Tech Note No. 4

by Pete Stark

More on Transistors

One of our eagle-eyed readers spotted a boo-boo in my earlier discussion on transistor replacement -- under some conditions, replacing an older germanium transistor with a modern silicon transistor may cause the circuit to oscillate!

The problem is most likely to occur in those transistors used as an emitter follower; these are mostly used as output stages on some of the pc boards that drive a potentially long shielded cable. You can identify an emitter follower by the fact that there is no resistor in series with the collector, and the output comes from the emitter. Furthermore, in most cases the base of the emitter-follower stage connects directly to the collector of the transistor before it.

I have not run across this problem in my own organ, but I have seen it in emitter follower circuits that have been breadboarded on the lab bench. I suppose Schober ran across this problem when they upgraded the RV-3 Reverbatape to an RV-3a, which used silicon rather than germanium transistors. They apparently found that transistor 118 (an emitter follower) sometimes oscillated, because they added a 100 pF capacitor, connected from the emitter to the collector of the transistor, with instructions to solder the capacitor under the board using very short leads. I suppose it might be a good precaution to do so with other emitter followers as well.

Transistors and Power Supplies

As I mentioned last time, early Schober transistorized organs used PNP germanium transistors because these were the first ones available. Toward the beginning of the 70's, though, NPN silicon transistors became more common (as well as better and cheaper), and so Schober gradually started to switch over, one board at a time. But because Schober owners could mix and match old and new boards in the same organ, Schober had to stay compatible; this led to some compromises.

PNP transistors require a negative collector voltage. In addition, Schober was apparently concerned with getting as much signal out of their boards as possible, to swamp out the fairly large amount of noise these old transistors generated, and so they used a fairly high voltage, -30 volts. This may not seem like much to you, but most modern transistor amplifiers use between 5 and 15 volts; today 30 volts is considered unusual in small-signal amplifiers.

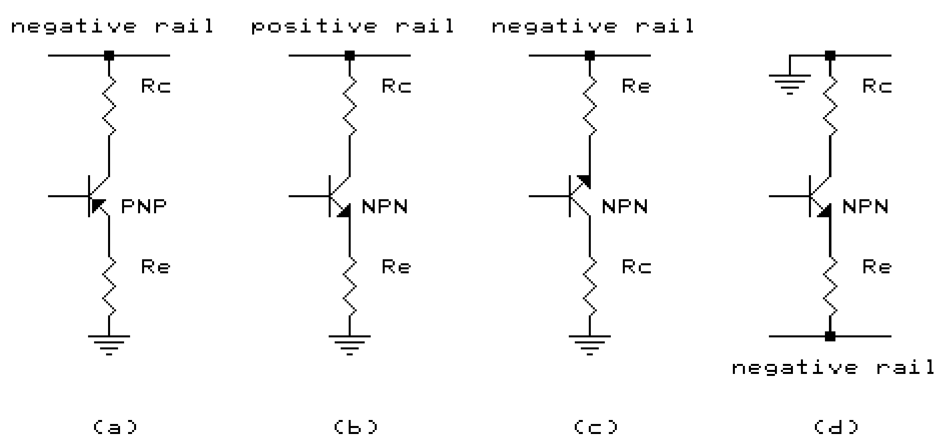

Figure 1 - Various ways of drawing PNP and NPN amplifier circuits

Figure 1*a* shows a typical PNP amplifier. The emitter lead (the one with the arrow) connects to ground, almost always through some kind of resistor (labelled Re in the diagram.) The base (the long vertical bar in the middle) is the signal input, while the collector (the top lead) connects to the -30 volt *rail* (usually, though not always, through resistor Rc.) The two lines coming from the power supply are often called rails; in this case, the -30-volt side is the negative rail, while the ground (which connects to the positive side of the supply) would be called the positive rail. [A slight detour -- to recognize what kind of transistor it is, remember that "the arrow always points toward the N." In this case, the arrow points to the middle portion of the transistor, so it is a PNP. If it points to one of the end leads, as in Figure 1*b*, then it is an NPN. End of detour.]

When you switch over to an NPN transistor, you simply use a *positive* voltage on the collector, as in Figure 1*b*. But remember -- Schober had to stay with a *negative* supply to stay compatible with their older organs, and this supply already had the positive rail grounded. So they rewired the transistor as shown in Figure 1*c*. In essence, the transistor is connected upside down. The emitter is connected to the negative side of the supply, while the collector goes toward ground. This makes the collector think it is more positive than the emitter, which keeps the NPN transistor happy.

But people aren't used to seeing the emitter on top; they prefer the emitter on the bottom and the collector on top, so Schober simply redrew the circuit as in Figure 1*d*. Now it looks more like Figure 1*a*, and so everyone stays happy. Almost.

Grounding

But there is a minor problem with this approach. A transistor amplifies the signal that exists between its base and emitter. If either the base voltage changes a little, or the emitter voltage changes a little, the transistor will assume that this is a desired input, and will amplify it. You can see how Schober used this in a number of places where they wanted to mix several different input signals. For example, in the stop filters, some of the filters feed the emitter of the first transistor, while others feed the base.

What this means is that any slight amount of noise in the emitter circuit will be amplified along with the desired signal, and will appear in the output. For that reason, the power supply lead that goes to the emitter side of the circuit must be absolutely free of noise. (Noise in the collector side of the power supply will also be amplified slightly, but not as much.) In most electronic equipment, the emitter side of the power supply is the ground, and so good grounding is essential in any piece of equipment. (Another detour: although the word "ground" may imply an actual connection to the ground -- as in a wire going to a rod buried underground, or to a cold water pipe -- that is not totally necessary. In most equipment, the ground is simply a common wire or connection, which acts as a common reference point for all signals in the device. If the equipment is mounted in a metal case or on a metal chassis, then that case or chassis usually forms the common ground connection. In a wooden organ, the ground is just a set of thicker wires, usually black, all connected together. End of detour.)

Schober was aware of this. They used thick wires for the ground and -30-volt power lines, and added a decoupler board with several hefty capacitors to filter the power supply voltage. Moreover, each board in the organ (except for some of the tone generators, whose output signal is large and so noise is not a problem) had a separate pair of ground and -30-volt wires go back to the decoupler board. Power and ground **never** "daisy-chained" from one board to the next to the next, because this would let noise from one board enter another board. Even when they used shielded wire, they never grounded both ends of the shield, because this would have provided a sneak ground path, letting noise from one board go directly to another.

Nevertheless, there were a couple of spots where they slipped up. For example, Schober had to issue a service bulletin for the Recital organ to fix a grounding problem. Rather than have a solid ground wire for the stop filters, they relied on a mechanical connection through a screw. As the organ aged, corrosion and dirt would increase the ground resistance, and noise would creep in. Providing a solid ground connection fixed that problem.

But changing from PNP to NPN transistors caused problems. While the ground line was fairly noise-free, the -30-volt power supply line was not quite as good. As long as Schober used only PNP transistors, that was OK because the collector of a transistor is not as sensitive to noise as the emitter circuit. But as you can see in Figure 1*d*, switching to an NPN transistor connects the emitter to the -30-volt lead. *Any* noise on that lead will immediately get amplified and will show up in the audio signal.

When you built your organ, you may have noticed a correction sheet, where Schober substituted a 2000 uf capacitor in the decoupler instead of a 1000 uf capacitor. While I have no absolute way of determining the timing of this change, I bet it occurred when they started using NPN transistors, because they had to decrease the noise on the -30-volt line.

Nevertheless, filtering the -30-volt line back at the decoupler board in the middle of the organ is really not enough; there should really be more filtering at any board that handles low-level signals and has NPN transistors in this "upside-down" circuit. I noticed this when I reworked my PTR-5 Preamplifier-Vibrato board, and added one more filter capacitor to it -- a 4700 uf 35-volt electrolytic capacitor (such as Radio Shack 272-1022), connected directly between the -30-volt power line and ground, right near where they enter the board (between the B1 and G1 pins, with the plus side of the capacitor going to G1.) This was sort of a brute-force approach, but I thought it was easier than cutting traces on the board to do it more elegantly.

I was feeling pretty proud of myself that I finally caught Schober at a boo-boo -- a sloppy design!

Well, as you can imagine, that didn't last long. I have since discovered that Schober *did* catch that mistake, and fixed it in the next version, the PTR-5a Preamp-Vibrato. Figures 2a and 2b below show what they did.

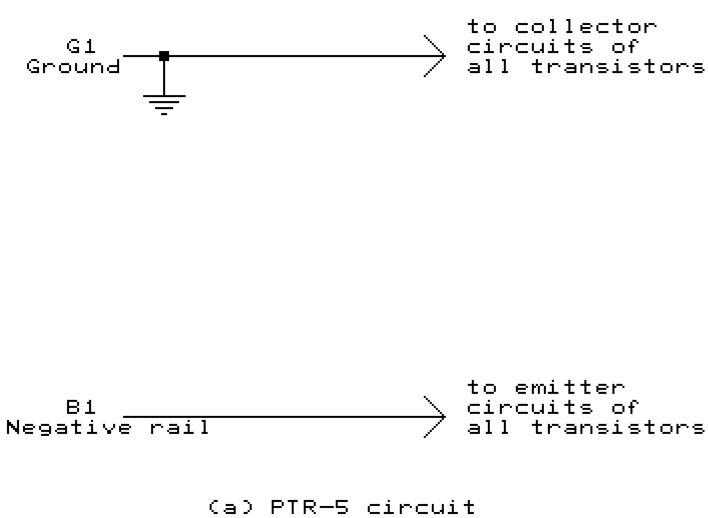

Fig. 2a - the original circuit in the PTR-5

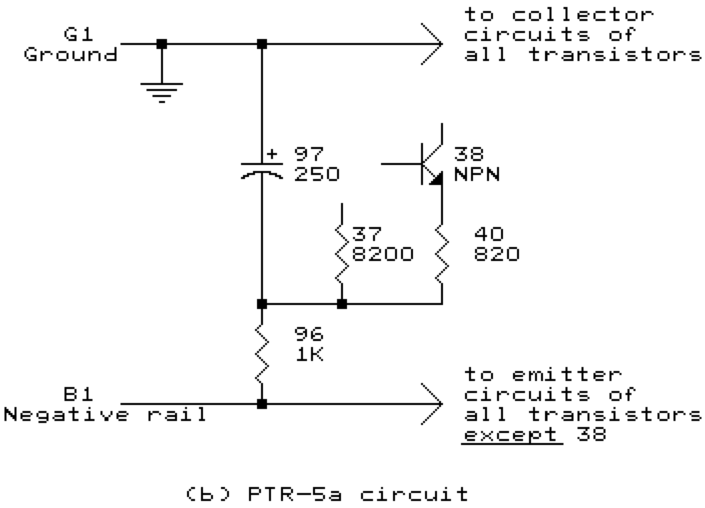

Fig. 2b - the revised circuit in the PTR-5a

The original PTR-5 in Fig. 2*a* was the first unit using NPN transistors; As we've discussed above, it had the positive rail (ground) feeding all the collector circuits, and the negative rail (-30 volts) feeding all the emitter circuits. But any noise on the negative rail would thus get into the signal. The problem was most obvious in the one stage that had the least signal, which was transistor 38.

Fig. 2*b* shows what Schober did. They disconnected the emitter of transistor 38 from the negative rail, and added a separate filter, consisting of resistor 96 and capacitor 97. Resistor 96 brought the negative voltage to the emitter circuit, but isolated it from any noise on the negative voltage line; capacitor 97 then provided a low impedance short to ground, removing any noise.

Well, that looks like all I've got room for this time. Hope I'm not boring any of you with my ramblings; if I am, just write to me: Pete Stark, pastark@cloud9.net.