

TITLE: A Full-House Engine Monitor On The Cheap

ISSUE: Feb '02

By Jim Weir
Humble Tinker, RST

I'm going to be right up front about this month's column. It isn't for the casual electronic tinkerer. You've got to have at least a smattering of a technical background and/or be willing to do heuristic research (that's engineerspeak for "mess around a lot") on your bench to make something that will work correctly in your airplane. I'm also willing to tell you that I have NOT actually built an entire system as I describe, but I have built each sub-part and gotten it to work correctly.

So, if you are willing to put in some time and trouble, I guarantee that what I'm about to show you will put the most sophisticated of the multi-thousand dollar engine monitoring systems to shame. What you are about to consider is a digital engine monitor that will accept any number of inputs and give you a digital readout of the input sensor. That is, you can input oil pressure, oil temperature, carb temperature, fuel pressure, fuel quantity, air temperature, and any other input you wish that can be converted to an electrical signal. The system as designed will take that input, massage it, and then run it to a digital gauge for a readout directly as the quantity measured. That is, if you measure your oil pressure in psi, the gauge will read directly in psi. If you measure in pascals, it will read directly in pascals. Gallons? Gallons. Squirds? Squirds.

If you read last month's Kitplanes® column, you are aware of a little digital meter that The Shack sells for about \$25 (p/n 910-4919 \$24.99). In January, we showed how to use this little gem to read battery volts and amps. Now we're going to take that same meter a step further and make it the focal point of the entire engine monitoring system -- the Kitplane Engine Monitor.

Right up front you've got to make a choice. This choice has three factors bearing on it -- how much space do you have on your instrument panel, how much money are you willing to spend, and how much do you trust lights to tell you that something is wrong.

Here's the deal... one choice is that you can have one of these little meters for each input at a cost of about \$30 an input. The other choice is that you can have one meter for the whole system of inputs, switch selected to the input of your choice with lights to monitor each input at a cost of about \$35 (plus sensors) for the whole system. Either way, the design is remarkably similar; cost and space are the real considerations.

Let's back up for a moment and see exactly what we've got. That little Rat Shack (Trumeter) digital meter has a full-scale fundamental range of 200 millivolts (0.2 volts) and a 4-digit readout with a selectable decimal point between each of the digits. That is, for an for-instance input of 153.2 millivolts, we could make the meter read 1532, 153.2, 15.32, or 1.532. That is nice, in that it will let US decide the resolution of the meter.

Let's take a concrete example that will use the numbers above to illustrate the point. Our good old EGT probe gives us 33 millivolts out for a flame temperature of 1532°F, and if we put that little voltage into an opamp with a gain of 4.65, the opamp will give us an output of 153.2 millivolts. Feed that voltage directly into the meter without putting in any decimal point and the meter will read 1532. There is even a little °F symbol on the meter, so if you choose to turn that symbol on instead of the decimal point, you will have the legend right there on the meter. Hoo ha.

Perhaps it might be wise of us to contemplate what this "opamp" circuit is going to look like, and perhaps throw another monkey wrench into the design. An "op-amp", as we have all come to know and love, is a little linear integrated circuit that comes in a 14 pin package, four individual amplifiers to the package. Each of the inputs

is going to use one complete package, at least for the "cheap" design. One amplifier to give us the gain we need to set the output voltage to a scaled multiple of the input voltage, one amplifier to turn on the "over" light, one to turn on the "under" light, and one to turn on the "OK" light.

Now let me diverge just the littlest bit from the analysis we did above. I don't like working down in the millivolt range. In the first place, most of our testers and multimeters don't work very well down that low, so you would have a real problem experimenting with this low of a voltage. In the second place, just a little temperature drift down in the microvolt range makes the output reading drift away from the calibrated output. So, instead of a 4.65 amplification factor in the above example, I'm going to have the opamp give me a 46.5 amplification for an opamp output voltage of 1.532 volts. Then, with a simple 10:1 resistive divider (R7/R2 on Schematic #1), I'm going to take that output and drop it back to the digital meter's 200 millivolt maximum input. This lets me work up in the volt range and then go back to millivolts only after I've done all the processing that I need to do. Since the gain of an opamp is given by the ratio of the feedback resistors, and since I included a variable "calibration" resistor R5 in the feedback loop, you can set the amplifier gain broadly over the range 44 to 54.

So, what's the drill on this light idea? Well, if we can define the limits we want for our upper and lower temperature range (or pressure, or fuel level, or squirts) then the output of our little scaling opamp will be fed not only to the digital meter, but to two other opamps that have been configured as comparators. We will compare the output voltage of the scaling opamp to preset voltages representing upper and lower limits, and if the output of the scaling amplifier falls above or below these limits, it will light the appropriate lamp. If the output is between these limits, a third amplifier acts as a NAND gate to turn on the green "OK" lamp. Schematic #1 shows this lashup using the EGT probe as the example.

In Schematic #1, I've arbitrarily set the low limit at 1200°F and the upper limit at 1700°F. You can certainly modify these limits by changing the ratio of R12/R11 for the high limit or R14/R13 for the low limit. Amplifier U1C acts as a simple NAND gate; if both U1B and U1D are low at the output, R15/R16 turns the green "OK" light on through U1C. If either U1B or U1D go high, R17 or R18 will turn U1C off.

So now for CHT, what have we? The exact same problem, only this time the output for a 352°F head temperature the thermocouple output is going to be something on the order of 10 millivolts. If we say that the indication on the digital meter ought to be 0352 (the leading zero will be blanked in the real meter), then the meter input needs to be 35.2 millivolts. With the permanent 10:1 voltage divider in place on the meter, this means the output of the opamp needs to be 352 millivolts. With a 10 millivolt input, this means that the gain of the opamp needs to be 35.2, which is done by simply replacing R3 with a 27K resistor, which will allow a variable gain between 28 and 38.

Now for some not-so-simple stuff. Then some *really* not-so-simple stuff. The n-s-s stuff comes with a "standard" automotive and aircraft fuel level, fuel and oil pressure, and air transducers that are "240 ohm" devices. That is, when the gauge is supposed to read zero (or minimum) the transducer looks like a 240 ohm resistor. When the gauge is supposed to read maximum, the transducer looks like a 30 ohm resistor. This presents two problems to our neat little scheme that we ginned up for the thermocouples. First of all, we are now stuck with a variable resistance instead of a variable voltage. Second of all, the resistance goes DOWN when the quantity goes up.

Let's resolve the "resistor to voltage" problem. And, at the same time, let's linearize the sensor to provide an industry standard 50 millivolt output. Then we can use the same opamp trick we used before (with just a TOUCH of modification) to provide a standard output to our digital meter. And, just for grins, let's presume that we are working with an oil pressure sender for which we'd like the output to read 0 to 80 psi, or 000 to 80.0 on the meter. This means that we've got to provide 80 millivolts to the meter, or 800 millivolts (0.8 volts) to the 10:1 divider R7/R2 on the input of the meter.

No problem...a 24K resistor (Schematic #2, R25) from the +5 supply to the 240 ohm transducer will give us 50 millivolts when the quantity is "zero", but will give us 6 millivolts when the quantity is supposed to be "full". Hmm...well, we know that we want 800 millivolts out for a change of 44 millivolts in, so an opamp gain of 18 will be quite sufficient. However, with a 240 ohm source impedance, we'd better boop (that's an engineering term) the opamp resistors up a bit so as not to unduly load the transducer. Now, to take care of the fact that we had to use the (-) inverting input of the opamp, and the fact that we've got full voltage with zero quantity, R27 and R28 will let us offset that full-voltage problem so that the output of the opamp is exactly zero when the transducer has zero quantity. Here's the calibration routine. Set R23 to mid-range. With zero pressure (or quantity) on the transducer, set R27 for the threshold where the output of the opamp just *starts* to come up. Perhaps ten millivolts or so. Then pump full pressure into the transducer and set the output for (in this case) 800 millivolts with R23. Let the pressure bleed off and reset R27 to 10 millivolts, then back to full pressure and reset R23 to 800 millivolts. Two or three iterations ought to be more than enough.

I didn't show the high-low-OK circuit on this opamp, but I assure you that it is done using exactly the same design technique that we used with the first thermocouple design. Of course, you will have to change the R11/R12 and R13/R14 ratios to account for the fact that the output of this amplifier only goes from zero to 800 millivolts, but that is a simple Ohm's law trick.

Now for the real problem, and one that I've got a "sorta" answer for in some circumstances, and a "real" answer for that is beyond the scope of a simple three-sheet column. The problem is this -- low to moderate temperature transducers use thermistors. Oil temp, carb temp, and water temp sensors are in this league. The problem with a thermistor is even worse than with the pressure sensors above and the problem is that thermistors aren't linear with temperature. As a matter of fact, the equation describing the thermistor uses natural log (base e , or 2.718) to describe the temperature-resistance characteristic. And, as a final straw, the same inversion problem we had with pressure senders (quantity goes up, resistance goes down) we also have with thermistors.

I've got a cheap and dirty solution and an elegant but difficult solution. The cheap and dirty solution I can give you within the confines of my space. The elegant but difficult solution I leave for those of you with a lot of experience in the field of logarithmic and anti-log amplifiers or programmable logic arrays. Good luck.

The cheap and dirty solution goes something like this -- you know fairly well the temperature range for which you are concerned. For example, with oil temperature, you really only care about 160° to 200°F. Anything below 160 is too cold, and anything above 200 is too hot. Similarly for carburetor throat temperature -- anything below 10° or above 50°F is simply not worth worrying about measuring accurately. And, certainly over these small ranges of thermistor operation, we can assume a certain linearity that the thermistor doesn't have over a much larger range.

For example, a standard thermistor has a resistance of 500 ohms at 160° and 250 ohms at 200°F. Certainly if we say that 500 ohms will be our standard 50 millivolt output, we can adjust the gain and offset using the same circuit that we used for the pressure measuring transducer above. Let's see how that might work...

If we raise the value of the transducer bias resistor to 56K (R34), then when the transducer is at 500 ohms with a 5 volt supply, the transducer voltage will be very nearly 50 millivolts. Since we want the output of our opamp to be 160 millivolts at this time (160°) then a gain of 3.2 is required. Raising the value of R33 to 160K takes care of this little job quite nicely.

The same back-and-forth iterative technique for calibration is required, but here you need to go back and forth between the limits you selected (160° and 200° in this instance) and adjust R30 for the low-temp reading and R29 for the high-temp reading. I've done it with two pans of water on the stove and two heat settings on the burners beneath the pans. It is messy, but it works. And, you only have to do it once.

As a parting shot, may I remind you of a capacitive fuel gauge system that we designed in this column back in June/July/August 2000 (and posted for your downloading pleasure at www.rst-engr.com/kitplanes)? Remember that it had a voltage output proportional to fuel quantity? And now you have the tools to convert that analog output to a digital meter that reads directly in gallons, don't you? Son-of-a-gun...a digital fuel gauge for nothing more than some cheap Shack parts. You gotta love this business.

Hey, stay tuned for next month. I'm going to take you on a very easy trip to convert your existing COM antenna into an emergency antenna for your handheld radio without losing the capability of the antenna for normal COM use...for less than \$1 in Shack parts. See ya then.

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.rst-engr.com and click on the "How To Use The Net" link. Back issues of this column (back through 1999) are available at www.rst-engr.com/kitplanes .

Photo/Drawing Log:

KPsch.pdf contains two pages of schematics. First page is referenced in the text as Schematic #1 and the second page is referenced as Schematic #2