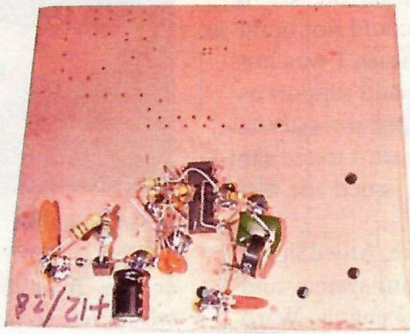
By Jim Weir

Check out this new and improved capacitive fuel gauge.

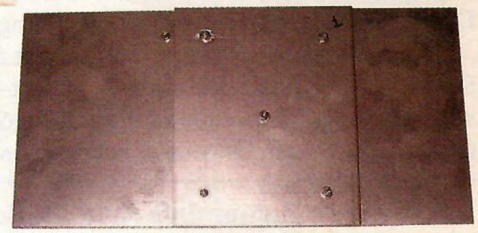
A decade ago I wrote an article on the theory and construction of fuel gauges. My homebrewed version appeared in the September '89 issue of KITPLANES®. We used metal capacitor plates in the fuel tank and some electronic gimcrackery to make the fuel level between those plates give an electrical signal proportional to fuel level.

Recently on the Internet newsgroups, a few folks were trying to make that old design work and were having some trouble with it. I rebuilt the circuit in accordance with those old drawings, and it appeared that everything was working just the way it did in '89.

But I was sort of vague back in those days on what to use as the actual gauge, and there were a couple of things that weren't quite as clear as they might be. Further, there are some engineering refinements I wanted to do to make the design as bulletproof as I could, so in the next few articles I'll build on the concept and try to improve on that project.



The oscillators are on the board, leaving room for next month's meter circuitry.



Custom-cut aluminum sheet, stainless-steel 4-40 screws, Nylock steel nuts, nylon shoulder washers and nylon spacer washers make up the fuel sensor assembly.

The Concept

Basically, a capacitive fuel gauge is nothing more than a variable capacitor with a gauge on the capacitor. As we know from basic electronics, any two conductors separated by an insulator make a capacitor. Whether those conductors are metal plates separated by air, or the earth separated from the moon by the vacuum of space, the principle is the same. It is also true that different insulators separating the plates make different values of capacitance. Thus, if we separate the metal plates by air, we come up with one value. If we put Teflon or waxed paper between the plates, we come up with a different value. In particular, if we put aviation gasoline between the plates, we come up with a capacitor with roughly twice the capacitance of the same plates separated by air.

The basis of this scheme is that a full tank of fuel will have metal plates separated by gasoline. As the gasoline is used, the capacitance will vary from a maximum when full of gas to a minimum when only air is present.

We measure the capacity of our metal plate capacitors in *farads* (after the English physicist Michael Faraday), and with our engineering metric prefixes, we can have microfarads (millionths of a farad), nanofarads (billionths of a farad), and picofarads (millionths of a millionth of a farad). In this application, for metal plates of a reasonable size, our gas-variable capacitor is going to be measured in picofarads.

The Variable Capacitor

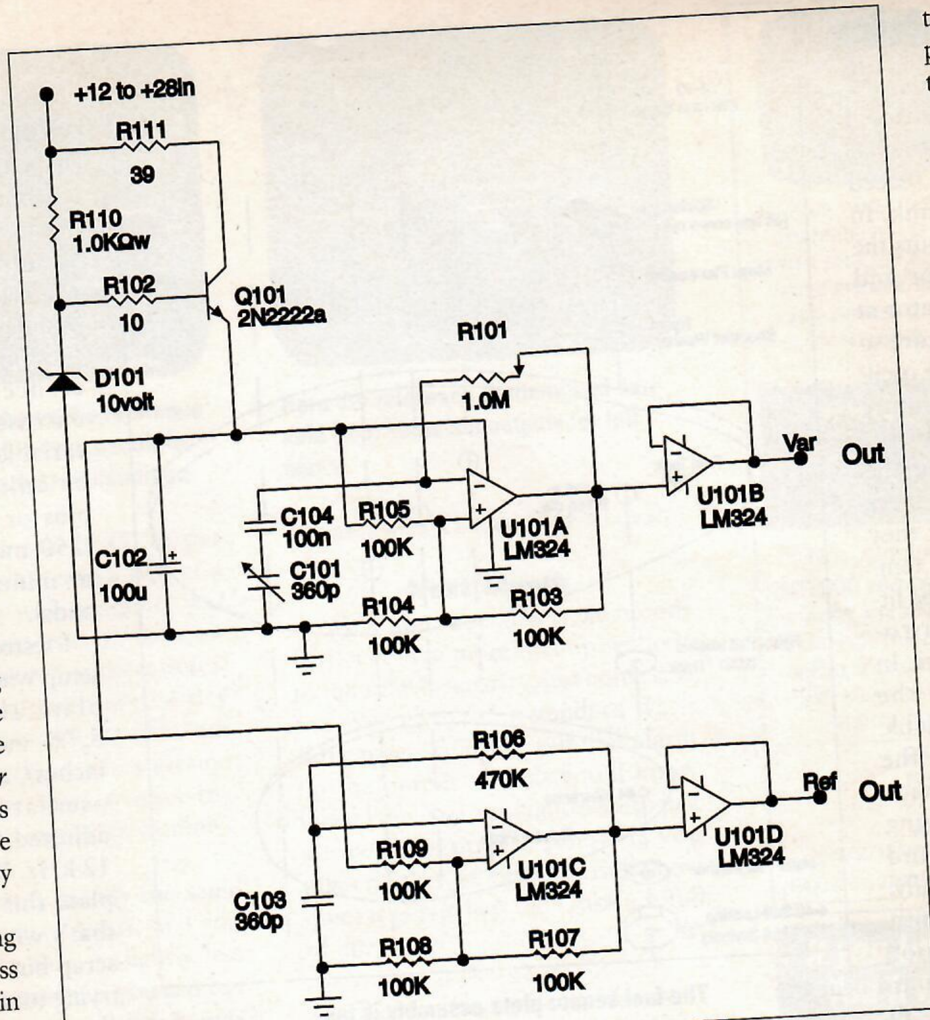
We went through a week of discussion on the Internet trying to decide the best configuration for the capacitor sensor plates. Some said it should be concentric tubes. Some wanted fancy machining. What we came down to when all was said and done was the old flat-plate scheme—for several reasons. First, they are extremely easy to make. Second, they can be made conformal—which means they can be curved and bent to match the tank configuration. Third, they can be made out of the same material that the tank is made of so you don't have to hunt up materials.

We also came to the conclusion that nearly every homebuilt being made will have 50 square inches of tank sidewall or splash plate that we can use for one side of the capacitor. One of the discussion participants did a chemistry search and found that nylon had good resistance to gasoline and was readily available in the sizes we needed for hardware for the spacers and washers for the insulated plate.

The hardware we settled on was stainless-steel 4-40 screws, nylock steel nuts, nylon shoulder washers to insulate the screws from the outside tank wall, and 0.031-inch-thick nylon spacer washers to separate the sensor plate from the metal tank wall.

Given all these sizes, we find that a

capacitor made like this with air as the dielectric will have a capacitance of about 350 picofarads (350 pf). When you fill the tank with gasoline, the capacitance will rise from this level until the plates are filled with gasoline so that the filled capacitance will be about 700 pf. The only problem remaining now is to figure out how to make a *capacitor meter* to measure this difference between empty and full tanks.



I'm not going to leave you glass tank folks out in the cold. You can easily use this scheme by embedding aluminum foil into one wall of the tank (or into a splash plate) and making a thin glass sensor plate with another sheet of aluminum foil embedded into the glass. Just remember to leave one small part of each foil exposed so that you can electrically connect to the capacitor plates. If you wish, you are certainly welcome to use brass shim stock instead of aluminum foil, and then you can solder connections to the brass instead of using a compression connection (screw, washer and nut).

Now if you read nothing else, *read this*! Use a very thin permanent insulator between the sensor plate and the tank wall. Whether you cut a thin piece of sheet nylon or cover the plate with a thin coating of epoxy/glass, I don't care. If those plates get too close together and touch, even though it is only a 10-volt arc, it is theoretically conceivable that you could ignite gas vapors if the conditions are just right. You might consider anodizing the sensor plate and then spotfacing the one screw hole that will have the solder lug for electrical contact to this plate on the back side. If I'm making it, I anodize. It is permanent and foolproof.

Use a little common sense not to get the rest of the circuitry around the gasoline or even worse, the fumes. A fire extinguisher wouldn't be a bad idea.

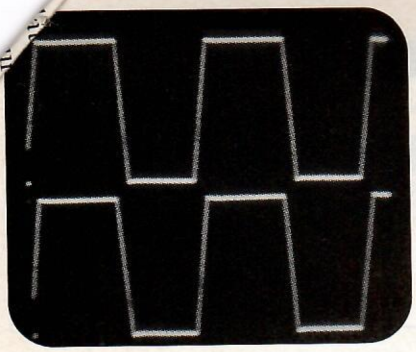
Can we stop there? Surely, you jest. Either that or you aren't yet used to the Weirish brand of bells and whistles this column is famous for. How about a two-bit alarm that you can set when the fuel tank quantity drops to any particular level that you choose?

Meter Oscillators, Part One

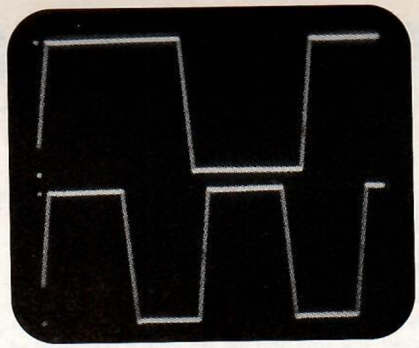
There are half a dozen different ways to measure capacitance. One of these ways is to put the capacitor into some sort of oscillator circuit and measure the resulting frequency of the oscillation. Not only is this method reliable and straightforward, when we finish, if you don't have quite the same plate area that we said we needed, we can juggle resistor values so that the rest of the meter doesn't know the difference.

The schematic of our variable oscillator shows that one section of our old favorite standby op-amp (LM-324) becomes a 4-kHz oscillator with empty tanks and a 2-kHz oscillator with full tanks using C101 as the gas-variable oscillator capacitor. We buffer the output of this amplifier with another section of op-amp so that any load that the rest of the meter puts on the oscillator won't pull or distort the frequency set by the tank capacitor.

Another oscillator and buffer uses the remaining two sections of op-amp. Instead of a *variable* capacitor, though, this oscillator will be called the *reference* oscillator, and we will use a stable fixed capacitor to set the frequency close to the frequency of the variable oscillator with empty tanks. The rest of the capacitor meter will then simply have to tell the difference between the frequency of the two oscillators.



The oscilliscope shows the reference (bottom) and variable (top) oscillator outputs for the empty tank condition.



Here the reference (bottom) and variable (top) show the outputs for full tanks.

fortitude (with a capital *G*) to put *just* the sensor plate into a pan and then fill the pan with gasoline, you should see the frequency of the variable oscillator drop to almost exactly half the frequency of the dry plates. Use a little common sense not to get the rest of the circuitry around the gasoline or even worse, the fumes. A fire extinguisher wouldn't be a bad idea.

(Jet-A is almost exactly the same dielectric constant as avgas, so if you want something that is slightly less flammable than gasoline, you can run this test with Jet-A, diesel or kerosene if you wish, and the results ought to be nearly identical. The dielectric constant of gasoline is 1.94; Jet-A equals 2.08. Watch out for gasohol with the alcohol constant of 30, and be wary of water with a constant of 80 or so.)

Next Month

We'll continue this next month with a couple more opamp sections to take the frequency and convert it to a voltage to run a standard Westach gauge. We'll also put that alarm on the output so that you'll know when your fuel has run down to just above your pucker point. If you think that's a bit much, consider how quiet it gets when the tanks are full of air. **KP**

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Check the Web

Please don't look at the photographs in any of these projects and say that there is something wrong with the schematic because the parts you count in the photo don't add up to the parts on the schematic. When I'm building a breadboard, I'm likely as not to use a high-value resistor or a junk capacitor as a tie point. That part has absolutely no effect on the circuit. I've tried my level best to make the schematic reflect the way that the circuit will work.

If you think that there is an error, you can go to my web page—www.rst-engr.com/kitplanes—and look to see whether that particular issue has any errors. Check the "oopsie" document that appears in every issue's separate web page.

Likewise, please don't write and say that the breadboard looks like junk and isn't space flight qualified. We all know that the first test circuit is built so that parts can be changed without dismantling the whole shooting match. No, I wouldn't fly with any of these first-cuts in my airplane. However, I would and have, and am, flying with the MK-II version of a lot of this stuff. I guess I could paraphrase an old German saying: "If you love sausage or prototypes, you should never watch either one being made." *—Jim Weir*