SDS Audio Labs

Tube DAC 3.5B

Assembly Manual

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Introduction:

The purpose of this manual is to be a guide to the proper assembly and maintenance of your Tube DAC. The board has been carefully laid out and constructed to make assembly easy and straightforward. The DAC itself has been designed to be very robust and to give years of trouble free service.

Theory of Operation:

This DAC consists of four separate parts, the decoder, the digital filter, the digital to analog conversion, and analog gain and buffering. The first part, is the decoder. The digital audio data enters the DAC via a coaxial input BNC connector. It uses the standard SPDIF standard 75Ω input impedance, but the DAC uses a BNC connector rather than an RCA jack. The data stream is capacitively coupled to a pulse transformer. The pulse transformer reduces common mode noise dramatically, and improves the performance of the input circuitry. The output of the pulse transformer goes to the input pins of the decoder chip. It also has a 75Ω resistor in parallel with the chip to set the input impedance. The decoder chip reconstructs the various clocks from the serial data stream. This chip uses a PLL (phase locked loop) to generate the clocks from the data stream. Sampling and status information are also extracted from the data stream.

The data and clocks then go to the digital filter. This filter removes any information from the data stream that is greater than half the sampling rate. The data coming out of this chip is oversampled by 8 times. This means that there are now 8 samples in the time that there was one going into the chip. This will be very useful because it will move the quantization noise generated by the DAC chip 8 times farther away from the audible band.

The data and clocks then go to the DAC chips. This is the heart of the DAC. The DAC chip used here are 20 bit models, that actually have two DAC chips inside each physical chip. They are operating in a complimentary “push-pull” fashion. The DAC chips output a very small current that is proportional to the number input.

The analog stage must take that current output and convert it into a voltage, amplify it if necessary, and buffer the signal so it can be sent to the pre-amplifier without serious degradation. The first task is to convert that very small (micro to millivolt) current into a voltage. There have been a myriad of schemes to convert that current to a voltage in other commercial DAC’s. Very fast op-amps are popular, as are a variety of very clever discrete schemes. The problem with these “active” current to voltage conversion (I/V) schemes is that they typically require many elements. In the case of an op-amp, there may be 40 transistors and a bunch of bulk silicon resistors and capacitors as well as a large amount of feedback involved in the process. And if that wasn’t enough, the current value changes very rapidly, so if the I/V stage isn’t designed perfectly, it can produce slewing induced distortion.

This DAC uses a much more simple scheme (thanks to Peter Campbell for this one). A small value resistor is placed from the output of the DAC to ground. Thus, via Ohm’s law (V=IR), a voltage proportional to the current is produced. There is only one user selected, passive element in the signal path. There is no risk of slewing induced distortion, and the signal path is as short as possible.

There is a downside to this approach. The DAC chip was designed to have it’s output pin always at ground potential. And it has a pair of diodes inside the chip to protect the output from any extraneous voltage on it. So that if the output rises to around 0.7 volts, the diodes start to conduct. This has the nasty side effect of clipping the signal. So the thing to do is keep the voltage generated across the I/V resistor as low as possible. But if the voltage is too low the signal to noise ratio will be compromised, because the signal will require too much gain. So there is a trade off. It turns out that the PCM-63 DAC chips from Burr Brown work very well using this resistor I/V scheme.

There is also a “Bipolar offset pin” on the PCM-63 DAC chip. This subtracts 2 mA of current from the output pin when it is connected to it. The reason they provide this feature is that a zero signal audio condition really is half scale in digital number terms (the audio signal must swing negative as well as positive). So the BPO pin sucks off half of the total possible output current. So the zero signal current with the BPO pin attached is zero. This may seem like a great idea, but it has a downside too. The current source is also made up of a bunch of transistors and bulk silicon resistors and capacitors. These things are best left out of the audio path.

So the BPO pin is shorted to ground where it pulls 2 mA of current off the ground plane. This means that the zero signal current is now 2 mA and it can be as high as 4 mA. So the resistor value must be lower than it normally would have been if the BPO pin was used. This zero signal current is not a problem because the analog stage is capacitively coupled, and a DC offset on the input is filtered out. A FFT analyzer was used to determine the resistance value for the I/V converter where the signal starts being clipped by the diodes. It turned out that a resistor larger than 116Ω caused harmonics to start to be generated from a pure tone. This design uses a 100Ω value. This provides a healthy 2 mV signal for amplification. The signal to noise ratio is not as high as it could be, it is very good all the same. With a good pair of tubes the DAC is dead quiet. The small voltage must now be amplified and buffered. This is done with a SRPP (series regulated push pull) vacuum tube stage.

The SRPP stage can be thought of as a standard resistance coupled triode gain stage, but instead of a large plate resistor, a constant current source is inserted between the power supply and the plate. This acts to make the gain stage much more linear, lowers the harmonic distortion, and provides a much lower output impedance than a single gain stage would have. This SRPP stage uses one half of a dual triode for the current source and the other half for gain. The output is capacitively coupled to the output jacks. The signal from the DAC is coupled to the grid of the gain tube via small resistor. This resistor reduces the likelihood of high frequency instability in the analog section by forming an RC filter with the input capacitance.

As was stated earlier, the output current changes very quickly, and that creates high frequency energy (quantization noise). The continuous audio signal is essentially made up of steps. Most commercial DAC’s filter this energy out. Many different filter topologies were tried, and they have all colored the sound and reduced the performance of the DAC in some way. So the analog stage was left unfiltered. The downstream audio components then act as a filter. Many people have balked at this approach, bringing up the potential for subharmonics being generated in the audio band and such. Those effects haven’t been noticed to date. And those who have listened to this topology have really liked the sound, many say it’s better than any other digital component they have heard. If some filtering is desired, a few pF of capacitance can be added between that plate and the grid of the signal tube. This will act to reduce the bandwidth of the tube, and roll off that high frequency energy. But try listening to the DAC unfiltered first. Due to the 8 times oversampling digital filter, this noise is at and above 352.8 KHz, which is very far above anything that is audible.

The combination of a passive I/V converter resistor and a simple unfiltered tube stage make this one of the simplest and shortest analog sections on the market today. It’s a belief of the designer that a short clean signal path is the best way to get the closest to the music.

These various DAC stages all need to be powered. And this is an area that simplicity doesn't always pay. This DAC uses 4 raw supplies and 8 separate regulation stages. It uses a totally separate transformer for the digital and analog sides as well. The DAC also has a split ground plane that is connected at a point near the mixed mode decoder chip. The digital side of the DAC requires two voltages. Most of the chips require 5 volts, but the DAC chips with their push-pull architecture, also require -5 volts. These voltages come from a full wave rectified supply that feeds a pair of adjustable regulators, with their adjust pins heavily decoupled. Adjustable regulators were chosen over fixed regulators because they are much better at keeping digital noise from being fed back out of them and back into the power line, only to come into the analog stage. The analog stage requires several voltages. The DAC chips analog section also requires plus and minus 5 volts. There is another full wave bridge supply feeding four adjustable regulators, thus each DAC chip has a dedicated regulator pair feeding it plus and minus power. The tube stage requires two power supplies as well. First the tubes require heater power. The heaters also have a regulated DC supply. An adjustable regulator is also used here as well, so the filament voltage can be changed by simply changing a resistor. The heater supply actually floats about 85 volts above ground, so the heater to cathode voltage is not exceeded in the tubes. The final power supply is the high voltage for the tubes.

There are many opinions out there on that is the best way to supply power to tubes. One school of thought is to use passive filtering via RC and inductive filters. This can be very musically satisfying, but creates a power supply that has a high impedance. This high impedance supply actually degrades the performance of the constant current source portion of the SRPP stage. Regulated supplies typically have amazingly low output impedances, but they can be electrically noisy (especially on transient demands), and some folks complain that they lack musicality. A semi-regulated power supply design was chosen, this gives the advantages of a regulated supply, with the quietness and musicality of a passive RC supply. First the high voltage from the transformer is full wave rectified and filtered. A string of zener diodes is biased via a resistor from this voltage. A capacitor is placed across the zener string to maintain the voltage precisely during varying loads, and the capacitor also filters out any diode noise. A pass transistor is referenced from the zener string. The drain of the transistor is attached to the raw supply. The gate is attached to the top of the zener string. The source is then sitting at the zener potential. This arrangement can provide much more regulated power than the analog stage could ever use. The output of the transistor then goes through a pair of small resistors and is filtered with a big pair of filtering caps. This final RC stage gives additional noise filtering and reserve power for the analog stage.

All the rectifiers are solid state. Many people seem to prefer tube rectification. Tube rectification produces much less electrical and RFI hash than solid state rectifiers. But tube rectifiers are very limited in how much capacitance can be used after them. And they generally make higher impedance supplies than solid state rectifiers. So what would be ideal is to have a solid state rectifier that wouldn't produce all that electrical hash. Well the secret is to absorb that hash with ceramic capacitors hung across each leg of the diode bridge. Each rectifier bridge has 4 ceramic caps to absorb that diode hash.

There are also capacitor power supply bypass caps right next to each chip where the power enters. The digital side uses tantalum capacitors, and the analog side uses film capacitors. The final capacitors in the high voltage supply also are bypassed with film caps.

Board Etching Tips:

The artwork is printed onto transparency film from a laser printer, print it three times. Cut out two of the prints with about a quarter inch of clear space around the circuit board image. Then carefully tape these two copies to the uncut one after carefully aligning the traces of the overlay to the uncut sheet's traces. When finished, there should be three perfectly stacked copies. This increases the contrast of the final image. When a transparency is printed with a laser printer, there are usually holes in the black printed parts. And the blacks aren't all that black when it is held up to the light. Overlaying makes the blacks much more black, and gets rid of the holes. Now the artwork is ready to use.

This method uses GC® positive sensitized boards and developer. The FR-4 fiberglass 1 Oz. grade board works very well (they can be gotten local electronics stores). The board emulsion is sensitive to UV light, A good source of UV to expose the board is a GE® sunlamp. The sunlamp is hung so the bottom of the bulb is about 12" above the board. The exposure time is 9 minutes. With a yellow incandescent bug light-bulb on, pull the protective coating off the board and carefully align the artwork on top of the board. Then cover the artwork with a piece of glass to hold the artwork against the board (just like making a contact print in photography). Then turn the sun lamp on for 9 min. If a sunlamp is unavailable, the sun at noontime (on a clear day) can be used exposing the board for about 20 minutes.

The exposed board gets dumped into the developer which has been mixed up beforehand. The developer says to use a 1:9 concentration of developer to water, but a 1:5 mix can be used, which works faster and can yield slightly better results. However the timing is more tricky, so it is not recommended for the first time. Submerge the board into the developer (A photography developer tray works very well), and rock the solution back and forth over the board. The exposed parts with start to dissolve. The emulsion is green and it will wash away exposing the copper underneath. This is the tricky part. The board must be removed when all the emulsion is off the exposed areas. If the board is removed too soon, the emulsion won't be completely dissolved off the exposed areas and it won't etch, if the board is in the developer too long all the emulsion dissolves and all that is left is a bare board. With the 1:9 solution this time window is about a minute, with a 1:5 solution it's about 20 seconds. The board is removed from the developer and washed off with room temperature water, then scrape at a an exposed area and see of there is any emulsion left there. if there is, place the board back in the developer for a few seconds. Repeat this as necessary until the exposed areas clear. With a little practice, it's pretty obvious when it's time to pull the board out. Do all the developing using the yellow bug light. When the board is done, wash it off and let it dry. Be careful of the emulsion, it's easily scratched, especially when fresh from the developer.

Next, drop the board into an etching solution. Ferric Chloride is available from the same electronic outlets where the GC® boards and developer are purchased or from Radio Shack®. Ferric Chloride is a nasty smelling, iodine looking, serious staining stuff. Pour out the developer from the tray, wash it out and add the etchant. Then put the board into the etchant and rock gently back and forth for about a half hour or so, until all the exposed areas are clear. Then remove the board and wash it clean. The emulsion can then be removed with acetone or alcohol.

Then all the holes need to be drilled in the board. A Dremel® moto tool works well for drilling the small holes, a small drill press would also work.

Parts List:

The following parts list is just a recommendation. many other parts will work as well or better than the ones specified here. Many people have substituted high grade resistors in the analog stage. Sprague Orange Drop polypropylene capacitors also work quite well as output caps. There isn't much to be gained by swapping out parts in the digital section however. The RCA jacks specified in the parts list are not very good quality, but it's hard to find decent RCA jacks for sale in electronics catalogs. If you would like a better grade of RCA plug, check with a high quality audio parts supplier. The part numbers listed are internal *Digikey* part numbers, except for the two power transformers, which are Toroid Corp. part numbers.

The transformers specified are very high quality torroidial designs, however they are very expensive. Other brands of less expensive transformers will also work quite well. The transformers and tubes can be purchased from *Antique Electronics Supply*. The digital filter must be purchased from *Seponix* (the sole US importer). The Decoder chip can be purchased from your local *Crystal Semiconductor* representative, call or write to Crystal to find the dealer in your area. Here are the addresses and numbers for the parts suppliers:

Antique Electronic Supply
6221 South Maple Avenue
Tempe, AZ 85283
Voice: (602) 820-5411
Fax: (602) 820-4643
http://tubesandmore.com

Crystal Semiconductor
PO Box 17847
4210 S. Industrial Dr.
Austin TX 78744
Voice: (800) 888-5016
Voice: (512) 445-7222
Fax: (512) 445-7581
http://www.crystal.com

Digi-Key Corporation
701 Brooks Ave. South
Thief River Falls, MN 56701
Voice: (800) DIGIKEY
Voice: (218) 681-6674
Fax: (218) 681-3380
http://www.digikey.com

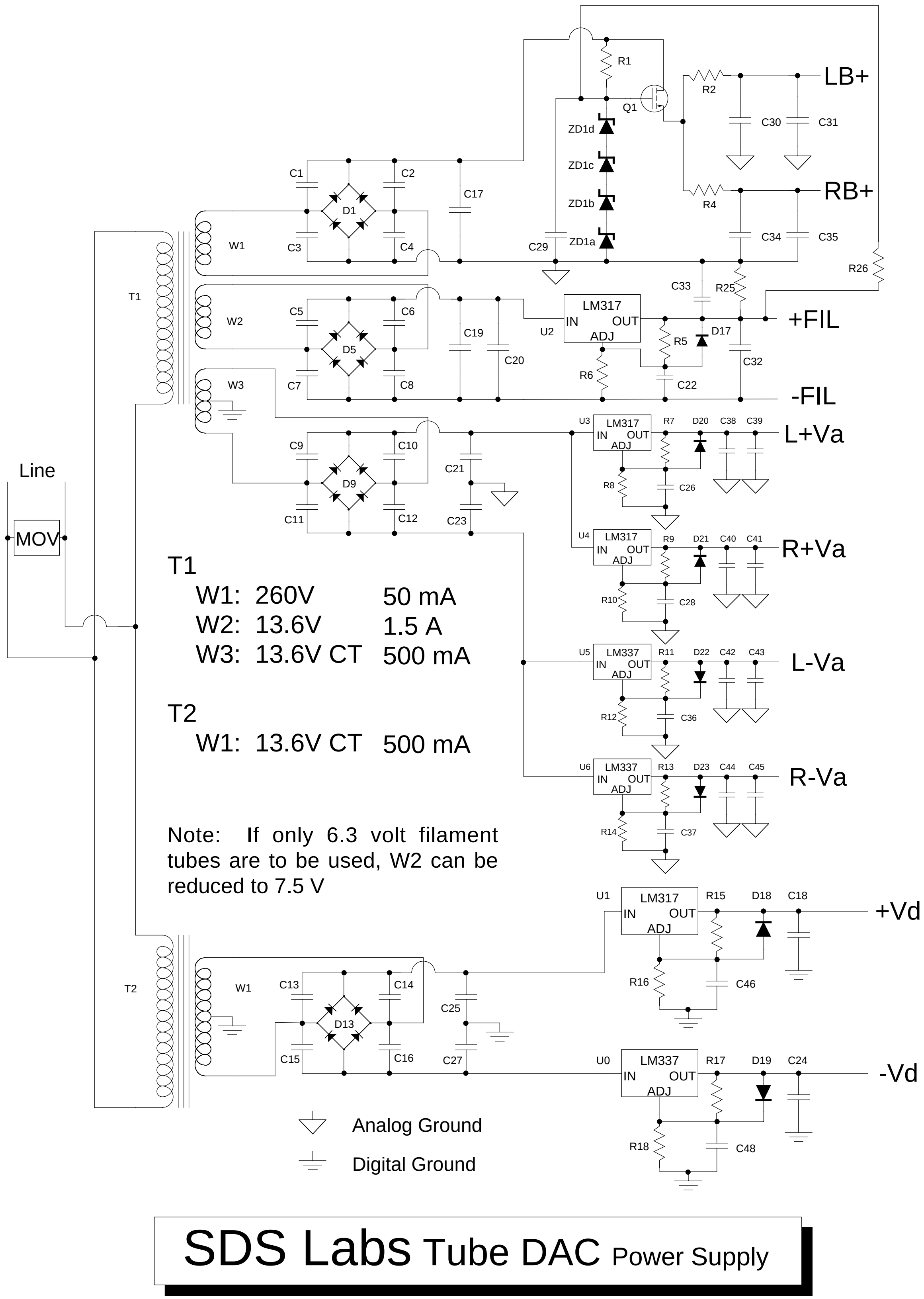
Seponix Corporation
2151 O'Toole Ave. Suite L
San Jose, CA 95131
Voice: (800) 237-4590
Voice: (408) 922-0133
Fax: (408) 922-0137
http://www.seponix.com/

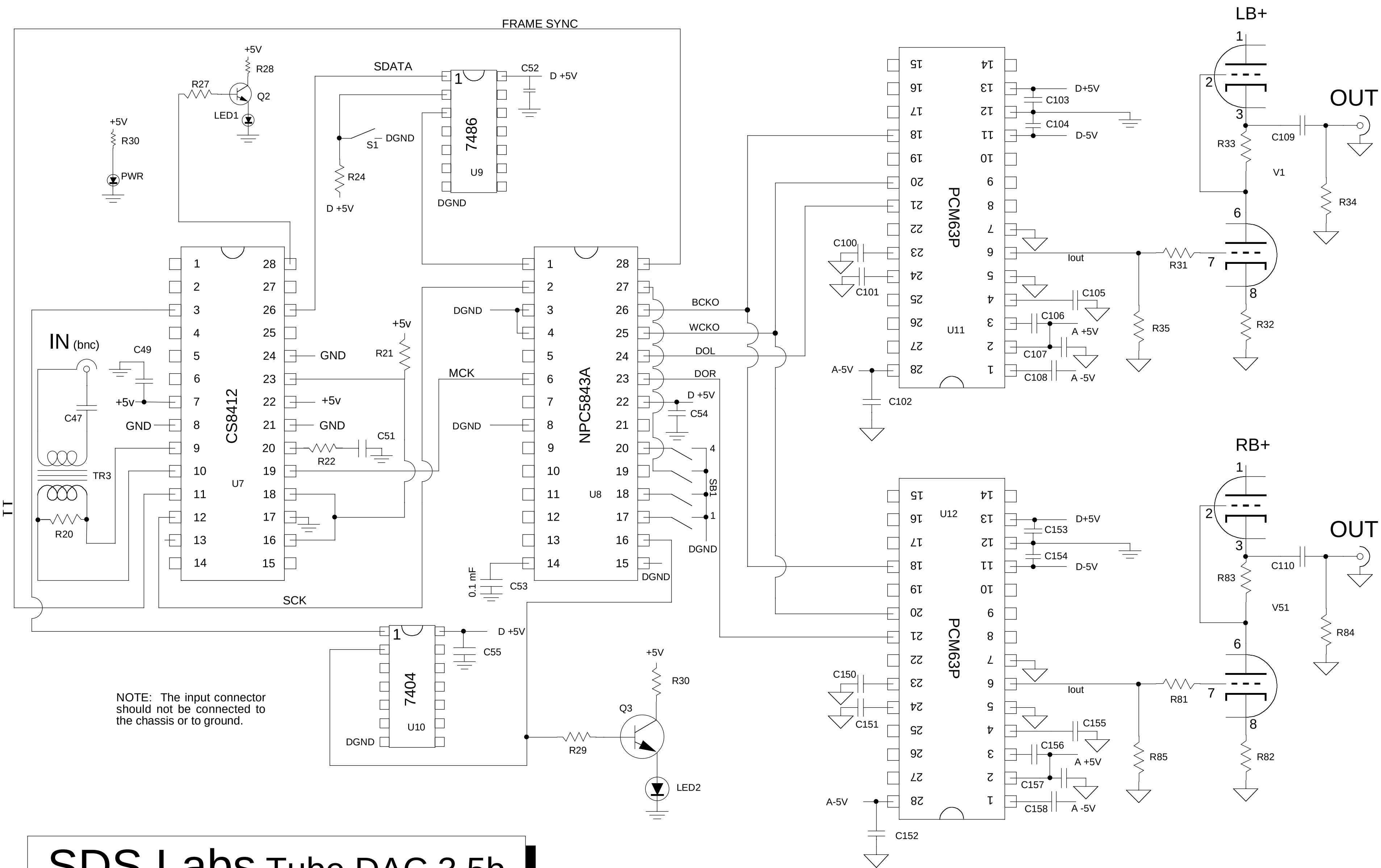
Toroid Corporation Of Maryland
2020 Northwood Dr.
Salisbury, MD 21801
Voice: (410) 860-0300
Fax: (410) 860-0302
http://www.toroid.com

Part #	Desription	Value	Voltage	Part Number	Page	Manufacturer	Price
TR1	Toroid Transformer	57 VA		707.082		Toriod Corp. Of Md	$ 39.95
TR2	Toroid (W/ Custom Winding)	54 VA		5651		Toriod Corp. Of Md	$ 170.00
TR3	Pulse Transformer	"1:1"		257-1015-ND	?	Schott	$ 9.61
U0	Adjustable Regulator	LM337T		LM337T-ND	p 122	National Semiconductor	$ 2.17
U1	Adjustable Regulator	LM317T		LM317T-ND	p 122	National Semiconductor	$ 1.30
U2	Adjustable Regulator	LM317T		LM317T-ND	p 122	National Semiconductor	$ 1.30
U3	Adjustable Regulator	LM317T		LM317T-ND	p 122	National Semiconductor	$ 1.30
U4	Adjustable Regulator	LM317T		LM317T-ND	p 122	National Semiconductor	$ 1.30
U5	Adjustable Regulator	LM337T		LM337T-ND	p 122	National Semiconductor	$ 2.17
U6	Adjustable Regulator	LM337T		LM337T-ND	p 122	National Semiconductor	$ 2.17
U7	Decoder Chip	CS8412-CP				Crystal Semiconductor	$ 30.00
U8	Digital Filter	NPC5843A				NPC	$ 23.50
U9	XOR Chip	7486		DM74LS86N-ND	p 113	National Semiconductor	$ 0.70
U10	Hex Inverter	7404		DM74LS04N-ND	p 113	National Semiconductor	$ 0.53
U11	20 Bit DAC Chip	PCM63P-K		PCM63P-K-ND	p 127	Burr-Brown	$ 41.50
U12	20 Bit DAC Chip	PCM63P-K		PCM63P-K-ND	p 127	Burr-Brown	$ 41.50
U7'	Chip Socket (machined pin)	28 Pin		AE7228-ND	p 97	Assman	$ 1.48
U8'	Chip Socket (machined pin)	28 Pin		AE7228-ND	p 97	Assman	$ 1.48
U9'	Chip Socket (machined pin)	14 Pin		AE7214-ND	p 97	Assman	$ 0.74
U10'	Chip Socket (machined pin)	14 Pin		AE7214-ND	p 97	Assman	$ 0.74
U11'	Chip Socket (machined pin)	28 Pin		AE7228-ND	p 97	Assman	$ 1.48
U12'	Chip Socket (machined pin)	28 Pin		AE7228-ND	p 97	Assman	$ 1.48
C1	Ceramic Capacitor	820 pF	1K V	P4127-ND	p 274	Panasonic ECK-series	$ 0.28
C2	Ceramic Capacitor	820 pF	1K V	P4127-ND	p 274	Panasonic ECK-series	$ 0.28
C3	Ceramic Capacitor	820 pF	1K V	P4127-ND	p 274	Panasonic ECK-series	$ 0.28
C4	Ceramic Capacitor	820 pF	1K V	P4127-ND	p 274	Panasonic ECK-series	$ 0.28
C5	Ceramic Capacitor	820 pF	1K V	P4127-ND	p 274	Panasonic ECK-series	$ 0.28
C6	Ceramic Capacitor	820 pF	1K V	P4127-ND	p 274	Panasonic ECK-series	$ 0.28
C7	Ceramic Capacitor	820 pF	1K V	P4127-ND	p 274	Panasonic ECK-series	$ 0.28
C8	Ceramic Capacitor	820 pF	1K V	P4127-ND	p 274	Panasonic ECK-series	$ 0.28
C9	Ceramic Capacitor	820 pF	1K V	P4127-ND	p 274	Panasonic ECK-series	$ 0.28
C10	Ceramic Capacitor	820 pF	1K V	P4127-ND	p 274	Panasonic ECK-series	$ 0.28
C11	Ceramic Capacitor	820 pF	1K V	P4127-ND	p 274	Panasonic ECK-series	$ 0.28
C12	Ceramic Capacitor	820 pF	1K V	P4127-ND	p 274	Panasonic ECK-series	$ 0.28
C13	Ceramic Capacitor	820 pF	1K V	P4127-ND	p 274	Panasonic ECK-series	$ 0.28
C14	Ceramic Capacitor	820 pF	1K V	P4127-ND	p 274	Panasonic ECK-series	$ 0.28
C15	Ceramic Capacitor	820 pF	1K V	P4127-ND	p 274	Panasonic ECK-series	$ 0.28
C16	Ceramic Capacitor	820 pF	1K V	P4127-ND	p 274	Panasonic ECK-series	$ 0.28
C17	Electrolytic Capacitor	68 uF	450. V	P6439-ND	p 242	Panasonic TS-Series	$ 4.12
C18	Electrolytic Capacitor	4700 uF	16. V	P6234-ND	p 227	Panasonic SU-Series	$ 1.72
C19	Electrolytic Capacitor	3300 uF	25. V	P6245-ND	p 227	Panasonic SU-Series	$ 1.85
C20	Electrolytic Capacitor	3300 uF	25. V	P6245-ND	p 227	Panasonic SU-Series	$ 1.85
C21	Electrolytic Capacitor	4700 uF	16. V	P6234-ND	p 227	Panasonic SU-Series	$ 1.72
C22	Electrolytic Capacitor	100 uF	6.3 V	P6201-ND	p 227	Panasonic SU-Series	$ 0.09
C23	Electrolytic Capacitor	4700 uF	16. V	P6234-ND	p 227	Panasonic SU-Series	$ 1.72
C24	Electrolytic Capacitor	4700 uF	16. V	P6234-ND	p 227	Panasonic SU-Series	$ 1.72
C25	Electrolytic Capacitor	4700 uF	16. V	P6234-ND	p 227	Panasonic SU-Series	$ 1.72
C26	Electrolytic Capacitor	100 uF	6.3 V	P6201-ND	p 227	Panasonic SU-Series	$ 0.09
C27	Electrolytic Capacitor	4700 uF	16. V	P6234-ND	p 227	Panasonic SU-Series	$ 1.72
C28	Electrolytic Capacitor	100 uF	6.3 V	P6201-ND	p 227	Panasonic SU-Series	$ 0.09
C29	Electrolytic Capacitor	10 uF	450. V	P6197-ND	p 227	Panasonic SU-Series	$ 1.14
C30	Electrolytic Capacitor	100 uF	400. V	P6433-ND	p 242	Panasonic TS-Series	$ 4.04
C31	Film Capacitor	1 uF	400. V	E4105-ND	p 267	Panasonic E-series	$ 1.42
C32	Electrolytic Capacitor	3300 uF	25. V	P6245-ND	p 227	Panasonic SU-Series	$ 1.85
C33	Film Capacitor	0.1 uF	250 V	E2104-ND	p 267	Panasonic E-series	$ 0.26
C34	Electrolytic Capacitor	100 uF	400. V	P6433-ND	p 242	Panasonic TS-Series	$ 4.04
C35	Film Capacitor	1 uF	400. V	E4105-ND	p 267	Panasonic E-series	$ 1.42
C36	Electrolytic Capacitor	100 uF	6.3 V	P6201-ND	p 227	Panasonic SU-Series	$ 0.09
C37	Electrolytic Capacitor	100 uF	6.3 V	P6201-ND	p 227	Panasonic SU-Series	$ 0.09
C38	Electrolytic Capacitor	4700 uF	16. V	P6234-ND	p 227	Panasonic SU-Series	$ 1.72
C39	Film Capacitor	0.1 uF	100. V	E1104-ND	p 267	Panasonic E-series	$ 0.29
C40	Electrolytic Capacitor	4700 uF	16. V	P6234-ND	p 227	Panasonic SU-Series	$ 1.72
C41	Film Capacitor	0.1 uF	100. V	E1104-ND	p 267	Panasonic E-series	$ 0.29
C42	Electrolytic Capacitor	4700 uF	16. V	P6234-ND	p 227	Panasonic SU-Series	$ 1.72
C43	Film Capacitor	0.1 uF	100. V	E1104-ND	p 267	Panasonic E-series	$ 0.29
C44	Electrolytic Capacitor	4700 uF	16. V	P6234-ND	p 227	Panasonic SU-Series	$ 1.72
C45	Film Capacitor	0.1 uF	100. V	E1104-ND	p 267	Panasonic E-series	$ 0.29
C46	Electrolytic Capacitor	100 uF	6.3 V	P6201-ND	p 227	Panasonic SU-Series	$ 0.09
C47	Film Capacitor	0.22 uF	100 V	E1224-ND	p 267	Panasonic E-series	$ 0.35
C48	Electrolytic Capacitor	100 uF	6.3 V	P6201-ND	p 227	Panasonic SU-Series	$ 0.09
C49	Tantalum Capacitor	47 uF	6.3 V	P2017-ND	p 255	Panasonic EF-series	$ 0.83
C51	Film Capacitor	0.047 uF	250. V	E2473-ND	p 267	Panasonic E-series	$ 0.22
C52	Tantalum Capacitor	47 uF	6.3 V	P2017-ND	p 255	Panasonic EF-series	$ 0.83
C53	Film Capacitor	0.1 uF	100. V	E1104-ND	p 267	Panasonic E-series	$ 0.29
C54	Tantalum Capacitor	47 uF	6.3 V	P2017-ND	p 255	Panasonic EF-series	$ 0.83
C55	Tantalum Capacitor	47 uF	6.3 V	P2017-ND	p 255	Panasonic EF-series	$ 0.83
C100	Film Capacitor	0.1 uF	100. V	E1104-ND	p 267	Panasonic E-series	$ 0.29
C101	Film Capacitor	0.1 uF	100. V	E1104-ND	p 267	Panasonic E-series	$ 0.29
C102	Electrolytic Capacitor	1000 uF	10. V	P5643-ND	p 236	Panasonic HFQ-series	$ 0.75
C103	Tantalum Capacitor	47 uF	6.3 V	P2017-ND	p 255	Panasonic EF-series	$ 0.83
C104	Tantalum Capacitor	47 uF	6.3 V	P2017-ND	p 255	Panasonic EF-series	$ 0.83
C105	Film Capacitor	1 uF	100. V	E1105-ND	p 267	Panasonic E-series	$ 0.73
C106	Film Capacitor	0.1 uF	100. V	E1104-ND	p 267	Panasonic E-series	$ 0.29
C107	Electrolytic Capacitor	1000 uF	10. V	P5643-ND	p 236	Panasonic HFQ-series	$ 0.75
C108	Film Capacitor	1 uF	100. V	E1105-ND	p 267	Panasonic E-series	$ 0.73
C109	Film Capacitor	2.2 uF	400. V	E4225-ND	p 267	Panasonic E-series	$ 2.92

C110	Film Capacitor	2.2 uF	400. V	E4225-ND	p 267	Panasonic E-series	$ 2.92
C150	Film Capacitor	0.1 uF	100. V	E1104-ND	p 267	Panasonic E-series	$ 0.29
C151	Film Capacitor	0.1 uF	100. V	E1104-ND	p 267	Panasonic E-series	$ 0.29
C152	Electrolytic Capacitor	1000 uF	10. V	P5643-ND	p 236	Panasonic HFQ-series	$ 0.75
C153	Tantalum Capacitor	47 uF	6.3 V	P2017-ND	p 255	Panasonic EF-series	$ 0.83
C154	Tantalum Capacitor	47 uF	6.3 V	P2017-ND	p 255	Panasonic EF-series	$ 0.83
C155	Film Capacitor	1 uF	100. V	E1105-ND	p 267	Panasonic E-series	$ 0.73
C156	Film Capacitor	0.1 uF	100. V	E1104-ND	p 267	Panasonic E-series	$ 0.29
C157	Electrolytic Capacitor	1000 uF	10. V	P5643-ND	p 236	Panasonic HFQ-series	$ 0.75
C158	Film Capacitor	1 uF	100. V	E1105-ND	p 267	Panasonic E-series	$ 0.73
D1	Diode Bridge	1.5A 1000V		W10G-ND	p 162	General Instrument	$ 0.88
D5	Diode Bridge	1.5A 1000V		W10G-ND	p 162	General Instrument	$ 0.88
D9	Diode Bridge	1.5A 1000V		W10G-ND	p 162	General Instrument	$ 0.88
D13	Diode Bridge	1.5A 1000V		W10G-ND	p 162	General Instrument	$ 0.88
D17	Diode	1A 1000 volt		1N4007GI-ND	p 162	General Instrument	$ 0.07
D18	Diode	1A 1000 volt		1N4007GI-ND	p 162	General Instrument	$ 0.07
D19	Diode	1A 1000 volt		1N4007GI-ND	p 162	General Instrument	$ 0.07
D20	Diode	1A 1000 volt		1N4007GI-ND	p 162	General Instrument	$ 0.07
D21	Diode	1A 1000 volt		1N4007GI-ND	p 162	General Instrument	$ 0.07
D22	Diode	1A 1000 volt		1N4007GI-ND	p 162	General Instrument	$ 0.07
D23	Diode	1A 1000 volt		1N4007GI-ND	p 162	General Instrument	$ 0.07
ZD1a	Zener Diode	62 V		1N4759ACT-ND	p 173	Diodes Inc. (ITT)	$ 0.25
ZD1b	Zener Diode	62 V		1N4759ACT-ND	p 173	Diodes Inc. (ITT)	$ 0.25
ZD1c	Zener Diode	62 V		1N4759ACT-ND	p 173	Diodes Inc. (ITT)	$ 0.25
ZD1d	Zener Diode	62 V		1N4759ACT-ND	p 173	Diodes Inc. (ITT)	$ 0.25
R1	Metal Film Resistor (2W)	47 K Ohm		47KW-2-ND	p 290	Yageo	$ 0.23
R2	Metal Film Resistor (1/4 W)	100 Ohm		100X-ND	p 289	Yageo	$ 0.11
R4	Metal Film Resistor (1/4 W)	100 Ohm		100X-ND	p 289	Yageo	$ 0.11
R5	Metal Film Resistor (1/4 W)	499 Ohm		499X-ND	p 289	Yageo	$ 0.11
R6	Metal Film Resistor (1/4 W)	2 K Ohm		2.00KX-ND	p 289	Yageo	$ 0.11
R7	Metal Film Resistor (1/4 W)	665 Ohm		665X-ND	p 289	Yageo	$ 0.11
R8	Metal Film Resistor (1/4 W)	2K Ohm		2.00KX-ND	p 289	Yageo	$ 0.11
R9	Metal Film Resistor (1/4 W)	665 Ohm		665X-ND	p 289	Yageo	$ 0.11
R10	Metal Film Resistor (1/4 W)	2K Ohm		2.00KX-ND	p 289	Yageo	$ 0.11
R11	Metal Film Resistor (1/4 W)	665 Ohm		665X-ND	p 289	Yageo	$ 0.11
R12	Metal Film Resistor (1/4 W)	2K Ohm		2.00KX-ND	p 289	Yageo	$ 0.11
R13	Metal Film Resistor (1/4 W)	665 Ohm		665X-ND	p 289	Yageo	$ 0.11
R14	Metal Film Resistor (1/4 W)	2K Ohm		2.00KX-ND	p 289	Yageo	$ 0.11
R15	Metal Film Resistor (1/4 W)	665 Ohm		665X-ND	p 289	Yageo	$ 0.11
R16	Metal Film Resistor (1/4 W)	2K Ohm		2.00KX-ND	p 289	Yageo	$ 0.11
R17	Metal Film Resistor (1/4 W)	665 Ohm		665X-ND	p 289	Yageo	$ 0.11
R18	Metal Film Resistor (1/4 W)	2K Ohm		2.00KX-ND	p 289	Yageo	$ 0.11
R20	Metal Film Resistor (1/4 W)	75 Ohm		75.0KX-ND	p 289	Yageo	$ 0.11
R21	Metal Film Resistor (1/4 W)	10 K Ohm		10.0KX-ND	p 289	Yageo	$ 0.11
R22	Metal Film Resistor (1/4 W)	1 K Ohm		1.OOKX-ND	p 289	Yageo	$ 0.11
R24	Metal Film Resistor (1/4 W)	10 K Ohm		10.0KX-ND	p 289	Yageo	$ 0.11
R25	Carbon Film Resistor (1/4 W)	1M Ohm		1.0MH-ND	p 288	Yageo	$ 0.06
R26	Carbon Film Resistor (1/4 W)	2.4M Ohm		2.4MH-ND	p 288	Yageo	$ 0.06
R27	Metal Film Resistor (1/4 W)	4.7 K Ohm		4.75KX-ND	p 289	Yageo	$ 0.11
R28	Metal Film Resistor (1/4 W)	332 Ohm		332X-ND	p 289	Yageo	$ 0.11
R29	Metal Film Resistor (1/4 W)	2 K Ohm		2.00KX-ND	p 289	Yageo	$ 0.11
R30	Metal Film Resistor (1/4 W)	332 Ohm		332X-ND	p 289	Yageo	$ 0.11
R30a	Metal Film Resistor (1/4 W)	332 Ohm		332X-ND	p 289	Yageo	$ 0.11
R31	Metal Film Resistor (1/4 W)	33.2 Ohm		33.2X-ND	p 289	Yageo	$ 0.11
R32	Metal Film Resistor (1/4 W)	680 Ohm		680X-ND	p 289	Yageo	$ 0.11
R33	Metal Film Resistor (1/4 W)	680 Ohm		680X-ND	p 289	Yageo	$ 0.11
R34	Metal Film Resistor (1/4 W)	1 M Ohm		1.00MX-ND	p 289	Yageo	$ 0.11
R35	Metal Film Resistor (1/4 W)	100 Ohm		100X-ND	p 289	Yageo	$ 0.11
R81	Metal Film Resistor (1/4 W)	33.2 Ohm		33.2X-ND	p 289	Yageo	$ 0.11
R82	Metal Film Resistor (1/4 W)	680 Ohm		680X-ND	p 289	Yageo	$ 0.11
R83	Metal Film Resistor (1/4 W)	680 Ohm		680X-ND	p 289	Yageo	$ 0.11
R84	Metal Film Resistor (1/4 W)	1 M Ohm		1.00MX-ND	p 289	Yageo	$ 0.11
R85	Metal Film Resistor (1/4 W)	100 Ohm		100X-ND	p 289	Yageo	$ 0.11
Q1	N Channel MOSFET	IRF740	400V	IRF740-ND	p 186	International Rectifier	$ 3.60
Q2	NPN Transistor	4401		2N4401-ND	p 158	National Semiconducto	$ 0.29
Q3	NPN Transistor	4401		2N4401-ND	p 158	National Semiconducto	$ 0.29
SB1	Dip Switch Array (4 switches)			A5304-ND	p 342	Amp	$ 1.44
LED1	Red LED (error)	(10 pack)		P300-ND	p 466	Panasonic	$ 1.96
LED2	Yellow LED (De-emph)	(10 pack)		P306-ND	p 466	Panasonic	$ 2.52
PWR	Green LED (power)	(10 pack)		P303-ND	p 466	Panasonic	$ 2.24
	Heat Sinks (10 Pack)			HS132-ND	p 101	Aavid	$ 11.65
V1	6DJ8/6922 Dual Triode						$ 10.00
	6DJ8/6922 Dual Triode						$ 10.00
	BNC connector	75 ohm		ARF1177-ND	p 69	Amphenol	$ 4.16
	Power Entry Module			CCM1115-ND	p 223	Corcom	$ 37.94
	RCA Jack			SC1134-ND	p 74	Switchcraft	$ 1.68
	RCA Jack			SC1134-ND	p 74	Switchcraft	$ 1.68
S1	SPST toggle switch			CKN1019-ND	p 329	C&K	$ 4.62
						Total:	$ 546.14

Schematic:

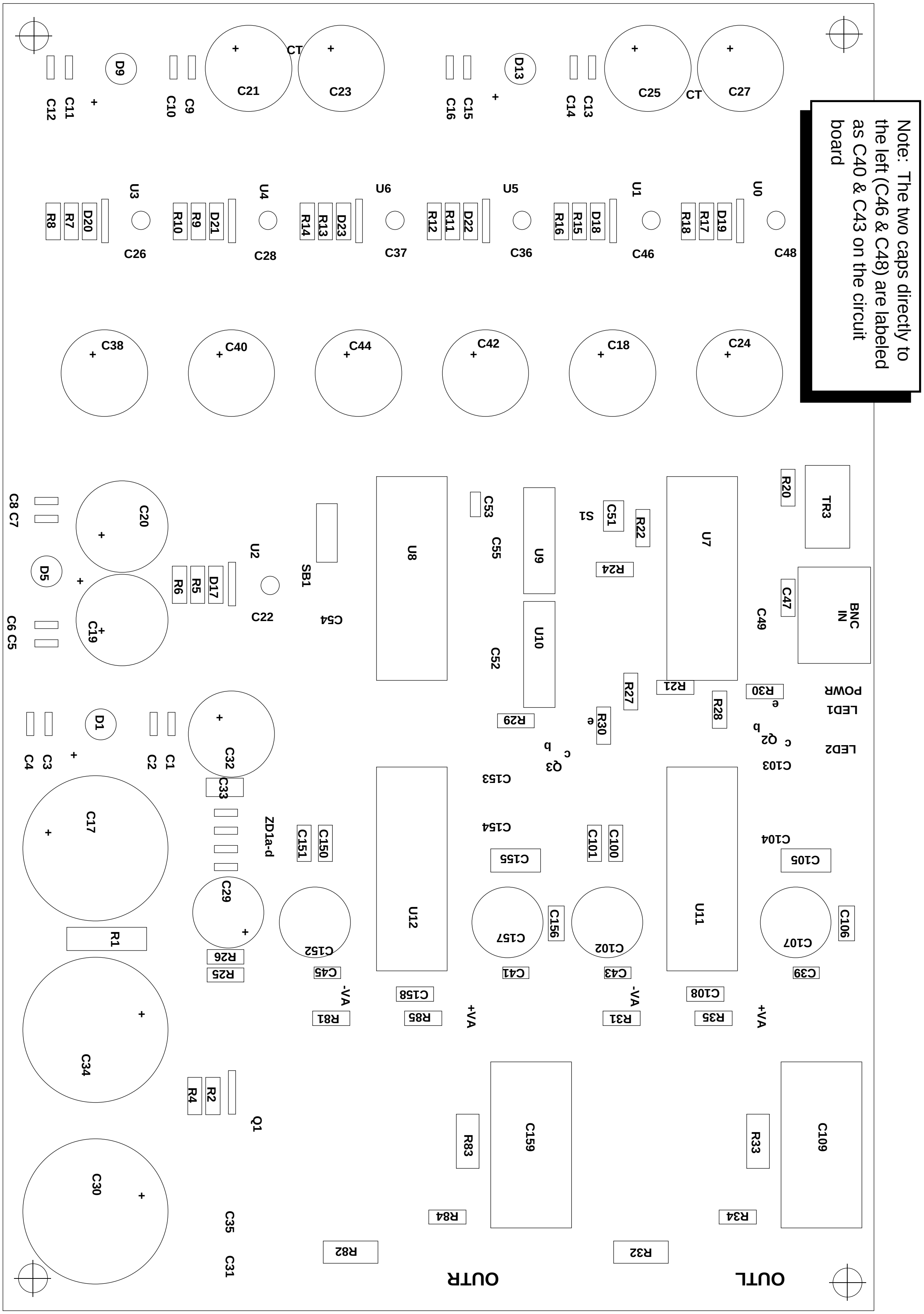

LB+
RB+
+FIL
-FIL
L+Va
R+Va
L-Va
R-Va
+Vd
-Vd
Line
MOV
T1
W1: 260V 50 mA
W2: 13.6V 1.5 A
W3: 13.6V CT 500 mA
T2
W1: 13.6V CT 500 mA
Note: If only 6.3 volt filament tubes are to be used, W2 can be reduced to 7.5 V
LM317
LM337
IN OUT
ADJ
Analog Ground
Digital Ground
SDS Labs Tube DAC Power Supply



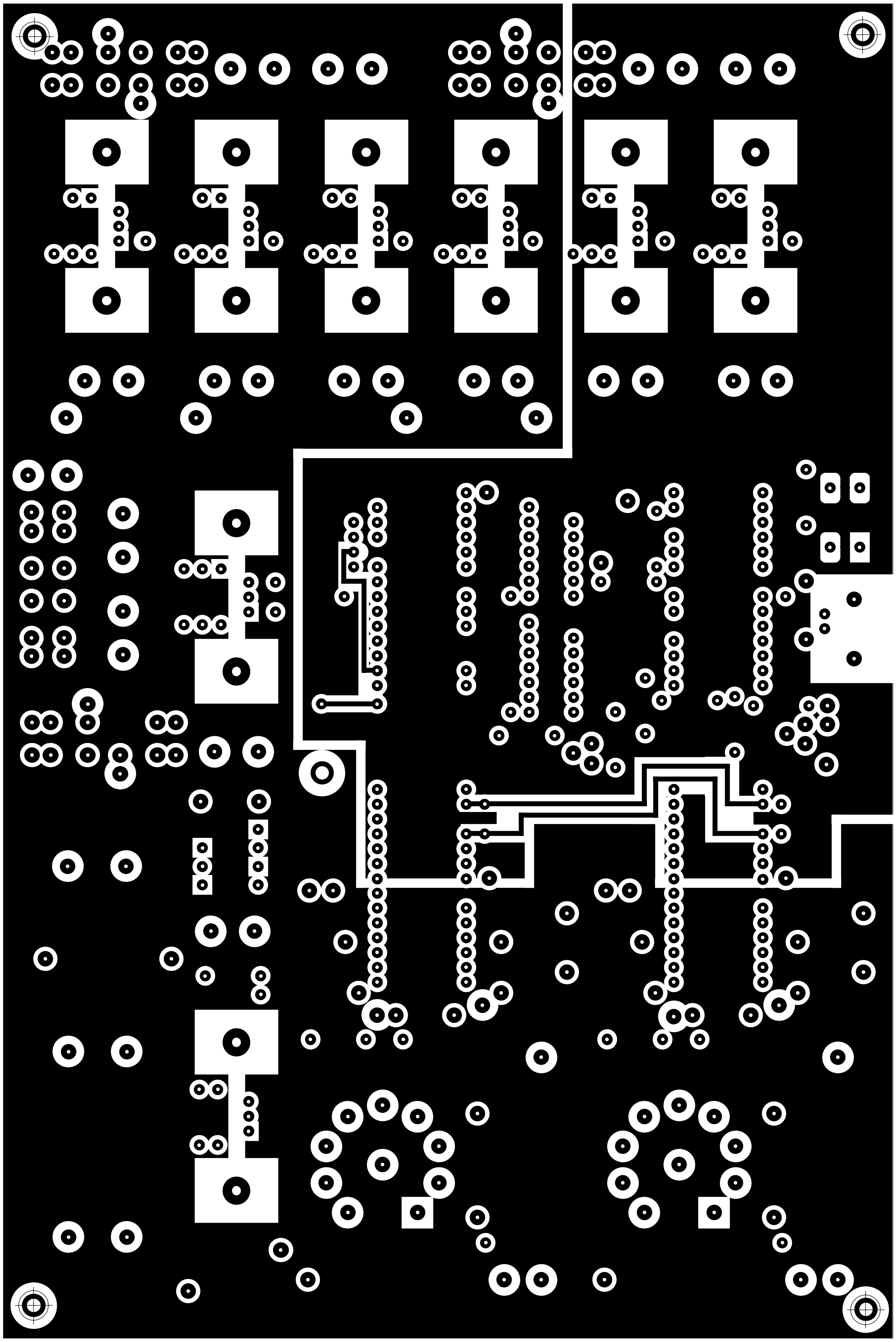
SDS Labs Tube DAC 3.5b

Switch			Switch		Switch	
1	2	Sample Rate	3	Filter	4	Clock
Off	Off	32.0 KHz	Off	153 Tap	Off	Free
On	On	44.1 KHz	On	25 Tap	On	Sync.
On	Off	48.0 KHz				
Off	On	De-Emph OFF				

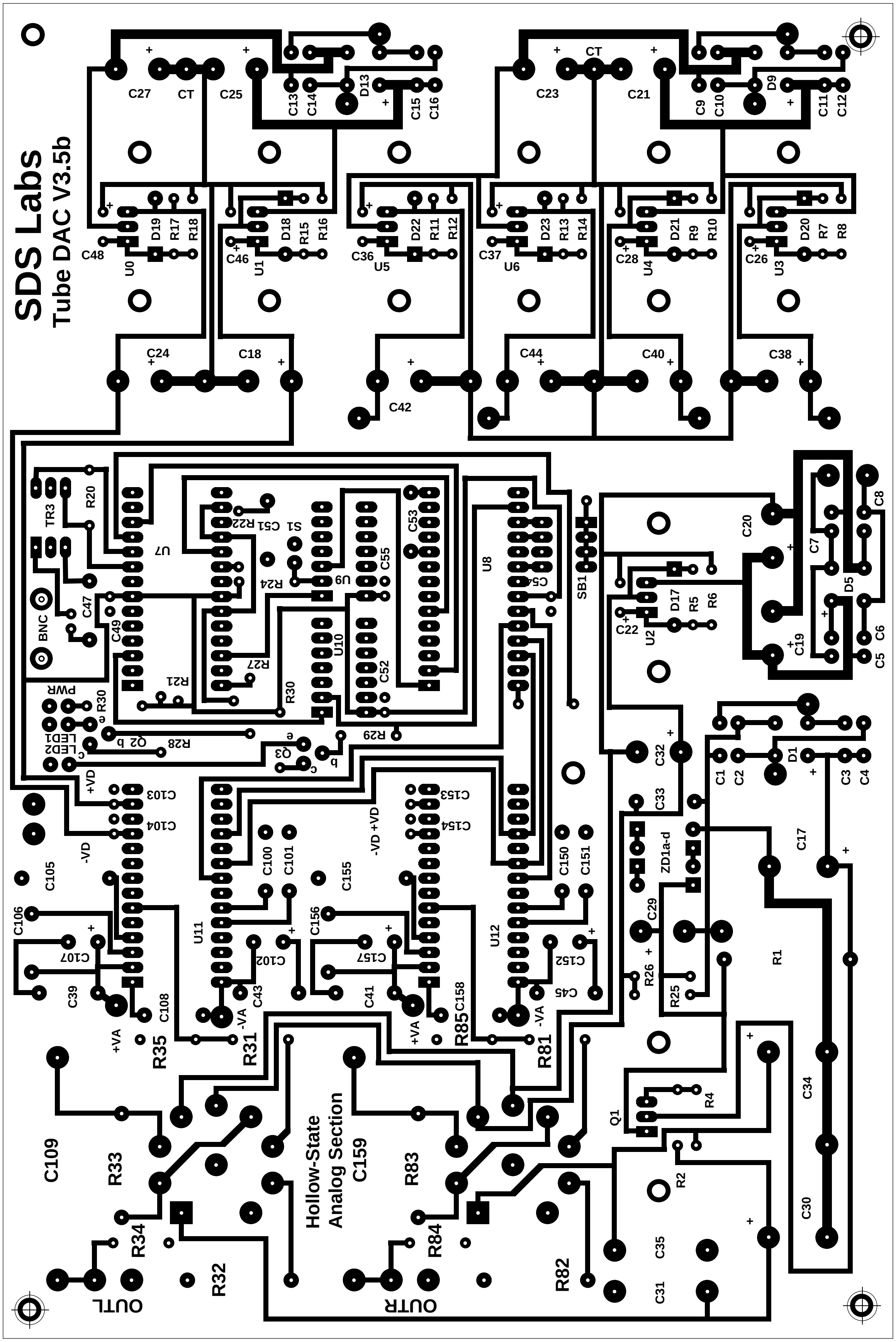
The Circuit Board (Component Outlines):



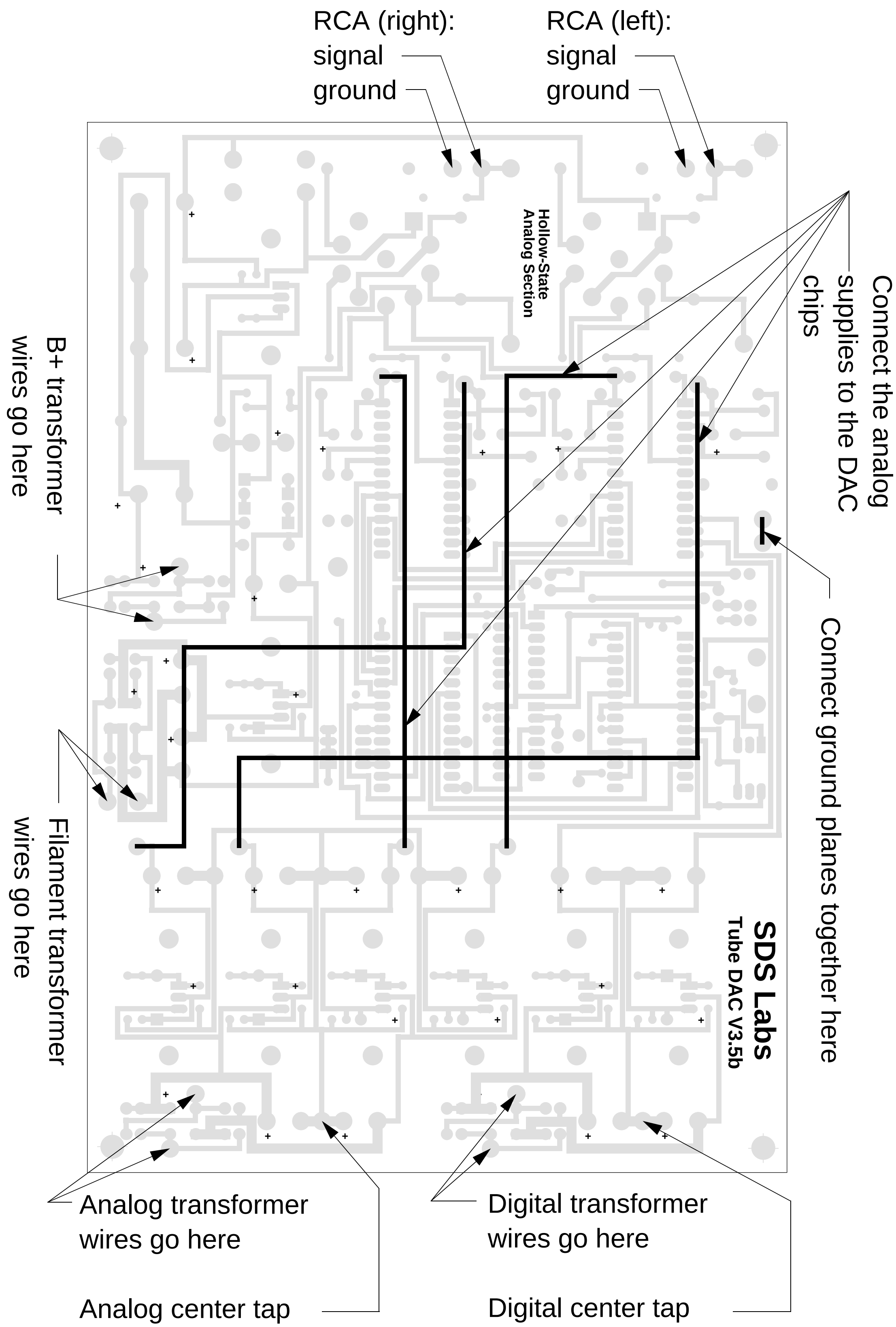
The Circuit Board (Ground Side):



The Circuit Board (Signal Side):



Wiring The Circuit Board:



Digital Filter Settings:

Switch			Switch		Switch	
1	2	Sample Rate	3	Filter	4	Clock
Off	Off	32.0 KHz	Off	153 Tap	Off	Free
On	On	44.1 KHz	On	25 Tap	On	Sync.
On	Off	48.0 KHz				
Off	On	De-Emph OFF				

The chart above summarizes the different filter settings. Set DIP switches 1 & 2 for the sampling frequency most commonly used. For CD's it would be 44.1 KHz. This sets the correct coefficients for the de-emphasis filter. If you also listen to DAT tapes (sampled at 48 KHz) don't worry about switching the filter each time, the difference in coefficients is very slight. In fact the error from having the switch set for the other frequency is actually less than the error in many de-emphasis filters implemented in the analog domain.

Switch 3 is an interesting one. The digital filter has two filter settings. The higher tap setting is a steeper filter, and is the one that yields the best measured performance. The second filter is a much more gentle sloped filter. The two setting have a slightly different sound, pick the one you like.

Switch 4 sets the filter in either free running or forced synchronizing mode. There may be a slight difference in jitter specs between modes, but it hasn't been noticeable in listening tests. If in doubt, keep it in Sync mode.

Customizing and Making Substitutions:

The analog stage as shown uses 6DJ8, 6922 or 7308 tubes. The DAC can be easily changed to accommodate quite a few different tubes. For tubes with twelve volt filaments, change the value of R5 from 499Ω to 221Ω. This will allow the use of the 12A_7 family of tubes and their variants. The values of resistors R32, R33, R82, & R83 may have to be changed to increase or decrease the bias current depending on the tube chosen. The sound of each tube can be tailored somewhat depending on the bias point chosen. The B+ voltage can also be adjusted by substituting different value zener diodes into the string. For example, using four 75 volt zeners would yield a B+ voltage of 300 volts.

If the filament supply chosen uses the 13.6 volt transformer winding (suitable for both 6.3 volt and 12.6 volt filament tubes), and 6.3 volt filament tubes are being used, a 5 ohm (10 watt) resistor can be inserted in series with one of the transformer leads going to the circuit board. This will reduce the power dissipated by the regulator and make it run cooler. If the DAC is only ever going to use 6.3 volt filament tubes, a transformer with a 7.5 volt filament winding can be used.

If different analog stage parts would like to be substituted, the following resistors are the ones to change, in order of importance: R35 & R85, R31 & R81, R32 & R82, R33 & R83, R34 & R84.

The output capacitors can also be changed. Polypropylene caps work very well. C109 & C110 are the most critical followed by (in order of importance): C31 & C35, C39 & C41 & C43 & C45.

Ideally the DAC should be housed in a metal case to shield your other components from the DAC's RFI. But it's not required. The prototype is still being used, and it is open to the world with no problems. If the DAC is enclosed in a metal case, make sure that the input BNC plug is insulated from the case, or the benefit of the input transformer will be lost.

Corrections:

There is an error in the labeling on the circuit board. There are two C40 and two C43 labels. The numbering on the *Component Outlines* included here is correct.