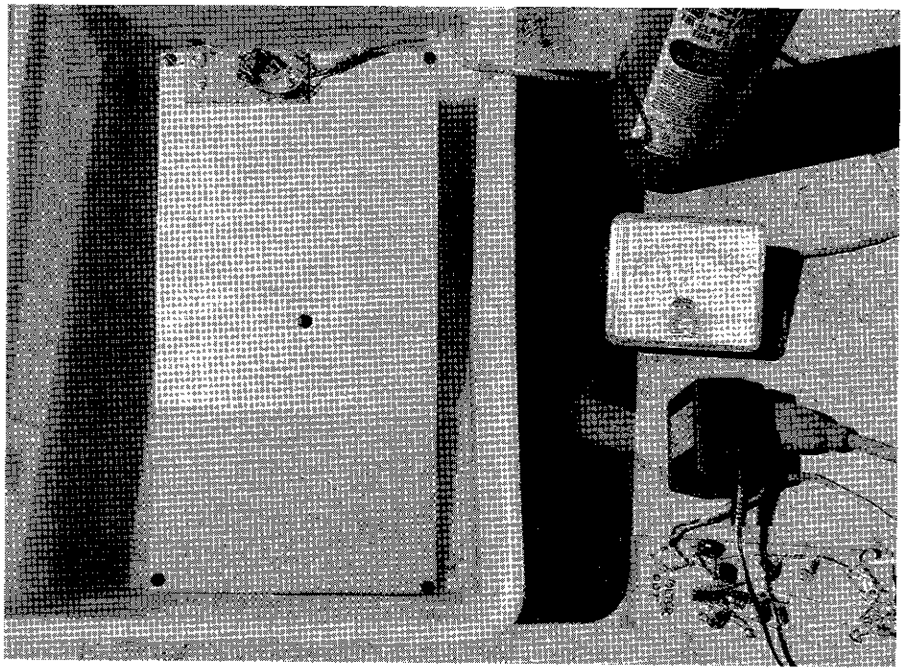
Gauging Fuel Quantity, Cheap

Make your own capacitance fuel gauge system.

BY JIM WEIR



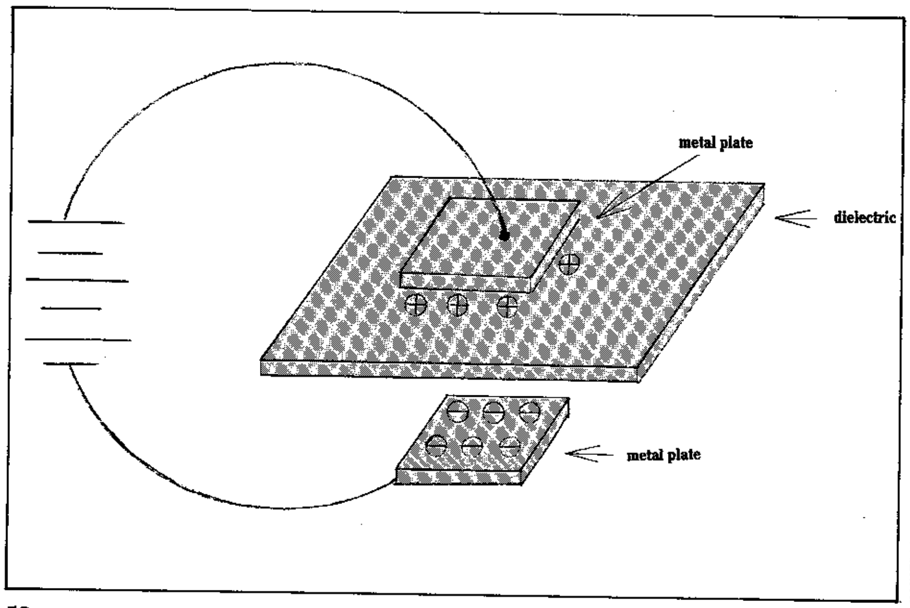
Fire extinguisher at the ready, we tried Jim Weir's capacitive fuel gauge in a pan of gasoline. The system appears stable and accurate.

If you bring two pieces of metal close together and separate them with an insulator, you have a *capacitor*. A good example of a homemade capacitor would be to take a pizza pan and cover it with a piece of waxed paper. Then nest another pizza pan on top of the waxed paper, making a pan-paper-pan sandwich. The two pans are the *plates* of the capacitor, and the waxed paper is the *dielectric*.

If you connected a battery to the pans, positive to one plate and negative to the other, "little black balls" of negative electricity would rush to the negative plate and "little red balls" of positive electricity would rush to the positive plate. Push and pull as they might on the waxed paper, they can't jump from one plate to the other through the waxed paper. (Think of it as little boy electrons on one plate and little girl electrons on the other with a waxed-paper chaperone in the middle —I think you get the picture.) The funny part is that I can now disconnect the battery and the negative and positive plates will retain their charge indefinitely. In theory, I could come back with a sensitive voltmeter a year from now and the voltage on the plates would be the same battery voltage that I initially charged the plates with.

The *current* that is available from our homemade capacitor is a function of how many little red and black balls I can get to line up on opposing plates. We call this number the *charge* of the capacitor, which is another way of measuring the *capacitance* of the capacitor. So, we have the *voltage* on the capacitor (measuring how excited the little black and red balls are), and the current (measuring how many of them there are).

Strangely enough, by changing the dielectric to another material, we can change the charge that any given voltage can produce on our capacitor. For example, if I very carefully removed the waxed paper from between the plates and let air fill in the space with the same gap between the plates, I would find that the capacitor would only measure one-third the capacitance that was present when waxed paper was the dielectric. Similarly, if I had a piece of Teflon the same thickness as the waxed paper and used that for the dielectric between the plates, I would find that the capacitance was more than 1500



ILLUSTRATIONS: JIM WEIR

Figure 1. An elementary capacitor.

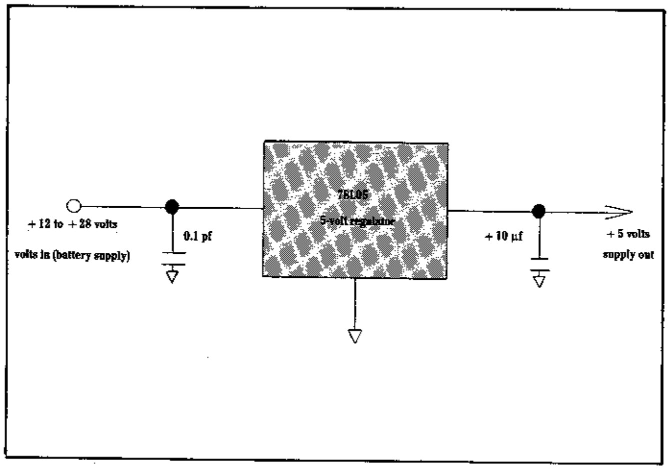


Figure 2. 5-volt regulator.

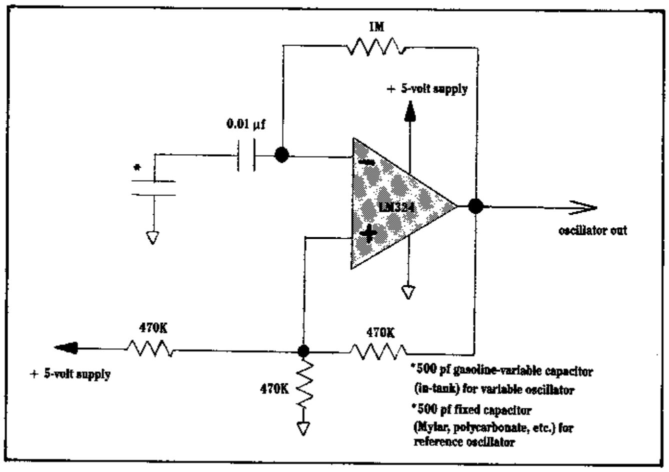


Figure 3. RC oscillators.

times the capacitance using air for the dielectric!

Because air is available nearly everywhere on the planet, we measure every dielectric with respect to air. Another way of saying this is to say that air has a *dielectric constant* of 1.0, waxed paper has a dielectric constant of 3.0, Teflon has a dielectric constant of 1500 and so on.

Now it gets interesting. Gasoline has a dielectric constant of 1.94 (call it 2.0 for ease of calculation). If I put my pizza plates vertically into your fuel tank, my capacitor will vary in capacitance as a function of how full your tank is! That is, with nothing but air in the tanks (empty), my capacitor will have a certain value (let's say about 100 *picofarads*). As I begin to fill the tank, the gasoline fills the air gap between the plates and the capacitance value rises until at full tanks the plates are totally separated by gasoline and the capacitance is now 200 picofarads.

Now the problem of measuring fuel quantity really resolves itself to figuring how to make a capacitor inside your fuel tank and how to measure its capacity.

The first part of the problem is relatively simple. Do you have metal tanks? The tank itself can be one plate, and

Figure 4. Integrator (two required).

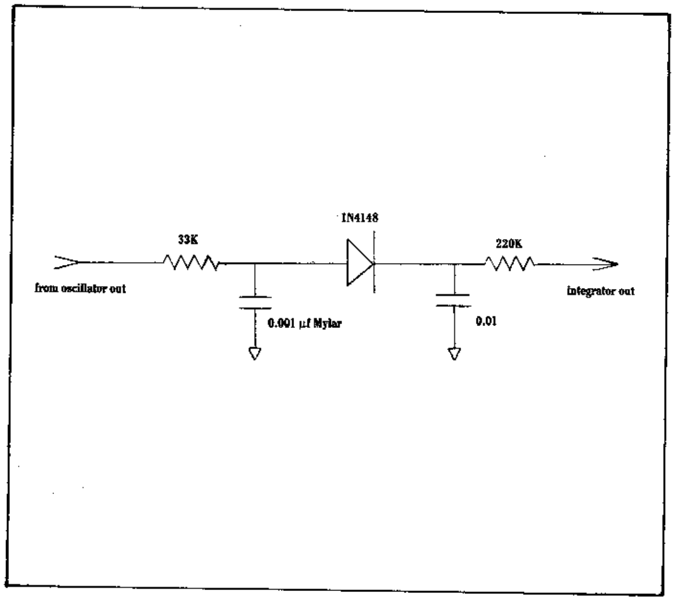
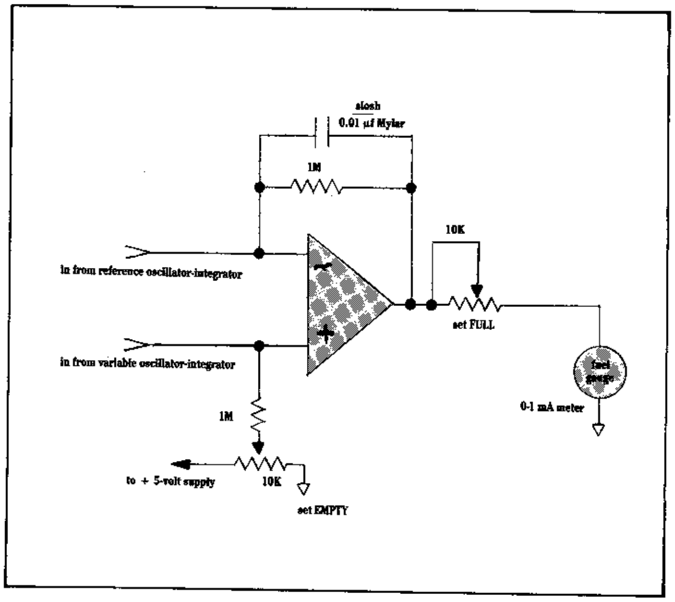


Figure 5. Output circuit.



bolting a simple flat metal plate to the inside wall using a few insulating spacers makes the second plate. Fiberglass tanks? No problem, make one of your splash baffles out of metal and bolt the second plate to it just like the above metal tank. Do you have tanks that need something other than a straight line curve fit between gasoline height and fullness of the tank? Nobody said that these plates had to be square, circular, or any other shape. Cut the plates to give the response curve *you* want. The only thing you need to be sure of is that the plates are insulated from one another.

As a practical matter, the smallest plate should have an area of about 1 square foot (0.1 square meter) and the plates should have a separation of about 0.062 inch (1.5 mm). This will give an "empty tank" air dielectric capacitance of about 500 picofarads. If you would prefer, you can use a *coaxial* capacitor (rod inside of tube) that has an "empty tank" capacitance of about 500 picofarads, and you are on your own to do the sizing calculations.

What we are now going to do is use that gasoline-variable (GV) capacitor in an integrated circuit resistor-capacitor (RC) oscillator. The *frequency* of the oscillator will be determined by the GV capacitor. With the components chosen as shown in Figure 1, the oscillator frequency is about 20 kHz for empty tanks and falls to about 10 kHz for full tanks. (Please note that the oscillator needs to be as close as possible to the GV capacitor and needs to be connected to the capacitor with leads as short as possible —certainly less than 6 inches (15 cm). My preference is to use 50-ohm coaxial cable between the capacitor and the oscillator.)

Out by the oscillator I am going to use a little four-component integrator that will take that square wave oscillator output and make a DC voltage proportional to the oscillator's frequency (a frequency-to-voltage converter). The DC output of the integrator is then run to a difference amplifier that we will be talking about in a minute.

We need to make a second "reference" oscillator out by the GV capacitor. Instead of a *variable* capacitor, though, the reference oscillator uses a fixed value. What this achieves is a circuit that is relatively insensitive to temperature. The theory is that the components will all drift somewhat with temperature, but that both the reference and the GV oscillators will drift in frequency the same way. If all we care about is the difference between the frequencies, and if they both drift the same way with temperature, the difference will stay the same.

Now comes your chance to take part in the design. All I care about from an engineering point of view is that both oscillators and both integrators remain at about the same temperature. If you want to run the rest of the circuitry inside the cockpit, that's fine. If you want the whole thing out in the wing, that's fine, too. From the output of the integrator to the input of the diff-amp you could have a No. 24 wire 100 miles long before you got even a 1% error in quantity. From the output of the diff-amp to the meter is similarly insensitive to wire length. The nice thing about putting the whole thing in the wing is that you can use a cheap four-section integrated circuit and do the whole thing with one chip. On the other hand, one argument for putting the diff-amp inside the airplane is that the "empty" and "full" adjustments might be easier to get to.

The differential amplifier simply amplifies the difference between the output of the GV oscillator's integrator and the reference oscillator's integrator. The output, then, is a voltage that goes from near zero to near 5 volts as a function of how full the fuel tank is. If you want to use a meter other than a 0-1 mA movement, that is fine, but remember that the integrated circuits will not put out much more than 20 mA. Of course, you could use an emitter follower to boost the amount of current, but that is a little beyond the scope of this article.

How Can We Get into Trouble With This System?

1. Gasohol. We are assuming pure gasoline with a dielectric constant of 1.94. If you use gasohol with alcohol's dielectric constant of 25 or so, you will totally mess up the system.

2. Water. Water in the gas will give huge errors because of the dielectric constant of water: 78.

3. Sparks in the system. BOOM. Loss of flying mechanisms. It could mess up your whole day.

First, all systems are run from a regulator that only allows 5 volts at 100 milliamperes maximum. It's very hard to get a spark from that low a power level.

Second, the sensor is DC-isolated from the system by a 0.01 microfarad capacitor.

Third, the output from the (−) inverting input of the IC is less than a microampere.

Fourth, if you really want to gild the lily, *anodize* the capacitor plate. Then even if the plates should touch, there would be no DC path.

If the regulator fails at the same time the isolation capacitor fails at the same time the integrated circuit fails at the same time the anodize layer fails, it's just going to be one of those days.

Some Comments on the Components

1. All of the parts for this little project are available at Radio Shack for less than $10.

2. The resistors can be any size you choose. The wattage is absolutely irrelevant. Same goes for the "full" and "empty" controls. The smaller you get parts, the easier it is to make things fit in tiny crevices.

3. The integrated circuit amplifier can be any garden-variety op-amp with the *exception* of what is called a "Norton" amplifier (LM3900 or equivalent). A good dual (two-section) op-amp is the LM358, and if you are going to use a single quad (four-section), then the LM324 is the beast you are looking for.

4. All capacitors should be fairly decent low-leakage types such as Mylar, plastic-film and the like. Voltage is irrelevant. There are only two exceptions to this rule: One is the 0.1 microfarad capacitor at the input of the 78L05 regulator, which doesn't need to be low-leakage but *does* need to be 50 volts or greater. The other exception is the 10 microfarad capacitor at the output of the 78L05, which needs to be an electrolytic or tantalum with a voltage rating between 5 and 20 volts. Remember that 1000 picofarads is the same as 0.001 microfarad or that one microfarad is a million picofarads.

5. The 1N4148 silicon diode in the integrators can be any low-leakage silicon signal diode, but the GV integrator diode and the reference integrator diode should be the same type.

6. Just for grins and giggles, if you get to experimenting with making the machine more temperature-stable than I made it, try fooling around with using a temperature-compensating capacitor for the 470-500 pf capacitor on the reference oscillator.

Happy experimenting. □

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