Tech Note No. 3

by Pete Stark

Hi again. Here are some more of my ramblings this month. I'm actually having a hard time writing these notes, because I don't know whether to keep them simple (and thereby insult a lot of readers' intelligence) or make them more erudite (and confuse everybody, including me!) If you folks have any preferences on what you'd like me to cover and how, let me know.

OK, now that I'm off the hook, here goes.

Noise

Several people have commented that they have had noise problems in their organ, and I thought I should devote just a bit of space to it.

In an organ, noise can be of four types:

(a) Hiss. This is that high-frequency stuff that sounds like "ssssssssssss". Hiss is caused by the random motion of electrons in electrical circuits and is always present to some degree. But early transistors were especially noisy; I found that replacing transistors in my organ cured almost all hiss. I can still hear a bit if I stomp down on the swell shoe and place my ear within about a foot of the speakers, but otherwise it's not too bad.

(b) Hum. This is that low frequency stuff that sounds like your cat sleeping on one of the pedals. It is usually caused either by a bad filter capacitor, or by a bad ground connection.

(c) Sing-thru (I made that word up.) This is a fairly soft sound that sounds like you've used 12 fingers to press down every key in the top octave of the keyboard. If you pay careful attention, you can actually hear the 12 different notes in there, all at once. Sing-thru occurs naturally in the way that Schober keys the audio in the keyboards, and is also caused by the fact that there are an awful lot of wires in an organ, carrying signals here and there, and there is a slight amount of leakage between adjacent wires. It can also be caused by bad grounds.

(d) Static or crackle. Part of this comes from the old transistors, but some can also come from dirty keyboard contacts.

Let's discuss hiss for a moment. Early transistors were very noisy, and replacing them is a tremendous improvement. But noise improvements are unfortunately made in very small incremental steps. Here's why.

Hiss is basically caused by the random motions of individual electrons. What you hear as hiss is actually the result of zillions of little noise sources, each one contributing a little bit of it, and each one moving differently from all the others. Imagine a big ship, with a lot of people on the deck. If they all move together from side to side of the boat at the same time (maybe there's a troublemaker with a megaphone, shouting "Everybody to Port! Now everybody to Starboard!"), their motions all add up and then can cause the boat to rock from side to side (and maybe even tip over if they do it right!)

But if they are all moving at random and different speeds and directions (and constantly changing their speeds and directions), their total movement will cause some occasional movement of the boat, but this will be fairly unpredictable and small, since at any given time people moving in one direction will be counteracted by other people moving in the opposite direction. The only time you will get a slight rocking effect on the ship is when you have slightly more people moving one way than the other, but because they are constantly changing their speeds and directions, it won't be long before you have more people walking the opposite way and cancelling the whole rocking motion. So the effect on the boat will consist of small and quick jerks back and forth, rather than the slow rocking back and forth you'd get if all these people were synchronized. This explains why noise is essentially a high frequency phenomenon.

Now, let's say that the effect of all these people is to produce 1 inch of sideways movement in the ship. If you now double the number of people on the deck, will you get 2 inches of movement?

It depends on how you do it. If you just put a whole new batch of newcomers on the ship, then the answer will be no. Even though the oldtimers can produce a 1 inch movement, and the newcomers can also produce 1 inch of movement, the chances of their ever being synchronized enough so that the movements caused by both groups are in the same direction at the same time are small. So doubling the number of people will increase the total movement, but not double it. (It turns out that the increase will be by a factor of 'square root of 2' , or about 1.414 inch. In terms of db, this is only 1.5 db more.)

If you put a bunch of newcomers on the ship and tell them to each pair up with an oldtimer and do exactly what he does, now you are synchronizing the newcomers with the oldtimers so they are doing exactly the same thing. Each time the oldtimers produce a 1 inch jerk, the newcomers do exactly the same thing, and now their movements add up because they are synchronized. So you get 2 inches of sway.

On the other hand, suppose you put a bunch of newcomers on the ship, but tell each one of them to pair up with an oldtimer and do the exact *opposite* of what the oldtimer is doing. Now all the newcomers cancel out all the motions of the oldtimers, and you get no movement of the ship at all.

So let's look at electrical noise. If you have two noise sources in the circuit and combine their outputs, you can get three cases: (1) If they are synchronized together, their effects will add and you can get twice as much noise; (2) if they are synchronized but in such a way that they oppose each other, then their effects cancel and you get less noise than you started; (3) if they are not synchronized (that is, they are random), then the total noise will go up, but will not be the sum of the individual noises.

Hum is generally caused by a 60 Hz or 120 Hz signal in the power supply output, or by a bad ground connection. If this causes hum to come out of two circuit boards, those hum signals will be synchronized in some way. Therefore they will either add up or cancel each other out in some way.

But hiss is caused by random motions of electrons; hiss noise coming from two different boards will not be synchronized, and so will increase but not add up.

What happens in this case is that the *powers* add, but not the voltages of the noise signals. Suppose you have two circuit boards, each of which generates 1 volt of noise, and whose outputs are combined. The total noise power in the output will double, but since the formula for power is P = V squared over R, (where *V* is the voltage and *R* the resistance), the voltage only has to go up by a factor of the square root of 2. Thus the total noise voltage will be 1.414 volts, not 2 volts (an increase of just 1.5 db.)

If you combine three such boards, the total noise power triples, but the voltage only goes up to 1.732 volts (which is the square root of 3).

Now suppose that you have three boards in your organ, and each one of them contributes 1 volt of noise to the output. Your total output noise voltage is now 1.732 volts. So you go to work on it, and you fix one of the boards so it generates no noise whatsoever (which is much better than you can really do in real life). Your first reaction is, "Wow! I've just reduced the noise by a third!" But it's not that simple. Since you still have the other two boards generating noise, you still have 1.414 volts of noise, so the total noise voltage only goes down by 18% (from 1.732 to 1.414 volts). Even that sounds good, until you realize that this is only 1.76 db, which is barely audible!

This is why it's so discouraging to tackle noise in an organ. You work on it, and you don't seem to be making much headway. Unless you have some fairly good test equipment so you can measure the noise and see it go down, you think you're not making any progress because you can barely hear the difference. The only way to make a significant dent is to minimize *all* the noise sources at the same time. I'm convinced this is why many Schober organ owners swapped out some of their Schober boards and went to other approaches, such as the Devtronix keying system.

But noise problems can be licked, if you tackle them in a systematic way. The problem is that you have to tackle them in a totally different way from what you'd do generally in electronics.

In most electronics equipment, such as a receiver or hi-fi system for instance, you have a small signal at the input to the system, you amplify it a lot, and you have a big signal coming out the output. For instance, in a hi-fi amp, the signal from the phono cartridge or tape head is really tiny; after being amplified, the signal going to the speaker is BIG. So a small amount of noise added near the output of the amp is unimportant, because it's so small compared to the BIG signal at that point, But the same small amount of noise at the input can be deadly because it can be stronger than the desired (and tiny) signal. So in electronics equipment in general, when you have a noise problem, you look at the input stage for a solution. That's the normal approach to a very common problem.

But in the Schober organ, you have exactly the opposite situation. The signals coming out of the tone generators are BIG; the signals coming out of the bus amps are BIG. Even the signals at the keyboards are pretty big. But the signals coming out of the stop filters, or the preamp-mixer, are tiny. So if you look for noise sources in the early stages of an organ (which is the first thing you'd normally do elsewhere), you're looking in the wrong place!

See, the Schober engineers were actually quite good. Oh sure, with today's technology we can do better, but within their 1960-70 time period, they did remarkably well. They *knew* they could have a noise problem, and so they took some precautions. For one thing, they used a fairly large power supply voltage; these days, having a -30-volt power supply is almost unheard of, but in those days it allowed them to use large signal swings to try to overwhelm the noise of the parts available to them at reasonable cost.

In the early stages of an organ, back near the keyboards or bus amplifiers, there is not much difference between very weak and very strong signals. The weakest occurs when you press one key; the strongest is when you press as many keys as you can with two hands. The ratio between the strongest and the weakest sounds is called the dynamic range; here the dynamic range is pretty small. The engineers could choose their voltage levels so that the strongest signals would be pretty big without causing distortion, and the weakest signal would then be perhaps 1/10 or 1/20 as big, still big enough that it would be comfortably above the hiss of the transistors.

But by the time you get to the output of the stop filters, or to the preamp, things are very different. The dynamic range is tremendous! The weakest signal is now one key in one stop. The strongest signal is 10 or 15 keys on each of two keyboards, in perhaps 20 stops, with two couplers. This is a tremendous difference between weak and strong, and this is where you run into problems. If you adjust the levels so the weak notes are comfortably above the noise, the strong signals will be so big that they distort. And if you adjust the strong signals so they are just below the distortion point, the weak signals are close to the noise -- or under it.

And by the time you get to the output of the preamp, things are even worse. The weakest signal is one note, one key, and the swell shoe all the way up. The strongest signal is with the swell shoe all the way down, plus ... well, you get the idea.

So the place to look for noise problems is at the output of the organ, not at the input stages. Whatever happens before the stop filters is pretty insignificant.

I'm running short on space, so let's get to the details -- what did I do on my organ?

On the Theatre Organ, the output from the stop filters goes to the preamplifier-vibrato board (where the signals from the two keyboards and pedals are mixed), then to the mixer-compressor, and finally to the main audio amplifier and speaker. So, after I got the amplifier and speaker set up, I started at the mixer-compressor, the last stage in the organ.

I adjusted the swell shoe to the midpoint, and got quite a bit of noise from the speaker. So I took a short jumper, and shorted (to ground) the input signal coming to the mixer from the preamp. The noise went down a tiny bit, but not much. What did all this mean? With the shorting jumper in, there was no input into the mixer and so any remaining noise had to come from the mixer itself. With the jumper out, the noise was slightly higher, indicating that there was also noise entering the mixer through the input. Here is where the theory comes in -- when two noise sources are added, their sum is just a bit louder than one.

So I took the mixer out, changed transistors, some resistors (overkill again), and all electrolytic capacitors. When I put it back in, I still had almost as much noise as before, so it sure looked like all this work didn't make much headway. But when I put in the shorting jumper at the input to the mixer, the noise almost completely disappeared; this proved that I had gotten rid of one noise source, though this didn't make much difference in the overall picture.

So then I went to the preamp-vibrato board. When I jumpered all its inputs to ground, the noise again went down a tiny bit, but not much. So I went to work on the preamp board, again replacing components. When I put it back into the organ I still had noise, but when I jumpered its inputs to ground, most of the noise again disappeared. So now I knew that the mixer and preamp boards were fairly "clean" and I was making progress.

So I went to the stop filter board. It has just too many inputs to jumper to ground, so I just took it out and reworked it, and behold -- the noise went down a lot when I reinstalled it. So I was finally making some progress. But there was still some noise, and so I looked for other sources. By shorting inputs to the preamp board and listening to the noise, I determined that the rest was coming from the pedal generator and my percussion board, and the rest is history.

The point here is that you have to be aware of how different noise sources add their signals. It's also important to have some understanding of decibels. For instance, when two equal noise sources add and increase the total noise to 1.414 of its original value, that difference is just 1.5 db, an amount which is not very noticeable. Conversely, removing one of two such noise sources reduces the noise by 1.5 db, which is again not very noticeable. So the point is that you can be making tremendous strides toward reducing your total noise, yet feel totally dejected because you barely notice any difference.

I better quit ... if I go on much longer, I will definitely run out of ------