When good opamps go bad...

If you mess with effects much, you've no doubt had the experience of finally getting your hands on a real, true, original old something-or-other pedal, and had your expectations of mega-tone pouring out of it dashed by a film of hiss; or alternately, having one of your vintage pedals start sounding worse and worse, and then simply quit. What's going on here? Do electronics devices just get old and decrepit?

Some do. Electrolytic capacitors for one have a limited lifespan. They're best viewed as an expendable item, good for maybe ten years, then needing replacement. They're kind of like really long life batteries. Even silicon PN junctions will rediffuse and go bad over an expected time of several centuries.

However, the explanation for the sudden increase in hiss in many old effects is more simple than wear-out of the active devices. The designs were themselves simple, and did not adequately protect the transistors and opamps from foreseeable degradation possibility.

The essence of wear-out

It's not commonly appreciated, but no transistor likes to have its junctions reverse biased until they start conducting. The energy involved in doing this will make the carefully diffused junction get more ragged and less well defined. It still works, but less well. The collector-base junction is pretty robust, being designed for the full Vceo rating of the transistor, but the base-emitter junction is delicate in all modern transistors.

It has to be. The way to get more gain and higher bandwidths in bipolar transistors is to make the base emitter junctions thin, abrupt, and very tightly defined. The doping profiles that make for good transistor functioning also make for a fairly low breakdown or zener voltage in the base emitter junction. The base-emitter junction of most modern transistors will reverse-conduct at between 5 and 7 volts. Germanium, oddly enough, was much better in this respect. Most old germaniums had base-emitter breakdowns of twenty to thirty volts.

If you cause reverse conduction in the base-emitter junction of a modern silicon transistor **even once** you will permanently degrade the noise performance of the transistor. How much it degrades depends on the transistor, the current flow, and many other variables, a lot of which reduce to the amount of energy you pour through the volume of the conducting base-emitter junction inside the semiconductor device. Other measures of the "goodness" of the transistor degrade too. The deceptive thing is that the degradation may not be immediately noticeable, but every time it happens you lose a little - just like hearing and noises loud enough to make your ears ring. Over time, the loss gets bad indeed.

Enter the opamp

The inputs of all bipolar operational amplifiers are simply the base terminals of two transistors in a differential amplifier that is the first gain stage of the innards. In a many opamps, the + and - terminals are simply two base-emitter junctions with the bases free and the emitters tied together. That means that if you pull them apart by more than something like 5.5V to 7.5V, you will reverse zener one of the input junctions. How much "pull-apart" the two bases can take before something gives is usually expressed as something like the "differential input voltage range". Exceed this and bad things happen to the opamp. Exactly how bad depends on how much energy gets to the base region, and that in turn depends on how much current flows through the junction for how long, and how tiny (and therefore sensitive to abuse) the junction is.

This can happen in several ways. In general, any time one or both of the inputs are connected to low impedance (i.e. high current capable) source of voltage, even very short transients can break the junctions.

That's an obvious problem when the inputs are tied to ground, a bias supply, or some other voltage, but there are some sneaky ones. For instance, all capacitors are low impedance sources of current at some frequency. An integrator circuit stores juice in its feedback capacitor, and if the + input is suddenly jerked the wrong way, the - input can be zapped before feedback can correct the problem. Likewise, a capacitor to ground, either power supply, or a bias supply can do the same, although a bias supply in the middle of two other power supplies may not have enough voltage to break a junction in a 9V-only battery circuit.

Even a follower circuit, with the - input tied to the opamp output can zap the - input. When the output of the follower is near the + power supply and a sudden negative transient comes along, the opamp's finite slew rate keeps it from responding instantaneously. The - input is zapped by the opamp's own output for the time it takes for the output to move down so it's within the differential mode input voltage range.

Slow death and sudden death

The damage we're talking about is not sudden failure. Damage to input junctions from the kind of zapping we've described won't outright kill a transistor. What it will do is make it just a little bit noisier, perhaps a little slower. The next zap makes it worse. Over years, imperceptibly, the hiss level rises. Some opamps do die from it. It's a common problem for old "741" style opamps for dying suddenly to be the only symptom in a dead effect. This can well be from accumulated input damage in many cases.

How to delay death

This one is easy - don't let the input junctions get reverse-broken. Ever see opamps with back-to-back diodes between the + and - inputs in pro-audio schematics? That's one cure. Those diodes will clamp the inputs from getting too far apart. They're big enough to eat a lot of current and keep it from getting to the opamp inputs. In normal operation as an amplifier, the inputs of an opamp should never get more than a few millivolts away from one another anyway, so being "clamped" by two diodes is not a limitation. Carefully designed audio equipment often adds a series resistor of maybe 1K to each input as well as the diodes to limit the input current the diodes can draw when they conduct.

Opamps mis-used by being applied as comparators (as in an integrator/comparator LFO circuit) can often have their inputs pulled apart by volts so adding series resistors to opamps used as comparators is a good idea, if a bit tricky to apply.

If you simply must use an opamp as a comparator, it's best to use the back-to-back clamp diodes and series resistors to add some "compliance" to the diodes at the inputs. This will let your voltage sense inputs swing more than a diode drop, but still protect the inputs of the opamp. Sizing the resistors gets tricky, though, because the kinds of voltages sensed by a comparator may well be moderate impedance sources themselves, and the input resistor can change the voltage being measured. The input resistors have to be large enough to not appreciably load the voltage being measured, but small enough to still pull the opamp inputs apart by the few millivolts needed to get full swing.

Of course, another view is that like electrolytics, opamps used as comparators are expendable as well. If you count on replacing them you can get away with mistreatment.

Other Devices

JFET input opamps usually don't die from reverse breakdown, they just get hissier and hissier. Back to back diodes work here as well.

Normal bipolar transistor amplifiers are prone to the same problems, but base-emitter breakover can happen in many more ways. The problem is that most transistor circuits have capacitors in them and those capacitors can hold enough voltage to break over the base emitter junction at power-up or power-down. This isn't too common with 9V circuits, but goose your MaximoDistortoMax pedal up to 18V or 24V and you can start getting enough voltage on emitter capacitors to reverse break the emitter-base when the power is turned off.

CMOS devices usually have gate voltage ratings in the 15V range, so they're not vulnerable to this kind of damage from the circuit itself. However, if an input ever does get broken over, it's permanent.

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