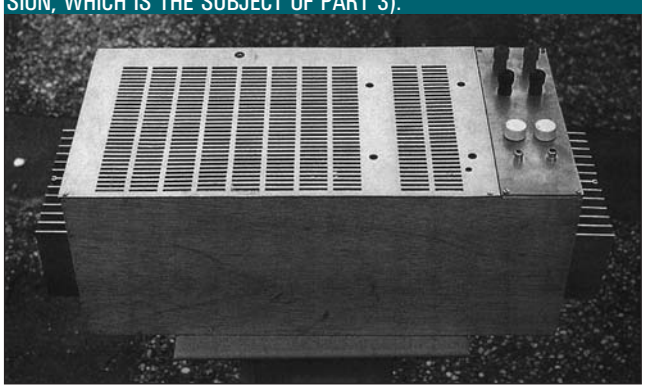
Tubes

A Study System: Part 1, The SE Amplifier

By Aren van Waarde

How simple can an audio system be, yet still convey the spirit of the music? This series of articles shows you how to build an enjoyable stereo using only two electronic tubes and two full-range loudspeakers.

PHOTO 1: THE AUTHOR'S COMPLETED AMP (SOLID-STATE VERSION, WHICH IS THE SUBJECT OF PART 3).



In my living room, I have a nice audio system with tube amplification and large bass horns. But unfortunately, most of my time is spent in the study behind the computer. The quality of the audio produced by the speaker set of this aged Pentium is poor. It was thus high time to heat the soldering iron. Surely I could do better than this!

My study is a large rectangular room (8 × 3½ meters) with a flagstone floor and a low ceiling (2.2 meters). One long and one short wall are covered with books. The other short wall is a French window, opening to the garden. Against the last wall there are two writing desks and an old cupboard (also filled with books). There are several skylights in the ceiling. The acoustics of the room are good.

For various reasons, I decided to give the single-ended tube (SET) amplifier a try. First, my junkbox contained several SE output transformers. Second, I have a large stock of tubes. I can't resist buying them when there is a sale (if you don't believe me, ask my wife!).

BOX GRAMOPHONE REDISCOVERED

Box gramophones from the late 1950s and early 1960s suggested the idea to use just one triode/pentode and one full-range loudspeaker per stereo channel. I have fond memories of a Dual turntable which my aunt and uncle owned. This player was my first introduction to classical music. It suffered from excessive hum, but sounded relatively nice. The Dual used one 6GW8/ECL86 per channel and oval full-range loudspeakers in vented enclosures. [Peter Baxandall designed an amazing one—*Audio Amateur*, Vol. 1, Nos. 2 and 3, 1970—Ed.]

The contents of my junkbox dictated the selection of tubes. It contained many PCL82 (16A8) valves of different brands, which were made for use in television receivers (e.g., Bush TV135). Such sets used the triode ("C" part of the PCL82) as AF preamp or frame time base oscillator. The pentode ("L" part) was the AF output or frame output valve. The 6BM8/ECL82 is nearly equivalent, but it has different heater demands.

The PCL82 was intended for television sets with heaters wired in series. This tube is heated with 16V (AC or DC), 0.3A. The ECL82 was used in sets with heaters connected in parallel. It requires 6.3V and 0.78A. You can buy new-old stock PCL82 valves from several mail-order companies (Alltronics, Antique Electronic Supply, House of Tubes, SND Tube Sales, Tubestore, and Vacuum Tubes Incorporated, to mention just a few). The 6BM8 (ECL82) is still being made—e.g., by Svetlana—so you can buy it virtually everywhere.

So the die was cast: one PCL82 per channel, triode wired as voltage amplifier, and pentode as power output tube. The pinout of the PCL82 is shown in *Fig. 1*.

THREE DIFFERENT PROTOTYPES

This seemed a very simple project, but proved not to be so in real life. The first prototype I made was based on a Svetlana Technical Bulletin for the 6BM8[1]. The Svetlana circuit does not use overall negative feedback, and there is no power supply decoupling between the anodes of triode and pentode. Unfortunately, the circuit did not work with a PCL82 due to problems with stability. Above a certain output level, the amp burst into oscillation. Although I tried to reduce the gain and to decouple the triode and pentode stages, the instability remained. On some DIY projects, amplifiers insist that they are oscillators, and oscillators stubbornly refuse to generate RF.

My second attempt was based on a circuit from a splendid old book: *Praktische Elektronica* (Practical Electronics), by Wim van Bussel (Kluwer Tech-

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Aren van Waarde is a biochemist working in the field of medical imaging (positron emission tomography). He has worked as a Ph.D. student and a postdoc at several universities (including Leiden and Yale Universities) before accepting tenure at the University of Groningen. His passion for audio started on his ninth birthday when his parents gave him a Philips kit. Most of his current audio equipment (loudspeakers, radios, tuners, pre- and power amps, both tube and solid-state) is homemade.

nical, Deventer, Holland, 1968, vol. 2, p. 98–109). Unfortunately, I own only two of the three volumes.

Van Bussel employed an ECL82. The cathode resistor of the triode was not bypassed with a capacitor and there was negative feedback from the secondary of the output transformer to the cathode of the triode. With a PCL82 from the junkbox, the circuit seemed to be OK. There was no audible oscillation even at high output levels.

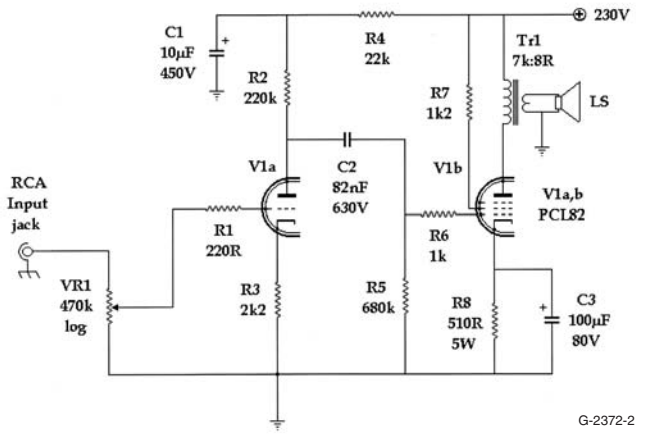
However, oscilloscope images indicated that square-waves were not well reproduced. There was visible ringing, because the feedback loop did not match the parameters of the output transformer. Worse still, the sound of the amp was lifeless and boring. I tried various resistor and capacitor combinations in the feedback loop, besides three different output transformers, but this was all to no avail.

At this point I almost decided to give up, until it occurred to me to consult the datasheets of the PCL82. My compatriot Frank Philipse has a huge website, from which you can download data for virtually every tube[2]. Frank's site includes two sheets for the PCL82, reprinted from the *Philips Electronic Tube Handbook*, one dating from 1956 and the other from 1970. Recently he has added sheets from two French sources: *Mazda* and *Radiotechnique*.

The Philips datasheets suggest the following part values. Triode section: plate voltage 200V, anode resistor 220k, cathode resistor 2k2. Pentode section: plate voltage 230V, signal grid resistor 680k, screen grid resistor 1k2 (non-decoupled), cathode resistor 490Ω, primary impedance of SE output transformer 6k.

Triode current is specified as 0.52mA under these conditions. Triode gain is 52× and maximal output of the triode stage 26V RMS at 1.6% total harmonic distortion. Quiescent current through the pentode stage should be 36.6mA in the absence of signal (30mA for the plate and 6.6mA for the screen grid). The signal grid of the pentode needs 7.8V RMS for maximum output power (3.25W at 10% total harmonic distortion). The current consumption should then increase to 42mA (31mA for the plate and 11mA for grid 2).

FIGURE 2: AMPLIFIER SCHEMATIC (ONLY ONE CHANNEL SHOWN, THE OTHER CHANNEL IS IDENTICAL).



PHILIPS OVERALL

A gain of 52 is reached when the cathode resistor of the triode is bypassed with a capacitor. A high gain was necessary in the past when a ceramic cartridge in the record player produced the music signal. In this modern age of soundcards and CD players, high sensitivity of the amp is not required. Thus, I decided to omit the cathode resistor bypass cap.

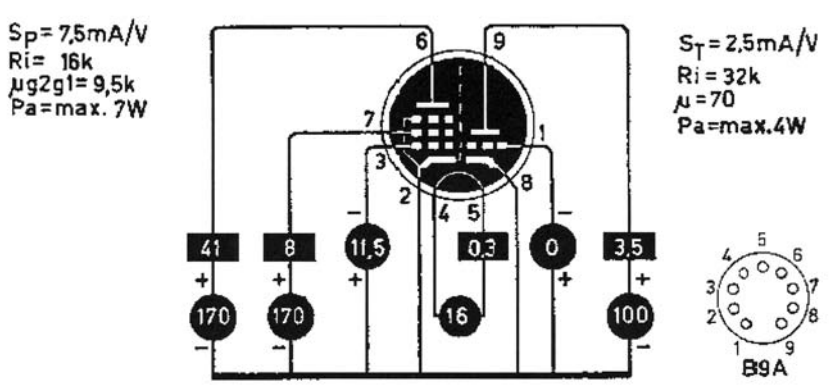
I added grid stopper resistors to the triode (220Ω) and pentode signal grids (1k). They may not be absolutely necessary, but they can prevent RF oscillations. Such instability may occur at only a certain setting of the volume control; it may not be directly audible but can manifest itself as increased noise, or a "hard" and "glassy" sound.

I determined the selection of the other parts by the contents of my junkbox. I did not have 490Ω (or 470Ω) resistors with a rating of 2W or greater, but the box contained several 510Ω 5W resistors, so I decided to use them. I had two medium-sized SE output transformers from discarded Philips radios with a 7.5k to 8Ω impedance ratio. Not exactly 6k to 8Ω, but close enough.

A prototype which I built according to the Philips specs worked perfectly and showed no instability on the scope. More important was the sound. Lots of "air" and life—just what I like! So I decided to construct a stereo version, using the Philips schematic and the two aged Philips SE output transformers (for other ways to obtain transistors, see reference 3).

The triode section of my PCL82s drew a little bit more current than the datasheets predicted (0.61 rather than 0.52mA). Finally, I ended up with the part values shown in *Fig. 2*. Measured voltages on the prototype were B+ 228V, plate of triode 84V, cathode of triode 1.35V, cathode of pentode 18.7V; cathode current of triode 0.61mA, and cathode current of pentode 36.7mA.

FIGURE 1: PINOUT AND SOME DATA OF THE PCL82 (DOWNLOADED FROM WWW.TUBEDATA.ORG, PICTURE TAKEN FROM *ELECTRONIC TUBE HANDBOOK*, MUIDERKRING PUBLISHERS, BUSSUM, HOLLAND. THIS BOOK HAS BEEN OUT OF PRINT SINCE 1973). THE NOVAL (9-PIN MINIATURE) TUBE SOCKET IS SHOWN FROM BELOW.



POWER SUPPLY

Single-ended amplifiers have a poor power-supply rejection ratio, so you need a quiet power supply. I used a CLC filter with additional RC decou-

FIGURE 3: PLATE VOLTAGE POWER SUPPLY. THE CIRCUIT FEEDS BOTH CHANNELS OF A STEREO AMPLIFIER.

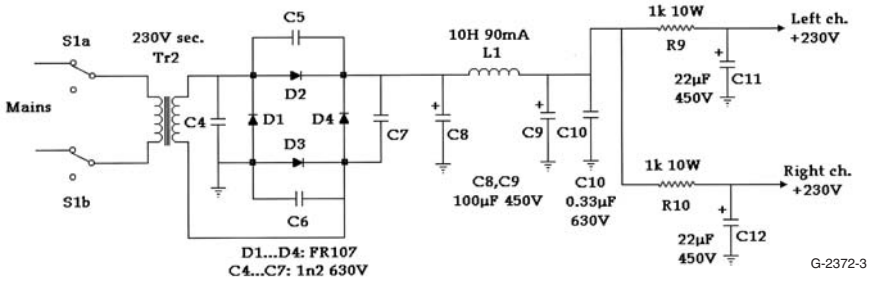
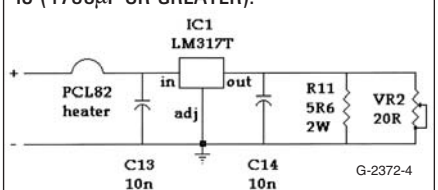


FIGURE 4: RECOMMENDED HEATER POWER SUPPLY (ONLY ONE CHANNEL SHOWN, THE OTHER CHANNEL IS IDENTICAL). DC INPUT TO THIS CIRCUIT SHOULD COME FROM A SUITABLE TRANSFORMER, BRIDGE RECTIFIER, AND LARGE ELECTROLYTIC (4700µF OR GREATER).



pling networks for channel separation (*Fig. 3*). I used fast recovery diodes in the bridge rectifier and bypassed them with capacitors to suppress switching transients.

You can heat the PCL82 either with AC or DC. I decided to use DC heating in order to minimize hum, but at this point I made a design error. The heater of each tube is fed by a 7815 with its ground pin lifted (two 1N4001 diodes connected in series between ground pin and earth), so that the regulator produces the required 16V. Although this setup does work, it is not wise to heat PCL82s in this way. Since the tubes were designed for series heating, I should have included a current-limiting or slow-start facility in the heater power supply.

When the heaters are fed by a voltage regulator, a large current (up to 1.5A!) flows during the initial few seconds. The heaters then produce a bright light, and after a short interval they begin to glow normally. Cold heaters have a low DC resistance, which causes the high inrush current. The resistance of the wire has a positive temperature coefficient. Therefore, the resistance increases when the heater becomes hot and the current rapidly settles down to the regular 0.3A.

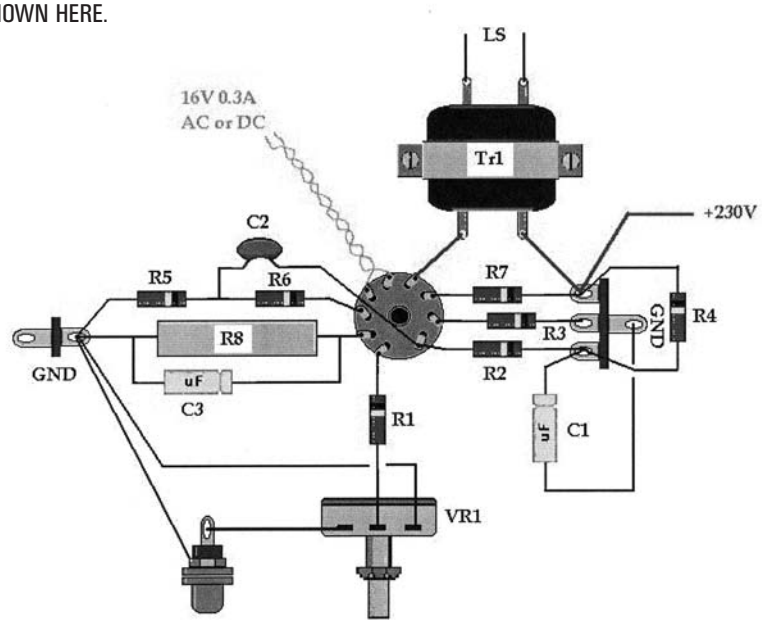
Since I am a lazy fellow, I have not yet changed my heater power supply. The amp has been functioning perfectly with the existing supply for more than two years. Apparently, Philips built tubes with reliable heaters that can stand a lot of mischief! But I advise you to use a more careful heating scheme. The simplest approach is to wire a LM317 adjustable voltage regulator as a constant-current supply (*Fig. 4*).

The lowest output voltage the LM317 can produce is 1.2V. Since in the circuit of *Fig. 4*, the ADJ pin is grounded, Vout will be 1.2V. According to Ohm's Law, a current of 1.2 (V) / 5.6 (Ω) = 0.214A will then flow through R11, which will dissipate a power of 1.2 (V)× 0.214 (A) = 0.26W. The PCL82 needs a heater current of 0.3A. Thus, an additional 0.086A (0.3 – 0.214) should flow through trimpot VR2. The wiper of this trimpot should be set to a value of 1.2 (V)/0.086 (A) = 14Ω. By careful adjustment of VR2, you can obtain a total current of exactly 0.3A.

The LM317 requires a voltage drop of at least 3V for adequate regulation, whereas a voltage drop of 1.2V occurs across R11 and VR2. Thus, the raw DC input to the LM317 should be at least 16 (voltage across PCL82 heater) + 3 + 1.2 = 20.2V. A transformer with an 18V secondary, B80C5000 bridge rectifier, and electrolytic cap (4700µF or greater) will produce more than 22.5V, which is sufficient. The LM317 will require heatsinking, since it dissipates 0.3W/V. In the example, the IC will dissipate 0.3×(22.5–16–1.2) = 0.3×5.3 = 1.6W.

A construction sketch of the amplifier is shown in *Fig. 5*. *Table 1* contains a parts list.

FIGURE 5: CONSTRUCTION SKETCH OF THE AMPLIFIER. FOR THE SAKE OF CLARITY, ALL COMPONENTS ARE DRAWN IN A SINGLE PLANE. IN REALITY, ALL COMPONENTS ARE MOUNTED PERPENDICULAR TO THE PLANE OF THE TUBE SOCKET. THIS ALLOWS YOU TO USE A SINGLE EARTH (GND) NODE FOR EACH AMPLIFIER CHANNEL AND NOT TWO SEPARATE NODES AS SHOWN HERE.



FINALLY, THE SOUND

How does this piece of junk sound? Based on the specs (*Table 2*), I anticipated mediocre performance. What can you expect from 2W per channel, with a harmonic distortion of several percent, a low-frequency cutoff point (–3dB) of 100Hz, and a relatively high output impedance?

Just for fun, I hooked it up to the large horns in my living room during the Christmas vacation of 2001. The audience consisted of my mother-in-law,

my wife, and my (then) eight-year old son (who are music lovers, not audiophiles). After the first few notes, our jaws dropped! We kept listening during the whole vacation period. Every day we played several CDs in succession and enjoyed it greatly. Since then, I use the little amp, with its own dedicated full-range loudspeakers, in our study.

PROS AND CONS

The amp shows the typical pros and cons of fleapower SE amplifiers.

I'll start with the pros. Reproduction of the midrange and treble region of the audio band is simply marvelous. Voices sound as though a real person was in the room, sibilants are not emphasized, and the intelligibility of vocal lines is unsurpassed. The instruments and tonal colors of an orchestra—especially of the strings—are presented in a realistic way. The positions of individual voices within a choir or of individual instruments within an orchestra are very well-defined in all three dimensions. Small details in recordings which cannot be perceived on other audio systems are now clearly audible.

Now for the cons. Poor recording techniques are mercilessly revealed. If the sound engineer has employed any tricks (e.g., close-miked the soloists in contrast to the accompanying orchestra, added a variable amount of electronic reverberation, changed the hall structure between tracks), you will immediately notice and strongly dislike it. Most recordings of popular music sound "artificial" and unpleasant for this reason.

You can use the amp only with loudspeakers of high efficiency (greater

TABLE 2

Measured Specs of Amplifier Prototype

LEFT CHANNEL

Output transformer	Philips part no. 30231 (1960s vintage)
Voltage gain	29.4× (136mV in for 2W out)
Output power	ca. 2W/8Ω
Frequency response	100Hz...30kHz (–3dB)

(but very slow LF rolloff, 25Hz still visible)

RIGHT CHANNEL

Output transformer	Philips part no. 1080770 189 (1938 vintage)
Voltage gain	29.4× (136mV in for 2W out)
Output power	ca. 2W/8Ω
Frequency response	95Hz. . . 20kHz (–3dB)

(slow LF rolloff, 40Hz still visible)

TABLE 1

PARTS LIST

(NB part numbers with accents indicate parts for 2nd channel)

AMPLIFIER

R1, R1′	220Ω 0.5W carbon
R8, R8′	510Ω 5W wire-wound (NB 490Ω according to datasheet)
R6, R6′	1k 0.5W carbon
R7, R7′	1k2 0.5 or 1W, carbon or metal oxide
R3, R3′	2k2 0.5W, carbon or metal oxide
R4, R4′	22k 0.5W, carbon or metal oxide
R2, R2′	220k 0.5 or 1W, carbon or metal oxide
R5, R5′	680k 0.5W, carbon or metal oxide
VR1, VR1′	variable resistor 470k, audio taper
C2, C2′	82nF foil cap, 400V or more (I used 1500V caps from dB Systems; use the best cap you have)
C1, C1′	10µF 450V electrolytic
C3, C3′	100µF 80V electrolytic
V1, V1′	PCL82 (16A8) (I used NOS valves from Philips)
Tr1, Tr1′	Output transformer 6k: 8Ω, 50mA or more (see ref. 3)

Two 9-pin (noval) tube sockets

B+ POWER SUPPLY

D1, D2, D3, D4	FR107 fast recovery diode (1000V 1A)
R9, R9′	1k, 10W wire-wound
C4, C5, C6, C7	1n2 630V MKT
C10	0.33µF 630V MKT
C11, C12	22µF 450V electrolytic
C8, C9	100µF 450V electrolytic
L1	Choke, 10H, 80mA or more (I used Amroh, NOS)
S1A, S1B	DPDT mains switch
Tr2	230:230V transformer (in the US, you need a 115:230V transformer)

RECOMMENDED HEATER POWER SUPPLY

Tr3	230:18V transformer, 1A or greater (in the US, you need a 115:18V transformer) (not shown in Fig. 4)
B1	B80C5000 bridge rectifier (80V 5A) (not shown in Fig. 4)
IC1, IC1′	LM317T adjustable voltage regulator (TO-220 case)
R11, R11′	5.6Ω, 2W (or 5W)
VR2, VR2′	trimpot 20Ω, cermet type
C13,C13′,C14,C14′	10nF ceramic or multilayer
C15	4700µF 35V electrolytic (or greater capacitance value) (not shown in Fig. 4)

Heatsinks, insulating material for the two LM317 ICs (TO-220)

REFERENCES

1. The 6BM8 schematic is at www.svetlana.com/graphics/TB/No10fig2.gif.
2. You can reach Frank's site through the domain name www.tubedata.org.

   The URL of the mother site is: home.planet.nl/~frank.philipse/frank/frank.html, with mirror sites in Germany, frank.pocnet.net and in Poland, www.mif.pg.gda.pl/homepages/frank. There is no relationship between Frank Philipse and Philips multinational, although his family name could suggest otherwise.
3. Of course, not every reader's junkbox will contain suitable output transformers. But everyone can buy these from various suppliers. Here are some suggestions (ranging from dirt cheap to more expensive solutions). You can buy second-hand, used transformers very cheaply from surplus stores (e.g., Play Things of Past, 9511 Sunrise Blvd, J-23, Cleveland, OH 44133; www.oldradios.com (subject to availability); or Jan Wüsten Elektronik, Rodauer Straße 38, 64372 Ober Ramstadt, Germany, www.fragjanzuerst.de). More expensive alternatives are new transformers from the Canadian manufacturer Hammond (e.g., Hammond P-T125E, P-T125CSE, P-T125DSE, P-T125ESE). Prices range from $60 to $75 for a pair of output transformers. Contact Jan Wüsten or Antique Electronic Supply (6221 S.Maple Ave., Tempe, AZ 85283, www.tubesandmore.com). Another solution is to buy a set of transformers for the "Scherzo" amplifier from Audiokit in Italy, www.audiokit.it. The price is 230 Euros for one power transformer and two output transformers. This is the most expensive solution, but rumor has it that the output transformers sound excellent, and potted versions are available.
4. Luca Chiomenti has described his own experiences with a PCL82 amplifier in the Italian magazine *Costruire HiFi* (nos. 24, 29, 36, 43). Luca calls his amp "Lo Scherzo." Scherzo means "joke," but "scherzo" is also a musical term. For various ways to increase the damping factor (i.e., to lower the output impedance) of a single-ended 16A8 amplifier without global negative feedback, study the schematics at Mr. Eguchi's website: members. nifty.ne.jp/rhizome/trnk. The language is Japanese, but the schematics are clear and the captions are in English. Mr. Eguchi has built at least six 16A8 amplifiers with various circuit topologies! A simple but effective PCL82 push-pull amplifier is shown on the following page: edimba.tripod.com/PCL82_PP/PCL82_PP.html. The language is Swedish, but you should be able to easily understand the circuit and the accompanying text.

than 90dB/W/m), lacking complex crossovers. Once I tried it on old bookshelf speakers from Acoustic Research (AR 4×)—forget it! But it sounds very good on single driver full-range speakers. I have listened for extended periods to the following models: 1) Jericho horns (Fostex FE208 Sigma driver, large backloaded horn), 2) La Petite Audiophile (Fostex FE103 Sigma driver, column-shaped vented enclosure), and 3) a speaker design of my own (Monacor SPH-60X driver, small vented cabinet). In the US, consult websites of Madisound, Parts Express, Solen, and other *aX* advertisers for drive units which are similar to the SPH-60X.

The most serious flaw is, of course, the following: low bass is missing. On my horn speakers, deep bass notes are audible but they have a smaller amplitude than the rest of the audio spectrum. On the two vented speaker systems which I tried, low bass is virtually completely absent. Above 100Hz, all is OK. Below 70Hz, you hear nothing.

I can live with this because the rest of the audio range is so good. If I choose to realistically reproduce a grand piano or the pedal notes of a large pipe organ, I should go to the living room. But if I wish to hear the tiniest details of a recording or experience the ambience of the recording venue as realistically as possible, I settle in the study and start "dreaming the hours away" (yes, old jazz recordings can sound good as well!). It is amazing that small transformers from table-top radios can produce such excellent sound. The folks at Philips must have used smart winding techniques.

If you build the amp with bigger output transformers (i.e., the more expensive Hammonds or the Audiokits, see reference 3), your frequency range will be extended (to less than 40Hz). But you'll need to pay a lot more.

For additional information on PCL82 amp building, consult various audio magazines and the world wide web[4].

Part 2 will describe the construction of a pair of single-ended tube amp-friendly speakers.

The diagrams shown here were drawn with TubePad5, a free program designed by amateur radio operator WD4NKA. *aX*