TITLE: Crowbar Protectors

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In the March '01 issue of Kitplanes® we talked a lot about fuses and such. We came to the conclusion that a fuse will open the battery circuit and not allow current to flow when something causes too much current to flow in the load circuit. This "something" could be a battery hot wire that inadvertently touches ground, a transistor or other electronic device malfunctioning, or a hamhanded technician with a wandering screwdriver.

Now we are going to make that fuse pop on purpose. The function of a "crowbar" circuit is to blow the fuse if the circuit voltage goes way too high for the health of the electrical system. (Historical note – the original "crowbar" circuit was just that – a crowbar clipped to the cab of a locomotive that the engineer could grab and short across the generator to blow the 500 amp fuse when the generator "ran away" due to circuit malfunction.)

Understand that when I say "fuse" I am speaking of a generic circuit protection device. "Blowing a fuse" and "popping a breaker" are the same thing for the purposes of this article, as are "replacing the fuse" and "resetting the breaker".

At any rate, what we want our crowbar circuit to do is to sense when the electrical system has gone well out of normal range for more than a fraction of a second and blow whatever fuse(s) we choose to blow to protect the expensive parts of the system. Most electronic circuits are tolerant of an instantaneous spike or two, but when the battery voltage gets above 16 volts for more than a tenth of a second or so, it is time to take action. The "action" is to make it seem that we have thrown a crowbar across the load, and the fuse should promptly blow, removing the high battery voltage from the protected load.

In 95% of our aircraft, the crowbar circuit will never be used. However, in the 5% of us that have experienced generator or alternator runaway, the price can be expensive – a few pounds of smoked silicon at a couple of thousand dollars a pound. If the gamble of $10 in parts against you being one of the unlucky 5% is one you are not willing to risk, then let's go ahead and build your crowbar circuit.

The entire function of the crowbar is to throw a dead short across a load when the voltage goes too high. How we do this is really quite simple, but *where* we do it is not easy to determine. For example, in a voltage runaway, do you want to pop the main fuse going to the generator or alternator, or do you want to just pop the fuse going to the regulator to shut down the generator? Or do you want to let the generator run wild and simply protect the radios? That is an electrical system design question and one that is a little beyond the scope of this discussion. However, in order to select parts we are going to have to make some assumptions.

Assumption #1 – the fuse that we want to blow is no more than 10 amps.

Assumption #2 – the electrical system is either a standard "14" or "28" volt system (the design will work well for either one with only one part change)

Assumption #3 – that we want to use parts that we can get from any of the popular mail-order companies (Mouser or Digi-Key) and not have to use special parts that are hard to find.

Having made these three assumptions, the design and construction of the crowbar is really quite simple. The whole circuit relies on the action of a rather specialized electronic device called a Silicon Controlled Rectifier, or SCR for short. In essence, an SCR is nothing more than a solid-state switch that is normally open. When the

SCR switch is thrown closed, it cannot be reopened without the dc supply voltage going to zero. Thus, if we put this SCR across the load we are trying to protect, it will draw practically zero current in the normal mode. However, should the voltage rise above our limit, the SCR will switch ON and stay on (conducting several dozen amps for a few milliseconds) until the fuse blows. When the fuse blows, the dc supply voltage going to the SCR goes to zero and the SCR resets itself for the next surge. If the surge was momentary, replacing the fuse will supply current to the load until the next time the over-voltage triggers the SCR.

"Throwing" the SCR switch involves nothing more than bringing one of the terminals (the gate) more than 0.6 volts higher than the cathode. And now the problem resolves itself to making a trigger circuit that will go from 0 volts to more than 0.6 volts when the battery bus overvoltages the load.

It certainly seems like the simple circuit shown in "A" would work. Here a simple voltage divider takes the 14 (or 28) volt bus and divides it down so that when the bus gets to 16 volts the gate gets to 0.6 volts. The 2500 ohm and 100 ohm resistive divider would certainly perform that function…except…that the "gate-cathode" is nothing more than a simple diode junction. So? Whassa big deal? Whassa big deal is that a silicon diode's nominal 0.6 volt junction voltage varies about 2 millivolts per degree Celsius (about 4 millivolts per degree Fahrenheit). That's not good. In the summertime you would be triggering at 15 volts and in the wintertime you would be triggering at 17 volts. Unacceptable.

Back to the drawing board. What simple, cheap device do we have that doesn't vary it's voltage with temperature? Well, it's not perfect, but a zener diode comes as close as we can get. And, if we pick that zener diode's voltage somewhere around 5 or 6 volts, we get the best possible temperature performance from the device. And, if we want something we can get at The Shack or *any* reasonably stocked supply store, a 5.1 volt zener is the easiest to get, cheapest, and lowest temperature drift of any diode on the market. Let's go with it.

Yeah, well, 5.1 volts isn't exactly what I had in mind for a trigger voltage. Somehow we have to compare this stable voltage with our bus voltage and turn on this "comparator" when the bus voltage exceeds 16 volts. Lessee, what do I have in the inventory that has two inputs that amplify the difference between the inputs…hmmm…did I hear OP-AMP from the crowd? You betcha. Two bits worth of op-amp will make this little gem stand up and play music if we ask it to.

Here's the drill. The (-) input of the op-amp is held at a constant 5.1 volts by D101, the 5 volt regulator diode. Until the (+) input gets above 5.1 volts, the output of the op-amp will be zero, or within a few hundred millivolts of zero. The resistive voltage divider R101, 102, 103 are chosen (and adjusted) to set the voltage at the (+) input so that when the bus voltage gets to 16 volts, the (+) input goes to 5.10001 volts and bingo, the output swings all the way to the power supply voltage. This is more than enough to turn on D102 (the SCR) which provides a hewmongous current path to the overvoltaged bus and blows the fuse (F101).

Now for a few refinements:

It is possible for the output of U101 to be a few hundred millivolts above ground in the "off" or low state. While this will *probably* not trigger D102 on, I wanted the device to be totally stable with regard to temperature. D102 and D103 make a 1.2 volt drop so that D102 will not trigger on until the output of U101 had gone past 1.2 volts.

We don't want very fast noise spikes to fire the crowbar. C101 (in conjunction with R101-103) forms a low-pass filter to remove noise spikes yet will allow the crowbar to fire if the bus voltage rises above 16 volts for more than one or two hundred milliseconds (0.1 to 0.2 second).

The only difference between the 12 and the 28 volt version of this crowbar is changing one resistor value (R103) so that R102 can be adjusted for the crowbar to fire at 32 volts in the 28 volt system and 16 volts in the 14 volt system.

The device I've chosen for Q101 (Teccor S4010L) will take 10 amps continuous, and 100 amps for 15 milliseconds or so while waiting around for the fuse to blow. It is a relatively cheap ($1.25) part from both of the mail-order supply houses we use and comes in an insulated case so you don't have to worry about providing a mica washer installation kit for it. You should bolt it to a business-card sized piece of metal just to keep the temperature during repeated usage under control, but if you don't plan on excercising it repeatedly, it needs no heat sink at all.

And a few thoughts:

I'd probably make one of these cheap little crowbars for each of my avionics bus breakers, but probably not for the alternator breaker or the alternator field breaker. The reason being, if my alternator runs away, the avionics breakers will pop and I'll certainly notice that when all my radios go dead. It then becomes MY decision as to whether to boil the battery dry in favor of keeping the lights and gyros going or pull the alternator or field breaker myself.

The standard way of testing something like this is to use a variable voltage power supply and a relatively low-current incandescent bulb to tell when you "triggered" the crowbar. Set R102 for minimum voltage at U101 (+) terminal and increase the variable power supply from 14 volts to exactly 16.0 volts. Slowly set R102 until the lamp lights. Bring the power supply all the way back down to zero (or switch it off, wait a while, and then switch it back on) and then bring it slowly up. It should not trigger until the power supply gets to 16.0 volts. If it triggers early, you weren't slow enough setting R102. And 16.0 volts isn't magic. It is generally the point that most of us figure that the electrical system is frying. If you or your electrical guru want another number between 14.5 and 16.5 volts, R102 is quite capable of adjusting anything you might want between these ranges. See schematic page 2 for the test setup we use here at RST.

Bob Nuckolls, over at the Aeroelectric Connection (www.aeroelectric.com) made a sweet little in-aircraft test box for this thing. Clever it is, and it costs you a few flashlight cells and another incandescent bulb or two. It uses 4 D-cells (out of your ELT out-of-code-date supply?) to boost your battery voltage 6 volts above nominal and will certainly light the bulb if the crowbar is working properly. We show this circuit on page 3 of the schematic section

Next month will be a follow-on to this crowbar article about an overvoltage device that simply removes the overvoltage supply from the equipment rather than blowing a fuse. After that we'll begin a two-parter on using the Radio Shack digital multimeter as a volt-ammeter for your airplane. On down the line we've got some stuff in mind for a new breed of speaker and headphone amplifier, then some more Palm stuff, and some stuff I haven't worked through yet. Stay tuned…and fly safe. Remember, more people are caused by accident than anything else.

Author's Note: Jim Weir is the chief avioniker at RST Engineering. He will be glad to answer avionics questions for this article or on any avionics subject in the Internet newsgroup rec.aviation.homebuilt. If you are having trouble with newsgroups, go to www.rstengineering.com and click on the "How To Use The Net" link.