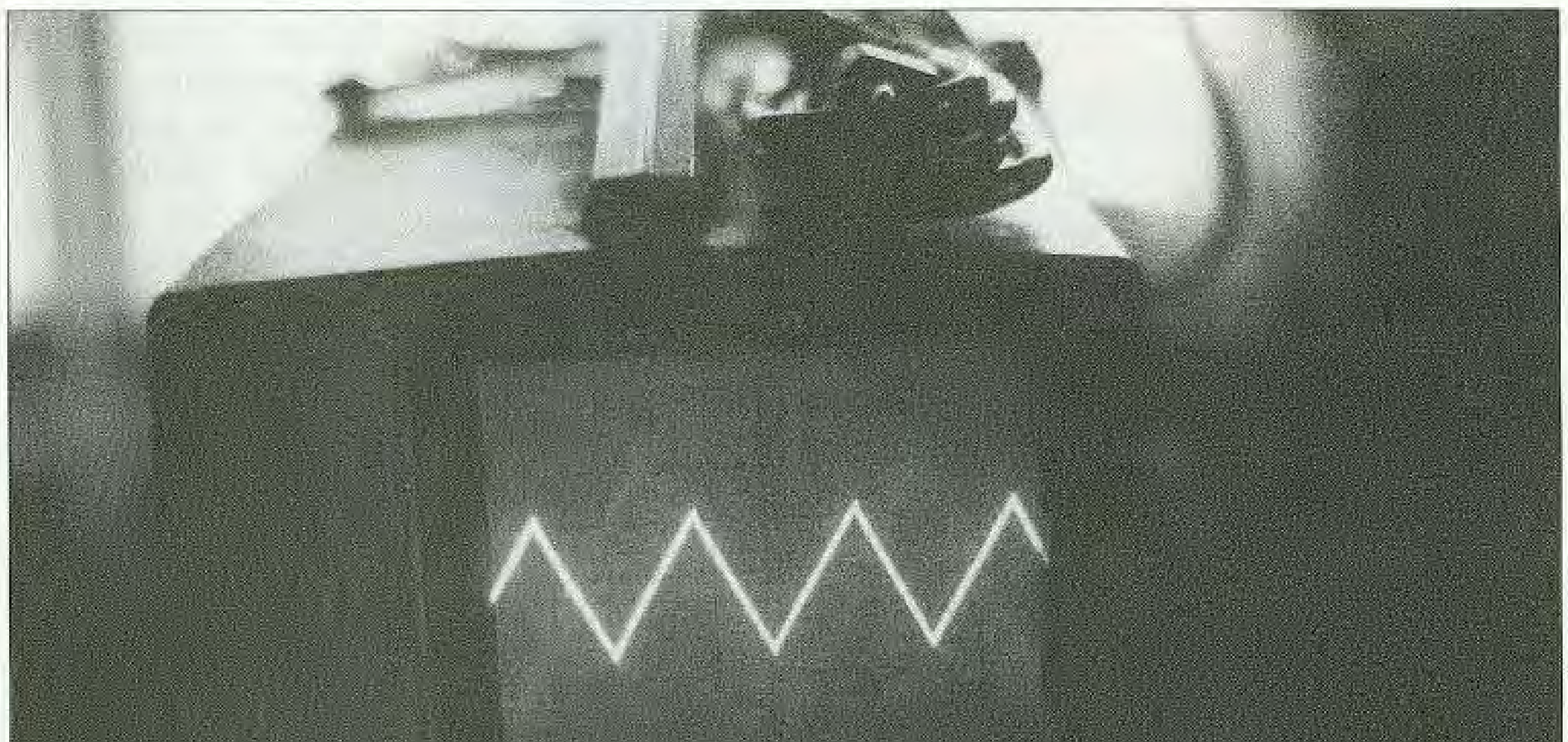
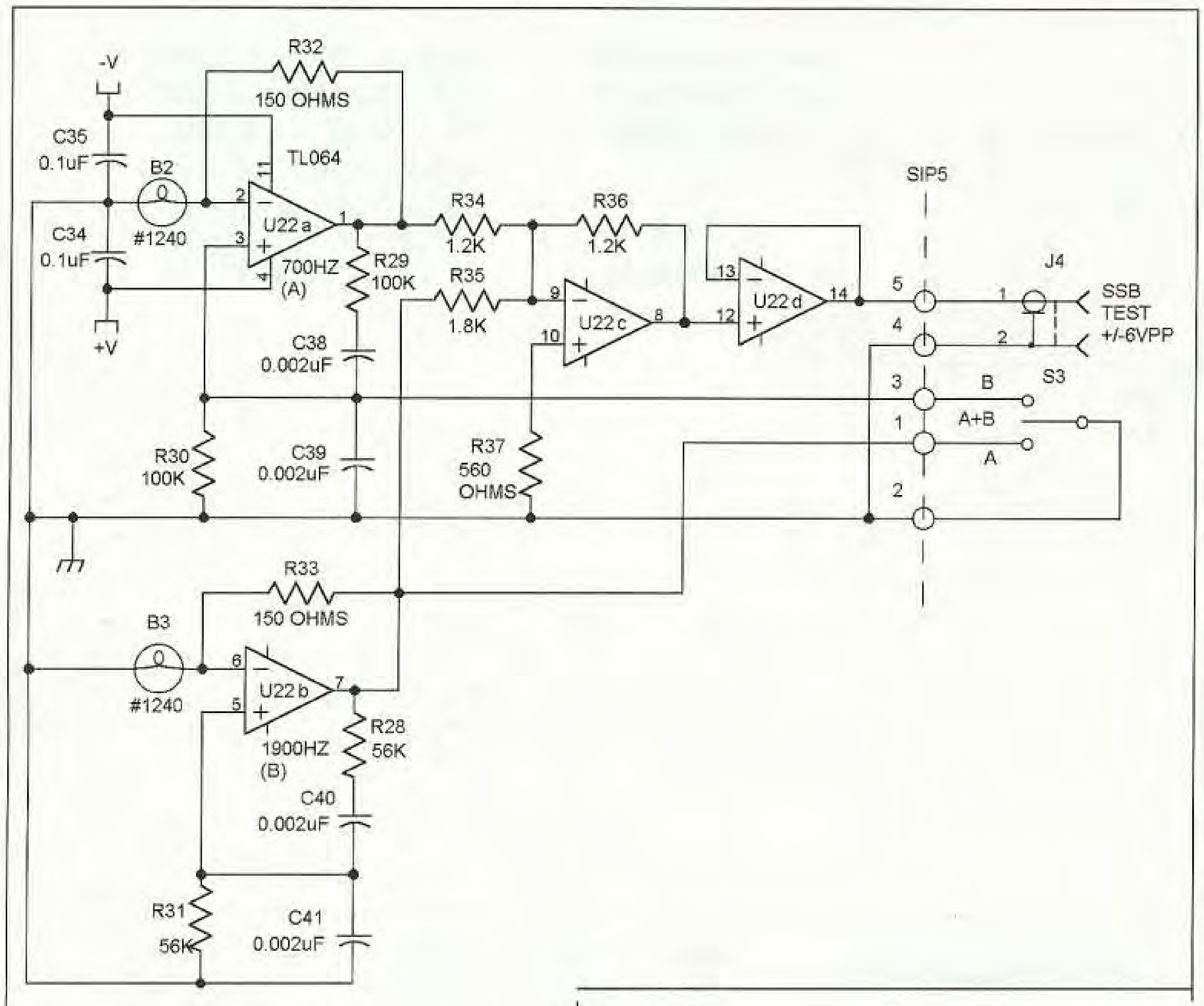


***Photo D.** Triangle wave.*



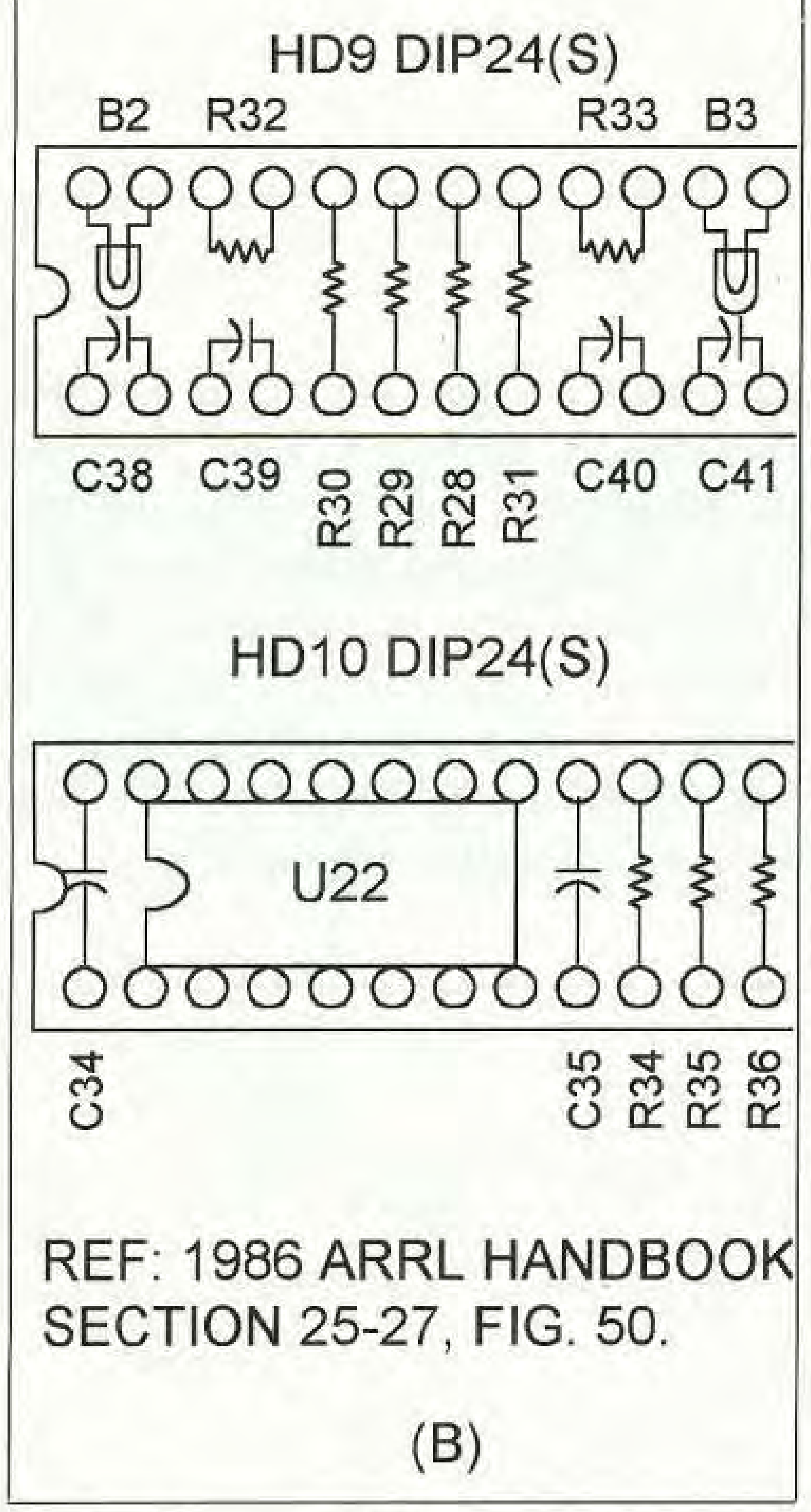
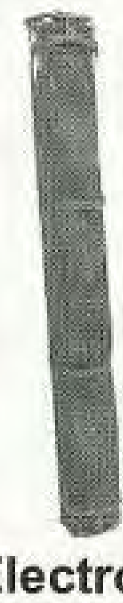
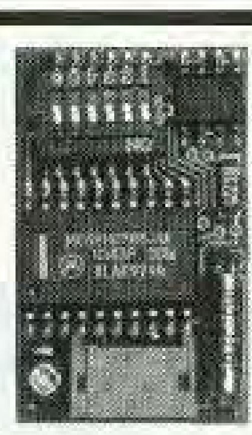


Fig. 9. Schematic, SSB tone test (optional).

placed on the jack to read the time base frequency of 32768 Hz (±1 Hz).

I need to make mention of resistors R28 through R36, which are used to





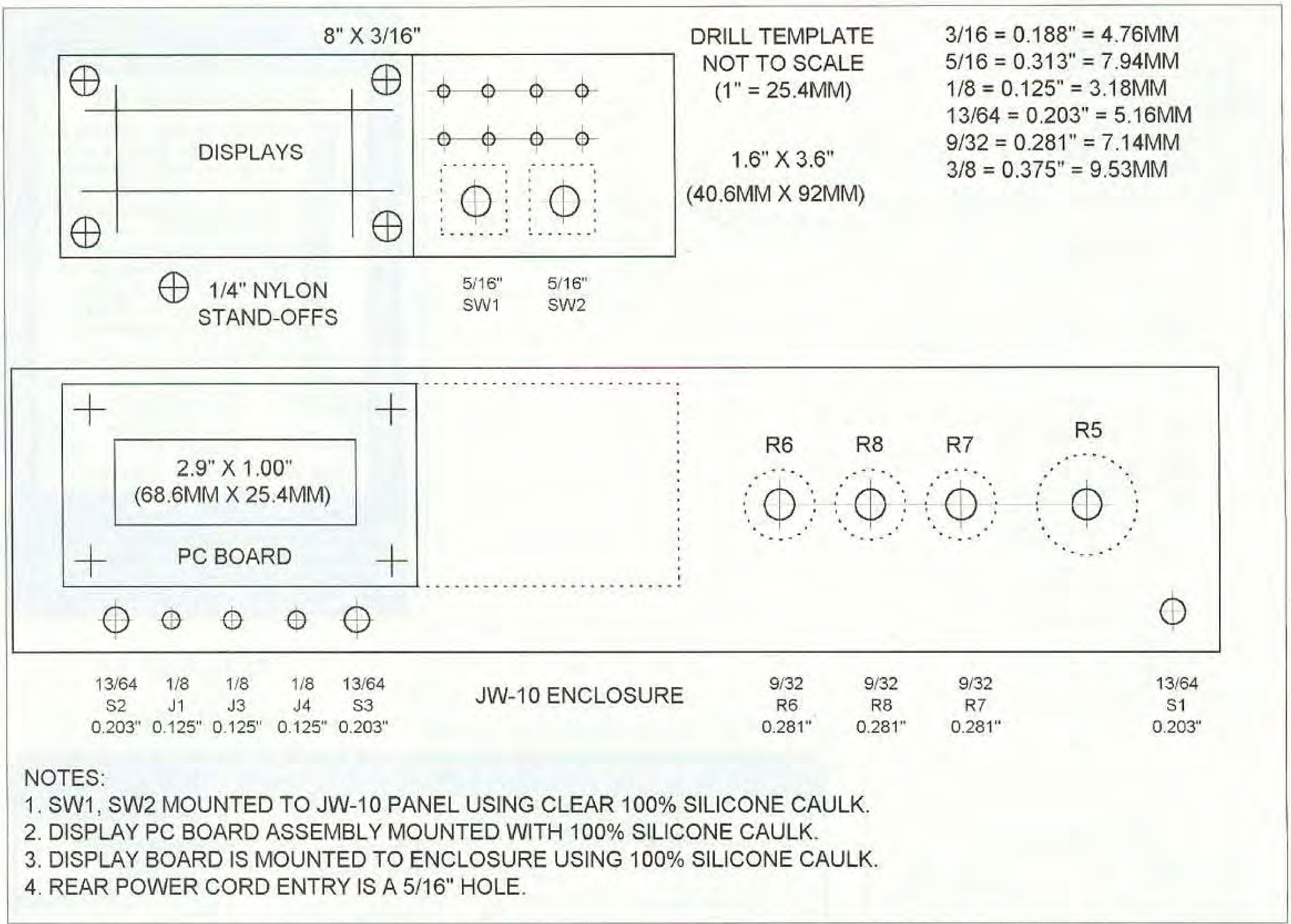



***Fig. 10.** Enclosure template.*

calibrate the frequency ranges. We are using timing capacitors which have tolerances of 5 and 10 percent and do require a selected resistance value to set the bottom end frequency of each of the four ranges. If you do not care about the exact setting, these resistors can be omitted. Use jumper wires in their place. The triangle, square, and pulse frequency goes from 1 Hz to about 15 kHz in the four ranges. The sine wave goes from 1 Hz to about 50 kHz in four ranges. The frequency counter measures the exact frequency in all bands, which is a marked improvement over a calibrated dial knob. The calibration is complete when you adjust the triangle wave to the same frequency as the sine wave. Set the sine wave in the second band and read the frequency. Then move to the triangle function and calibrate it to the same frequency by adjusting R14. That is all there is to it! Well, that is about it for this project! It took quite a little bit of time to design this one, but I feel it was well worth the trouble.

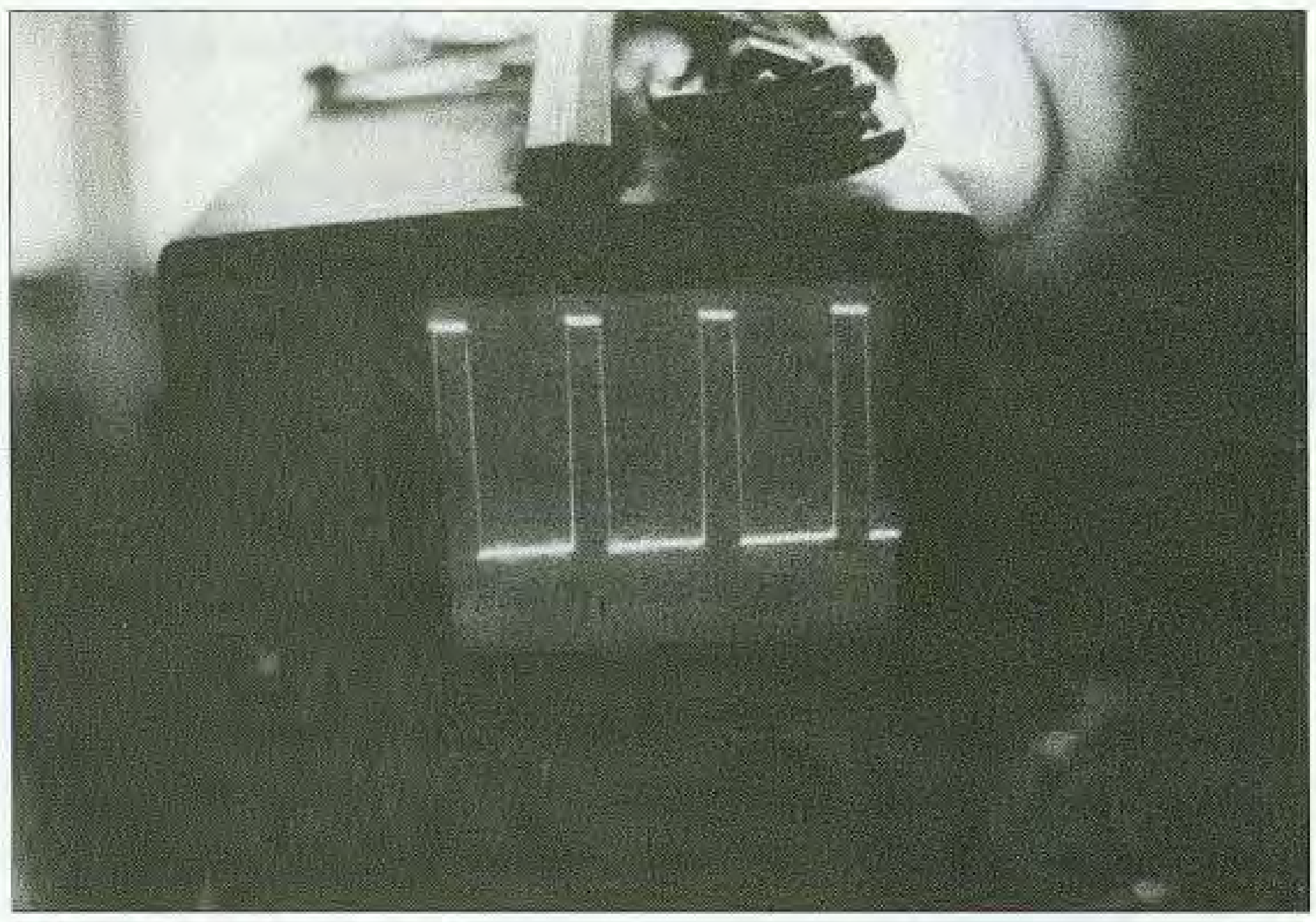


***Photo E.** Pulse wave.*

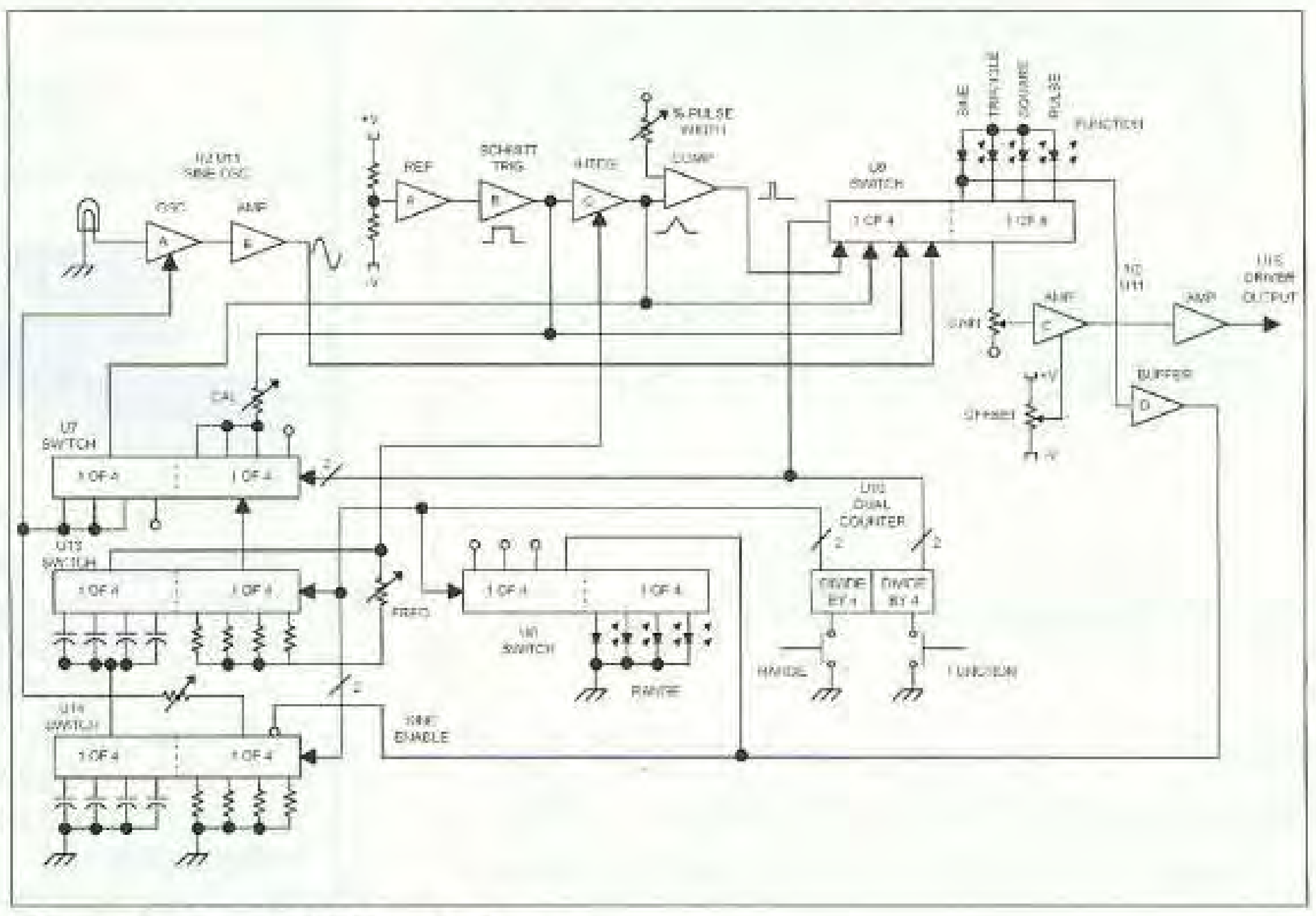


***Fig. 11.** Overall block diagram.*

HEADER		ITEM	PINS
HD-1	R9	22K RES	6,13
HD-1	R10	15M RES	7,12
HD-1	R11	10K RES	5,14
HD-1	R12	2200 RES	2,17
NOTE:	C13--C17	0,1MF CAP	Part of IC's
HD-1	C19	100PF-NPO CAP	8,9
HD-1	C20	10PF-NPO-CAP	15,16
HD-1	C21	0,01MF CAP	1,18
HD-1	C22	0,01MF CAP	3,4
HD-2	R3	220 RES	8,11
HD-2	R4	220 RES	2,17
HD-2	C10	100MF CAP	15,16
HD-2	C11	100MF CAP	3,4
HD-2	D1	1N5232 DIODE	9,10
HD-2	D2	1N5232 DIODE	1,18
HD-2	Q1	PN2222 TRAN	12,13,14
HD-2	Q2	PN2907 TRAN	5,6,7
HD-3	R13	150 RES	5,20
HD-3	C23	0,1MF CAP	23,24
HD-3	C24	0,1MF CAP	1,2
HD-3	C25	0,1MF CAP	11,12
HD-3	C26	0,1MF CAP	13.14
HD-3	C42	0,001MF CAP	7,8
HD-3	C43	0,01MF CAP	9,10
HD-3	C44	0,22MF CAP	15,16
HD-3	C45	4,7MF CAP	17,18
HD-3	B1	#1240 Bulb (3mm)	21,22
HD-4	R15	1K RES	5,20
HD-4	R16	1K RES	6,19
HD-4	R17	330 RES	10,15
HD-4	C27	0,1MF CAP	24,23
HD-4	C28	0,1MF CAP	1,2
HD-4	C29	0,1MF CAP	21,22
HD-4	C30	0,1MF CAP	11,12
HD-4	C31	0,1MF CAP	13,14
HD-4	C52	0,1MF CAP	3,4
HD-4	C18	0,1MF Cap (Axial)	9,16
HD-5	R18	1K RES	10,15
HD-5	R19	1K RES	11,14
HD-5	R37	560 RES	1,24
HD-5	R11	100K RES	12,13
HD-6	R20	1K RES	1,24
HD-6	R21	33-1W RES	2,23
HD-6	R22	10K RES	5,20
HD-6	R23	10K RES	6,19
HD-6	R24	330 RES	7,18
HD-6	R25	330 RES	8,17
HD-6	C51	10PF-NPO CAP	21,22
HD-7	D5-D12	LED's	-----
HD-8	C46	0,001MF CAP	5,6
HD-8	C47	0,01MF CAP	7,8
HD-8	C48	0,22MF CAP	17,18
HD-8	C49	4,7MF CAP	19,20
HD-8	R39	--- CAL RES	1,24
HD-8	R40	--- CAL RES	2,23
HD-8	R41	--- CAL RES	3,22
HD-8	R42	--- CAL RES	4,21
HD-8	R43	--- CAL RES	9,16
HD-8	R44	--- CAL RES	10,15
HD-8	R45	--- CAL RES	11,14
HD-8	R46	--- CAL RES	12,13
U-15	R26	10K RES	1,16
U-15	R27	22K RES	2,15
U-15	C32	0,1MF CAP	3,4
U-15	C33	0,1MF CAP	13,14
U-11	C34	0,1MF CAP	1,18
U-11	C35	0,1MF CAP	9,10
U-12	C36	0,1MF CAP	1,18
U-12	C37	0,1MF CAP	9,10
HD-9	R28	56K RES	5,20
HD-9	R29	100K RES	6,19
HD-9	R30	100K RES	7,18
HD-9	R31	56K RES	8,17
HD-9	R32	150 RES	21,22
HD-9	R33	150 RES	15,16
HD-9	C38	0,002MF CAP	1,2
HD-9	C39	0,002MF CAP	3,4
HD-9	C40	0,002MF CAP	9,10
HD-9	C41	0,002MF CAP	11,12
HD-9	B3	#1240 Bulb (3mm) T-1	23,23
HD-9	B4	#1240 Bulb (3mm) T-1	13,14
HD-10	R34	1200 RES	10,15
HD-10	R35	1800 RES	11,14
HD-10	R36	1200 RES	12.13
HD-10	C34	0,1MF CAP	1,24
HD-10	C35	0,1MF CAP	9,16
HD-10	U22	TL064A IC	2-7,17-23
PC Board	R1,R2	56-1W RES	------
PC Board	C1,C2	6800 MF CAP	------
PC Board	C3-C4	0,01MF CAP	------
PC Board	C5-C8	0,1MF CAP	------
PC Board	C9	100MF CAP	------
PC Board	C12	220MF CAP	------
PC Board	DB1	Diode Bridge	------
PC Board	L-1	Choke	------
PC Board	U-1	LM-2940CT	------
PC Board	Z-1	MOV	------
PC Board	SIP	SIP's	------
PC Board	R14	10K-10T-Trim POT	------
JW10 Front	R5A,R5B	10K-10T POT	------
JW10 Front	R6	100K-1T-POT	------
JW10 Front	R7,R8	10K-1T-POT	------
SO1,2,3,4	U2-U5	DIP18	
SO5	U6	DIP16	
SO6,7,8	HD1,2,8	DIP18	
SO9,10	U12,U13	DIP18	
SO11-SO17	U7-U10.U13-15	DIP16	
SO18-SO25	HD3-HD10	DIP24(S)	
SO26,27	U16-U21	DIP24(W)	
END	NOTE:	SO1-SO5 Sockets Author used sockets with on board 0,1MF capacitors...vice DIP18.	

Table 2. Header component pinout locator.

Good luck on yours! I can answer reasonable questions if I receive an SASE with the request. For those folks who would like more research information, I have included some references.

References

1. *Ham Radio Magazine,* Sept., 1979; Aug. 1980; June 1982; April 1988.

2. *Electronic Design Magazine,* July 1993.

3. *National Semiconductor Op Amp Data Book.*

Parts sources

1. Hosfelt Electronics, catalog 1-800-524-6464.

2. Jameco Electronics, catalog 1-800-831-4242.

3. Mouser Electronics, catalog 1-800-346-6873.

4. Digi-Key Electronics, catalog 1-800-344-4539.

5. Ten-Tec, Inc., catalog 1-800-231-8842.