

Once in a while we may encounter a total failure of a MAF sensor, one that is, perhaps, short circuited or internally open. Much more common, however, are failure modes in which the MAF sensor has become unreliable, underreporting or overreporting the true airflow into the engine. Indeed, as we shall see, many MAF sensor failures actually result in both underreporting *and* overreporting!

Before we get down to brass tacks, a brief review of the basics of MAF systems is in order. Fuel control systems for most modern gasoline engines are centered either on MAF or MAP (manifold absolute pressure). MAF systems, which, as their name suggests, measure the weight of incoming air and then meter the appropriate amount of fuel to ensure efficient combustion, are potentially more precise, although MAP systems, which calculate fuel requirements based on engine load, have historically demonstrated greater reliability.

As you already know, combustion is most efficient when the ratio of air to fuel is approximately 14.7:1 *by weight*. Mass and weight are essentially synonymous in the presence of a sufficiently strong gravitational field such as the Earth's. Thus, knowing the weight of the air entering the engine allows the engine controller to meter the exact amount of fuel required to achieve efficient combustion. The controller commands the fuel injectors to open for an amount of time calculated to be sufficient to allow the correct weight of fuel to enter the engine, providing that the fuel's pressure is known. Fuel delivery is fine-tuned by applying fuel trim corrections derived from the closed-loop feedback of the oxygen sensor(s).

If the entire system is working as designed, fuel trim corrections, expressed as a percentage deviation from the base fuel delivery programming, will be within 10% (either positive or negative) of the programmed quantity. In the absence of a MAF-specific diagnostic trouble code (DTC), what would first lead us to even suspect that a faulty MAF sensor might underlie a particular driveability problem?

To function correctly, *all* of the air

# SUCCESSFUL MAF SENSOR DIAGNOSIS

BY SAM BELL

A broad range of seemingly unrelated or contradictory driveability complaints may arise from MAF sensor performance faults. Use this guide to navigate out of a diagnostic thicket or, better still, to avoid one entirely.

Photoillustration by Harold Perry; photos courtesy Wells Manufacturing Corp.

entering an engine's combustion chambers must be "seen" by the MAF sensor. This means that any vacuum or air leak downstream of the sensor will result in insufficient fuel metering, causing a lean condition in open-loop operation and higher-than-normal fuel trim values in closed-loop. When we encounter a MAF sensor-equipped vehicle exhibiting these symptoms, we need

to check for unmetered airflow first. Remember, too, that unmetered airflow may not require an external air leak. An incorrectly applied or faulty PCV valve can result in incorrect MAF data where the PCV intake through the breather hose is *upstream* of the MAF.

So, the first two rules of MAF sensor diagnosis are:

1. Find and eliminate all external air



or vacuum leaks downstream of the MAF sensor. When in doubt, use a smoke machine, or *lightly* pressurize the intake manifold and spray with a soap & water solution.

2. Verify that the manufacturer-specified PCV valve is correctly installed and functioning as designed. (This is one instance where precautionary replacement may be cost-justified.)

Only after these two steps have been completed can you safely proceed with other diagnostics. The foremost clue that the fault lies with the MAF sensor itself will be excessive fuel trim corrections, usually negative at idle, more or less normal in midrange operation and positive under high load conditions (see “How Contamination Affects Hot-Wire & Hot-Film MAF Sensors” on page 32).

While there are several distinct MAF sensor technologies ranging from hot-wire or hot-film to Karman vortex and Corialis sensors, and while MAF sensor outputs may take the form of variable frequency, variable current or a simple analog voltage, the diagnostic principles remain largely the same.

Let's start with Ford vehicles, for a couple of reasons. First, they are so widespread that most of us are familiar with them. Second, most MAF sensor-equipped Ford products make use of a PID (Parameter IDentification) called BARO (barometric pressure). Up to 2001 models, this was an inferred, or calculated, value generated by the PCM (powertrain control module) in response to the maximum MAF flow rates observed on hard wide-open throttle (WOT) acceleration. Where this calculated BARO PID is available, it is of great diagnostic value, since it can confirm MAF sensor accuracy, if only under high flow rate conditions.

To use the BARO PID, you must first know your approximate local barometric pressure. You might consult the BARO PID on a known-good MAP sensor-equipped vehicle. Alternatively, your local airport can provide this data. Do not rely on local weather stations, however, since these usually report a “corrected” barometric pressure. If weather information is the only available source, a rule of thumb is to subtract about 1 in. of mercury (1 in./Hg) for every 1000 ft. of elevation above sea level. This will yield a rough estimate of your actual local barometric pressure. For greater accuracy, you can purchase a functional barometer for something less than \$40. Compare this data with the BARO PID. A large discrepancy here—say, more than 2 in./Hg—should direct your suspicions toward the MAF.

Confirm your hypothesis as follows: First, make sure you have followed the steps outlined in the two rules above. Next, record all freeze frame data and all DTCs, including pending DTCs. If the OBD monitor readiness status for oxygen sensors shows READY, proceed to the next step. If it doesn't, refer to the procedures in the following paragraph now. Next, perform a KAM (Keep Alive Memory) reset and drive the vehicle. Make sure your test drive

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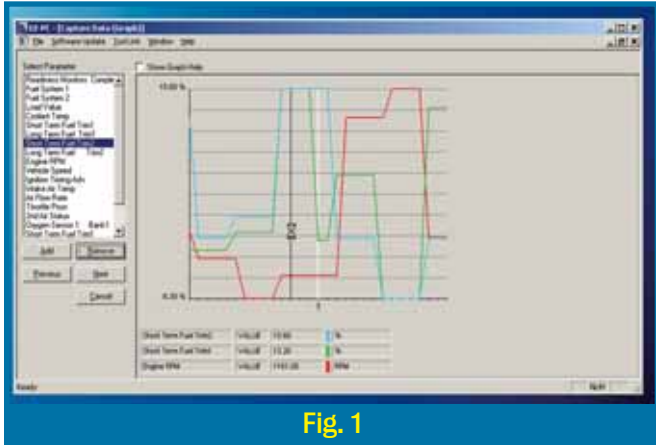


Fig. 1

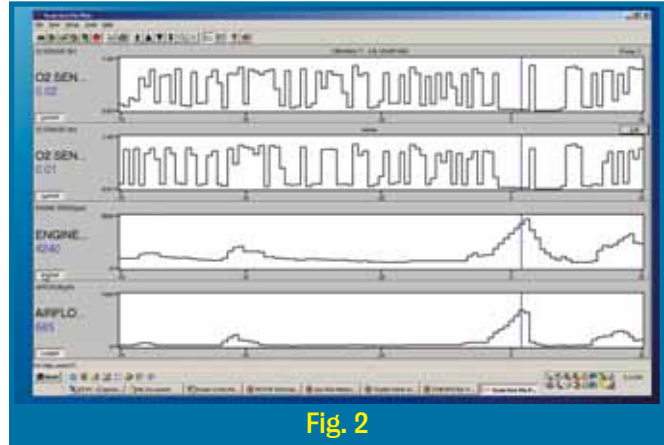


Fig. 2

Screen captures: Sam Bell

includes at least three sustained WOT accelerations. (It's not necessary to speed to accomplish a sustained WOT acceleration. Rather than a WOT snap from idle, an uphill downshift at 20 to 30 mph is usually sufficient. The WOT prescription can be met at throttle openings as low as 50% to 70%.) The BARO PID should update from its default reading by the end of the third WOT acceleration. If it's now close to your local barometric pressure, the MAF sensor is not likely to be faulty. If BARO is not close, try one of the cleaning techniques explained in the sidebar "Keeping It Clean" on page 34, then again reset KAM and take a test drive. If the BARO is still out of range, a replacement MAF sensor is in your customer's future. Unfortunately, in many 2002 and later Fords, the calculated BARO PID is supplanted by a direct BARO reading

taken from a sensor incorporated into the ESM (EGR System Management) valve, greatly lessening its diagnostic value for our current purposes.

If the oxygen sensor monitor status showed INCOMPLETE above, you'll have to verify O<sub>2</sub> sensor accuracy and performance before performing the KAM reset procedure. Use a 4- or 5-gas analyzer to determine whether the air/fuel ratio is correct in closed-loop operation. The notes about lambda ( $\lambda$ ) below should help.

Outside of the Ford family, MAF sensor diagnosis is more difficult. Large fuel trim corrections—either positive or negative—are often the only initial pointer to MAF sensor problems. Again, any and all air leaks downstream of the MAF sensor must be repaired first. Since accurate fuel trim corrections depend on correct O<sub>2</sub> sensor out-

puts, you must verify the functionality of these sensors first. The easiest and fastest way to do this is by checking lambda, a type of measure of the air/fuel ratio. (For a detailed explanation, see my article in the September 2005 issue of MOTOR.) If the O<sub>2</sub> sensors are functioning correctly, lambda at idle should be very nearly equal to 1.00 in closed-loop. You may wish to check this also at 1500 to 1800 rpm to verify adequate mixture control off idle. Once lambda is found to be correct, the O<sub>2</sub> sensors are proven good. Then any fuel trim adjustments must result from unmetered or incorrectly metered airflow or from incorrect fuel delivery.

Distinguishing between fuel delivery problems and MAF sensor problems can be very frustrating. Start by verifying fuel pressure *and* volume. (Those who rely on pressure alone may regret

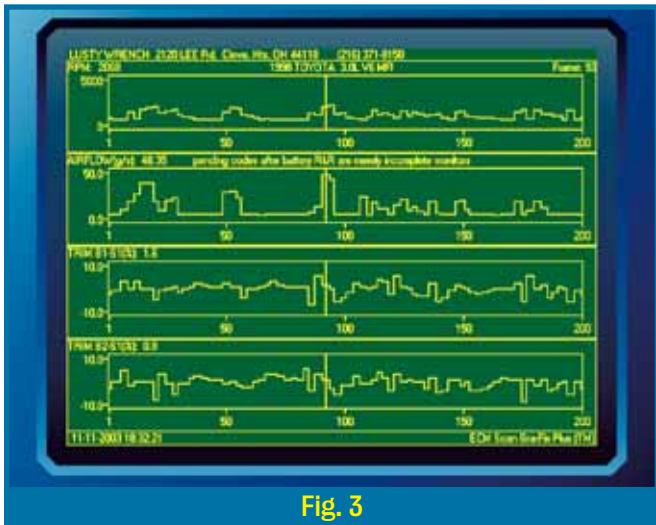
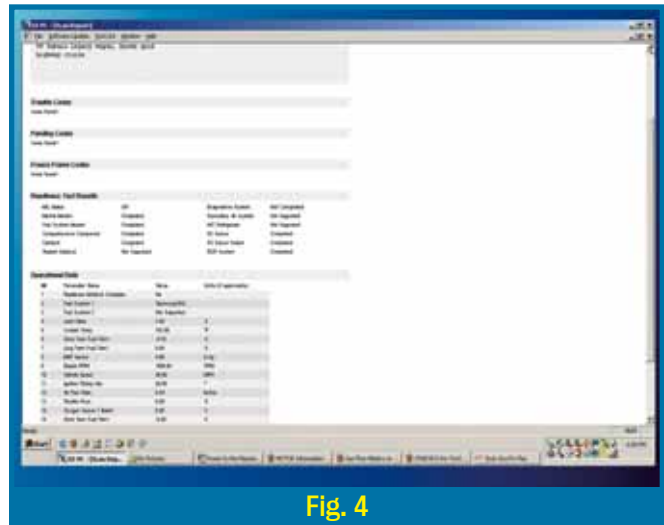


Fig. 3



# SUCCESSFUL MAF SENSOR DIAGNOSIS

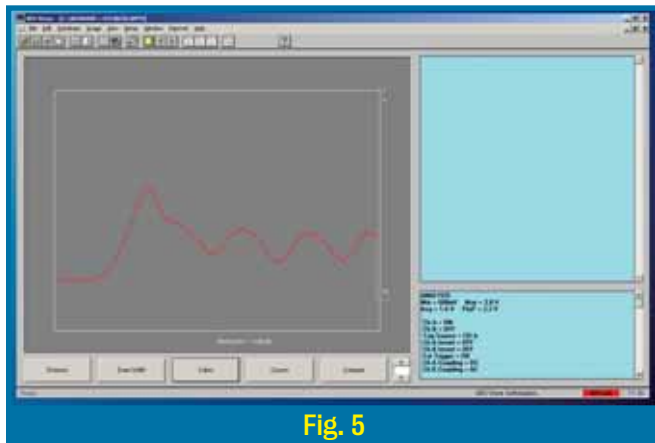


Fig. 5

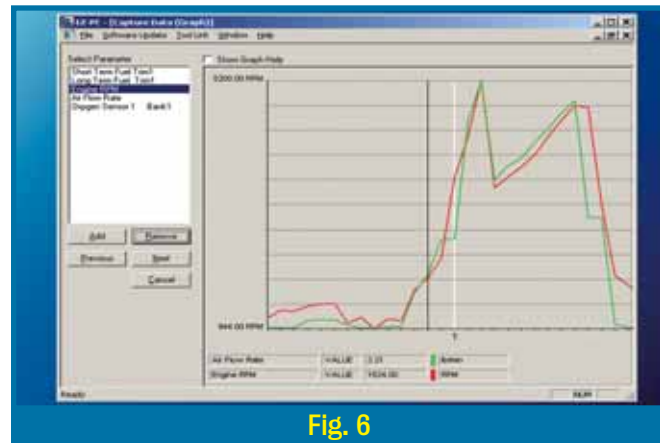


Fig. 6

it.) Use your scan tool to record critical data PIDs and graph them for analysis. Here are a couple of examples:

In Fig. 1 on page 30, taken during a period of closed-loop operation, short-term fuel trims (blue and green traces) for each bank were above 13% at 1100 rpm (red trace), yet dropped sharply negative at 3600 rpm, proving that inadequate fuel delivery was *not* the problem. The values indicated in the legend boxes correspond to the readings obtained

at the indicated cursor position (vertical black line). The vertical white line indicates the trigger point for the recording. Subsequent diagnostics focused on the MAF sensor and the PCV system.

Take a look at the scan data graph shown in Fig. 2. It shows a car whose faulty fuel pump was unable to deliver sufficient fuel under high load conditions. Notice the very low O<sub>2</sub> sensor readings (displayed in blue) corresponding to the cursor (black vertical

line just to the right of the zero time stamp). Fuel pressure was within spec at idle and at about 2000 rpm, but volume was very low. The sudden drop-off in O<sub>2</sub> activity in response to hard acceleration is a characteristic observed in many instances of MAF sensor faults as well.

Ultimately, known-good snapshots, waveforms and other data sets are invaluable. Take a look at the scan snapshot in Fig 3. Does it show good fuel trim and appropriate MAF sensor readings?

Since total fuel trim stays well within the 0 ±10% range throughout the trace, it's a good bet that the MAF sensor is working well, at least under the sampled conditions.

How about the data set shown in Fig. 4? In fact, the snapshot was taken during open-loop, closed-throttle deceleration when fuel was not being injected, so the O<sub>2</sub> sensor PID makes sense. It's actually a substituted default value inserted whenever the vehicle is in closed-throttle decel mode. What about the reported MAP value? A reading of 4.00 in./Hg shows very high engine vacuum, which jibes with the reported TPS PID. The fuel trim data is within the usually accepted range of 0 ±10%. Good data can come in a variety of formats.

Of course, waveform captures from your scope are often all that are needed to confirm a faulty MAF sensor. In our shop, we've found that a snap-throttle MAF test for Ford products should always produce a peak voltage of at least 3.8 volts DC. The snap-throttle test is

## How Contamination Affects Hot-Wire & Hot-Film MAF Sensors

Hot-wire and hot-film MAF sensors calculate airflow based on monitoring the current required to maintain a constant temperature in the sensing element. When dirt accumulates, the additional surface area allows greater heat dissipation at low airflow rates. The dirt, however, also functions as an insulator, with an overall net resistance to heat transfer at very high airflow rates.

At idle and under relatively low flow/load rate conditions where the majority of operation may take place, the surface area effect usually predominates, causing a rich condition with fuel trim corrections usually in the range of -10% to -5%. At sustained high flow/load rates, the insulative effect usually takes over, causing a lean mixture needing fuel trim corrections as high as +30%.

Worse still is a complex case of

“mass confusion” that may arise under hard acceleration when long-term *negative* fuel trim corrections, learned in closed-loop under low-flow-rate conditions, are applied precisely when *positive* fuel trim corrections would be more appropriate. So, for example, when the system goes to open-loop during hard acceleration where the MAF is already *underreporting* airflow by up to 30%, the PCM may subtract an *additional* 10% to 15% (LTFT) from the normal fuel delivery calculation, leaving the system as much as 45% leaner than desired!

In midrange operation, the two effects (surface area and insulative properties) may roughly cancel each out, with fuel trims being more or less normal. Additionally, the exact chemistry and configuration of dirt buildups can vary, changing the balance of power between the surface area and insulative effects.

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performed the same way as for ignition analysis. The idea is not to race the engine, but simply to open the throttle abruptly to allow a momentary surge of maximum airflow as the intake manifold gets suddenly filled with air. It's critical that the throttle be opened (and closed) as quickly as possible during this test.

The waveform in Fig. 5 on page 32 is from a known-good MAF sensor. Note the peak voltage of 3.8 volts. The rapid rise and fall after the throttle was first opened is normal and reflects the initial gulp of air hitting the intake manifold walls and suddenly reaching maximum density, greatly reducing subsequent flow. The exact shape of the waveform may vary from model to model, based on intake manifold and air duct (snorkel) design.

What's the relationship between MAF and engine speed? As Fig. 6 shows, rpm and airflow rate track one another closely under the moderate acceleration conditions during which this screen capture was taken. The similarity of the shapes of the two traces shown

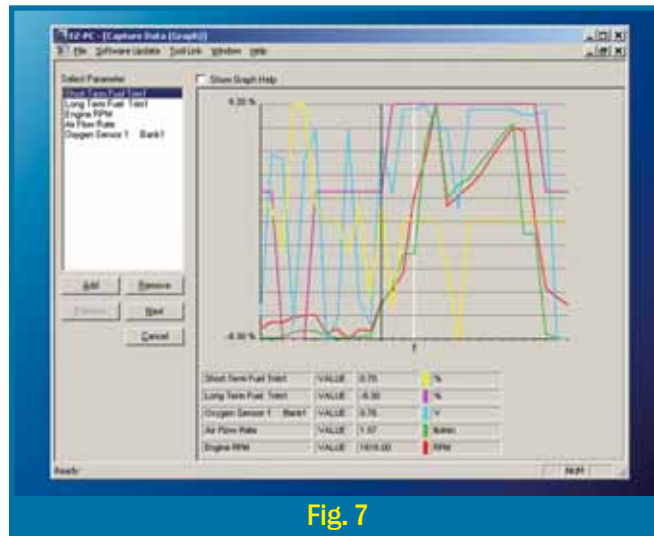


Fig. 7

here *suggests*, but does not *prove*, that the MAF sensor is functioning well under these conditions. If the airflow report was consistently increased or decreased by the same factor, say 10% or even 50%, the shape of its graph would remain the same.

Consider the additional plots presented in Fig. 7 above. Does the extra data shed any light on the MAF sensor's accuracy? Or is this just an example of too much information?

Since short-term and long-term fuel

trims remain within single digits throughout, we can be reasonably sure that the MAF sensor is functioning correctly. Do we really benefit from looking at the O<sub>2</sub> sensor data here? We could probably do almost as well without it, since we have both STFT and LTFT, but the O<sub>2</sub> trace (blue) serves as an additional cross-check on the validity of the fuel trim calculations. More importantly, the O<sub>2</sub> sensor trace proves both that an appropriately rich mixture was obtained on hard acceleration and that applied fuel trim corrections were effective

throughout the captured data set.

I said at the outset that hard failures were relatively rare, but they do occur from time to time, and I owe it to you to discuss this type of failure as well as intermittent failures. Open-circuited or short-circuited MAF sensors usually set a trouble code, most frequently P0102 or P0103 (low input and high input, respectively). P0100 is a nonspecific MAF sensor circuit fault, while P0104 indicates an intermittent circuit failure. Checking scan data is a vital first step toward successful diagnosis of any of these codes. On pre-OBd II vehicles especially, unplugging a faulty MAF sensor will often restore a minimum degree of driveability as the PCM reverts to TPS, rpm and/or MAP as fuel determinants. Certain mid-'80s GM vehicles were notorious for intermittent MAF sensor failures. These usually could be easily recreated by lightly tapping with a small screwdriver on the MAF sensor housing at idle. A noticeable stumble occurring with each tap clinches the condemnation (Fig. 8, page 36).

Of course, backprobing the MAF sensor connector for voltage drops at both the power and ground terminals KOER is a required step before any final condemnation. The coincidence of VBATT and MAF both showing 0.0 volts cannot be ignored. Neither should the mouse nest in the MAF, nor the gnawed wires throughout the engine compartment.

Why is this a hard diagnosis? Conta-

### Keeping It Clean

**M**ost MAF sensor failures result from contamination. Sometimes the dirt is visible, but more often it's not. Technicians have tried a variety of cleaners, with mixed success. Many use an aerosol brake/electrical parts cleaner, waiting until the MAF sensor is cold. A Ford trainer in my area swears by the most popular consumer glass cleaner. Several top technicians report good results from steam cleaning, while others prefer a spray induction cleaner.

The vast majority of technicians warn that the MAF sensor may be damaged by any type of cleaning where the electrical connector is not held upright. This is particularly true where strong chemicals are used, as they may pool and work their way

into the delicate electronic circuitry.

To avoid future contamination, be wary of oiled air filters or any that appear likely to shed lint. Poor sealing of air filter housings may contribute to contamination. Never spray an ill-fitting air filter with a silicone lubricant or sealer; such sprays are likely to render the MAF sensor inaccurate. If an engine produces excessive blowby gases, these may contaminate the MAF sensor, as well. Be sure any specified filter breather element is installed. If none is specified, but oil accumulates in the air intake housing, the MAF sensor or associated intake ducts, be sure to investigate and remedy the cause to prevent repeat failures. Be sure to check manufacturers' TSBs, the iATN archives and other sources as well.

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minated MAF sensors often *overreport* airflow at idle (resulting in a rich condition and negative fuel trim corrections) while *underreporting* airflow under load (resulting in a lean condition and positive fuel trim corrections).

This double whammy makes diagnosis more difficult for a number of reasons: First, many technicians incorrectly eliminate the MAF sensor as a potential culprit because they expect it to show the same bias (either over- or underreporting) throughout its operating range. Second, a lack of a direct MAF fault DTC (such as P0100) is often mistaken to mean that the MAF sensor *must* be good. Third, the symptoms mimic (among other possibilities) those of a vehicle suffering from low fuel pump output coupled with slightly leaking injectors or an overly active canister purge system. Even sluggish, contaminated or

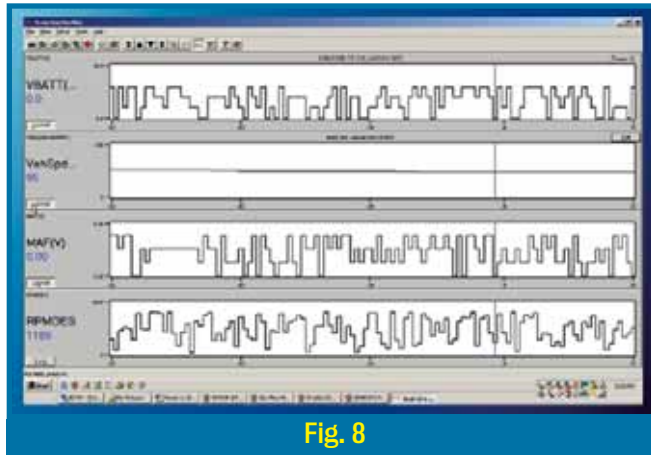


Fig. 8

biased oxygen sensors may cause similar symptoms. Without appropriate testing, it's hard to distinguish—just by driving—among certain ignition or knock sensor faults and MAF sensor malfunctions. Additionally, since MAF sensors are somewhat pricey, many technicians are afraid to condemn them, fearing either the customer's or the boss' wrath if their diagnosis is not borne out. Perhaps

the biggest obstacle is lack of a comprehensive database of known-good waveforms, voltages and scan data against which to compare the suspect.

My own data set features known-good scan data and scope captures made KOEO, at idle and on snap-throttle. In general, these three data points should be sufficient to identify a faulty MAF sensor even before it sets a fuel trim code.

A bad Bosch hot-wire MAF sensor may be the result of a failed burn-off circuit. Don't

simply replace the sensor; make sure the burn-off is functional. (The purpose of the burn-off is to clean the hot-wire of contaminants after each trip.) Burn-off is usually a key OFF function after engine operation exceeding 2000 rpm. Burn-off circuit faults may be in the PCM or a relay. The hot-wire should glow visibly red during burn-off.

So what can we conclude from all this? A broad and seemingly unrelated or even contradictory range of fuel system-related driveability complaints may arise from MAF sensor performance faults. Fuel trim data showing excessive corrections from base programming casts strong suspicion on MAF sensor performance issues. After recording all DTCs and freeze frame data, many experienced techs recommend unplugging a suspect MAF sensor to see if basic driveability is improved. Scope traces at idle and on snap-throttle acceleration help verify MAF sensor guilt or innocence.

As usual, a library of known-good scan data and waveforms is invaluable. The Min/Max voltage feature on your DMM may not be fast enough to catch actual peak voltage on a snap-throttle test, but is usually sufficient for verifying performance of frequency-generating (digital) MAF sensors. If your scope is capable of pulse-width triggering, using that function will provide exact captures of digital MAF sensors in snap-throttle testing.

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