Tech Note No. 10

by Pete Stark

Last time, we talked about combining audio outputs, and got sidetracked into discussing chorus effects etc. So let's return to the original topic.

Combining Parallel Outputs

When you combine outputs from several different filter circuits, the best you can do within the organ is to try to minimize bad effects. For example, when you add one more stop, you should make sure that the sound gets louder, and not softer. In other words, you must make sure that adding more stops causes addition of the signal voltages, not cancellation. The Schober organ design does just that.

If you look at the circuitry of the stop filters, you will note that the outputs of the stop filters do not all connect together at the same point. What happens is that each of the filters delays the signal by a slightly different amount. If two filters delayed the signal by just the right amounts so that one's output goes positive at the exact instant that another's output goes negative, then connecting them together would cause cancellation, and therefore a drop in volume rather than an increase. The Schober Theatre Organ design gets around this by inverting one of the two signals -- flipping it upside down so positive changes to negative, and vice versa. In this way, both signals will go positive at (or near) the same time, so they add rather than cancel. The Schober stop filters do this inversion by sending some of the signals to the base of the mixing transistor, while others go to the emitter. This takes advantage of the fact that a signal going to the base of a transistor gets inverted at the output, whereas a signal going to the emitter does not. (In the Recital Organ, this inversion is not done. I think the reason is that the Recital Organ stop filters are much milder and do not affect the delay as much, so this is probably not as much of a problem there.)

So back to Fred Henn's organ. Since all this inversion and stuff is actually done within the stop filters, if he simply duplicates the existing circuitry to add one more keyboard (with an additional keyboard, an additional bus amplifier board, and an additional set of stop filters) then the signals will be such that they can be readily added without cancelling. In effect, the design is already done for him. But note that he doesn't get much in the way of new sound for this effort. If he plays a 8' Tibia middle C on one keyboard, and the same 8' Tibia Middle C on the new keyboard at the same time, the two sounds will be identical, and will simply add. The effect will be that of one pipe, amplified, not two pipes.

So Fred is going one step farther -- he is also installing an additional set of oscillators for his new keyboard. Now he can play the same note on the two keyboards, and get the effect of two similar (though not identical) pipes playing at the same time. The Chorus Effect, you see. Neat. But now he doesn't have to worry about cancellation at all, since there is no such thing. With two oscillators (or pipes) tuned slightly differently (as they will be, since there's nothing he can do -- or even would *want* to do to tune them the same) there can never be constant adding or constant cancellation of the two signals. So he's in the clear on that account.

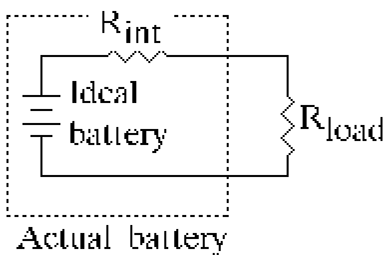
How About a Short Circuit?

But that then brings us up to the second aspect of this -- can he simply connect two signals together without causing a short circuit?

Let's look at it like this. Suppose you have a 6-volt car battery (such as from an old VW, or from a golf cart.) Can you connect a screwdriver across its terminals? You better not, because the car battery will push so much current through the screwdriver that the screwdriver may melt from the heat. The battery will probably get damaged, but even beyond that, you might get burned by the hot screwdriver, or the screwdriver might get welded to the battery leads and cause something else to melt, or you might get some ferocious sparks, or ... you get the idea. Not a safe thing to do.

On the other hand, can you connect a screwdriver across the terminals of a 9-volt transistor radio battery? Sure. You'll ruin the battery if you do it for more than a few seconds, but you won't melt the screwdriver or hurt yourself. It's not a reasonable thing to do, but it's not unsafe.

So what's the difference? Why is it OK on a 9-volt battery, but not on a 6-volt battery? The difference is not just the voltage, but the so-called internal resistance, which is related to the power-handling capacity.



An actual ("real-world") battery (shown in the dotted box in the figure) can be thought of as an ideal battery in series with some internal resistance called Rint. When that real-world battery is connected to a load, such as resistor Rload, we get a complete circuit that connects the ideal battery, the internal resistance Rint, and the load resistance Rload, all in series. All the current into the load has to go through Rint first.

The ideal battery is sort of a figment of our imagination, though. It's a battery whose voltage is constant no matter what we connect to it, and which can supply an unlimited amount of current (now you see why you need a good imagination!) For instance, we can think of a 9-volt transistor radio battery as starting with a 9-volt ideal battery and some internal resistance in series with it.

If we now disconnect the battery from the load and measure its voltage, there won't be any current through Rint (assuming you have a good voltmeter), and so there won't be any voltage lost across it. In other words, we will still measure the full 9 volts at the terminals of a 9-volt transistor radio battery.

But as soon as you connect the battery to a load, the current through Rint causes a slight voltage drop across it, and the voltage left at the terminals of the actual real-world battery drops below 9 volts. And the heavier the load we connect, the more we lose in Rint, and thus the lower the output voltage.

Now here comes the clincher. The smaller the Rint, the more current you can draw from the battery before the output voltage drops below a usable level. A 12-volt car battery in decent shape, for instance, might have an Rint of just 0.025 or 0.05 ohms. When starting the engine, you can pull 100 or 200 amperes from it, and the voltage will only drop from 12 down to 8 or 9 volts. Low enough to dim the lights (if you have them on), but still enough to turn over the engine and start it.

A brand new alkaline 9-volt transistor radio battery, on the other hand, may have an Rint of 2 to 5 ohms. With that much internal resistance, its output drops drastically as soon as you try to draw some real current out of it. So here is the secret of our screwdriver experiment: with a car battery, the internal resistance is so low that the battery can push a LOT of current through the screwdriver, possibly melting part of it. The 9-volt radio battery, on the other hand, can't push enough current through to cause any damage, except to itself.

As a matter of safe practice, the value of Rload should almost always be much larger than Rint. One shouldn't connect a load resistance so small that too much current will be drawn from the battery. The reason is that excessive current through Rint will cause it to heat up, which will damage the battery.

There is another way to look at it: the internal resistance Rint should not have too much voltage lost across it. That is, if the voltage under load drops a lot from the voltage with no load, there's something wrong. For instance, if your house wiring measures 120 volts, but drops to 90 volts every time the air conditioner starts, you're losing too much and should have it looked into. The air conditioner is putting too much of a load on the wiring.

How much voltage drop is too much? Depends. Some equipment is built to take it. For instance, car batteries are built to take a big drop during starting -- but only for a short time. Most car instruction manuals tell you to wait a minute or two before trying again if your car doesn't start after 30 seconds or a minute.

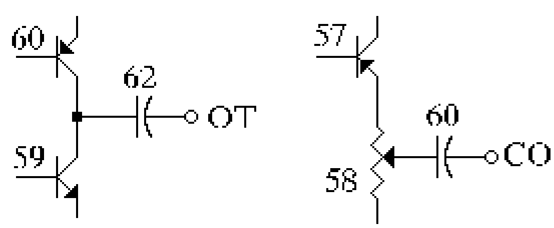
So what does all this have to do with audio? Just this: whenever we connect an audio source to an audio load, the source has an internal resistance (which we usually call the output resistance), and the load has a load resistance (which we call the input resistance.) The general rule of thumb is that, to avoid damage to the source, the load's input resistance should be much higher than the source's output resistance (that is, the internal resistance of the source.)

Don't get misled by speaker connections. We all know that a 8-ohm speaker is supposed to be connected to an 8-ohm amplifier output, and so on. But that's a fake. When they label an amplifier output 8 ohms, they don't really mean that its output resistance is 8 ohms; they are only saying that that particular output works best with an 8-ohm speaker. In reality, the output resistance of a power amplifier's 8-ohm output is usually below 1 ohm. So when we connect an amplifier with an output resistance of 1 ohm or less to a speaker with an input resistance of 8 ohms, that's quite safe and satisfies our general rule of thumb that the input resistance should be a lot higher than the source's output resistance.

OK, back to Fred Henn's question -- can he connect the outputs of two preamp-vibratos to one mixer-compressor? The important part of that question is really this -- is it safe to connect the outputs of two preamp-vibratos together?

Connecting the two preamp-vibrato outputs together basically makes each one the load on the other. In this case, the output (internal) resistance of one becomes the load resistance of the other, and the load resistance on each one is also equal to its output resistance. This violates our rule that the load resistance should be a lot higher than the output resistance.

Whether that is going to cause a problem, though, depends on whether there is any extra resistance in the output which would serve to limit any damaging currents. So let's look at the output of the Theatre Organ preamp-vibrato circuit, and compare it with, say, the mixer-compressor circuit.

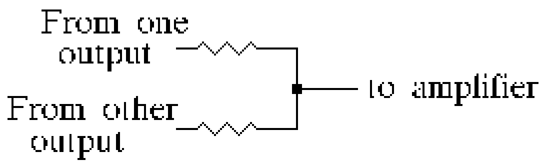


Preamp-Vibrato Mixer-Compressor

We see that in the preamp-vibrato circuit, the OT output comes (through capacitor 62) from a couple of transistors, and there is no resistance in series with the output. On the other hand, in the mixer-compressor, the output comes from transistor 57, but has to go through level potentiometer 58. Whether any part of pot 58 is between the transistor and output CO depends on whether the pot is turned to maximum level (with the sliding terminal all the way up), or at some middle level (with the sliding terminal part-way or even all the way down.)

In the case of the preamp-vibrato, connecting the OT output from one preamp-vibrato to the OT output of another would not be a good idea because both OT outputs have a relatively low output resistance, and would wind up fighting each other. In the case of a mixer-compressor, two CO outputs could be connected together, but only if both level controls 58 are at least part way down. Since there's no guarantee that everyone ever servicing the organ would remember to keep them part way down, that's not a safe assumption to make.

Hence the solution is to add some external resistance, like this.



The two resistors increase the load resistance that each of the outputs sees, and so prevent problems. What value of resistor? Well, if it's too small, it doesn't do the job. If it's too big, you lose too much signal in it. Without doing the calculations, I'd guess that the output resistance of either the preamp-vibrato, or the mixer-compressor with level control 58 all the way up, is somewhere under 100 ohms. So 1K or so should be big enough.