Tech Note No. 5

by Pete Stark

Well, I must confess that I haven't been as active in the past few months as I had wished; in fact, I did so little that, when it came time to write two months ago, I had no progress to report and nothing to write about. (Fred Henn kindly got me off the hook by including Martin Boehling's letter.) I'm only now getting back into the groove, but in the meantime I received a letter from Bill Bruce of Sebastopol, California, mentioning two problems that he'd like help with. That gives me a wonderful out -- discuss his questions, rather than admit my own lack of progress.

Hum and Thud

Bill mentions two problems with his Recital model: one is a background hum, not too intrusive, but definitely there, though it is reduced a lot if his Reverbatape is bypassed. The hum begins about two seconds after turning on the organ. The other problem is a loud noise when he turns his organ off. Bill says it is hard to describe the sound -- it's sort of like dropping a large book on a carpeted floor, except louder. Sounds like a pretty loud "thud" to me.

Well, I don't have the Recital model, but I think I can give some suggestions on how to go about finding out the cause, and fixing it. Let's tackle the thud first, because I bet it's a lot more annoying.

Most older power supplies, such as those in the Schober organs, are the *linear* type, whereas most newer power supplies are the *switching* type. In a linear power supply, the AC power from the power line is directly connected to a large power transformer, which drops the voltage from around 120 volts down to whatever the solid-state circuits need. The output from the transformer is AC, just like the input from the power line. AC stands for alternating current, meaning that the current alternates directions. At one instant of time, all the electrons may be rushing along one of the wires from the outlet toward your organ, while a fraction of a second later, the current direction reverses, and all the electrons are rushing back toward the outlet again. This reversal is done at the rate of one complete cycle of in-and-back every sixtieth of a second, or a total of 60 cycles per second, which is now called 60 Hertz or 60 Hz. (A friend of mine likes to say that the electric utility has a lot of chutzpah to sell you electricity, only to yank it back a fraction of a second later, so they can sell it to you over and over again!)

Inside your power supply, the AC current is rectified by some diodes into DC. In DC, or direct current, the current flows only in one direction, but as it comes out of the rectifier diodes, this one-directional flow comes in spurts, synchronized to the 60 Hz repetition rate of the original AC, but (as long as all four of the rectifier diodes are OK) at twice the frequency, or 120 spurts per second. These spurts are called *ripple*. If the ripple somehow gets into your audio circuits, it will cause hum. Hence the bursts of electrons are evened out by one or more filter capacitors, whose job is to act as big storage tanks for electric charge. When a spurt of electrons arrives from the diodes, the capacitor stores the overflow, and then delivers the extra current in a more even flow when the electron spurt is over.

In a linear power supply, the AC power into the transformer is at the power line frequency of 60 Hz, while the ripple is at 120 Hz, both of which are fairly low. This requires a fairly large transformer (the general rule is that the lower the frequency, the more iron the transformer needs), and also large capacitors (because there is a relatively long time between the spurts of current coming out of the rectifier diodes, and so the capacitor has to store a lot of the overflow charge and deliver it over a longer time.)

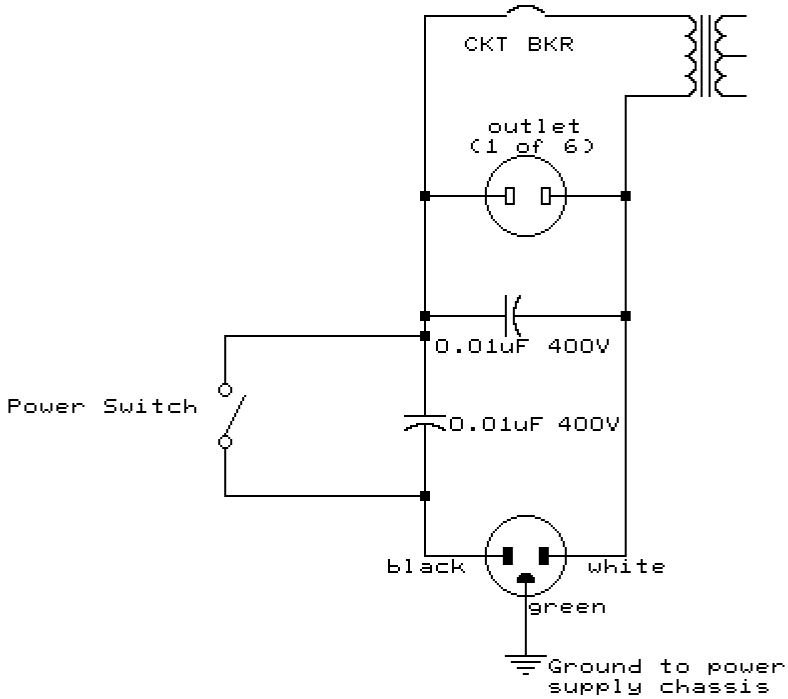
(A little detour: modern switching power supplies, such as those used in personal computers, use a different approach. They take the 120-volt 60 Hz AC straight out of the power line, immediately rectify it with just a bit of filtering, and then use it to drive a pair of switching transistors which generate a high frequency AC current. This high frequency then goes into a transformer which lowers the voltage to a more reasonable level; its output is then rectified and filtered by a capacitor, just as in a linear power supply. The big difference is that the transformer and filter capacitors can be much smaller, because they operate at a much higher frequency. This approach, while more complex, turns out to be cheaper, especially since the switching transistors can do a double job of also regulating the power supply output voltage to a constant value. End of detour...)

Back to the linear power supply. When you turn off the power switch, two things happen. First, opening the switch suddenly turns off the power to the transformer in the power supply. The diodes immediately stop rectifying, but the output power drops fairly slowly because the filter capacitor still has some extra overflow charge, so most of the organ circuitry remains powered up for a second or two longer. So the first thing to ask is whether the loud thud occurs the instant the switch is turned off, or whether it occurs a second or two later.

If the thud occurs a moment *after* the switch is turned off, then the problem is a bit more difficult to solve. Somewhere in the organ or its amplifiers, the collapsing voltage in the power supply is causing a big voltage transient. I suppose putting in a master volume control between the organ and the amplifier would work, as long as you remember to turn down the volume before shutting off the power.

Much more common is a thud *the instant* the switch goes off. The transformer in the power supply is made up of an iron core, around which are wound several hundred turns of wire. This is the same construction as is used to make inductors, and inductors have one annoying habit -- they don't like rapid changes of current. If there is a current going through an inductor and you suddenly try to turn it off, the inductor will do everything it can to keep that current going. It will even create a big spark across the switch contacts in the attempt to keep the current flowing. Since it takes quite a bit of voltage to make a spark jump through the air, the inductor generates a big voltage spike to do it. (This is how the ignition coil in a car generates the spark across the spark plug. But at the same time, a spark jumps across the points in a conventional distributor, which the car makers solve by connecting a condenser -- the old name for a capacitor -- across the points.)

When you turn off your organ, this big voltage spike, and the spark generated across the switch contacts by it, creates interference which can be picked up by nearby circuits. The solution involves two approaches: (a) try to reduce the size of the spark as much as possible, and (b) try to keep the interference from getting into the other organ circuits.



The customary approach to reducing the spark is to get some 0.01 microfarad capacitors *(rated at a minimum of 400 volts -- don't use any low voltage capacitors!)* and connect one across the switch (preferably inside the power supply), and another across the primary (power line side) of the power supply transformer (see the diagram above). While you're working on the power supply, it would also be a good idea to replace the two-wire line cord with a three-wire cord, and make sure it is plugged into a three-wire outlet. Connect the green wire in the line cord to the metal chassis of the power supply, the black wire to the switch, and the white wire to the other side of the power circuit. For safety, and also as a matter of good practice, the circuit breaker should also be in the switched side of the circuit, so I'd rewire the power supply circuit as shown in the diagram. *Caution: making a mistake in this wiring can be lethal; consult a qualified technician or engineer if you have any doubt about how to do this.* The idea is basically this: In the house wiring, one side of the 110-volt circuit (the side connected to the white wire) is grounded, while the other side (the one connected to the black wire) is `hot'. Both the switch and the circuit breaker should be in the hot side; the `cold' or grounded side should never be switched.

(Incidentally, it would be nice to continue the three-wire concept also to the six receptacles mounted on the power supply for accessories; but there's just no room for such niceties.)

The second part of the solution is to keep the remaining spark interference from getting into the organ circuits as much as possible. The organ design has two problems here.

The main culprit, I think, is the long wire from the power supply, through the cabinet and up to the power switch. That big voltage spike goes right up through that wire to the switch, and the wire acts like a transmitting antenna, just radiating its interference all over the place.

The other culprit is that the organ is full of unshielded wires that carry audio all over the place; every one of these acts as a little pickup antenna to pick up any interference in the neighborhood. Some of these operate at a high impedance, which tends to especially pick up a lot of garbage (I wonder how many of you hear local CB operators or taxicabs on your organ???) There's not much you can do about these, so you have to work on the power switch wiring.

One way to minimize the radiation of noise from the power switch wire would be to shield it. Belden makes a shielded wire rated to carry 300 or 400 volts, but I don't have a Belden catalog and don't know the number; I would definitely *not* use plain shielded wire for fear of a fire hazard. (and there isn't enough room to put in metal conduit to carry the wire.) The wire should also be routed far away from any other wires.

Another way is to put a relay into the power supply to do the actual switching, and use the main power switch only to operate the relay. I suppose the easiest solution would be to disconnect the power switch at the power supply, and mount a separate on-off switch right on the supply. A neat idea would be to rig up some sort of gizmo to allow you to operate the switch from the front of the organ via a speedometer cable or a long shaft.

Hum problems

Unlike the thud, hum can be introduced in many different ways. I think the first step should be to find out where it enters the system -- is it in the organ itself, in the Reverbatape, in one or more amplifiers, or where?

To make this job easier, you should first draw yourself a complete diagram showing how each of the modules of your system connects to the others. Schober was great on giving out diagrams of individual boards, but they skimped on providing a complete diagram which showed all the boards connected together. I did this for my theatre organ, and it was a great help in figuring out just what signal goes where (and also in figuring out how Schober did their multi-channel modifications.

Once you have a clear picture of the signal path, it's a matter of isolating and disconnecting signals until the hum level changes. Unfortunately, I'm about to run out of room, so I will continue on this topic next time.