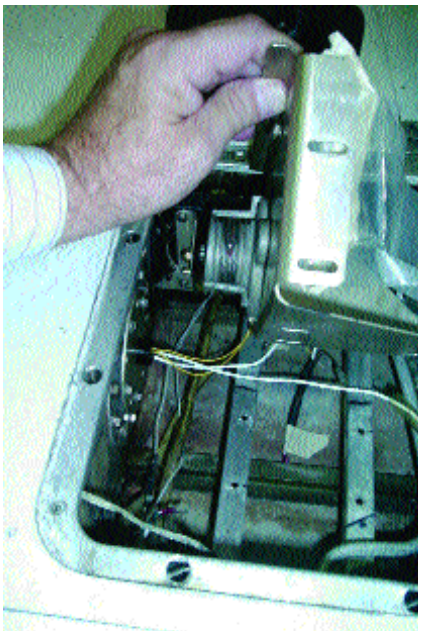
CHASING PICOFARADS

Troubleshooting Capacitive Fuel Indication Systems

BY BRAD PRIMM

Troubleshooting capacitive fuel indication systems is not part of the normal avionics routine and it would be a big stretch of the imagination to think that a Radio Class I, II or III rating somehow covers it. So why am I writing this article? In the world of aircraft maintenance, when the mechanics see wires attached to it, or complicated electronic testing procedures are required, they come to the avionics shop for help. The following troubleshooting scenario is based upon real experiences. The names have been changed to protect the innocent.

The problem. A new customer with a 1973 Cessna 340 came to the shop with a carefully prepared, single-spaced, type written note explaining his fuel quantity problems. The problems included, but were not limited to, intermittent or erratic readings on all tanks, the right aux tank never reads more than two thirds full, and the quantity of the right main tank somehow influences the reading of the right aux tank. The customer had the aircraft to several maintenance shops and one even replaced the entire main wiring harness in the wings in an effort to fix the problems. The customer noted that the right aux tank couldn't be adjusted to read full despite numerous attempts by several shops. Here is where most sane technicians would have bowed out gracefully. Obviously from reading the failure history, there is more than one problem and that makes troubleshooting exponentially more difficult.



Autopilot servo is held out of the way to show fuel probe stand-off and wiring is in its native element.

Cessna 340 fuel quantity indicator

Basic theory. Before going into this troubleshooting scenario any further, let's cover some general fuel indicating theory, specifically for the Cessna 340 system. Cessna twins started utilizing capacitive fuel probe indicating

systems in 1970. These systems are very reliable, very accurate and have no moving parts. As the fuel level decreases in the tank, the probe capacitance changes as air replaces fuel as the dielectric in the probe. This capacitance change is sensed by a signal conditioner, which drives the fuel indicator in the cockpit. The typical probe capacitance on the Cessna 340 will change by a measly 15 to 30 picofarads. Obviously with this small of a change, the wiring must be in top-notch shape.

In the case of the twin-engine Cessna 340, the main fuel tanks are in the wingtips. In addition, if the aircraft has the extended range option, there is an inboard and outboard auxiliary tank in each wing with two probes in the inboard aux tank and one probe in the outboard aux tank. The two auxiliary tanks cannot be selected individually and are read as one tank on the gage in the cockpit. Each tank probe gets a HI-Z, shielded wire and a LO-Z unshielded wire. The auxiliary tank probes are daisy chained together and two sets of HI-Z/LO-Z wires come back to the signal conditioner. One set is for the main tank and one set is for the aux tanks. The two HI-Z center conductors are shorted together at the signal conditioner plug and the signal conditioner selects one of the LO-Z wires to read the fuel quantity in the selected tank. This means that a problem in either HI-Z coax will affect the readings of both the main and aux tanks.

There is a left and right signal conditioner on the 340 and each has an internal relay to switch between measurements of the main or auxiliary tanks. Each signal conditioner can display only the main or aux tank fuel quantity (not both) on a shared meter movement in a dual left/right fuel gage. The selection of which tank is displayed on each side is determined automatically for the pilot when he selects either main or aux tanks with his engine fuel selectors. In addition, there is a momentary override switch under the fuel gage that allows the pilot to view the fuel quantity in the tanks that are not selected by the left or right fuel selectors. Are you confused yet?

Barfield 2548 test unit with adapter harnesses and test lead package.

Except for the switching, the system is rather simple when you analyze it. Capacitive probe(s)- interconnect wiring- signal conditioner- interconnect wiring-meter movement. The signal conditioners for the Cessna 340 are mounted on a round panel under each wing, just outboard of each engine. Depending upon the type of aircraft, the signal conditioner function may be located within the fuel gage itself. The signal conditioners contain the empty/full adjustments to the indicating system.

The fun begins. Back to our troubleshooting scenario. When the mechanics first looked at the aircraft, it was noted that playing around with the fuel quantity circuit breakers would cause the right side indication to intermittently quit and go to zero. Both breakers were replaced. Also, the maintenance procedure for the fuel quantity system calls out for a special test set for troubleshooting and adjustment. Who needs a test set when you have mechanics? Our theoretical shop had a Barfield 2548G/GA test set but, it hadn't been calibrated since 1989 and the basic test lead package was missing. In addition to the test set and basic test lead package, you must also have a special adapter harness for each specific aircraft type (most adapter harnesses cover several models) so that the test set can be inserted in-line between the signal conditioner and the probe system to make measurements and adjustments.

It is possible to empty the tanks and set the empty adjustment without any adapters or harnesses so that is what was done. It seems logical that you could just fill the tanks and set the full adjustments without the test set. That was attempted and it seemed to work except for the right side auxiliary, which didn't come up to full. Also, the right side kept going intermittently to

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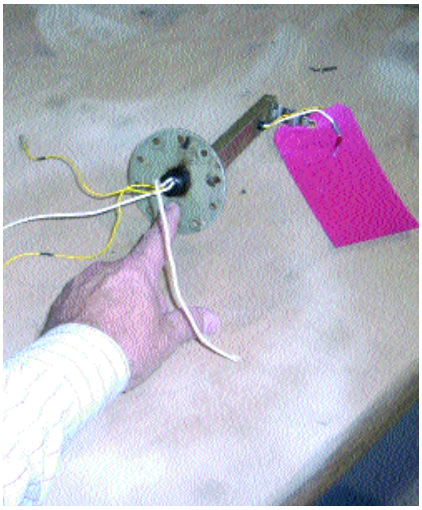
zero again. A note of caution, the empty and full adjustments interact with each other and this is why the aircraft maintenance procedure does not allow for using this method. It would be extremely inefficient to drain and fill the tanks several times to ensure that no more adjustments are necessary. Besides Avgas is highly flammable and the less it is handled the better.

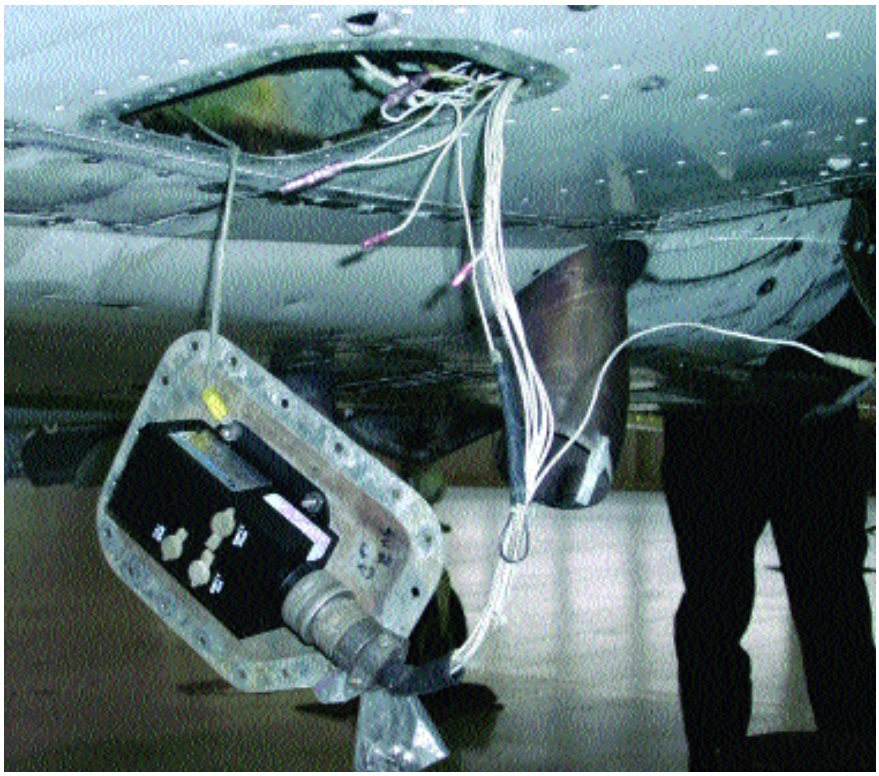
The right inner aux tank fuel probe was ordered and replaced. Both signal conditioners and the dual fuel gage were sent out for repair and reinstalled with fresh 8130-3 tags showing their repaired status. After reinstallation, the right side indication was totally dead. In addition, the mechanics ordered in a rental test set (theirs could not be calibrated in time and Barfield needs several weeks to build up the adapter harnesses after receipt of an order). The rental test set was connected using the adapter harness and the general procedure for the test set was followed but the results showed that both wing harnesses were open circuits. At this point the mechanics gave up and called in the cavalry.

Donning his Fuel Crusader Cape, our theoretical avionics technician bravely approaches the aircraft. Almost instantly he notices the loose BNC bulkhead connector on the rented test set's front panel. This connector is utilized for the insulation resistance checks of the fuel capacitance wiring. A quick call to the vendor and permission is given to break the inspection seals, open the test set, and tighten the connector. He found the center conductor wire had broken away from the BNC terminal and after a quick repair, the test set was back in business (the failure did not affect calibration).

Before proceeding however, our Caped Crusader noticed that the rental box did not come with the supplemental adapter harness instructions. A quick call to the helpful folks at Barfield and he had the supplemental instructions in his email within minutes. Now armed with the aircraft maintenance manual instructions, the Barfield 2458 manual, and the 101-0411 adapter harness supplemental instructions, he proceeded with calibration and testing. The procedures are detailed and must be followed to the "T." Pay particular attention to the installation of shorting caps on the unused HI-Z and LO-Z lines, when to connect or not connect the grounding jack of the test set to airframe ground, and when to connect the adapter harness to the signal conditioner.



Defective potted feed-through on stand-off assembly.



Signal Conditioner, note the adjustments marked on case.

This last caution is very important. DO NOT connect the tester to the signal conditioner when you are troubleshooting. The only time you really need to connect the tester to the signal conditioner is when you are calibrating the system. If you connect the test box to the signal conditioner when doing insulation or capacitance checks, you could damage the internal circuitry of the conditioner plus get erroneous test results.

Why was the right side fuel quantity indication dead? After all, the mechanics had just installed freshly

tagged signal conditioners and fuel gage. Our avionics technician went into the cockpit, played around with the circuit breakers, and the right side would occasionally come alive. The breakers had already been replaced; could the mechanics have put in another bad breaker? Slim chance. What if the power spikes to the signal conditioner from exercising the breakers were "shocking" it into submission? A quick swap of signal conditioners revealed that the freshly repaired, right side conditioner's 8130-3 wasn't worth the paper it was printed on and back to the shop it went.

System insulation measurement. Before doing any adjustments to the system, always verify the insulation integrity of the fuel system HI-Z shielded wire and LO-Z wires first! As stated above, the capacitance changes measured by the system are very small. Because of this, most specifications on the wiring to the probes require a minimum of 1000 megohms resistance between HI-Z to ground, HI-Z shield to ground, HI-Z to HI-Z shield, LO-Z to … etc. The test set employs a special low voltage Megohm meter to measure this. Do not use a 500 volt megger for obvious reasons! During these checks, the adapter harness is not connected to the signal conditioner and the tanks are defueled.

The resistance checks revealed numerous problems on both sides. Troubleshooting the wiring, our persistent avionics technician found the harness section for the inner aux tank, on the right hand side, was reading less than 10 megohms. This was the probe that was just replaced! After the mechanics extracted the probe assembly again for further testing, he found the splice in the potted feed-through was bad and not field repairable. A new harness and standoff assembly was ordered and installed. The probe was reused. Also, on the left side, the main tank pigtail harness was reading less than 900 megohms. Redoing a splice in one of the lines repaired this problem. On both sides, the harnesses were carefully inspected and all of the Cessna quick-disconnects for the probe harnesses were cleaned and retentioned.

Our Caped Crusader also found a broken shield for the main tank HI-Z shielded wire at the R/H signal conditioner plug. In the meantime, the signal conditioner came back from the shop with another proud 8130-3 and an explanation that there were intermittent connections on the internal PC board.

System capacitance measurement. With the resistance checks done, the system was checked for proper capacitance. This procedure allows you to measure the capacitance of the fuel probes and associated wiring to make sure they fall within design limits. A bad probe or open pigtail will be found with this procedure. In a nutshell, the procedure uses the capacitance bridge of the test set to measure the capacitance of each main and aux tank system. The tanks must be drained empty before starting this procedure. In our little scenario, no further problems were noted.

System calibration. This procedure is used to adjust the empty and full settings on the signal conditioners. The signal conditioner is connected to the adapter harness for these adjustments. The procedure is done with empty tanks and this allows the technician to bounce between the empty and full adjustments of the signal conditioner until no further improvements to the calibration can be made. The test set is used to simulate the capacitance of the probe (or probes) with full tanks. The procedure is repeated for each main tank and each set of aux tanks. The adjustments went fine.

More woes. After calibration, the test set and adapter were removed from the aircraft and all panels were reinstalled. The tanks were filled and the system was checked for accuracy. Our avionics technician carefully watched the fuel gages while the mechanics filled the tanks in 10 gallon increments to make sure that the accuracy and linearity of the gage readings were acceptable. After a satisfactory check for fuel leaks and system operation, the aircraft was almost returned to service when the right side fuel quantity indication went dead again. Having been there before, our technician quickly swapped signal conditioners and the problem traveled. Son of a…pup! Back to the repair shop went Mr. Signal Conditioner.

Third time's a charm. The tanks were re-drained on the right side, the re-re-repaired signal conditioner was re-installed, the test set was re-rented, the system was re-adjusted and the aircraft was re-run. Oh yeah, and the customer was re-billed. All is well that ends well.

Below is a summary list of typical causes for certain fuel gage indication problems. It is assumed that you have already swapped signal conditioners to eliminate them as the cause of the problem. Remember to always swap the signal conditioner back to its original position unless you are prepared to recalibrate to the new side.

Pegged (high) readings. The signal conditioner and wiring harness to the probes are very susceptible to moisture. If any water gets into the connector at the signal conditioner, the fuel gage will read high or even be pegged off scale. Dry out the signal conditioner connector and see if the problem

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goes away. If so, seal the connector from water contamination. Another cause of this type of indication problem is a short between the LO-Z1 (main tank) and LO-Z2 (aux tank) wires.

Pegged (low) readings. A short between HI-Z and LO-Z will cause a reading pegged to the lower meter stop (below zero) of the gage.

Constant (never changing) reading in lowerhalf of gage. A constant indication around the lower half of the gage can be caused by a grounded, HI-Z wire.

Full indication until almost empty. If a tank reads full continuously until it is almost empty, suspect a fuel probe that has come free from its mounting bracket and is laying horizontal on the bottom of the tank.

Constant empty indication. A short between the LO-Z wire and ground or the LO-Z wire and HI-Z shield can cause this type of problem.

Fluctuating needle. Poor shielding, loose terminals, corroded connectors or intermittent shorts can cause erratic needle movement. Exposing the wire runs and flexing the wires can help to isolate the problem.

Lucrative specialty. Because avionics technicians are skilled in wiring repair, understand electrical concepts, and utilize complicated test sets on a daily basis, they are the logical choice to troubleshoot these types of systems. Obviously, if you are an independent avionics shop, it will be necessary to get a limited rating to work on fuel indication systems. Specialty work such as this can be lucrative for the shop that develops a reputation for getting the problems fixed. Barfield's website at www.barfieldinc.com provides detailed lists of test sets, instruction manuals and adapter harnesses available for use on these systems.

May you quickly catch and subdue all the picofarads that you chase. q

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