GDi Fueling System

A Logical Approach To Driveability Concerns

Objectives

- Discuss the functionality of the direct fuel injection system components
- Discuss how the components work as a system
- Describe the feedback loop we refer to as fuel trim
- Demonstrate how to leverage data PIDs from the scan tool
- Demonstrate the driveability road test
- Interactive case studies

Let's Keep It "Simple"

- Comprehendible
- Meant to be applicable
- Aids in analysis
- Increases efficiency and Accuracy

The Load

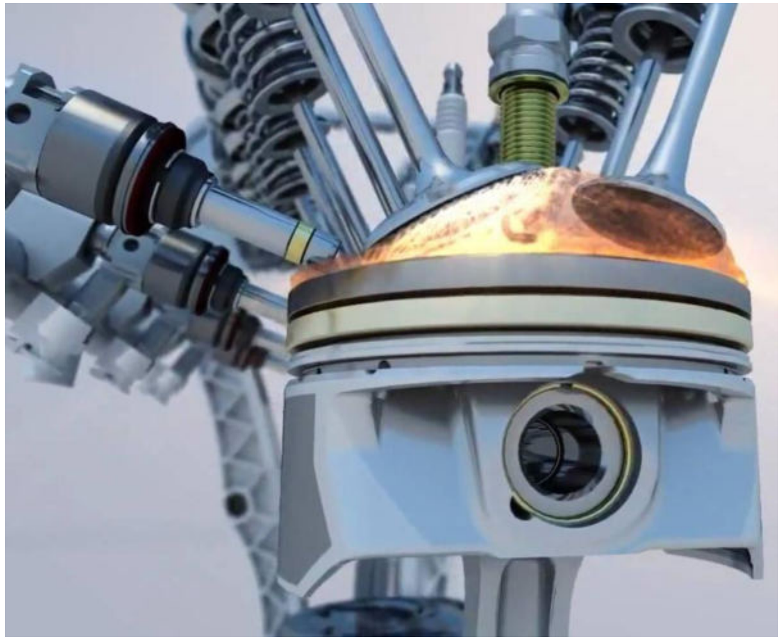
Calculated Load

- *CALC_LOAD or Engine Load*
- *Compared to breathing capability at WOT*
- *Reads 100% @ WOT*
- *Disregards atmospheric pressure*

Absolute Load

- *ABS_LOAD*
- *Compared to swept-volume*
- *Can read well over 100%*
- *Better reflects volumetric efficiency*

Introduction to Gasoline Direct Injection (2004)



Precision Delivery

- Match actual to desired fuel rail pressure (FRP)
- Better MPGs
- Lower poisonous tailpipe emissions
- Reduction of Green House Gases (CO2)

More Stringent Tailpipe Emissions Standards

- Nox management: Lambda <1.00
- CO management: Lambda >1.00
- CO2 management: Increased output/decreased combustion chamber

Fuel System Goals

Port Injection

- "Stoichiometry" (14.7:1)
- Narrow band of operation
- CAT can function
- Harmful tailpipe emissions minimized
- High CO2 output

Direct Injection

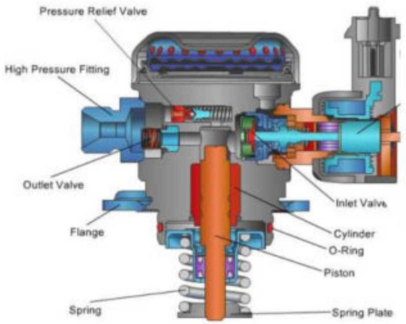
- Focus on CAT functionality
- Wide band of operation
- WRAF and better strategies allow for it
- New inputs
- Rear fuel trim
- Can CAT function?

GDI Benefits

- Rail pressure reaching about 3000 psi (>200 bar)
- Directly in-cylinder
  - *Vaporized/atomized format*
  - *Injector/spark timing optimized*
  - *Injection events per cycle*
  - *Catalyst supportive strategies*
  - *Higher compression? NOx control*
  - *Lean strategies/better control (WRAF)*
  - *Increased cold-start volatility*
  - *Atkinson cycling*

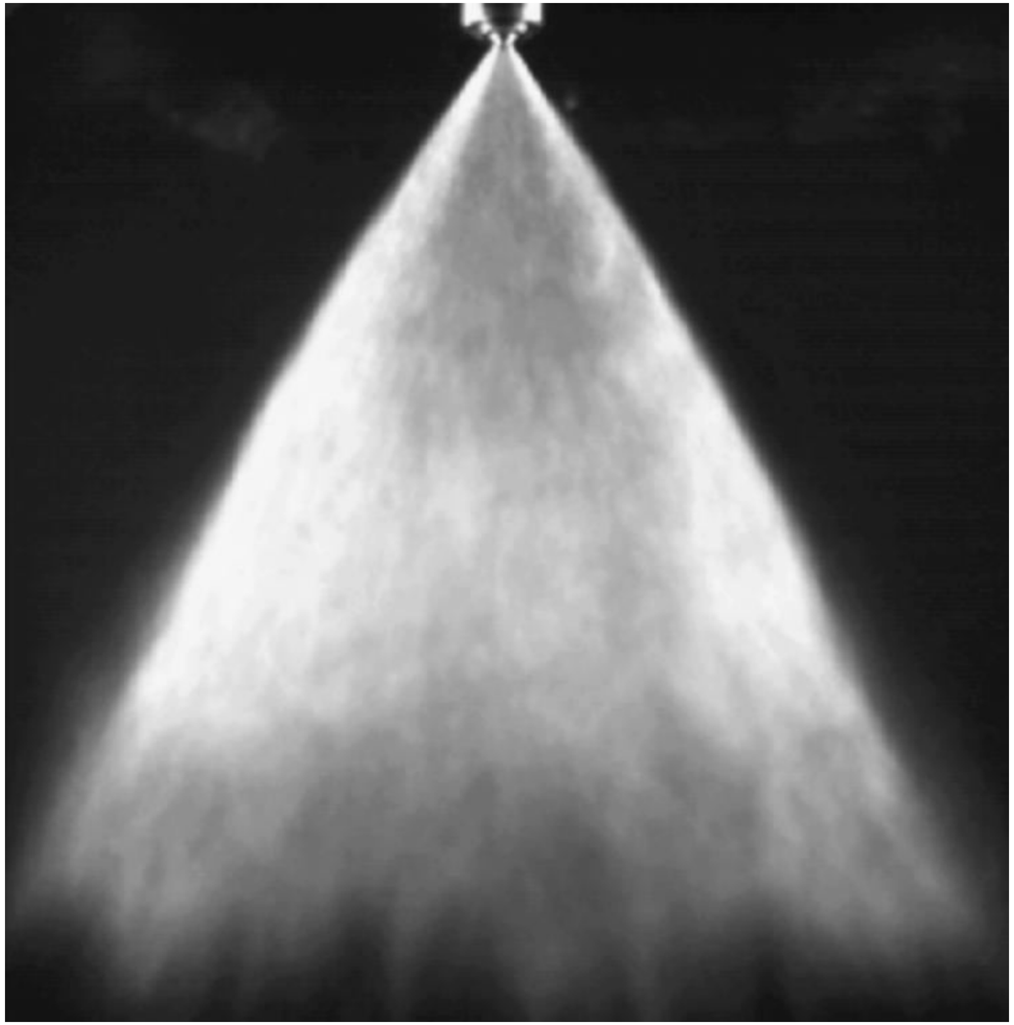
GDI Disadvantages

- More complex fuel system
- Engine wear/HPFP drive
- New/unfamiliar strategies
- More data to analyze/digest
- Soot/carbon/Spray patterns
- NOx/Sulphur issues
- Maintenance more critical
- Engine pushed to limitations



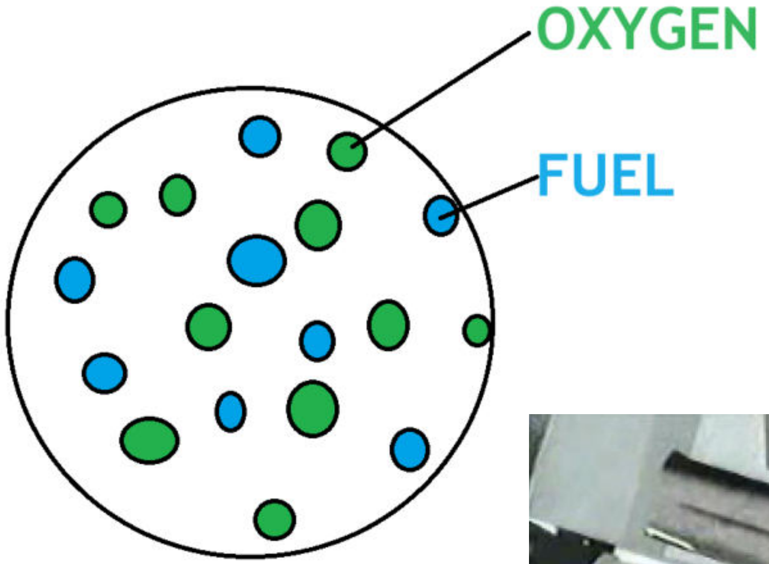
GDI Modes of Operation…

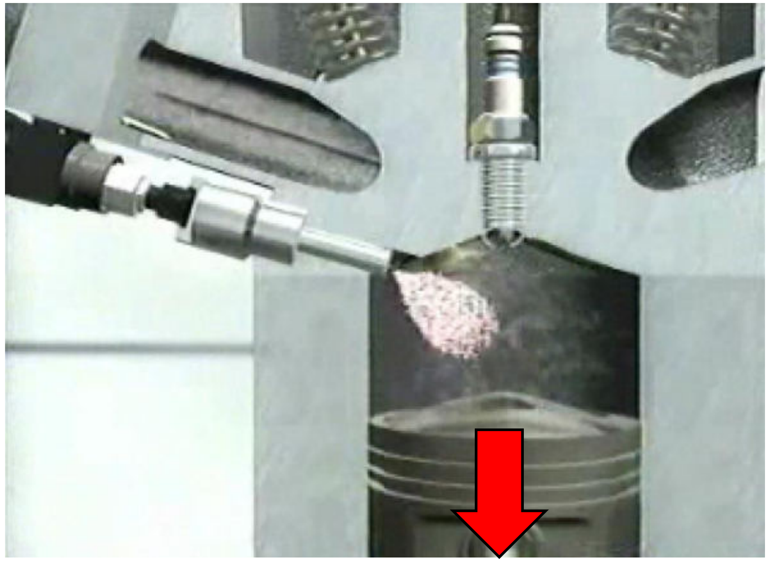
- Homogeneous
- Stratified
- Homogeneous-stratified
- Homogeneous-lean
- Homogenous knock-protection
- Stratified catalyst-heating



Homogenous Mode

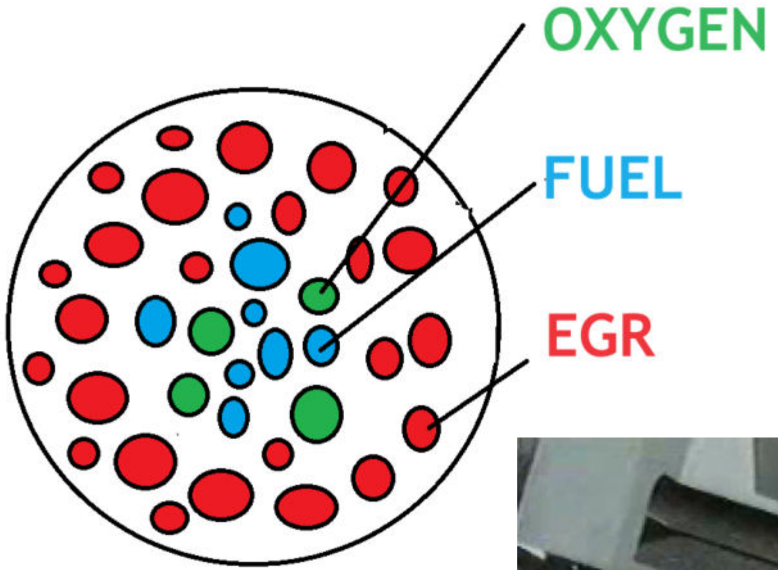
- A uniform composition of particles
- Similar to port injection
- Direct-injected with air charge
  - *Start-up*
  - *High load*
  - *Time is limited*
- Lambda approximately = 1.00

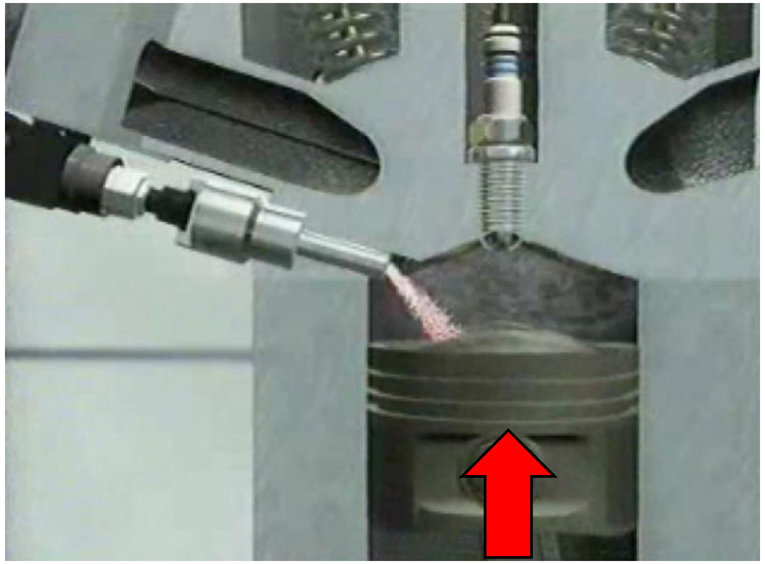




Stratified Mode

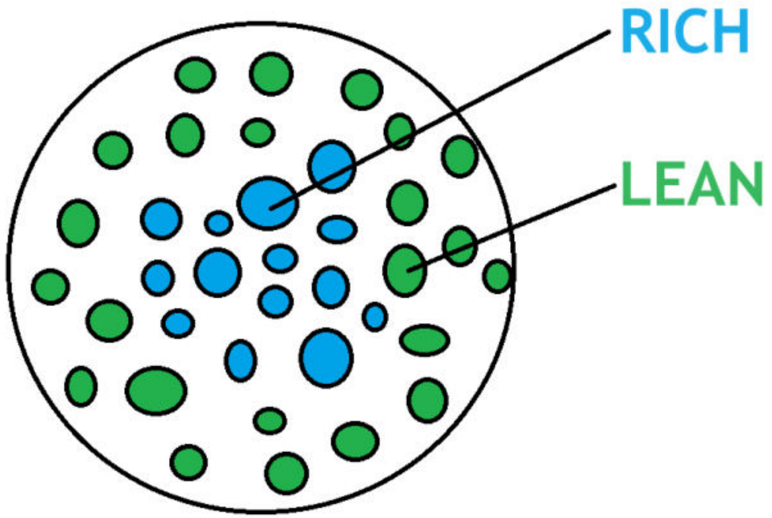
- A/F charge, curtain of EGR
- Specially-designed pistons
- Direct-injected before spark occurs/centered
- Decreased thermal losses thru cylinder walls
    - *Light loads*
    - *Increased fuel economy*
- Lambda = >1.00
    - *Open throttle/reduced suction losses*
    - *EGR effect = carbon/soot*
    - *High sulfur production/ 90-seconds storage*





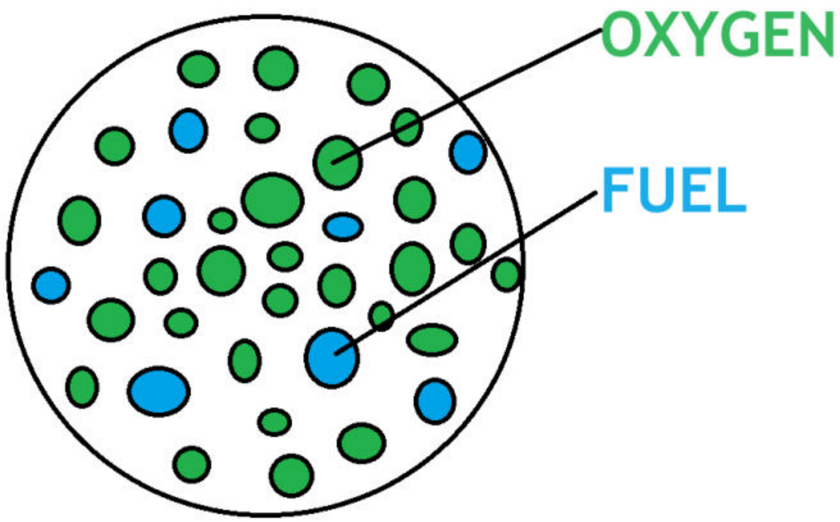
Homogenous-Stratified Mode

- Transition between modes
- Moderate to higher loads
- Maintains good driveability (happy driver)
- Rich A/F surrounded by lean A/F
- Two injection pulses
    - *During intake (homogenous)*
    - *Prior to initiating compression*



Homogenous-Lean

- Smooths mode transitions
- Direct-injection during intake stroke
- Improved fuel economy (leaner/longer)
  - *Higher engine speeds*
  - *When stratified mode can't be used*
- High-throttle/reduced suction losses
- Lambda = >1.00



Homogenous Knock-Protection

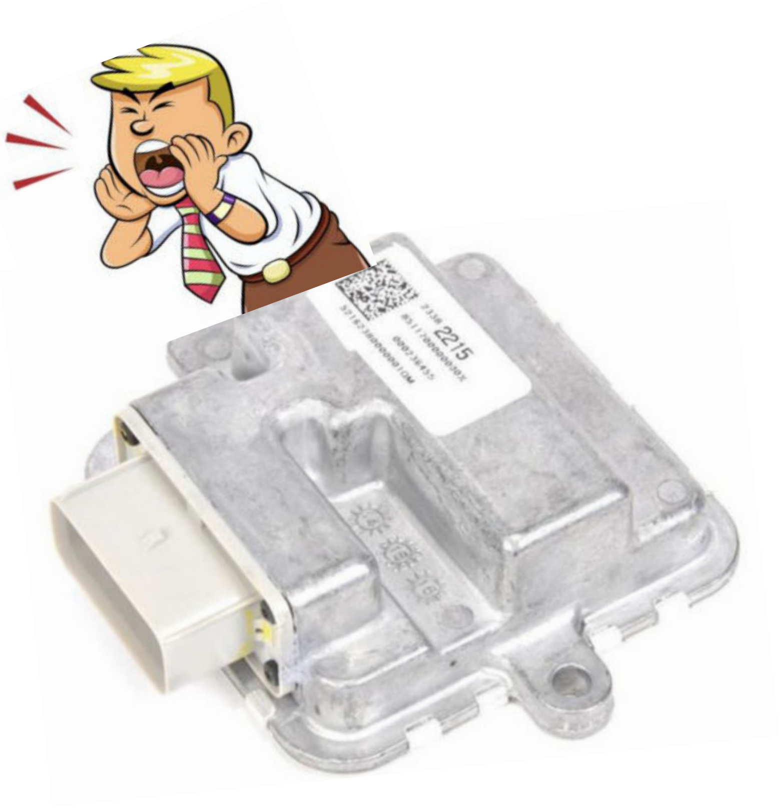
- Reduces "ping"
- Two injection pulses
  - *During intake stroke*
  - *During compression stroke (Quenching)*
- Second pulse reduces cylinder temperatures
- Lambda = variable with second pulse

Stratified Catalyst-Heating

- Heats/cleans NOx converter
- Two fuel injection pulses
  - *First prior to ignition (Stratified)*
  - *Second after TDC-C*
- 650 degC for desulfurization
- Combustion continuing in exhaust system
  - *Delayed injection*
  - *Delayed ignition*

Low Pressure Fuel Supply...

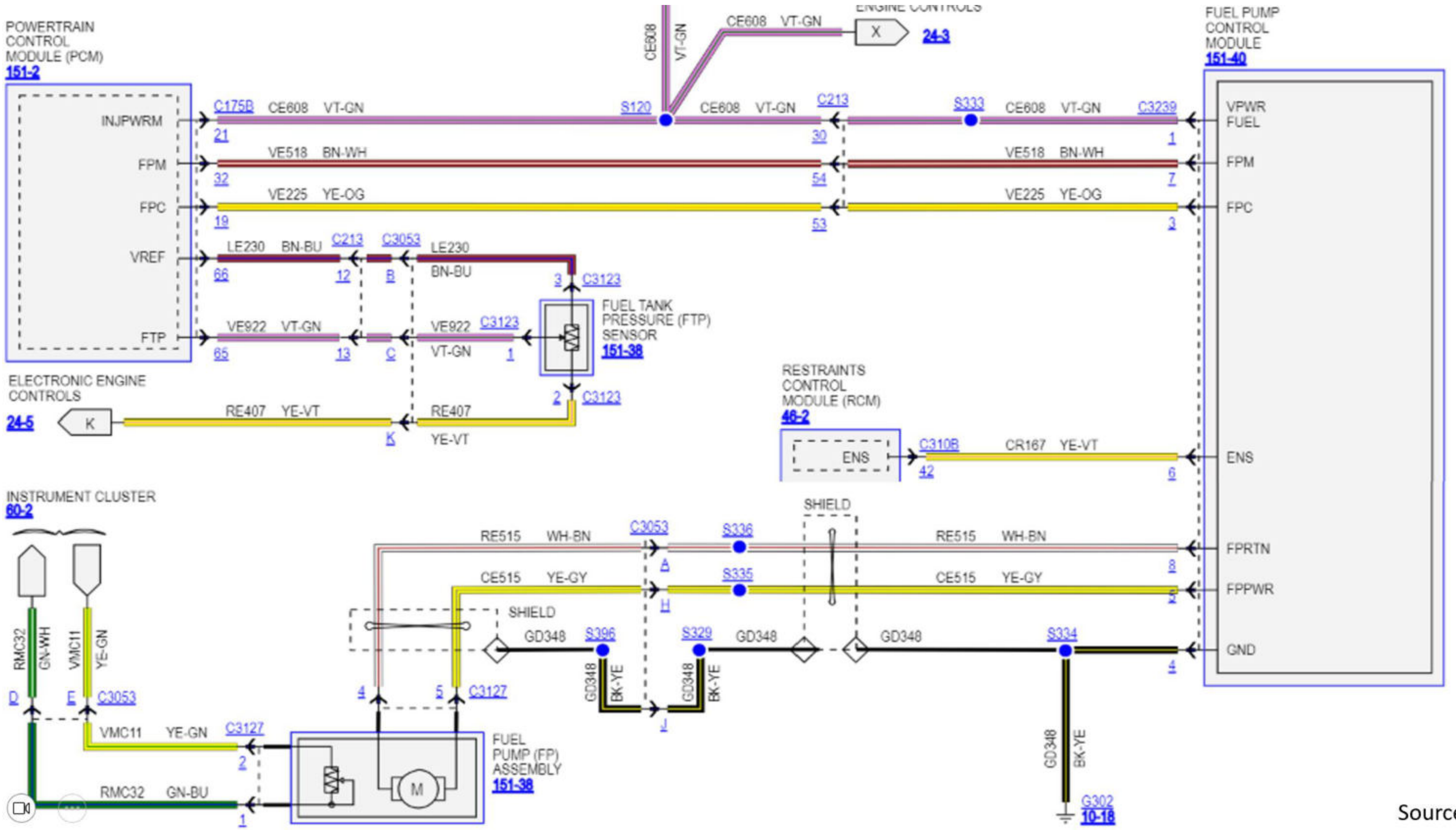
Low Pressure Pump Operation…



Low Pressure Pump Operation…

Low Pressure Pump Operation

Example of Common Configuration



Source: Motologic

Can’t Have “High” Without “Low”

- Takes low-pressure to make high-pressure
- Returnless system
- Brushed/brushless
- May offer pressure sensor input
- Supply is variable to match load
    - *Duty-cycled*
    - *Hi/Low speeds*
    - *Variable*

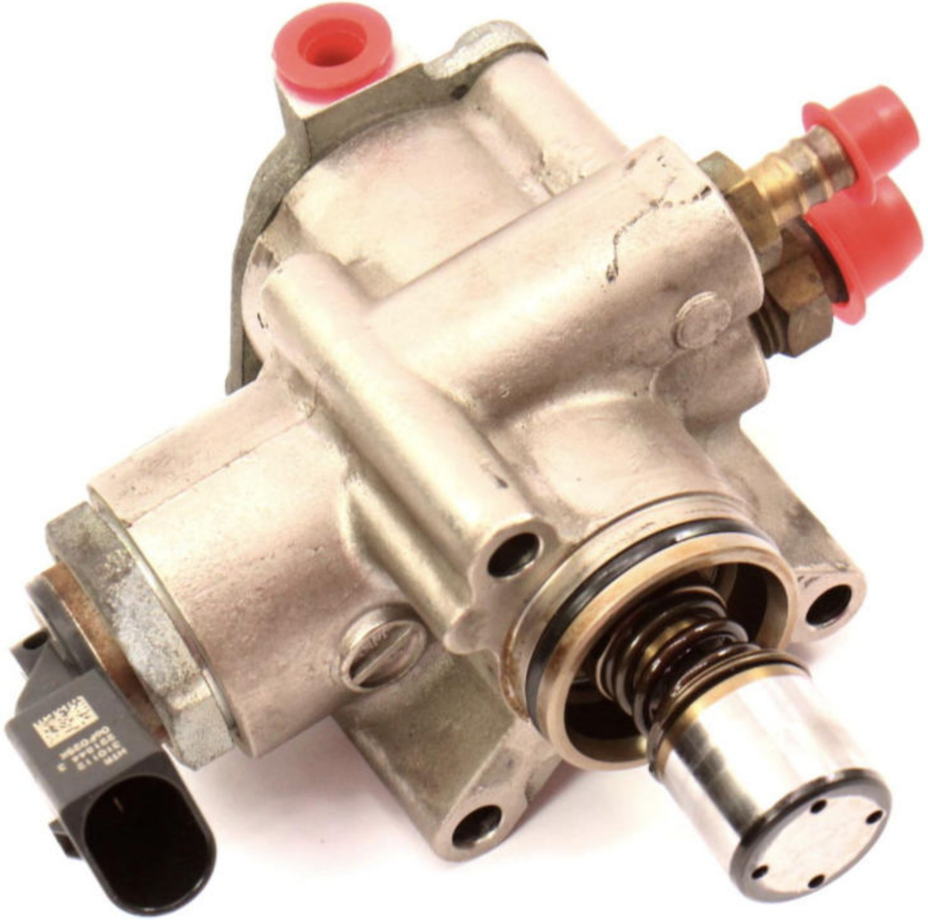
High Pressure Supply System...

High Pressure Fuel Pumps (HPFP)

- Fed fuel from low-pressure system
- Mechanically driven
- Traps/squeezes fuel (Crankcase can fill with fuel)
- Always moving with engine
- Single or multi-piston designs
- Generates pressure when commanded
- Proper engine oil (CRITICAL)
- Timed to engine (CRITICAL)
  - *Intake camshaft*
  - *Exhaust camshaft*
  - *Timing chain directly*

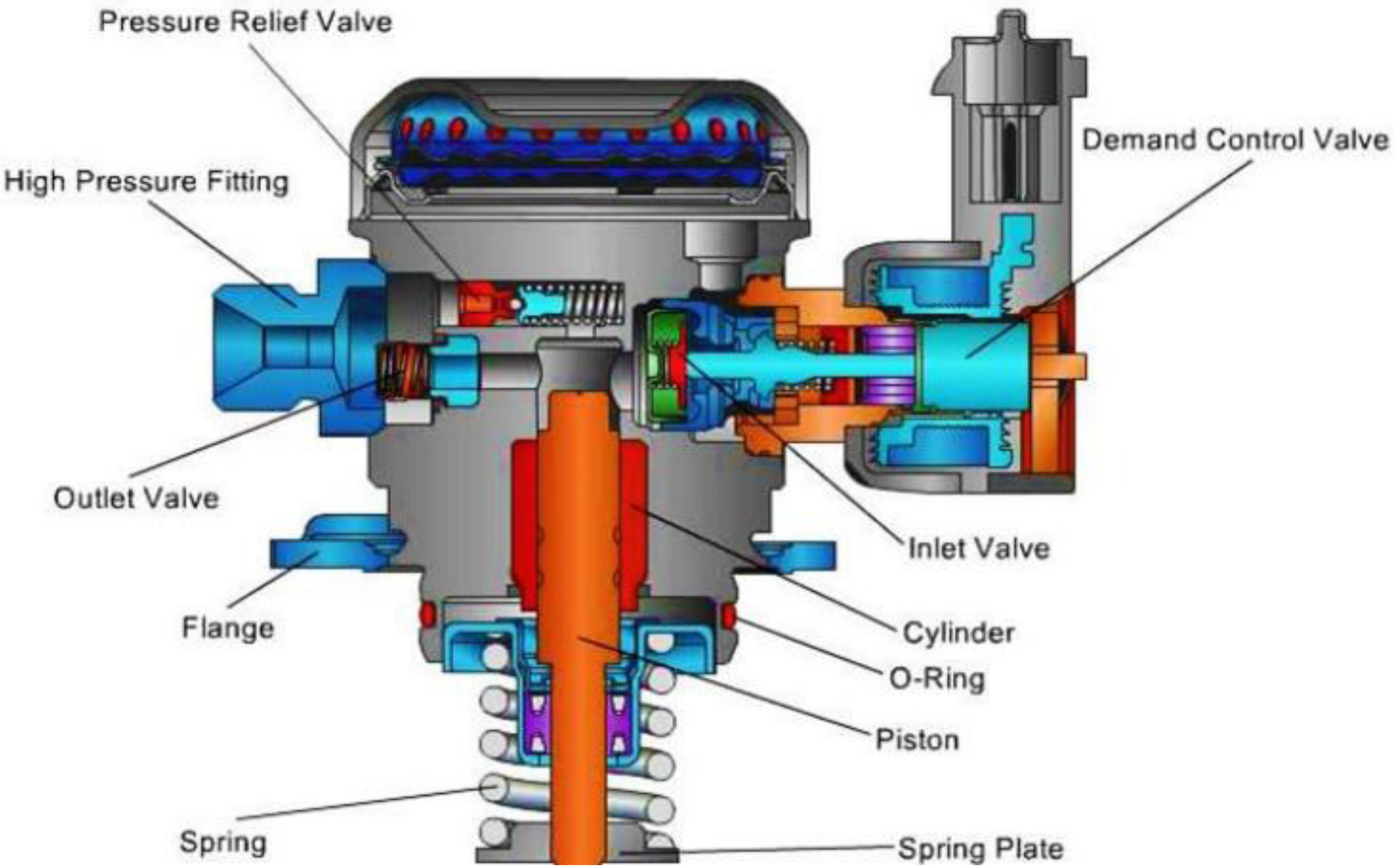
HPFP Operation...

- Driven mechanically (camshaft/chain/rotary)
- Pump strokes multiple times per engine cycle
- Pressurized fuel trapped between HPFP/injectors
- Coupled to Fuel Volume Regulator Valve (FVR)
    - *ECU actuates FVR*
    - *FVR traps fuel in pump*
    - *Pressure builds with shrinking chamber*
    - *Fuel displaced with FVR open*
    - *Normally-Open / Normally-Closed*



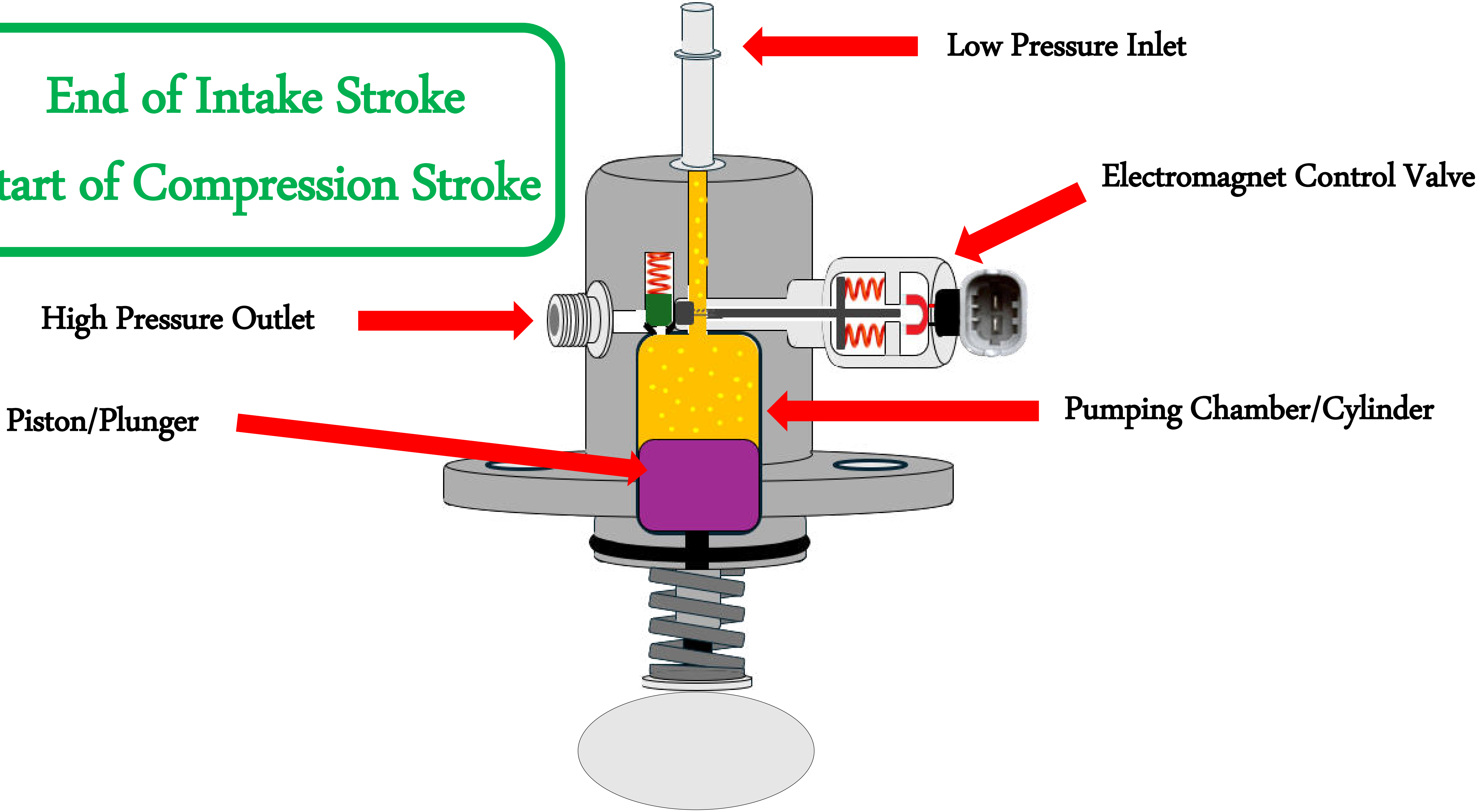
HPFP Exploded View

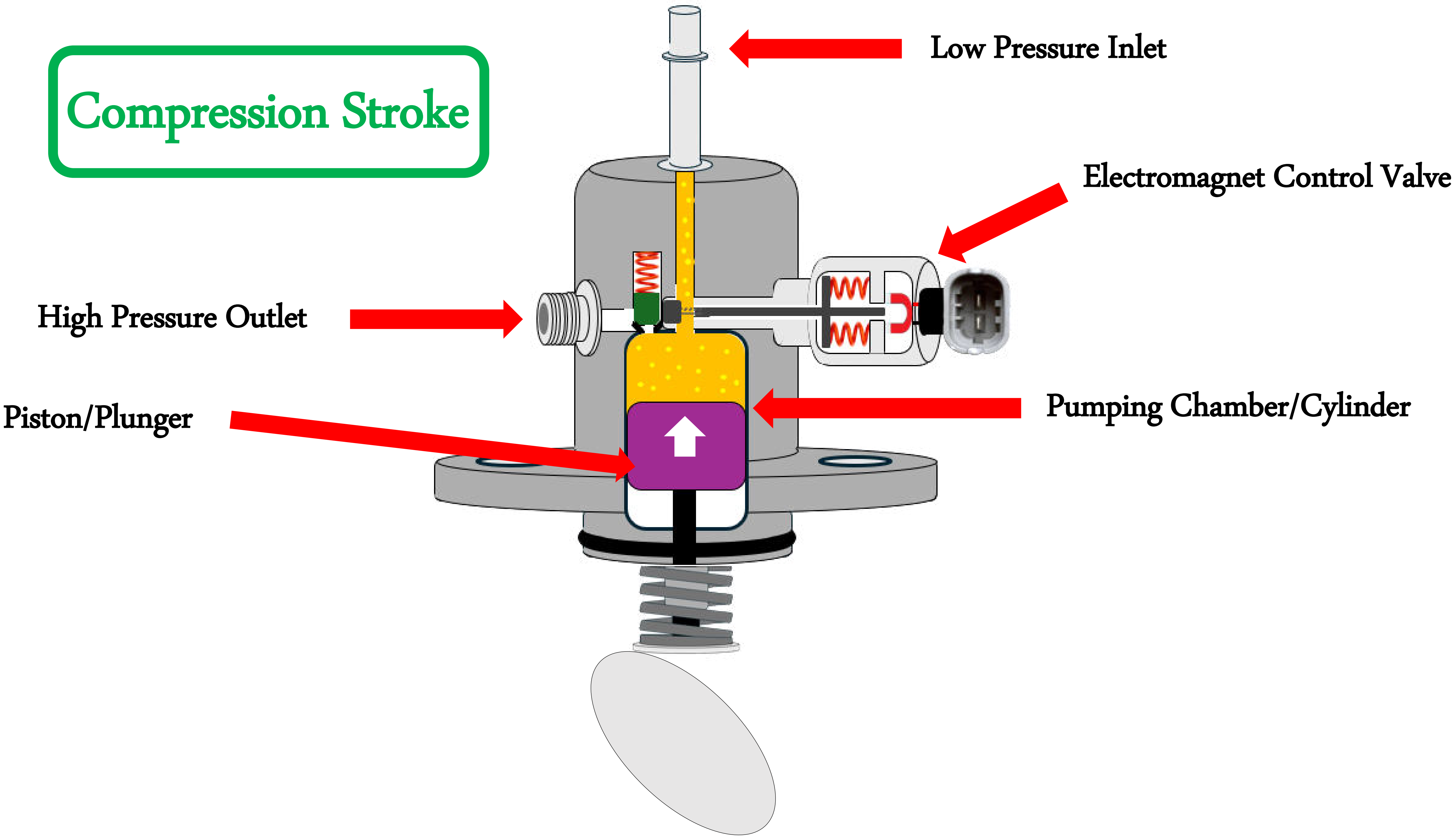
- Fuel volume regulator inlet valve
- Fuel volume regulator solenoid (FVR)
- Pump chamber
- Piston
- Outlet check valve
- Outlet fitting
- Pressure relief valve



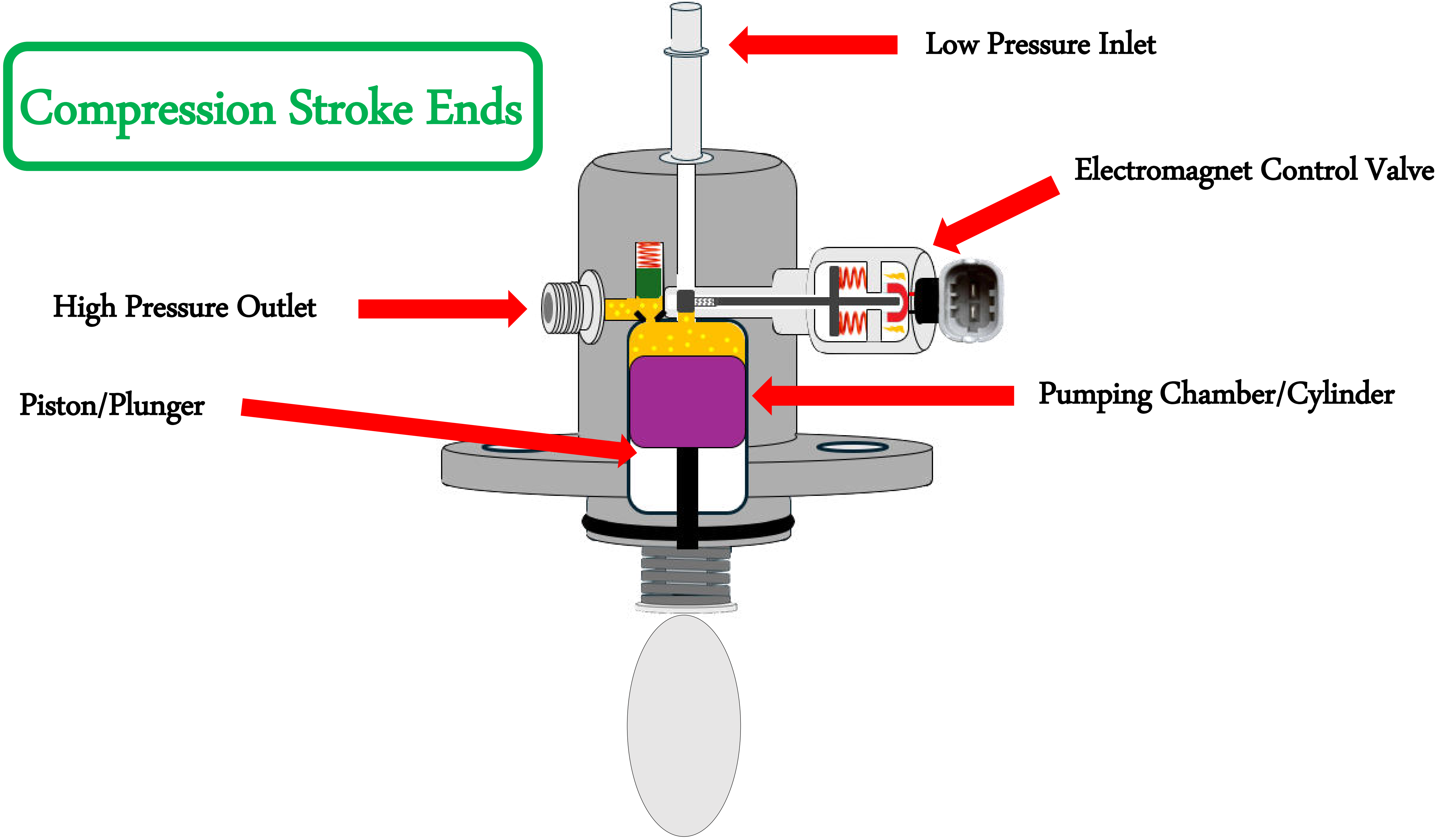
Source: Dr. Norman Nall and Bill Peek: Dead On Diagnostics

End of Intake Stroke
Start of Compression Stroke

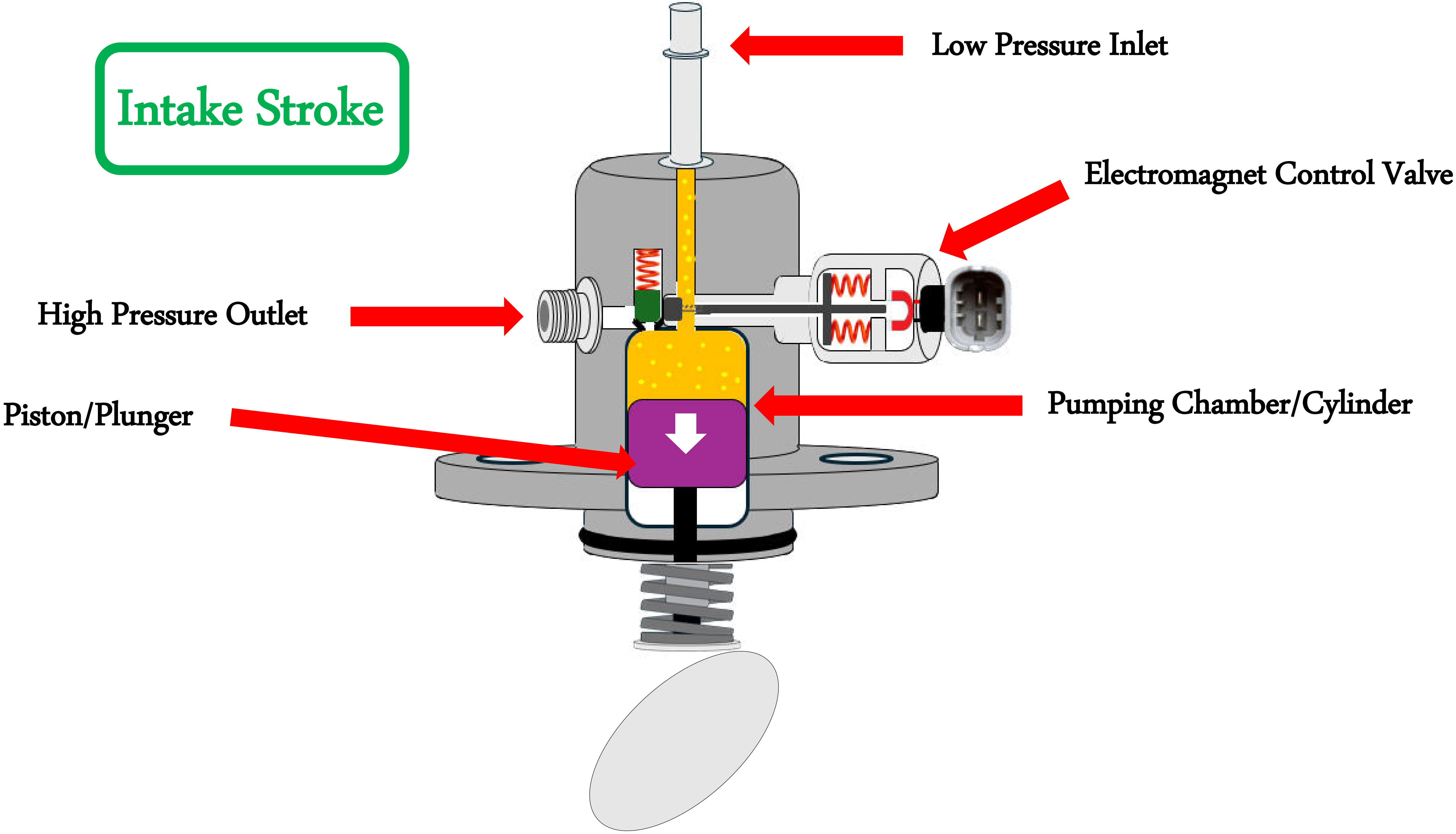



Compression Stroke
Low Pressure Inlet
Electromagnet Control Valve
High Pressure Outlet
Piston/Plunger
Pumping Chamber/Cylinder

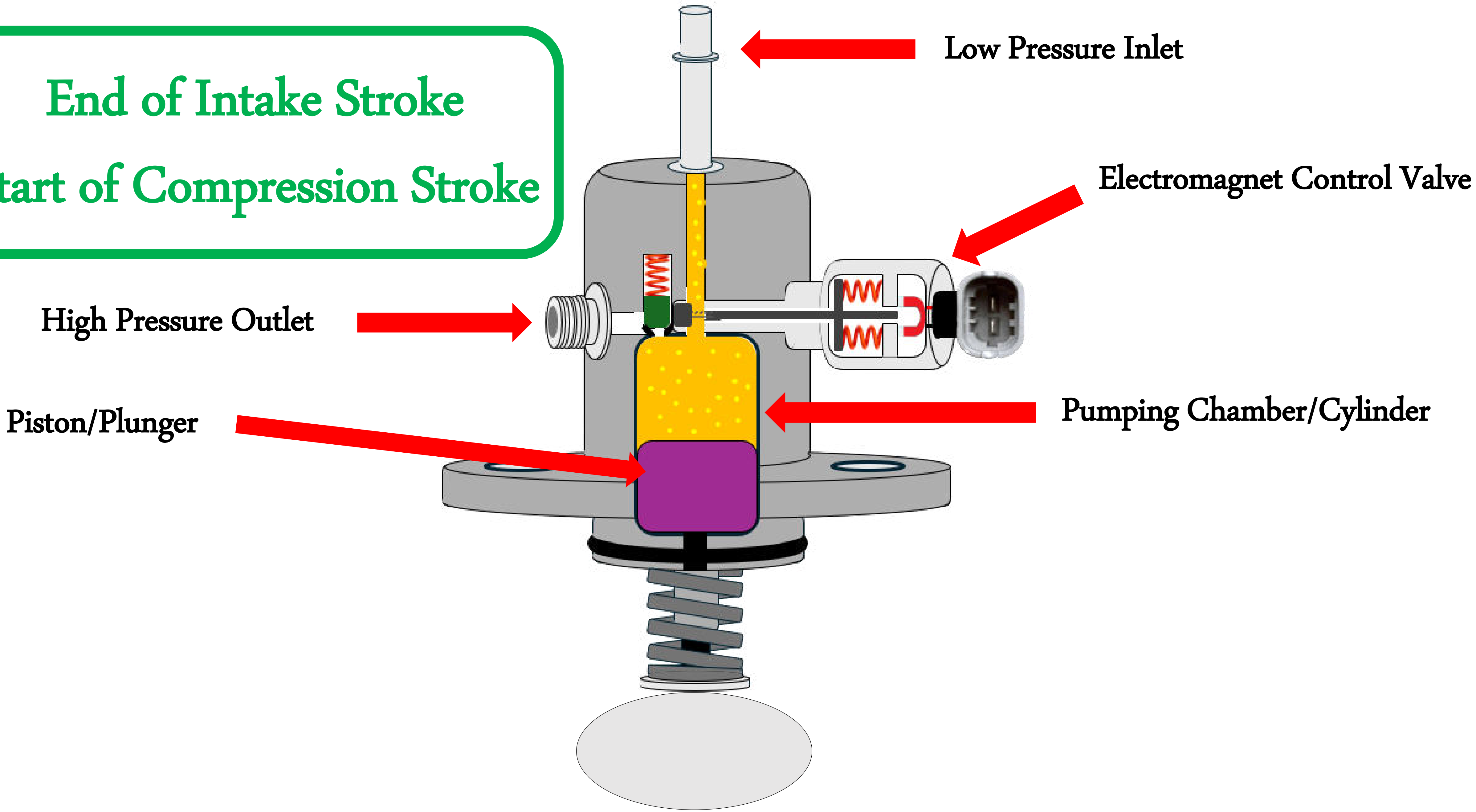
Compression Stroke Ends

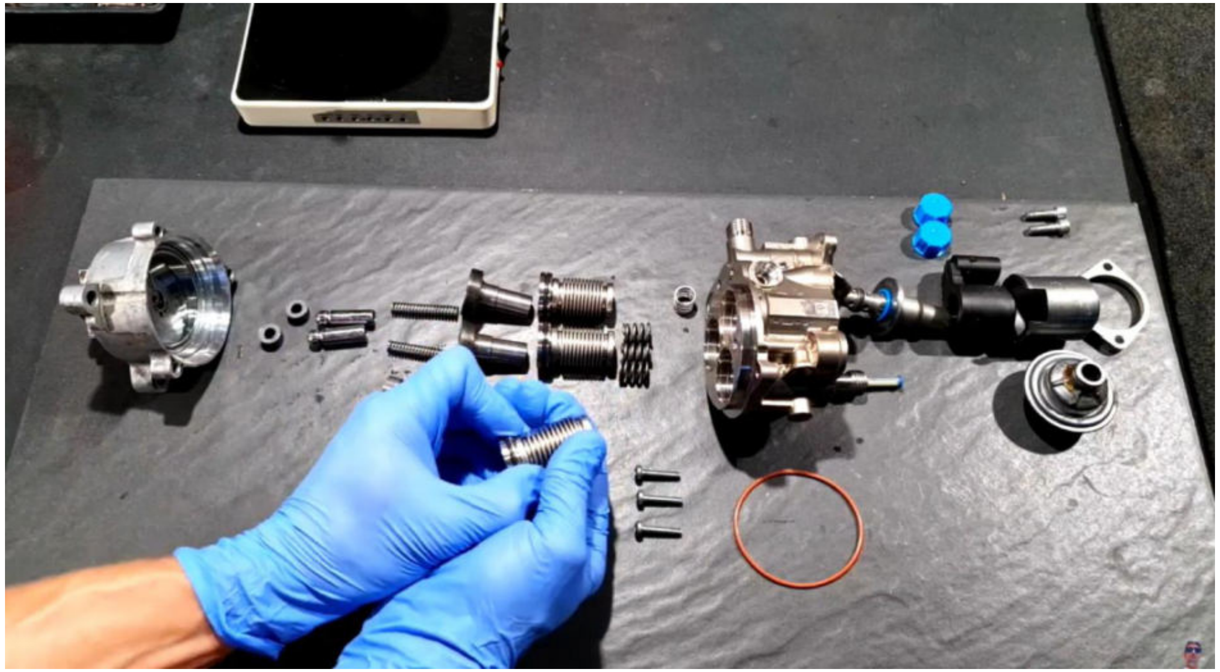
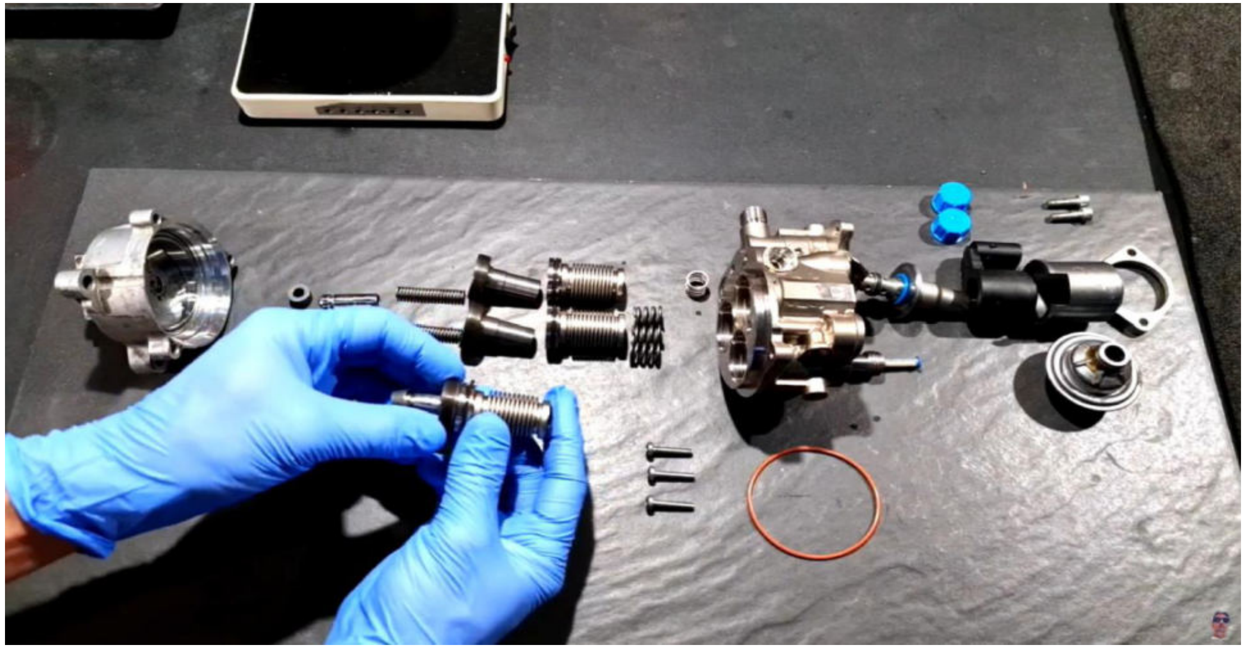
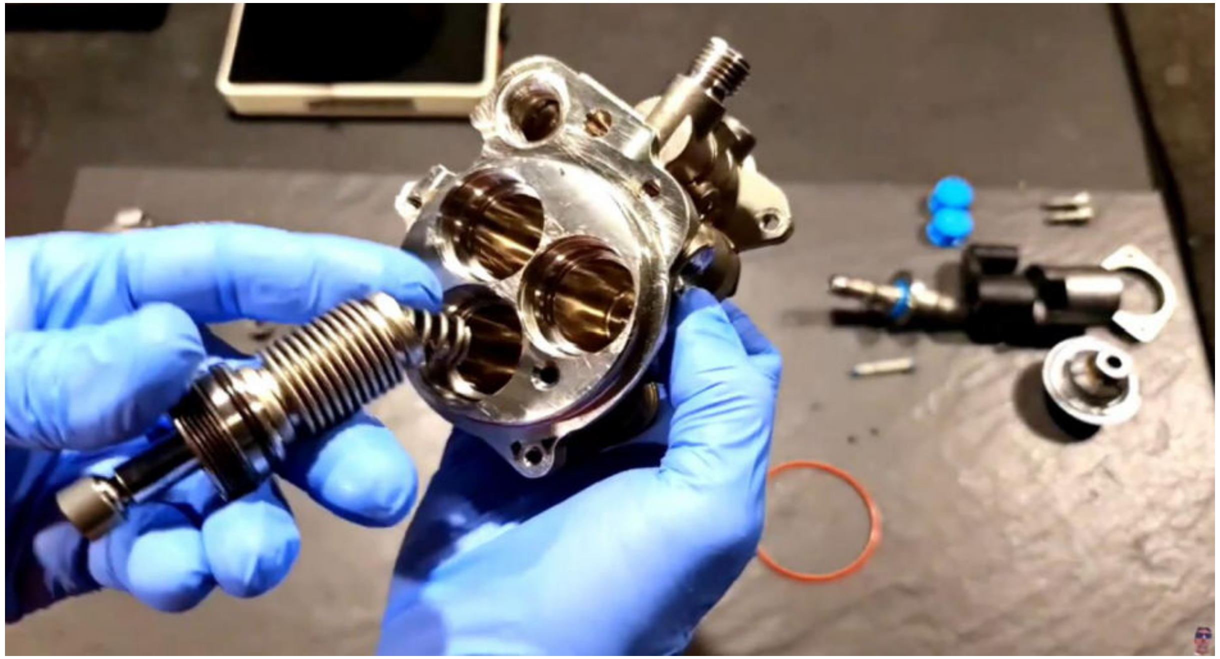


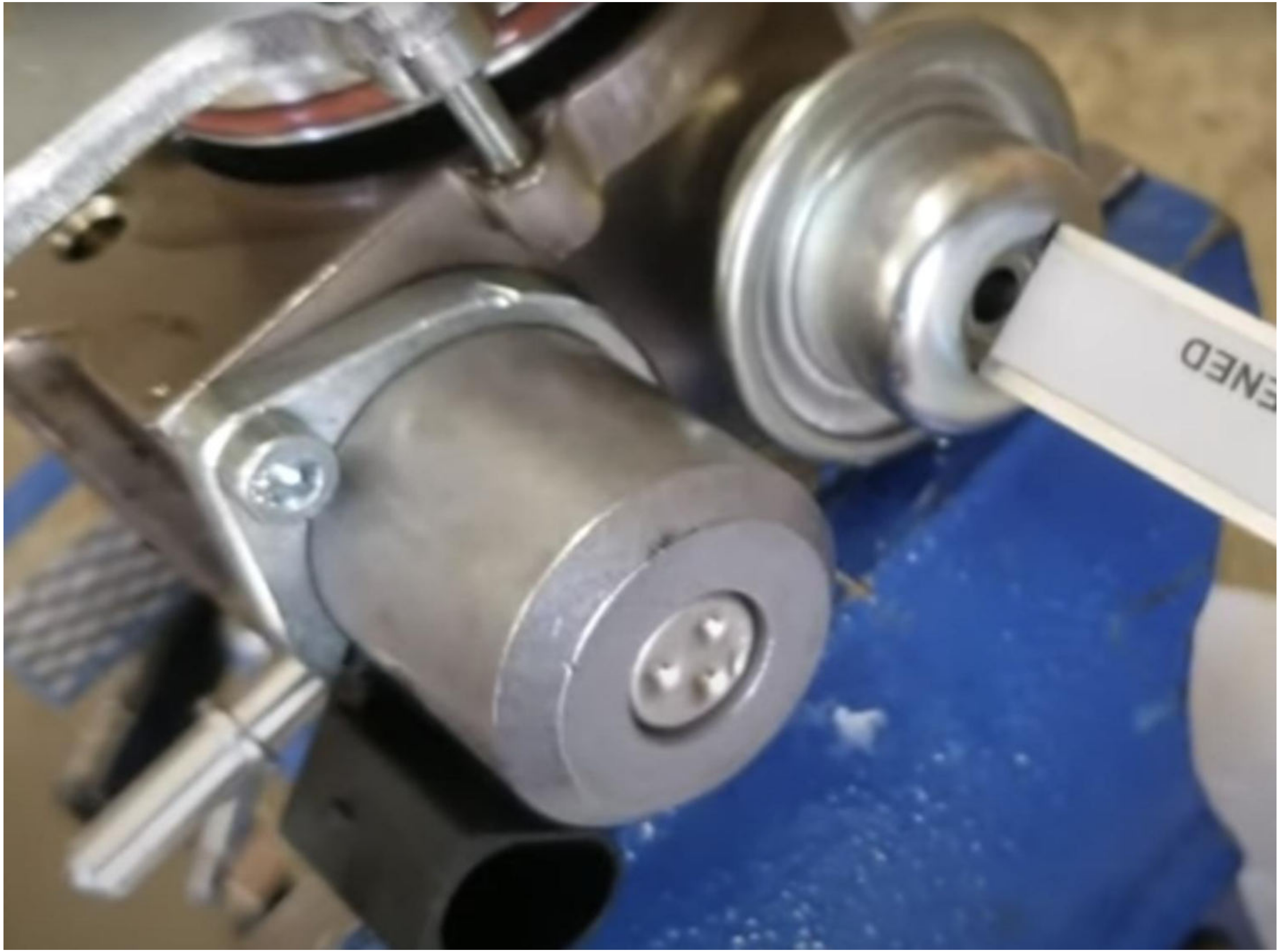
Intake Stroke



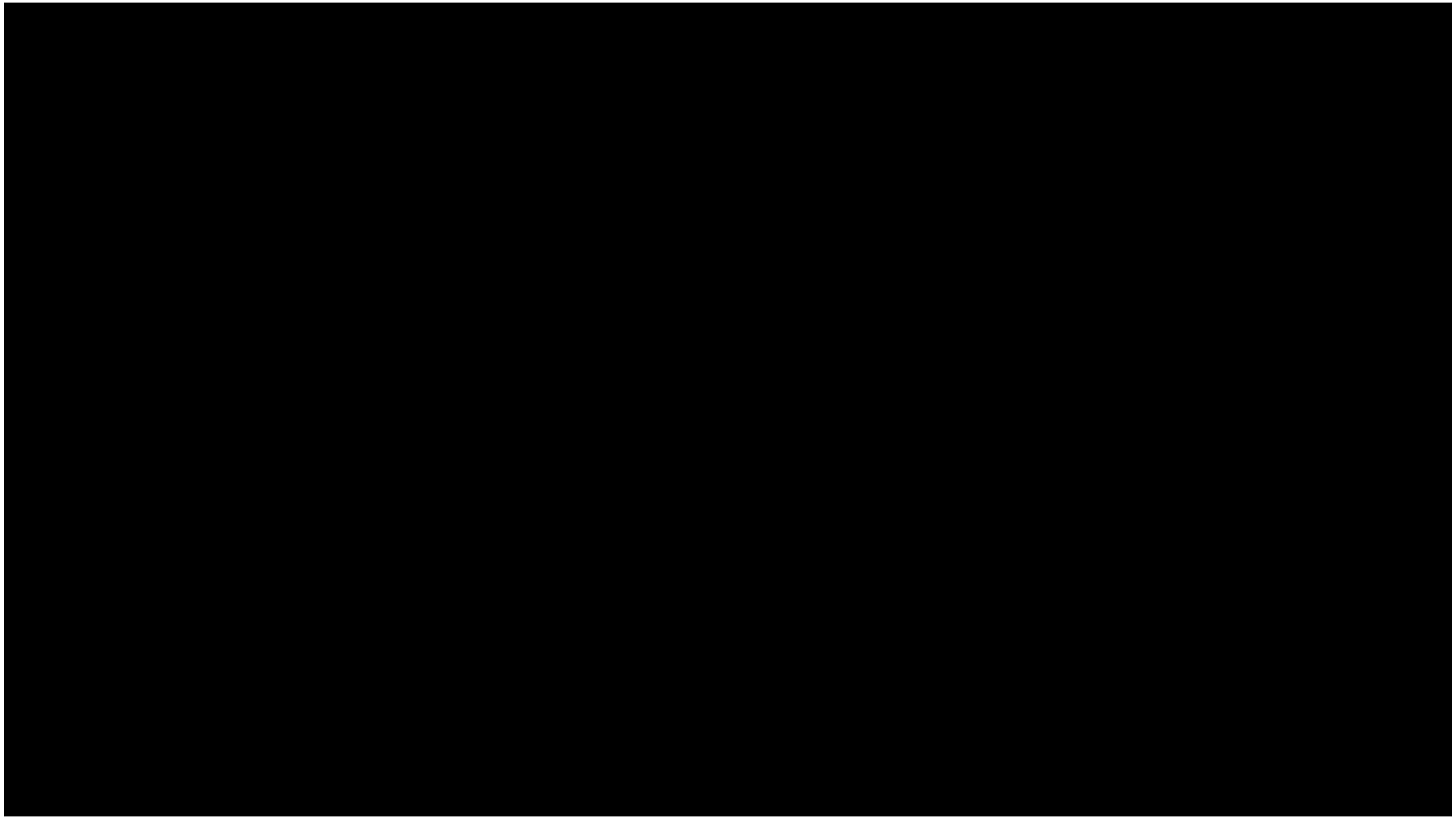
End of Intake Stroke
Start of Compression Stroke



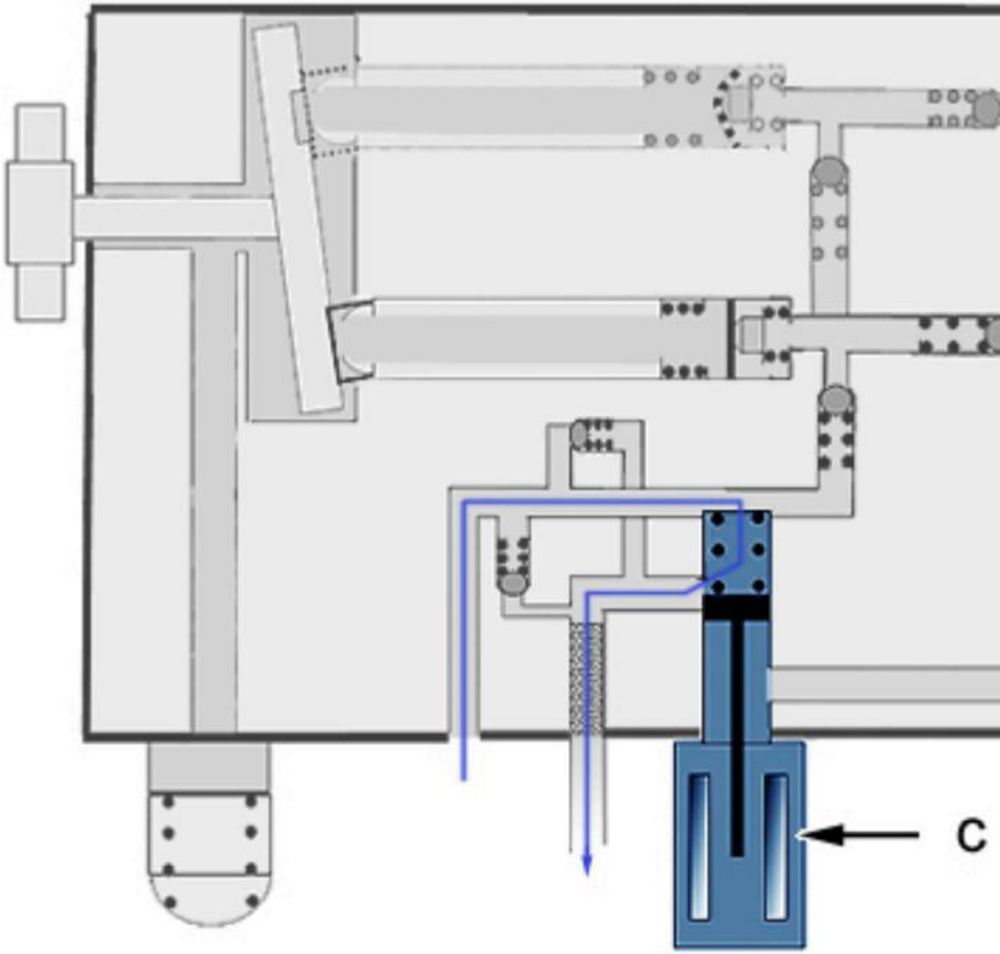


Rotary High Pressure Fuel Pump



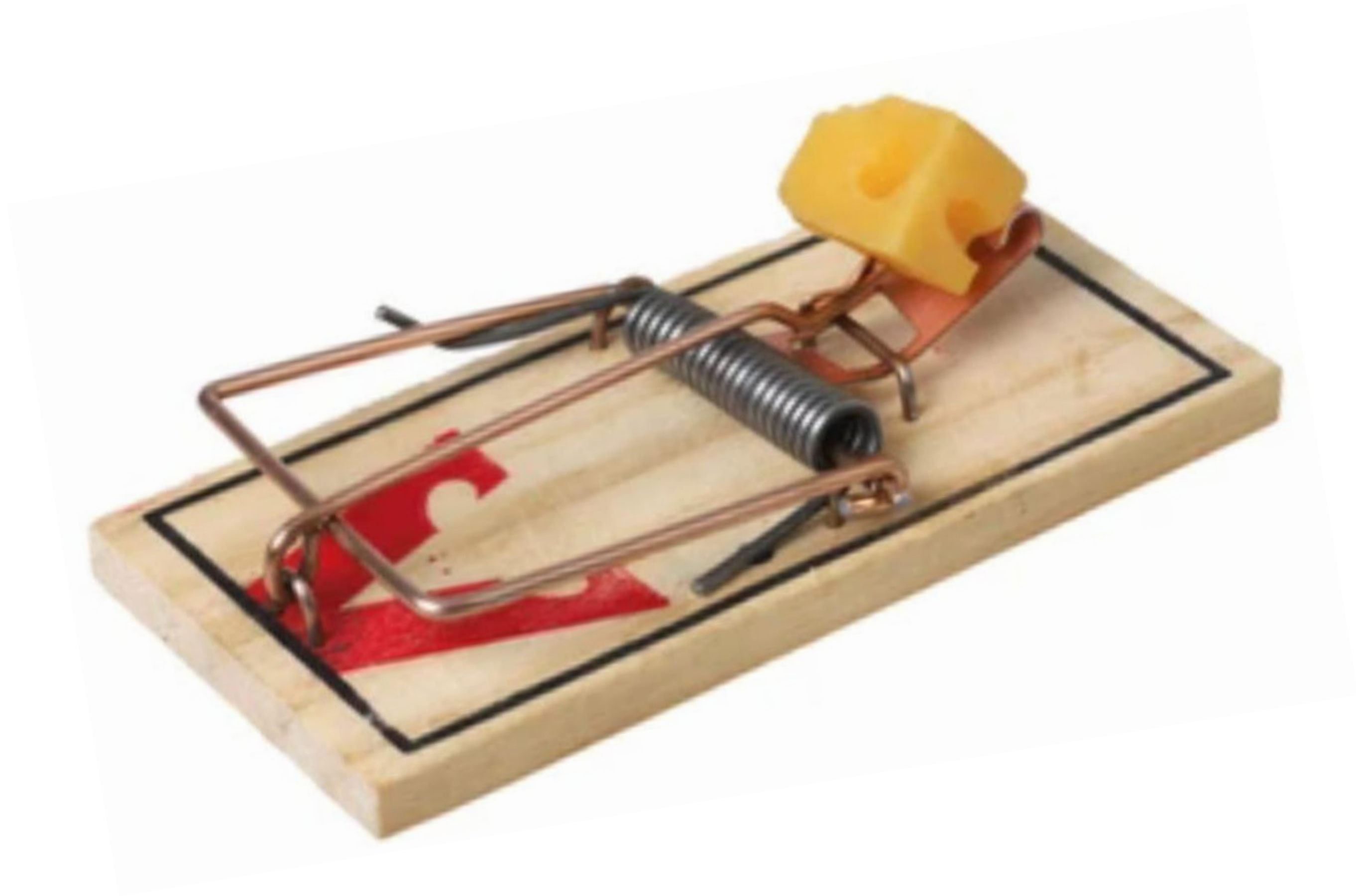
Credit & Source: M.Ovidiu

Rotary High Pressure Fuel Pump



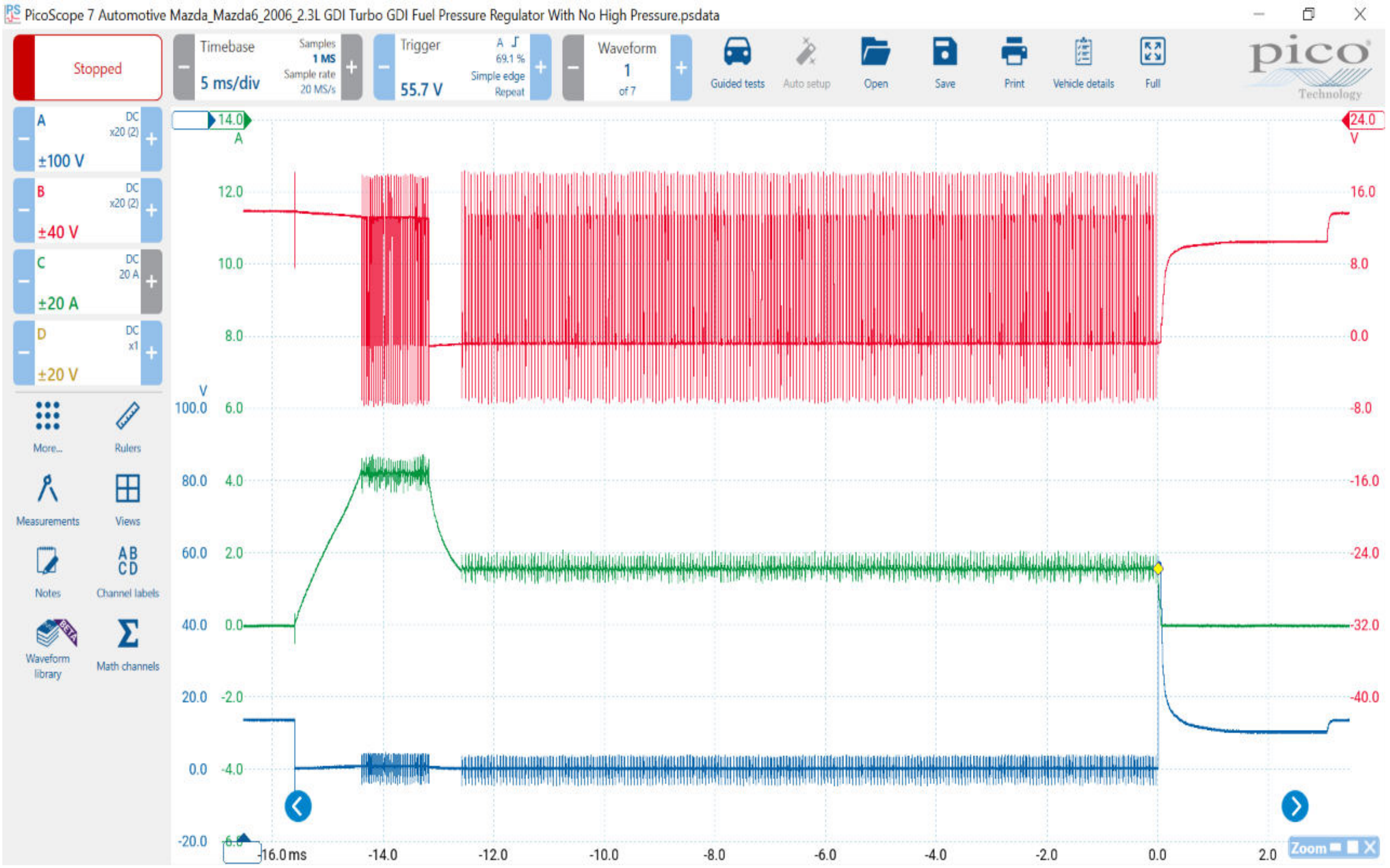
Utilized Pump Strokes

- Multiple lobes stroke pump
- Same strokes every cycle
- Load/RPM based
- Matches FRP to desired pressure
- Not all strokes utilized (Configuration)
  - *Only when trap door shuts*
  - *Function of FVR*
  - *Normally-open/Normally closed?*



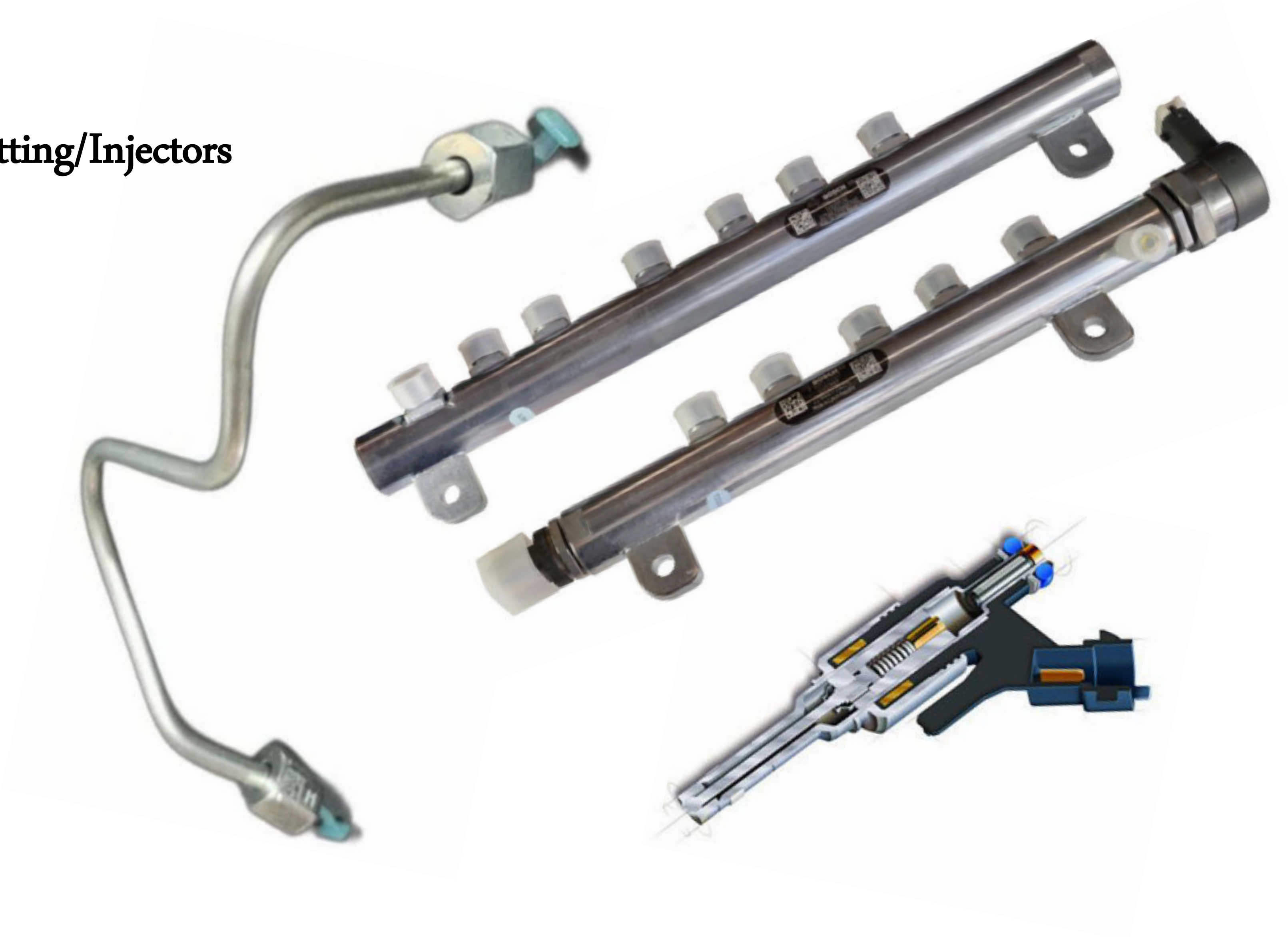
HPFP Regulator Waveform

- 2 wire solenoid
- Scope leads on high & low
- Control circuits
- Check voltage & current
- Driver's ability to control current
- Shorted Coil



Injector Rail and FRP Sensor

- Positive seal between HPFP outlet fitting/Injectors
- One-time use typically
  - *Metal-to-metal seal*
  - *Lubricate with engine oil only*
  - *Torque is critical*
- Sensor provides feedback to ECU
  - *3-wire device*
  - *Pressure transducer*

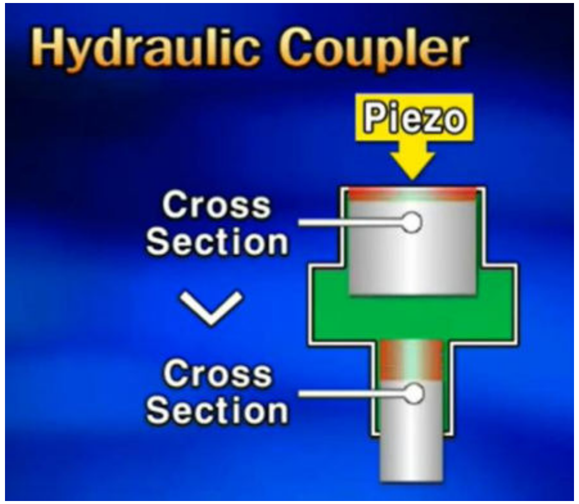


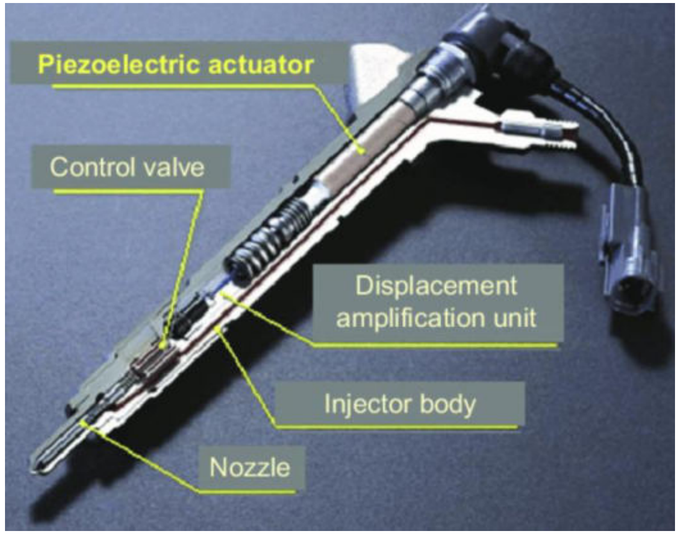
Fuel Injector Design

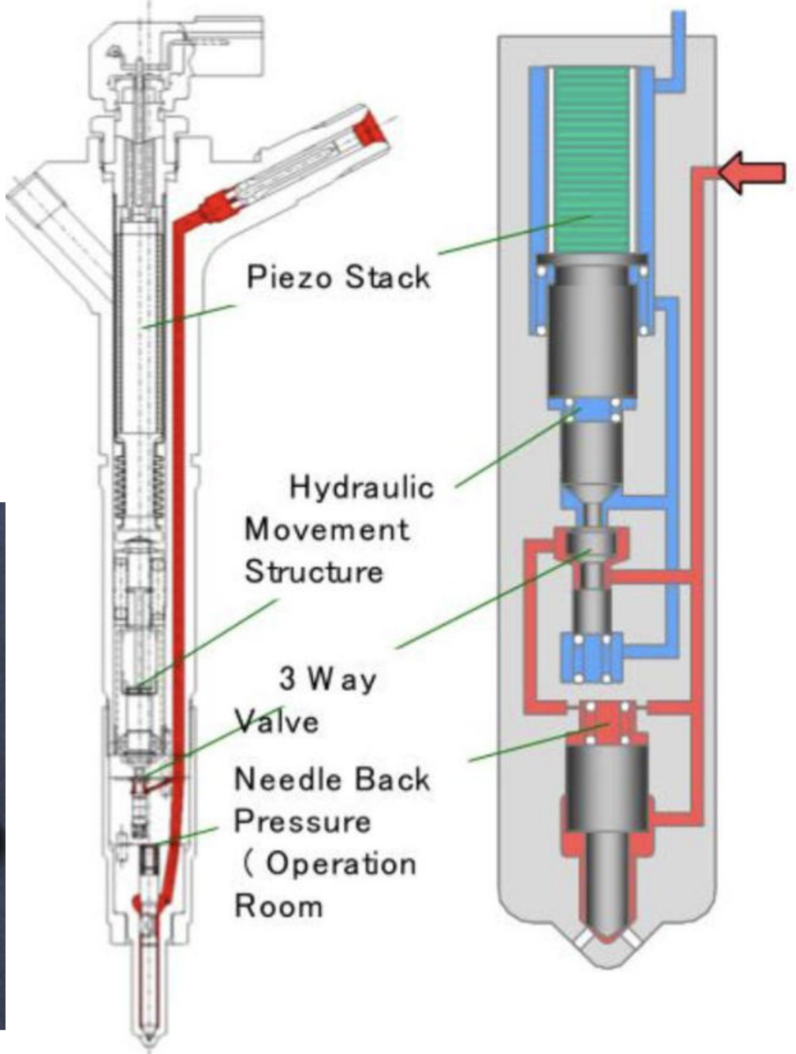
- Precision delivery required (Atomization)
- Similar control to diesel injectors
- Higher voltage and amperage (CAUTION)
- Limited time to deliver fuel
- Multiple injection events per cycle possible
- Cylinder compression opposes injection
  - *No longer injected in intake manifold*
  - *Directly into combustion chamber*
  - *Exposed to harsh environment*
  - *Special service procedures*

Piezo Fuel Injector

- Electricity excites piezo element stack
- Causes stack to expand
- Fuel lubricates/cools
- Hydraulic actuator
    - *Actuates injector*
    - *Very swift and precise control*
    - *Hydraulic = Fuel or Sealed Fluid*





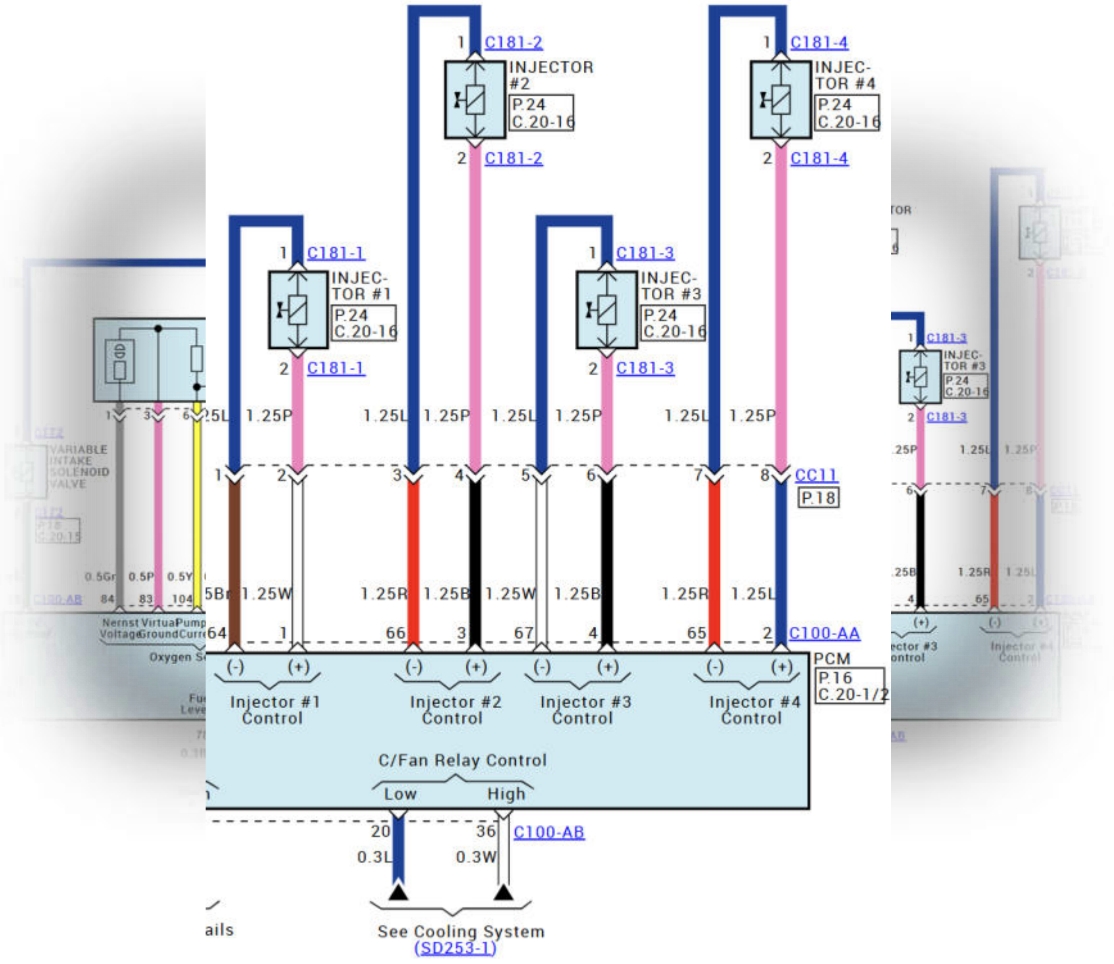


Saturated Coil Injector

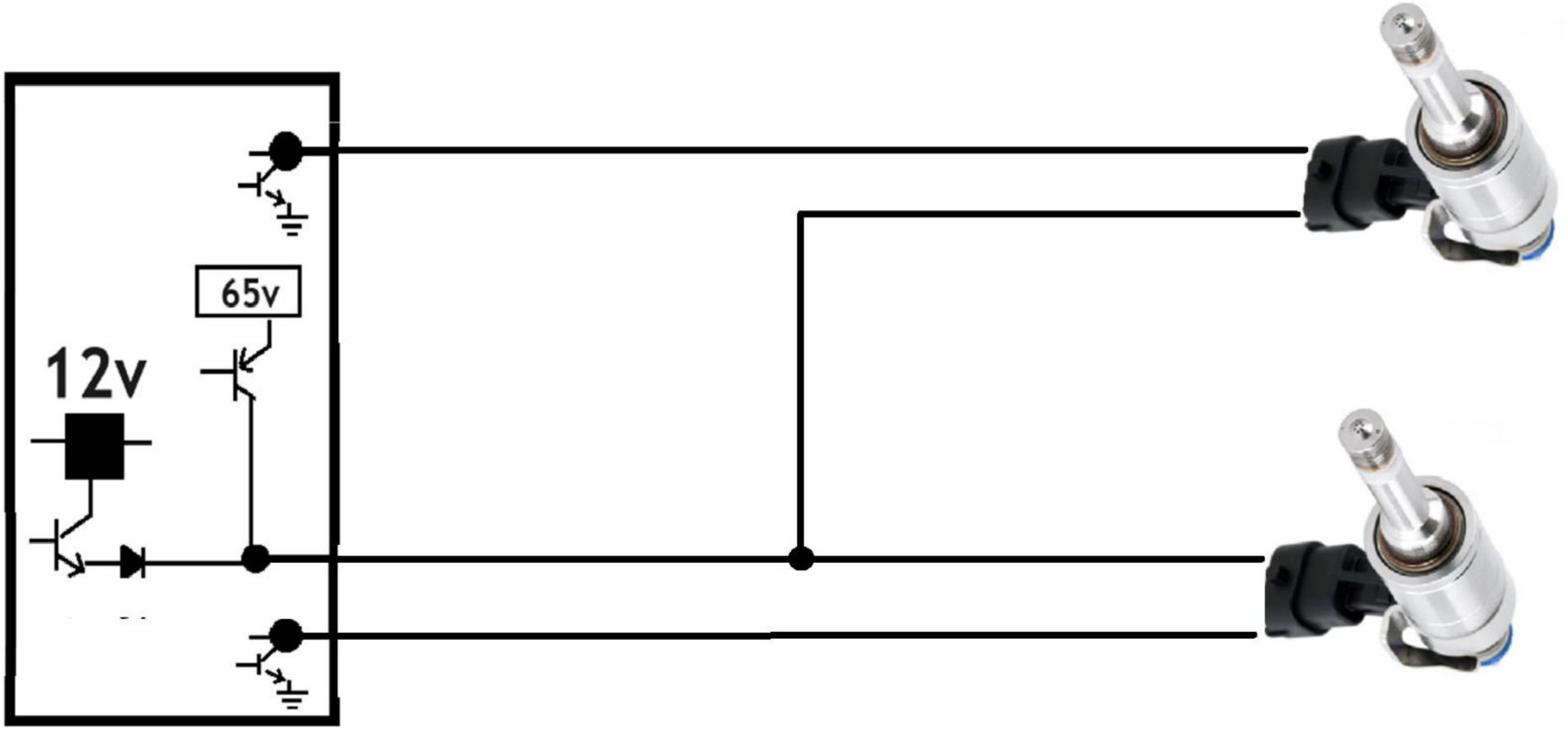
- Similar to conventional port injectors
- Operates at approximately 90 volts and 15 amps
- Long nozzle to reach combustion chamber
- Specially designed seals to trap combustion
  - *Single-use*
  - *Special replacement procedure*

Fuel Injector Control

- Controlled on voltage-side and ground-side
- Capacitive power stage (peak-and-hold)
- Shared power supply
    - *Unfamiliar waveform produced*
    - *Best evaluated via voltage and current*

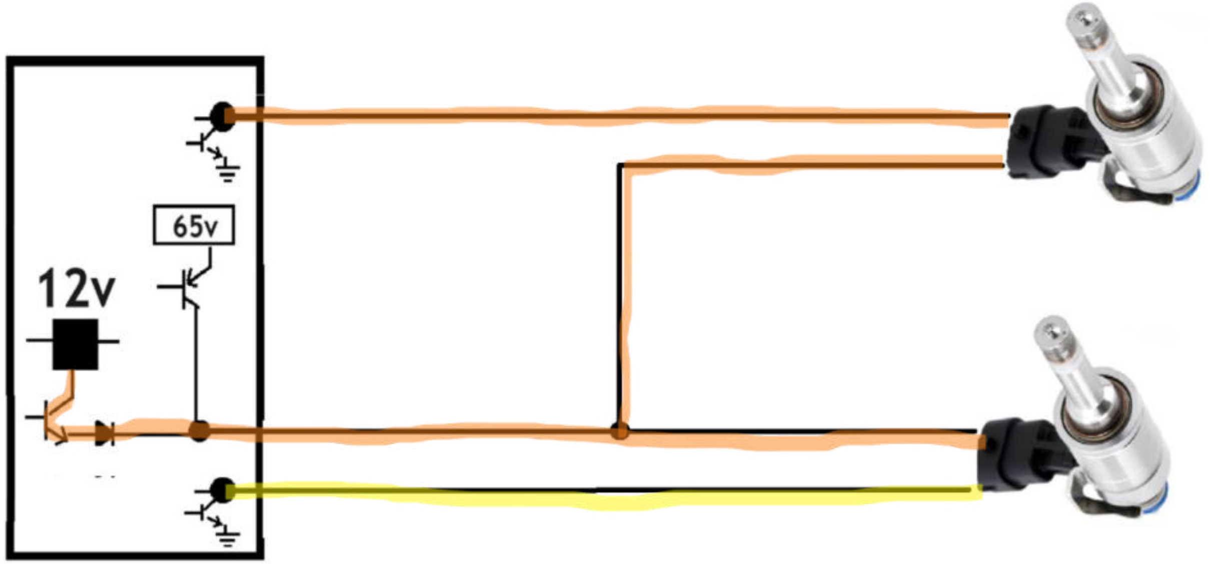


Shared Power-Stage Supply...



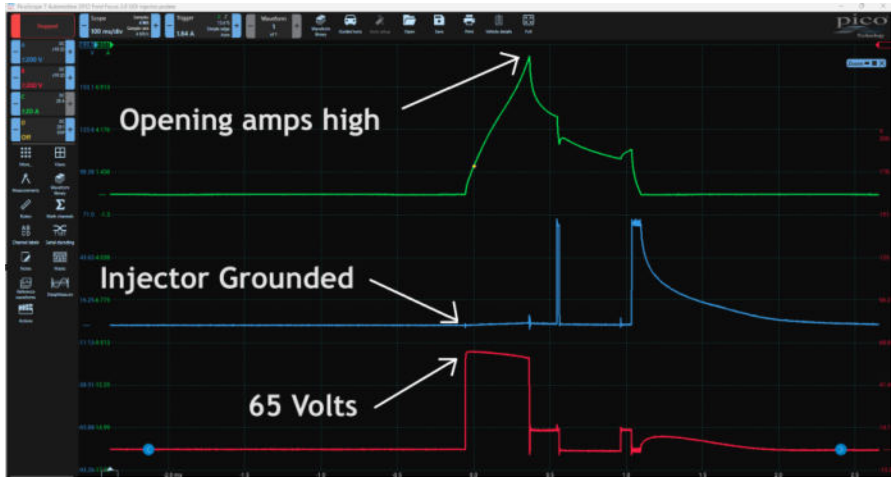
Injector Primed for Opening

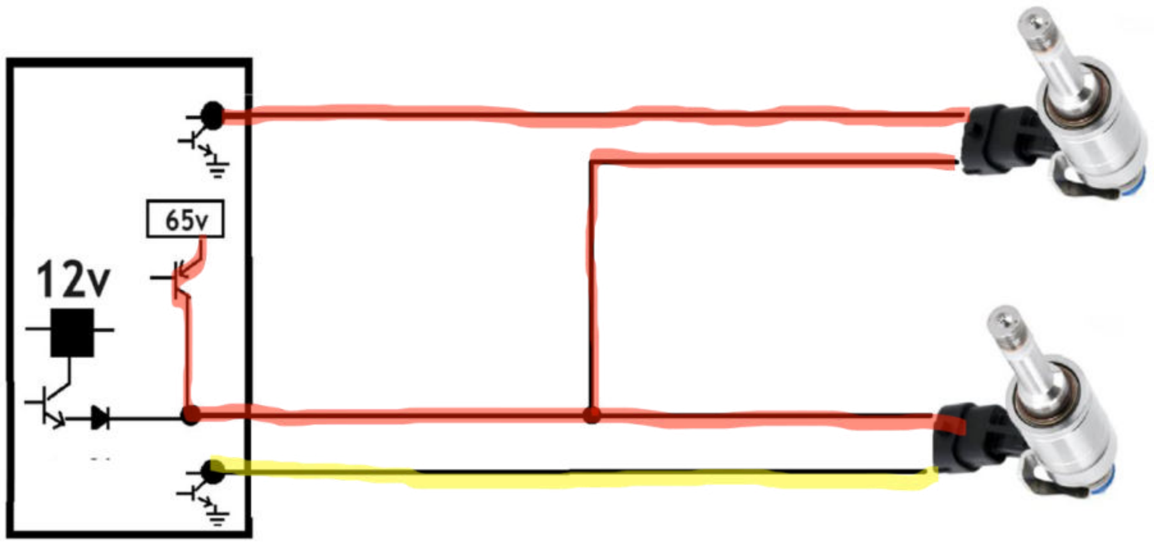
- ECU allows injector to saturate (piezo style)
- Low voltage builds magnetic field
  - *12v system*
  - *Injector remains closed*



Initial Opening (Peak)

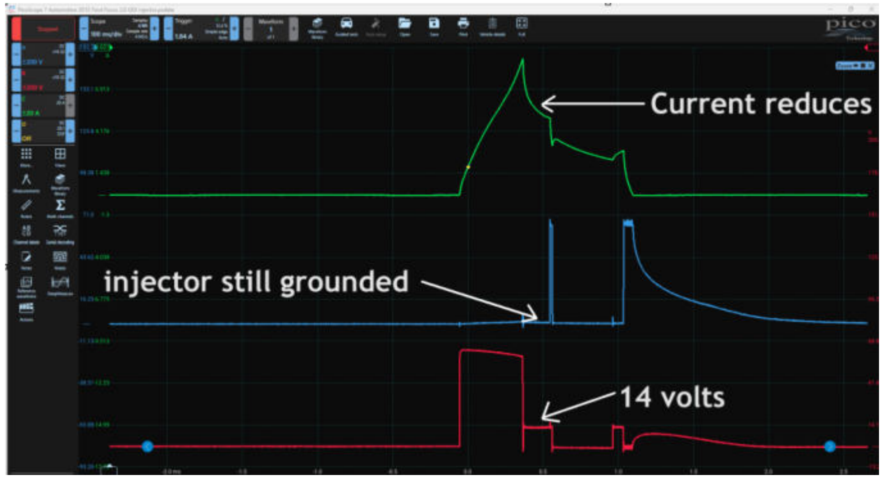
- ECU driver discharges capacitor into injector
- Injector amperage increases significantly
  - *Ohm's law*
  - *High current/faster response*
  - *Injector open rapidly*

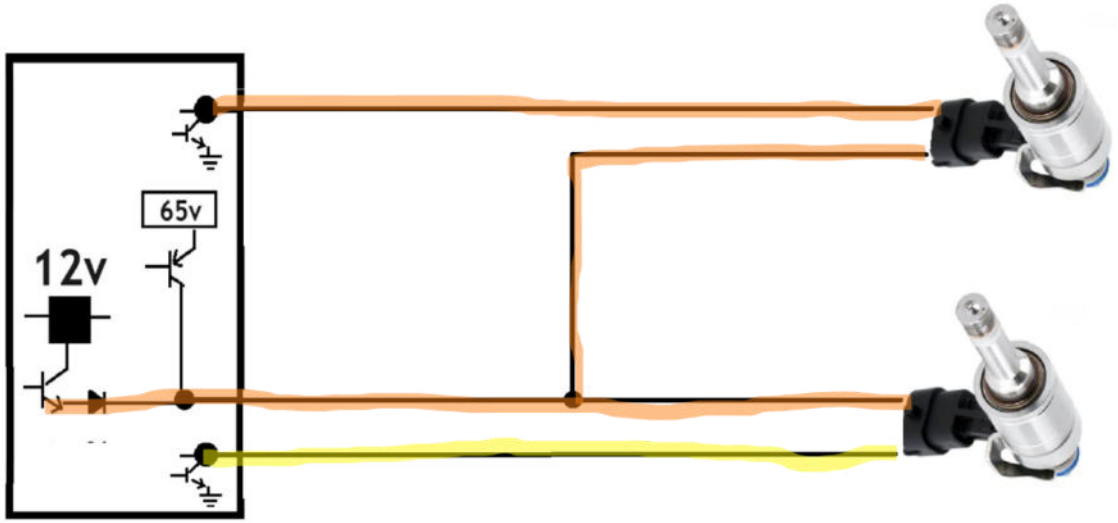




Injector Open (Hold)

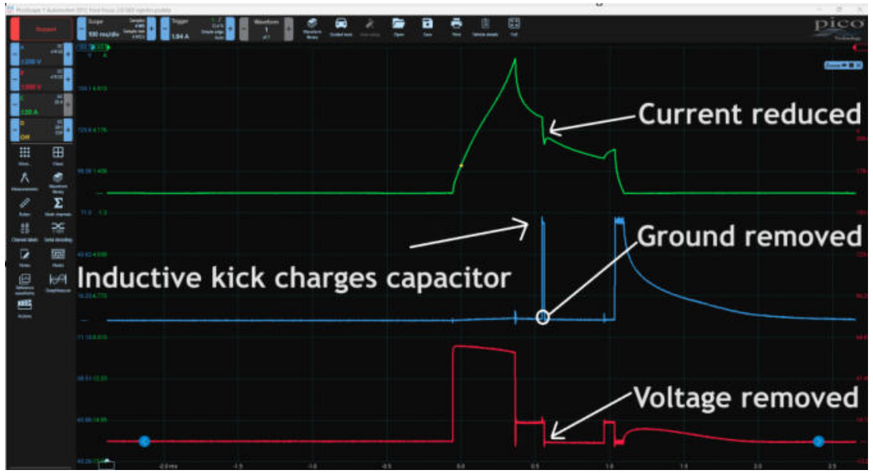
- ECU driver switches
- Low-voltage applied to circuit
  - *Ohm's law*
  - *Current reduces with voltage reduction*
  - *Injector remains open*

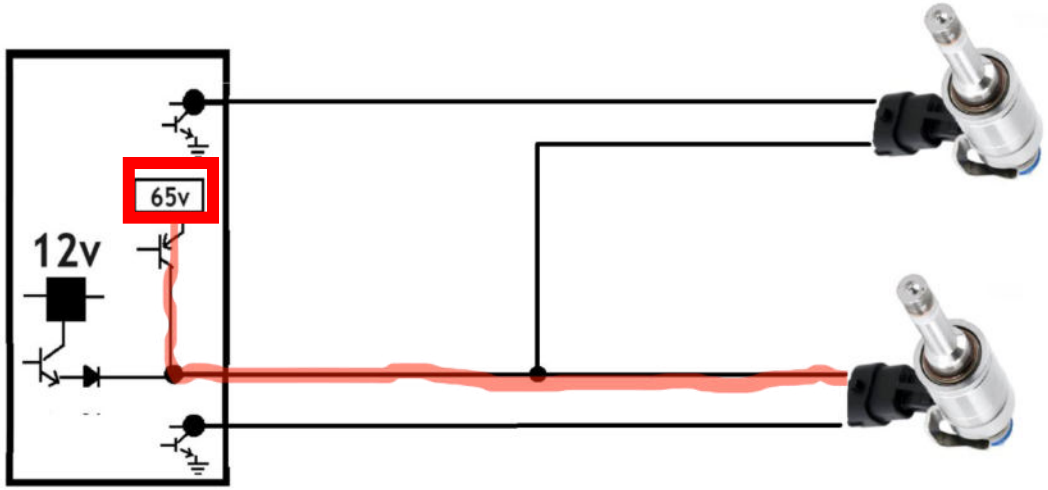




Injector Circuit Momentary Turn-off

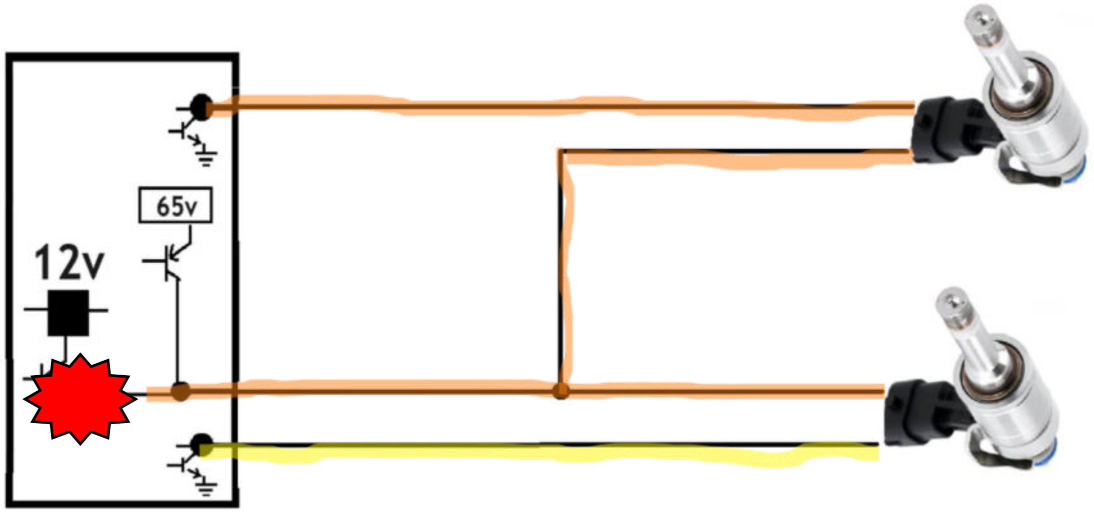
- Injector de-energized
- Injector ground control released
- Control-side referencing capacitor
  - *Injector magnetic field collapses*
  - *Induces inductive kick*
  - *Charges capacitor for subsequent initiation*





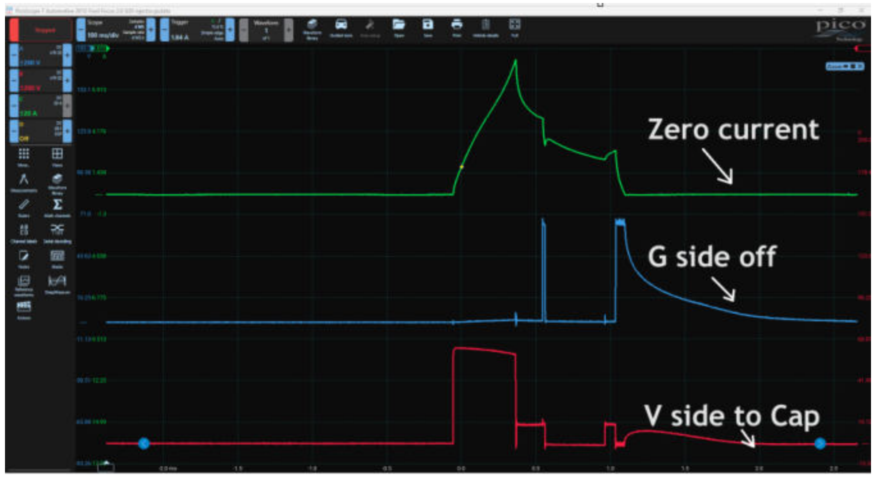
Current Limitation

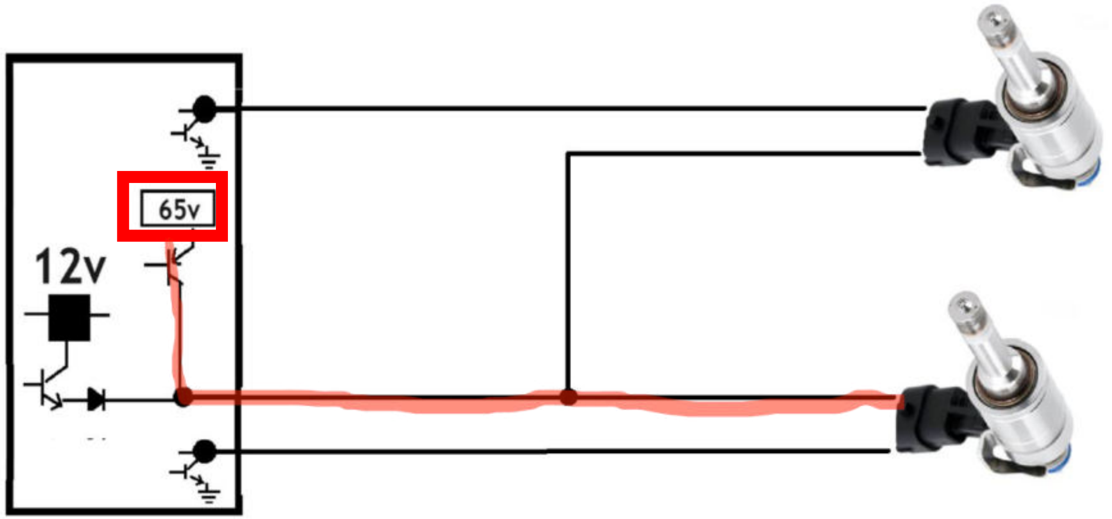
- Injector grounded
- 12v supply is pulsed rapidly
  - *Occurs in microseconds (uS)*
  - *Meters fuel delivery*



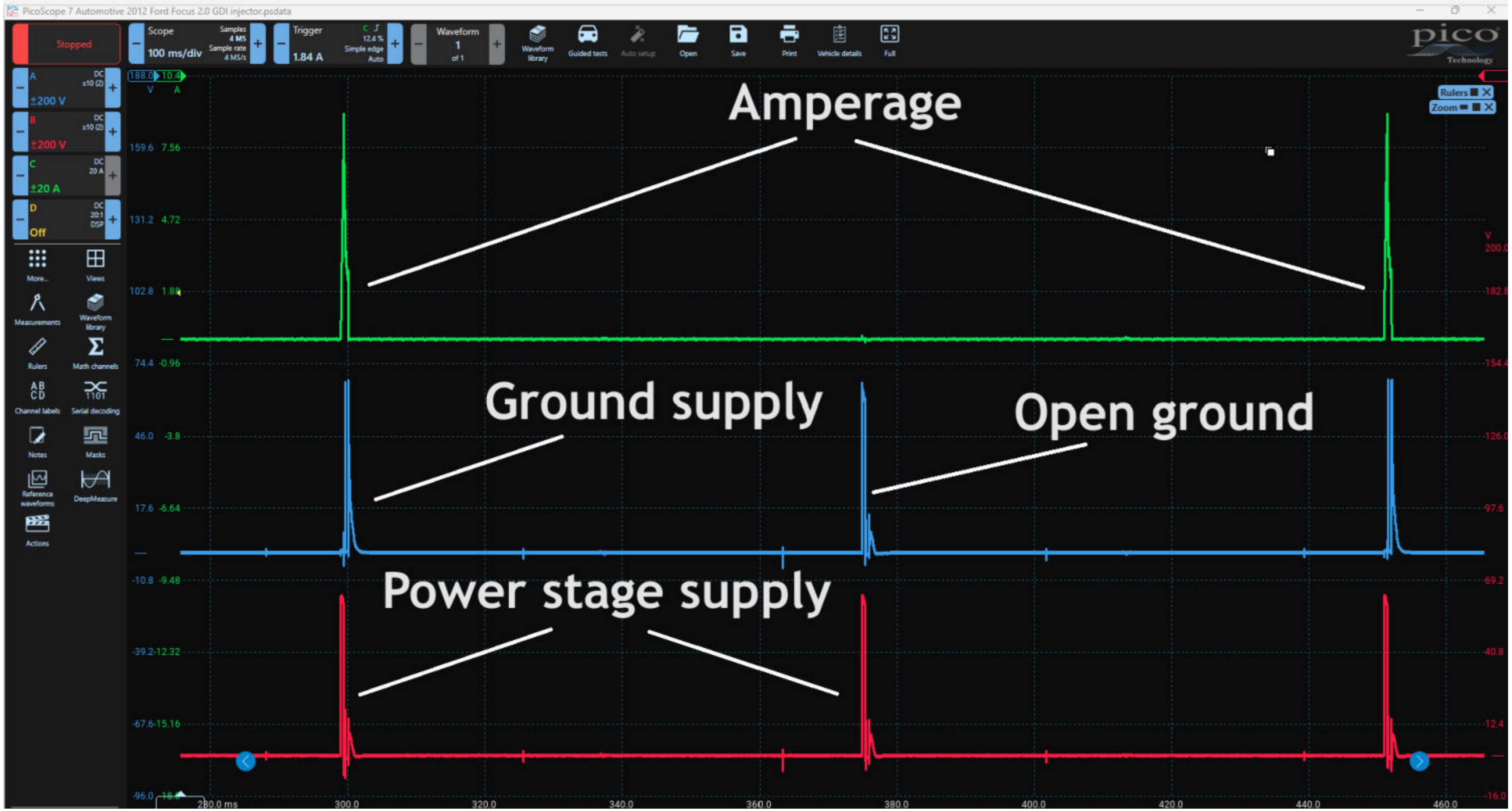
Injector off

- Power supply released
- Ground supply released
    - *Current vanishes*
    - *Magnetic field collapses*
    - *Inductive kick occurs*

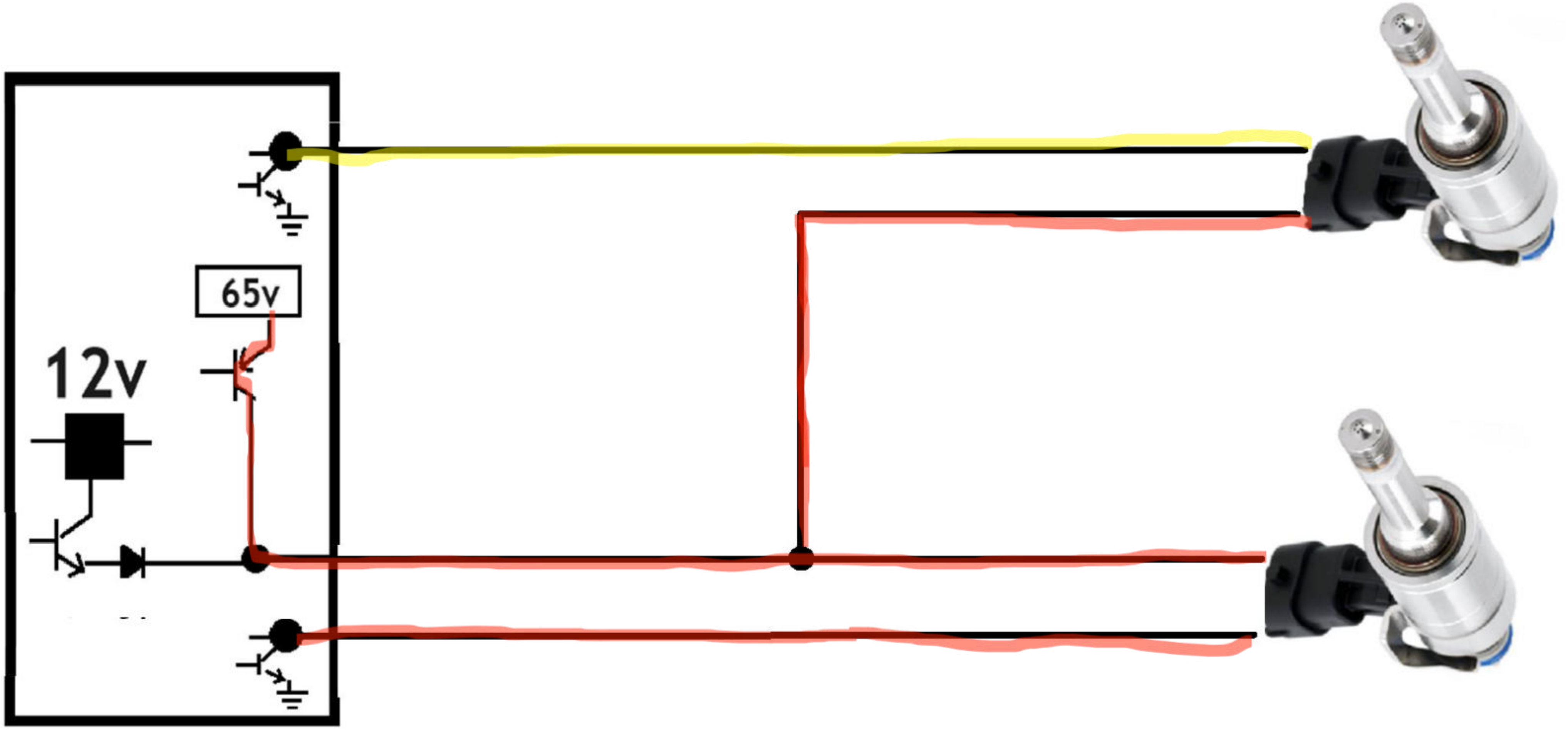




Shared Power-Stage Supply…

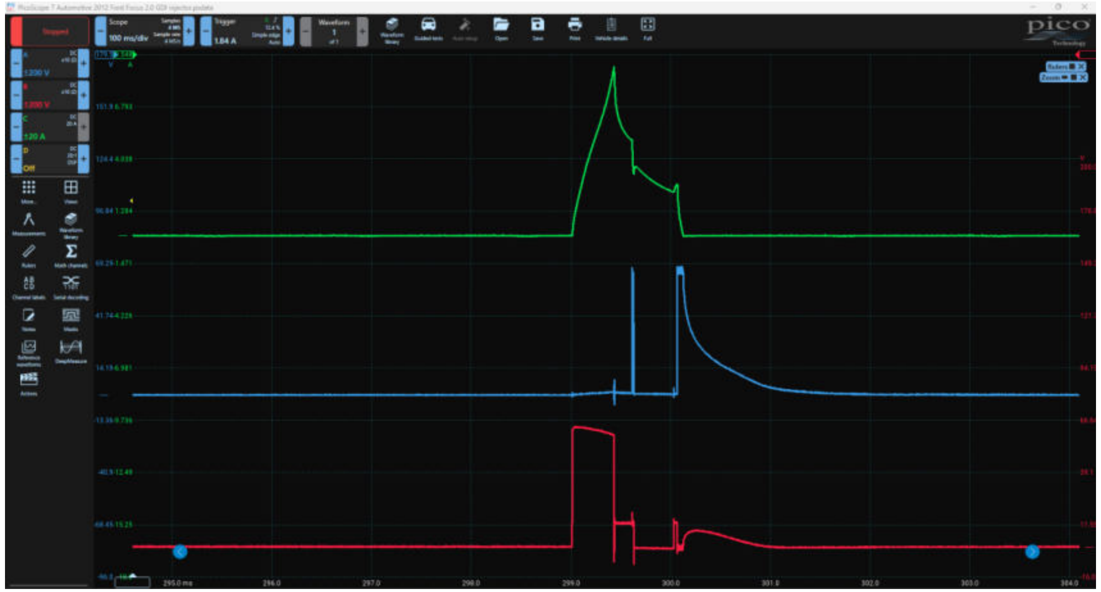


Paired-Injector Operation



Shared Power-Stage Supply

Energized Injector

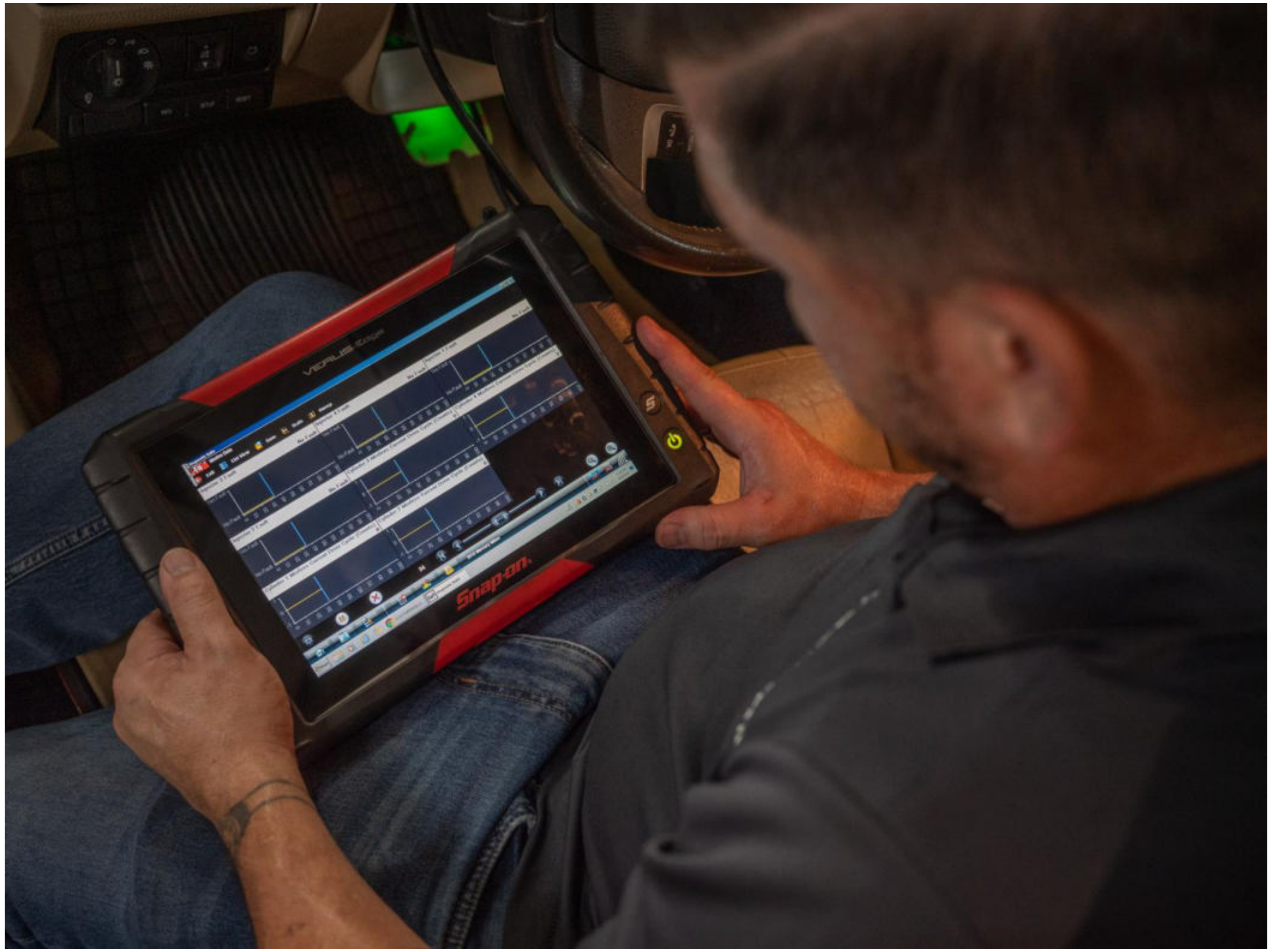


De-energized Injector

Let’s Analyze Data!

GDI, From the Driver's Seat

- Let the PIDs tell the story
- Divide and concur
- G-tests lead to P-tests
- Game plan
  - *Breathability*
  - *Fueling*
  - *Corrective factor*
  - *Failure strategy*



Breathability

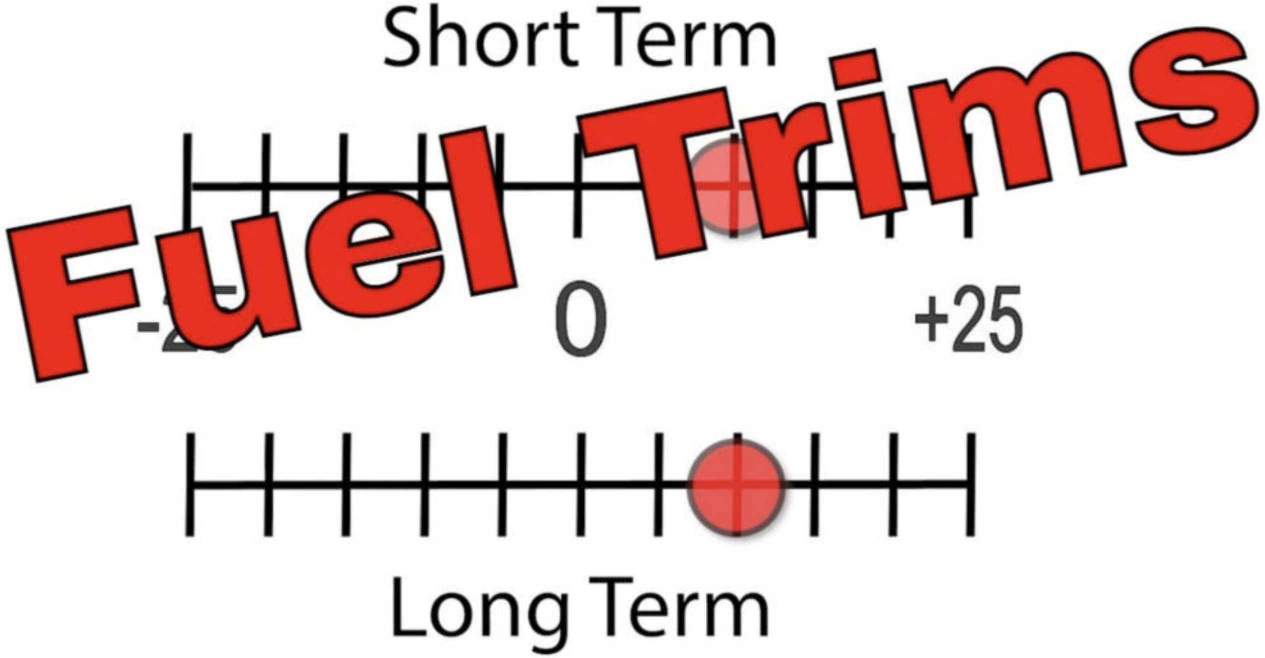
- Is there enough air moving through the engine at the time?
- Fuel comes from air measured
- If "air" isn't correct, performance suffers
  - *Unmetered air, fuel miscalculation*
  - *Poor pumping abilities*
  - *How will ECU respond?*

Fueling

- Is there enough fuel delivered for the air pumped?
- Low-pressure sensor/ FRP sensor inputs
- PCM to FPCM command/low-Pump performance
- FVR and HPFP performance
- Injector performance
- If "fuel" isn't correct, performance suffers
  - *Poor fuel delivery skews intended A/F ratio*
  - *Compensation takes place*
  - *Default strategies may present*

Corrective Factor

- Are adaptive strategies at play?
- Adaptives can mask driveability issues and offer clues
- Have the thresholds been crossed?
    - *Pump fuel trim*
    - *Short term fuel trim*
    - *Long term fuel trim*
    - *Rear fuel trim*
    - *Total fuel trim*



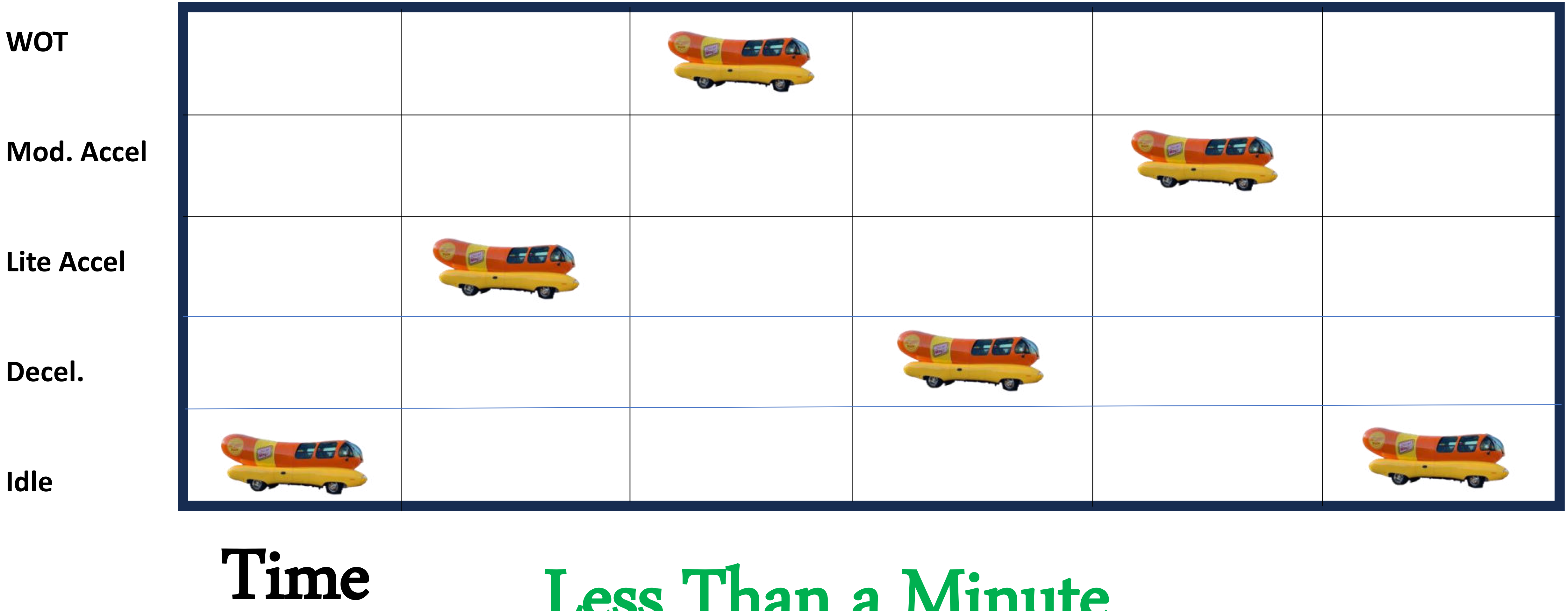
Protection Strategies

- Protection against damage/pollution
- Can be cause of exhibited symptoms
- Can confuse technicians
    - *Low-power/closed throttle*
    - *Reduced throttle opening*
    - *Poor performance*

Systematic Analytical Approach

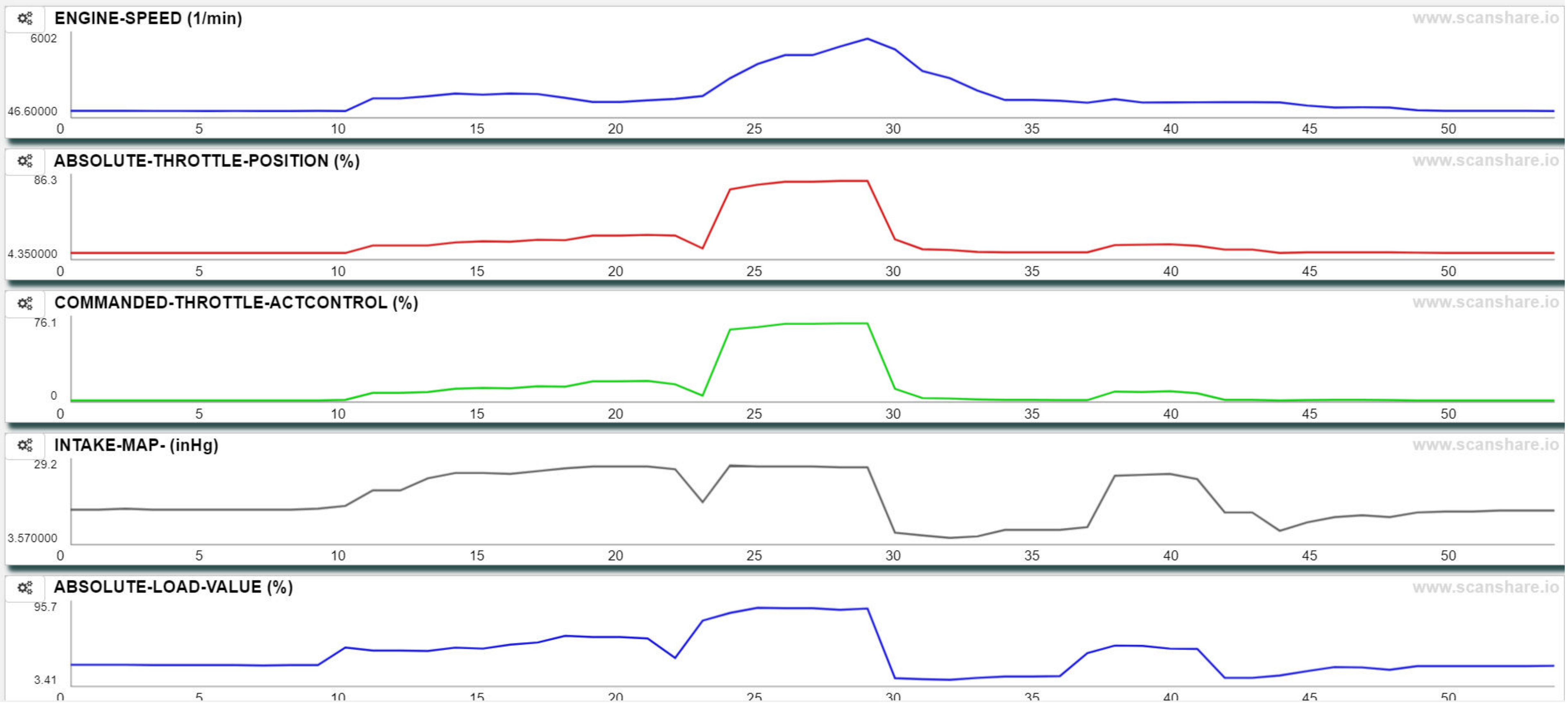
- Gather data to make diagnostic decisions
- Road test flushes faults to surface
- Divide data into groups
- Analyze data PID groups like puzzle pieces
- Assemble puzzle pieces
    - *G test vs. P tests*
    - *Data driven analysis*
    - *Limited hands-on testing*

Driveability Test Drive



Less Than a Minute

Driveability Test Drive



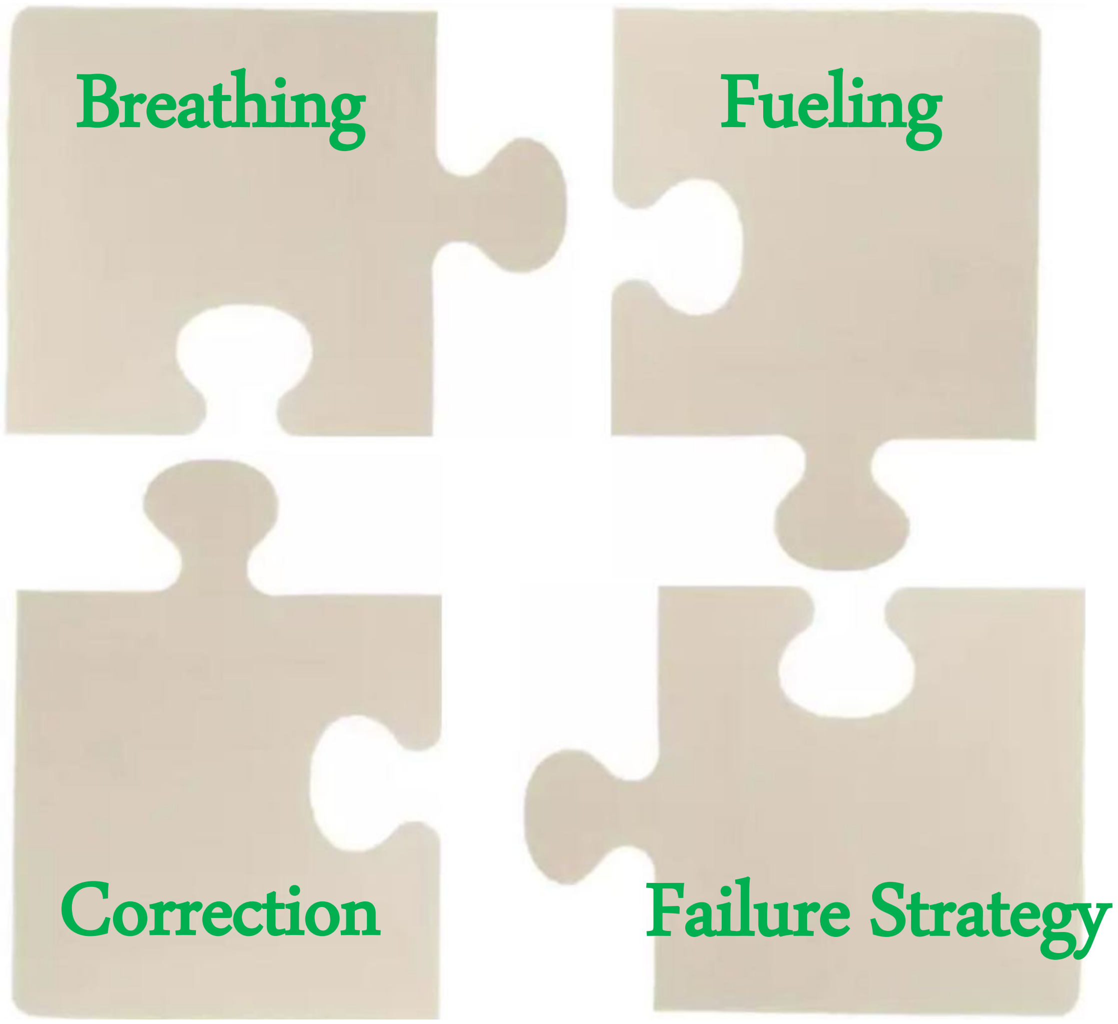
10 Sec Idle | 15 Sec Light Acceleration | 5 Sec WOT | 5 Sec Decel | 10 Sec Cruise | 10 Sec Idle

Use Caution

- Limit PIDs captured
  - *Refresh rate*
  - *Maintain sanity*
- Save “files”
  - *Manipulate after capture*
  - *Share, save to cloud*
- Use scan tool buffer
  - *Action/reaction testing*
  - *History provided*
  - *DO NOT VIEW WHILST DRIVING*

Parameter Identifiers Groups (PIDs)

- Smaller groups per section
- Include PIDs reflecting operating conditions
- Answers questions we have about driveability
- Prevents confusion
- Organizes thought process
- Focus



Airflow PIDs

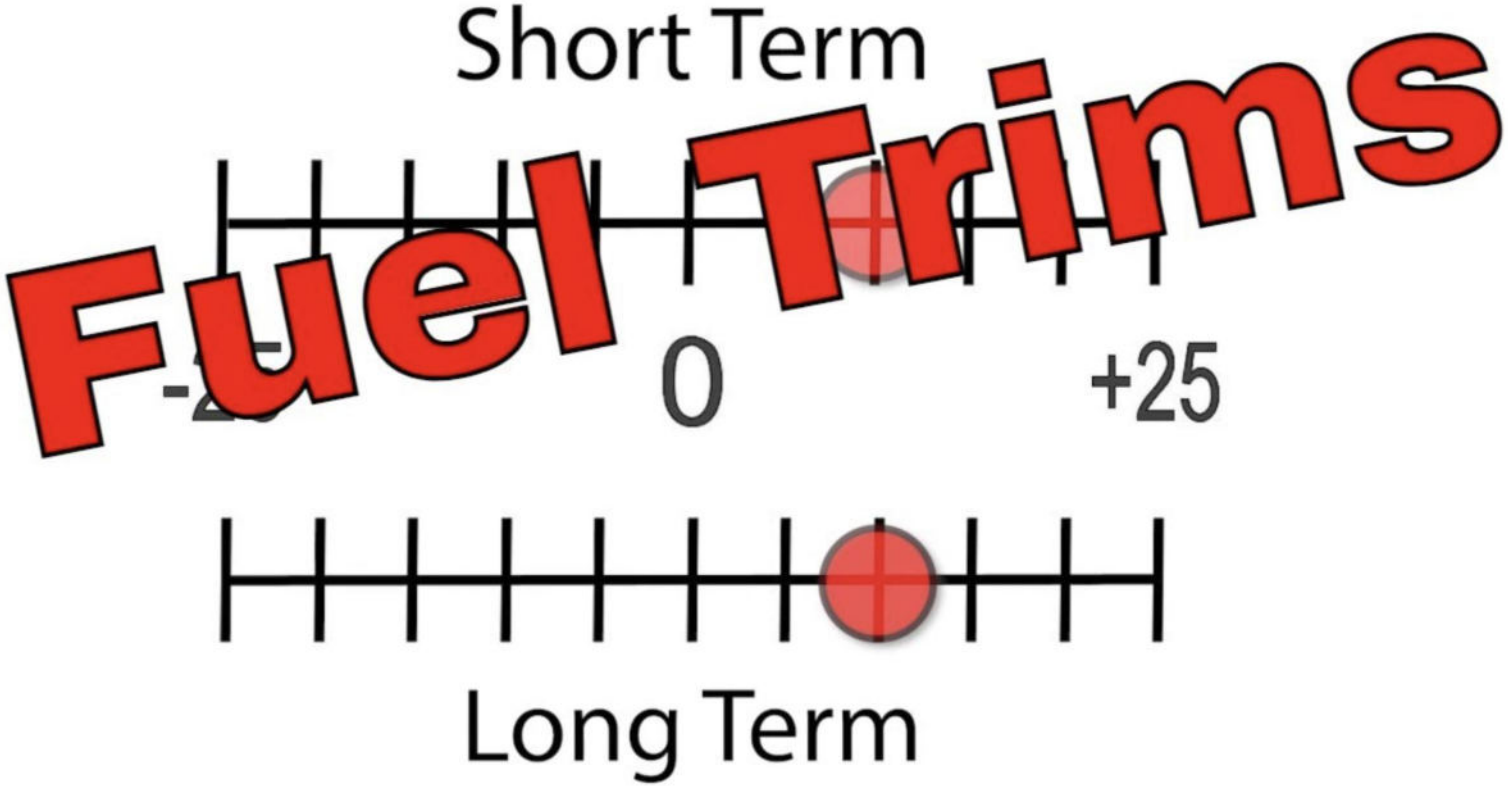
- RPM
- MAP
- MAF
- Calc_Load
- ABS_Load
- APP (actual/desired)
- TAC (actual/desired)
- IAT
- BARO
- Boost

Fuel PIDs

- HO2s / WRAFs
- Low-pressure system fuel pressure
- Fuel rail pressure (FRP)
- Equivalence ratio (EQR) or Lambda
- Fuel system loop status
- Commanded EQR or Commanded Lambda
- Load PIDs
- Throttle PIDs

Adaptive PIDs

- STFT
- LTFT
- Rear Fuel Trim
- EQR
- Loop Status
- RPM
- Load PIDs
- Throttle PIDs



Protection PIDs

- Fuel system loop status
- MIL commanded "ON"
- "Reduced Power" message/symbol
- Throttle
  - *Desired position*
  - *Actual position*

Verify Sensor Accuracy

- Key-ON, Engine OFF
- After 8hr cold-soak
- Monitor PIDs statically
  - *Pressure*
  - *Temperature*
  - *Position*
  - *Voltages*

Be aware of how PIDs are referenced

Tech Support Case Studies…

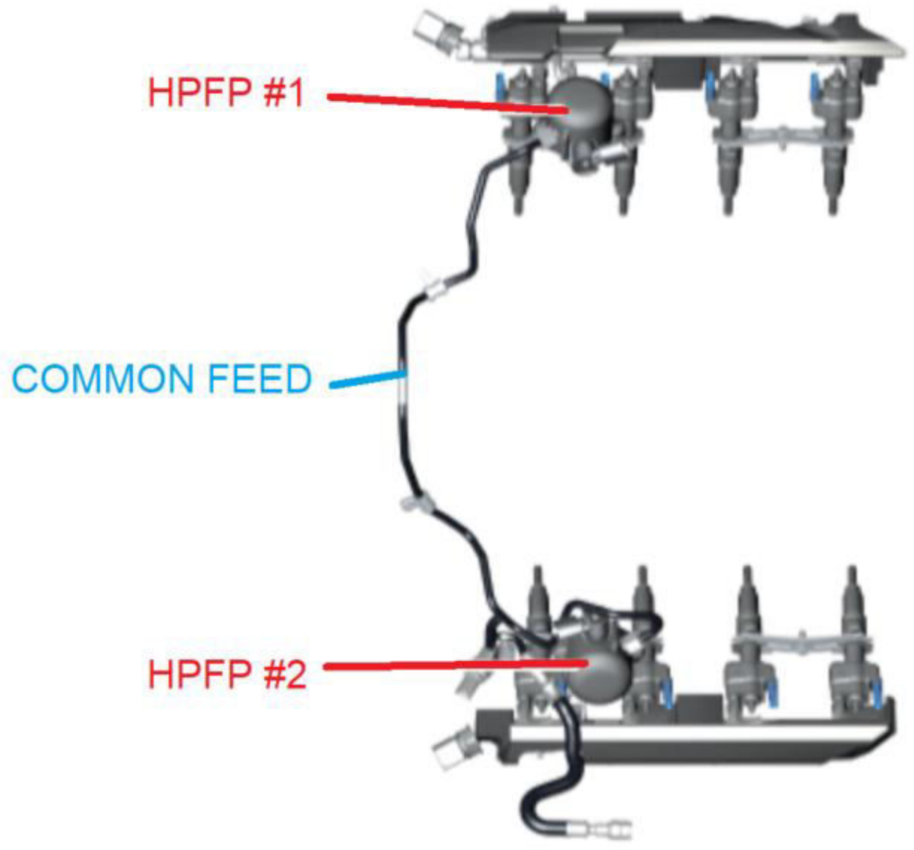
- Fixed over the phone
- Acquired AFAD PIDs
- Performed Driveability Road Test
- Preliminary data led to the pinpointed testing

2014 BMW X6

P0303 sets above 4000 rpm

Subject Vehicle Background

- V8 engine
- Turbo charged
- Twin independent GDI (pumps/rails/FRPs)
- 2 MAFs
- P0303, loaded above 4000 rpms



How is the Vehicle Performing?

- Lean under heavy load
- Command near stoichiometry
- Lambda 1.36 (36% lean)
- Rear HO2 sensor @ .074 V (not visible)
- Load is dropping?

Why is the engine under fueled?

Possible Causes of Under Fueling

- Faulty GDI high pressure pump(s)?
- Faulty low pressure fuel supply pump system?
- Restricted injectors?
- Air mass calculation?
- Faulty WRAF sensor?
- Faulty Rear HO2 sensor?

Is the Engine Breathing Correctly?

- Injection based upon airflow
- Engine is not pumping adequately
- Can an engine breath efficiently with throttle closed?

Take notice of the throttle position

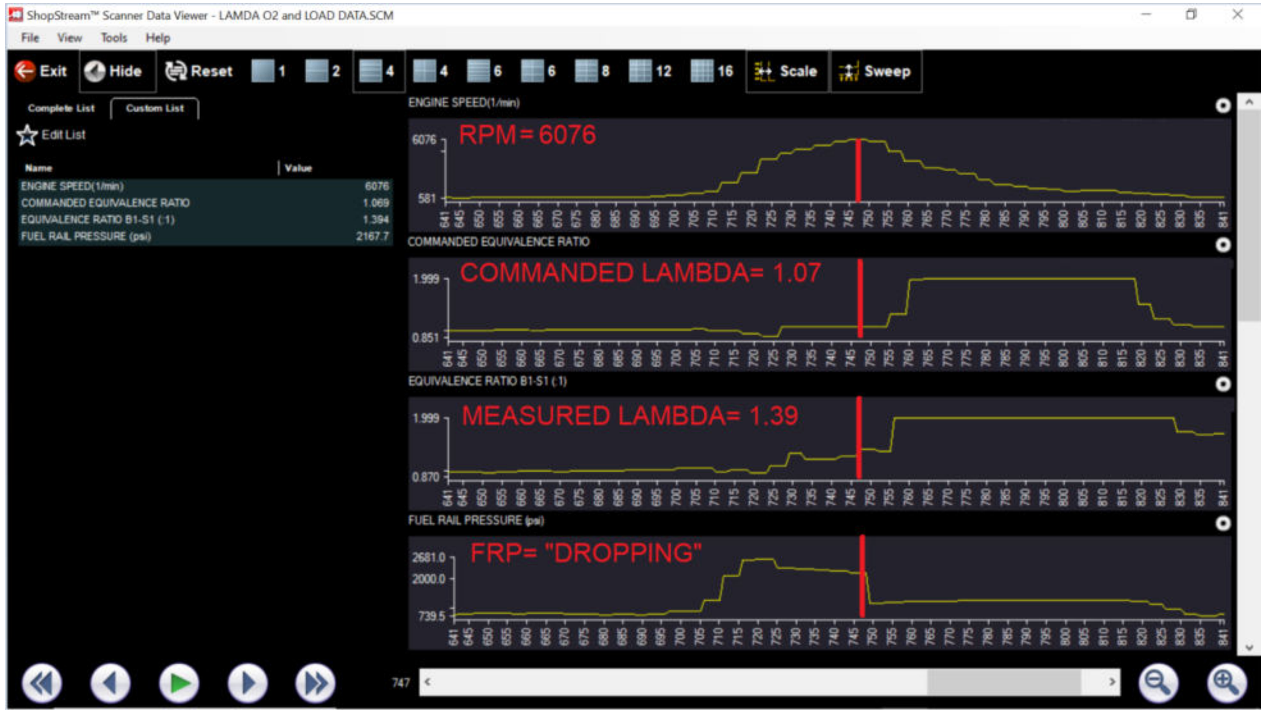
Why Command the Throttle Closed?

- Newer strategy
- How to correct for a lean condition?
  - *Increase fuel delivery to maintain A/F ratio*
  - *Reduce airflow to maintain A/F ratio*

Not the "cause," but the "effect"

Is the Engine Being Fueled Correctly?

- Road test under load
- 39% lean of stoichiometry (Lambda 1.39)
- Increase in load, decrease in FRP
- Occurred on both banks



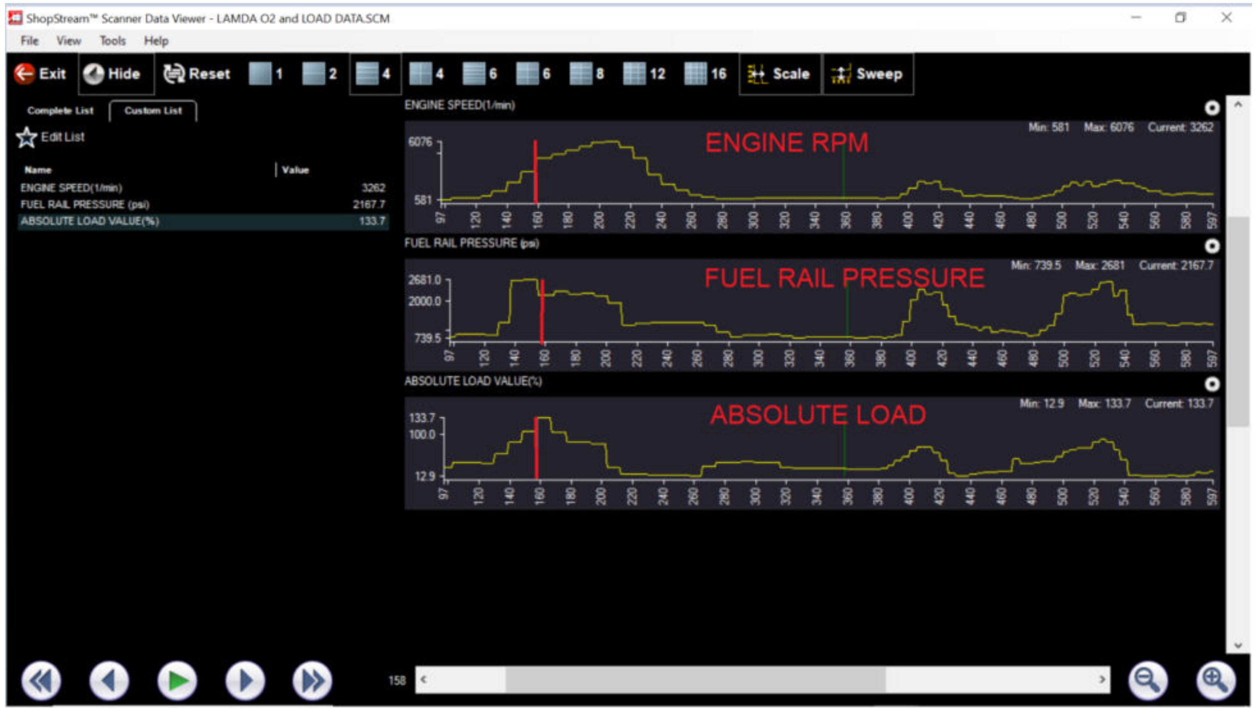
Why would FRP be dropping?

Potential Causes of Low FRP

- Poor high pressure pump operation?
- Advanced cam timing issue?
- Control solenoid issue/control issue?
- Poor low pressure supply issue?

Chicken or the Egg?

- Which dropped out first?
- Compare PIDs
- Use cursor to measure
- Breathability issue is the "effect" of fuel issue



FRP dropped first, must chase that root-cause fault

Where Do We Go From Here?

- Replace both high-pressure fuel pumps?
- Replace the GDI injectors?
- Replace the low-pressure supply pump (in-tank)?
- Gather more info about low pressure supply system?

2019 Honda Fit

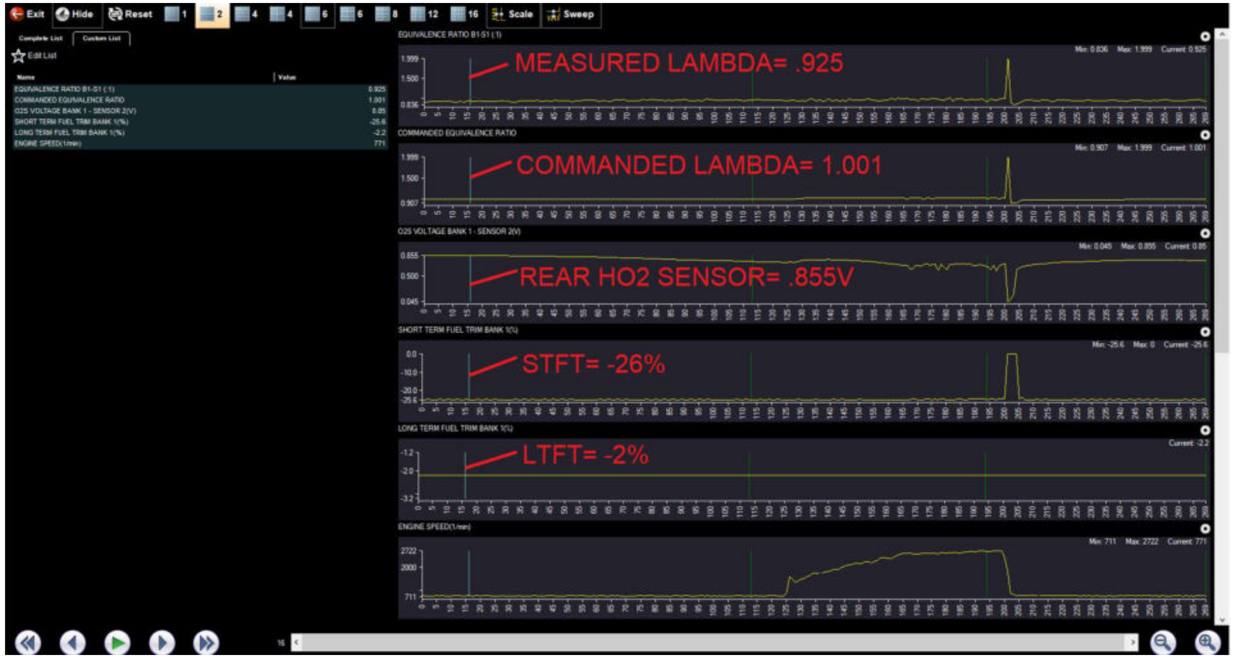
P0172- Bank #1, Rich Condition

Subject Vehicle Background

- P0172-Bank #1, Rich condition
- 4-cylinder twin cam, naturally aspirated
- MAF strategy
- Vehicle was taken on a driveability road test

How is the Vehicle Performing?

- Commanded stoichiometry
- Lambda indicates 8% rich
- HEGOs both indicate "Rich"
- PCM attempting to compensate (trim)



Why is the engine over fueled

Possible Causes of Over Fueling

- Rail pressure too high
- MAF over estimating
- Exhaust leak (air ingested)
- Faulty fuel injectors
- Contaminated oil
- Fuel contamination
- Skewed HEGOs?

How is the Engine Breathing?

- Idle speed of 741 rpm
- MAF value of 2.4 gps is accurate
- -32% fuel correction is present

Fault is not breathability related

Change the Running Conditions

- Eng speed elevated to 2600 rpm
  - *Load?*
  - *Fuel demand?*

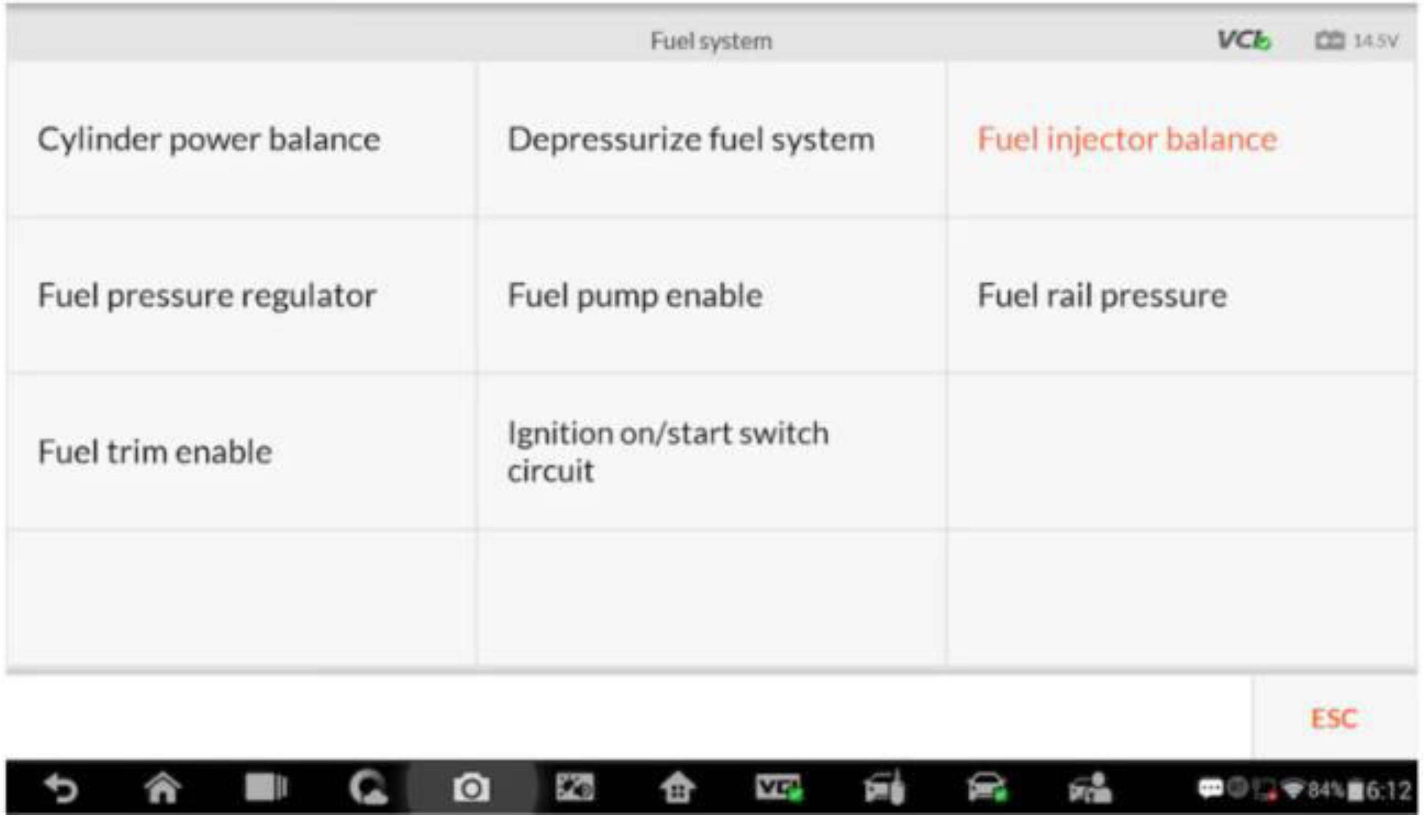
- What does this test prove?
  - *No leaking purge valve*
  - *No dribbling injectors*

Only a few possibilities…still in the driver's seat!

Remaining Possibilities

- Rail pressure too high?
- Exhaust leak (air ingested)?
- Contaminated oil?
- Fuel contamination/composition?

- Faulty fuel injectors



Diagnosis and Repair

- Road test to confirm fault
- Alter conditions to reveal fault
- Eliminate the impossible
- Focus on the probable
- Easy tests first

Minimal time under the bonnet!

Preliminary Diagnostics Summary

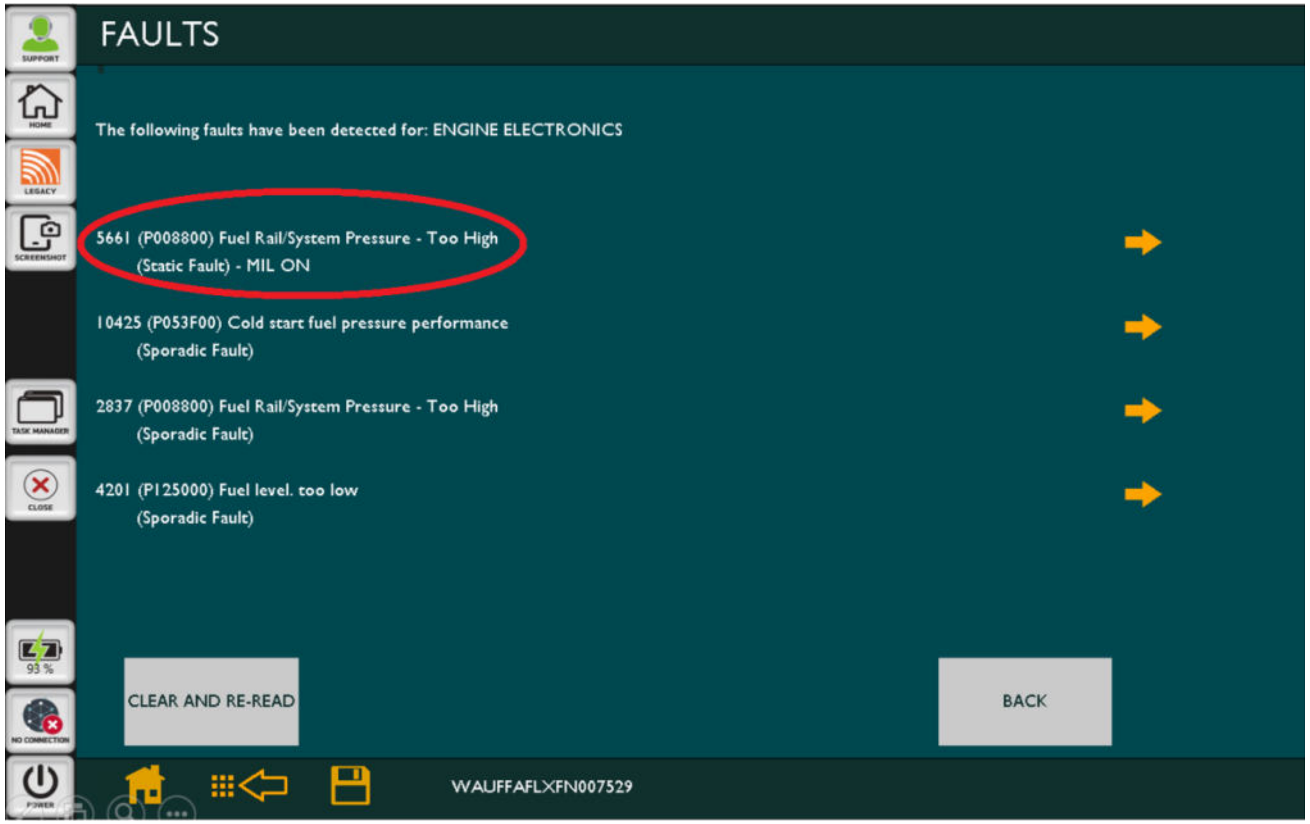
- Proper interrogation
- Design you PID groups
  - *Breathability*
  - *Fueling*
  - *Corrective Factors*
  - *Protection strategies*
- Carry out your Diagnostic Test Drive
- Analyze ALL GROUPS before diagnosis

2013 Audi A4 2.0L

High Rail Pressure

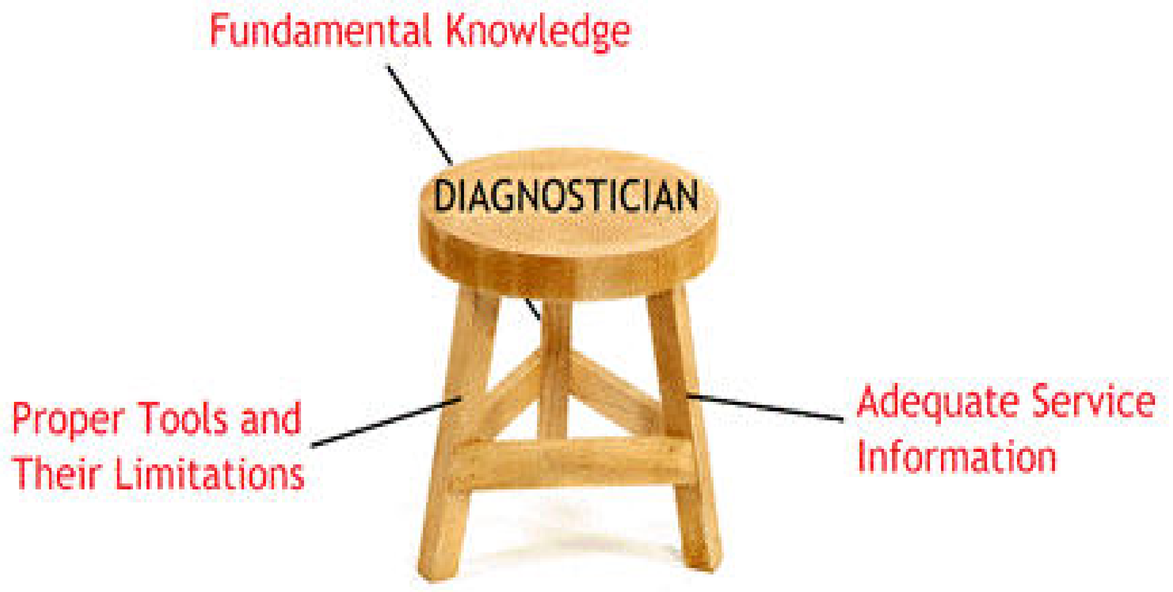
Towed From Another Workshop

- Shop states "High fuel rail pressure"
- Previous repair attempts:
  - *HPFP replacement (x2)*
  - *Fuel rail pressure sensor replacement*
- Scan DTCs…P008800 "Pressure too high"



Fundamental Knowledge

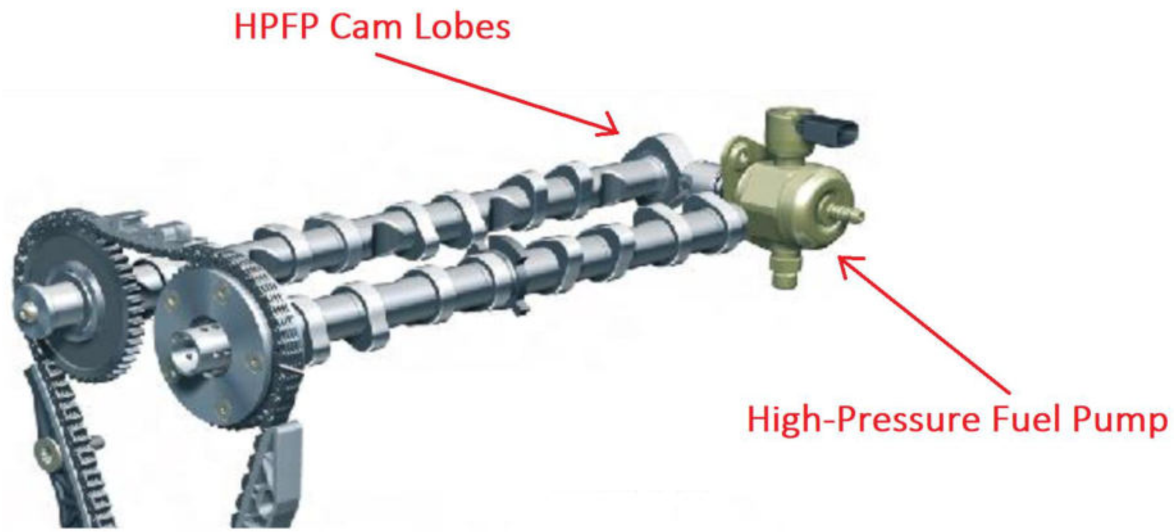
- The HPFP produced more fuel pressure than desired
- PCM recognized the fault
- Logical process likely eliminates:
  - *Low-pressure fuel pump failure*
  - *Fuel pump control module failure*
  - *HPFP failure (would lack pressure)*
  - *FRP sensor (replaced already, low on suspect list)*



Causes of Higher-than-desired rail pressure?

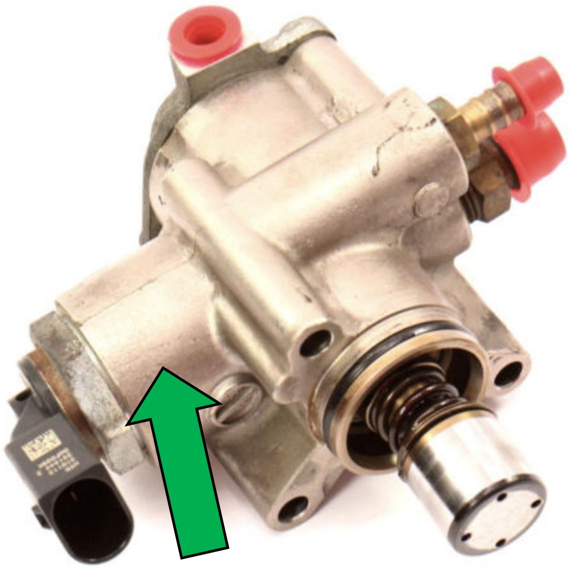
How Rail Pressure is Made

- HPFP is driven by exhaust camshaft (Configuration?)
- Four lobes stroke pump piston
  - *Pumped stroked 4x per cam rotation*
  - *Fuel must be trapped to produce pressure*
  - *Fuel volume regulator valve must close*
- FRV solenoid attached to pump assembly (Configuration?)



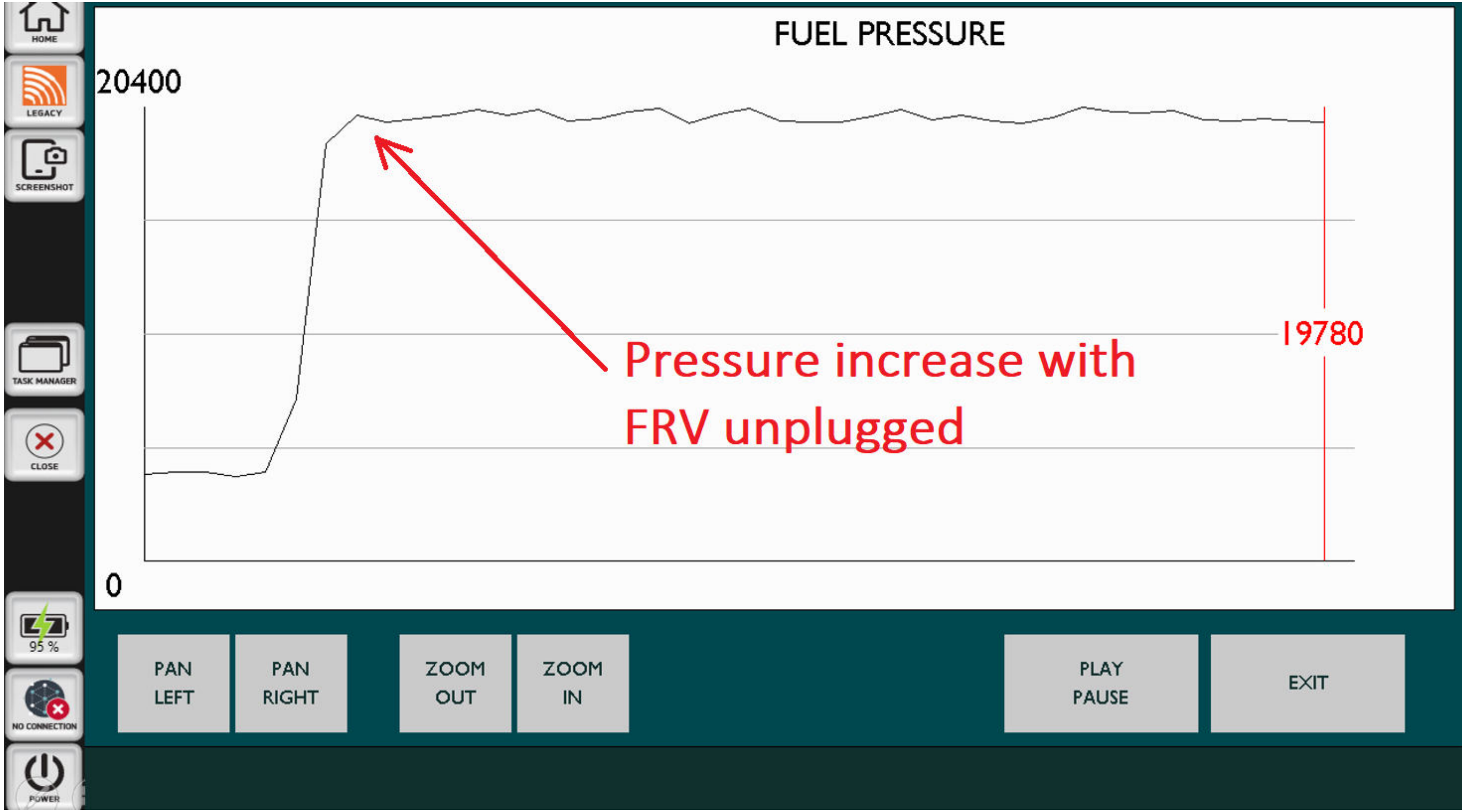
FRV Functionality

- FRV acts like a trap door
- Piston action generates pressure against FRV
- Open valve allows fuel displacement
  - *Normally-Open*
  - *Normally-Closed*



Which design are we dealing with?

An Experiment



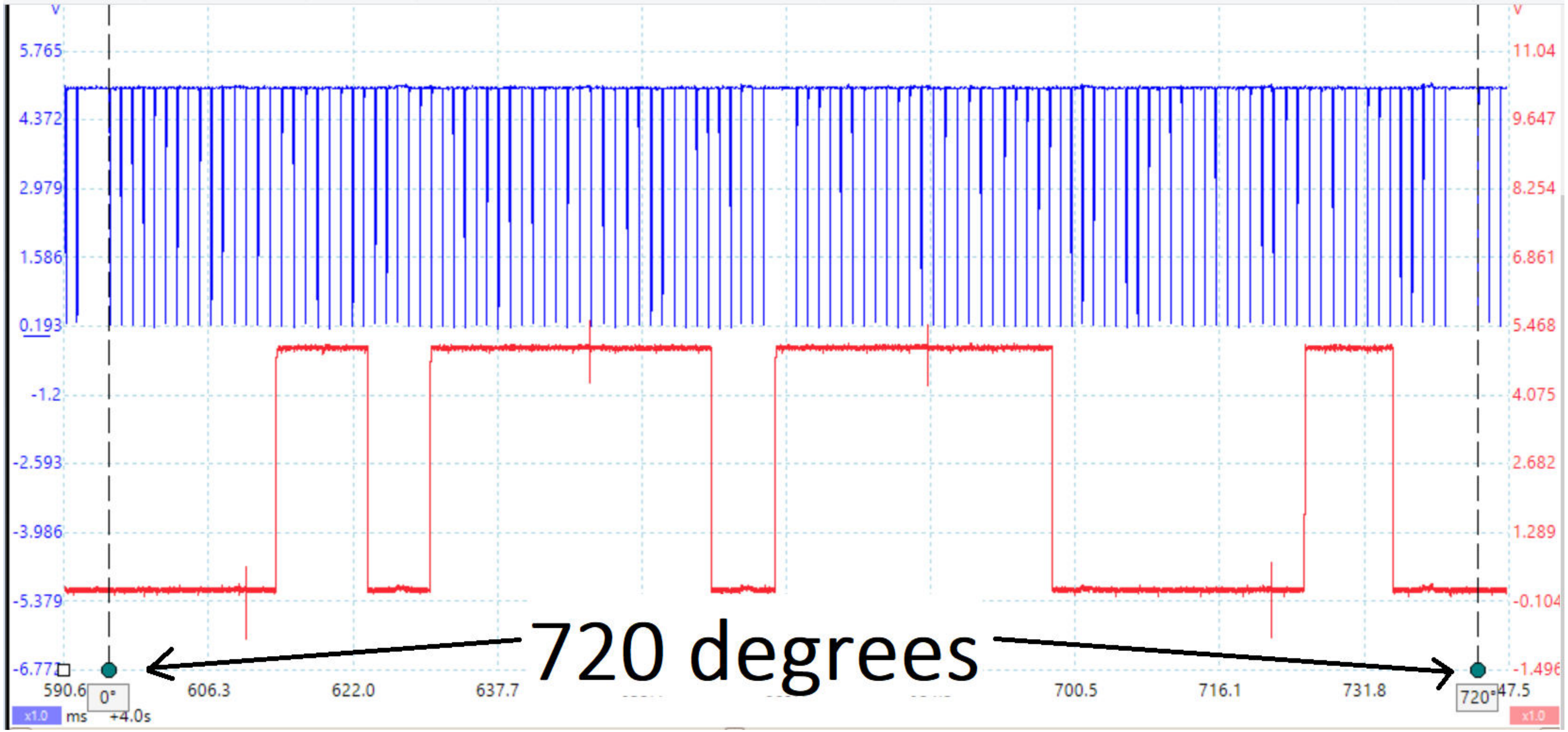
FRV Timing is Critical

- PCM energizes FRV to limit rail pressure
- Could the FRV be malfunctioning?
- Could PCM be sending incorrect command?
- Could the engine be out of time?
  - *No DTCs reflecting timing fault*
  - *Engine performs well*

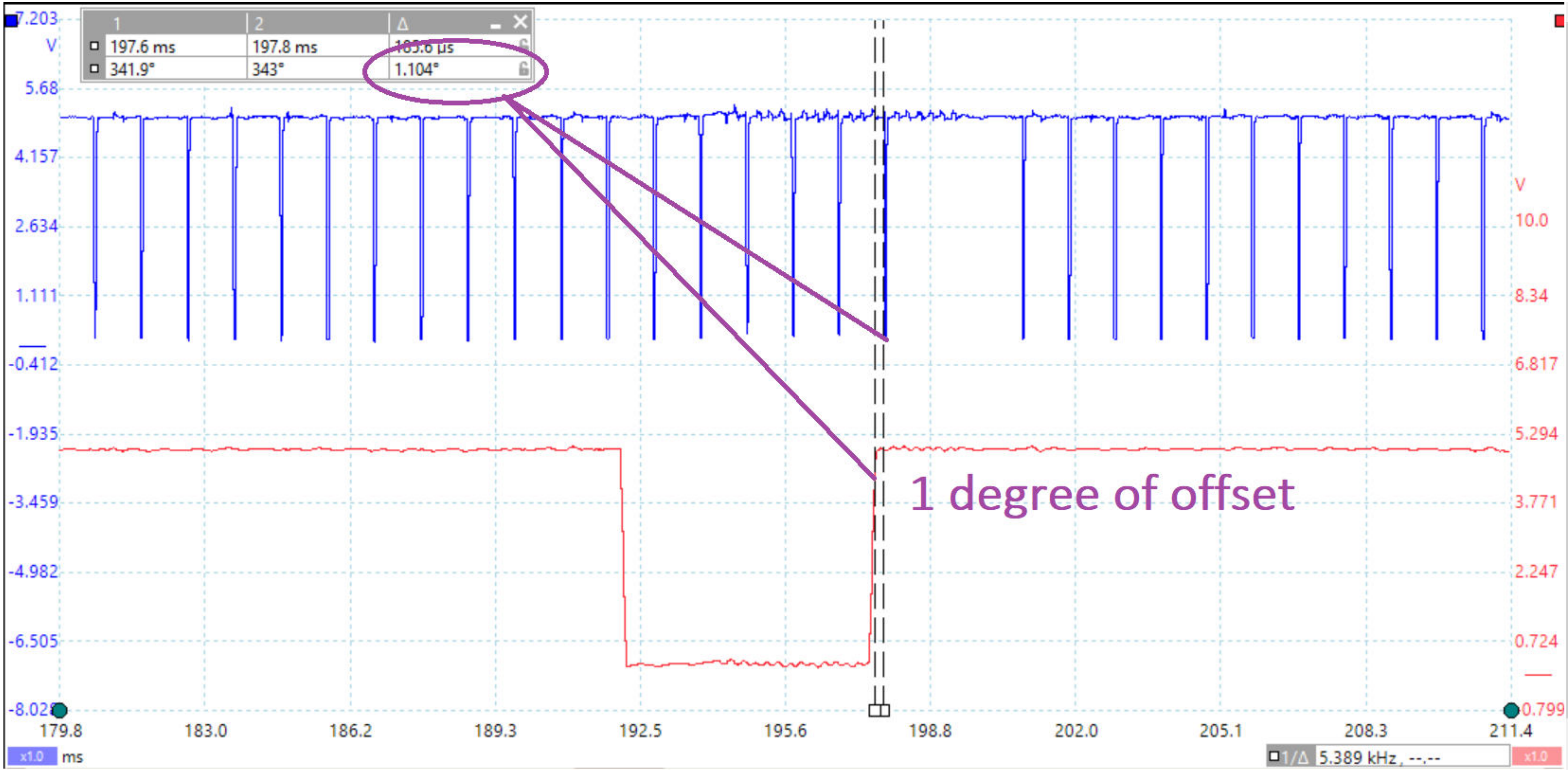
Thinking This Through…

- DTCs result from thresholds crossed
- Pump generates pressure with FVR closed
- Camshaft driven
- If cam is late, pump piston is late
- FRV timing same (relative to crank angle)
  - *FVR driven closed with more piston stroke*
  - *More stroke, more pressure*

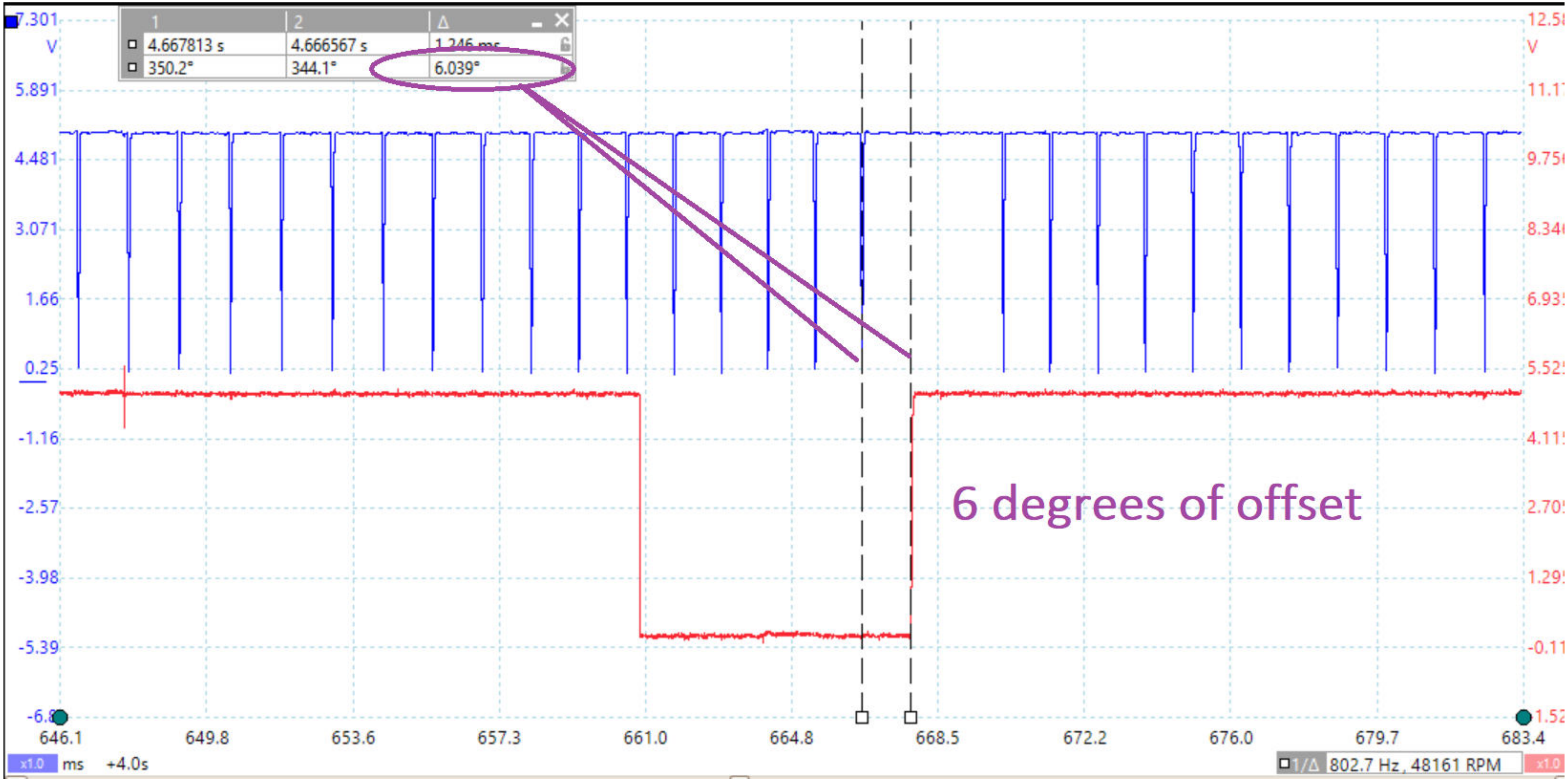
Determining Cycle time



Known-Good Capture

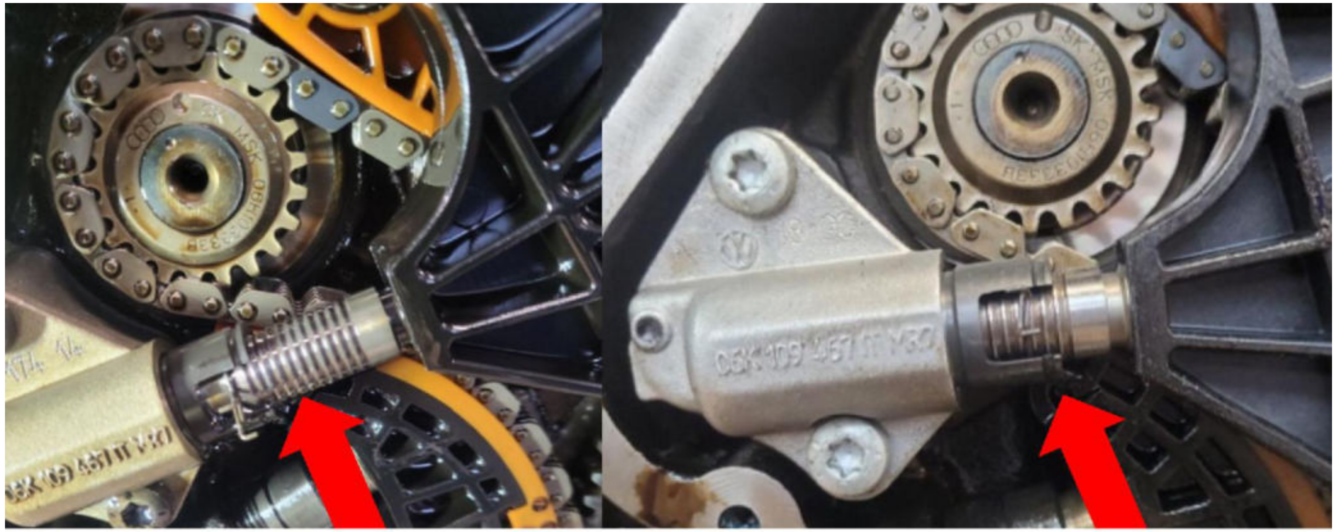


Suspect-Engine Capture



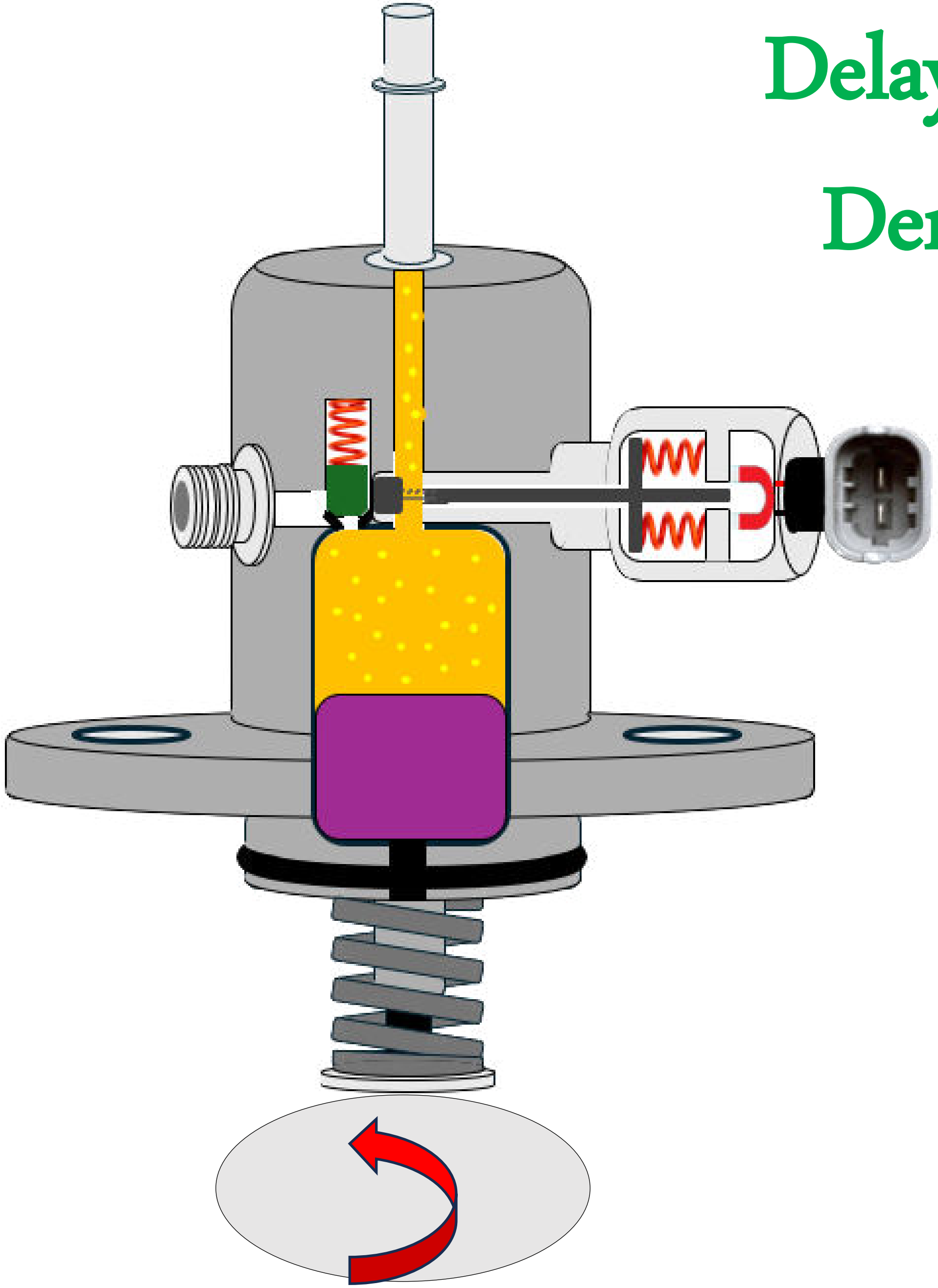
Results

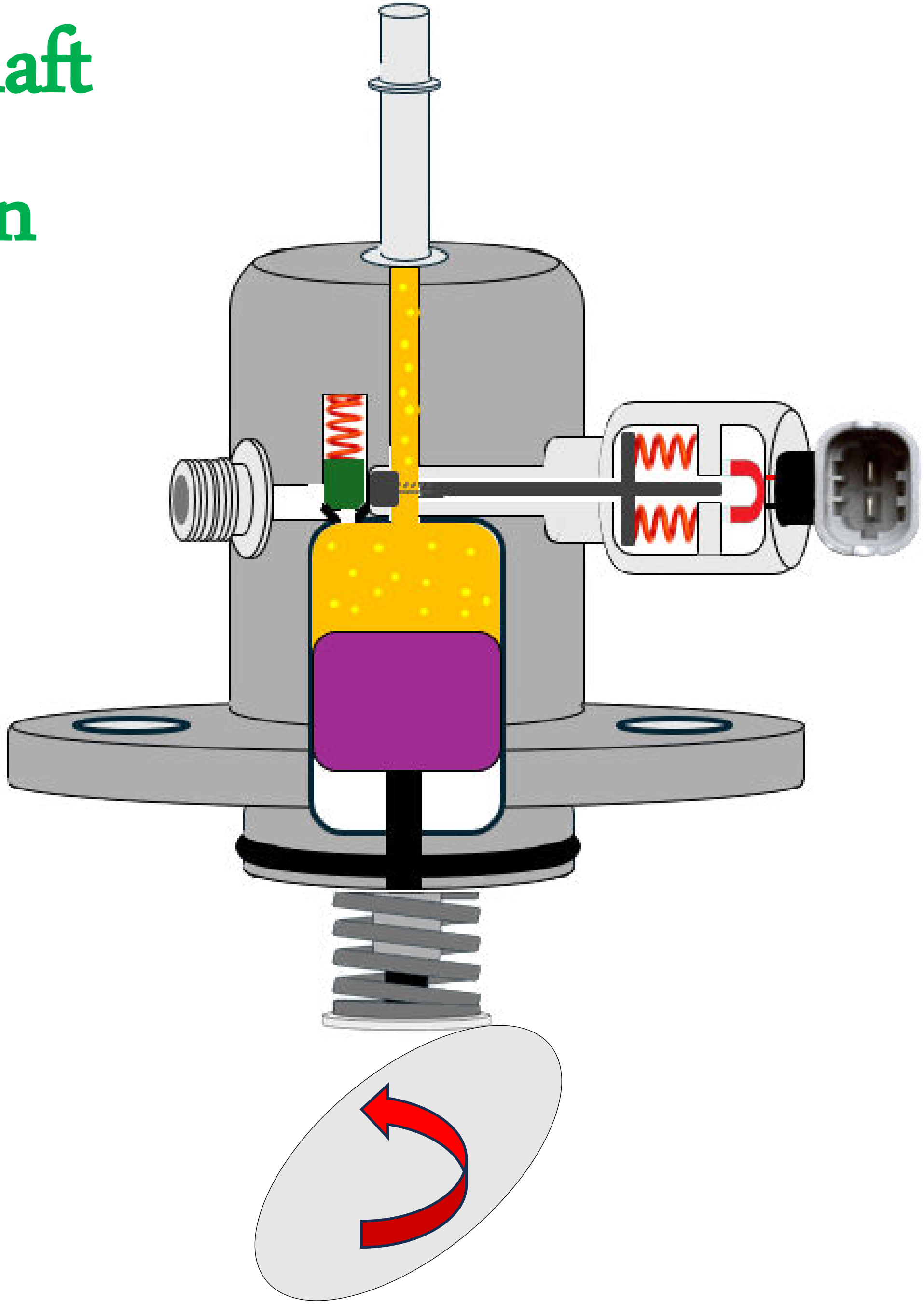
- Camshaft 5 degrees retarded (Stretched)
- Late camshaft = higher-than-desired FRP
- Low volume HP fuel system
- Justified disassembly
- No Timing DTCs?
    - *11 deg. threshold for DTC was not crossed*
    - *Breathability not drastically effected*



BAD GOOD

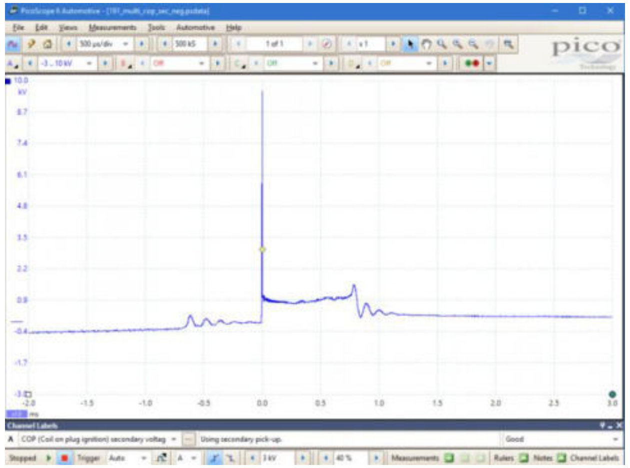
Delayed Camshaft Demonstration





Stepping-Stones from Preliminary Diagnostics

- **Causes of misfires:**
  - Engine mechanical
    - *Compression*
    - *Breathability*
  - Fuel Injectors
    - *Control*
    - *Spray pattern*
  - Ignition system
    - *Primary*
    - *Secondary*
  - Carbon issues
    - *VE*
    - *Density-misfires*



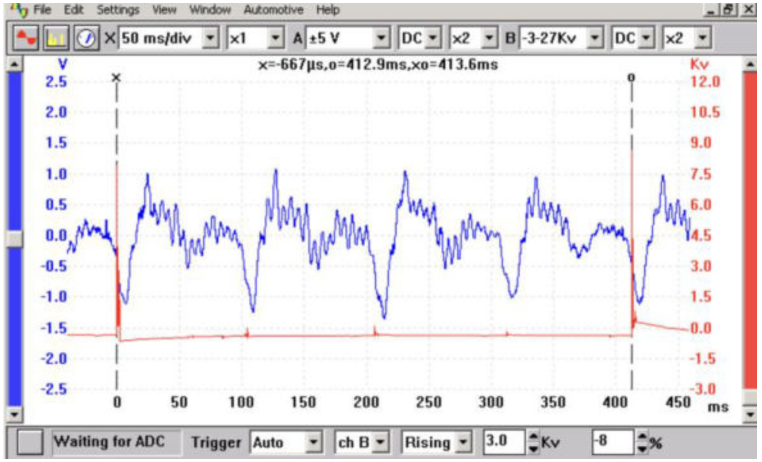
Ignition Waveform

- Combustion through the eyes of the scope
- Primary or secondary
- Efficiently obtained
- Applies to virtually all spark-ignition ICEs
    - *Become familiar with "good"*
    - *Bad becomes easily visible*

CAUTION: Use attenuation

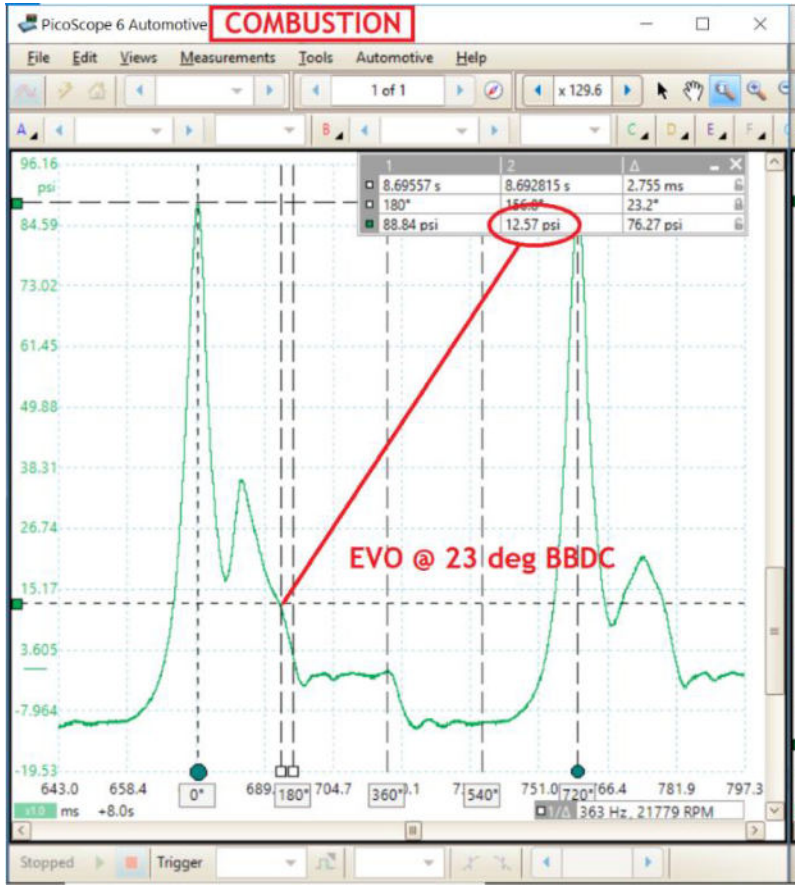
Engine Mechanical Testing

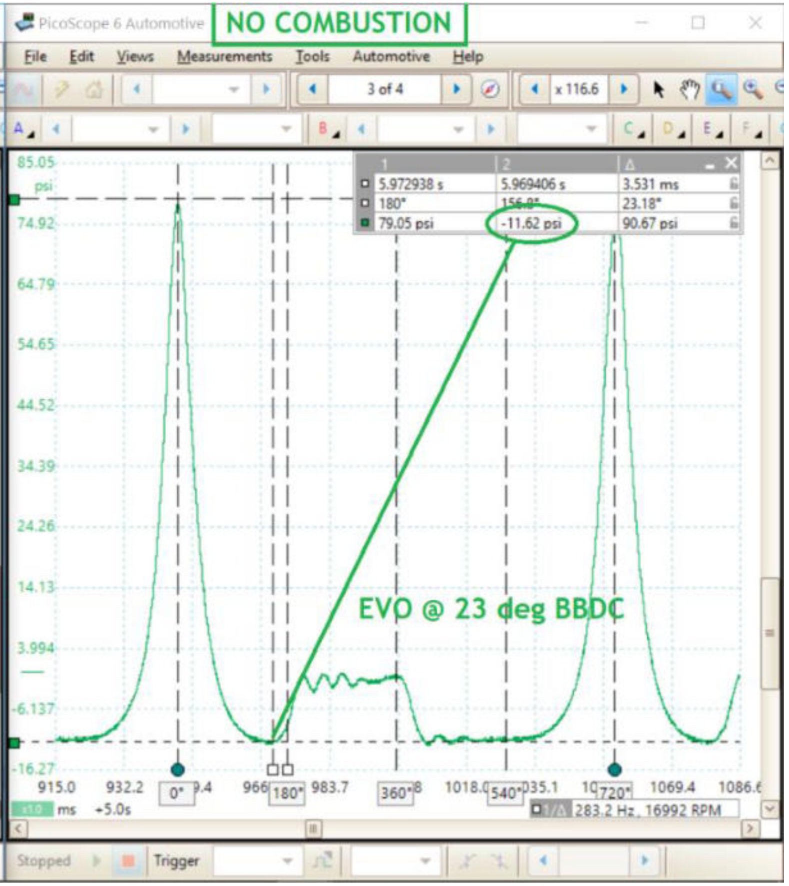
- Pressure transducers can indicate flow characteristics
- Cranking-Intake waveforms
  - *WOT*
  - *Delta sensors*
  - *WPS-delta mode*



Misfire Detection @ Tailpipe

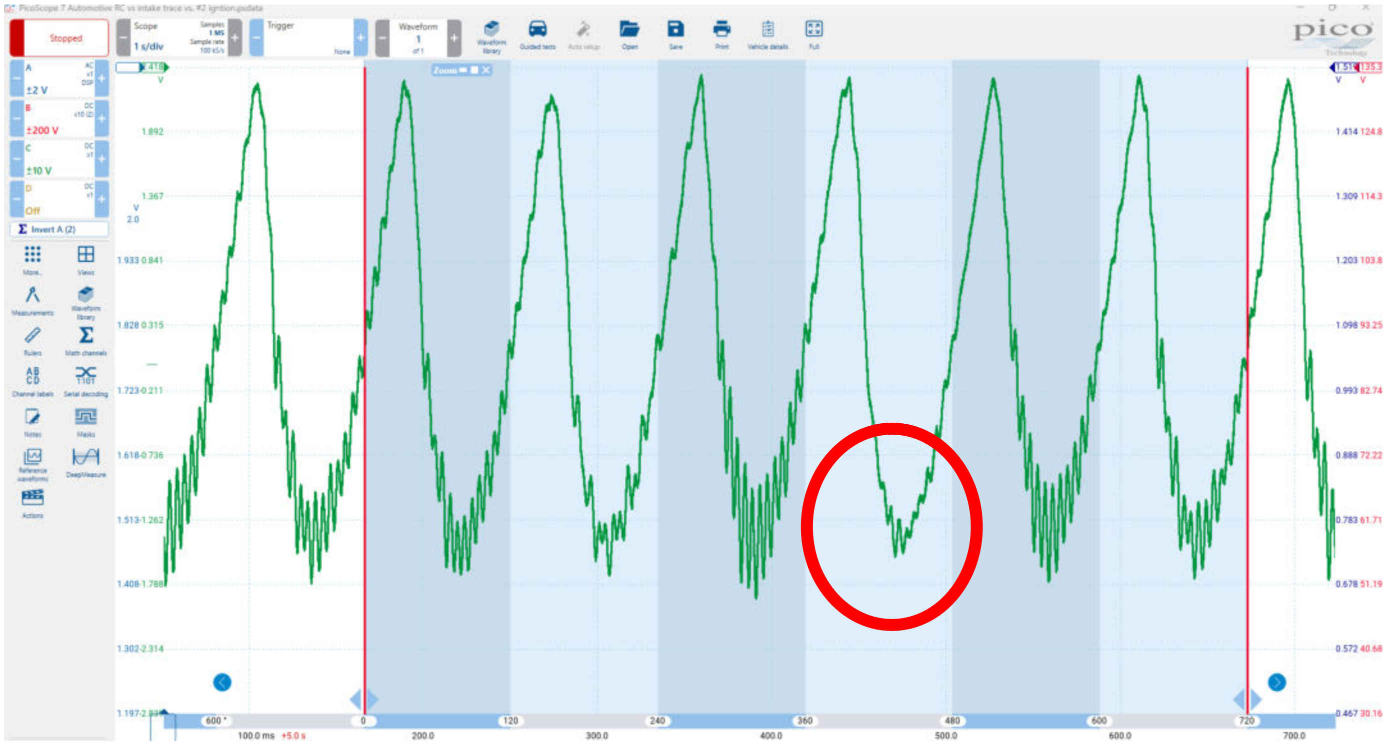
- Combustion = Pressure @ EVO
- Misfire = Vacuum @ EVO
  - *Exhaust gas has inertia*
  - *Dollar-bill test*





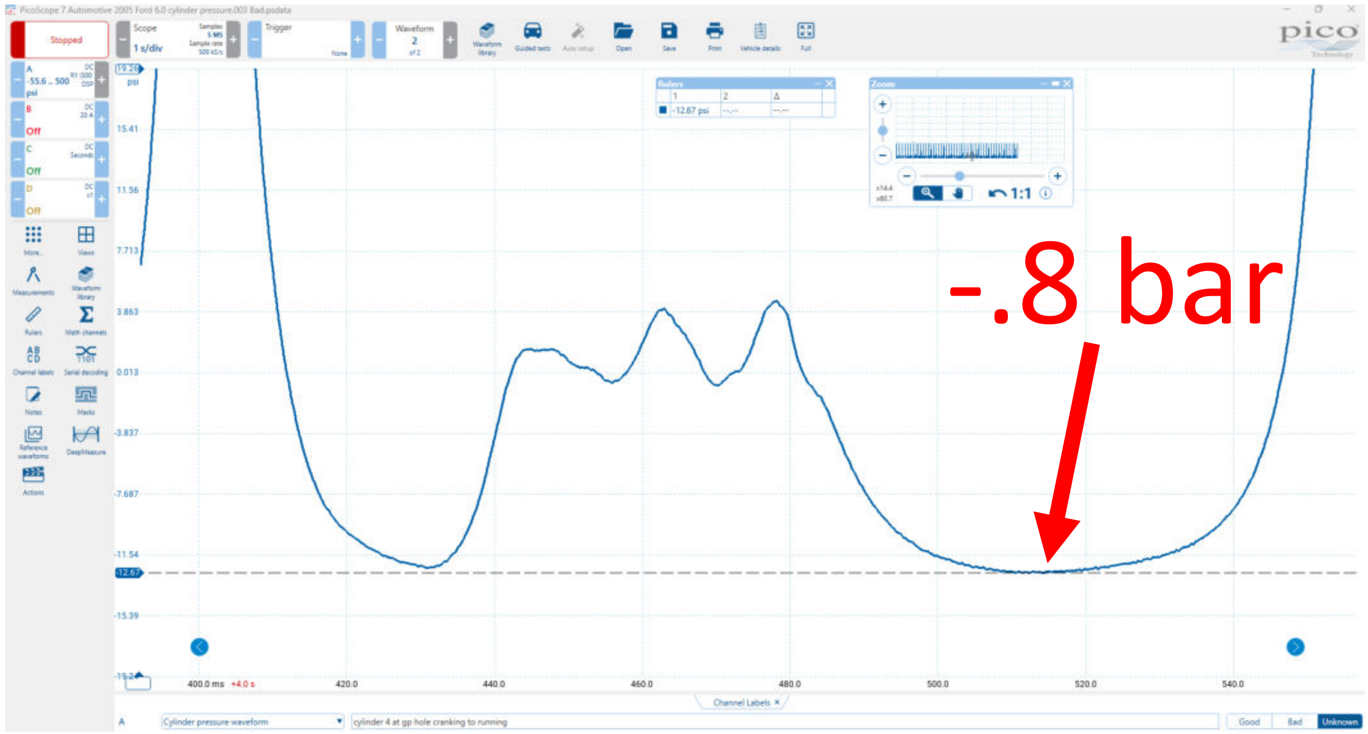
Cranking Intake Waveform

- Comparison from one pull to the rest
- All pulls should be similar
- Look for the "odd-man-out"
    - *Zoom/filter appropriately*
    - *Partition the waveform*
    - *Compare pulls*
    - *Note pull for suspect cylinder*



In-cylinder Pressure Testing

- Carbon creates restriction
- Hinders cylinder fill
- Driving conditions dependent
  - *High flow reveals fault*
  - *Cylinder can't inhale*
  - *Induction creates negative pressure*



Approaching Low-Pressure Systems

- Fuel pressure bi-directional controls
- Pump trim reset
- Holding pressure
- Fuel pressure sensor accuracy
- Current ramping/Lab scope testing
- Action/Reaction testing

Scan Tool Testing Low-Pressure System…

- Scan DTCs
- Command vs actual
- Bi-directional controls
    - *Drive FPCM with scan tool*
    - *Monitor command duty-cycle*
    - *Monitor feedback duty-cycle*

Fuel Pump Commands

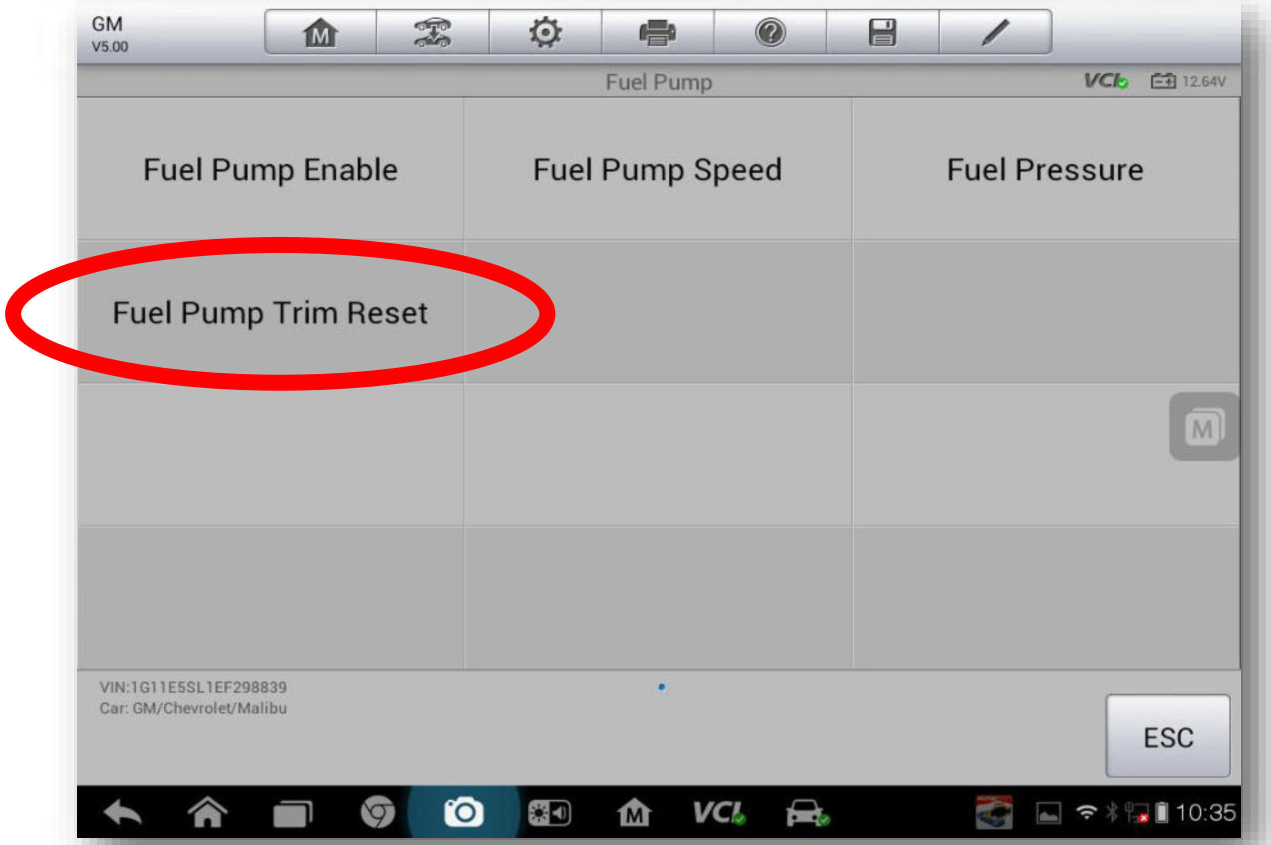
- Varies per YEAR/MAKE/MODEL (Service info)
- Duty-cycle based
- Can compensate for issues (Fuel pump trim)
- Several example commands used
  - *Invalid/off*
  - *Normal operation*
  - *Full-ON*
  - *Valid/OFF*

Fuel Pump Monitor

- Varies per YEAR/MAKE/MODEL (Service info)
- Duty-cycle based
- Several commands used
  - *Invalid data received*
  - *Normal operation or SRS Event Invalid*
  - *Problem with secondary circuit (Fuel Pum*

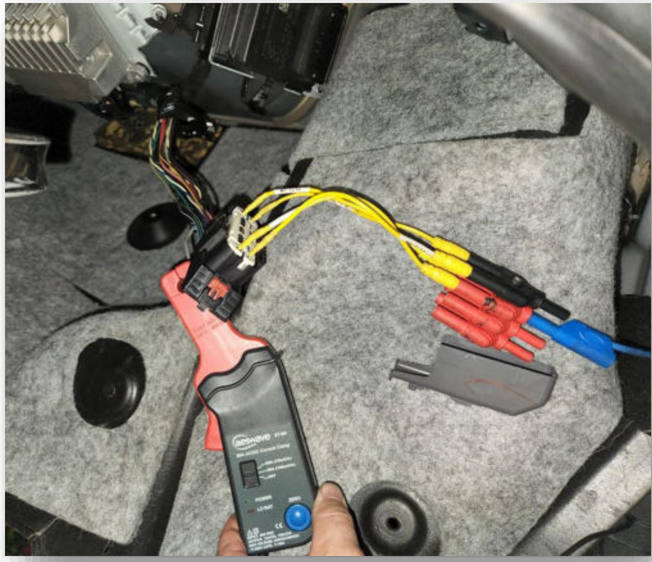
Fuel Pump Trim Reset

- PCM can compensate for low-pressure system
- Communicate with FPCM
- Increased pump command
- Must be reset after repairs



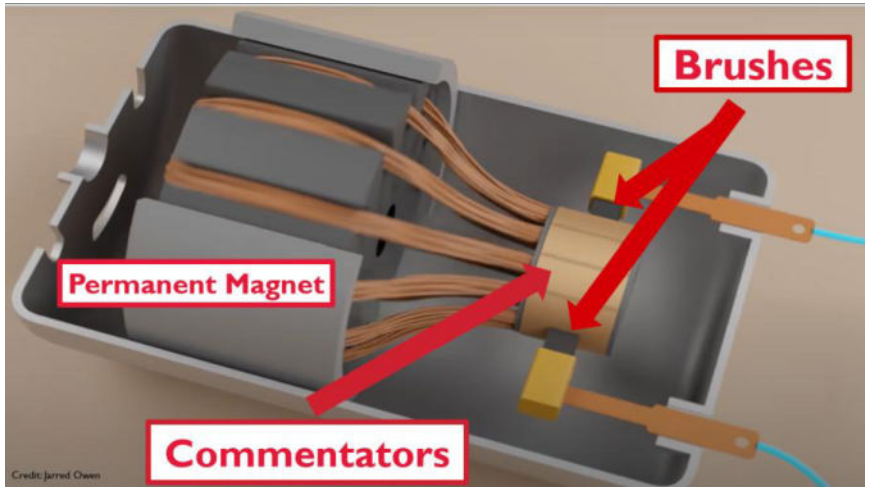
Scope Testing Low-Pressure System…

- Action / Reaction testing
- FPDM easy access (Configuration)
- Bypass testing
- Multi-channel lab scope
  - *Current = Pump circuit*
  - *Voltage = Command FPCM-to-Pump*
  - *Voltage = Request PCM-to-FPCM*
  - *Voltage = Voltage FPCM-to-PCM feedback*

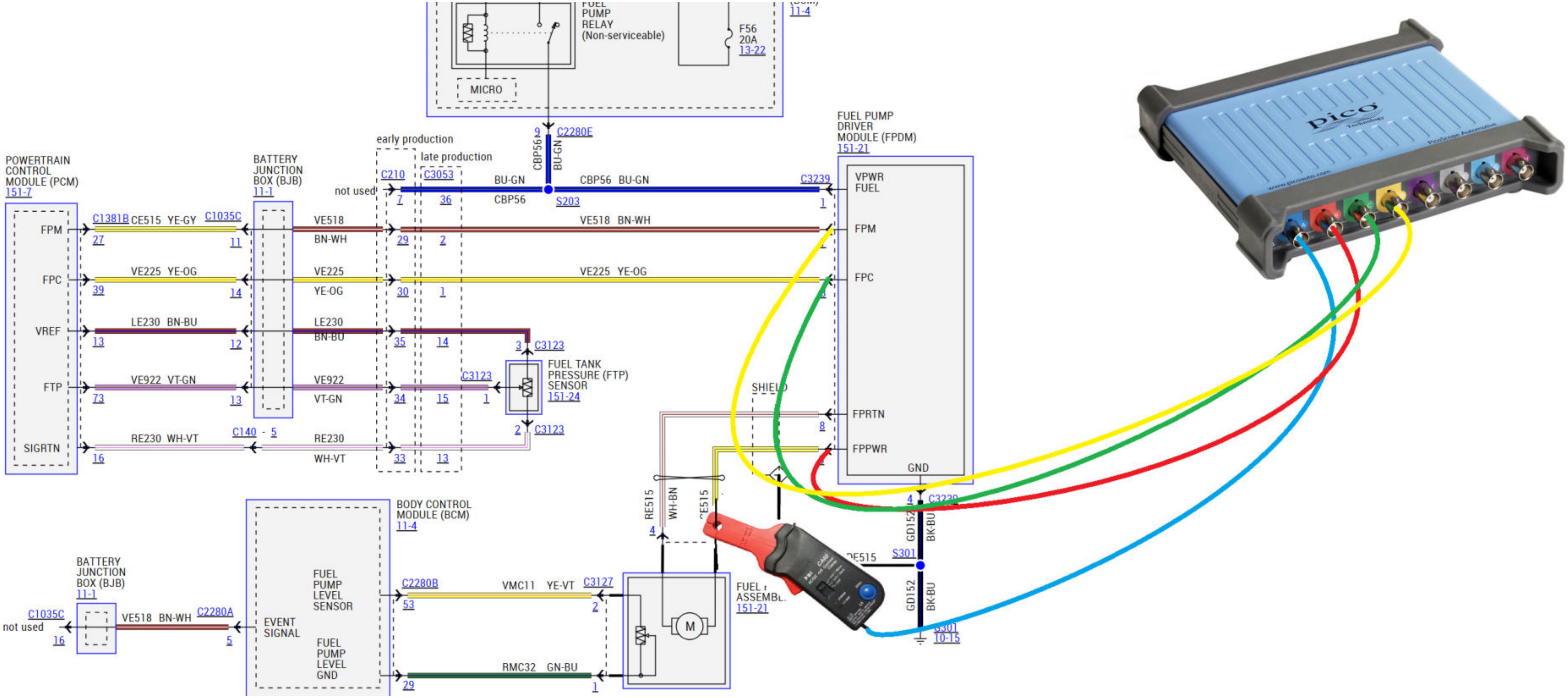


Current = Work Performed

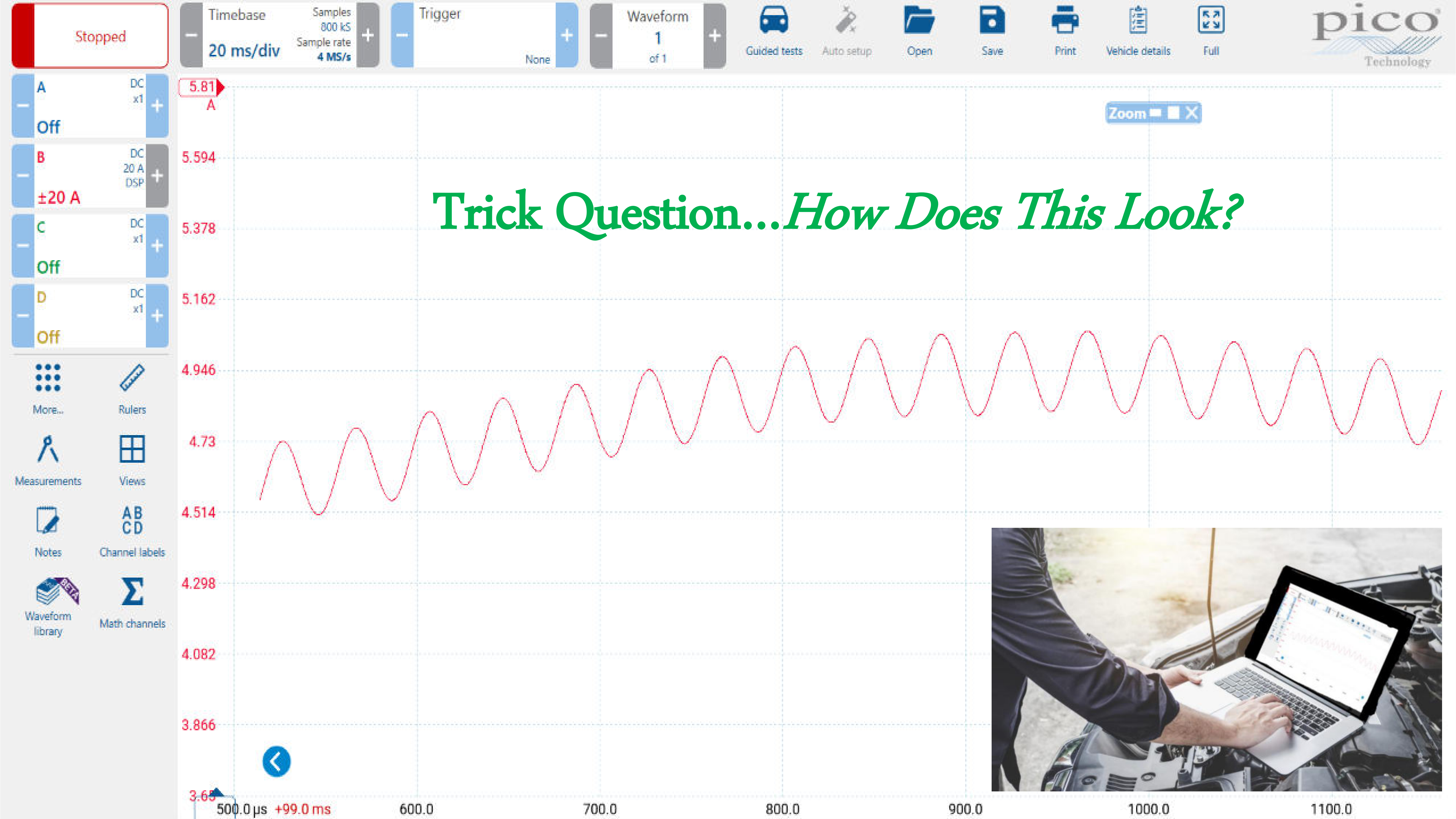
- Monitor Pump operation
  - *Pump speed*
  - *Pump average current*
  - *Pump armature health*

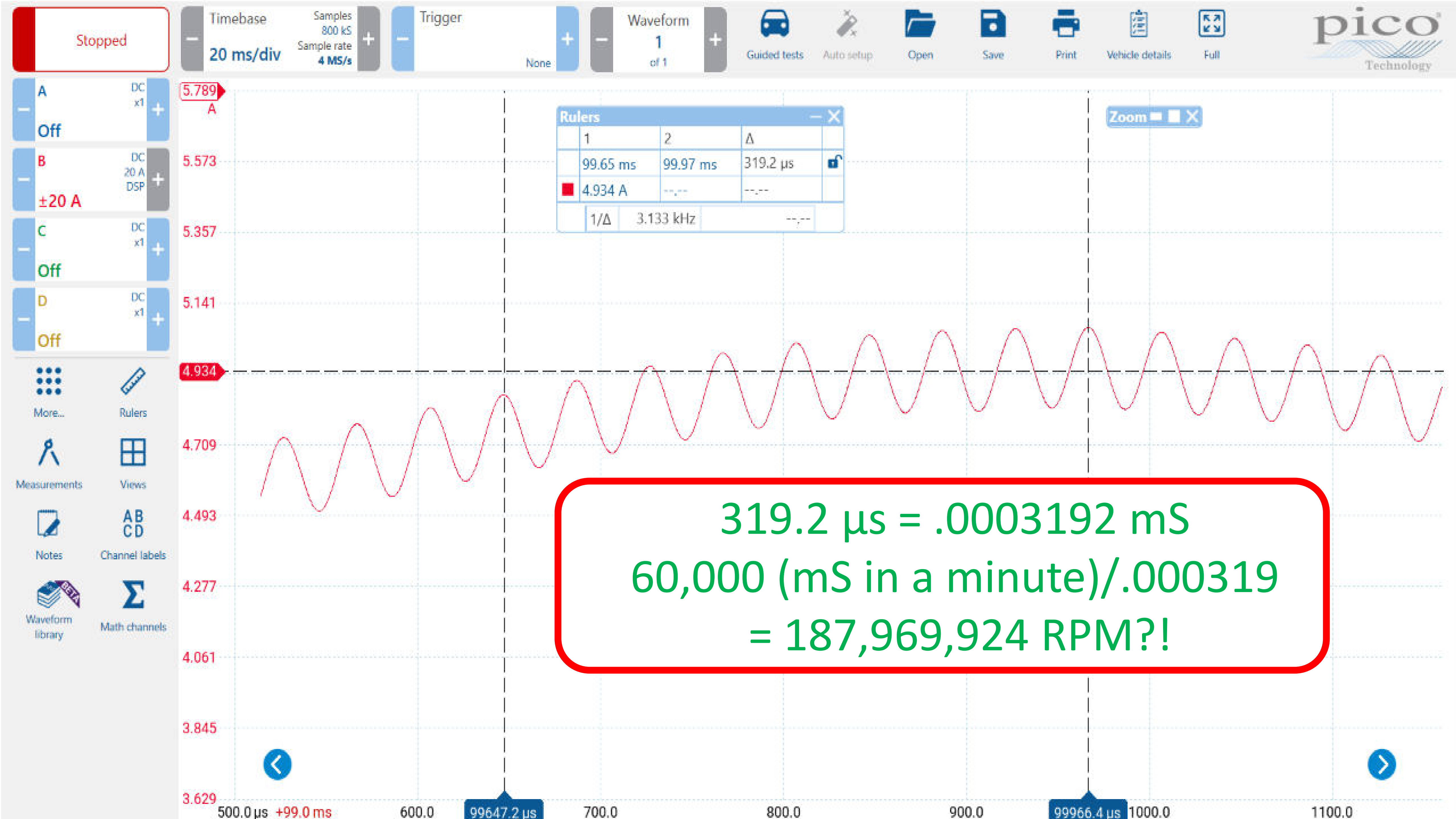


Low-Pressure Pump Wiring Diagram



Trick Question...*How Does This Look?*



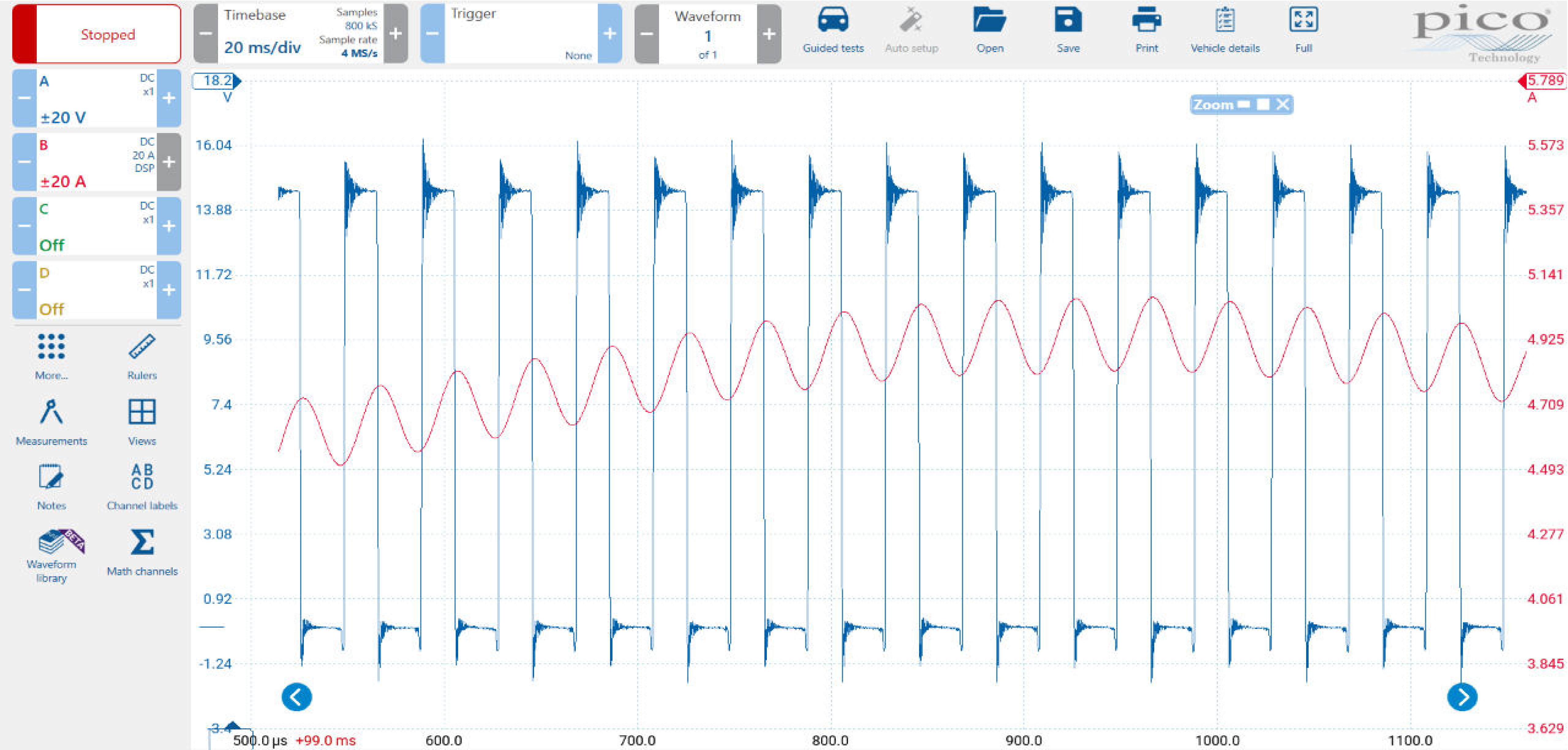


319.2 µs = .0003192 mS

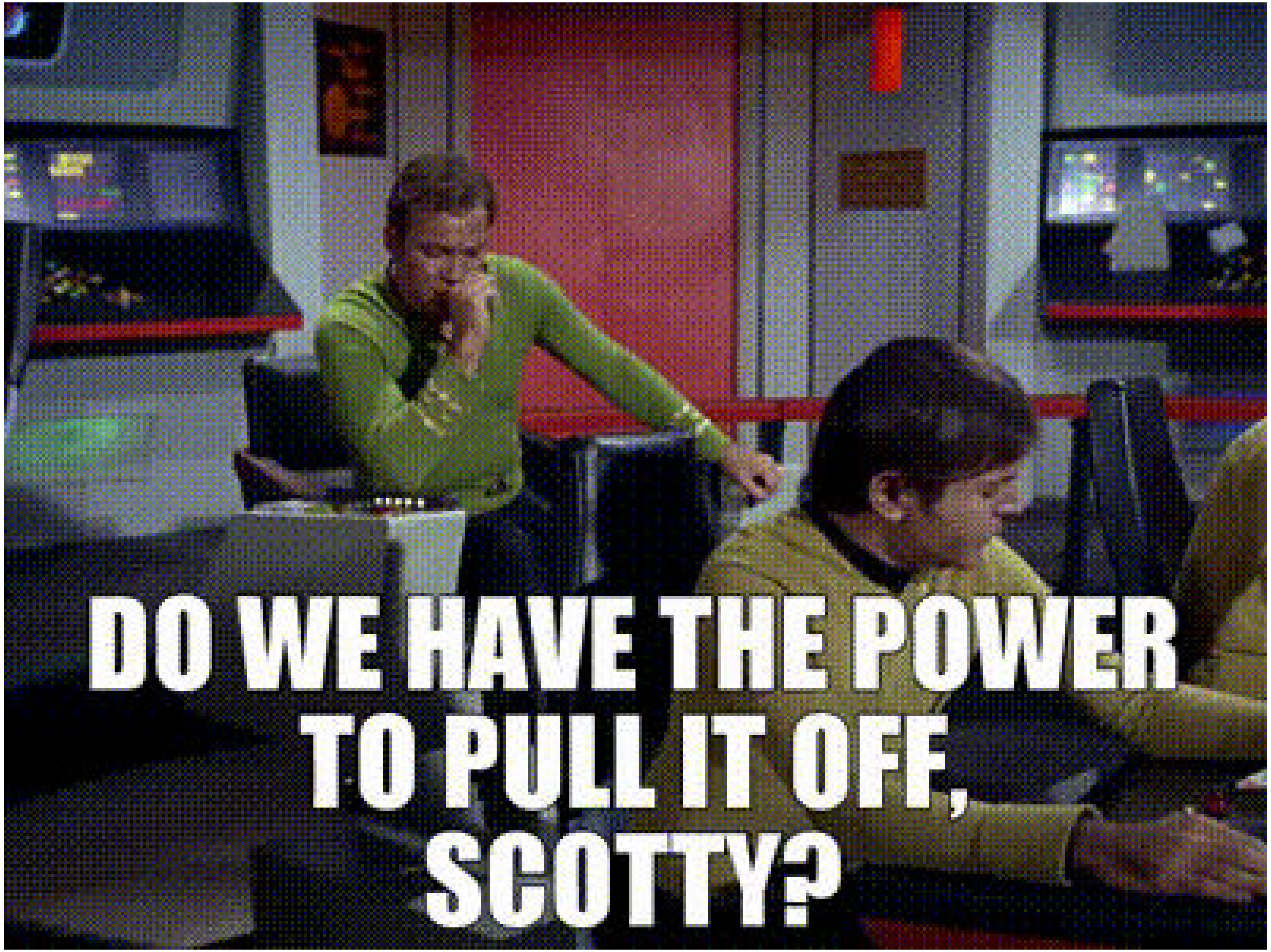
60,000 (mS in a minute)/.000319

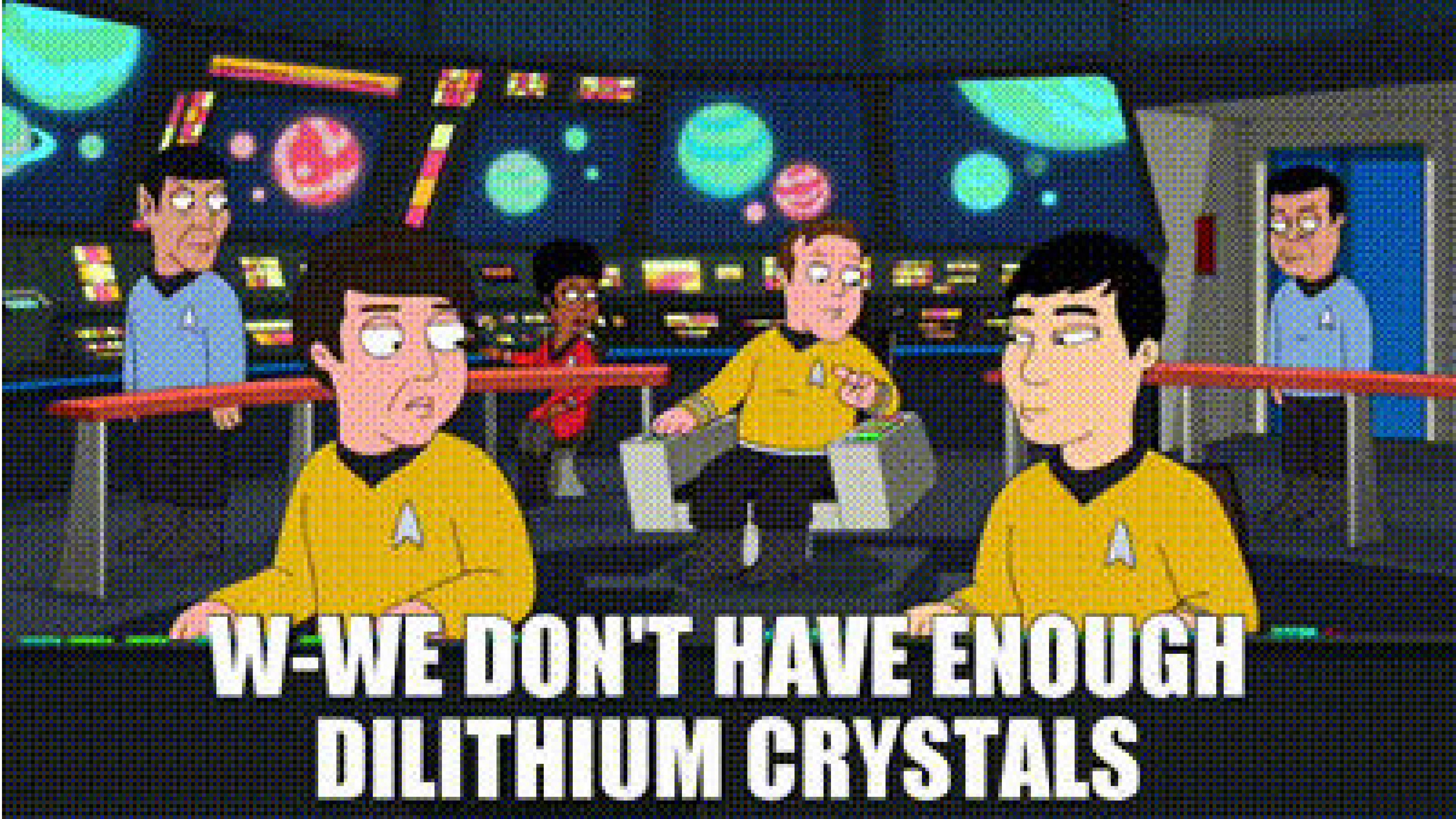
= 187,969,924 RPM?!

Variable Speed Fuel Pump



We need the pump to run at 100%




W-WE DON'T HAVE ENOUGH
DILITHIUM CRYSTALS

GM
V7.20

GM > Automatic selection > Control unit > Fuel pump control module > Active test   VCM 15.0V

Fuel pump(Fuel pump control module)

Fuel pump command	70.0	%
Fuel pump command	69.8	%
Ignition 1 signal	14.3	V
5V reference 1	4.99	V
Desired fuel pressure	300	kPa
Fuel pressure sensor	579	kPa
Fuel pressure sensor	3.82	V
Fuel pump command	On	
Short term fuel pump trim	1.00	

Bi-Directional = 70% Max

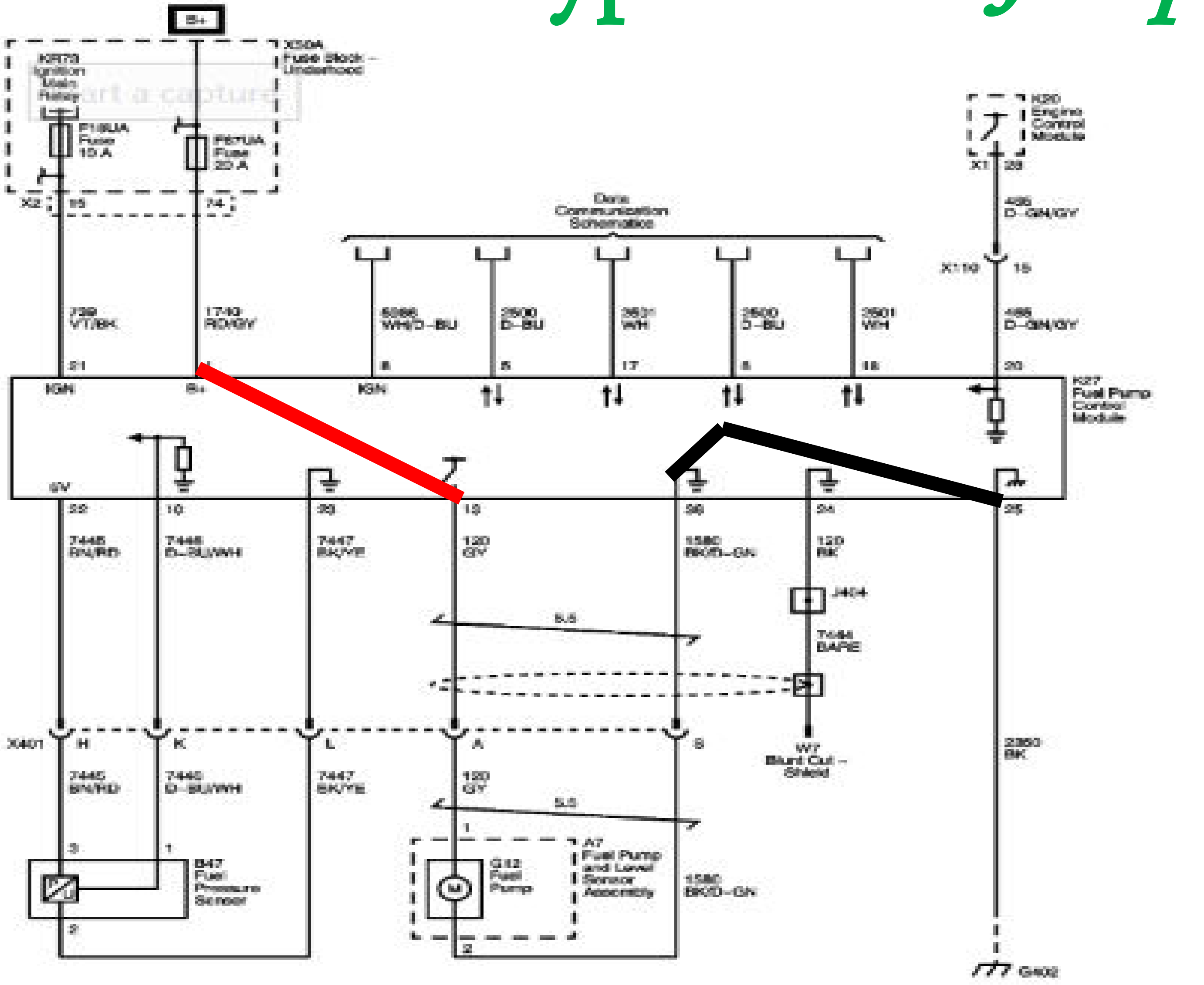
VIN: 1G1PF5SCXC7270455
Info: GM/Chevrolet/Cruze

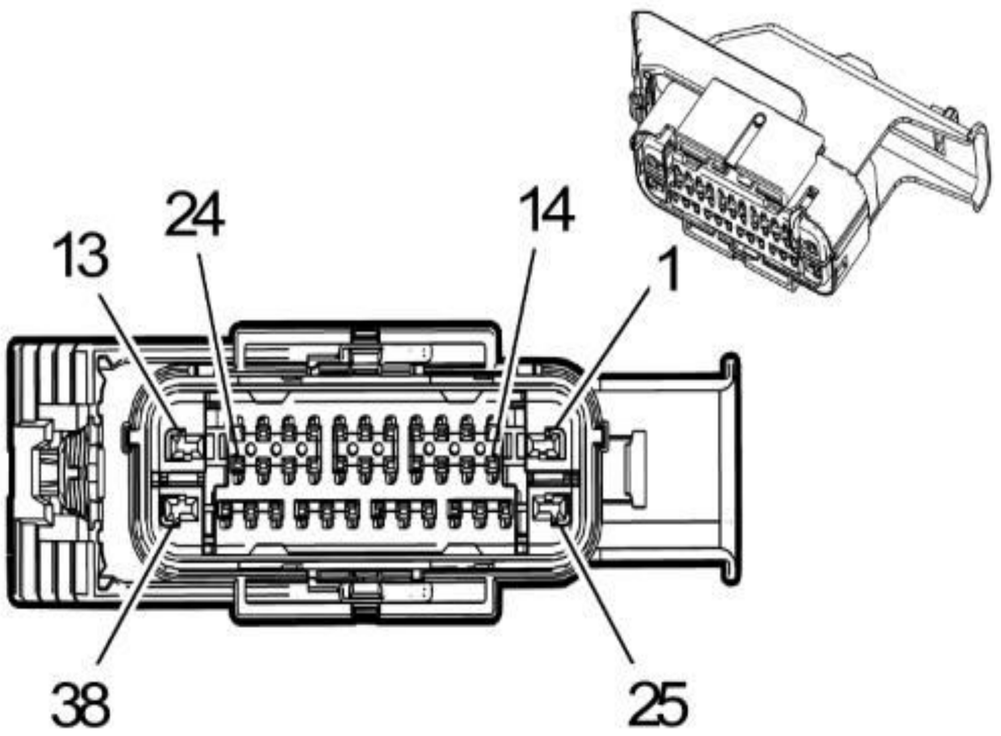
Increase | Decrease | ESC

99% 12:11


I'm giving her all she's got, Captain!

Bypass Test: *Jump the Supply*

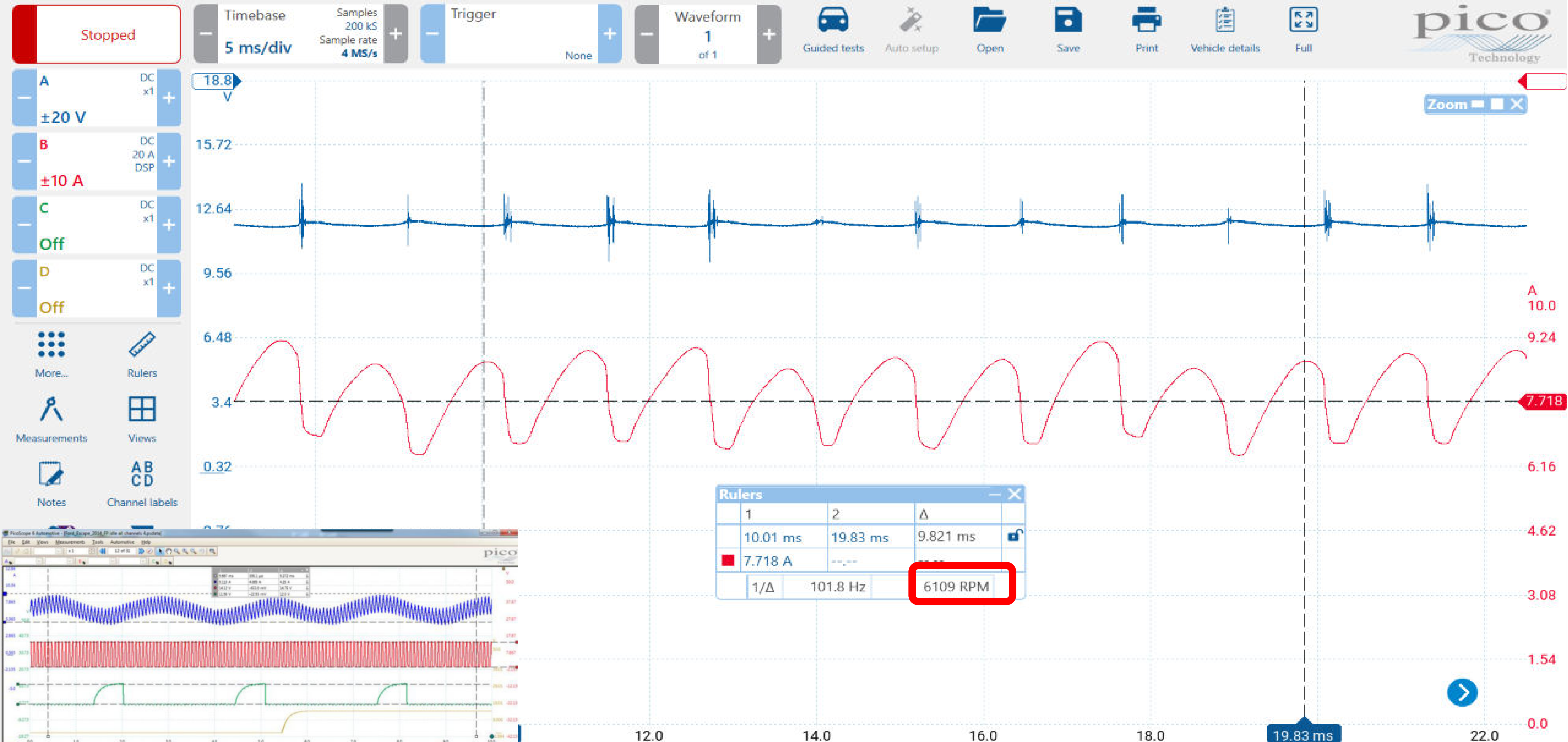




Credit: GM From Identifix

Yes! Let's Jump the B+ & B- from the FDCM directly to the fuel pump

Got It!



Stopped
Timebase
5 ms/div
Samples 200 kS
Sample rate 4 MS/s
Trigger
None
Waveform
1
of 1
Guided tests
Auto setup
Open
Save
Print
Vehicle details
Full
A DC x1 ±20 V
B DC 20 A DSP ±10 A
C DC x1 Off
D DC x1 Off
More...
Rulers
Measurements
Views
Notes
Channel labels
Zoom
Rulers
1 2 Δ
10.01 ms 19.83 ms 9.821 ms
7.718 A
1/Δ 101.8 Hz 6109 RPM
7.718
19.83 ms

Approaching the High-Pressure System Fault

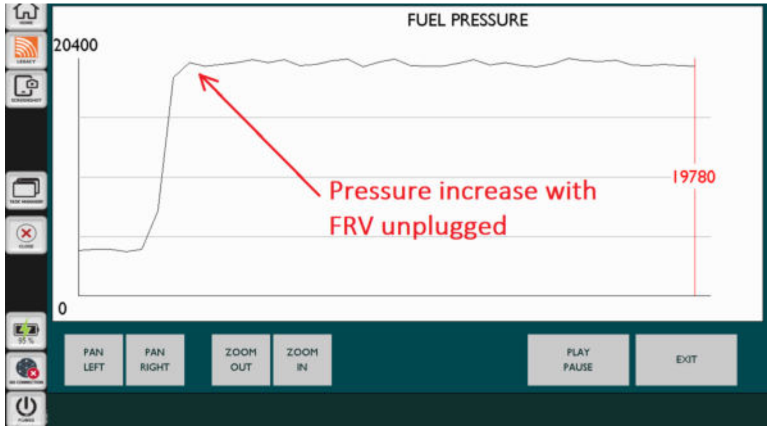
- Rail pressure
  - *Effected by RPM*
  - *Effected by Duty-cycle*
  - *Effected by INJPW*
- Process of elimination
- Proper signal to solenoid
- Accurate FRP signal
- No leaks
- Healthy mechanical drive
- HPFP replacement… ONLY after all has been proven

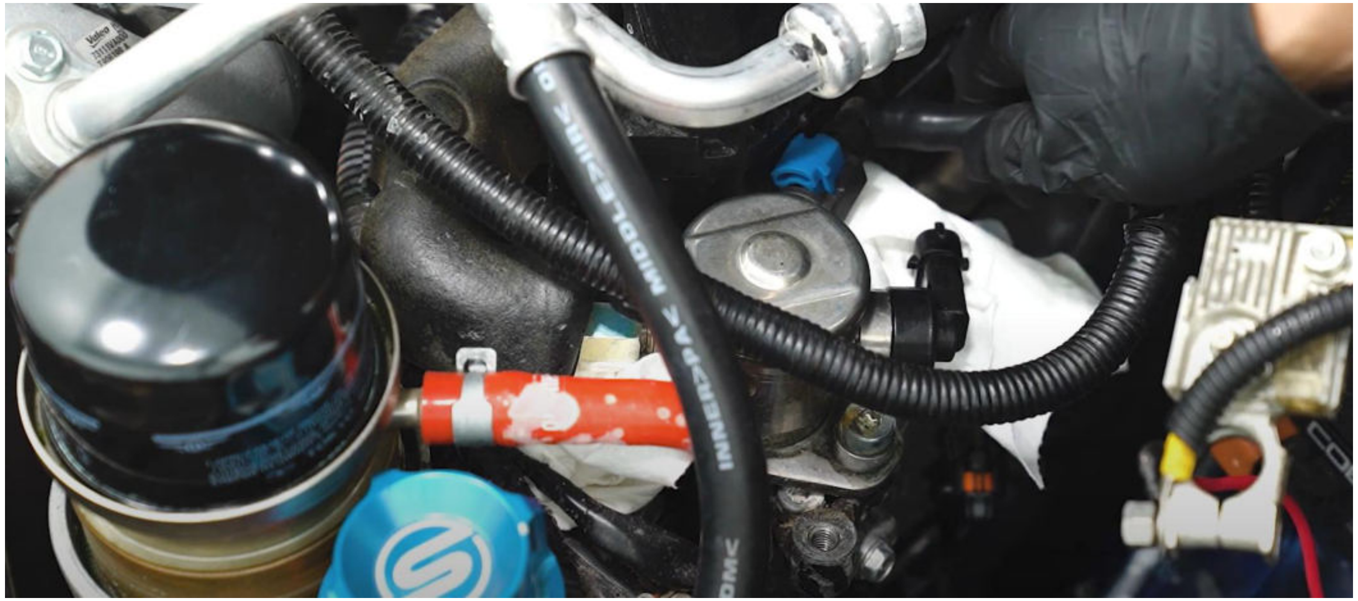
Hot-Soak FRP Monitoring

- Pressure should increase with heat
- Low-volume / High pressure
- If pressure decays over time
  - *Past injector*
  - *Past HPFP check valve (pump failure)*
  - *Past HPFP (into crankcase)*

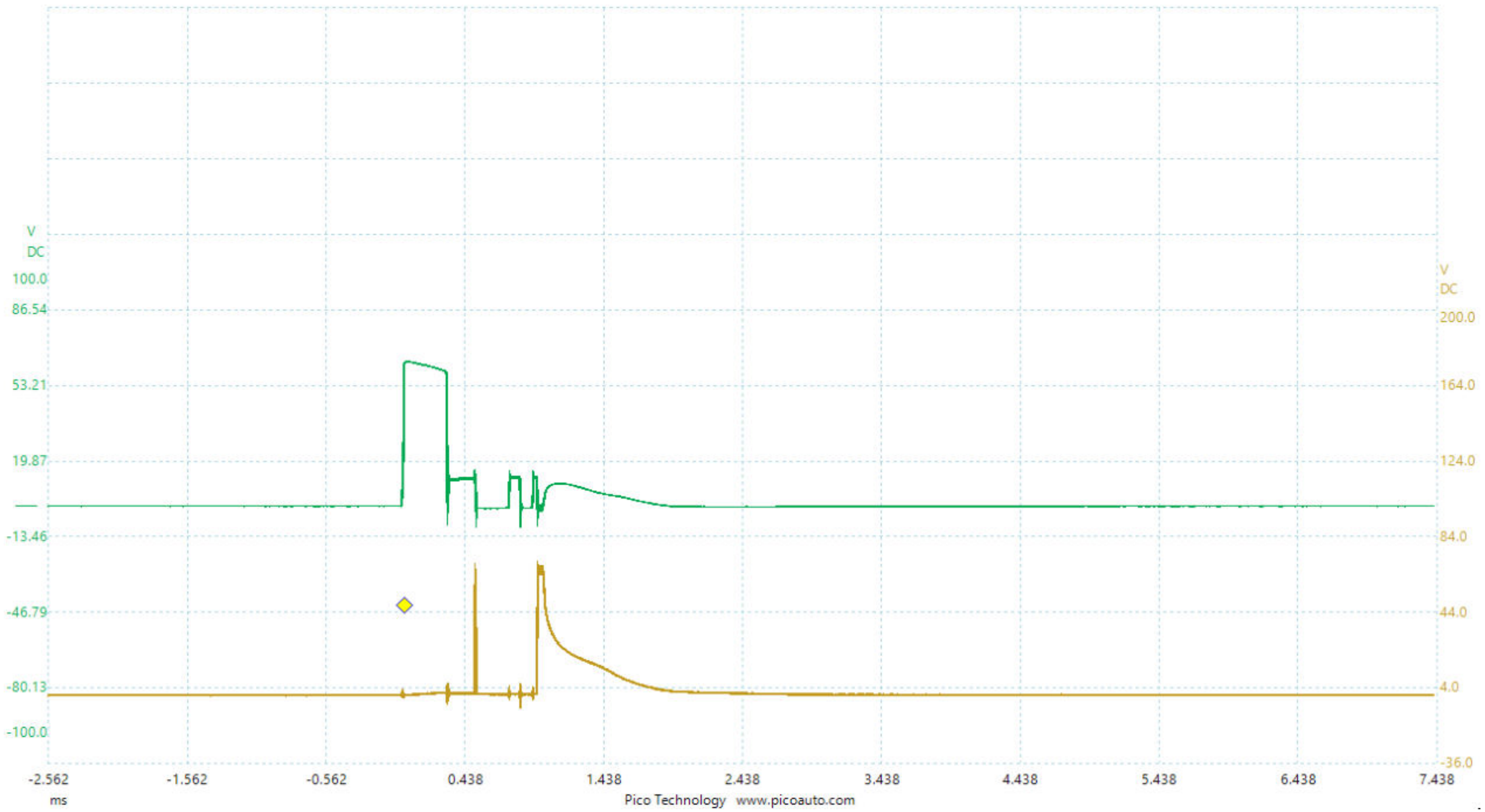
HPFP Deadhead Test

- Configuration dependent
  - *Normally-open*
  - *Normally-closed*
- Highest stress on HPFP
  - *Low rpm (idle)*
  - *Full stroke utilized*
  - *Highest pressure/toughest conditions*



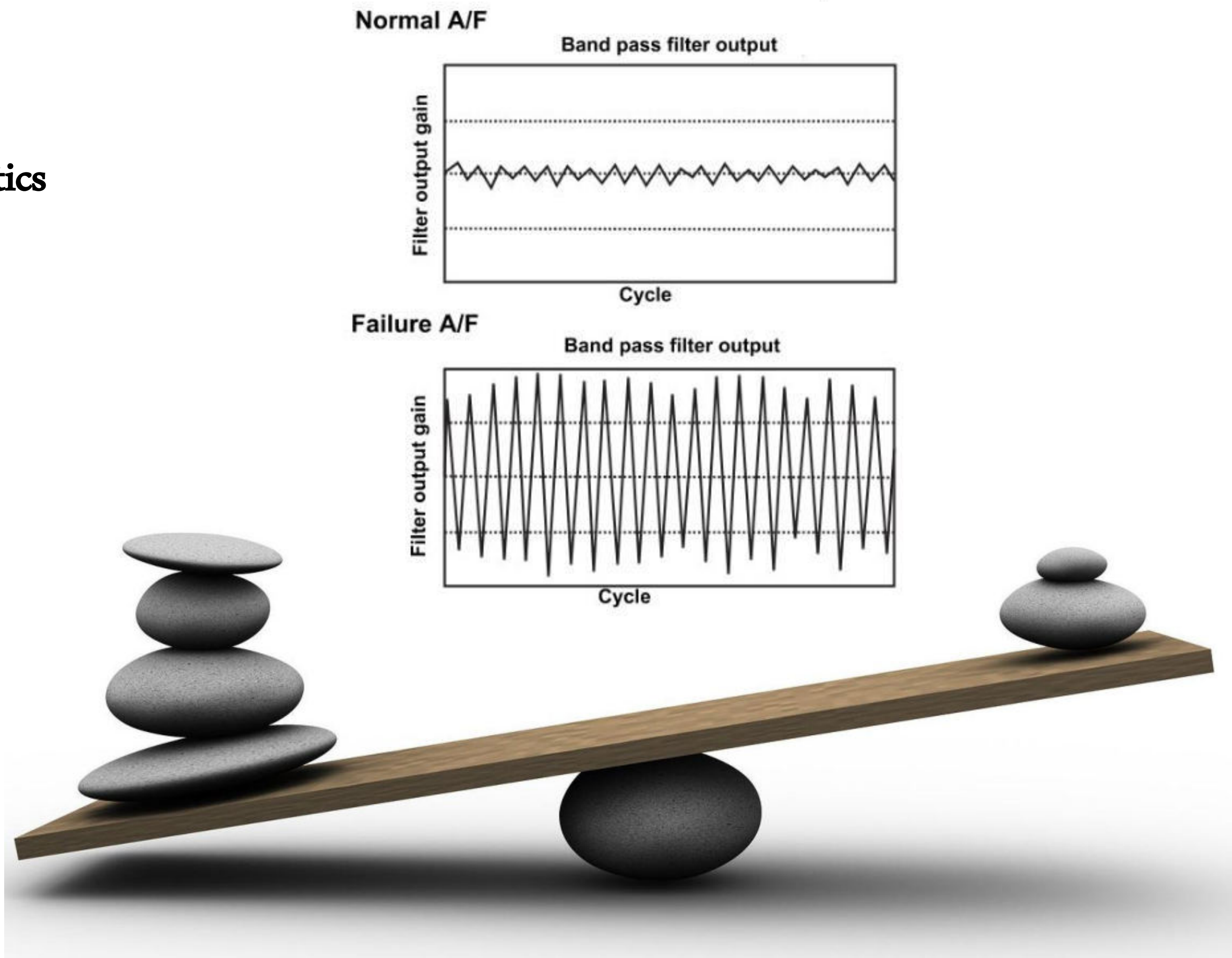


Results: Dead-Head Testing



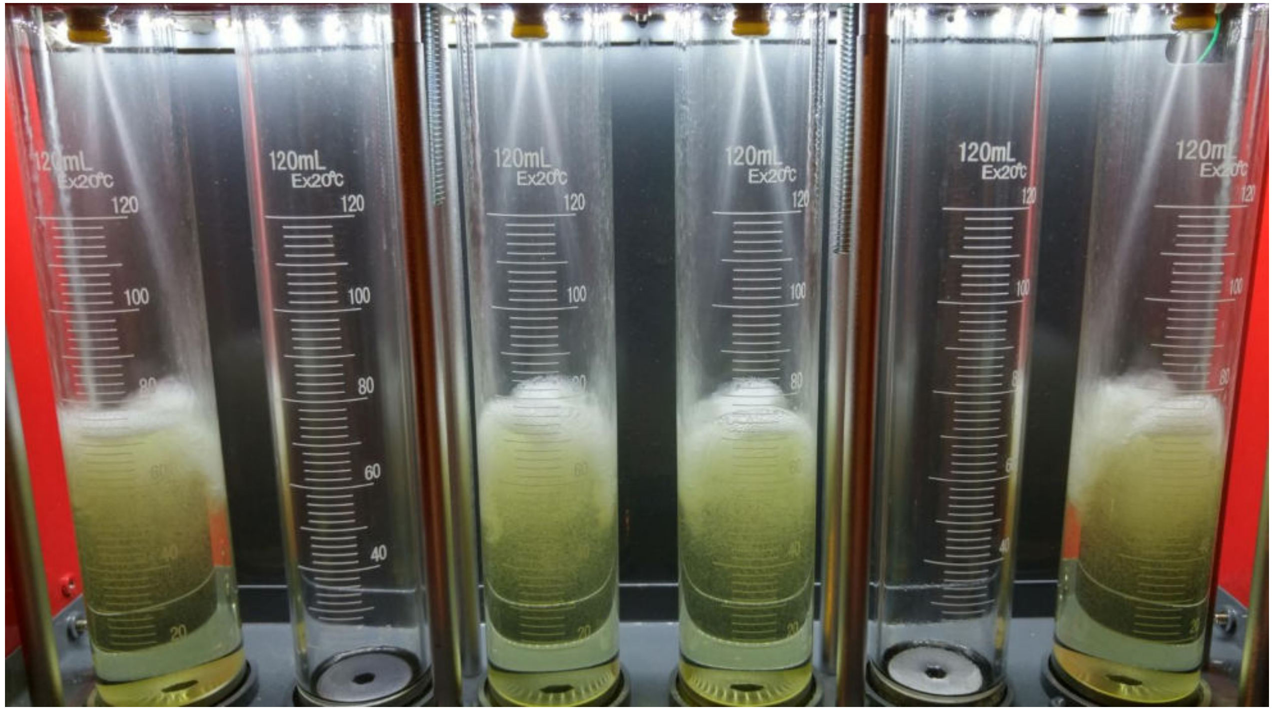
A/F Ratio Imbalance DTCs (P219A or P219B)

- Rich or lean cylinder-to-cylinder imbalance
- HO2 sensor frequency and amplitude characteristics
  - *Closed loop*
  - *Warmed-up*
  - *No EVAP enrichment*
- Intake / Exhaust modifications, leaks
- Poor injector spray patterns
- HO2 or WRAF performance
- Fuel contamination
- Combustion quality (mechanical / ignition?)



GDI Injector Balance Testing…

- Relative flow characteristics
- Helps single out cause of misfire
- Right from the driver's seat!
- Scan tool Bi-directional control
  - *Differs from port injection*
  - *Analysis of test results tedious*



Unanticipated Test Sequence

- Obtain and record pressure drop for each injector
- Calculate total injector-drop (omit suspect injector)
- Find average pressure-drop
- Multiply by 0.20 (20% acceptasble variance)
- Can't exceed acceptable variance

Delta-Lambda Demonstration

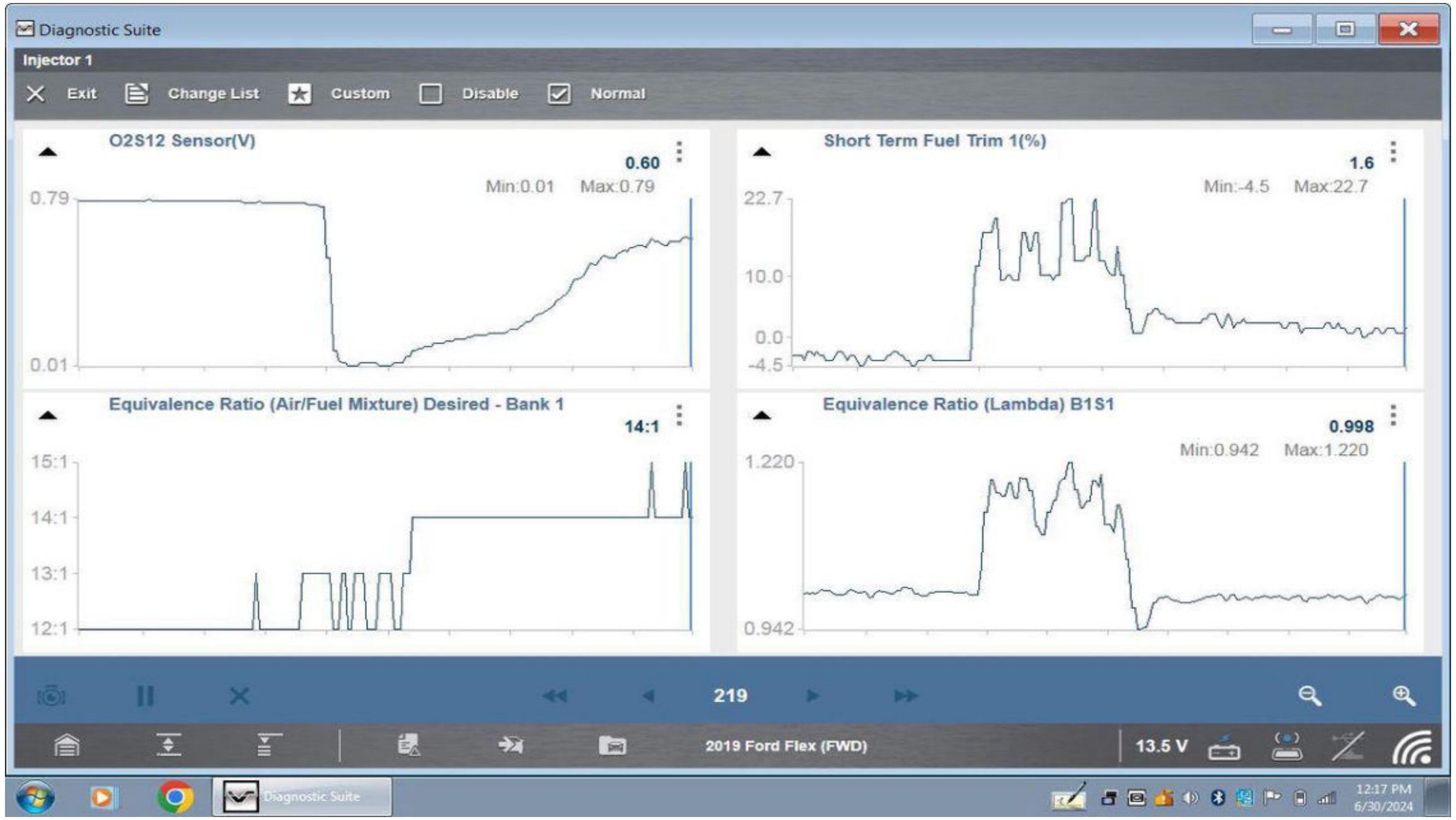
- Scan Tool Bi-Directional Test
- Disable Each Injector One at a Time
- Monitor EQ_Ratio / Lambda
- Compare Lambda Change of Each Cylinder

- Three Vehicle Demonstration
- Port Injection with Wide-Band Sensor
- GDI Injection with Narrow-Band Sensor
- GDI Injection with Wide-Band Sensor

2019 Ford Flex 3.5L
Port Fuel Injector Balance
Wide Band Sensor

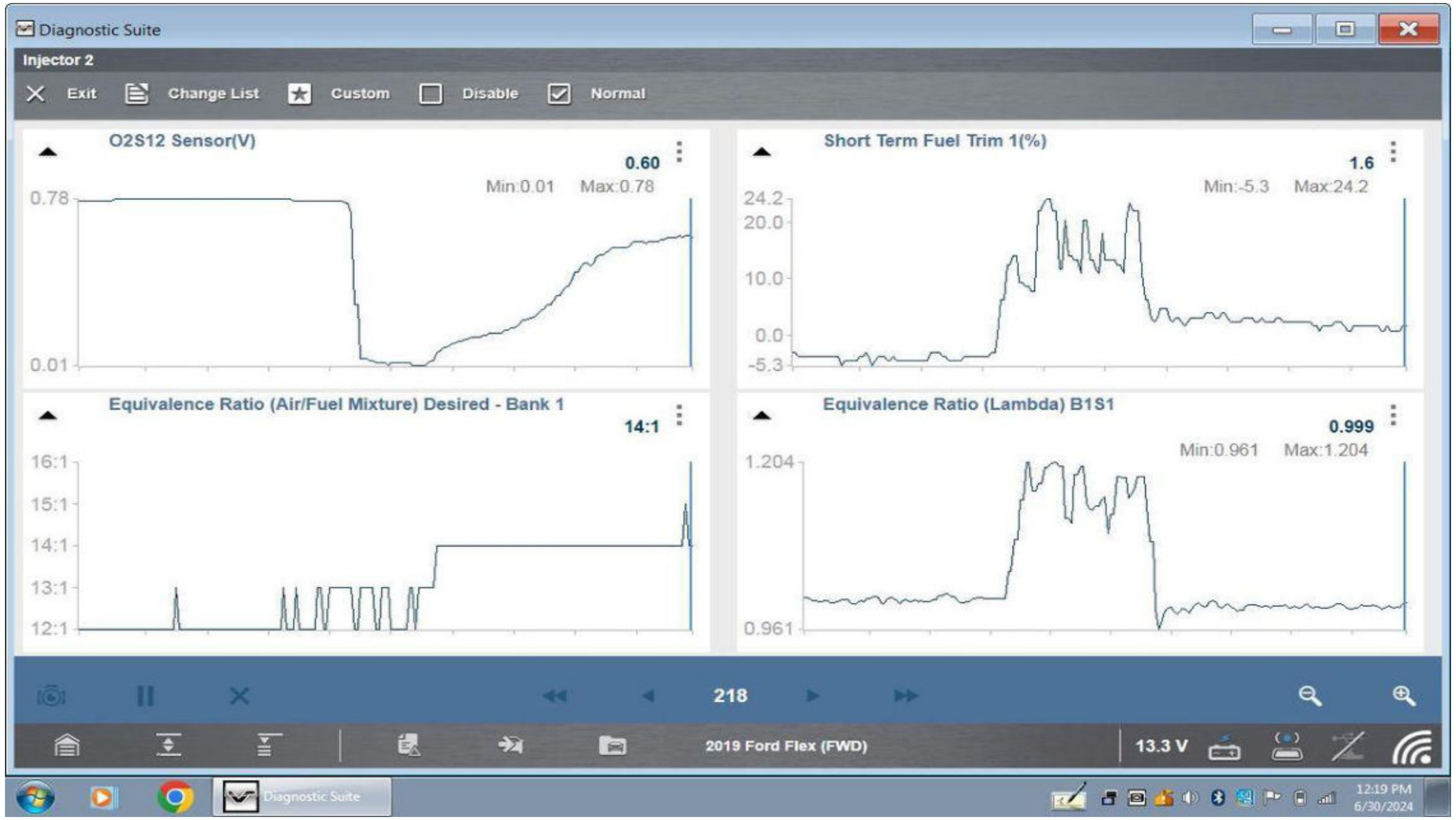
Cylinder #1 Disable

- Port Injection with Wide-Band Sensor
- EQ_Ratio (Lambda) = 1.22
- Downstream Sensor = .01(V)
- Short Term Fuel Trim = 22%



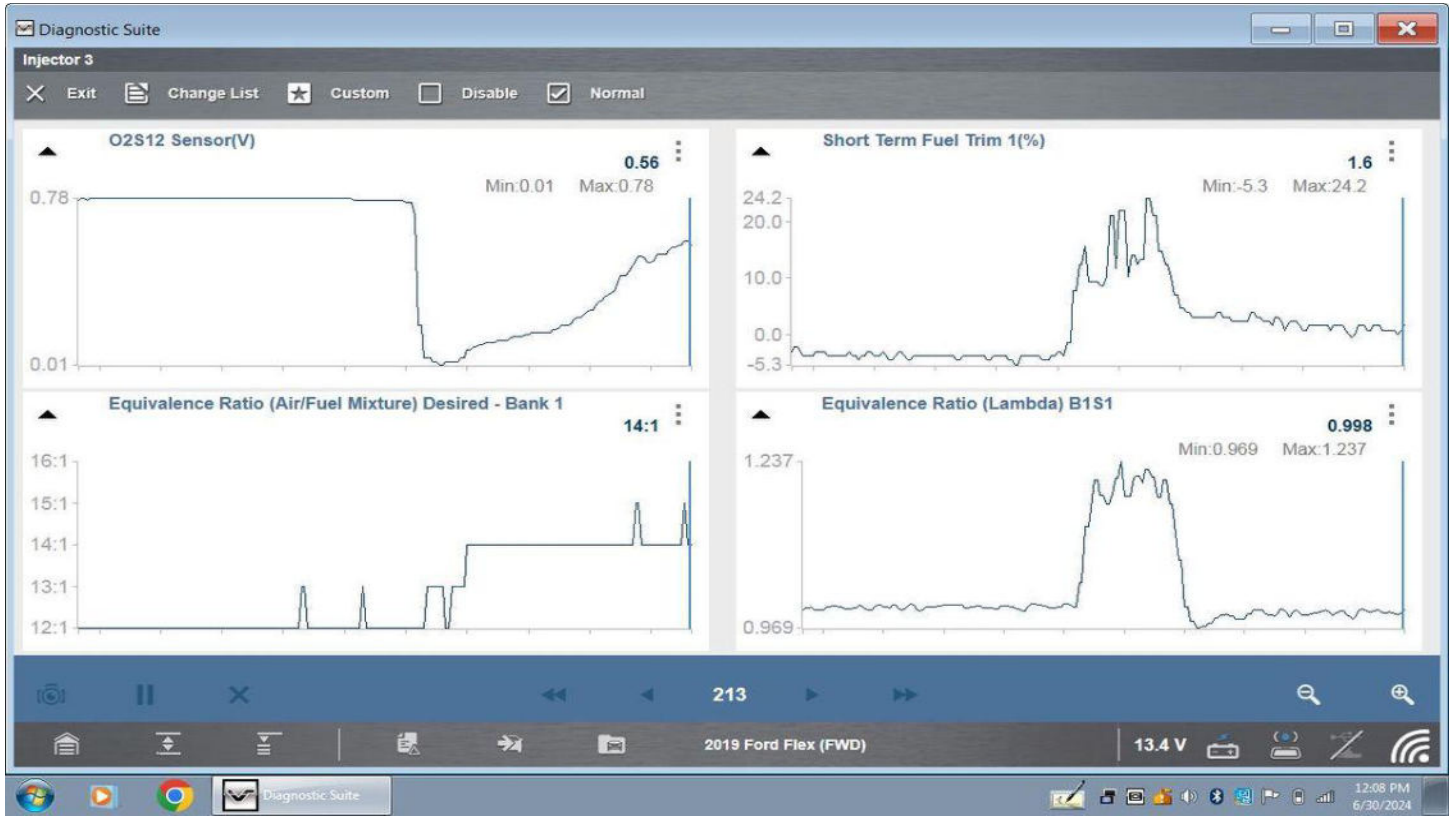
Cylinder #2 Disable

- Port Injection with Wide-Band Sensor
- EQ_Ratio (Lambda) = 1.20
- Downstream Sensor = .01(V)
- Short Term Fuel Trim = 24%



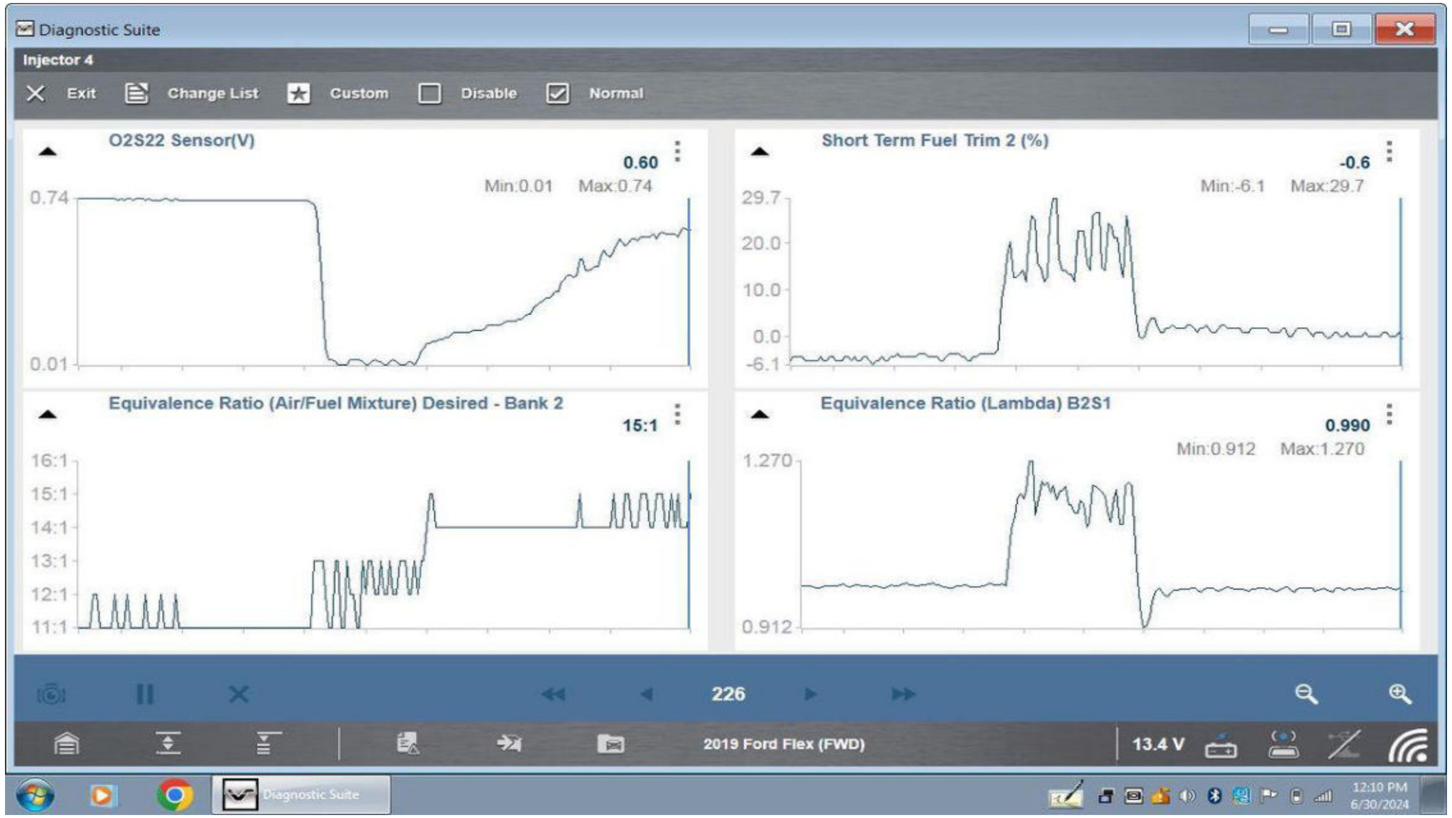
Cylinder #3 Disable

- Port Injection with Wide-Band Sensor
- EQ_Ratio (Lambda) = 1.23
- Downstream Sensor = .01(V)
- Short Term Fuel Trim = 24%



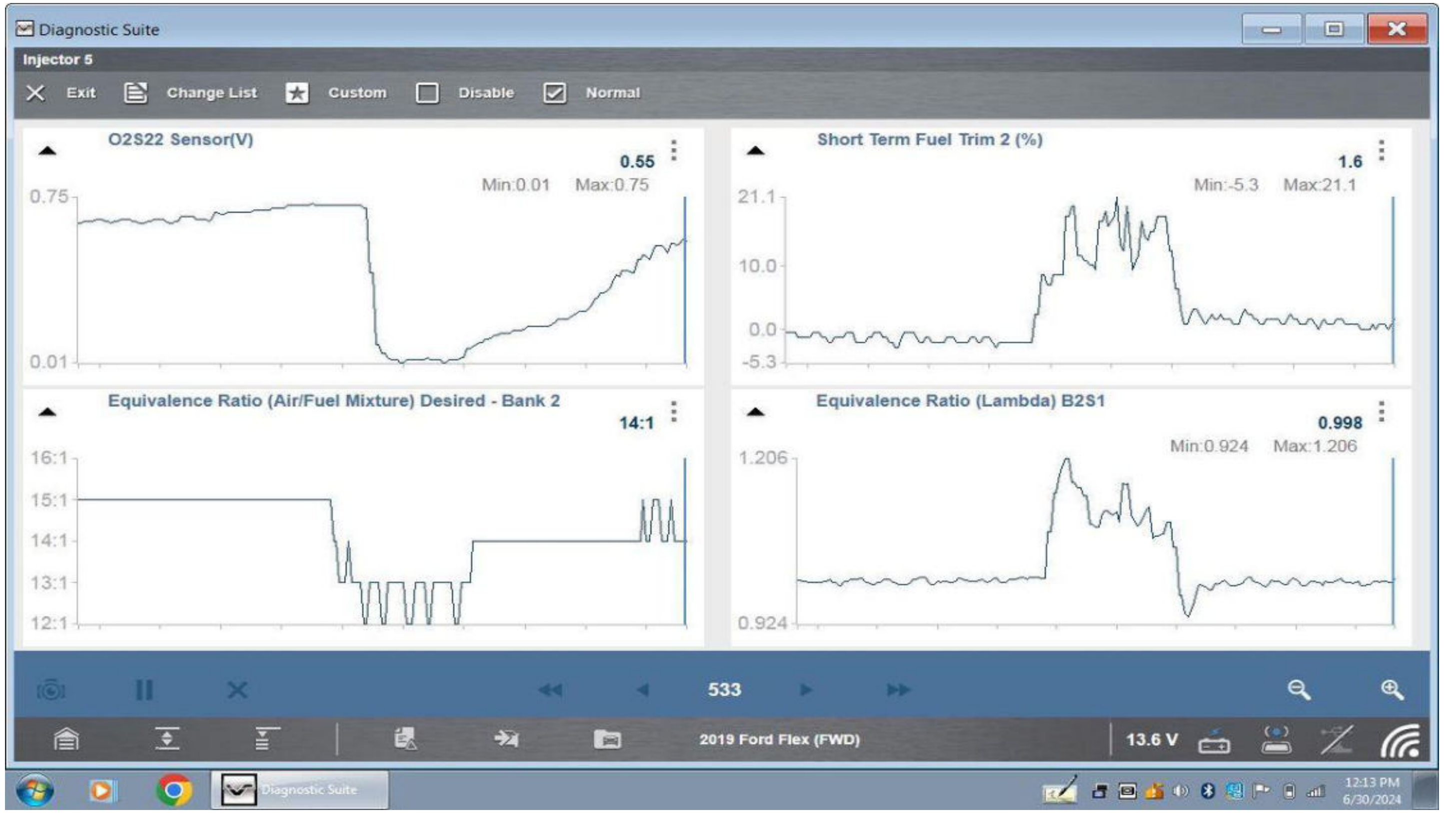
Cylinder #4 Disable

- Port Injection with Wide-Band Sensor
- EQ_Ratio (Lambda) = 1.27
- Downstream Sensor = .01(V)
- Short Term Fuel Trim = 29%



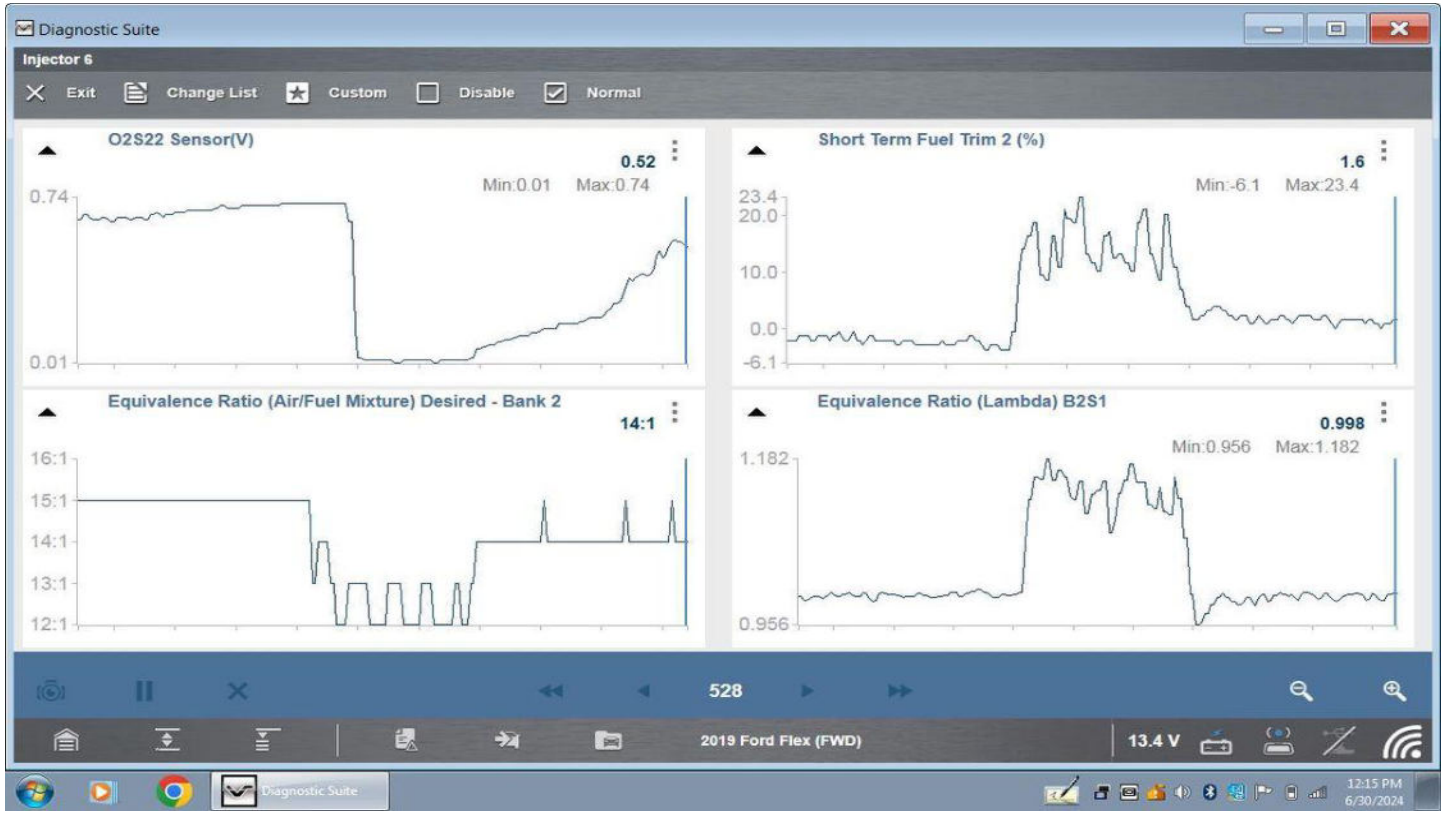
Cylinder #5 Disable

- Port Injection with Wide-Band Sensor
- EQ_Ratio (Lambda) = 1.20
- Downstream Sensor = .01(V)
- Short Term Fuel Trim = 21%



Cylinder #6 Disable

- Port Injection with Wide-Band Sensor
- EQ_Ratio (Lambda) = 1.18
- Downstream Sensor = .01(V)
- Short Term Fuel Trim = 23%

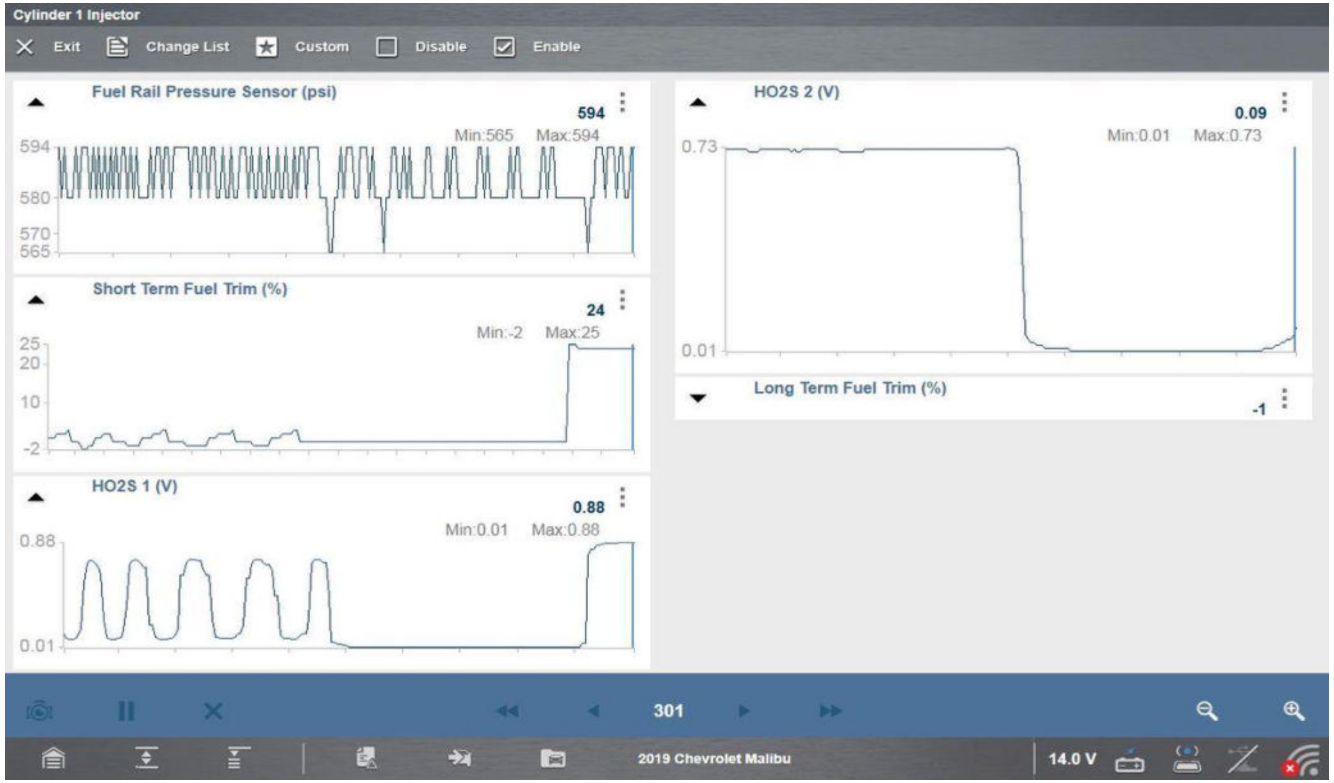


2019 Chevy Malibu 1.5L
GDI Injector Balance with Narrow Band Sensor

- GDI with Narrow-Band Sensor
- No EQ_Ratio
- Commanded EQ_Ratio Stays @ 1.00 in Closed Loop
- Compare Upstream Sensor (V), STFT
  & Rail Pressure (Preferably Voltage)

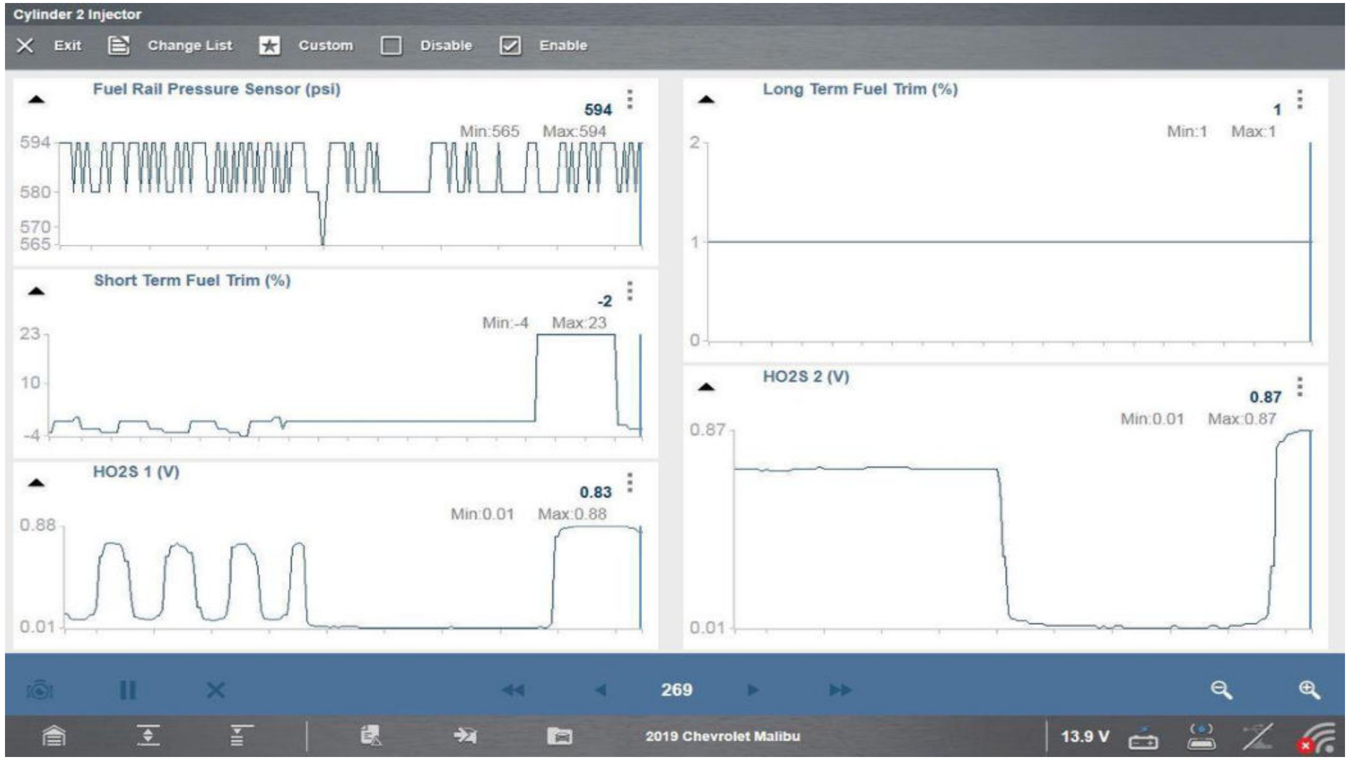
Cylinder #1 Disable

- GDI with Narrow-Band Sensor
- HO2S 1 (V) = .01
- HO2S 2 (V) = .01
- Short Trim Fuel Trim = 24%
- Fuel Rail Pressure Sensor = 561 PSI



Cylinder #2 Disable

- GDI with Narrow-Band Sensor
- HO2S 1 (V) = .01
- HO2S 2 (V) = .01
- Short Trim Fuel Trim = 23%
- Fuel Rail Pressure Sensor = 565 PSI



Cylinder #3 Disable

- GDI with Narrow-Band Sensor
- HO2S 1 (V) = .01
- HO2S 2 (V) = .01
- Short Trim Fuel Trim = 23%
- Fuel Rail Pressure Sensor = 565 PSI

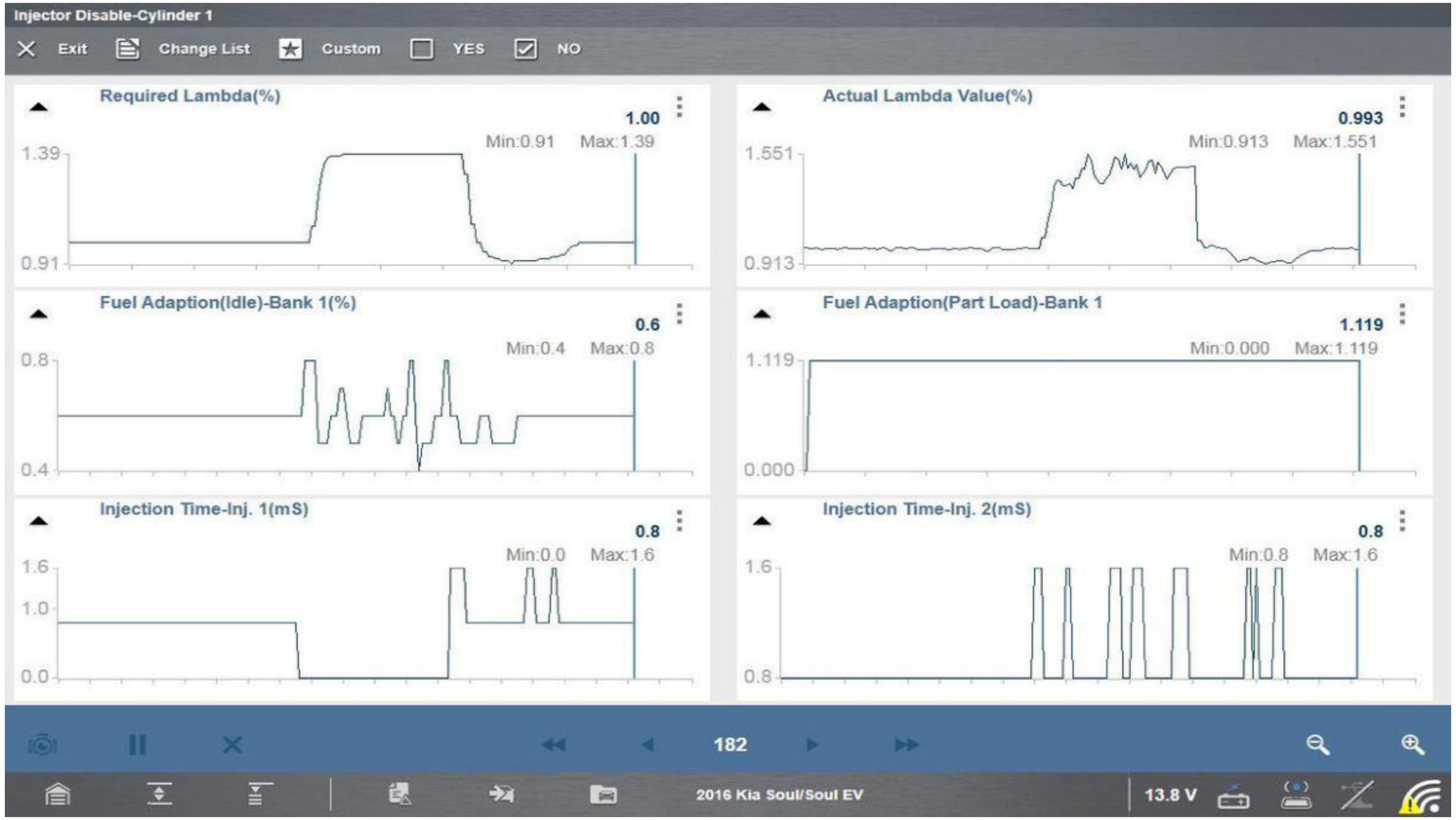
Cylinder #4 Disable

- GDI with Narrow-Band Sensor
- HO2S 1 (V) = .01
- HO2S 2 (V) = .01
- Short Trim Fuel Trim = 23%
- Fuel Rail Pressure Sensor = 565 PSI


2016 Kia Soul 1.6L
GDI Injector Balance
Wide Band Sensor

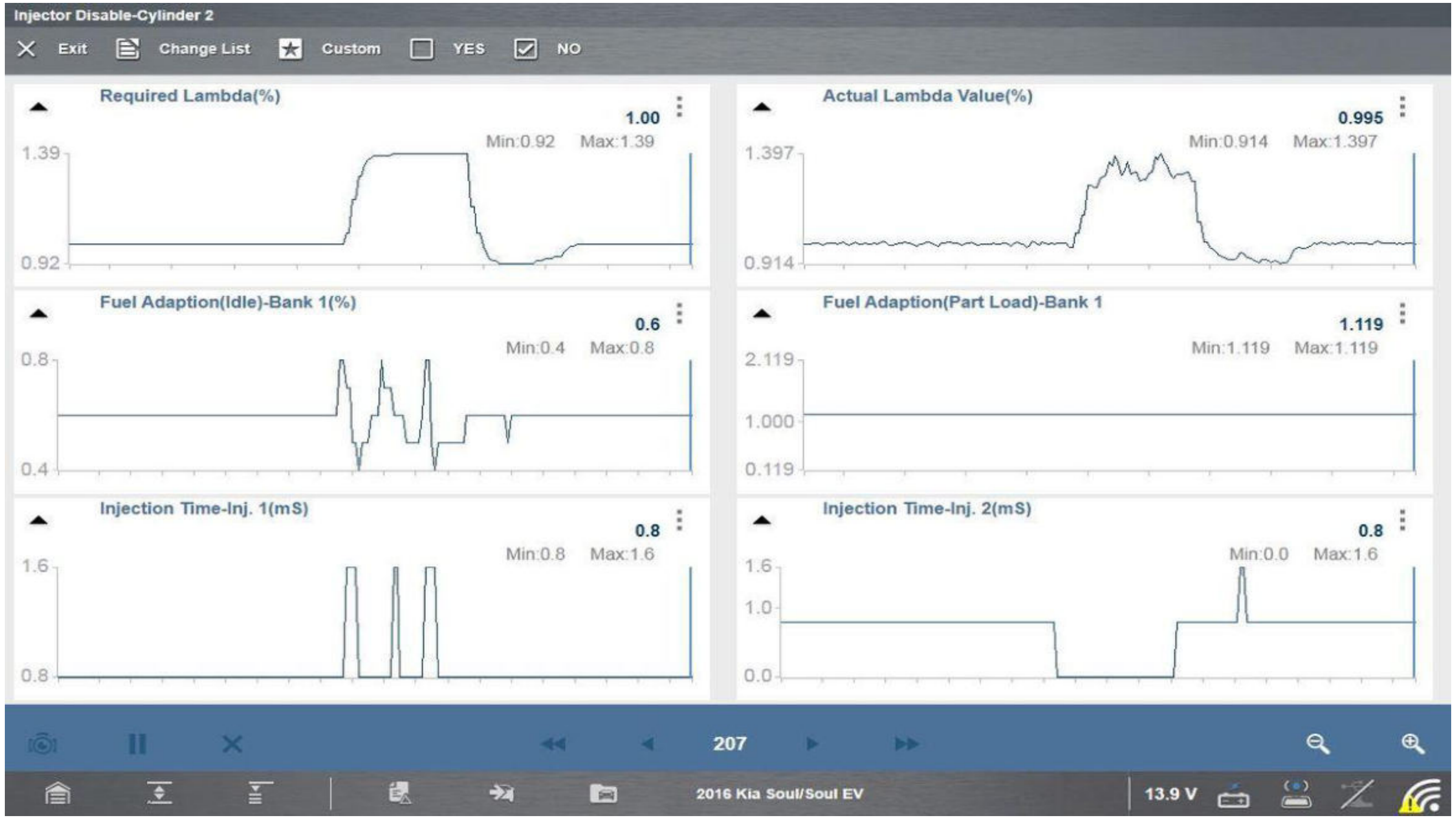
Cylinder #1-Disable

- Required Lambda: 1.39?
- Actual Lambda: 1.55
- Cylinder #2 Injector On-Time: 1.6ms



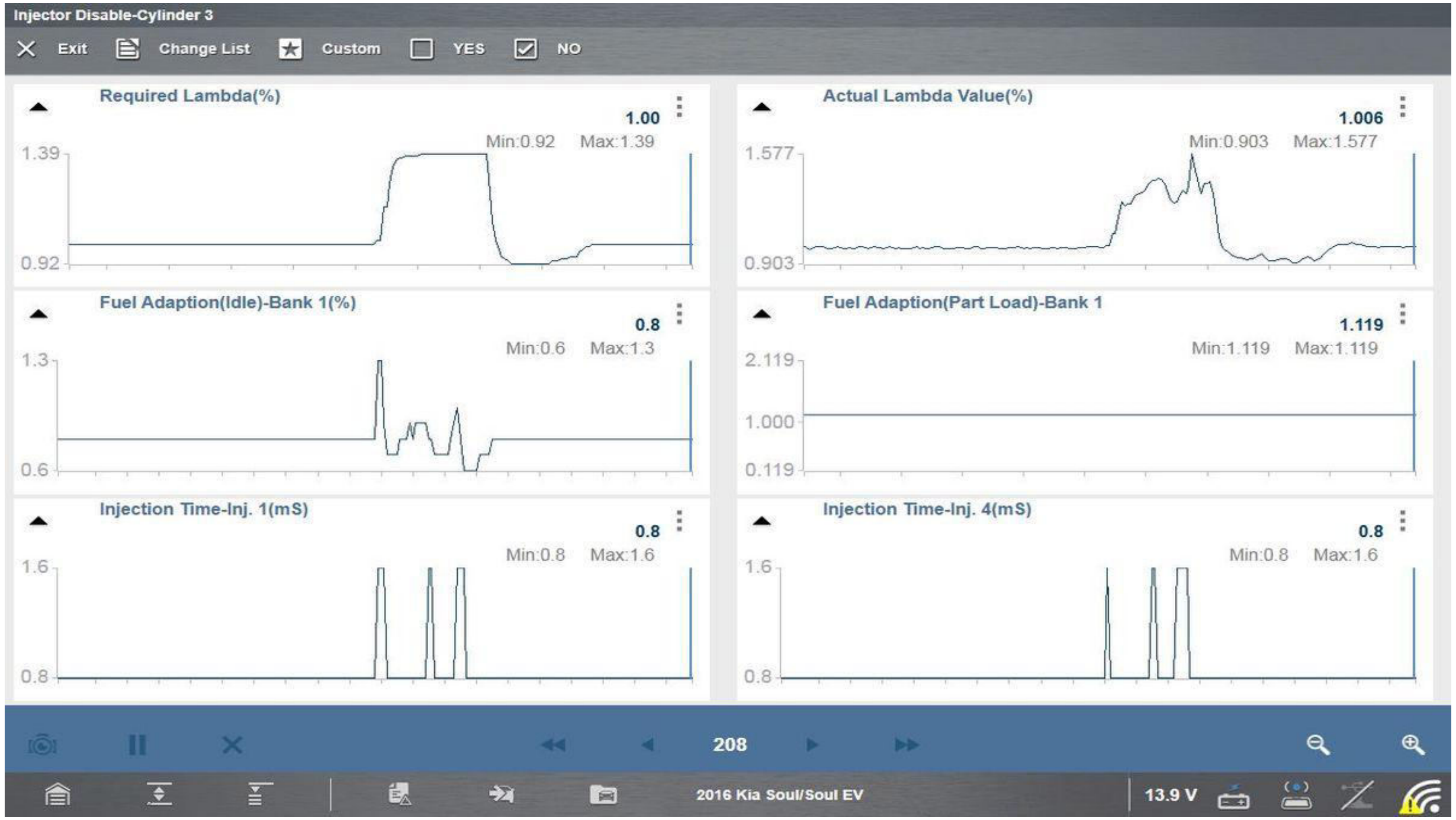
Cylinder #2-Disable

- Required Lambda: 1.39?
- Actual Lambda: 1.39
- Cylinder #1 Injector On-Time: 1.6ms



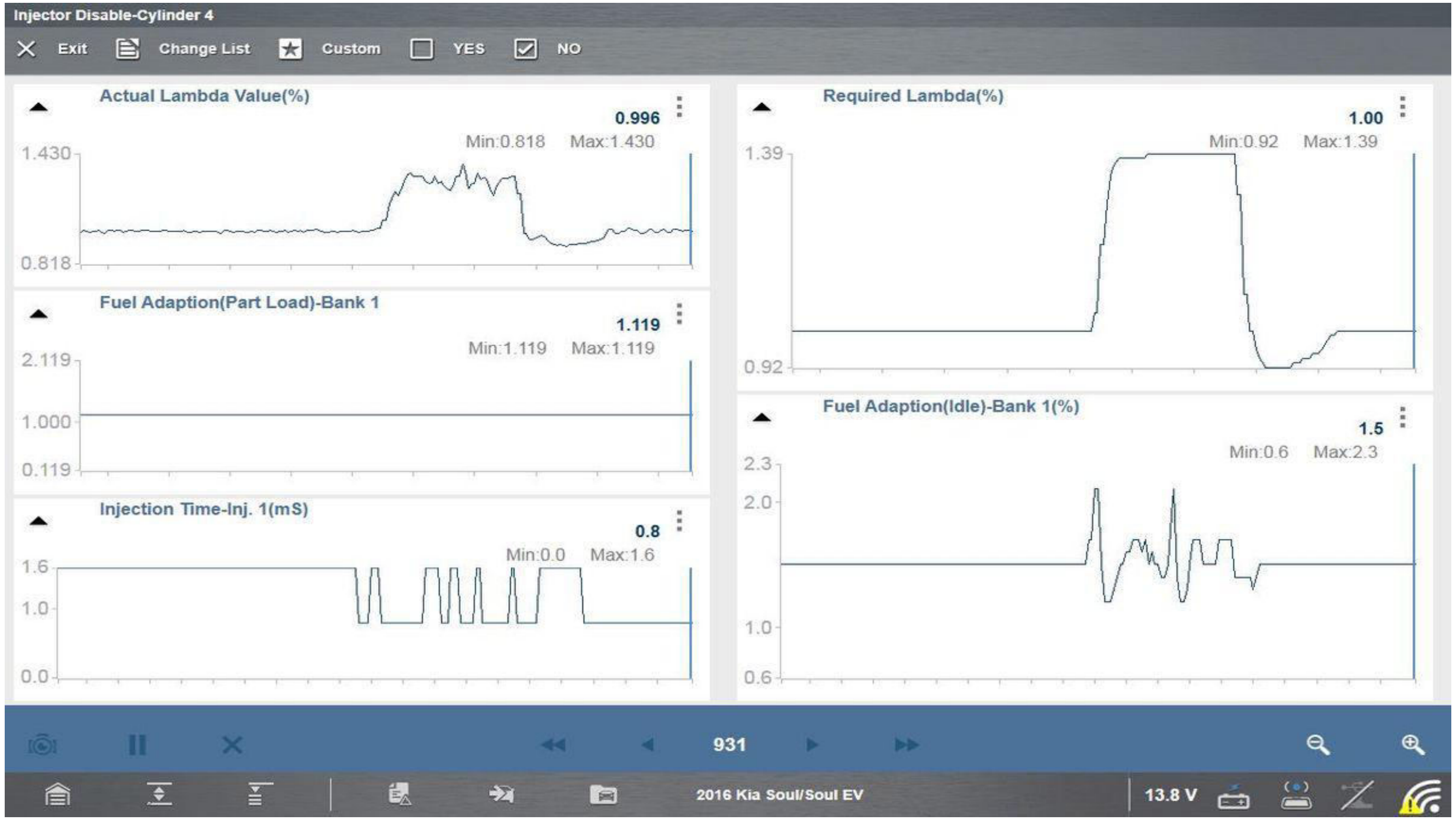
Cylinder #3-Disable

- Required Lambda: 1.39?
- Actual Lambda: 1.57
- Cylinder #1 Injector On-Time: 1.6ms



Cylinder #4-Disable

- Required Lambda: 1.39?
- Actual Lambda: 1.43
- Cylinder #1 Injector On-Time: 1.6ms

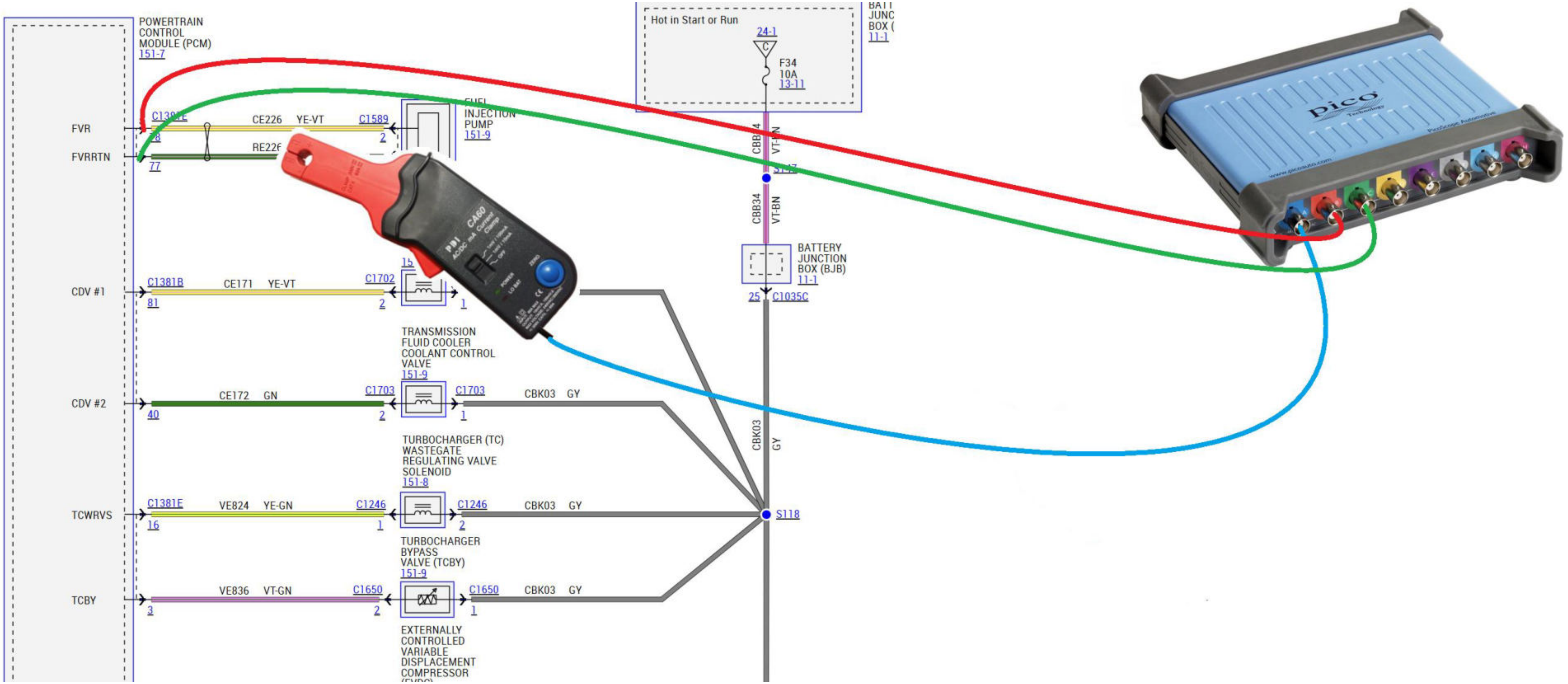


Scope Testing High-Pressure Pump (FVR)…

- Action / Reaction testing
- Access varies between vehicles
- Multi-channel lab scope
    - *Current = Pump circuit*
    - *Voltage = Command PCM-to-FVR*
    - *Voltage = Ground PCM-to-FVR*

CAUTION: Use attenuation

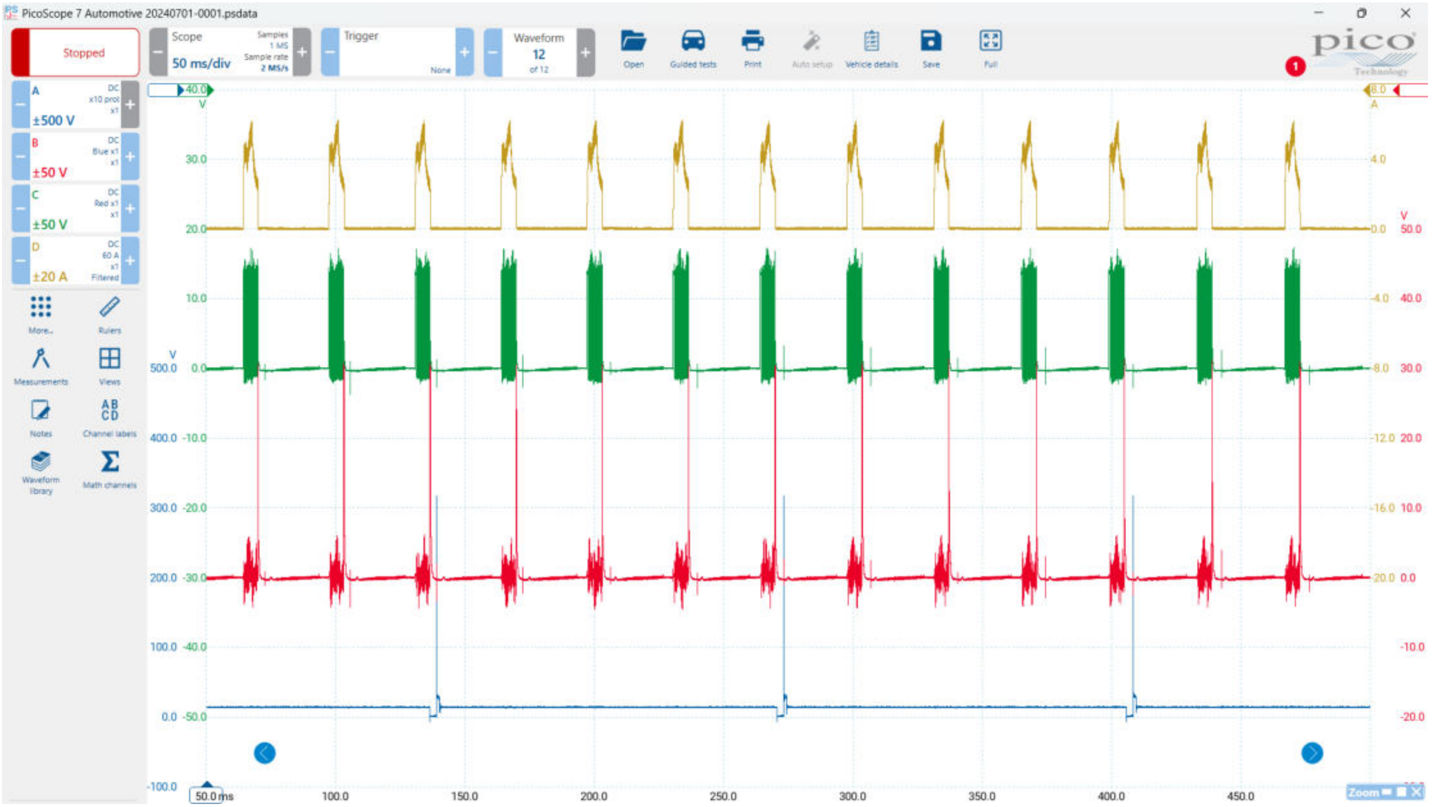
HPFP Wiring Diagram




2016 Kia Soul 1.6L
High Fuel Pressure
Regulator Control

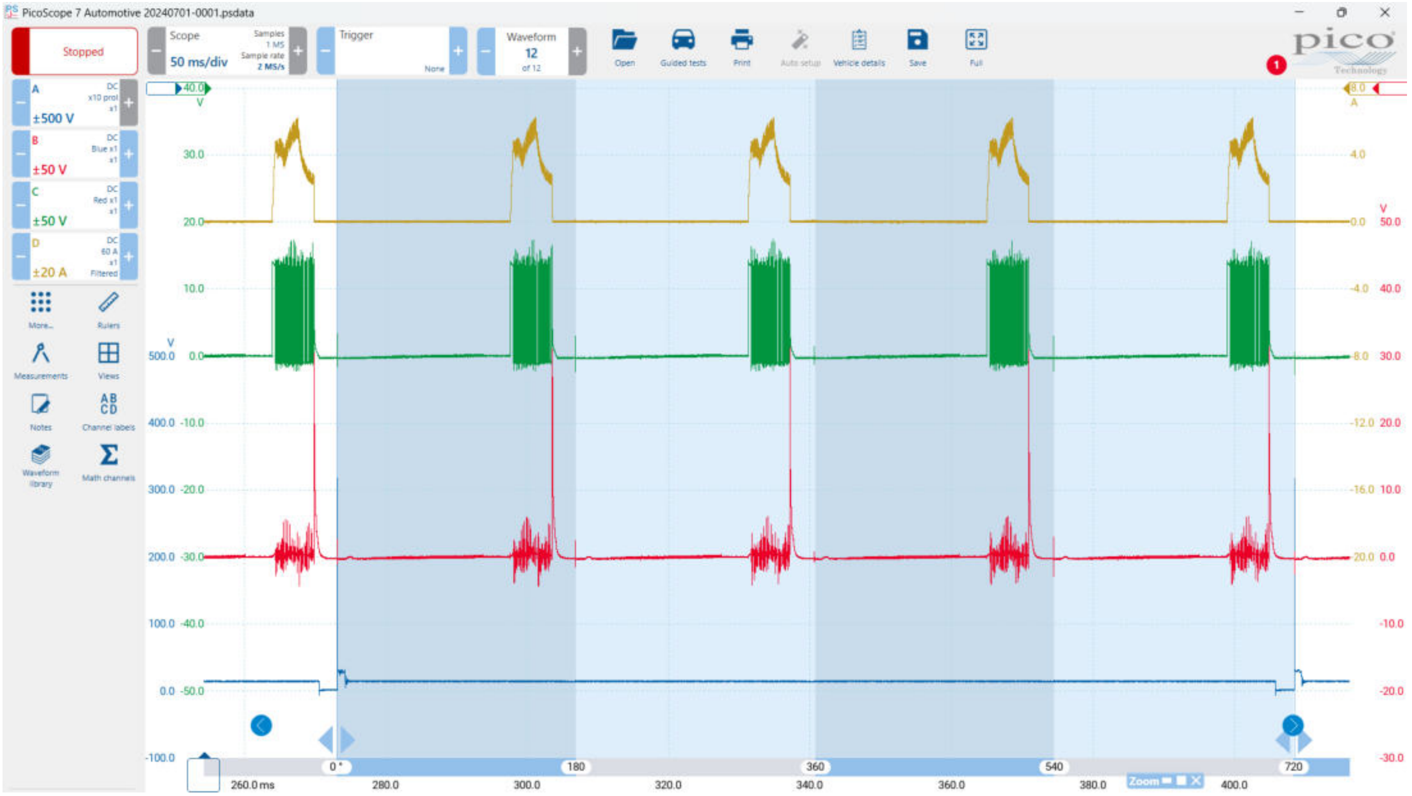
HPFP FVR Control…

- Trend view
- Multiple cycles on screen
- Cyle-to-cycle comparison
- Four waveforms tell the story
  - *FVR current*
  - *FVR Voltage feed control*
  - *FVR Ground feed control*
  - *Primary Ignition (for reference)*



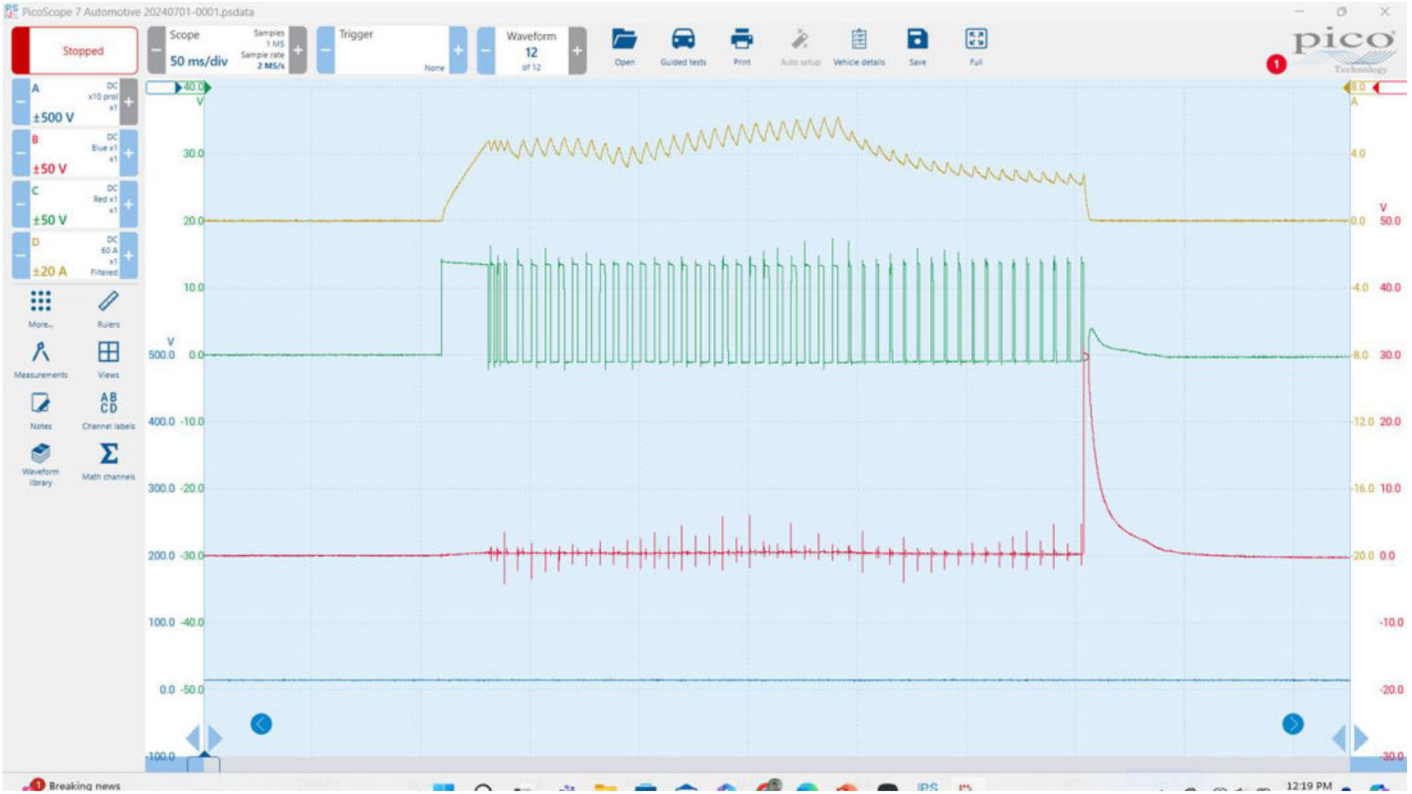
ZOOM 1

- Zoom in to one complete cycle
- Better resolution
  - *Cylinder-to-cylinder comparison*
  - *FVR control*



ZOOM 2

- Zoom in to one single event
- Better resolution
  - *Frequency of pulses*
  - *Pulse-width*
  - *Pintle bump*
  - *Inductive kick*

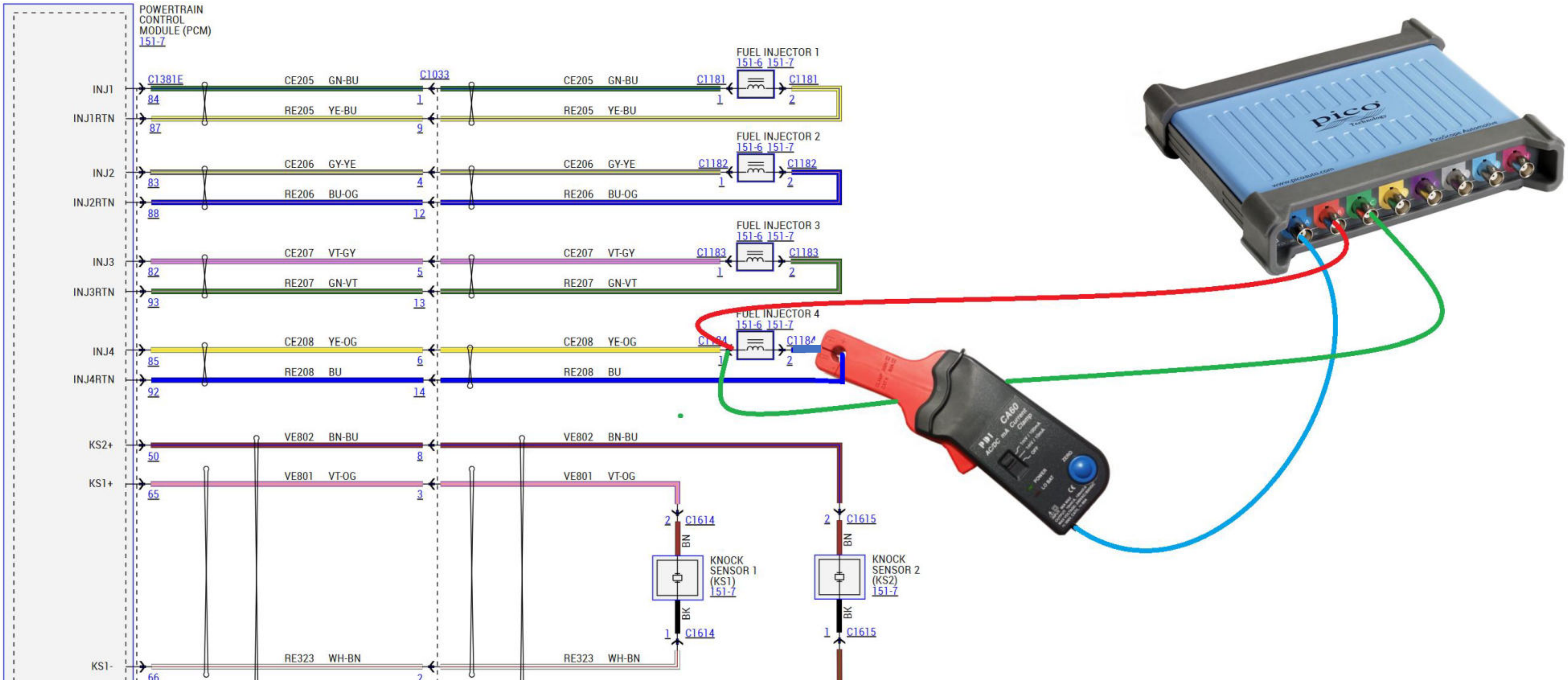


Scope Testing Direct Injectors…

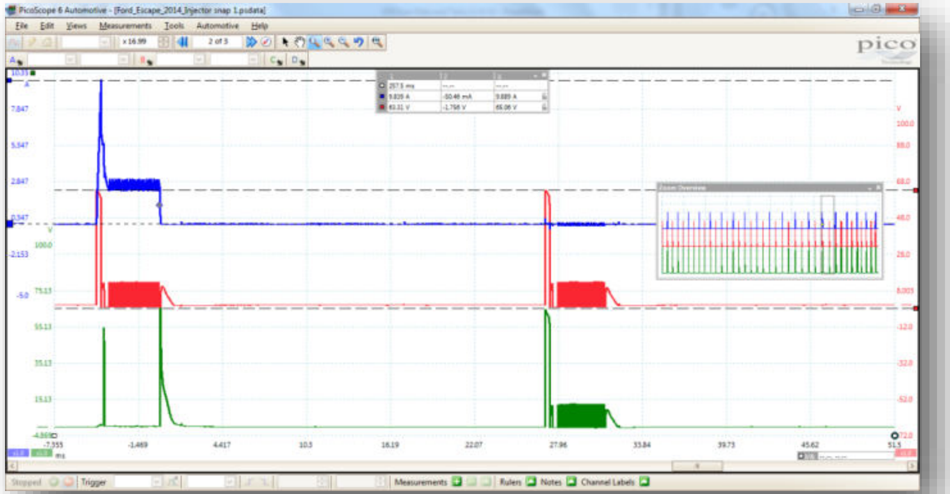
- Action / Reaction testing
- Access varies between vehicles
- Multi-channel lab scope
    - *Current = Injector circuit*
    - *Voltage = Command PCM-to-Injector*
    - *Voltage = Ground PCM-to-Injector*

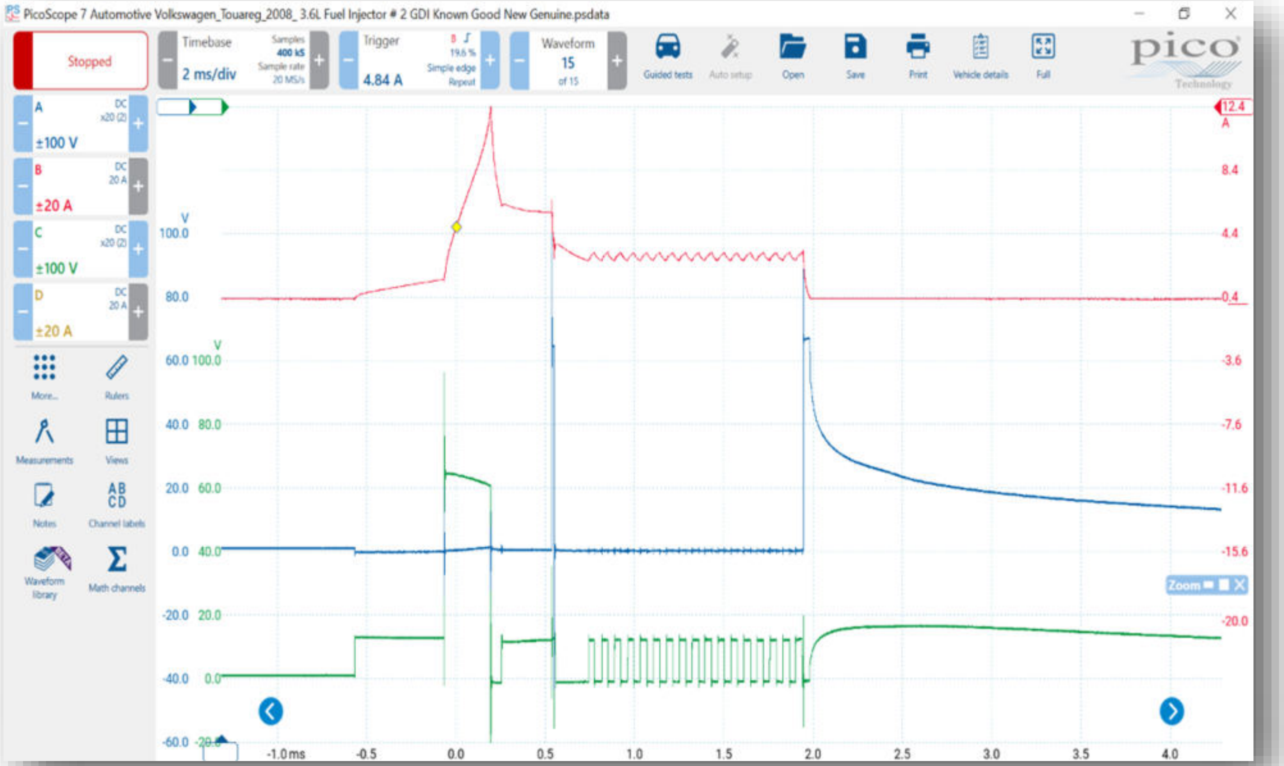
CAUTION: Use attenuation

Direct Injectors Wiring Diagram



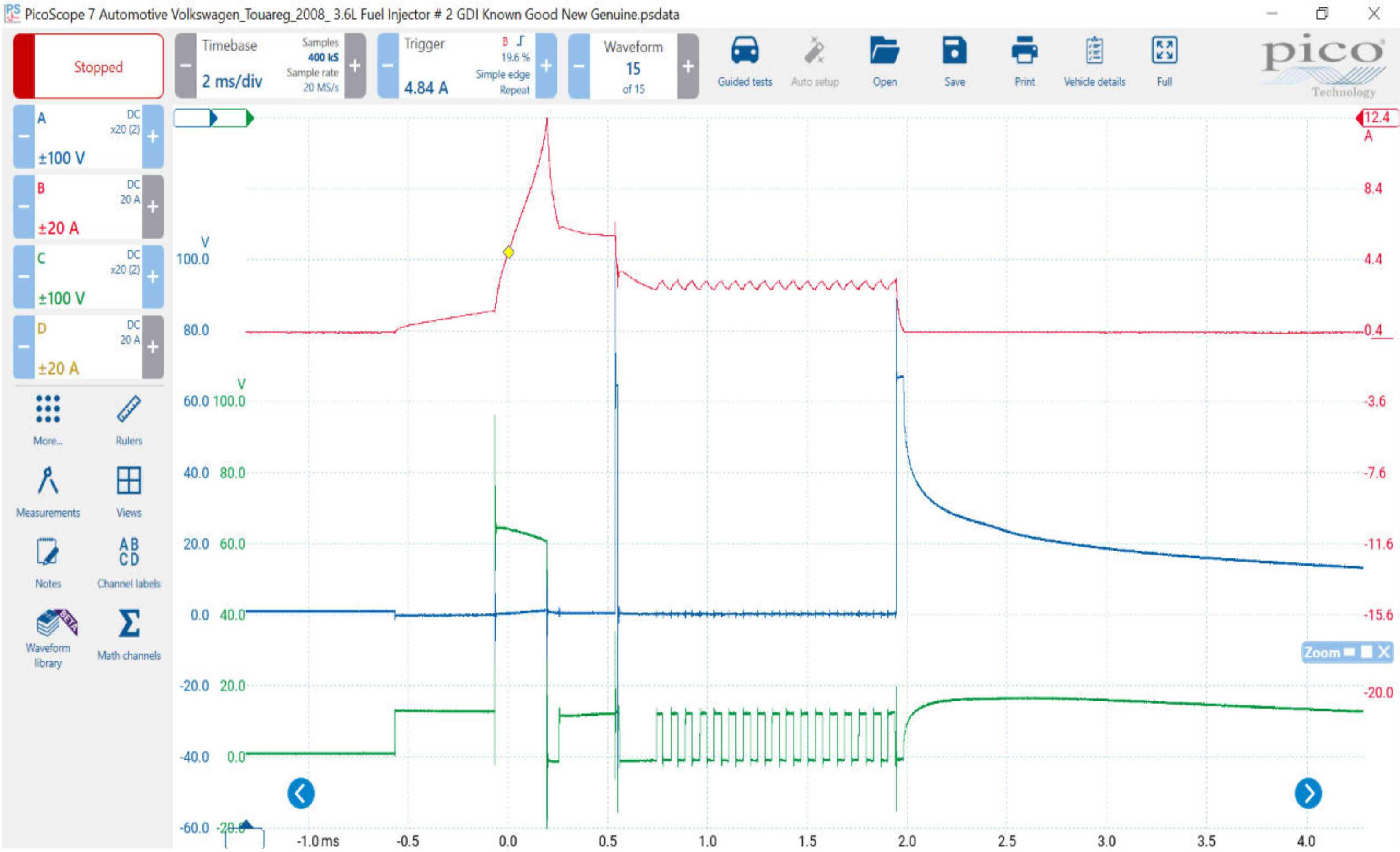
Scope Testing Direct Injectors…





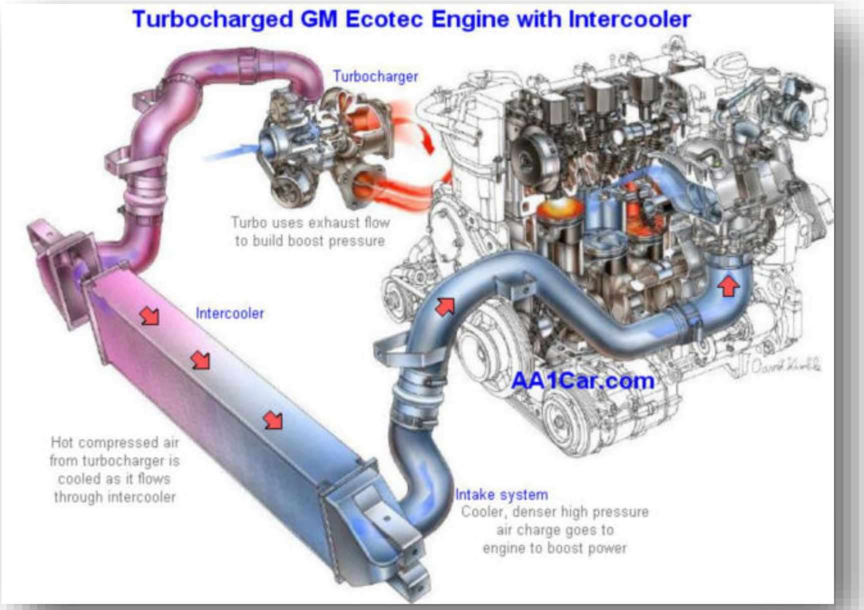
GDI Injector

- 2 Wire Solenoid
- Scope Leads On High & Low
- Control Circuits
- Check Voltage & Current
- Drivers' Ability To Turn On
- Shorted Coil
- Pintle Hump?
- Comparative Analysis



Testing Induction System For Leaks

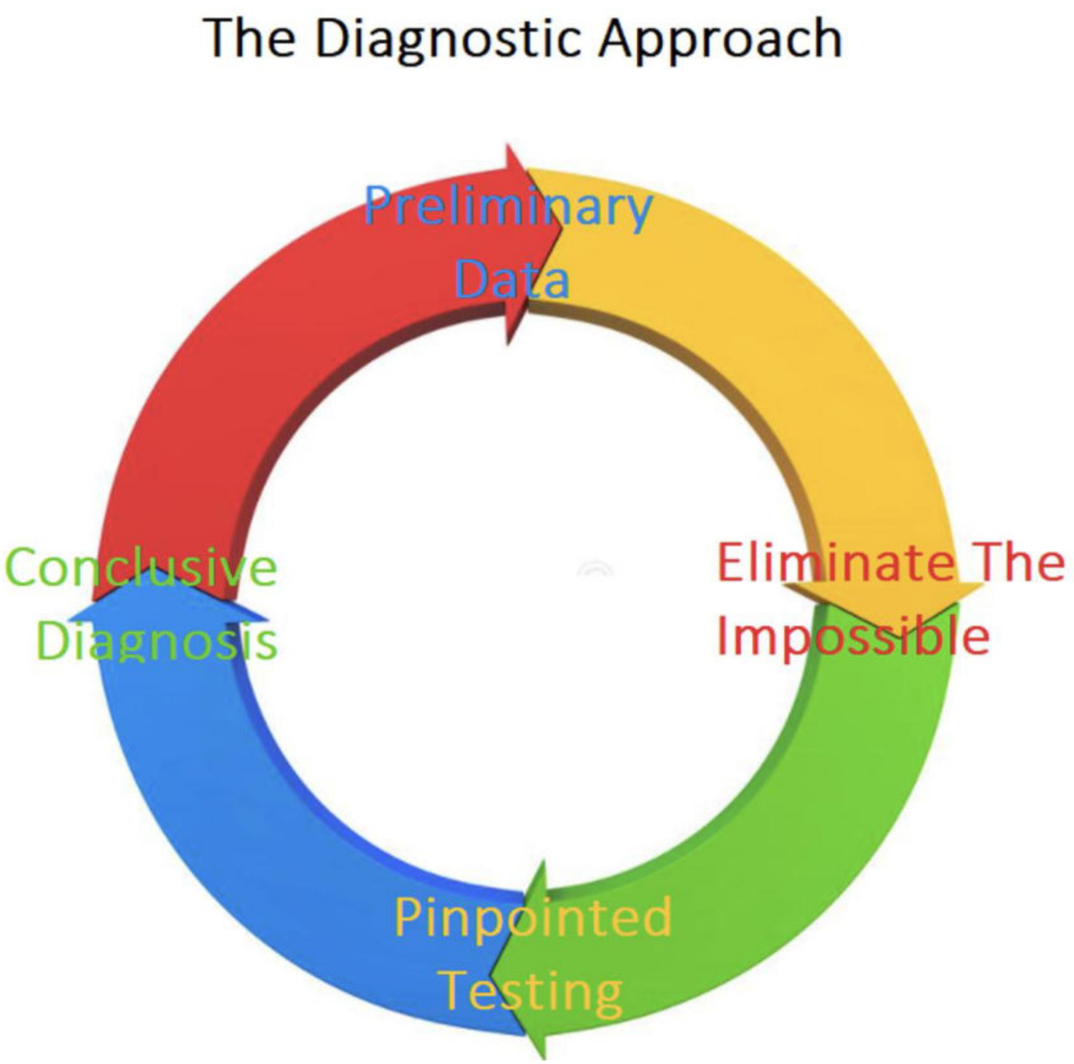
- Visual inspection
- Smoke testing
- Propane



CAUTION: High Pressure

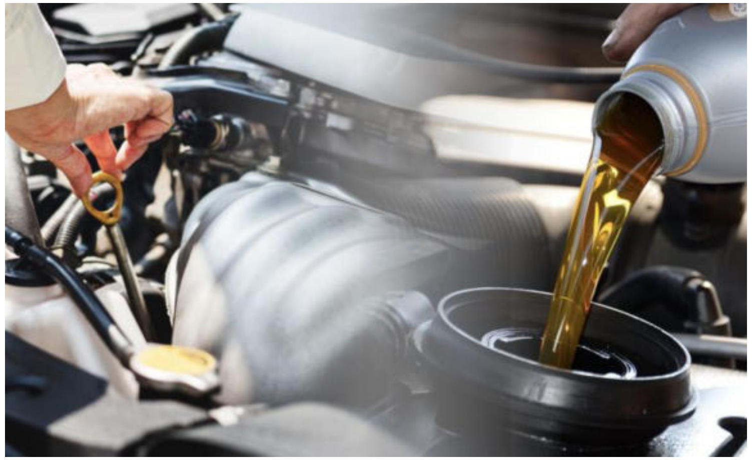
Post-Fix Verification

- Repeat failed-tests
- Reduces/eliminates comebacks
  - *OBD status*
  - *Scan data PIDs*
  - *Bi-directional control*
  - *Driveability road test*
  - *Smoke testing*
  - *Propane testing*
  - *Gas analysis*



Maintenance Is Critical

- Maintain ECU software levels
- Use quality materials and fluids
- Use the CORRECT filters and fluids
    - *Follow service specifications*
    - *Follow proper service intervals*
    - *Induction system maintenance?*



Carbon Issues

- Direct-Injection
- Blow-by / PCV system
- Poor maintenance
- Temperatures
- Countermeasures:
    - *Pour-in treatments (oil/fuel)*
    - *Fog-in treatments*
    - *Media blasting*

Chemical Treatments

- Best used as preventive maintenance (Service info!)
- Not great as a “Fix”
- Chemically dissolves carbon and limits production
- Not all are created equally
  - *Sticky rings*
  - *Collapsed lifters*
  - *Stuck phasers*
  - *Stuck OCVs*
  - *Noisy tensioners*
  - *Cleans port and Direct injectors*

Pressurized Treatments

- Best used a preventive maintenance (Service info!)
- Can be used as a "Fix"
- Uses staged chemicals for different carbon types
  - *Three chemicals*
  - *Strategized delivery*
  - *Pulsed pneumatically*

Media Blasting

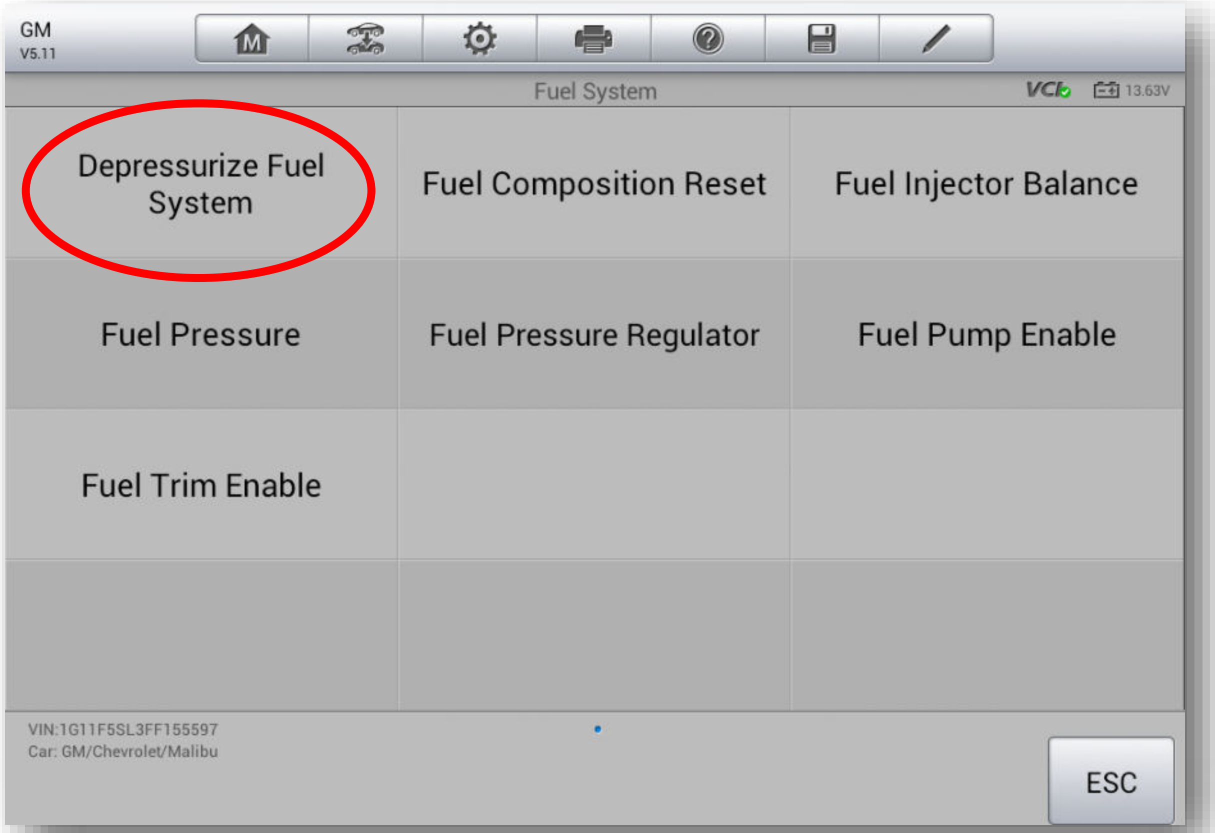
- Not recommended for preventive maintenance
- Great for restoring proper engine operation
- Labor intensive
- Messy process
- Instant return-on-investment
  - *Walnut shells*
  - *Dry-ice / Nitrogen*

Low-Speed Pre-Ignition

- GDI vaporizes oil
- Higher compression
- Turbo charging
- High load conditions
- Auto-ignition of oil droplets

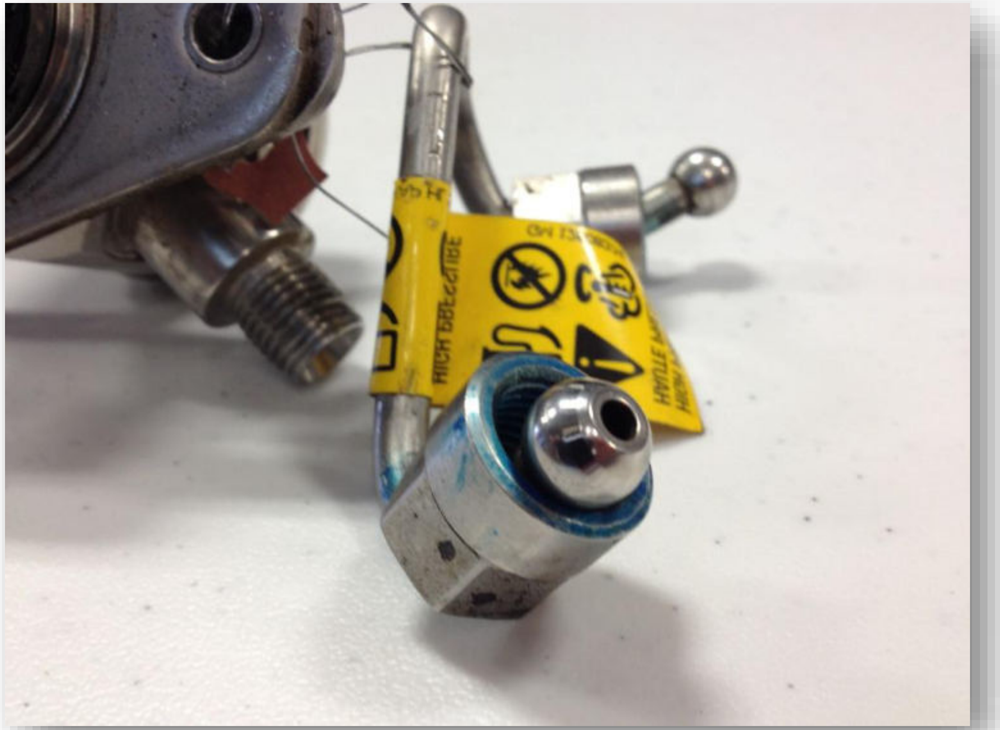
Depressurizing Fuel System

- High-Pressure fuel system can reach 200 Bar
- Fuel can pierce skin and damage components
  - *Ouch!*
  - *Poisoned*
- Scan tool command
- Disable HPFP FVR and run engine



Follow Service Repair Information!

- Replace components as prescribed
- Pressurized / atomized fuel
- Won't see "drips"
- Best to test with HC detection



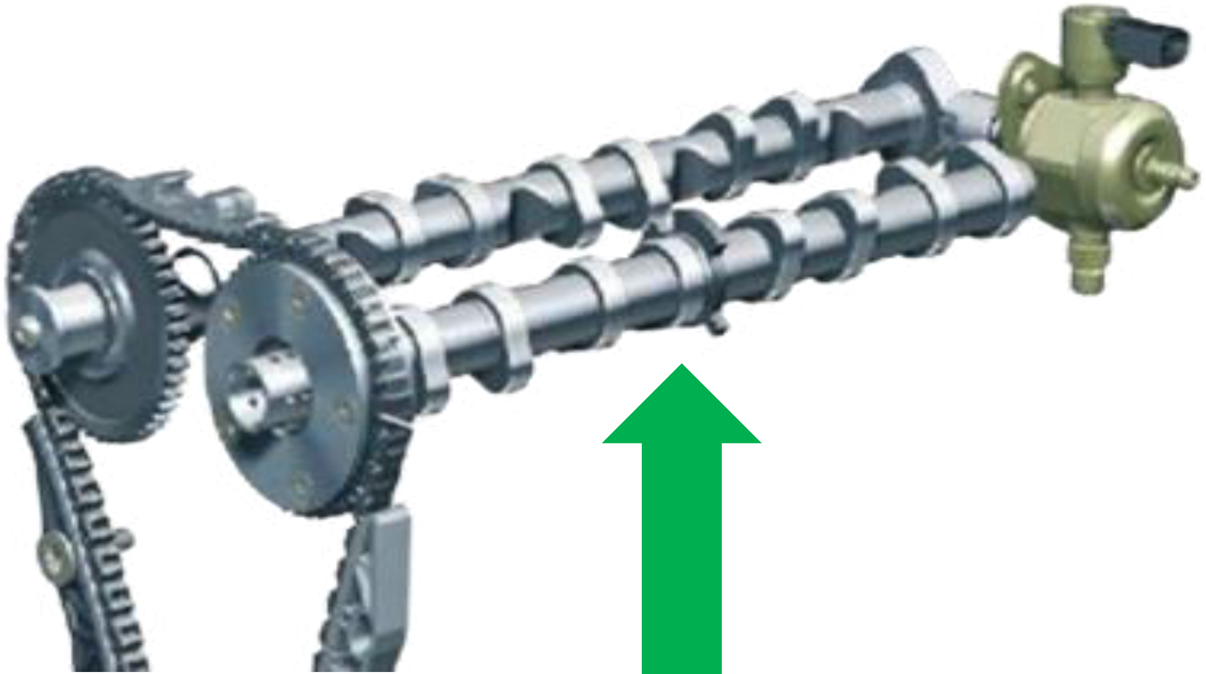
2006 MazdaSpeed6

Extended Crank & No Power

VIN #: JM1GG12LX61103470
Diagnosed: 8-14-17

Fault Code Retrieved

- P0012 (Bank 1)
- Actual Cam Timing is 10° Retarded from Target
- 5 Seconds or More
- Oil Control Valve in Feed-back Range
- ECT Above 20°C (68°F)



P0012 | Intake Cam Position Timing Over Retarded Bank 1 Fix It!

Camshaft Sensor Reluctor

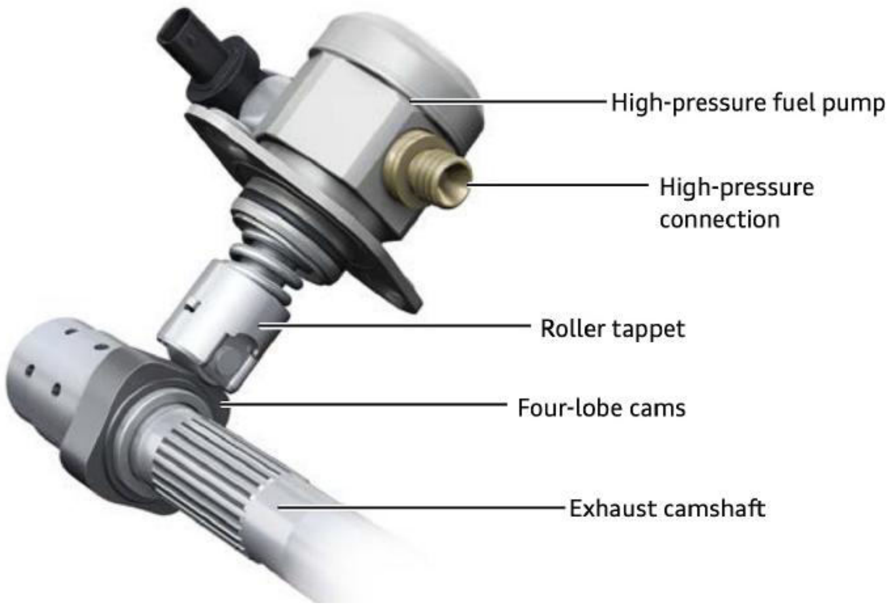
Scan Data

- Rail pressure set value = 725 PSI
- Actual value of rail pressure = 47 PSI
- Fuel pressure gauge verifies good low-pressure
- No high pressure = Low Power

Determine cause of low rail pressure

Significance of Cam Timing

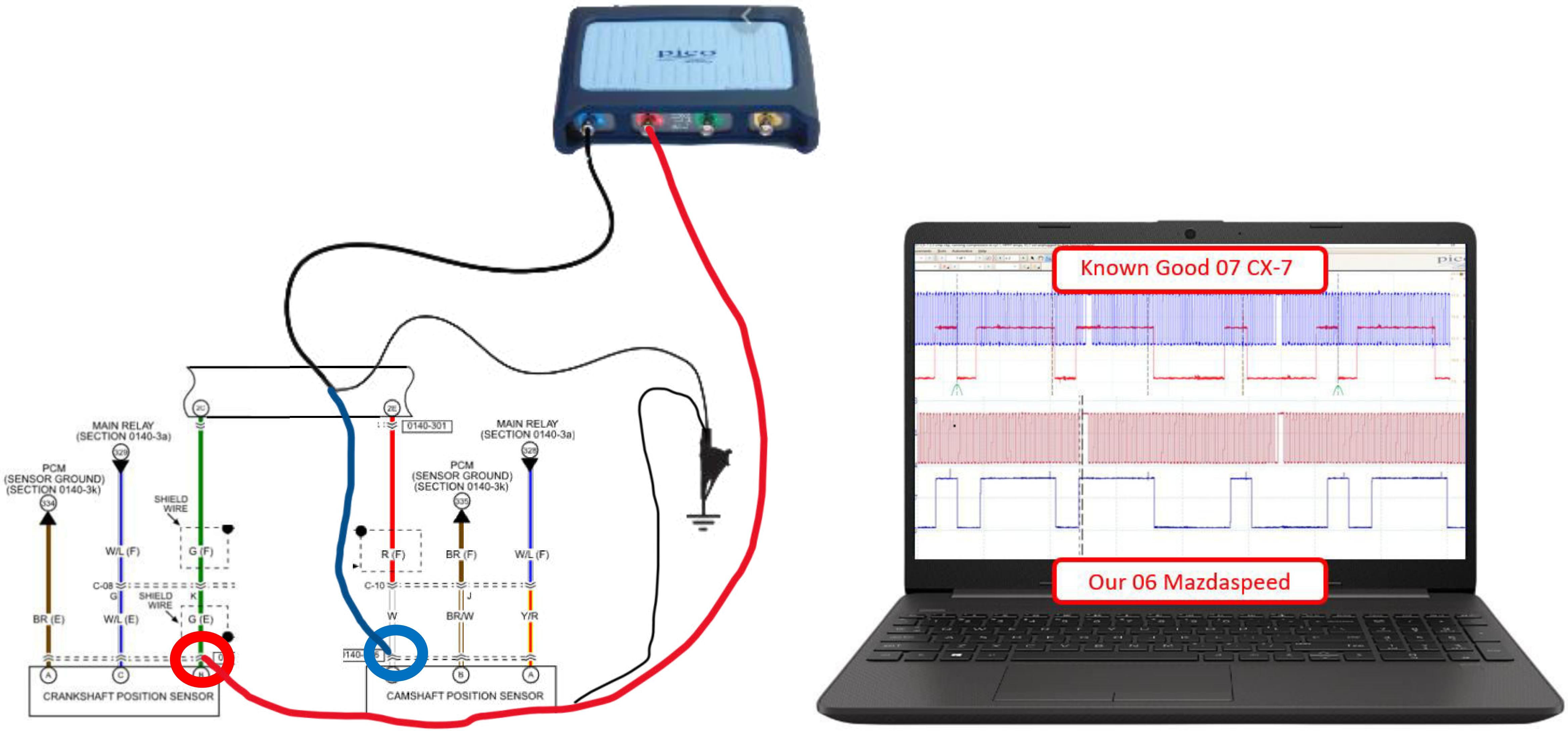
- Camshaft timing is critical
  - *ECM (DME) uses cam sensor signal for pressure control*
  - *Incorrect cam timing = Wrong pressure control timing*



Checking Camshaft Timing...

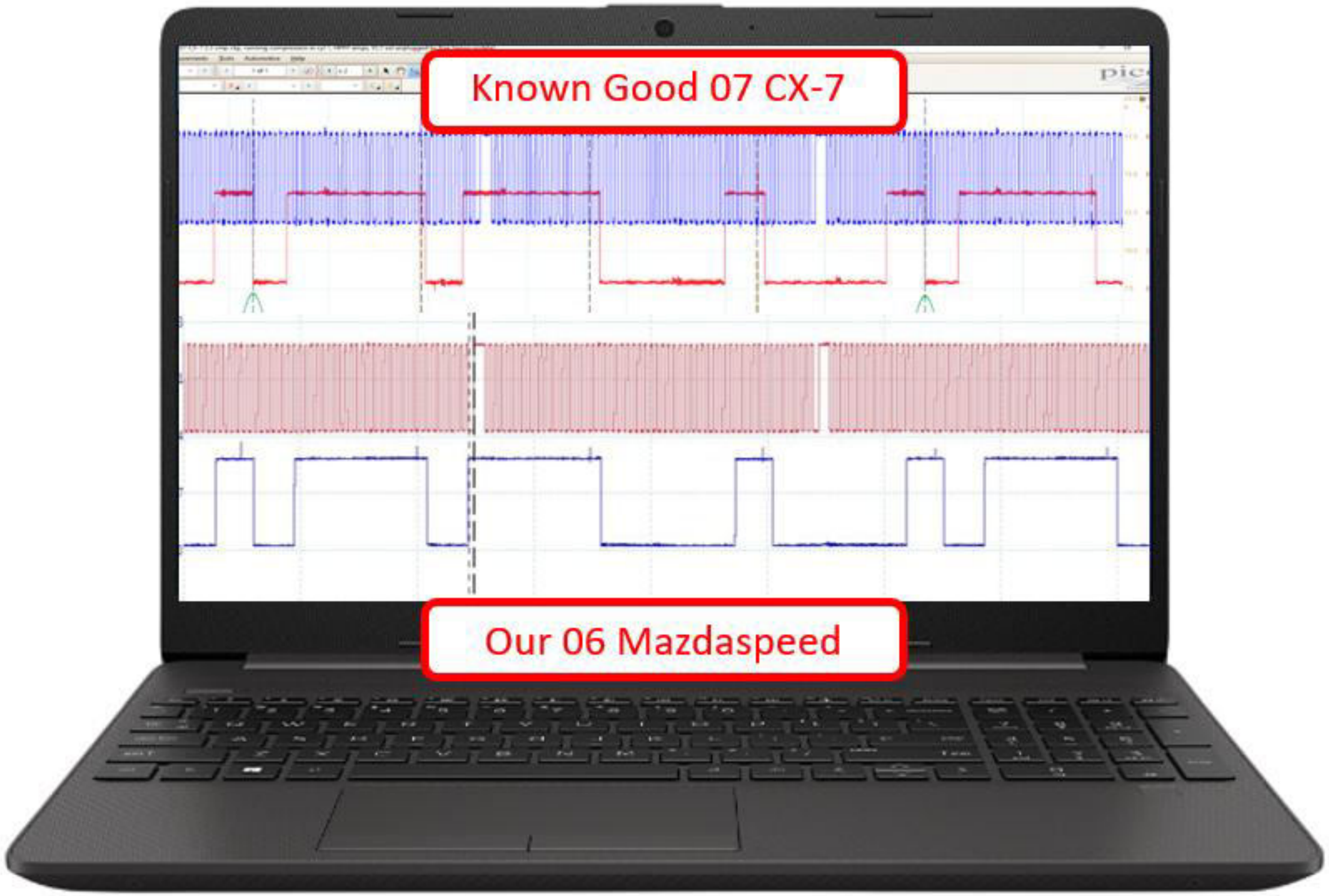
- Don't Disassemble
- Scope all the Things!
- Oscilloscope Waveform
  - *Crankshaft Vs Camshaft Signal*
  - *Reference Known Good & Compare*

Crankshaft vs. Camshaft Correlation



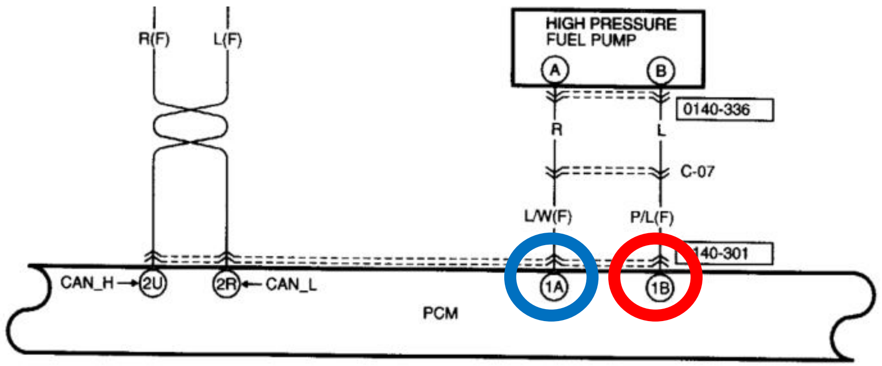
Crankshaft vs. Camshaft Correlation

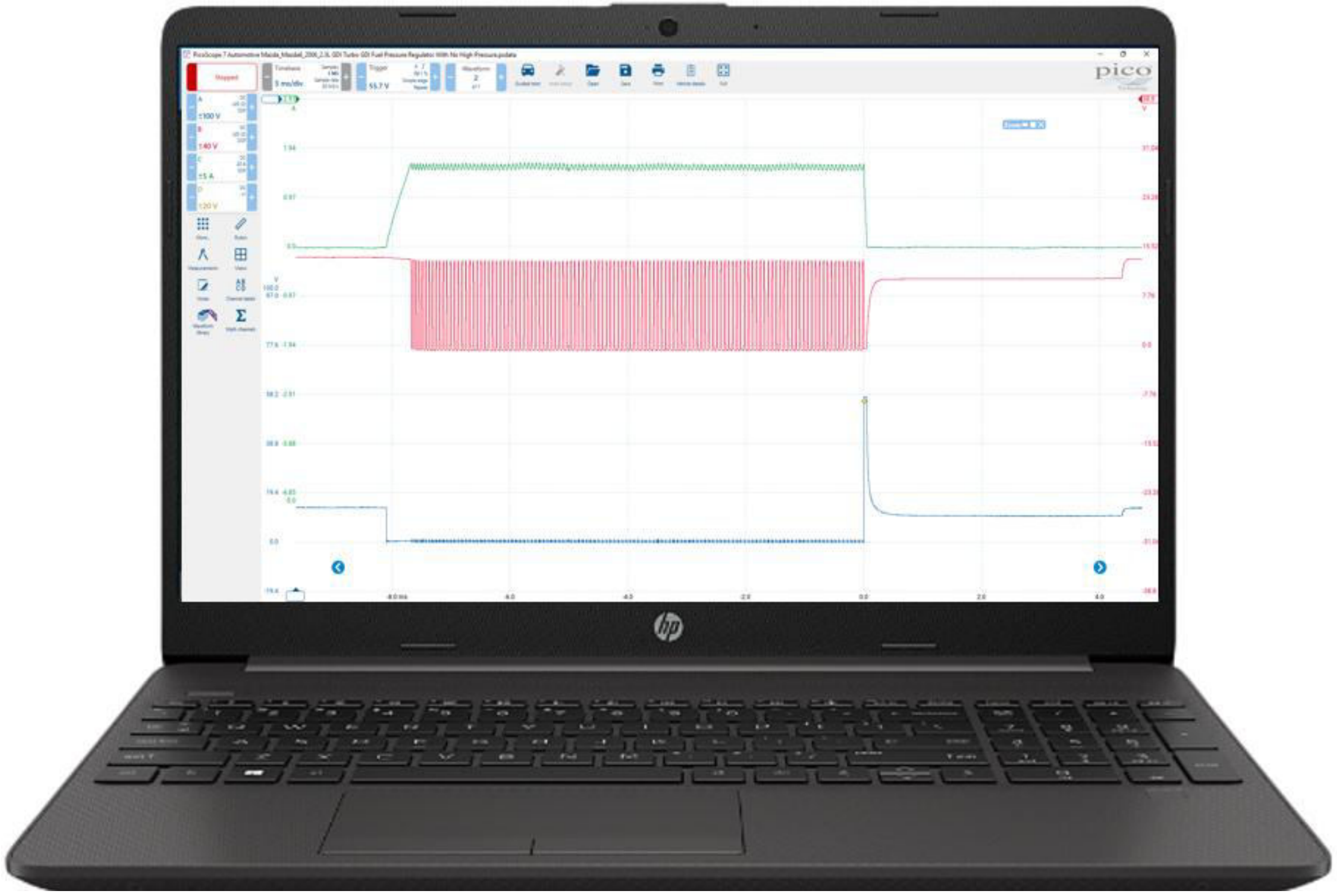
- No "MazdaSpeed 6" reference available
- 2007 CX-7 is identical
  - *Never assume!*
  - *Good enough for us to proceed*



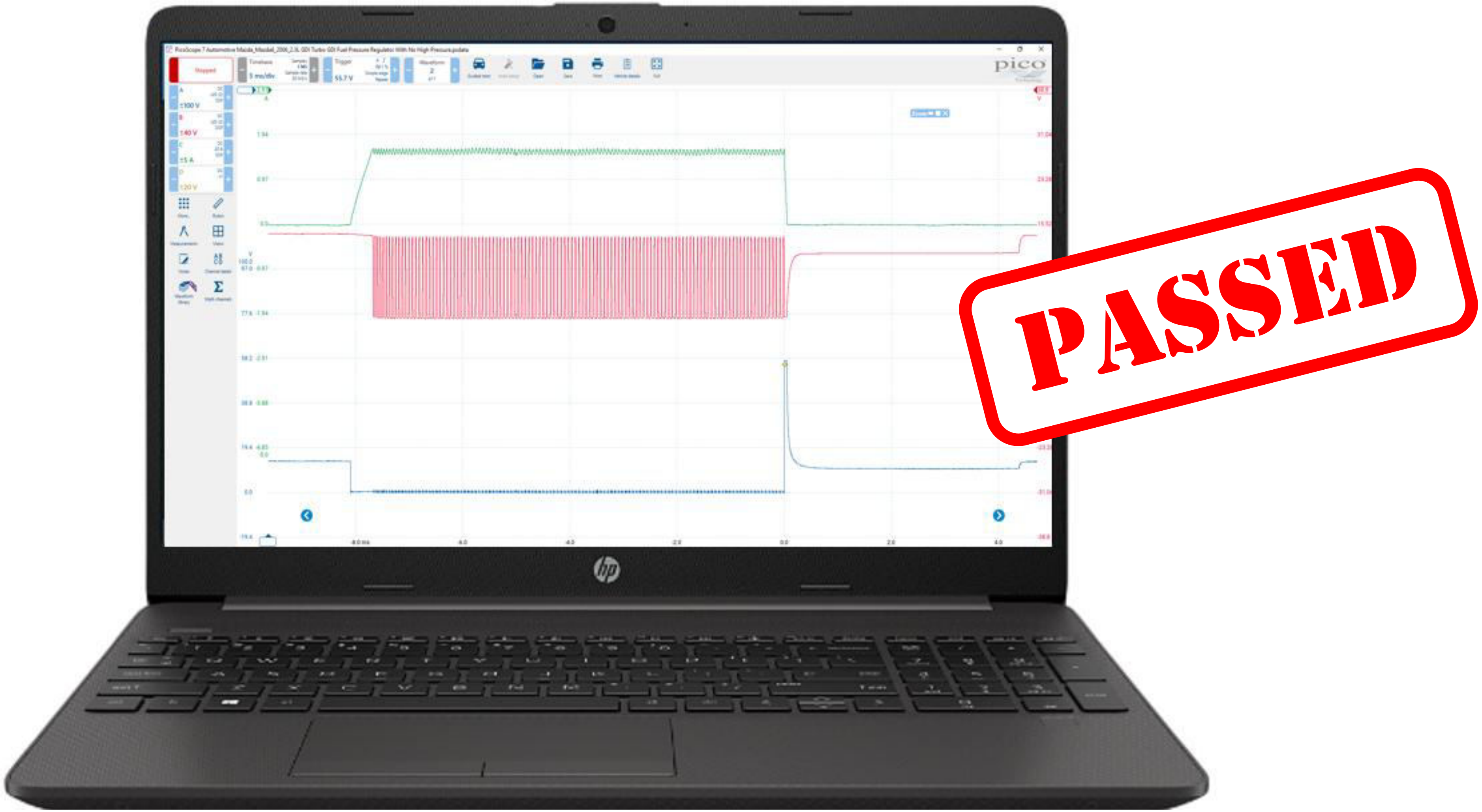
High Pressure Fuel Pump Control Circuits

- Current Flow Increases or Decreases Pressure
- Circuit Faults Could Cause Low Pressure
- Scope Needed for Dynamic Test
  - *Blue Trace = Ground Side Control*
  - *Red Trace = Voltage Control*
  - *Green Trance = Control Current*





High Pressure Fuel Pump Control Circuits

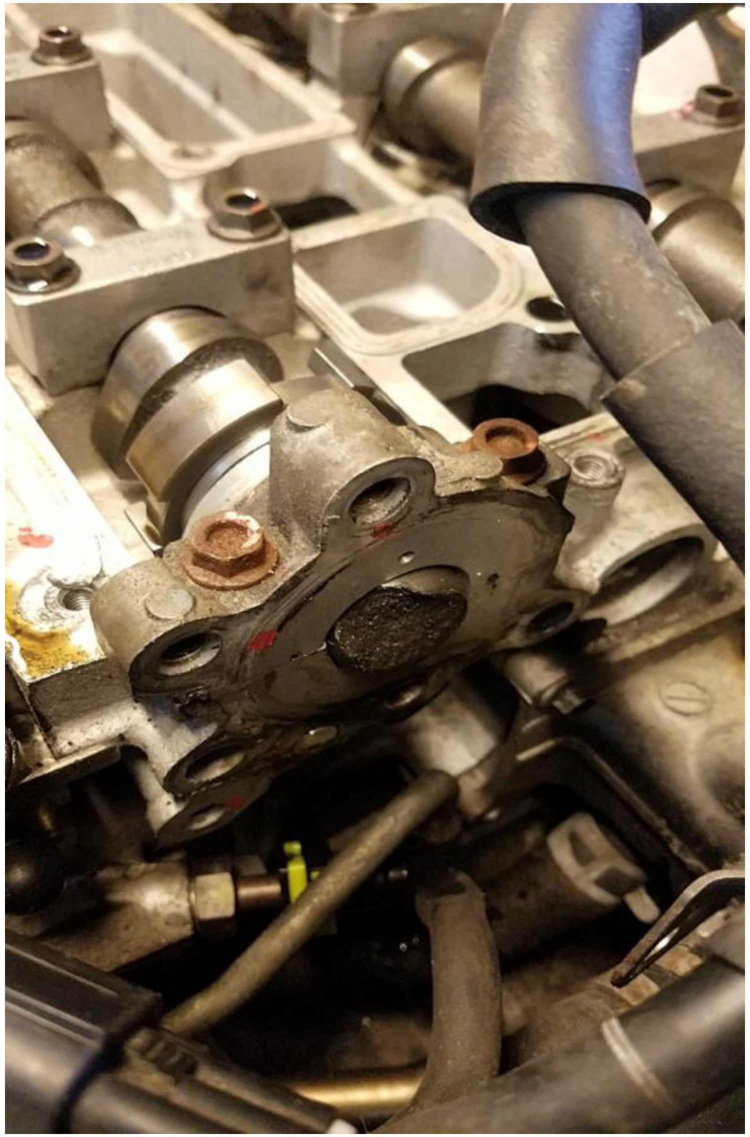


Justified Invasive Inspection…

- Physical Inspection Required
- Check Tappet Wear/Damage
- Camshaft Lobe or Drive Wear/Damage
- Pump Damage
- Final Elimination Step

Fuel Pump Tappet Missing

Broken Camshaft



This Part of the Camshaft

Is Not Attached To This Part

2006 Mazdaspeed6

Low Power And Backfiring During Cruise & Acceleration

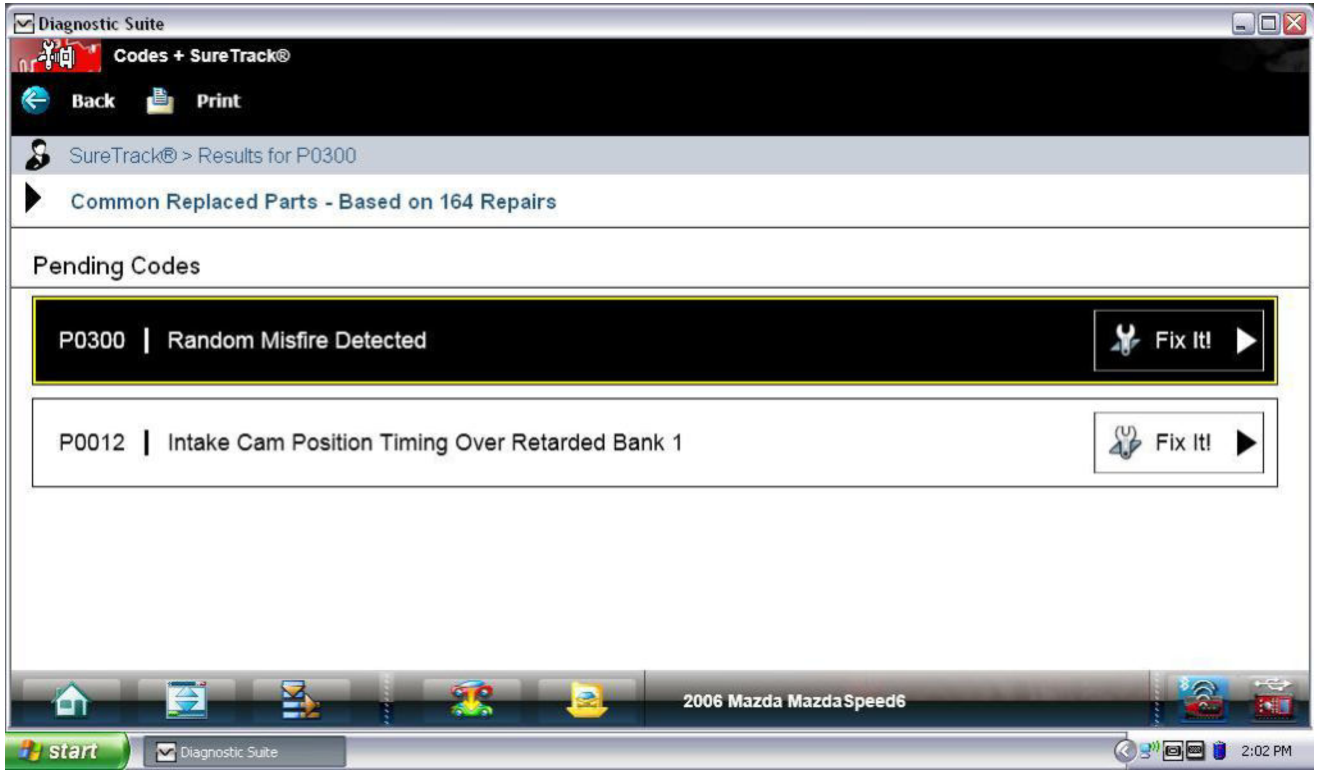
VIN #:

JM1GG12LX61103470

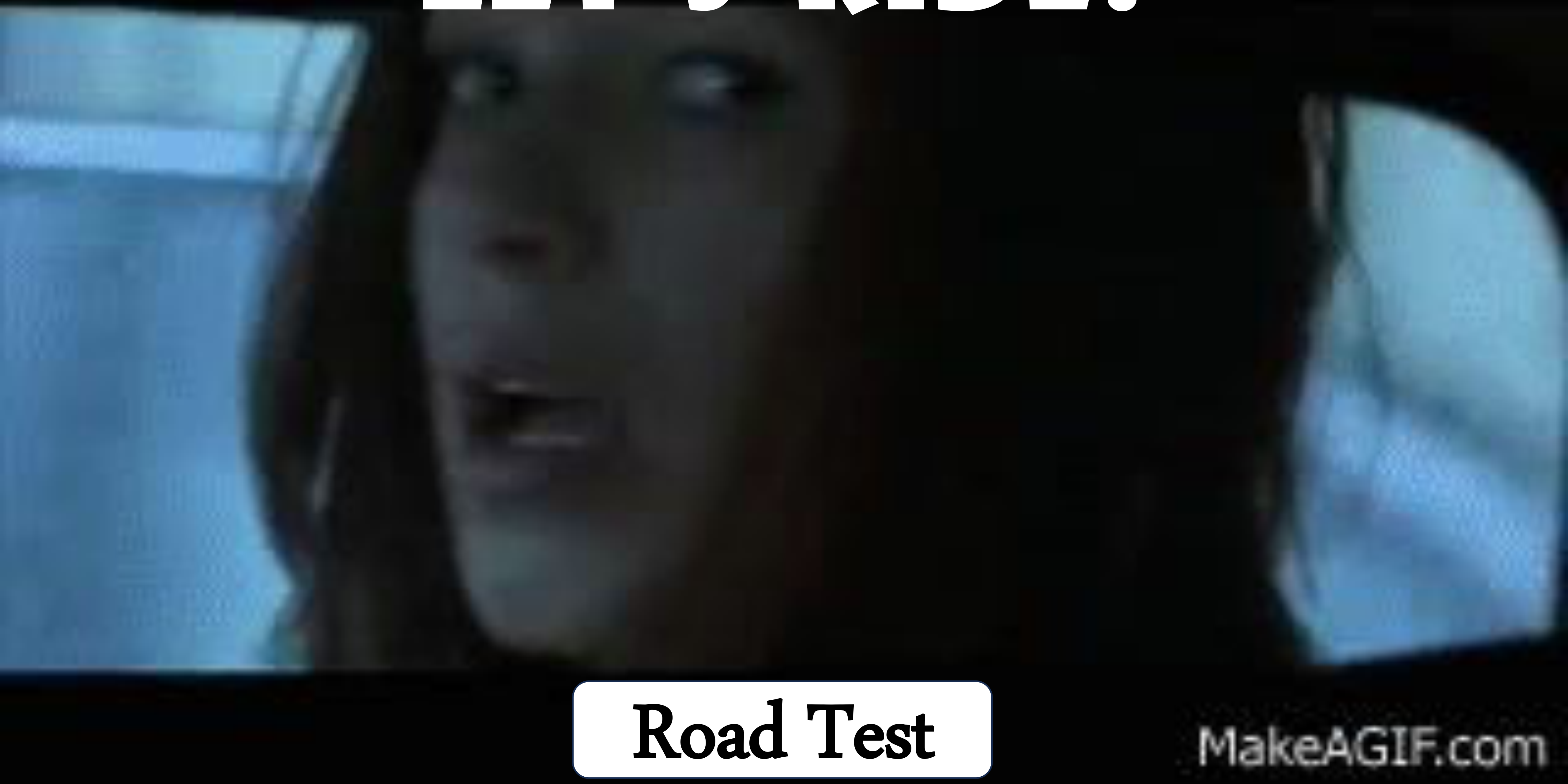
Mileage: 122,066

Retrieved Fault Codes

- The P0012 DTC is not new
- The symptoms are new
  - *Is the P0012 Related?*

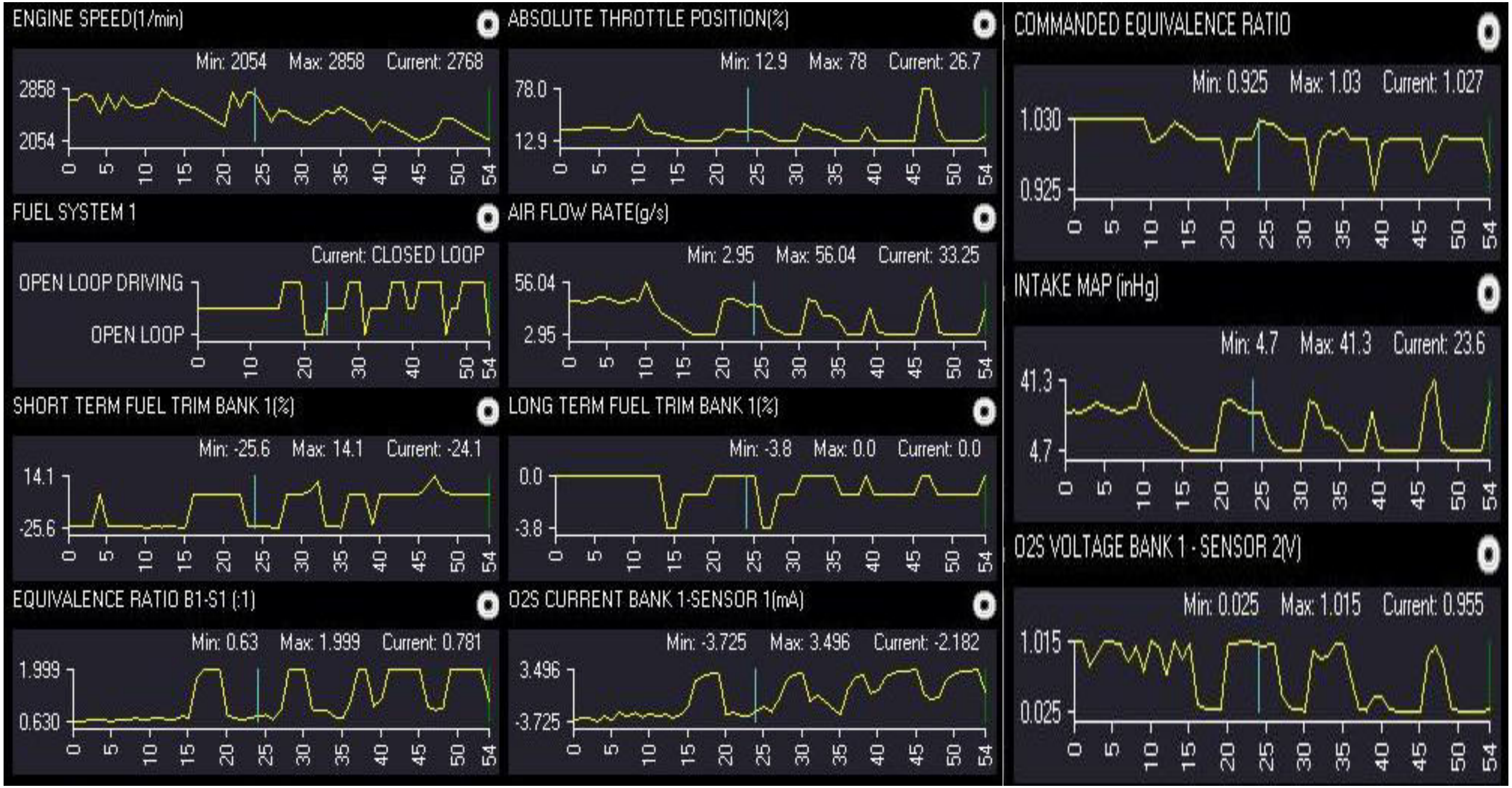


LET'S RIDE!



Road Test

Did We Duplicate The Symptom?



What Does It Mean?

- Commanded EQ-Ratio: 1.027
- EQ-Ratio: .781
- O2S Bank 1-Sensor 1 Current: -2.182 mA
- O2S Bank 1-Sensor 2 (V) .955 V
- Short Term Fuel Trim: -24.1%

We Did Duplicate The Concern? *Yes!*

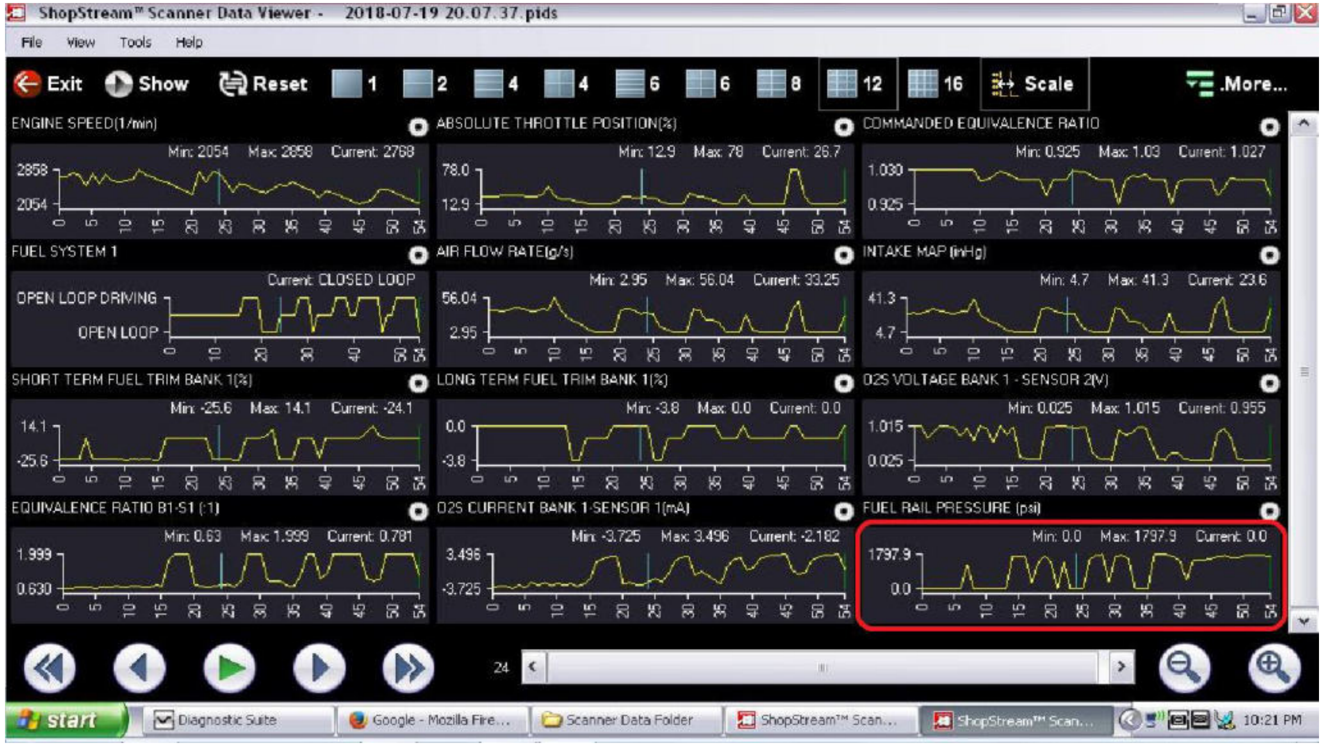
- Ran well for a minute then ran rough.
- The symptoms became more severe.
- The symptoms were present at idle, when we returned to the shop.

Let's Work Through This!

- Commanded Equivalence Ratio = approx. 1.00 (Requesting stoichiometry)
- Equivalence Ratio = < 1.00 (Rich condition)
- The Upstream WRAF = -2.18 mA (Rich condition)
- The Downstream HO2S = >950 mv (Rich condition)
- STFT = -25% (Compensating for a rich condition)

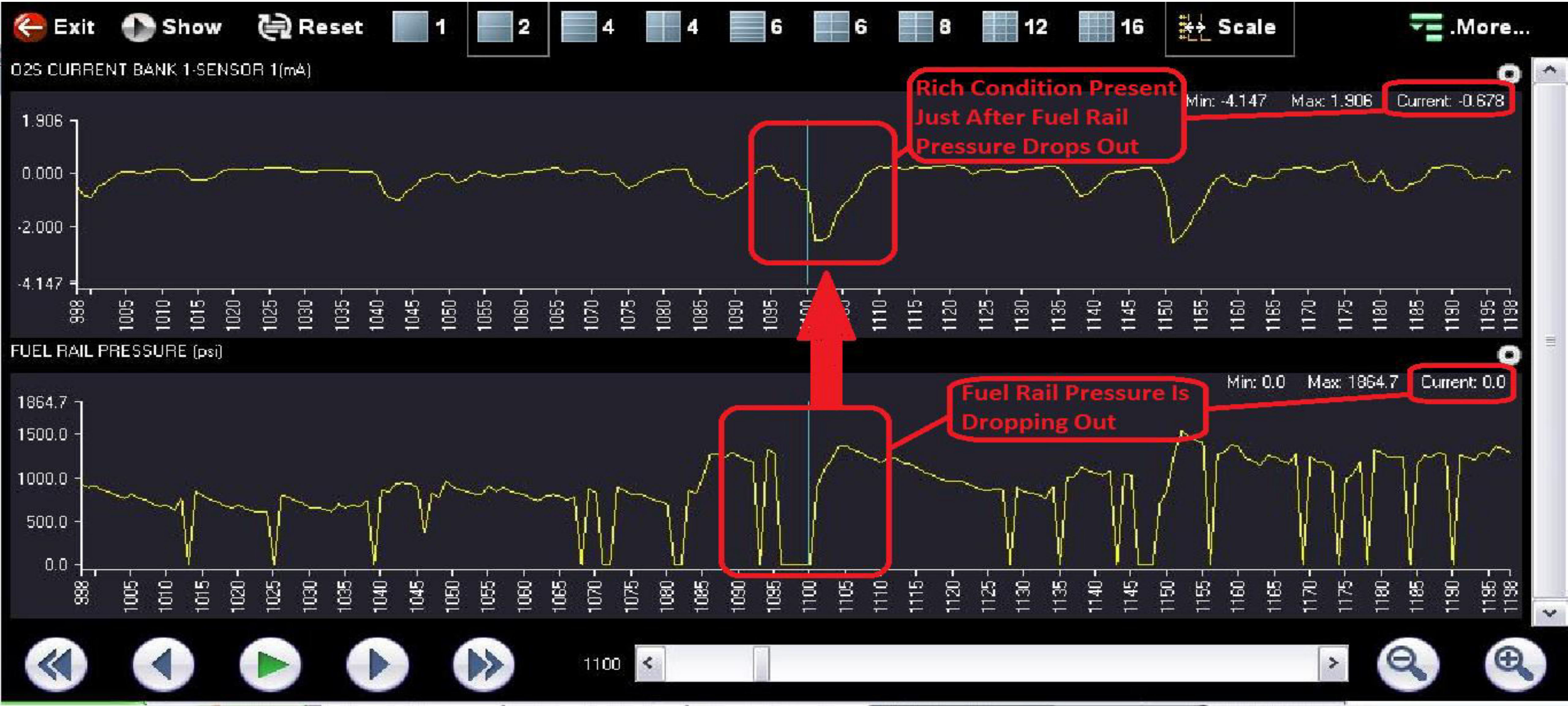
New Data Set_*How About Now?*

- FRP = ZERO, during running condition
  - *1700 psi…*
  - *Then 0 psi…*
  - *Then back to 1700 psi in 5 frames?*



Rich condition… with no fuel rail pressure?

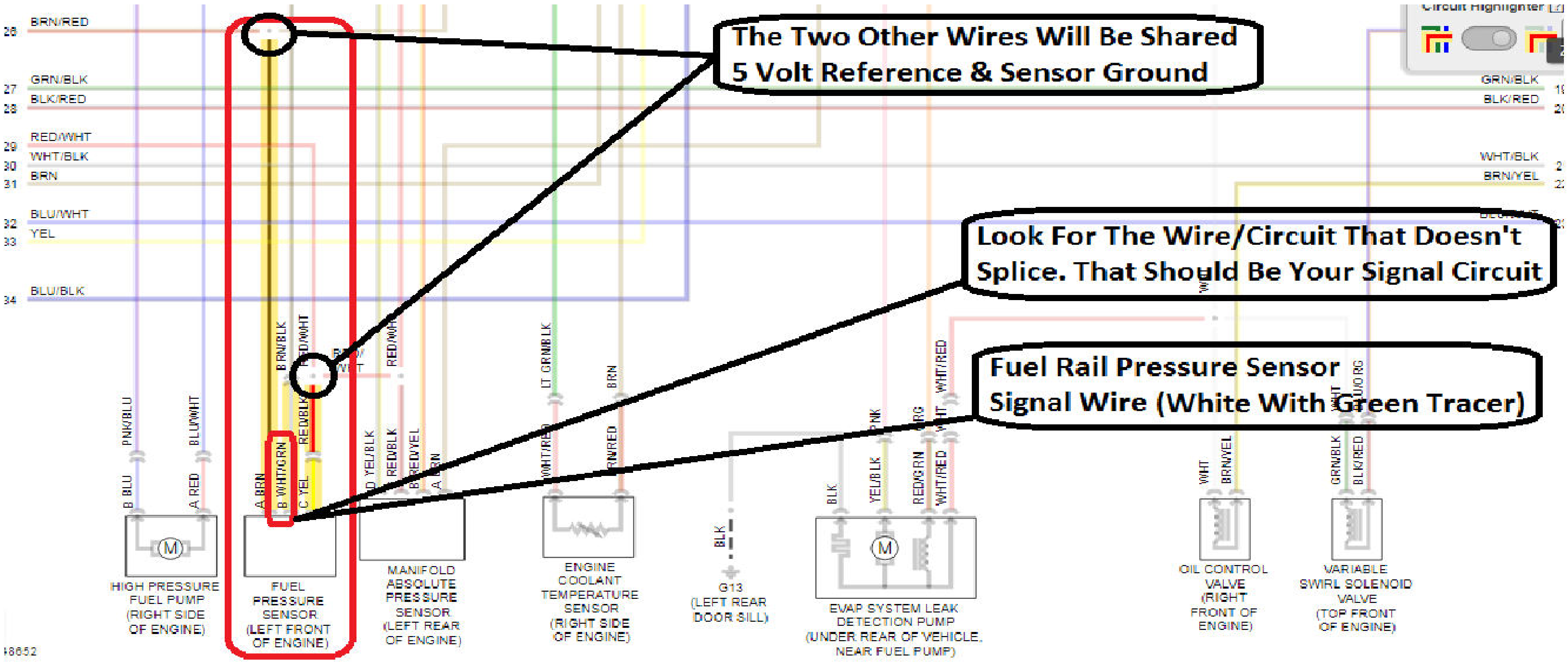
What's Next?



Exit
Show
Reset
Scale
.More...
O2S CURRENT BANK 1-SENSOR 1(mA)
Rich Condition Present Just After Fuel Rail Pressure Drops Out
Min: -4.147
Max: 1.906
Current: -0.678
FUEL RAIL PRESSURE (psi)
Fuel Rail Pressure Is Dropping Out
Min: 0.0
Max: 1864.7
Current: 0.0
1100

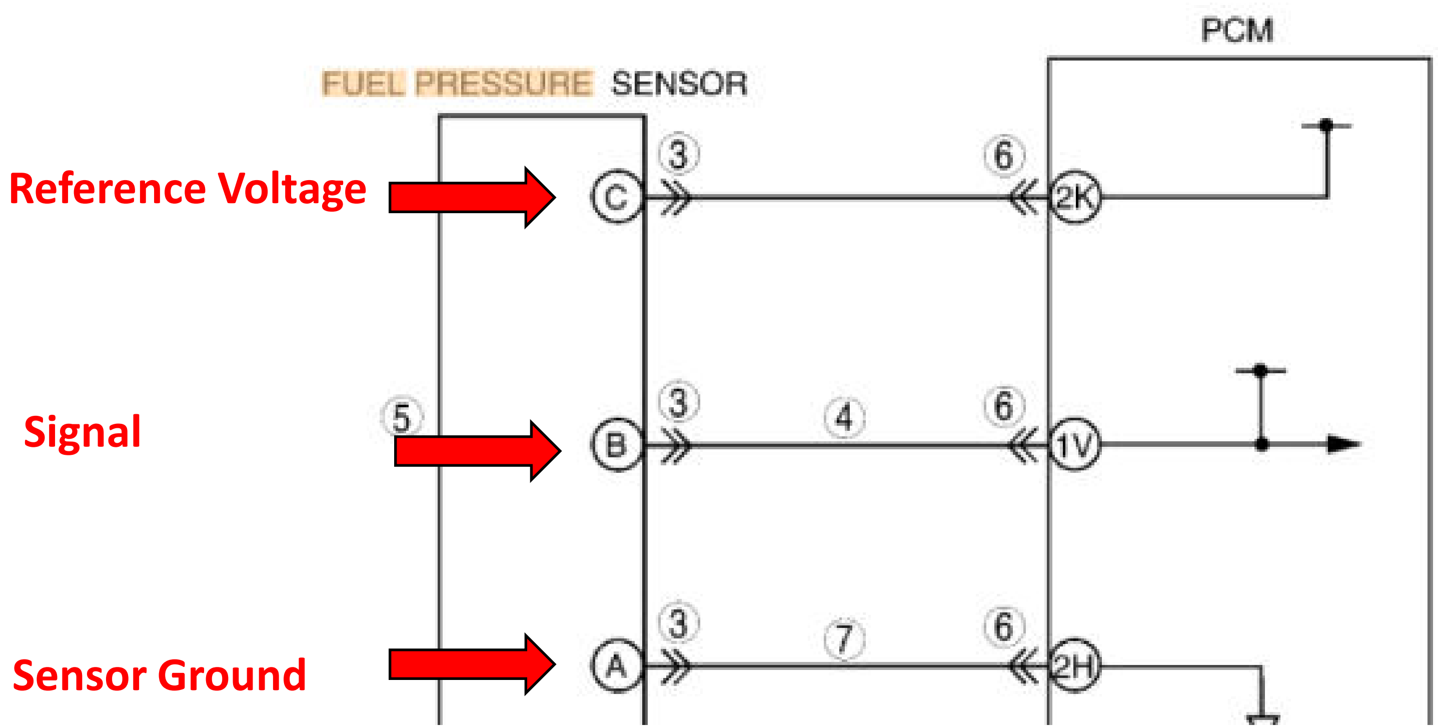
Pinpoint Test:

Measuring the Circuit vs. Processed Scan Data…



Pinpoint Test:

Measuring the Circuit vs. Processed Scan Data…



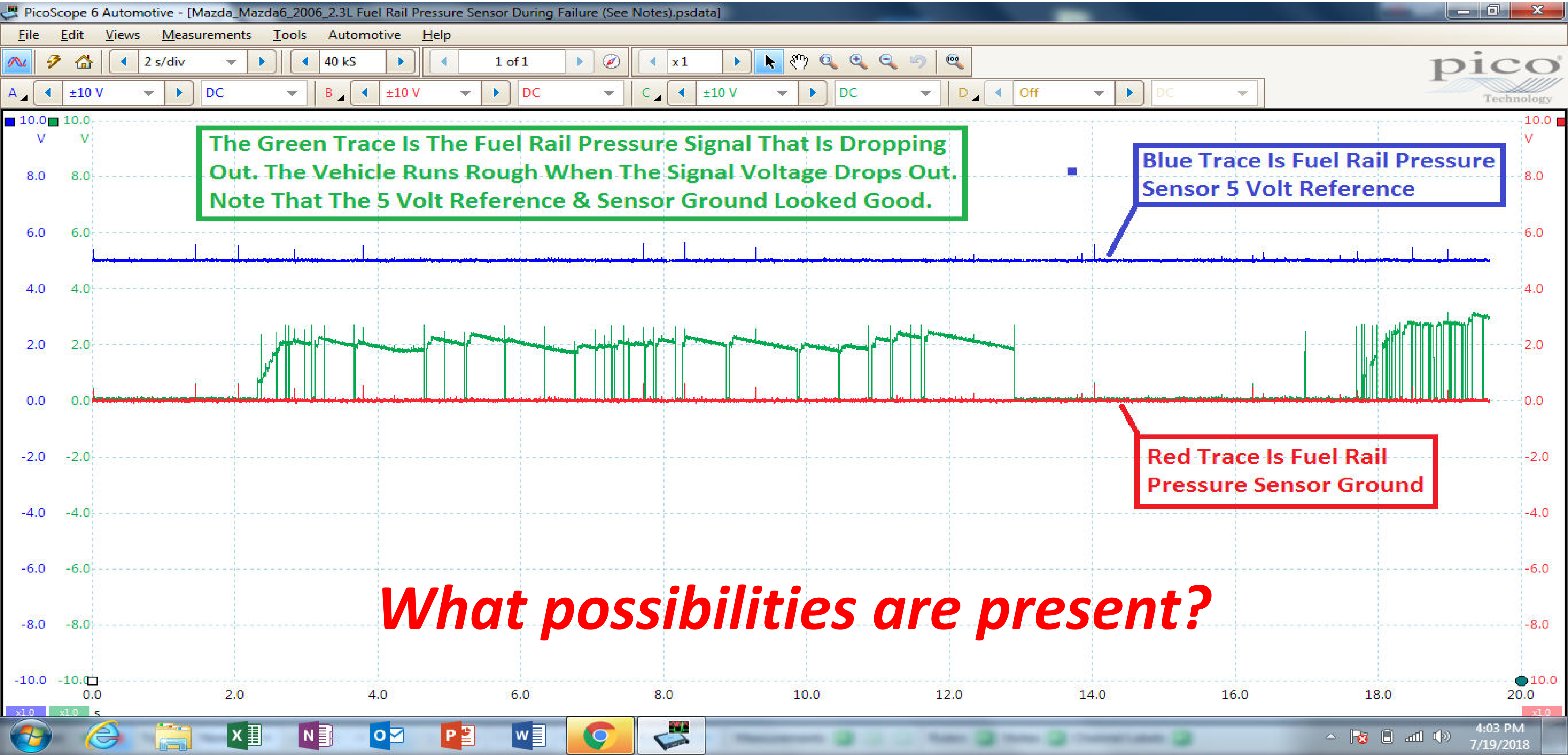
Why measure all three circuits?

Credit: Motologic

Pinpoint Test:

Measuring the Circuit vs. Processed Scan Data…

Does This Agree With Our Processed Data?



Pin Drag Test

- Drag test "passes"
- Process of elimination
- Sensor requires replacement
  - *Needs fuel rail assembly*
  - *Includes FRP sensor*
  - *Follow service procedures*

Scan Data After Fuel Rail Replacement

- The Vehicle Is Fixed!
- No Apples-To-Apples Comparison
- No Fuel Rail Pressure Dropout

We still have a variable cam timing fault, but the client declined to investigate. We were disappointed to say the least!

2014 Chevrolet Silverado 1500 5.3L

Rough Running & Low Power After Transmission Replacement

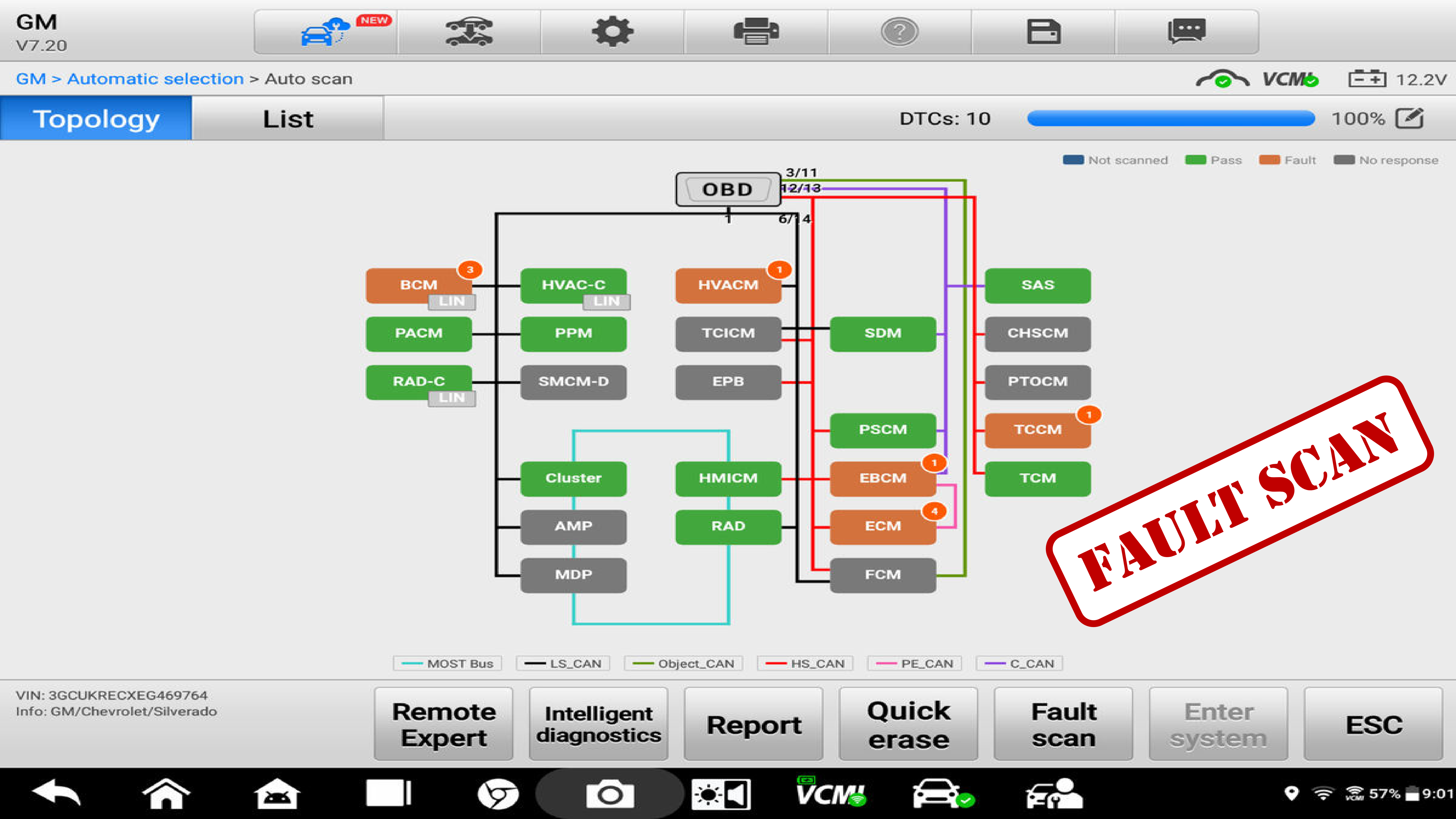
VIN: 3GCUKRECXEG469764

Mileage: 134,261

Diagnosed 6/27/22

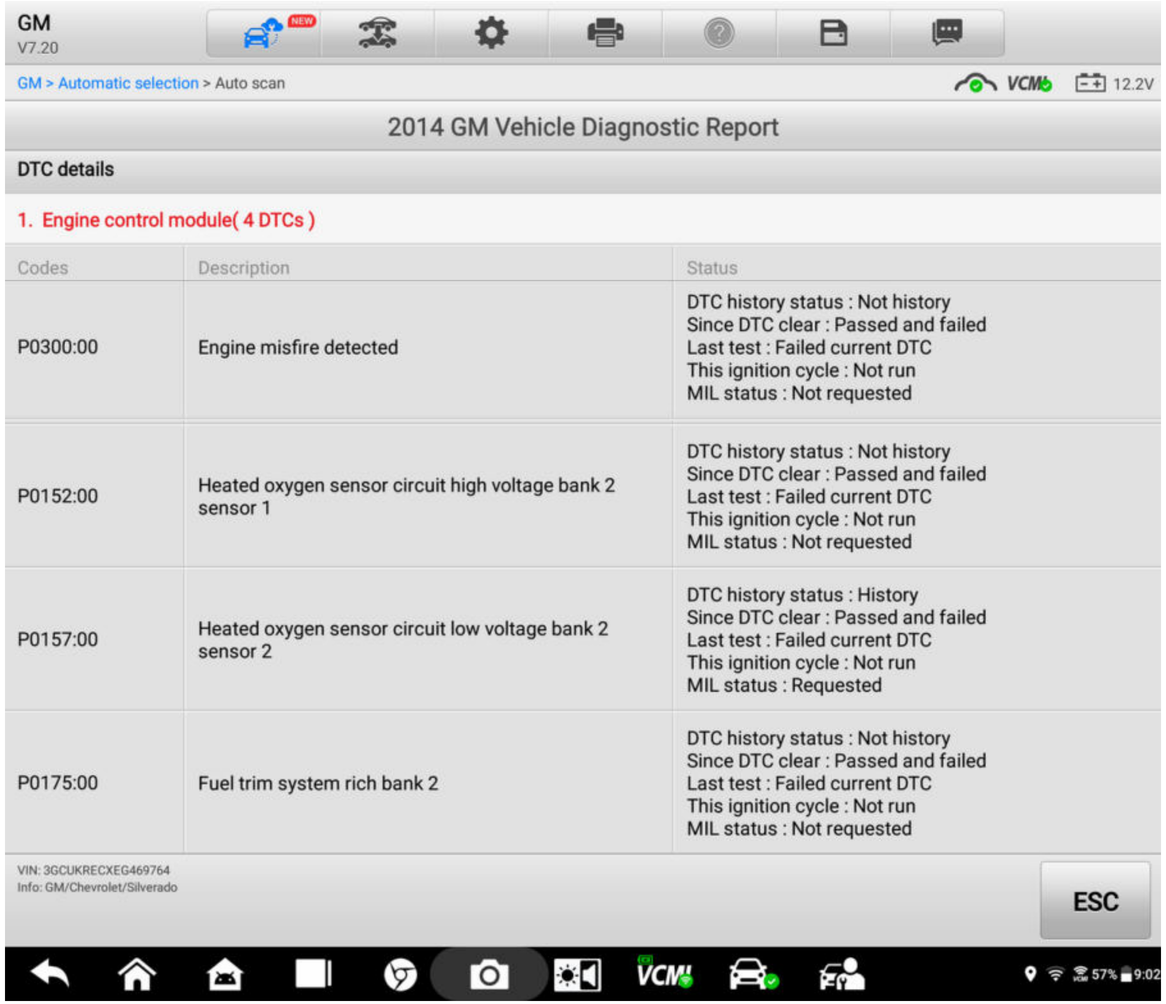
Back Story

- Runs rough two days after transmission repair
- Two different dealerships “couldn’t figure it out”
- Our client (shop owner) found oxygen sensor unplugged & melted
- Replaced sensor with aftermarket part but no change


GM
V7.20
NEW
GM > Automatic selection > Auto scan
VCM
12.2V
Topology
List
DTCs: 10
100%
Not scanned
Pass
Fault
No response
OBD
3/11
12/13
6/14
BCM
LIN
HVAC-C
LIN
HVACM
SAS
PACM
PPM
TCICM
SDM
CHSCM
RAD-C
LIN
SMCM-D
EPB
PTOCM
PSCM
TCCM
Cluster
HMICM
EBCM
TCM
AMP
RAD
ECM
MDP
FCM
FAULT SCAN
MOST Bus
LS_CAN
Object_CAN
HS_CAN
PE_CAN
C_CAN
VIN: 3GCUKRECXEG469764
Info: GM/Chevrolet/Silverado
Remote Expert
Intelligent diagnostics
Report
Quick erase
Fault scan
Enter system
ESC
57%
9:01

Retrieved Fault Codes

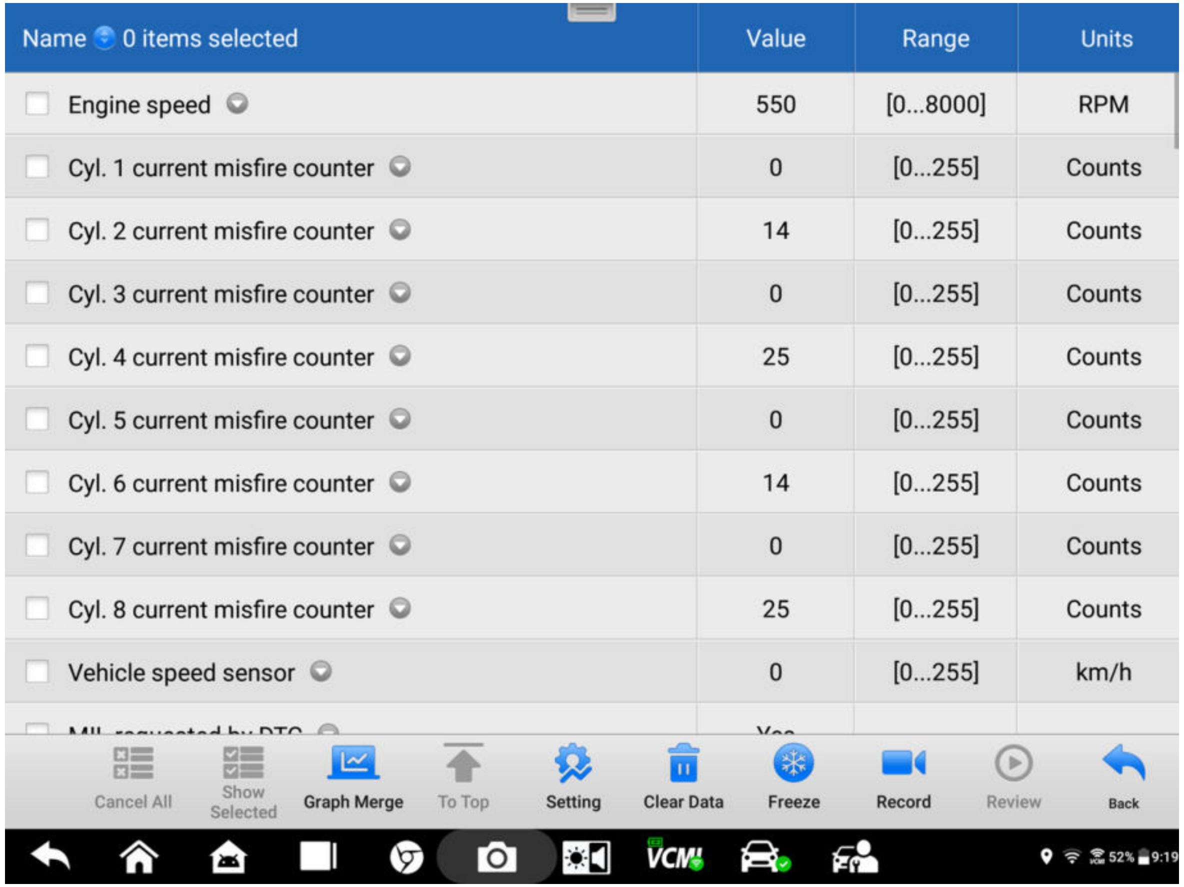
- Engine misfire
- O2S Bank 2 – Sensor 1+2 DTCs
- Performance or circuit DTCs?
- Fuel trim DTC
    - *Misfire cause or effect?*



Codes	Description	Status
P0300:00	Engine misfire detected	DTC history status : Not history Since DTC clear : Passed and failed Last test : Failed current DTC This ignition cycle : Not run MIL status : Not requested
P0152:00	Heated oxygen sensor circuit high voltage bank 2 sensor 1	DTC history status : Not history Since DTC clear : Passed and failed Last test : Failed current DTC This ignition cycle : Not run MIL status : Not requested
P0157:00	Heated oxygen sensor circuit low voltage bank 2 sensor 2	DTC history status : History Since DTC clear : Passed and failed Last test : Failed current DTC This ignition cycle : Not run MIL status : Requested
P0175:00	Fuel trim system rich bank 2	DTC history status : Not history Since DTC clear : Passed and failed Last test : Failed current DTC This ignition cycle : Not run MIL status : Not requested

Misfire Data

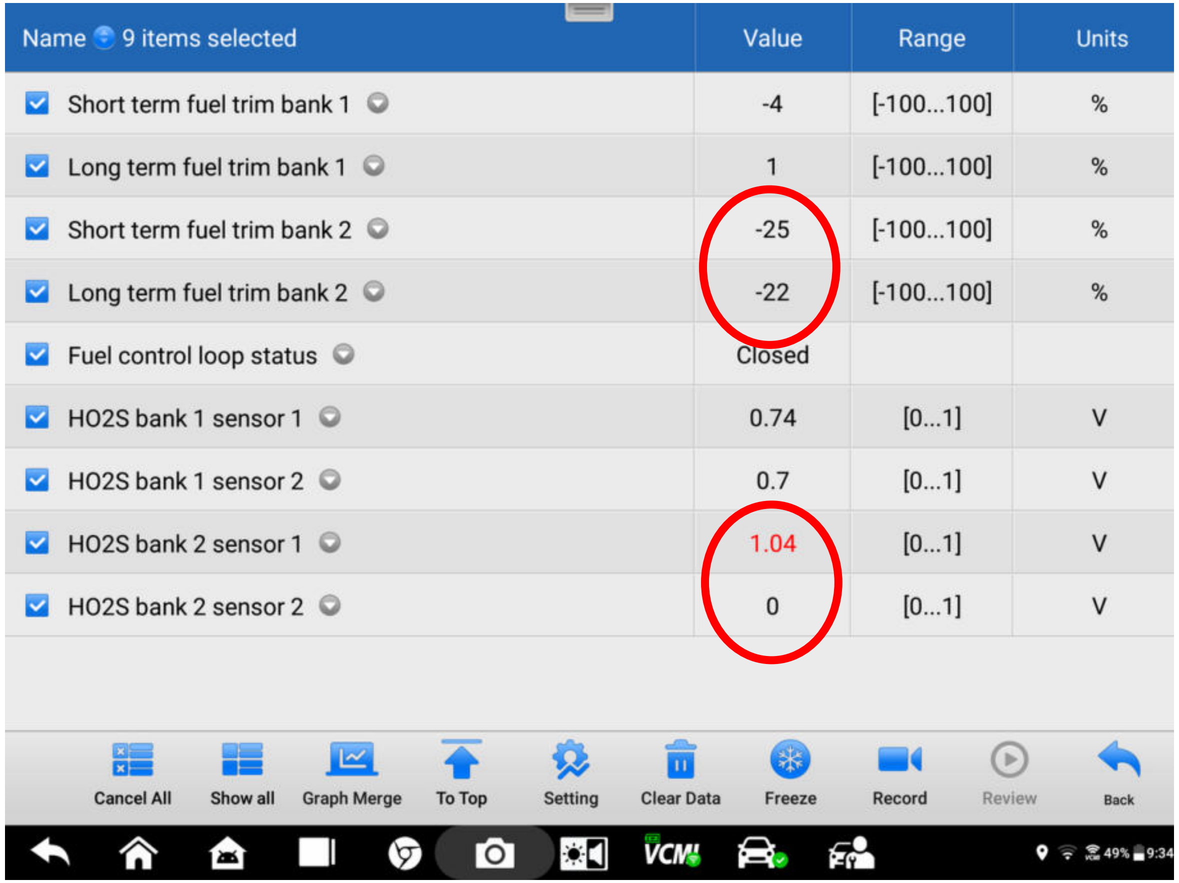
- Is there a trend **(YES!)**
- Let the data guide you
- Low-hanging fruit
- What is common to misfiring cylinders
  - *They're All On Bank 2!*



Name 0 items selected	Value	Range	Units
Engine speed	550	[0...8000]	RPM
Cyl. 1 current misfire counter	0	[0...255]	Counts
Cyl. 2 current misfire counter	14	[0...255]	Counts
Cyl. 3 current misfire counter	0	[0...255]	Counts
Cyl. 4 current misfire counter	25	[0...255]	Counts
Cyl. 5 current misfire counter	0	[0...255]	Counts
Cyl. 6 current misfire counter	14	[0...255]	Counts
Cyl. 7 current misfire counter	0	[0...255]	Counts
Cyl. 8 current misfire counter	25	[0...255]	Counts
Vehicle speed sensor	0	[0...255]	km/h

Engine Data Comparison

- Symptoms Present?
- Data Agree With Codes?
- Misfires: Cause Or Affect?



Be There With Me!

- Runs Rough In Closed Loop
- Clears Up In Open Loop

- General experience
  - *Bank 2 Sensor1 is highly suspect*
- Models specific experience
  - *Replacement HO2 sensor heater relearn?*

HO2 Sensor Heater Resistance Learn

- ECM pulse width modulates HO2S heater
- Resistance increases over time
- Performance degrades over time
  - *ECM compensates*
  - *Relearn needed with new sensor*

HEATED OXYGEN SENSOR RESISTANCE LEARN RESET CAUTION (DANGERS, WARNINGS, AND CAUTIONS)

Heated Oxygen Sensor Resistance Learn Reset Caution

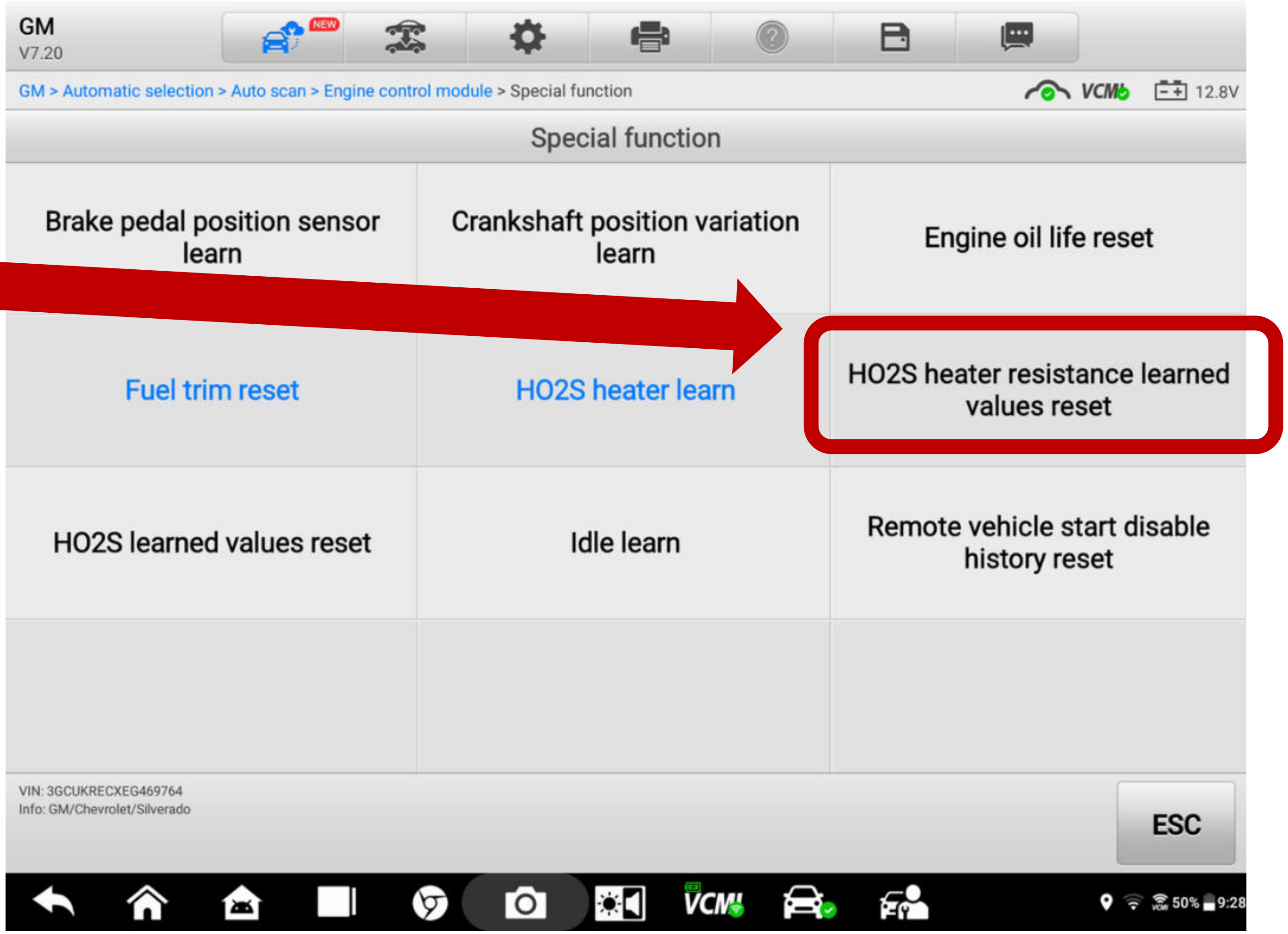
Caution: When replacing the HO2S perform the following:

- A code clear with a scan tool, regardless of whether or not a DTC is set
- HO2S heater resistance learn reset with a scan tool, where available

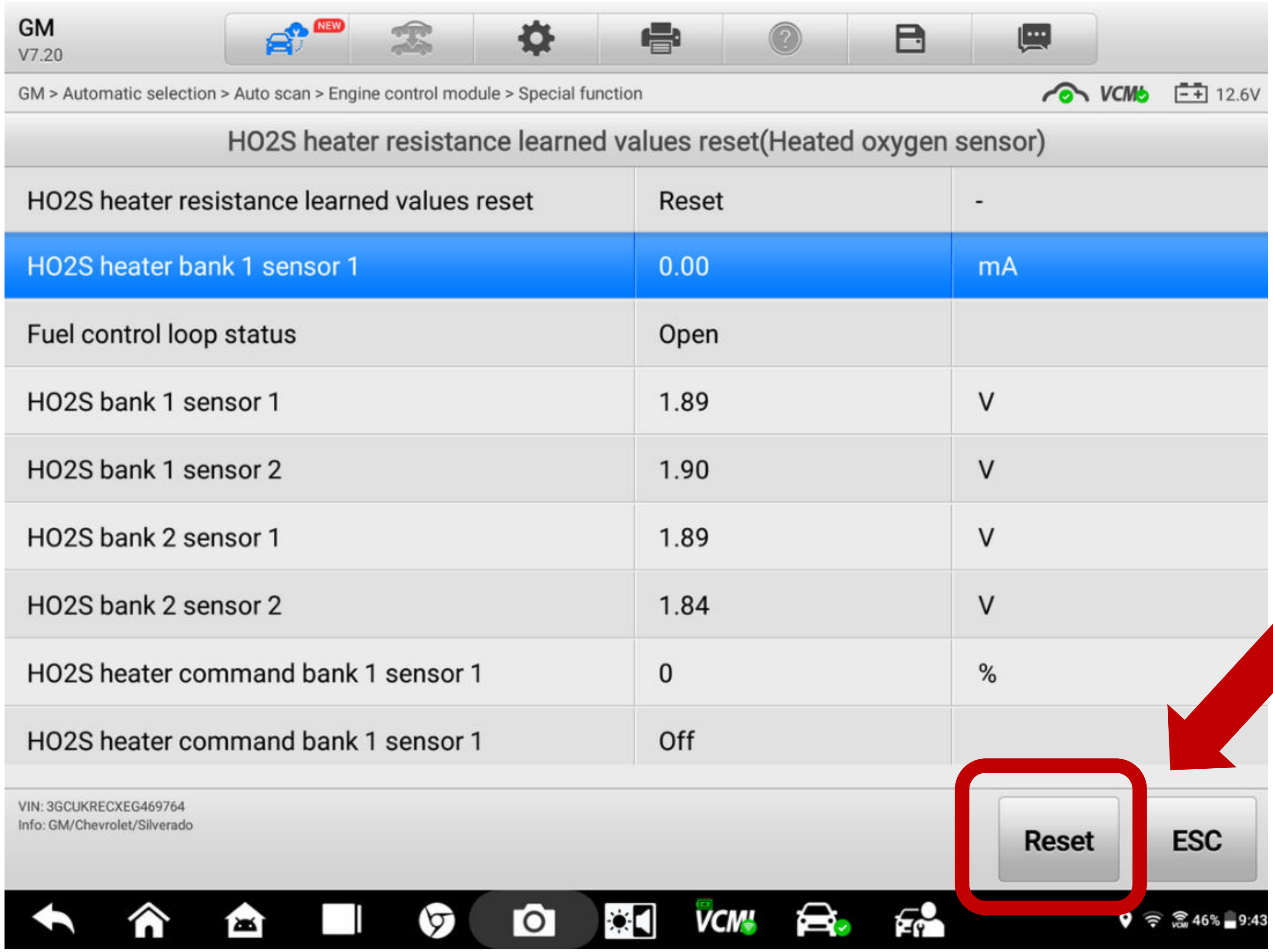
Perform the above in order to reset the HO2S resistance learned value and avoid possible HO2S failure.

Special Function: HO2S Heater Learn Walk-Through

- Go To Special Functions
- Click HO2S Heater Resistance Learned Value Reset



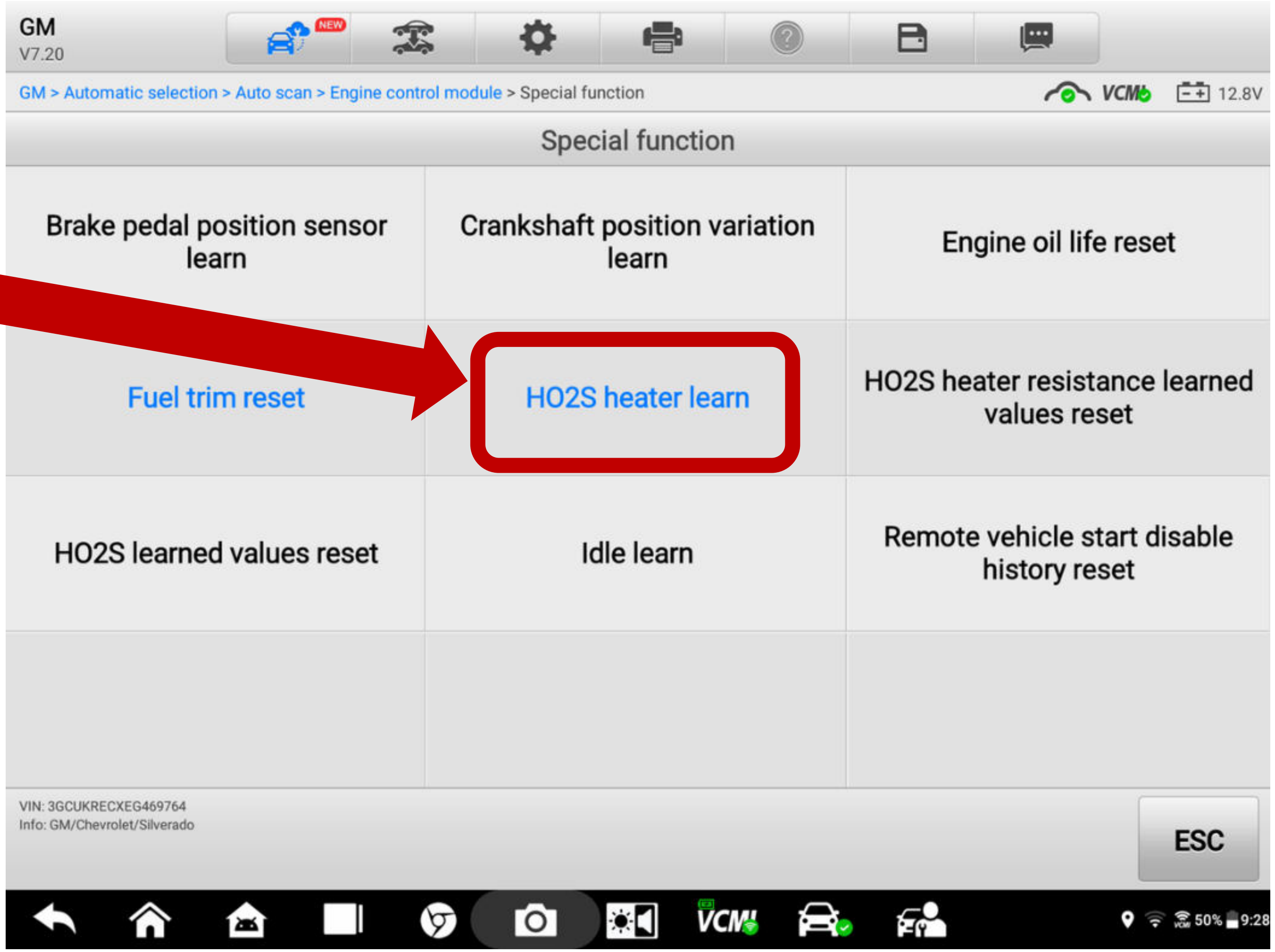
Special Function: HO2S Heater Learn-Walk Through



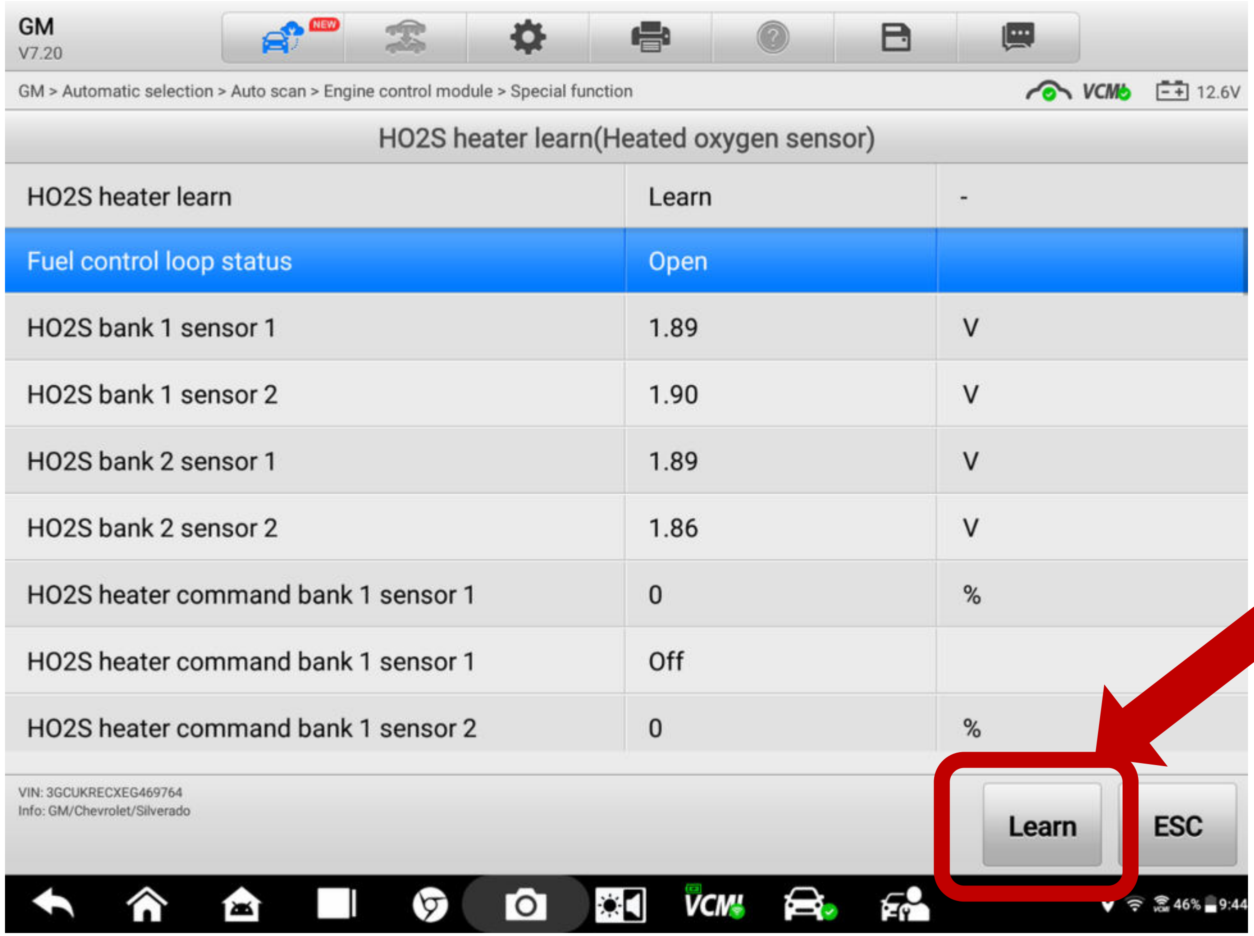
Click Reset

Special Function: HO2S Heater Learn Walk-Through

- Go To Special Functions
- Click HO2S Heater Learn



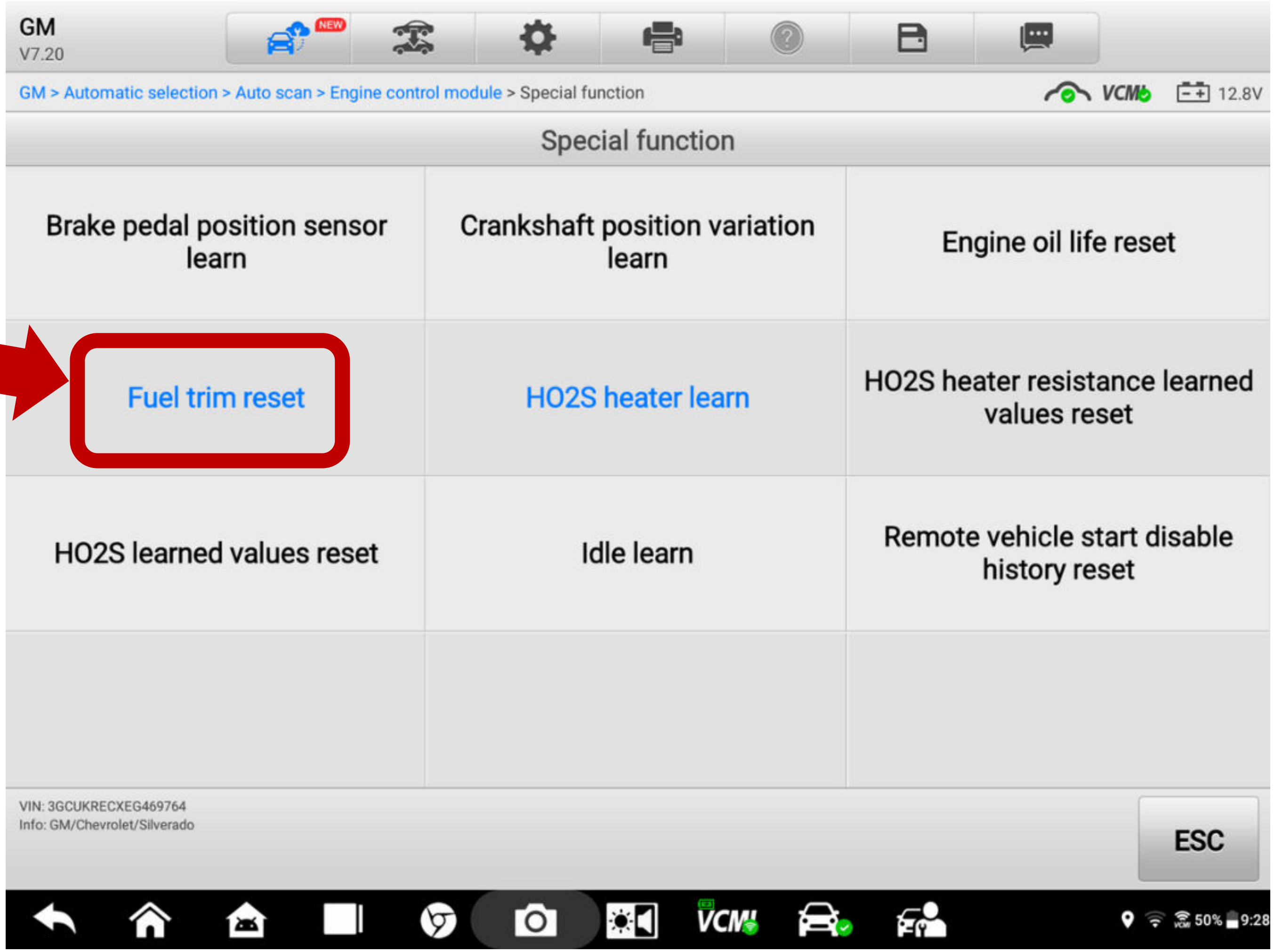
Special Function: HO2S Heater Learn-Walk Through



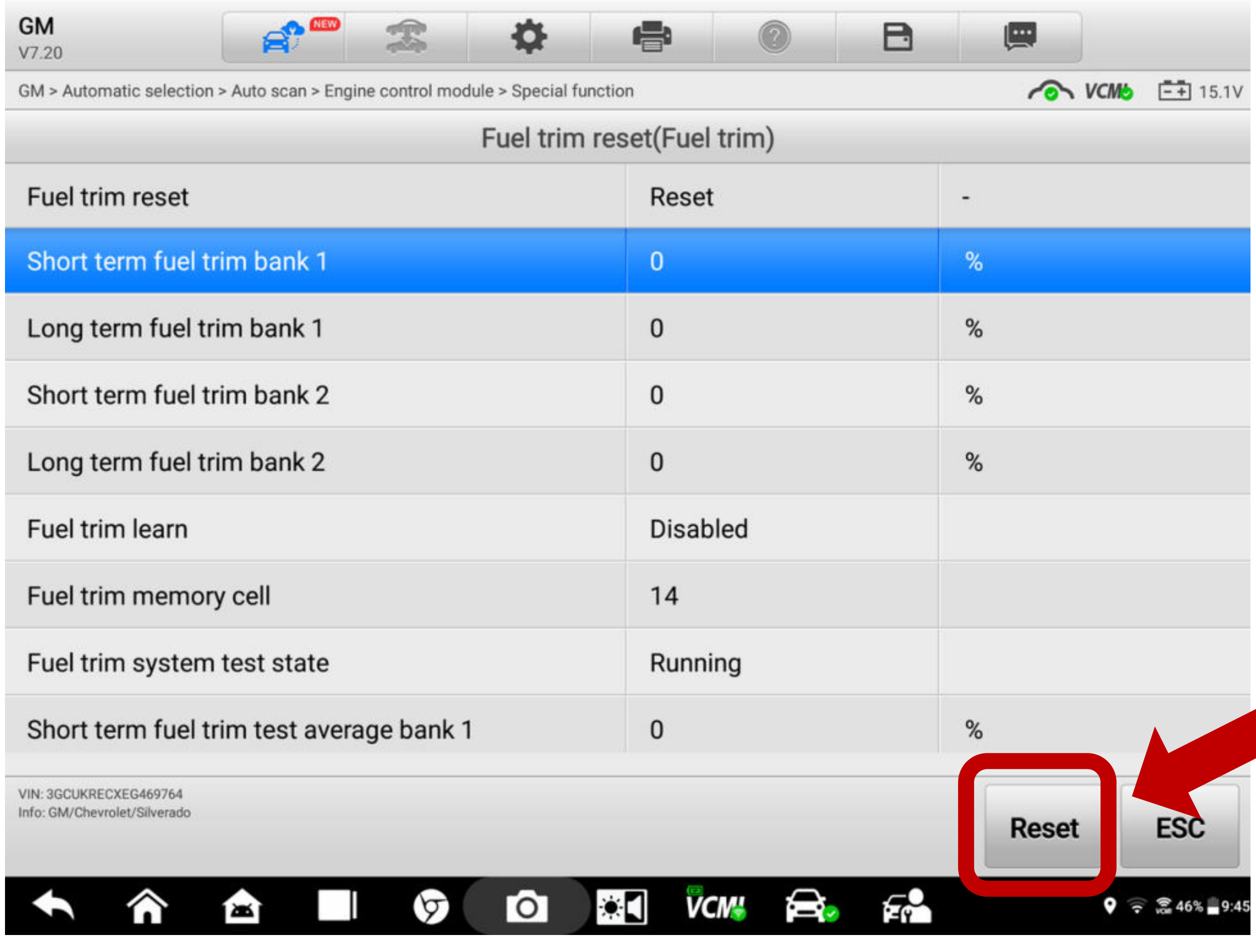
Click Learn

Special Function: Fuel Trim Reset Walk-Through

- Go To Special Functions
- Click Fuel Trim Reset



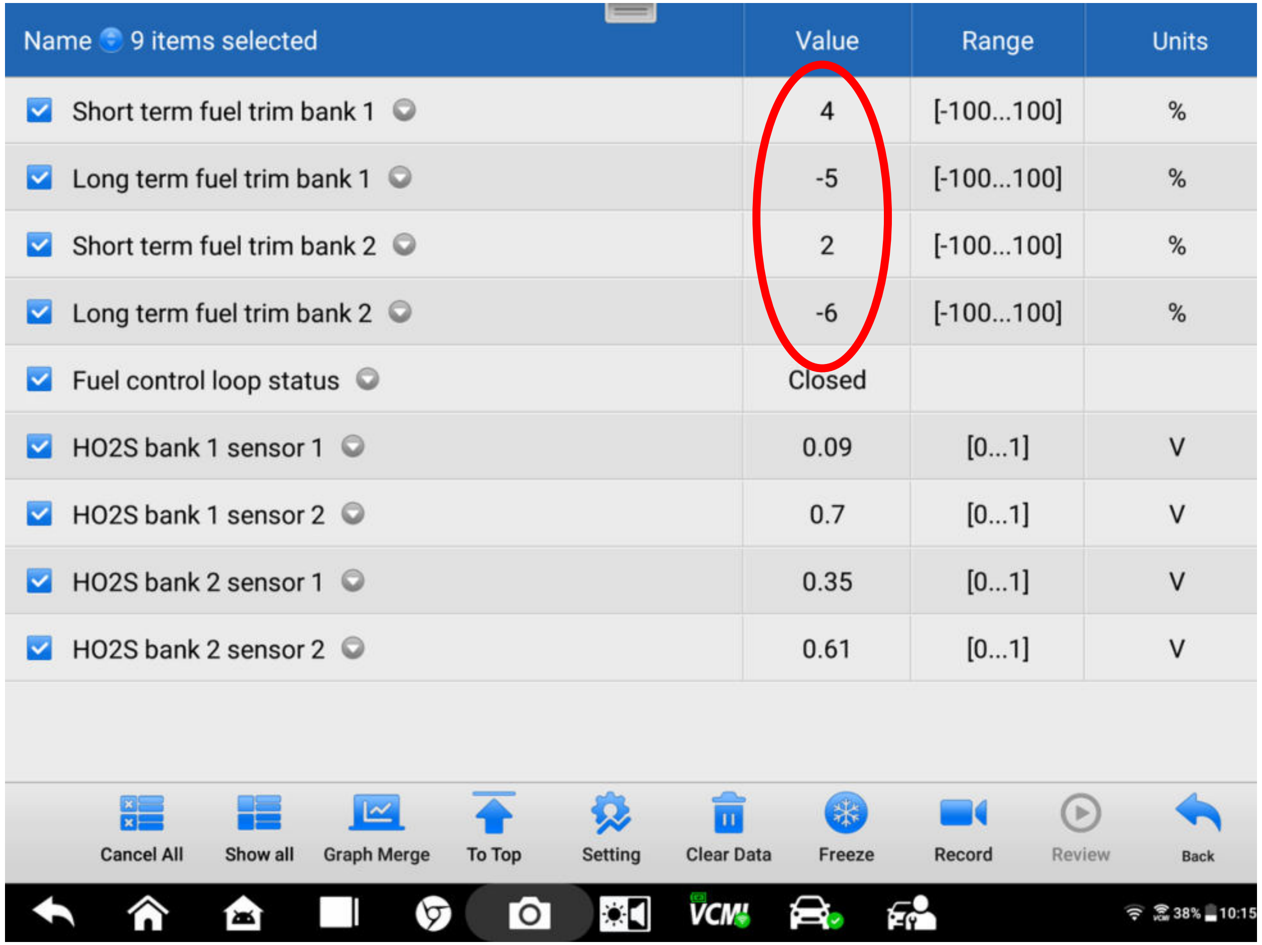
Special Function: Fuel Trim Reset Walk-Through



Click Reset

Data After Relearn

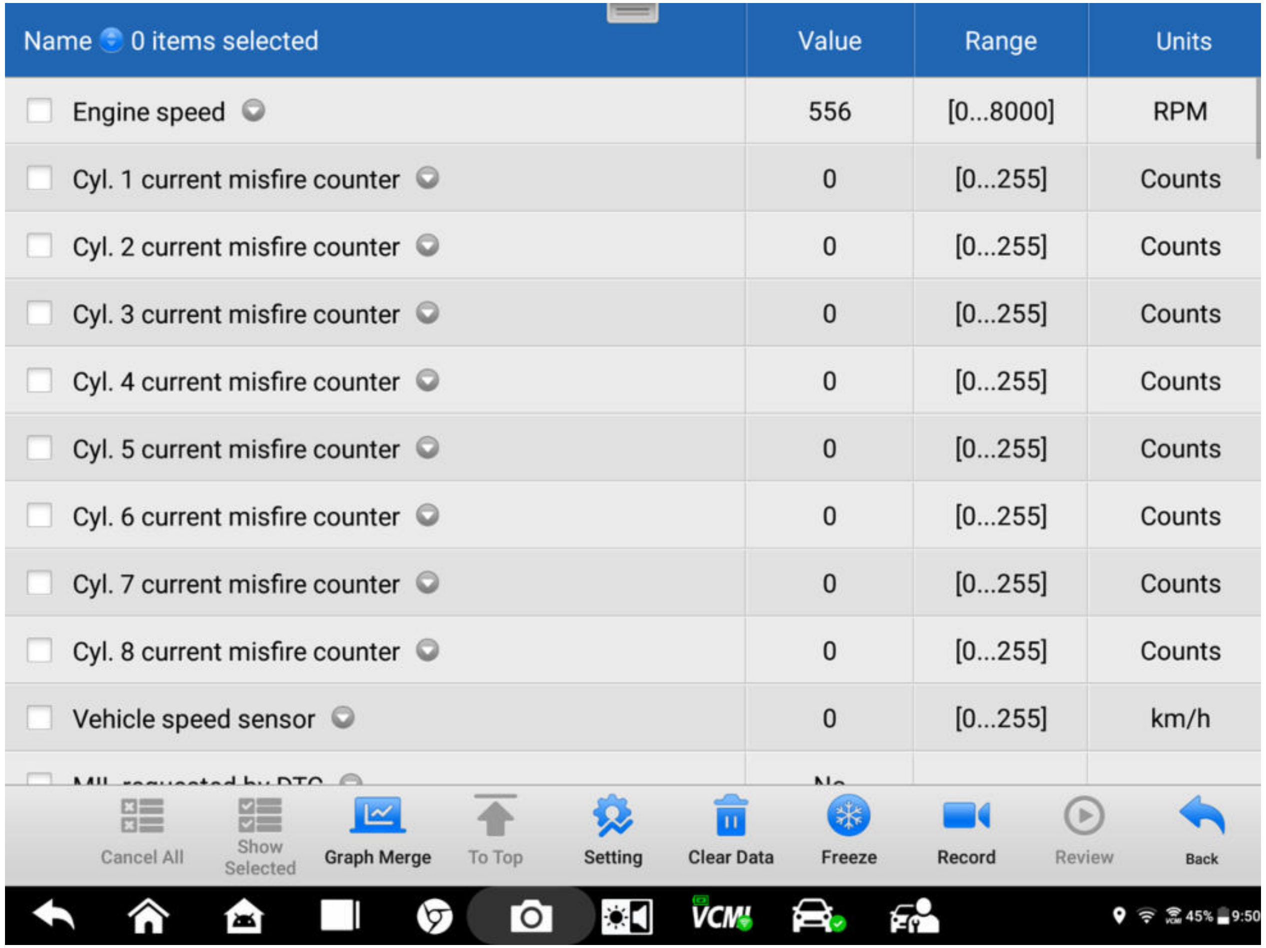
- Not Graphed But…
- Both Upstream O2S Switching
- Both Downstream O2S Agree
- Bank 1 Total Fuel Trim: -1%
- Bank 2 Total Fuel Trim: -4%



Name 9 items selected	Value	Range	Units
Short term fuel trim bank 1	4	[-100...100]	%
Long term fuel trim bank 1	-5	[-100...100]	%
Short term fuel trim bank 2	2	[-100...100]	%
Long term fuel trim bank 2	-6	[-100...100]	%
Fuel control loop status	Closed		
HO2S bank 1 sensor 1	0.09	[0...1]	V
HO2S bank 1 sensor 2	0.7	[0...1]	V
HO2S bank 2 sensor 1	0.35	[0...1]	V
HO2S bank 2 sensor 2	0.61	[0...1]	V

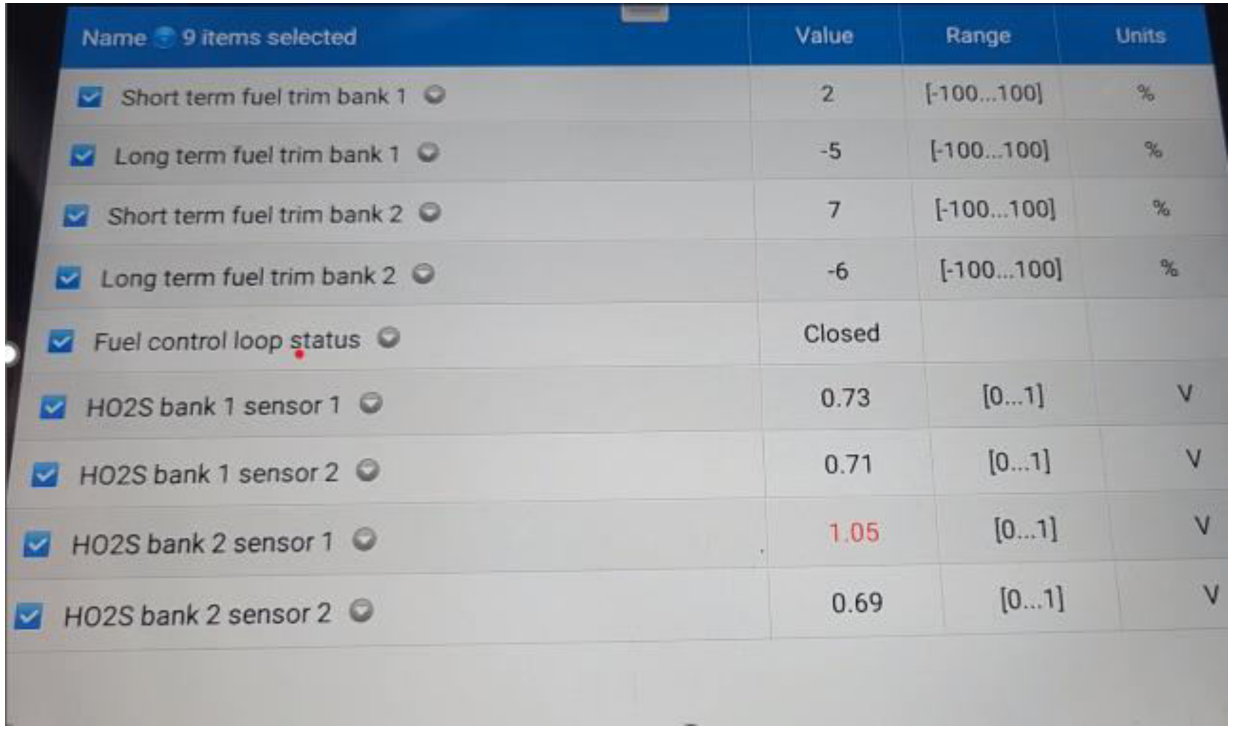
Data After Relearn

No Cylinder Misfires Present!



Name 0 items selected	Value	Range	Units
Engine speed	556	[0...8000]	RPM
Cyl. 1 current misfire counter	0	[0...255]	Counts
Cyl. 2 current misfire counter	0	[0...255]	Counts
Cyl. 3 current misfire counter	0	[0...255]	Counts
Cyl. 4 current misfire counter	0	[0...255]	Counts
Cyl. 5 current misfire counter	0	[0...255]	Counts
Cyl. 6 current misfire counter	0	[0...255]	Counts
Cyl. 7 current misfire counter	0	[0...255]	Counts
Cyl. 8 current misfire counter	0	[0...255]	Counts
Vehicle speed sensor	0	[0...255]	km/h

Runs Great But…

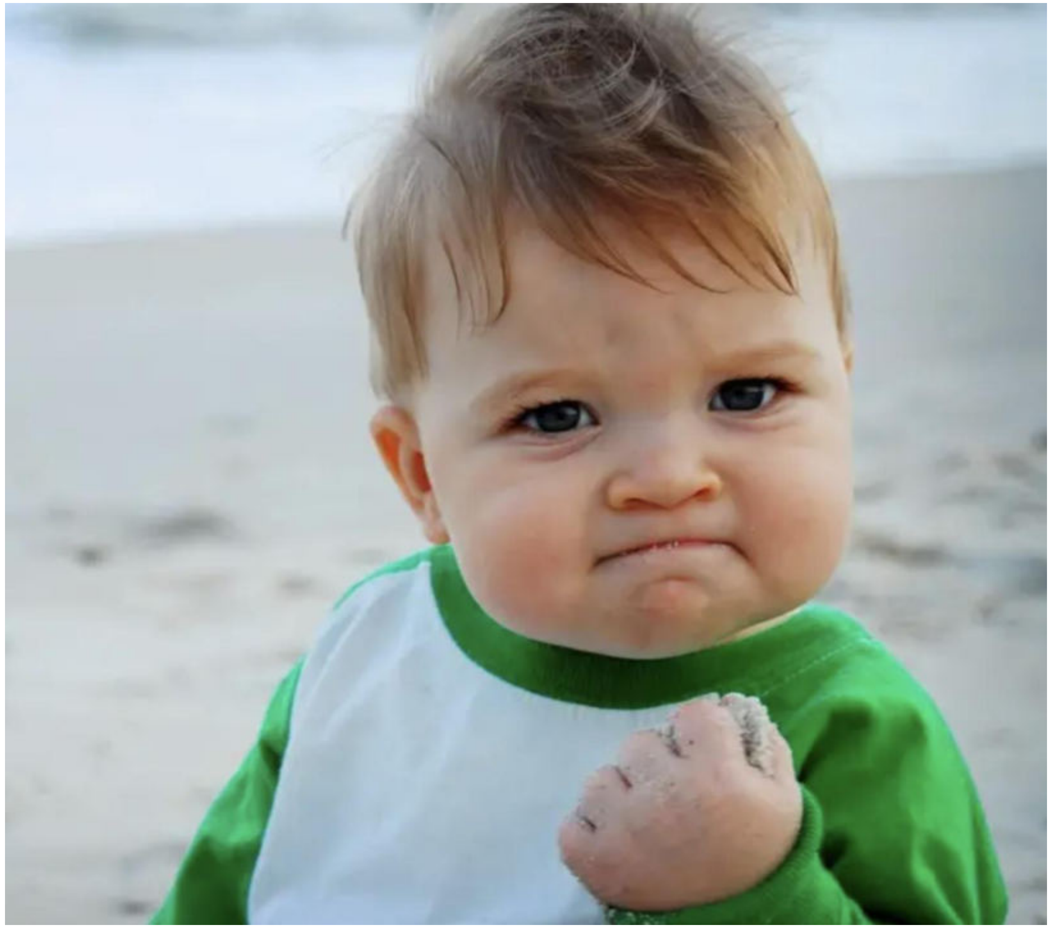


Name 9 items selected	Value	Range	Units
Short term fuel trim bank 1	2	[-100...100]	%
Long term fuel trim bank 1	-5	[-100...100]	%
Short term fuel trim bank 2	7	[-100...100]	%
Long term fuel trim bank 2	-6	[-100...100]	%
Fuel control loop status	Closed		
HO2S bank 1 sensor 1	0.73	[0...1]	V
HO2S bank 1 sensor 2	0.71	[0...1]	V
HO2S bank 2 sensor 1	1.05	[0...1]	V
HO2S bank 2 sensor 2	0.69	[0...1]	V

The Bank 2 upstream sensor still climbs over 1 volt

Update: GM HO2 Sensor Installed

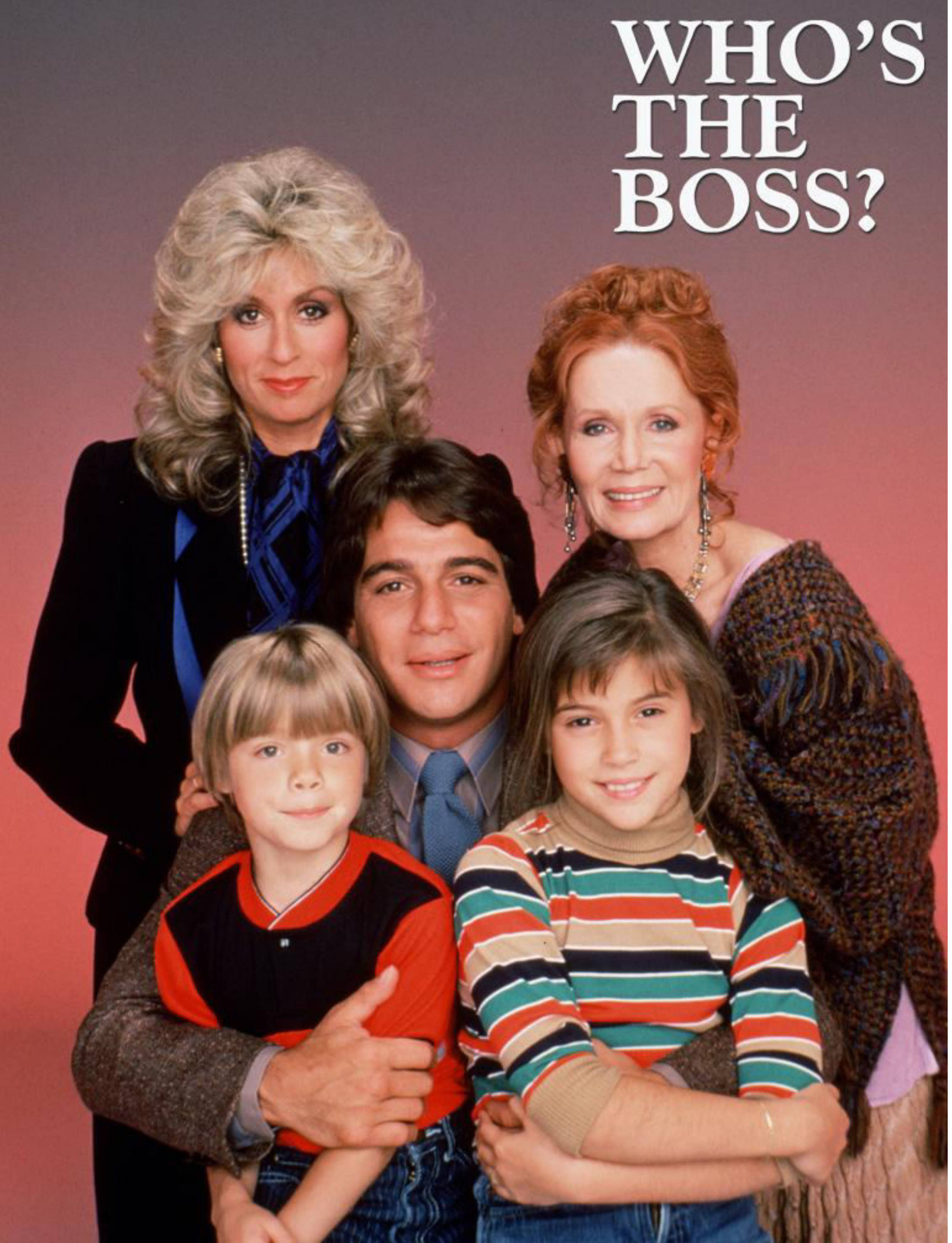
- Genuine HO2 Sensor Installed
  - *Cleared Up After Installing A Genuine Sensor*
  - *Yes, They Relearned The New Sensor*
  - *Runs Well & Never Returned*



2017 Kia Soul 1.6L Rough Idle & Stall

VIN: KNDJN2A2XH7880354

Mileage: 98,438



Runs Rough, No Power & Stalling

- Shop replaced HO2S (No change)
- Shop requests ECM reprogramming
- TSB available to correct concern
- Will a software update fix it?
- The client is "The Boss"

Checking The VIN#

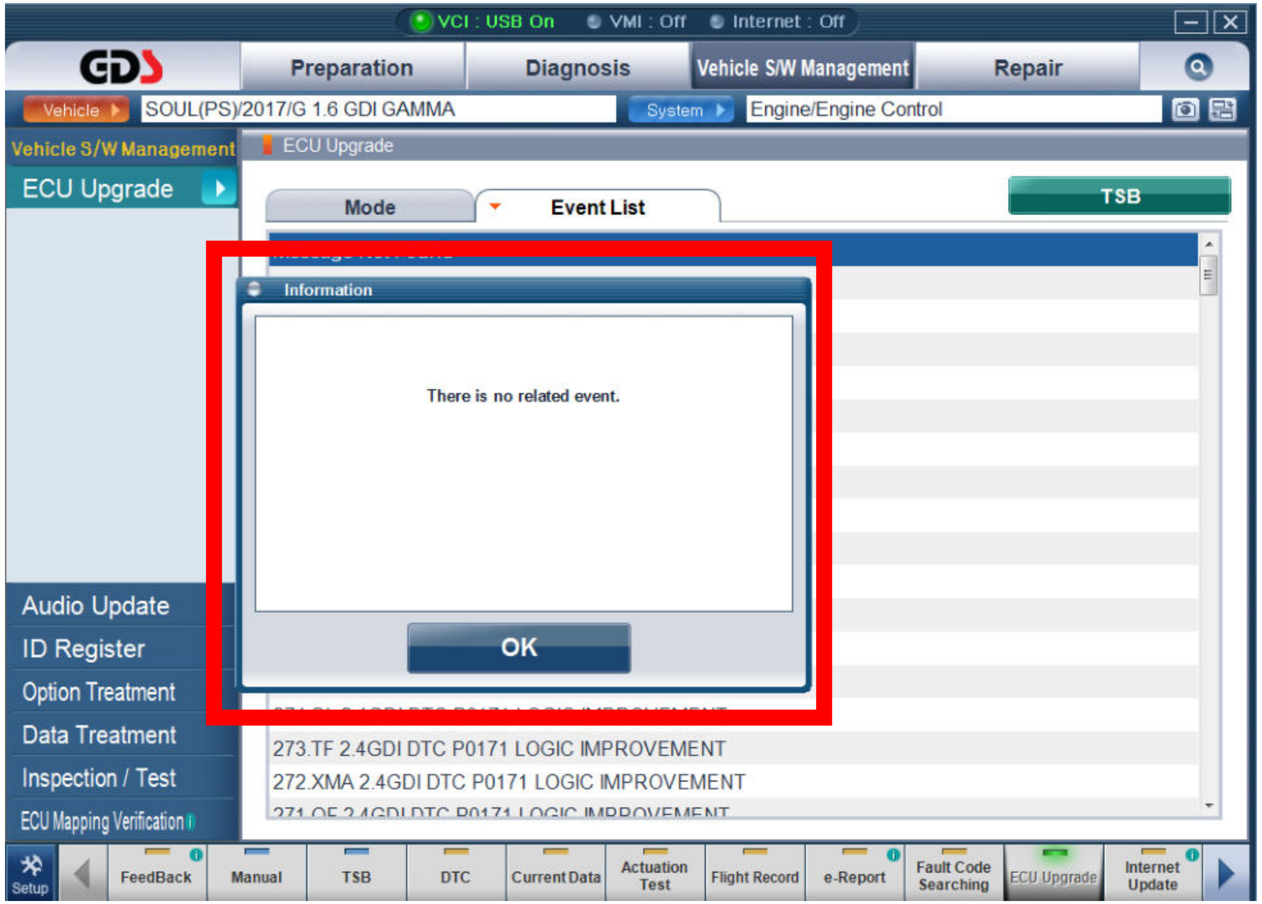
- The VIN in the module Matches the vehicle
- Not an unprogrammed used module

Getting the Calibration Number

- Is there an update available?
  - *Sometimes a comparison is needed*
  - *Current calibration vs latest calibration*
  - *Some programming applications auto-compare*
- Vehicle manufacturer & programming application dependent

Checking For Update Hyundai / Kia GDS

- There are no updates for our module?
- Old application could be a factor
  - *Former factory scan tool*
  - *KDS is current factory scan tool*
  - *KDS is tablet based*
  - *Hyundai vs Kia, separate interface*



Retrieved DTCs

P0030 | HO2S Heater Control Circuit Bank 1 Sensor 1

- Finding the root-cause problem
- P0030 "Heater control fault" DTC
- Wide-band application
  - *Heater's more critical than with narrow-band*
  - *Could be massive clue*

DTC • G 2.0 NU GDI • Engine > Engine Control • P0030 HO2S Heater Control Circuit (Bank 1 / Sensor 1) • DTC Information

Report a problem with this article

DTC Description

The PCM monitors the Heated Oxygen Sensor (HO2S) heater circuit. If the PCM detects an open in the heater control circuit, the PCM sets DTC P0030.

DTC Detecting Condition

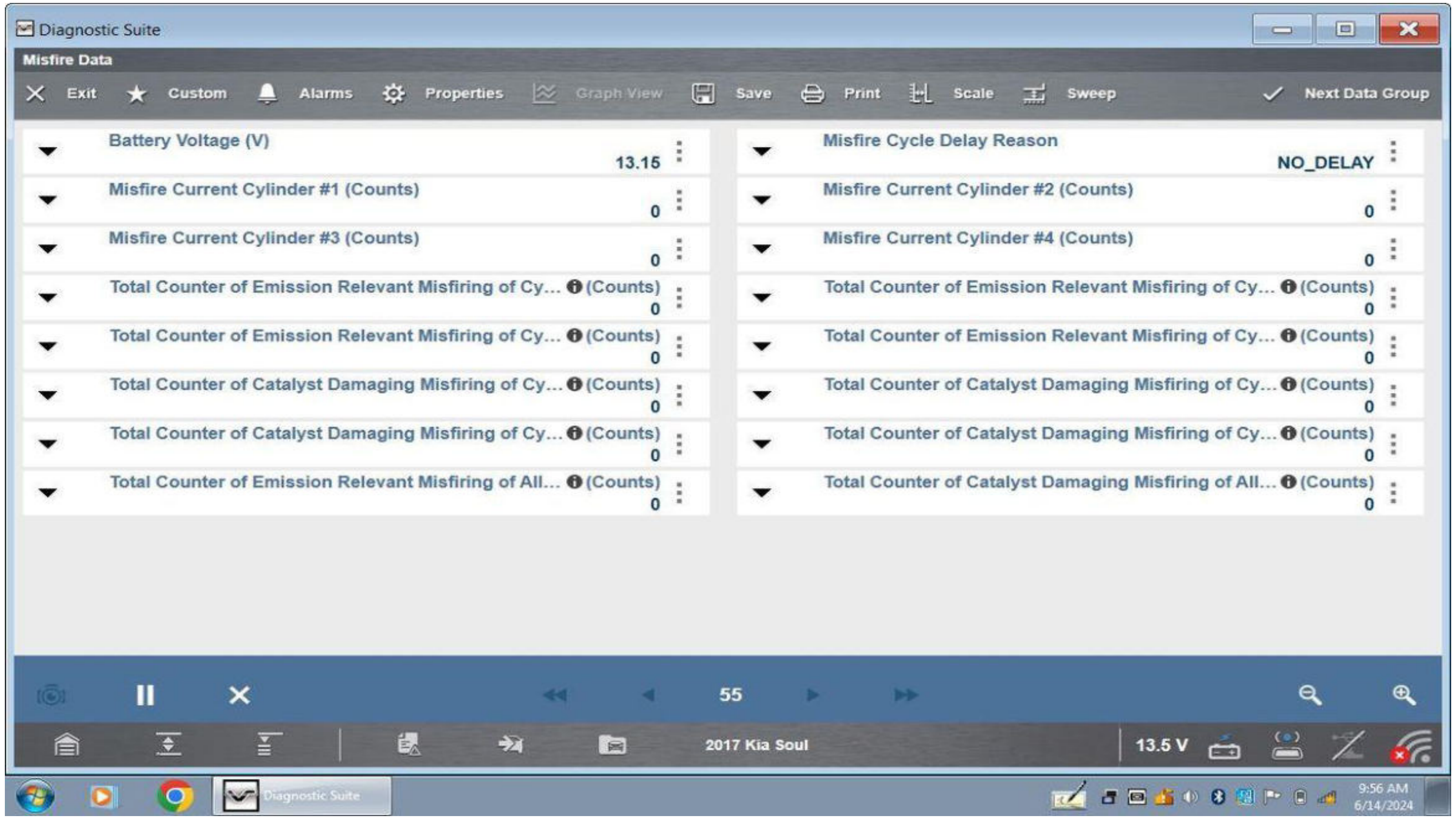
Item	Detecting Condition	Possible Cause
DTC Strategy	• Electrical check.	1. Poor connection 2. Open circuit 3. HO2S (S1)
Enable Conditions	• Ignition ON.	
Threshold Value	• Open circuit	
Diagnostic Time	• Continuous.	
Mil On Condition	• 2 driving cycles.	

Freeze Frame Data

- Data recorded when DTC sets
- Always document
- Understanding conditions is helpful
- Especially helpful for “intermittents”
    - *Data may offer clues*

How's It Running?

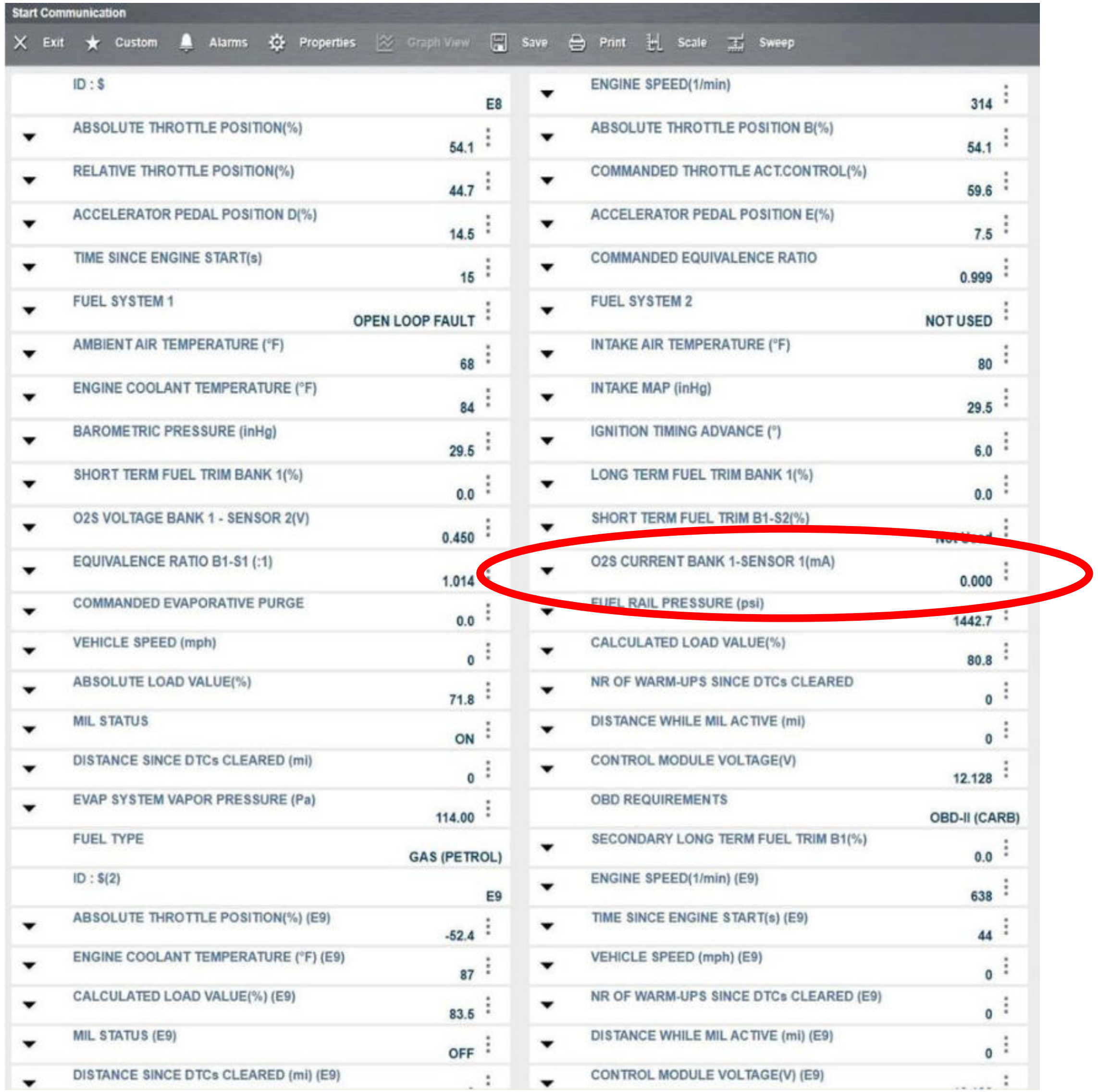
Misfire Data



ZERO Misfires?

Global Data

- Is the fault present? (Did we duplicate the concern?)
  - *Yes! Difficult to keep running*
- How can we tell?
  - *Engine RPM*
  - *Load*
  - *Manifold pressure*
  - *Throttle position*
  - *Fuel rail pressure*
  - *Loop status*
  - *EQ-ratio & HO2S current, etc.*
- Does this data offer us direction?
  - *Yes! remember the fault code?*



Visual Inspection Is Key

The upstream sensor was unplugged!

Throttle Held OPEN to Prevent Stall…

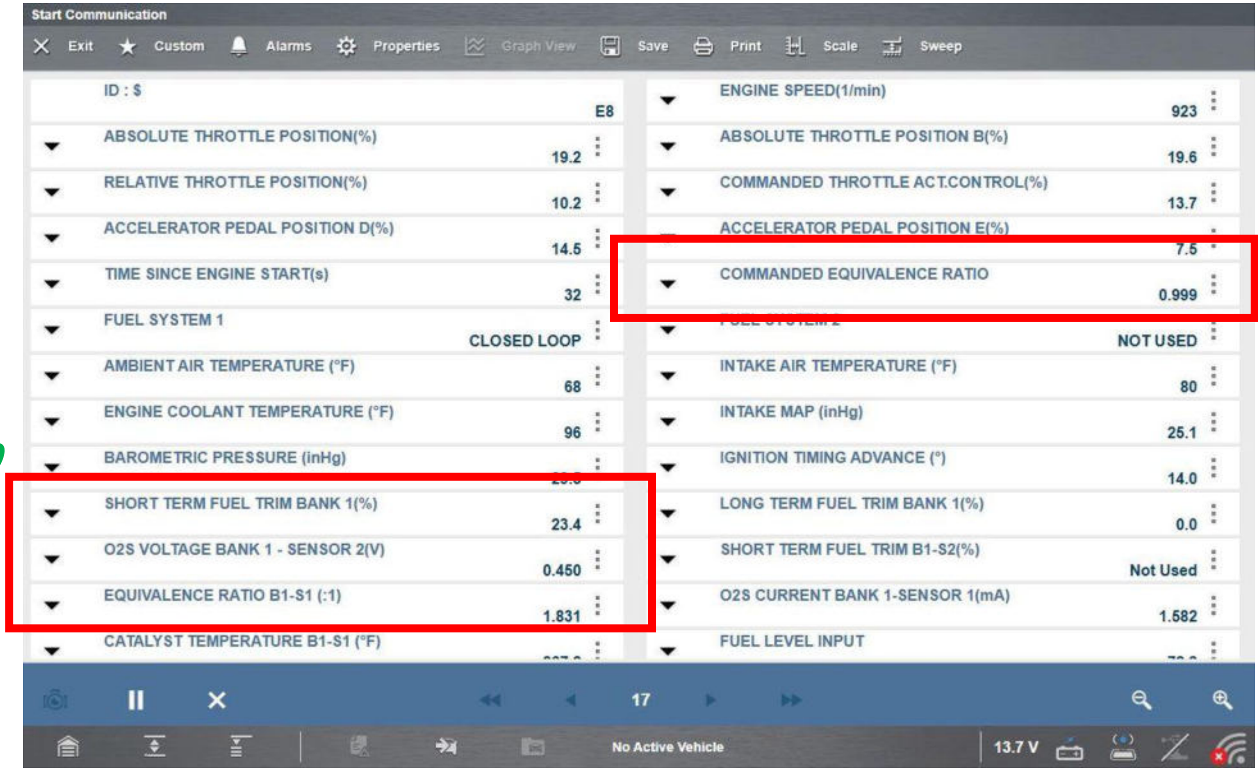
- Intake MAP = Barometric Pressure
- Engine Stalling
- Very Open Throttle
- Commanded Open
- No Driver Request

INTAKE MAP (inHg)	29.5
BAROMETRIC PRESSURE (inHg)	29.5
ENGINE SPEED(1/min)	314
ABSOLUTE THROTTLE POSITION B(%)	54.1
COMMANDED THROTTLE ACT.CONTROL(%)	59.6
ACCELERATOR PEDAL POSITION E(%)	7.5

We disconnected throttle, engine now runs. We can gather & analyze data

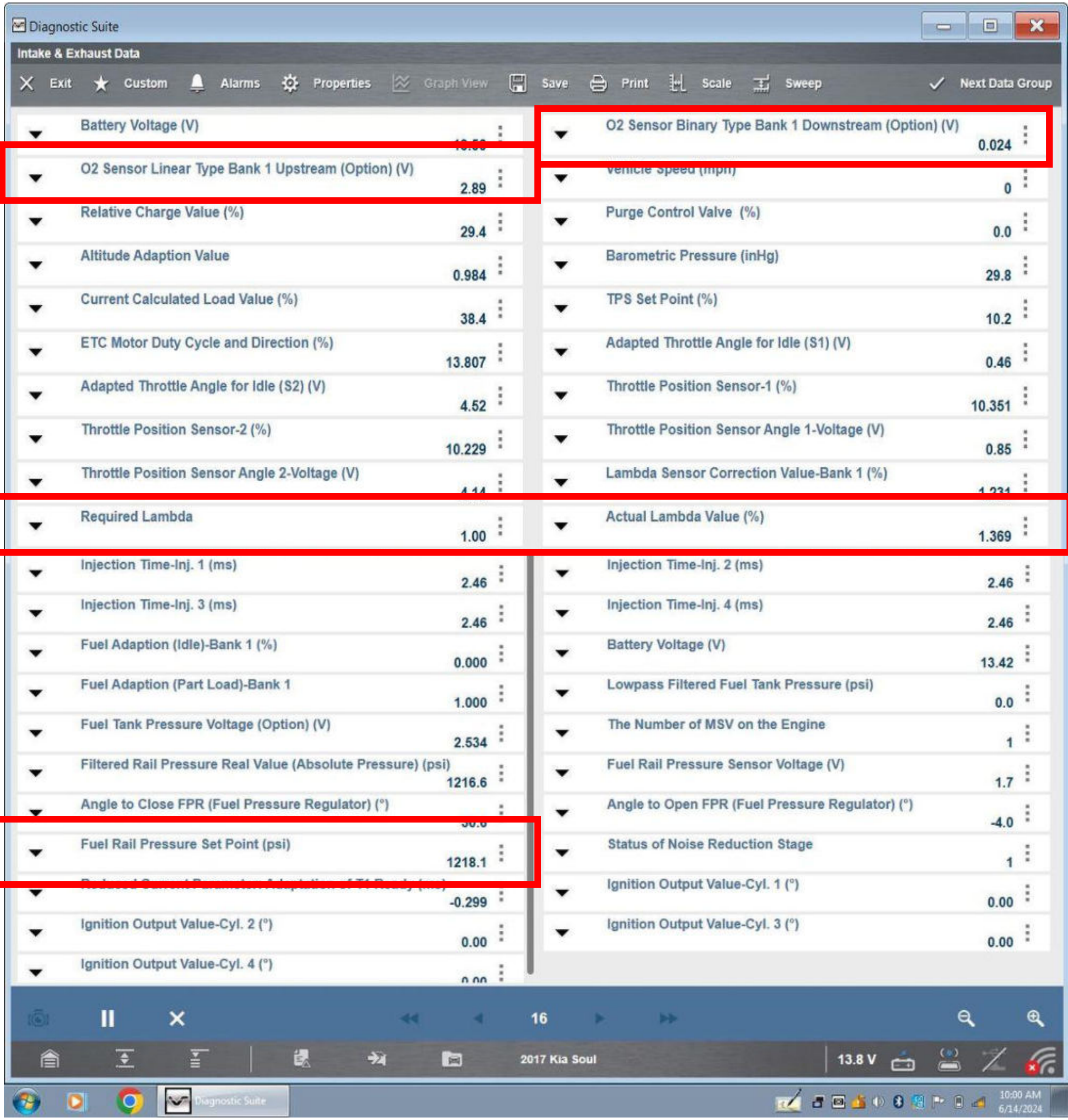
Global Data After Connecting HO2S

- Is it fixed? Are we finished?
  - *No!*
- Is it in fuel control?
  - *No!*
- How can we tell?
  - *Commanded EQ-ratio = 1.0 whilst EQ-ratio > 1.00*
- Is the ECM trying?
  - *Yes, closed loop & positive fuel trims*



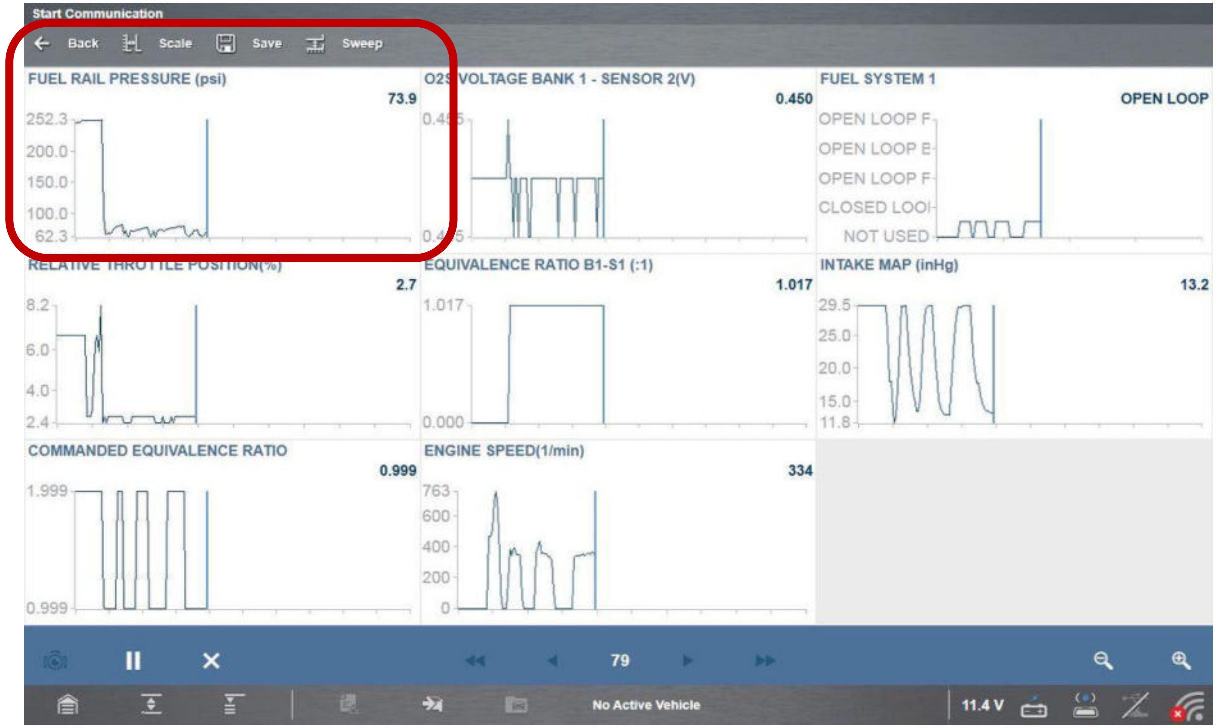
Enhanced Data Comparison

- Commanded Lambda vs Actual Lambda = Lean
- Upstream sensor voltage instead of mA = Lean
- HO2S binary downstream = Lean
- Elevated fuel rail pressure = Lean Compensation
- Elevated GDI injector on-time = Lean Compensation



Understanding High-Pressure System & Verifying Inputs

- Some Default To high Pressure
- Most Default To Low Pressure
    - *Disconnect HPFP Regulator & Monitor Rail Pressure*
    - *Compare To Low Pressure (74 psi)*
    - *Low pressure PID alone not conclusive*

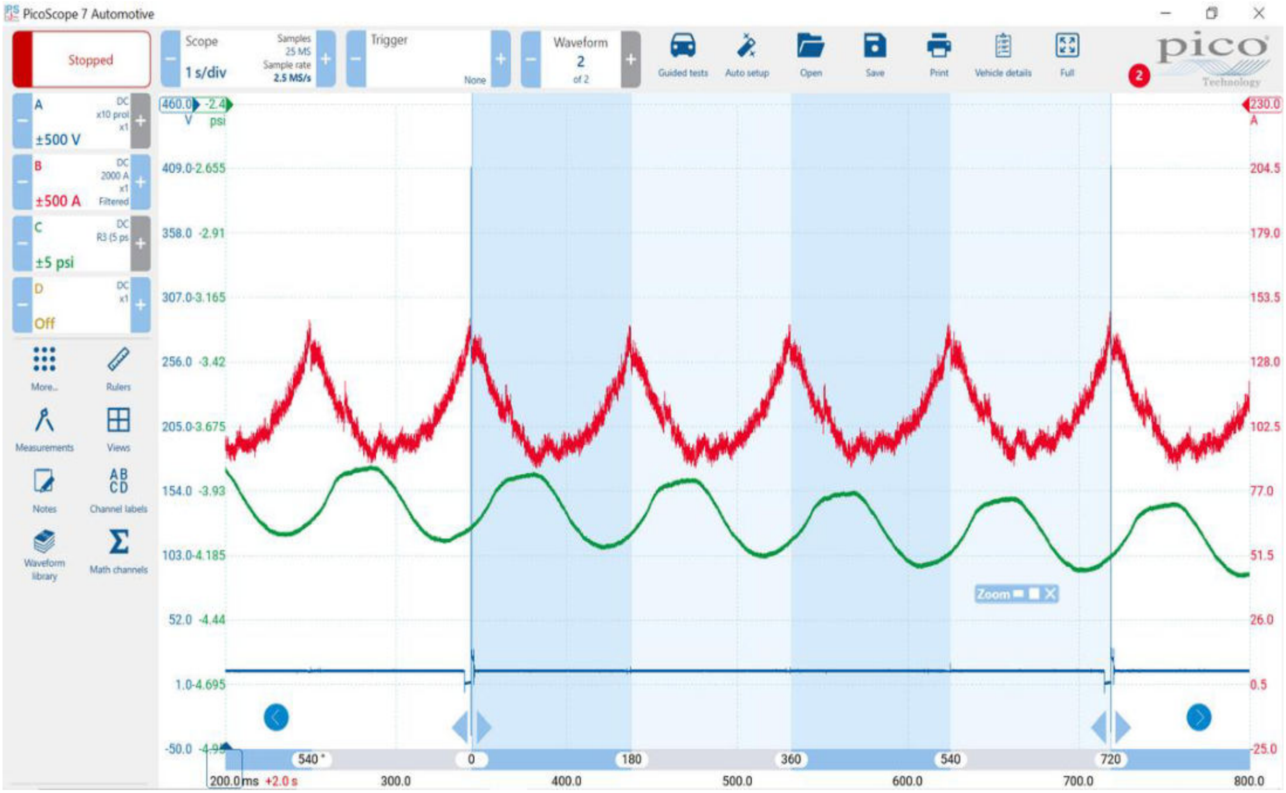


Fuel Delivery System

Items		Specification
Fuel Tank	Capacity	54 lit. (14.3 U.S.gal., 57.1 U.S.qt., 47.5 Imp.qt.)
Fuel Filter	Type	Paper type
Fuel Pressure	Low Pressure Fuel Line	480 ~ 520 kPa (4.89 ~ 5.30 kgf/cm², 69.6 ~ 75.4 psi)
	High Pressure Fuel Line	2.0 ~ 15.0 MPa (20.4 ~ 153.0 kgf/cm², 290.1 ~ 2175.6 psi)
Fuel Pump	Type	Electrical, in-tank type
	Driven by	Electric motor
High Pressure Fuel Pump	Type	Mechanical type
	Driven by	Camshaft

RC Test For Mechanical Integrity

- Quick mechanical integrity test
- Ignition sync for ID & timing
- Include intake pressure = Powerful combination
    - *Even starter amperage peaks*
    - *Sufficient peak-to-valley delta*
    - *Even intake pulls*
    - *Ignition timing = Good*

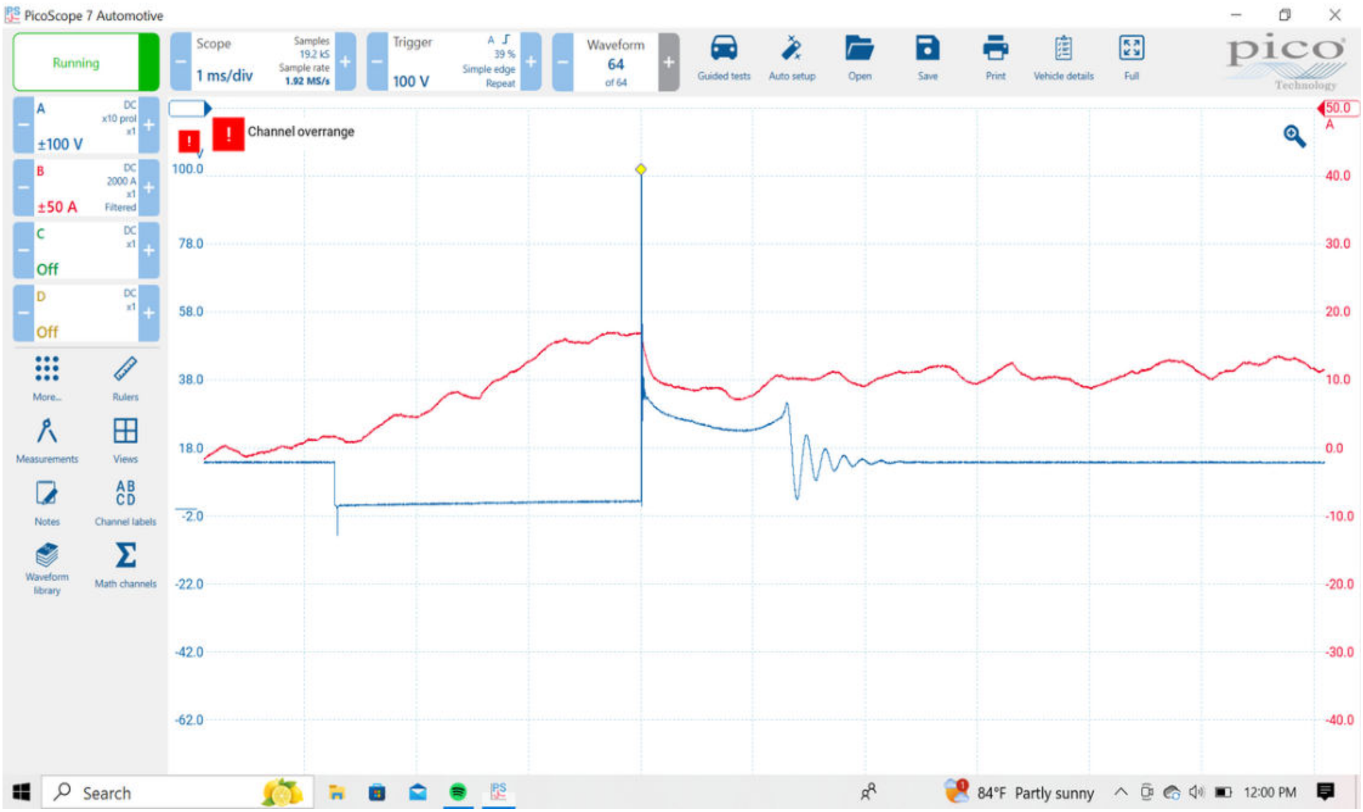


Ignition Analysis (Cylinder #1)

- Cylinder 1 primary ignition voltage
- Primary ignition current
  - *No ignition misfire present*
  - *Other potential clues present*

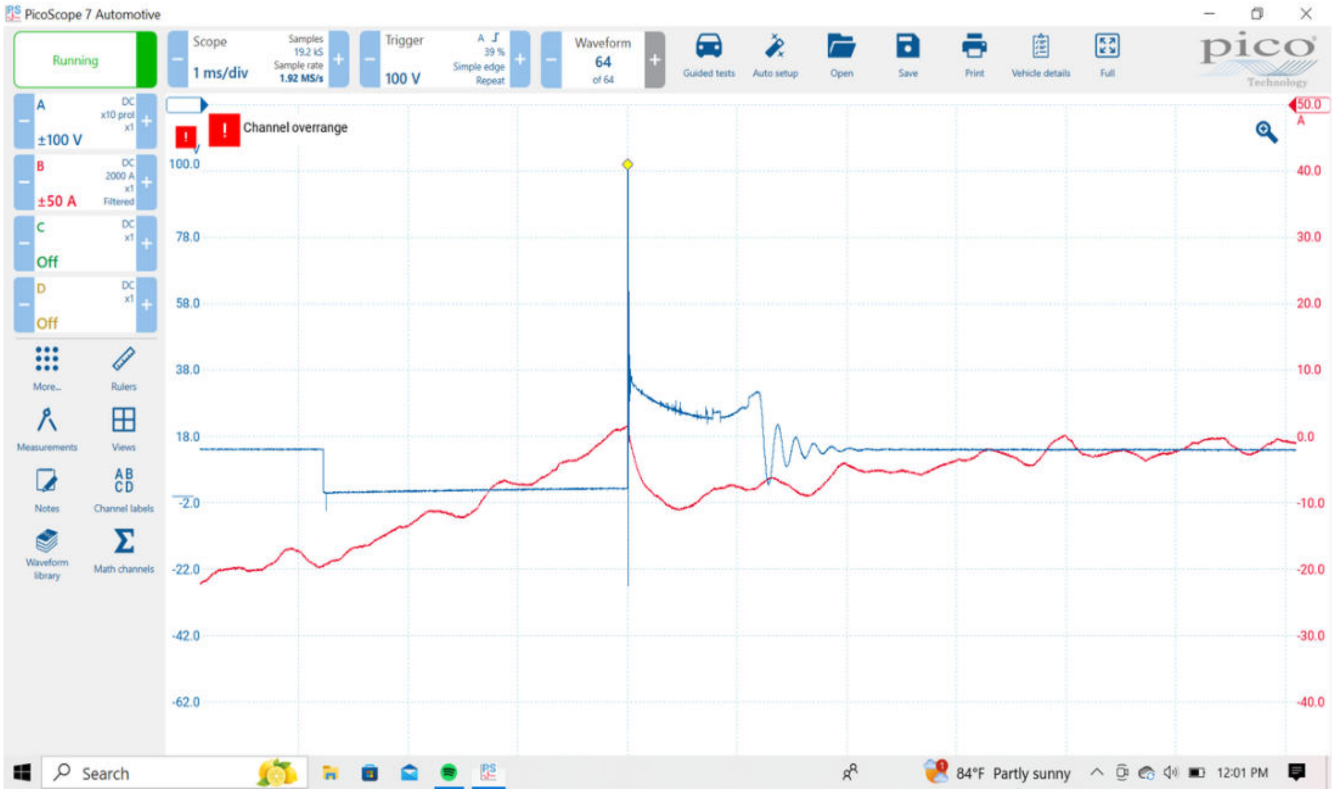
Ignition Analysis (Cylinder #2)

- Cylinder 2 primary ignition voltage
- Primary ignition current
  - *No ignition misfire present*
  - *Other potential clues present*



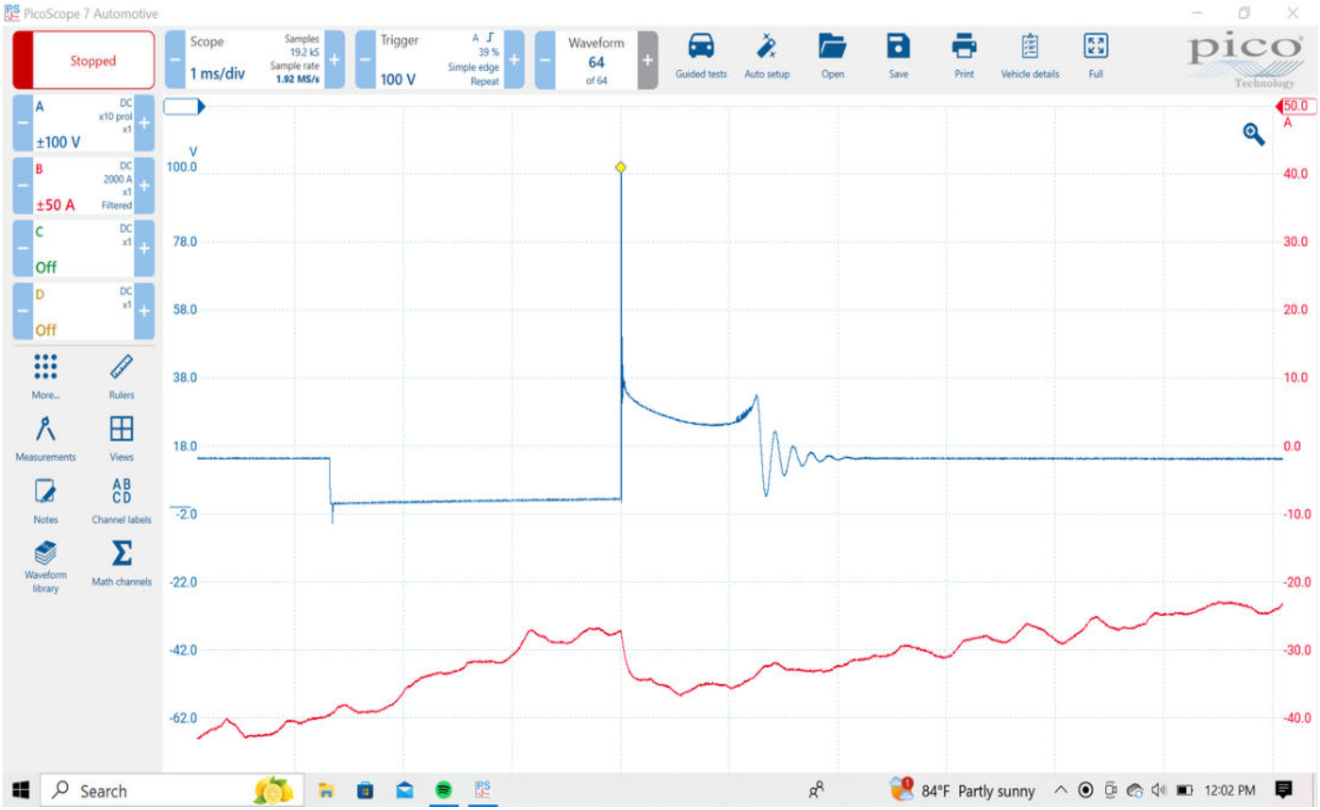
Ignition Analysis (Cylinder #3)

- Cylinder 3 primary ignition voltage
- Primary ignition current
  - *No ignition misfire present*
  - *Other potential clues present*



Ignition Analysis (Cylinder #4)

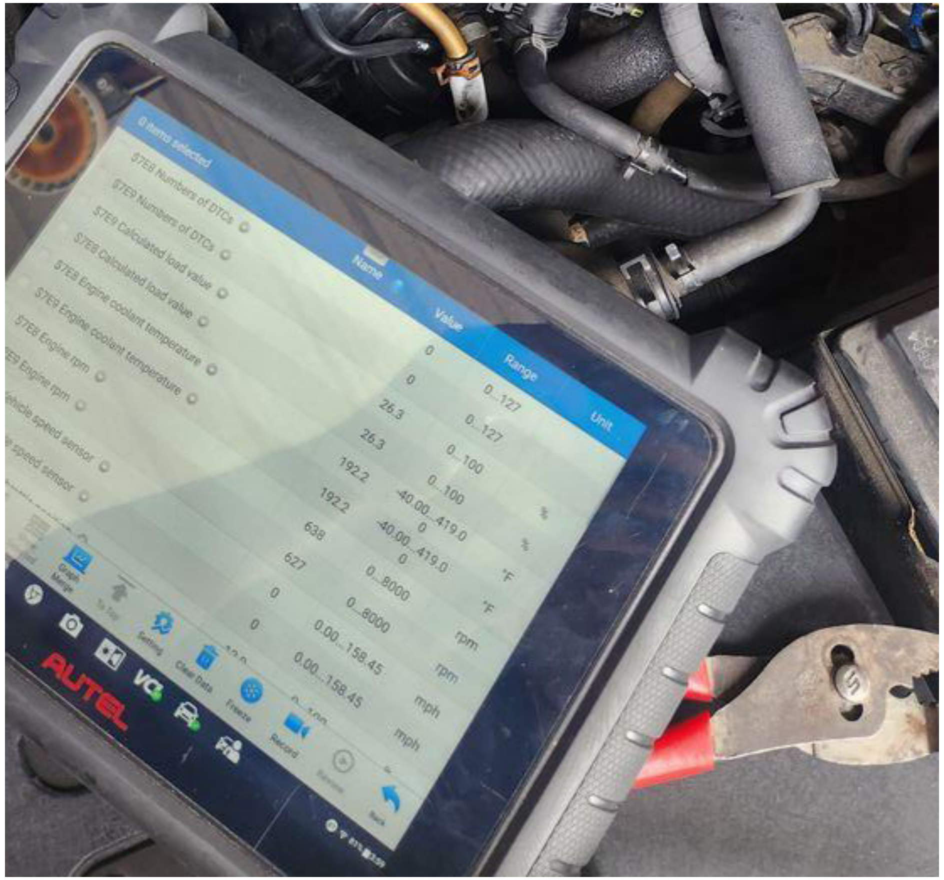
- Cylinder 4 primary ignition voltage
- Primary ignition current
  - *No ignition misfire present*
  - *Other potential clues present*



Other Characteristics

- Barely runs
- Will idle with throttle disconnected
- Not in fuel control but trying
- Lean condition
  - *Adequate rail pressure*
  - *Engine mechanically sound*
  - *Ignition okay*

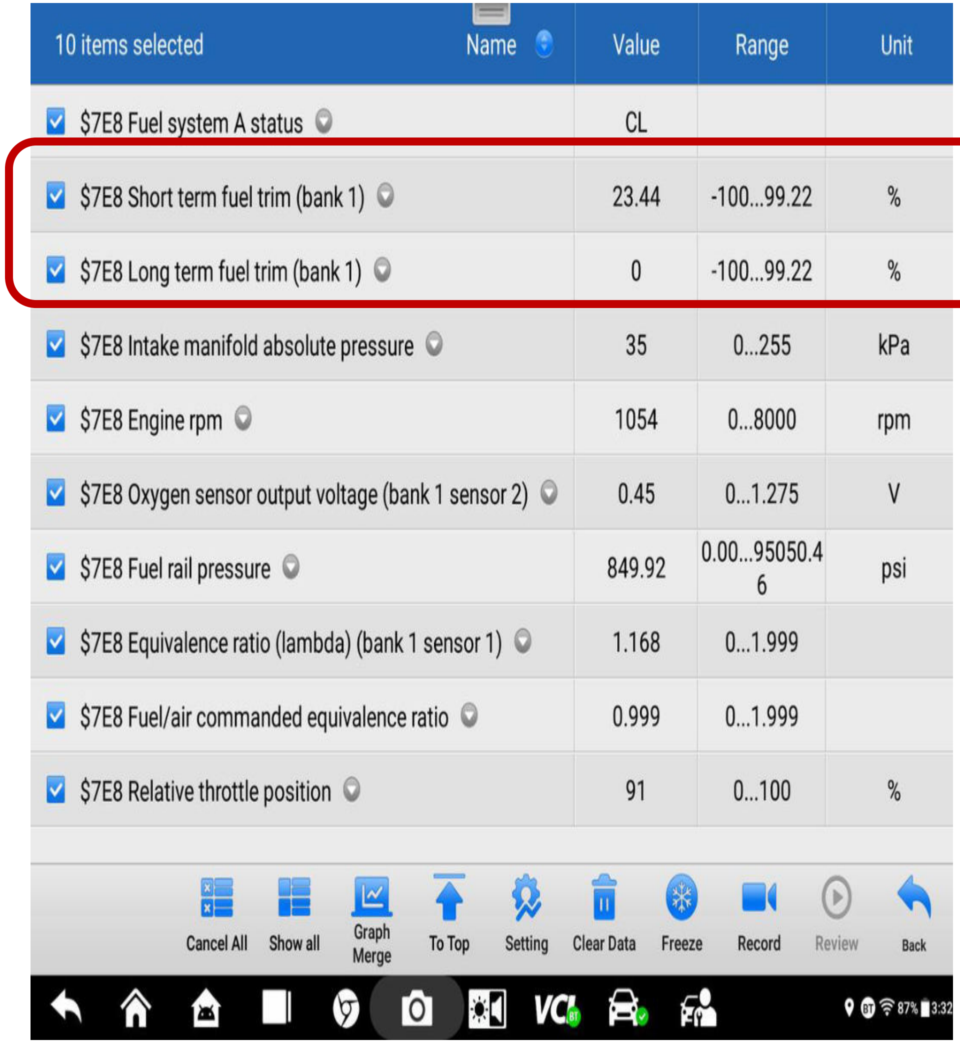
Propane Enrichment…



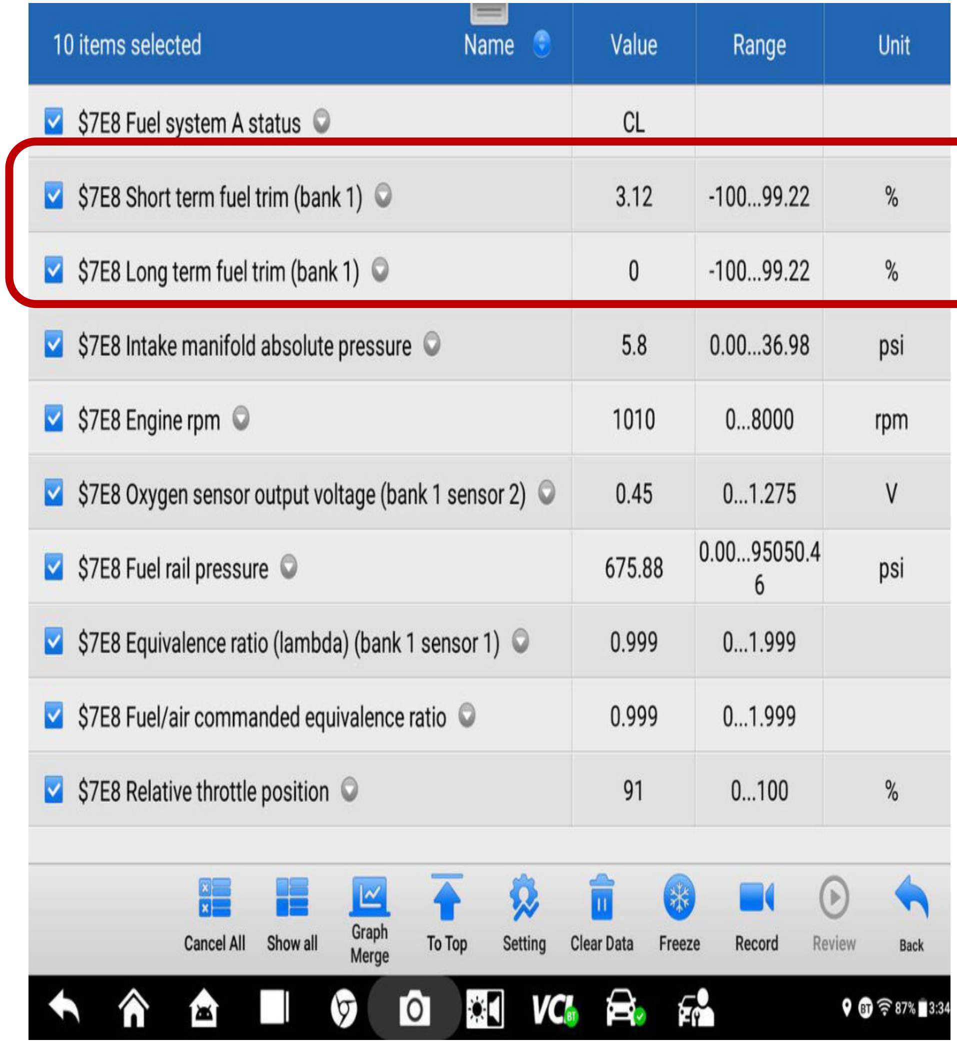
Monitor feedback sensors for accuracy & determine if driveability improves

Smooth As Silk!

Watching The Improvements…

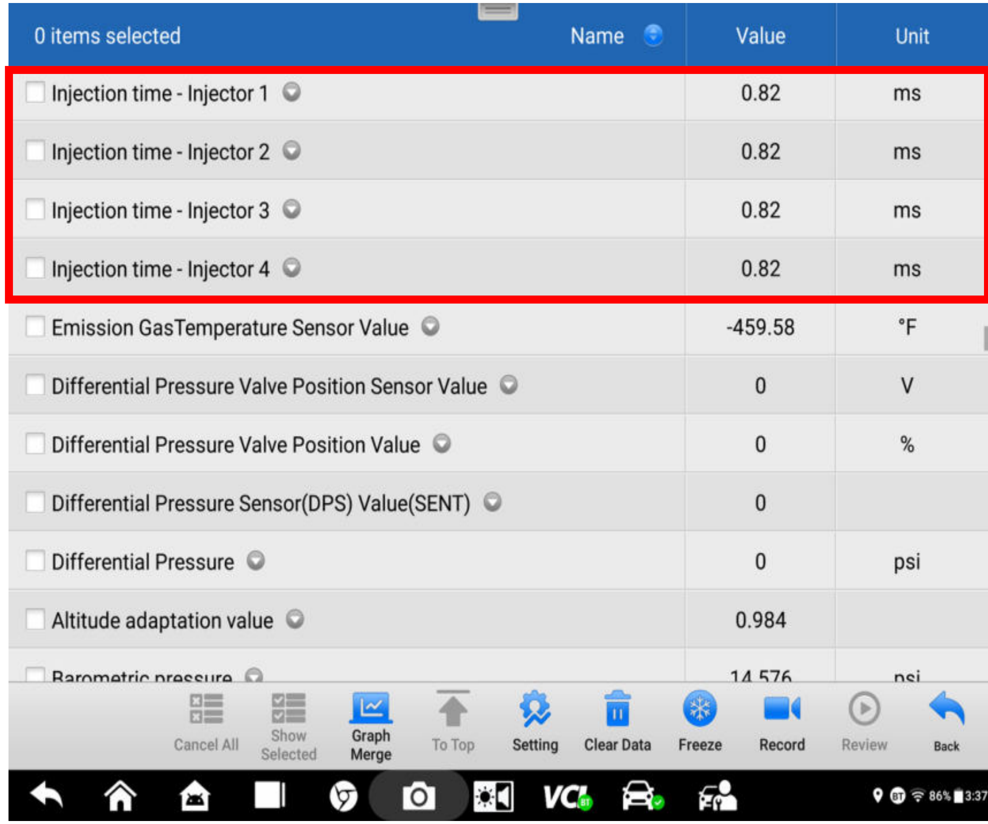


10 items selected Name	Value	Range	Unit
$7E8 Fuel system A status	CL		
$7E8 Short term fuel trim (bank 1)	23.44	-100...99.22	%
$7E8 Long term fuel trim (bank 1)	0	-100...99.22	%
$7E8 Intake manifold absolute pressure	35	0...255	kPa
$7E8 Engine rpm	1054	0...8000	rpm
$7E8 Oxygen sensor output voltage (bank 1 sensor 2)	0.45	0...1.275	V
$7E8 Fuel rail pressure	849.92	0.00...95050.46	psi
$7E8 Equivalence ratio (lambda) (bank 1 sensor 1)	1.168	0...1.999	
$7E8 Fuel/air commanded equivalence ratio	0.999	0...1.999	
$7E8 Relative throttle position	91	0...100	%



10 items selected Name	Value	Range	Unit
$7E8 Fuel system A status	CL		
$7E8 Short term fuel trim (bank 1)	3.12	-100...99.22	%
$7E8 Long term fuel trim (bank 1)	0	-100...99.22	%
$7E8 Intake manifold absolute pressure	5.8	0.00...36.98	psi
$7E8 Engine rpm	1010	0...8000	rpm
$7E8 Oxygen sensor output voltage (bank 1 sensor 2)	0.45	0...1.275	V
$7E8 Fuel rail pressure	675.88	0.00...95050.46	psi
$7E8 Equivalence ratio (lambda) (bank 1 sensor 1)	0.999	0...1.999	
$7E8 Fuel/air commanded equivalence ratio	0.999	0...1.999	
$7E8 Relative throttle position	91	0...100	%

Injector On-Time



Before

After


CONDEMNED
This
is unsafe and its use
has been prohibited
DATE
PROPERTY ADDRESS
BUILDING OFFICIAL
OWNER'S NAME
This Card Must Not Be Removed Under Penalty Of Law
Recommend What?



Virus Download

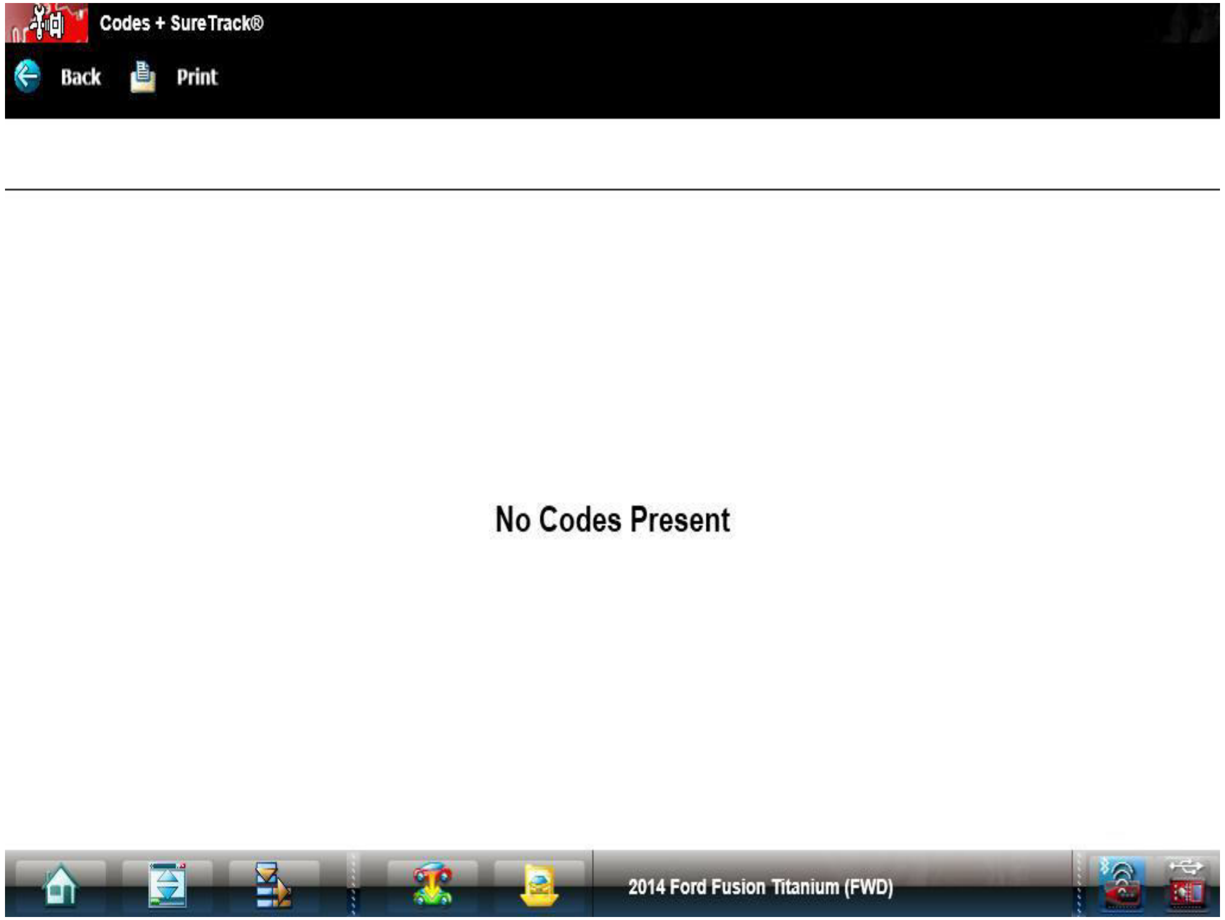
2014 Ford Fusion 2.0L EcoBoost

Limited Throttle Response

VIN # 3FA6P0K97ER373325

Mileage: 51,649

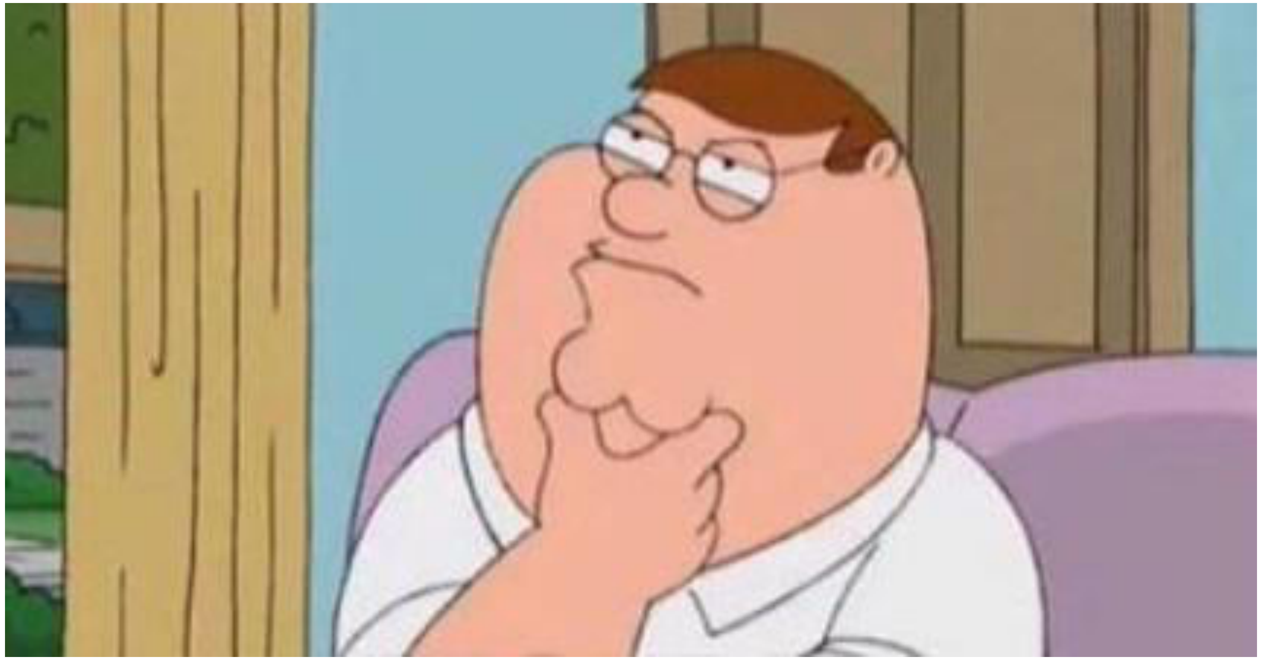
Scan DTCs + Visual Inspection



Actual vs. Commanded Throttle?

Consider the Clues + Narrow Our Focus

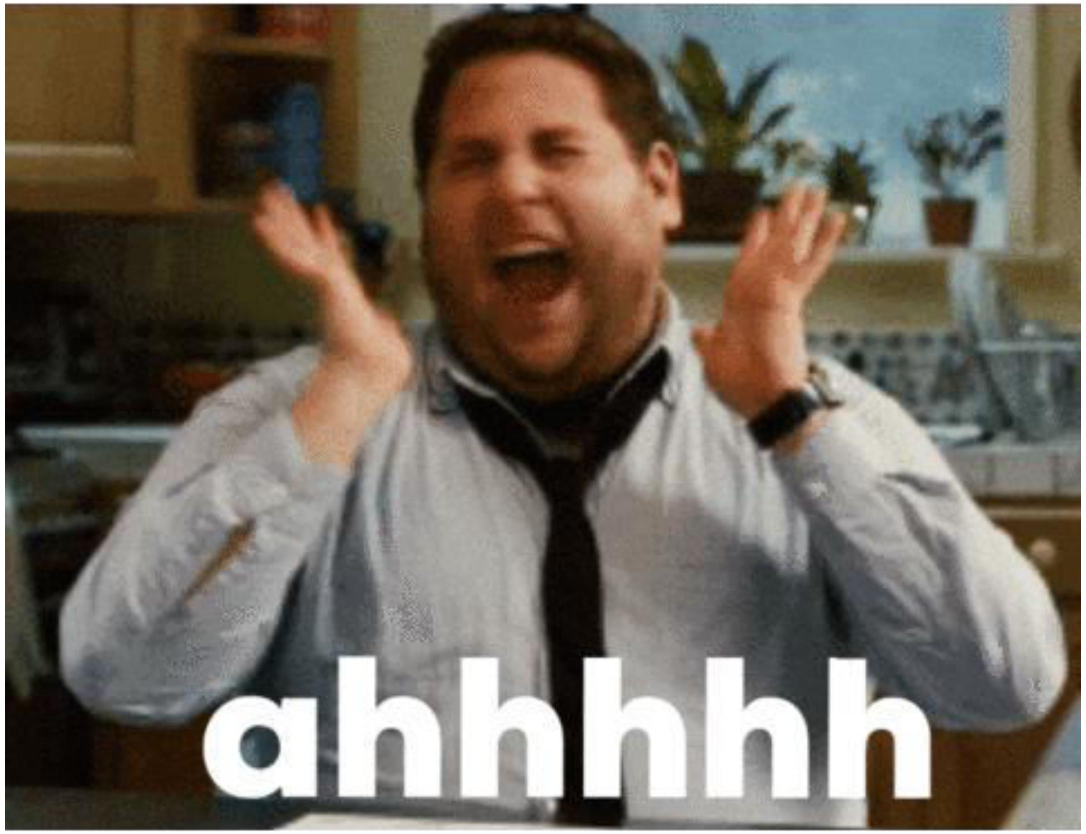
- PCM sees throttle request (APP)
- PCM ignores request
    - *Rules out APP circuit faults*



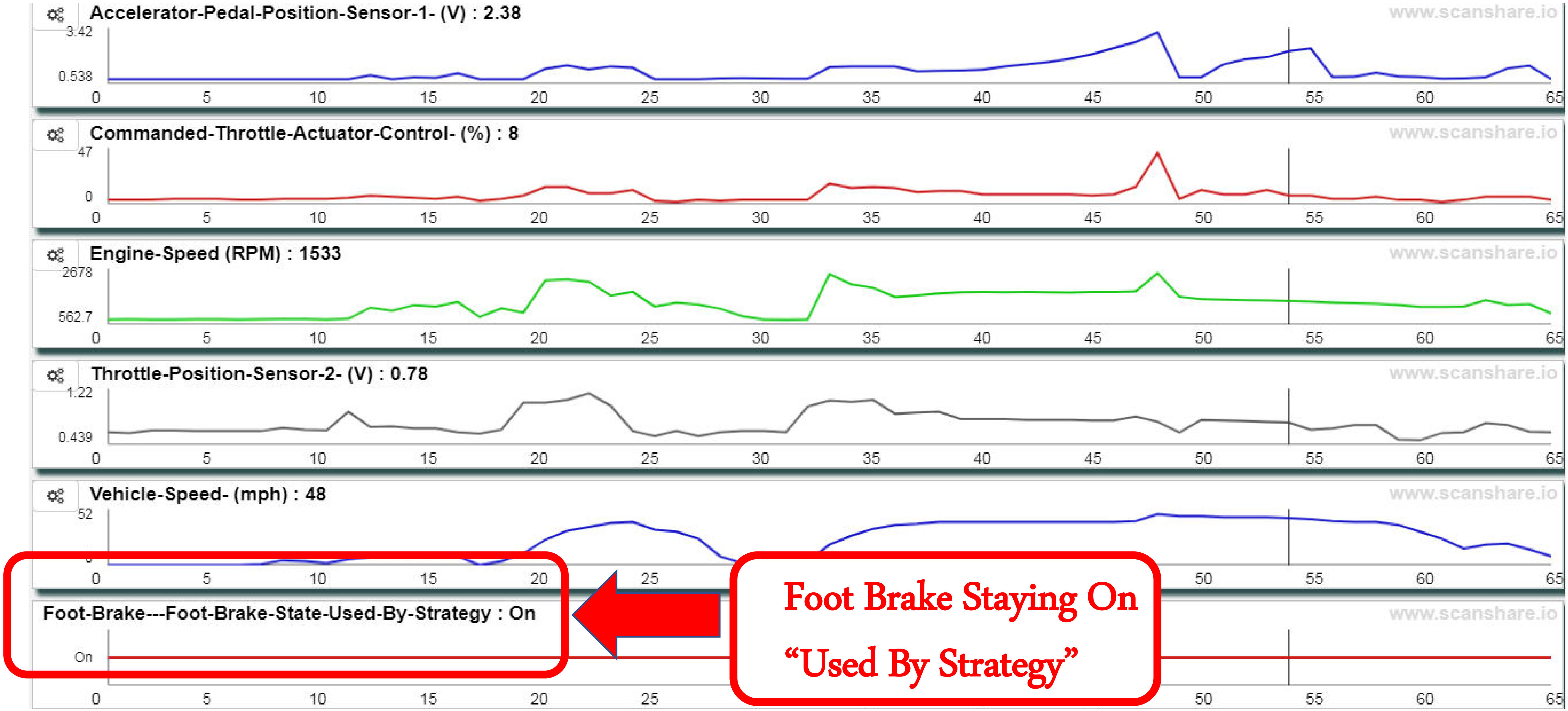
Is this a default strategy?

PCM Default Strategy?

- Why no DTCs?
- Why's the PCM ignoring the APP?
  - *Desired vs actual low side fuel pressure?*
  - *Desired vs actual fuel rail (high side) pressure?*
  - *Desired vs actual cam timing?*
  - *Desired vs actual boost/map pressures?*
  - *Desired vs actual EQ ratio (Air/Fuel ratio's)*



Another Look at Scan Data

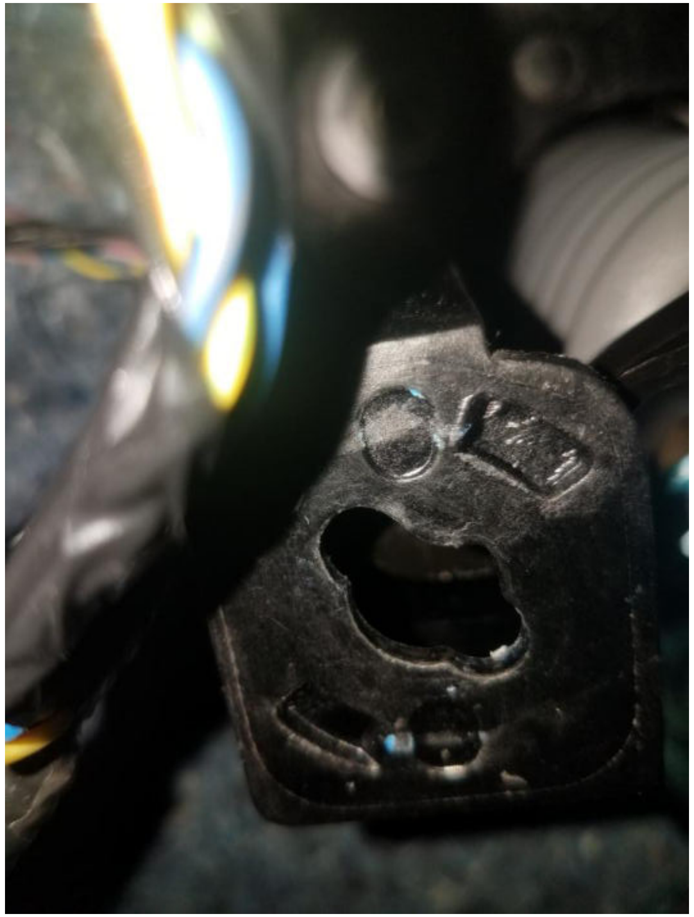


A Potential Clue

- Okay, we're not Sherlock Holmes
- Is this the brake pedal switch button?
    - *If so, that explains the brake switch PID*

Testing Our Theory

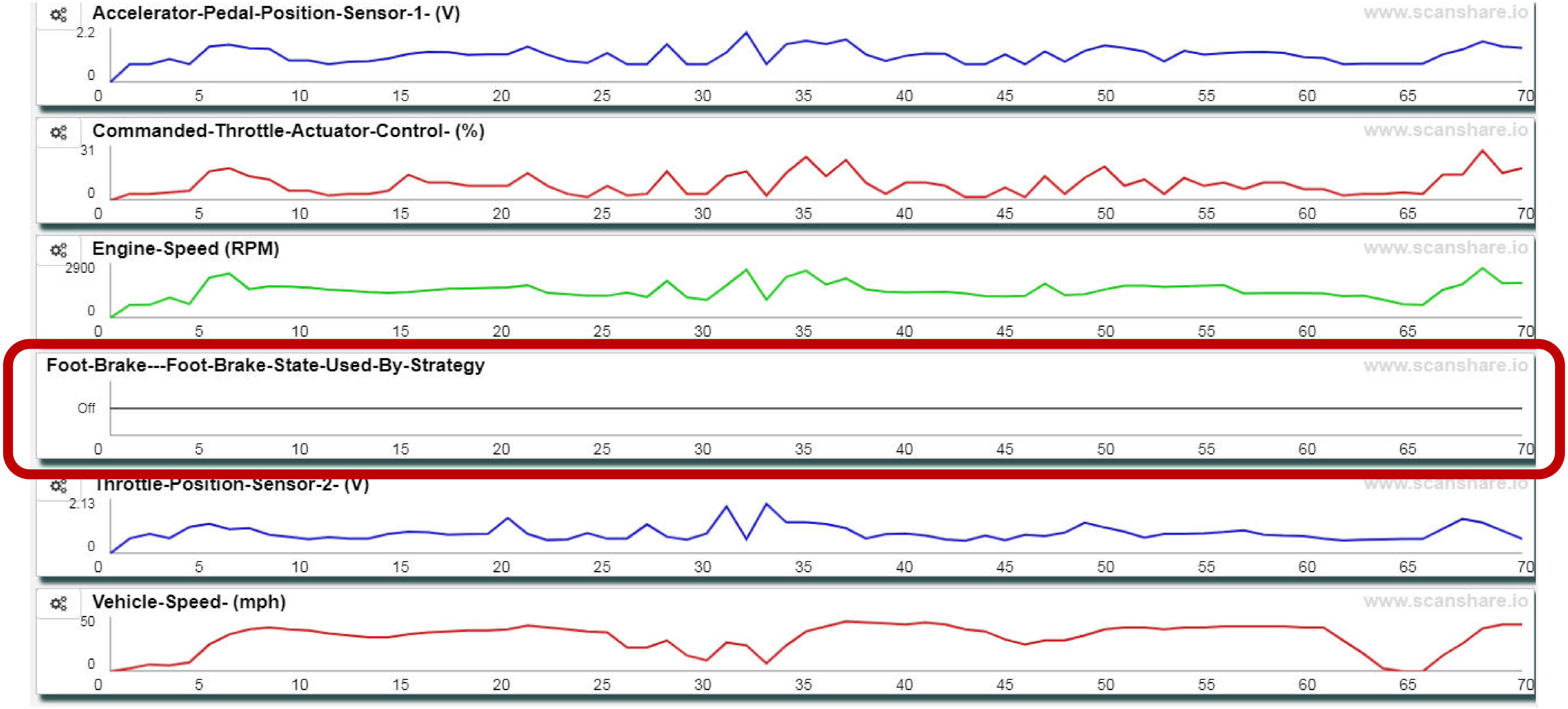
Removed Brake Switch



Button Missing

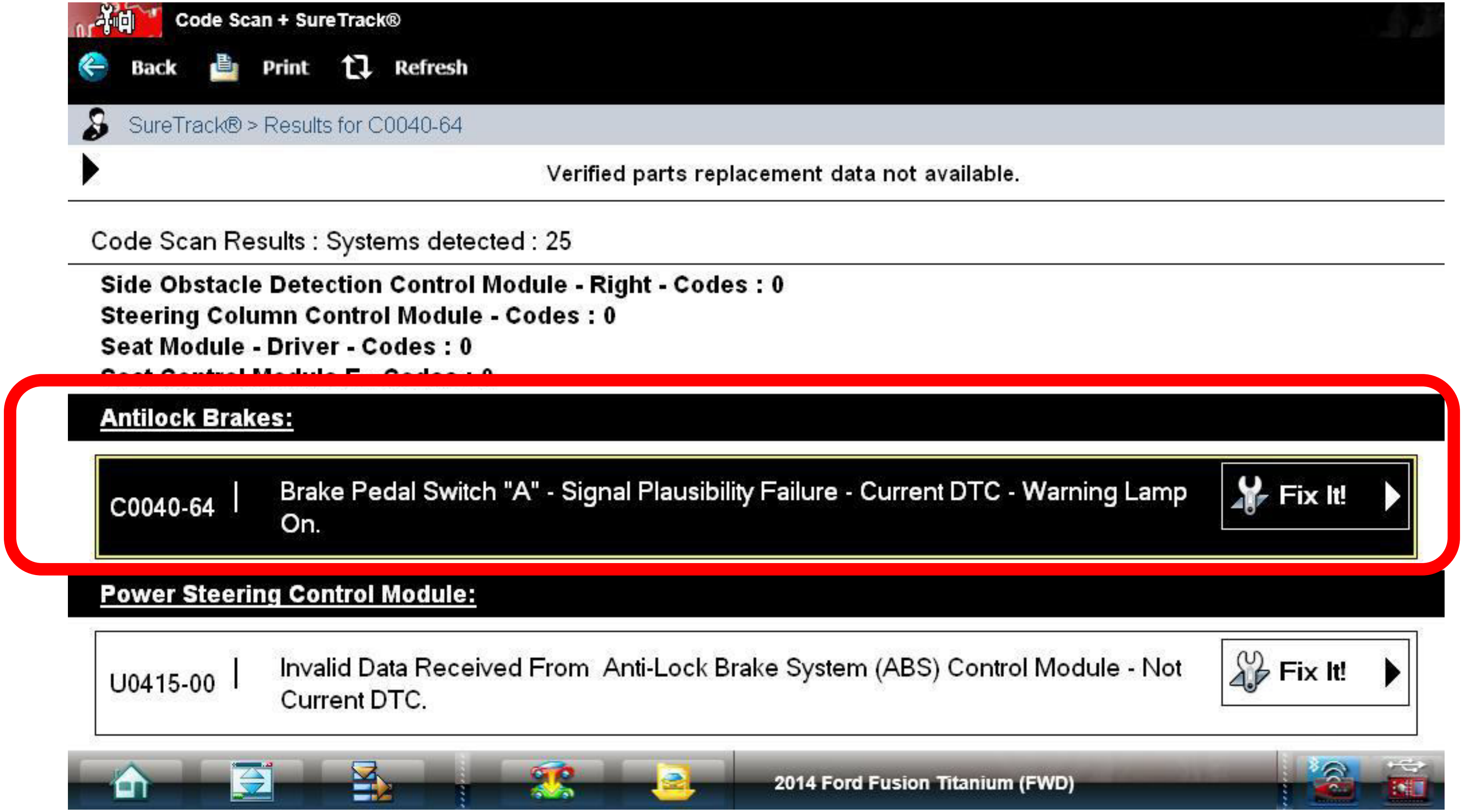
Temporarily Closed Switch

Success



Accelerator-Pedal-Position-Sensor-1- (V)
www.scanshare.io
2.2
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
Commanded-Throttle-Actuator-Control- (%)
www.scanshare.io
31
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
Engine-Speed (RPM)
www.scanshare.io
2900
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
Foot-Brake---Foot-Brake-State-Used-By-Strategy
www.scanshare.io
Off
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
Throttle-Position-Sensor-2- (V)
www.scanshare.io
2.13
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
Vehicle-Speed- (mph)
www.scanshare.io
50
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70

A Missed Clue: *Check Codes In All Modules*



2019 Honda CRV
Cold Start Rough Running

VIN# 2HKRW5H34KH420089
Mileage: 60,804

Codes Retrieved

- P0300 Random cylinder misfire
- P0302 Cylinder 2 misfire
- P0303 Cylinder 3 misfire
- DTCs match symptoms
  - *Probably Related*

Honda > Automatic selection > Auto scan VCM 12.8V

2019 Honda Vehicle Diagnostic Report

DTC details

1. PGM-FI(3 DTCs)

Codes	Description	Status
P0300	Random Misfire	Confirmed DTCs
P0302	No2 Cylinder Misfire	Confirmed DTCs
P0303	No3 Cylinder Misfire	Confirmed DTCs

2. ABS/VSA(1 DTC)

Codes	Description	Status
U0401-68	(ECM Failure)	Confirmed DTCs

3. Multiplex Integrated Control Unit(1 DTC)

Codes	Description	Status
U128D	Relay control module lost communication with gauge control module(VSP/NE frame)	Confirmed DTCs

4. EPS(1 DTC)

Codes	Description	Status
U0416-68	(VSA system malfunction)	Confirmed DTCs

Cold Start Misfire Data

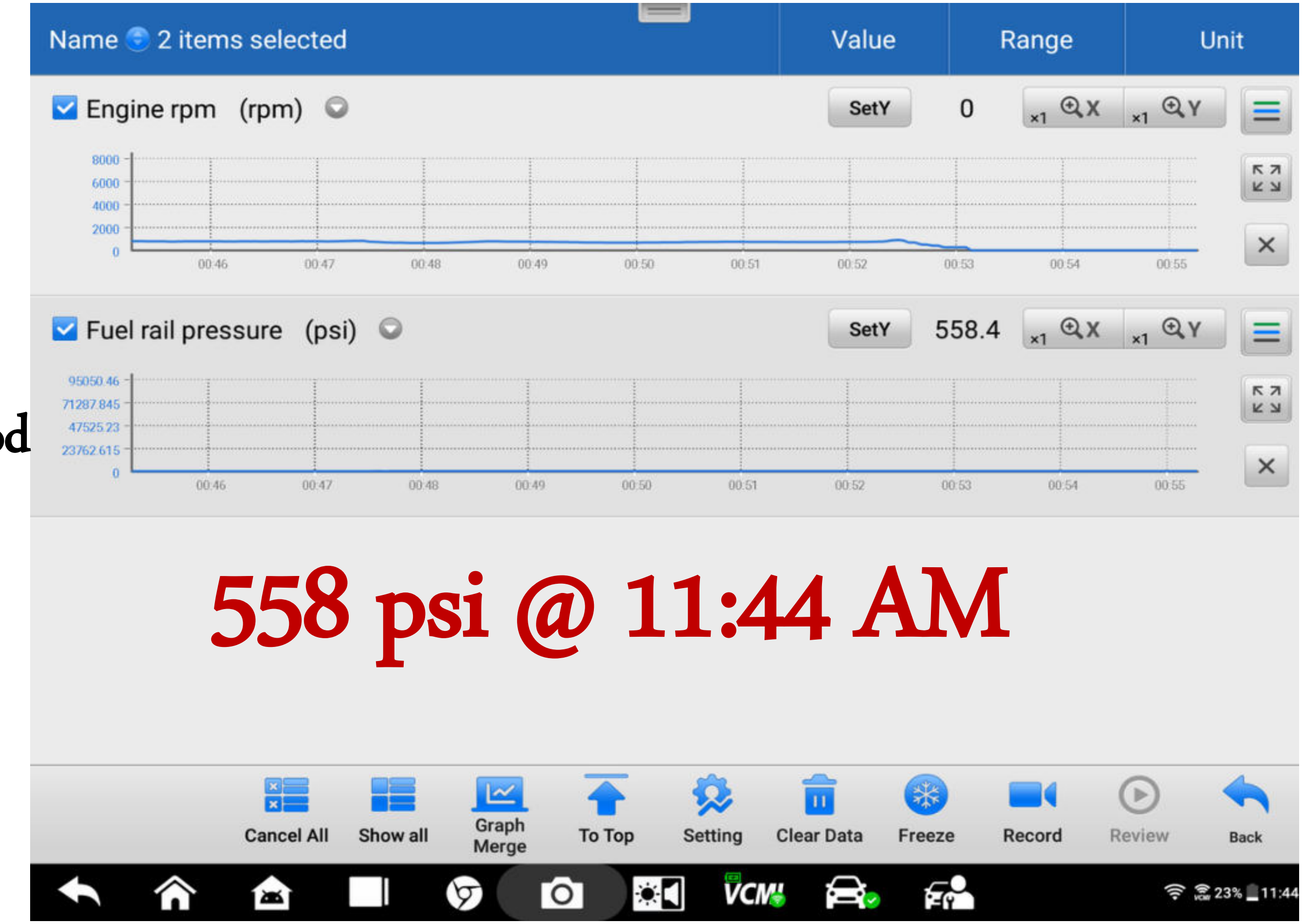
- Runs rough at start-up
- Misfires correlate with DTCs
- Common causes of cold start misfire:
  - *Leaking Fuel Injector*
  - *Head Gasket Leaks*
  - *Carbon*

Name 3 items selected	Value	Unit
Cyl3 Total Misfire	8	
Cyl4 Total Misfire	0	
Cyl1 Misfire	0	
Cyl2 Misfire	4	
Cyl3 Misfire	8	
Cyl4 Misfire	0	
Misfire Cycle	281	
Cyl1 Misfire B	0	
Cyl2 Misfire B	4	
Cyl3 Misfire B	8	
Cyl4 Misfire B	0	

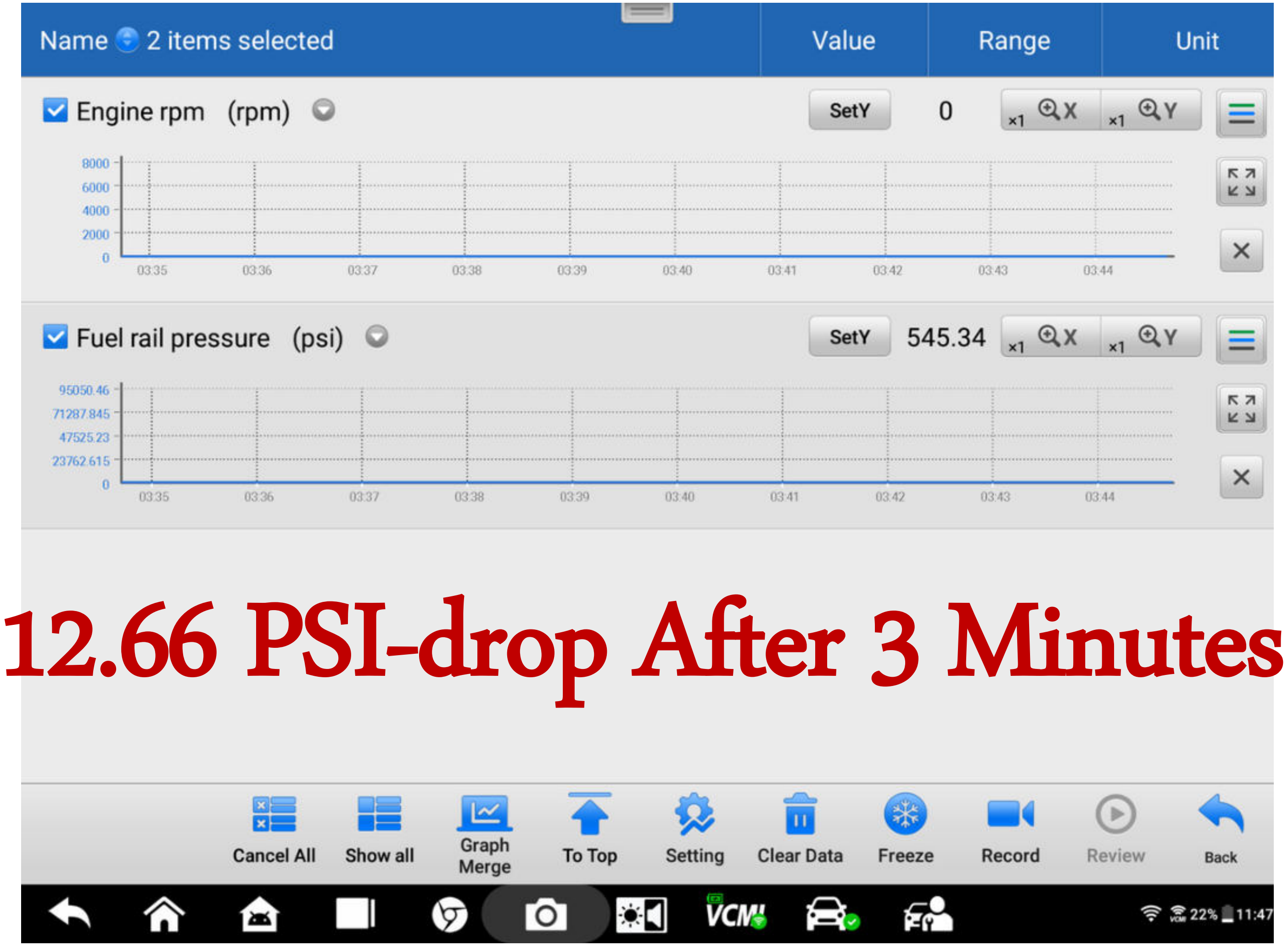
Cylinders 2 & 3 are misfiring

Monitoring For Leaking Injectors…

- Very Little Fuel Rail Volume
- Normal Pressure Release = Injectors Only
  - *Engine Off = No Injection Event*
  - *Engine Off = No Pressure Drop*
- Piston Pump Should Hold Pressure For Extended Period
- Under Hood Heat Will Cause Short Term Increase

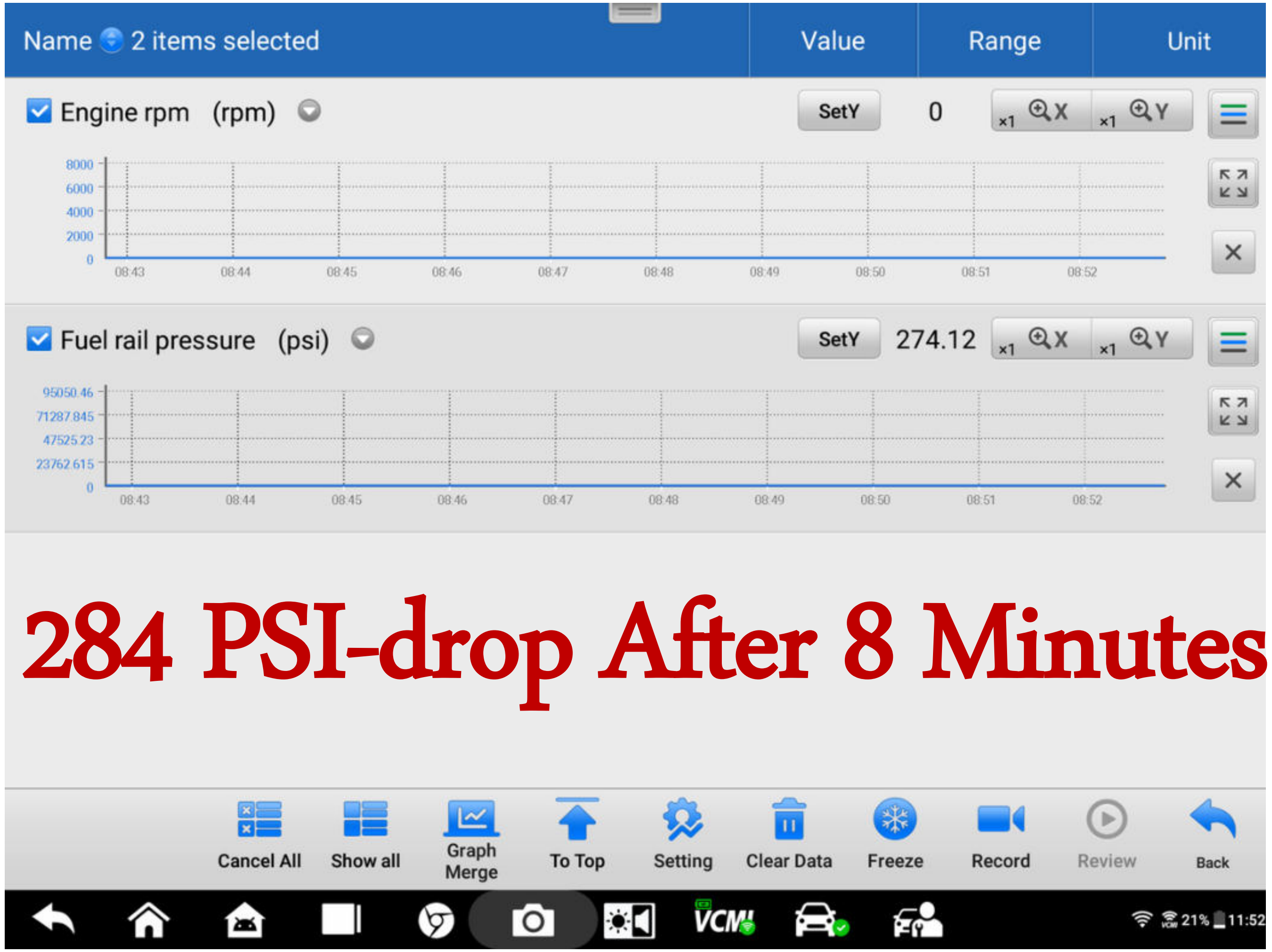


Monitoring For Leaking Injectors...

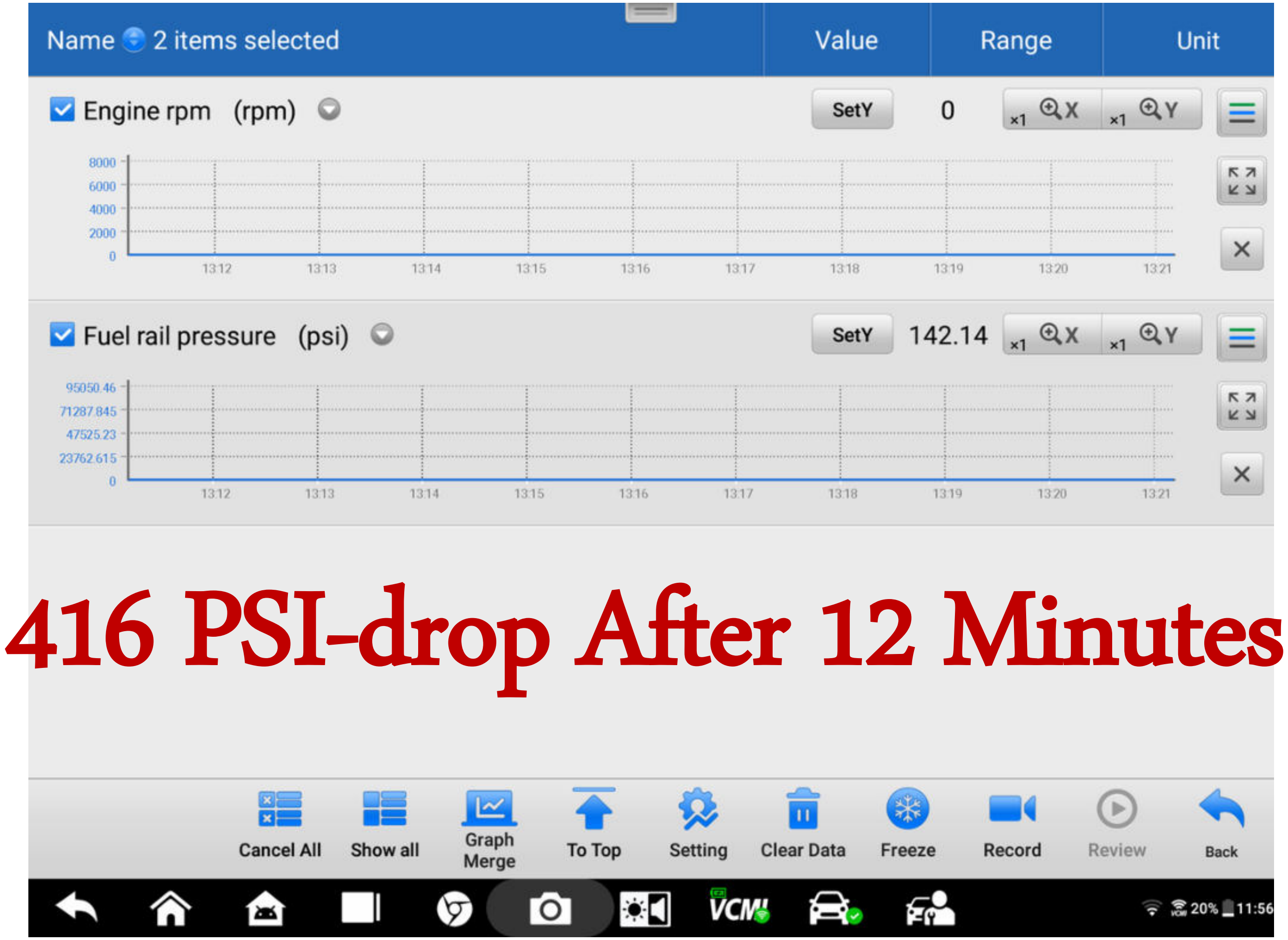


12.66 PSI-drop After 3 Minutes

Monitoring For Leaking Injectors...

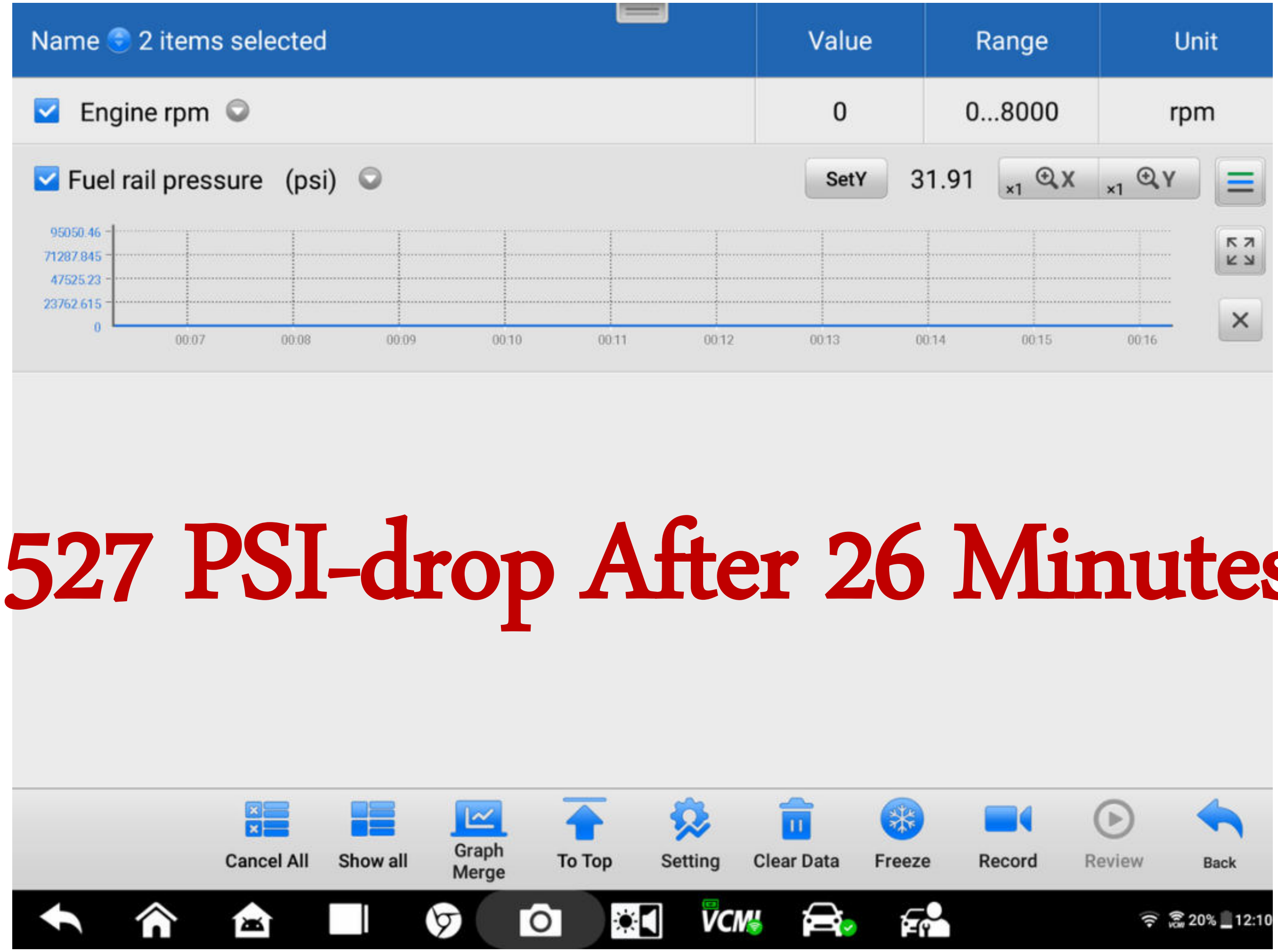


Monitoring For Leaking Injectors…



416 PSI-drop After 12 Minutes

Monitoring For Leaking Injectors...

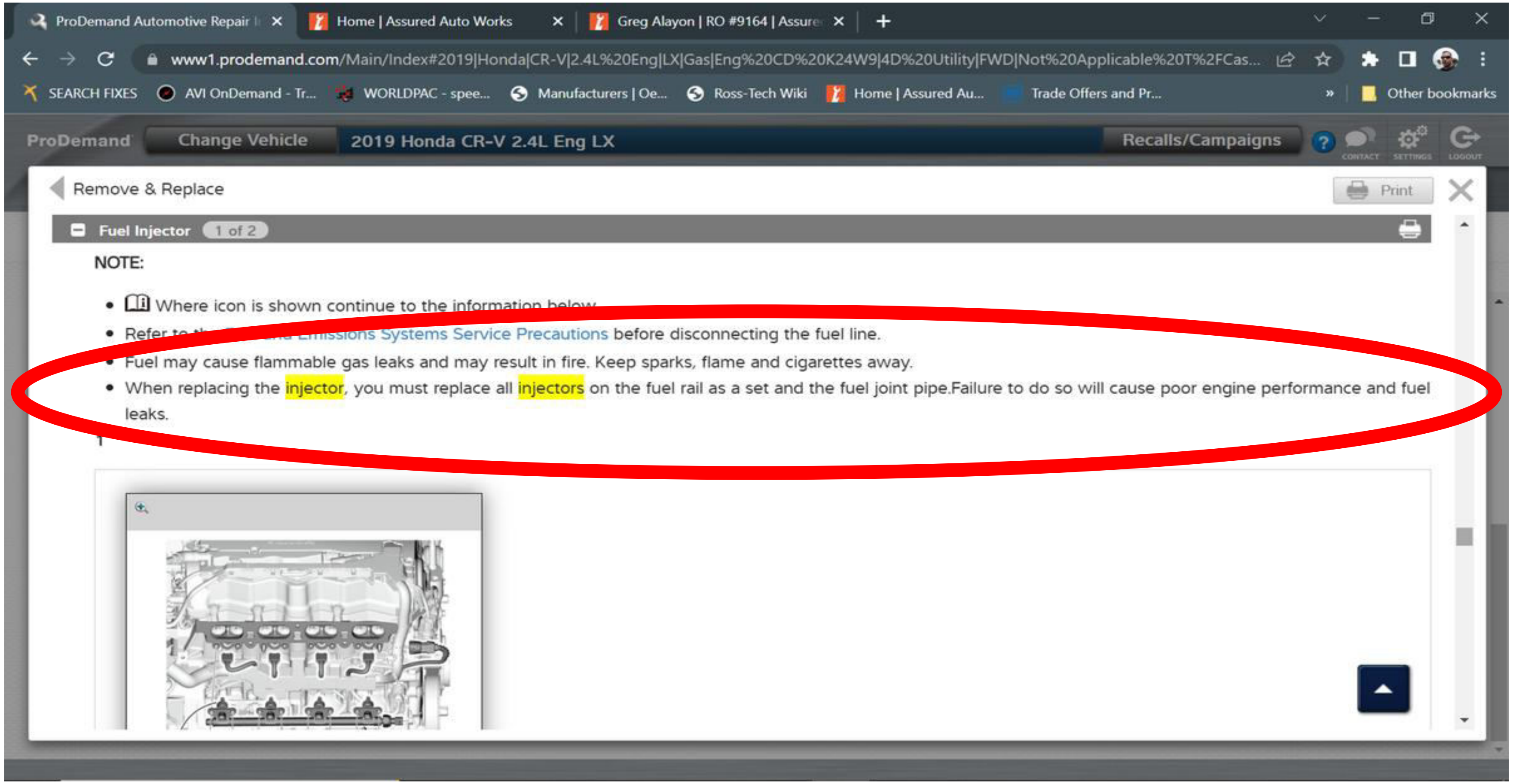


527 PSI-drop After 26 Minutes

What are some possibilities?

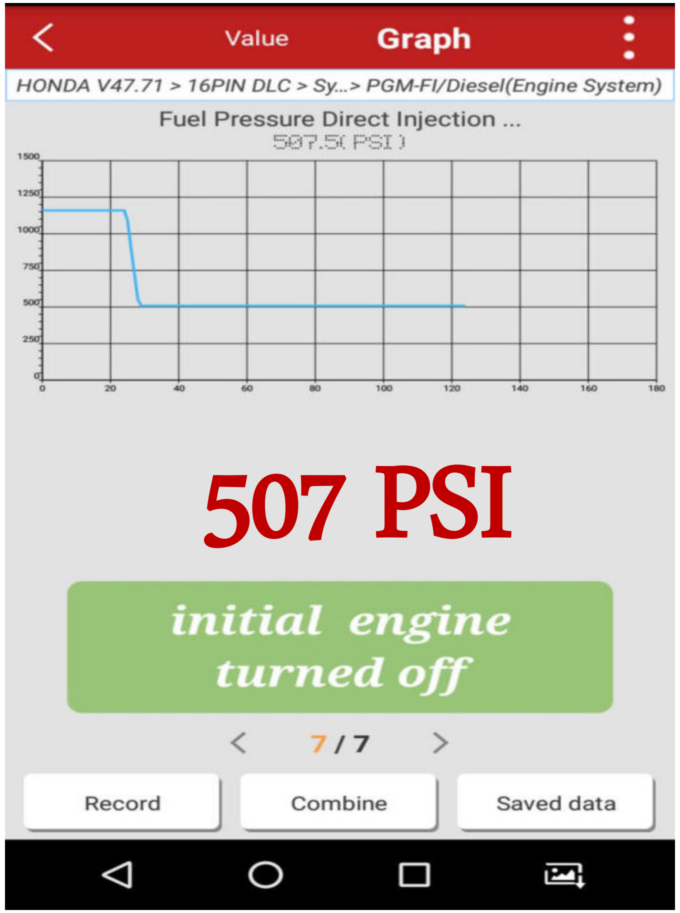
Another Justified *Arrow In the Target*

All For One & One For All!

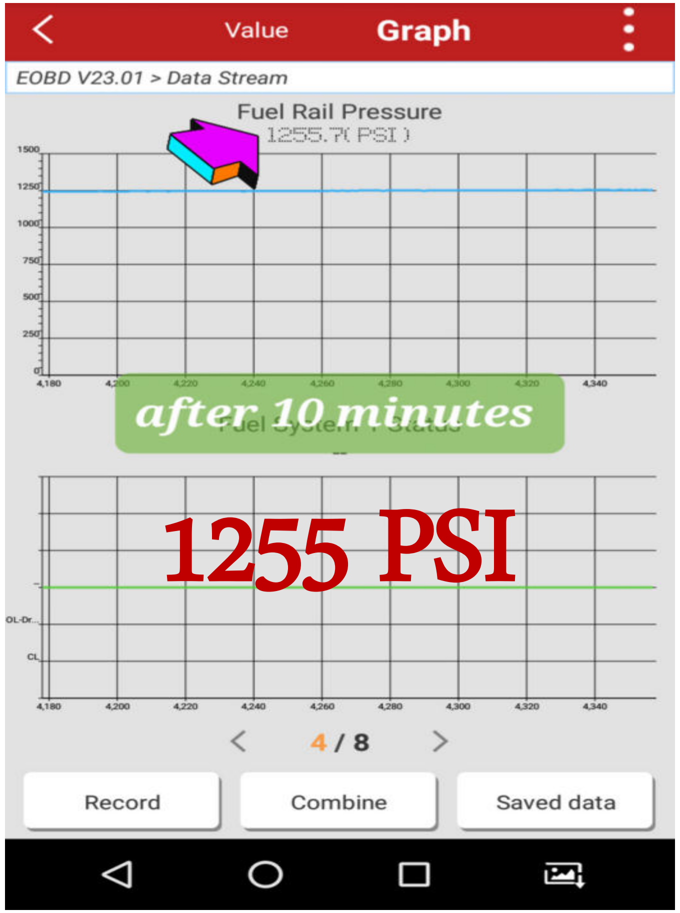


We recommended & Replaced All 4 Injectors

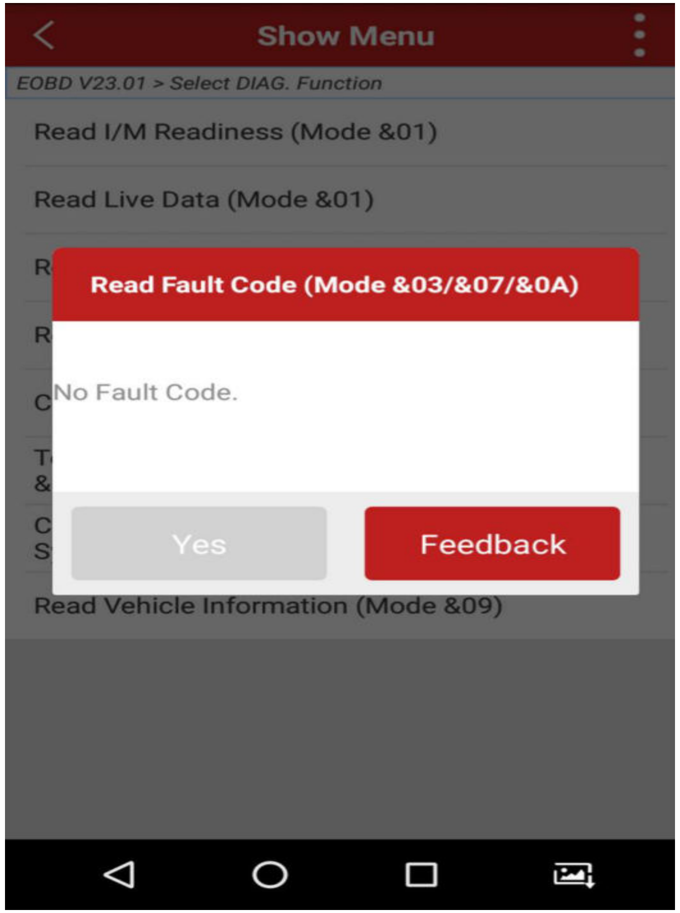
Post Repair Data & Codes



Rail Pressure After Shut Off



10 Minutes Later

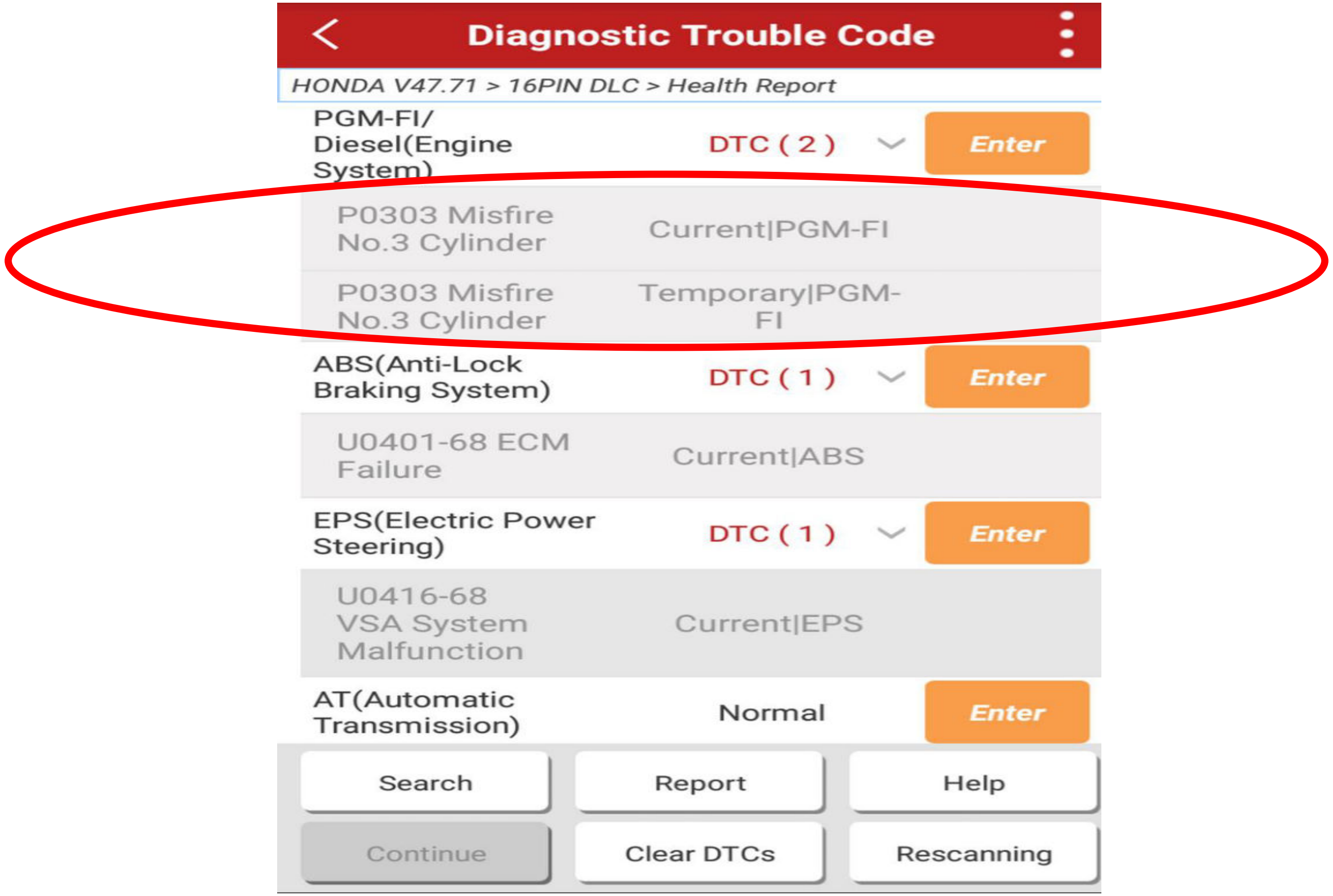


Runs Well & No Codes


I EAT SUCCESS
FOR BREAKFAST


They're Back!
Same Symptoms!
VIN# 2HKRW5H34KH420089
Mileage: 60,804
Diagnosed: April 2023

Duplicate & Retrieve Codes



Cylinder 3 Again!

FRP Decay


Start Communication
Exit
List View
Save
Scale
Sweep
FUEL RAIL PRESSURE (psi)
171.1
2775.2
2600.0
2400.0
2200.0
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
171.1
786 800 820 840 860 880 900 920 940 960 980 1000 1020 1040 1060 1080 1100 1120 1140 1160 1180 1200 1220 1240 1260 1286
Over 200 PSI-drop In 500 Frames
1286
No Active Vehicle

Coolant Leaking in Cylinder #3

- Removed cylinder #3 spark plug
- Verified fluid in cylinder #3
- Initially assumed fluid was fuel
  - *Determined fluid was anti-freeze*
  - *Video scope confirmed leaking head gasket*

Where Did We Go Wrong?

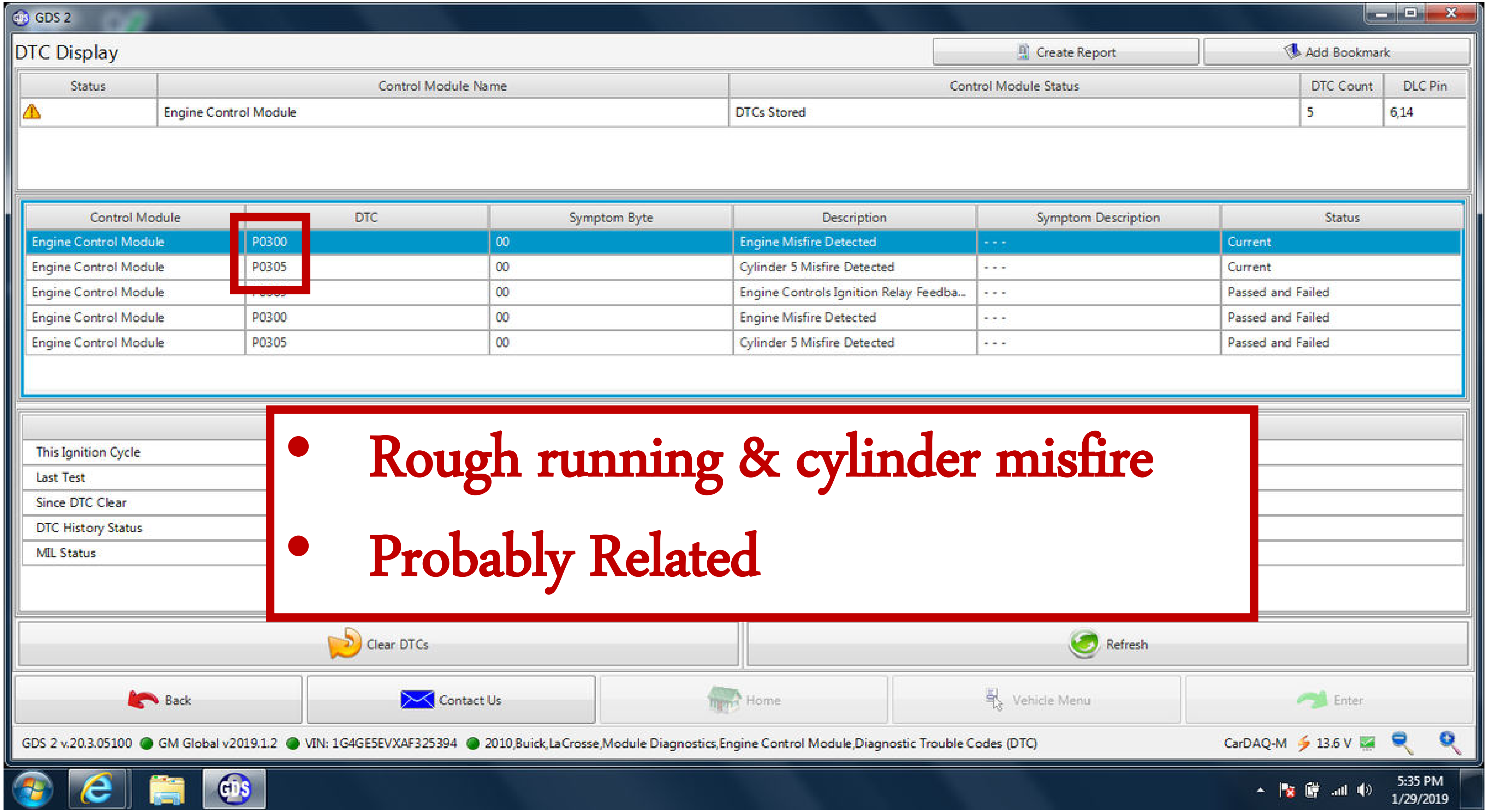
- Initially, misfired at cold start-up
- Fuel decay was determined to be injector leak down
- Fuel decay gone with injector replacement

- Vehicle returns with same symptom
- Fuel pressure decay returns…leak is confirmed to be head gasket (?)

2010 Buick Lacrosse 3.6L Runs Rough & Fuel Odor

VIN: 1G4GE5EVXAF325394
Mileage: 91,31
Diagnosed: Jan 2019

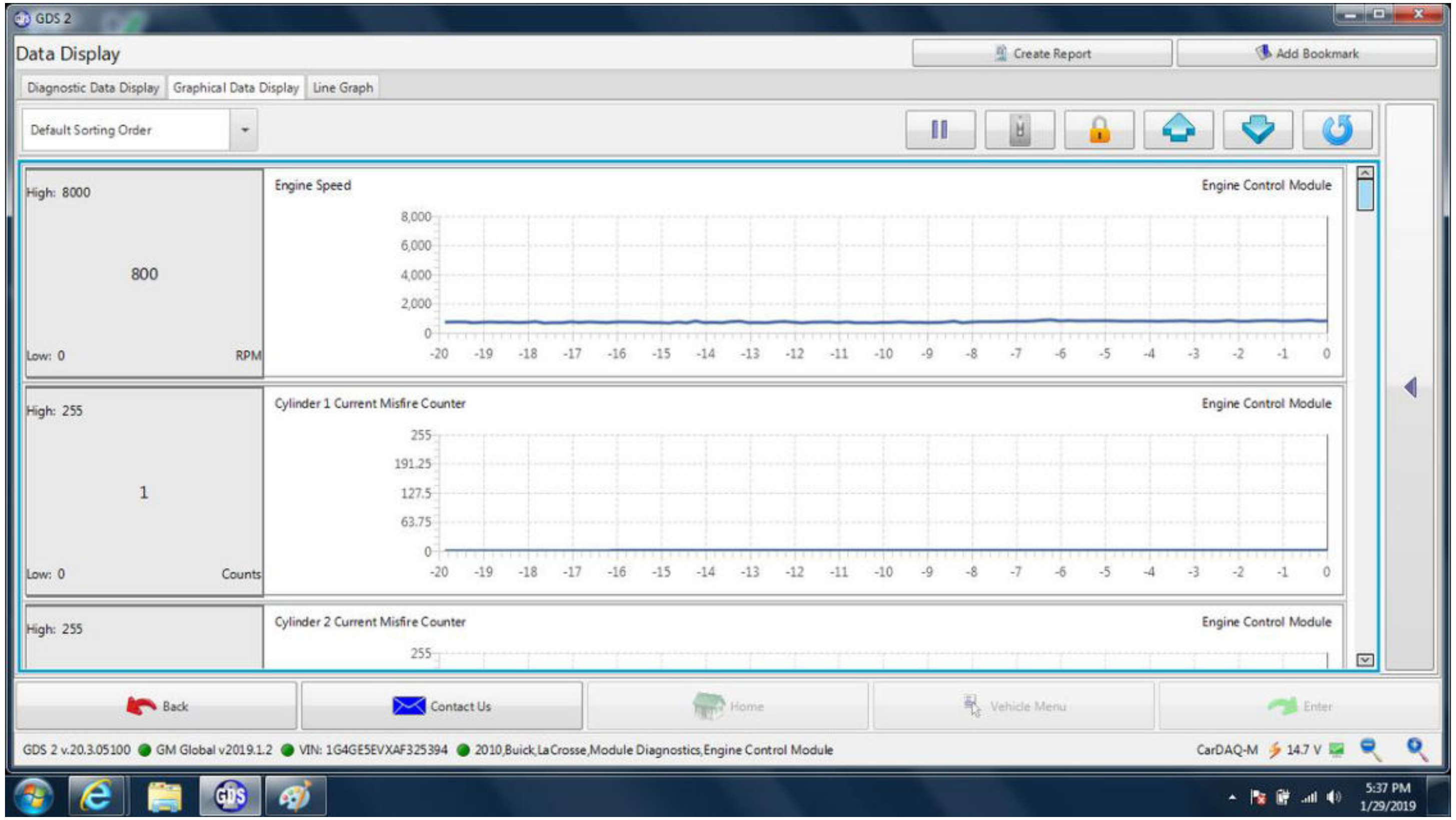
Stored DTCs



- Rough running & cylinder misfire
- Probably Related

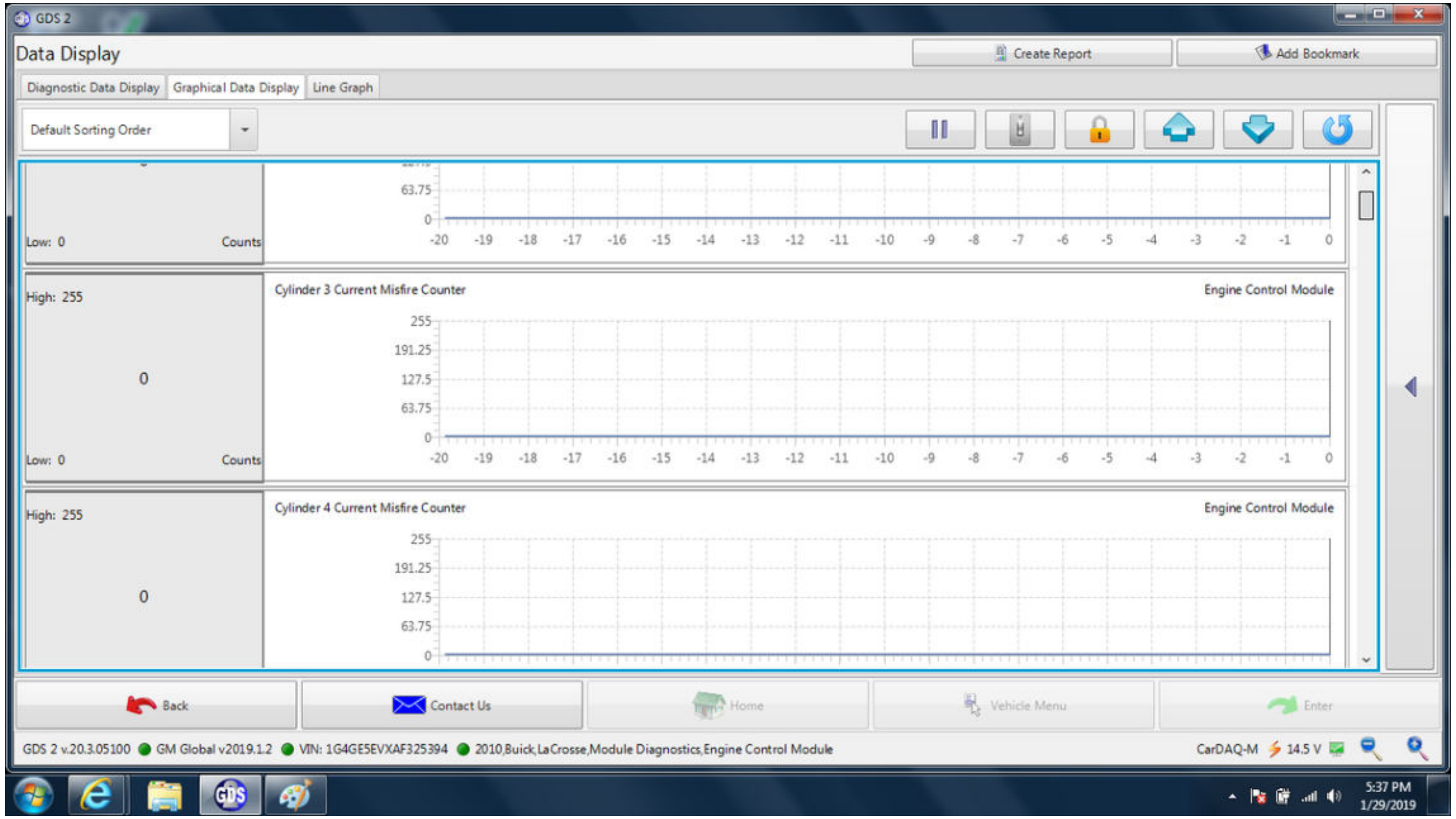
Current Misfire Data…

- Idle speed
- Cylinders 1 or 2
    - *No misfires*



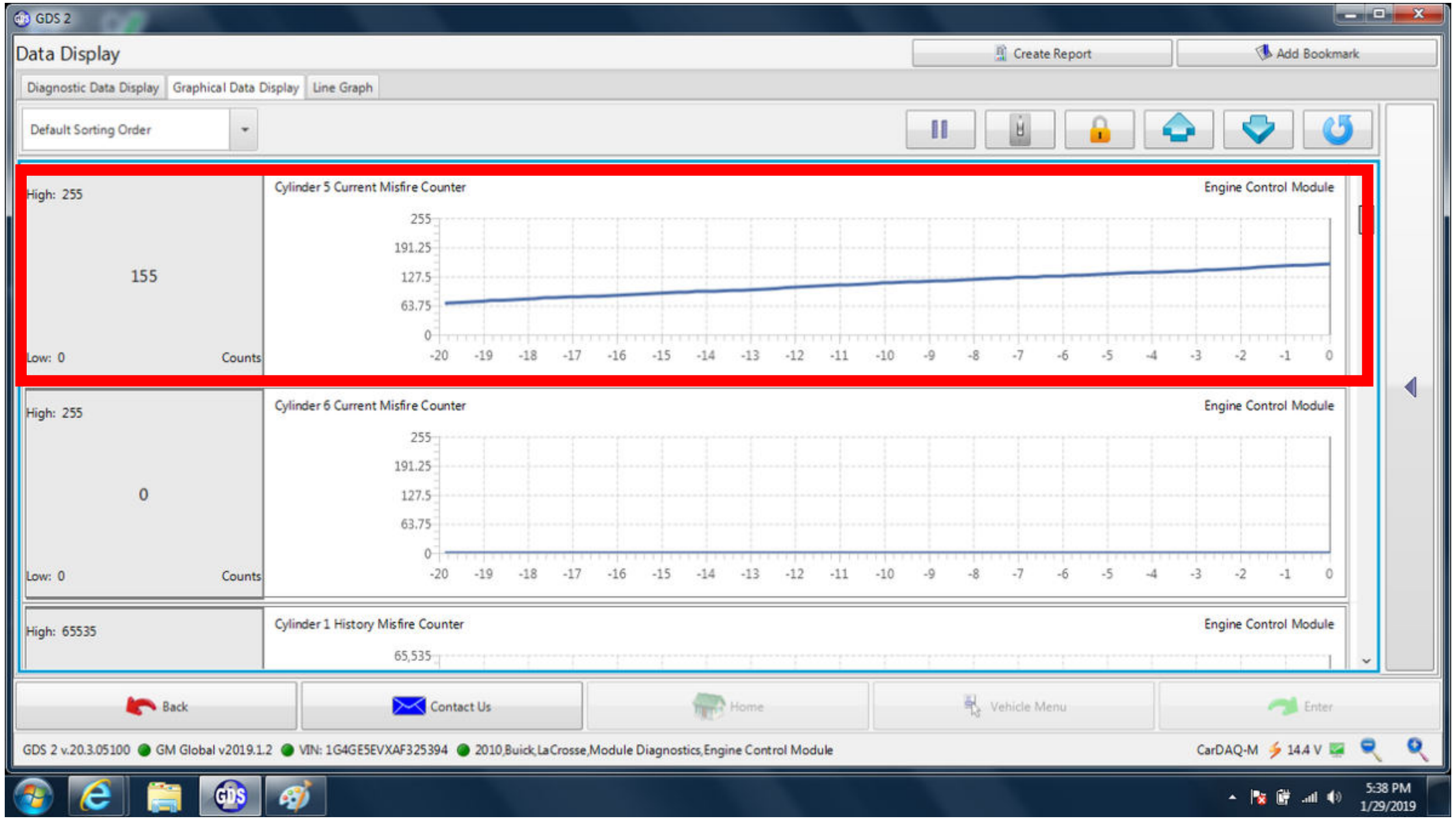
Current Misfire Data…

- Idle seed
- Cylinders 3 or 4
  - *No misfires*

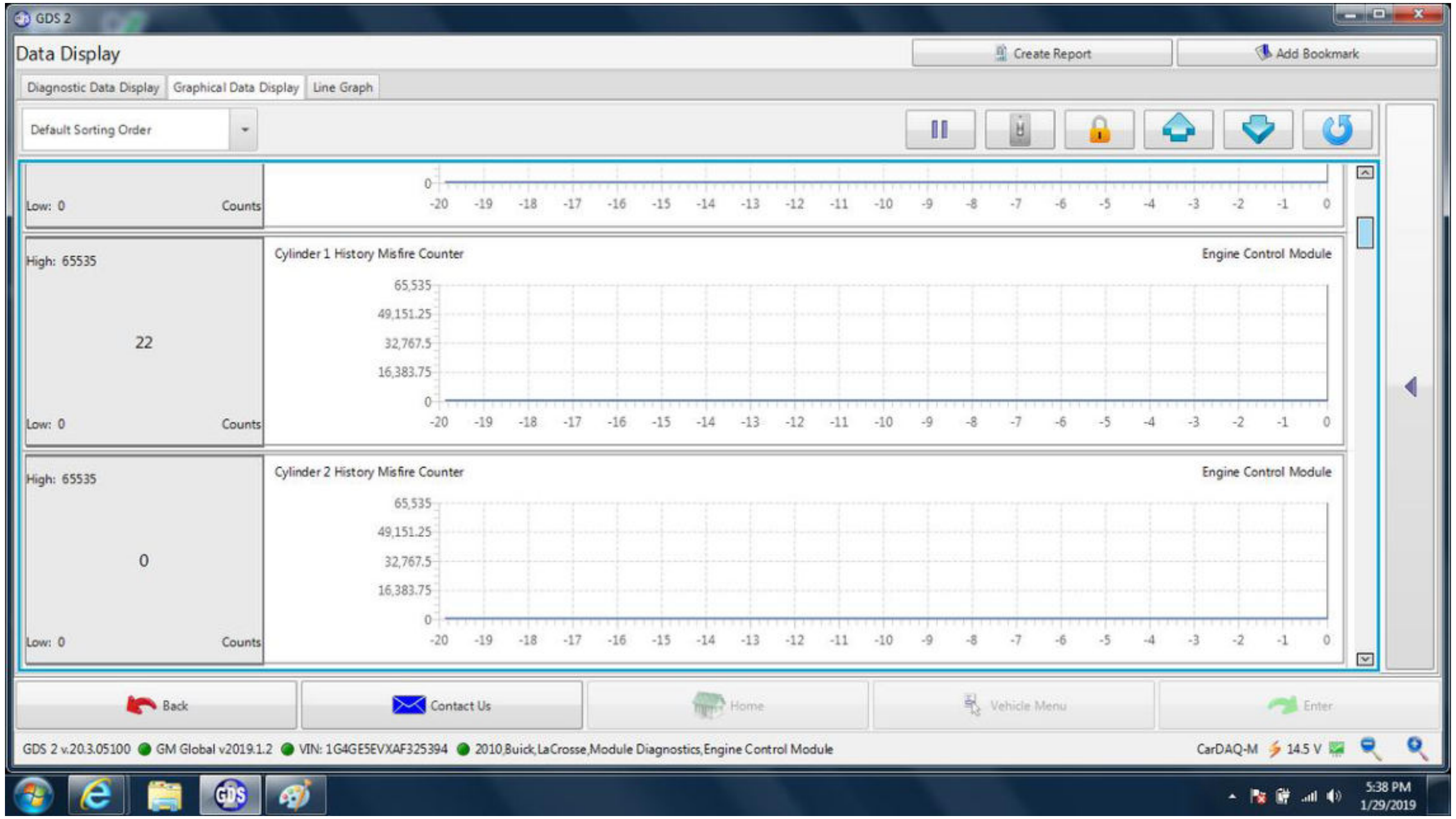


Current Misfire Data

- Idle Speed
- Cylinders 5 or 6
  - *Lots of Cylinder 5 Misfires*
  - *Smoke at tailpipe*
  - *No Cylinder 6 Misfires*



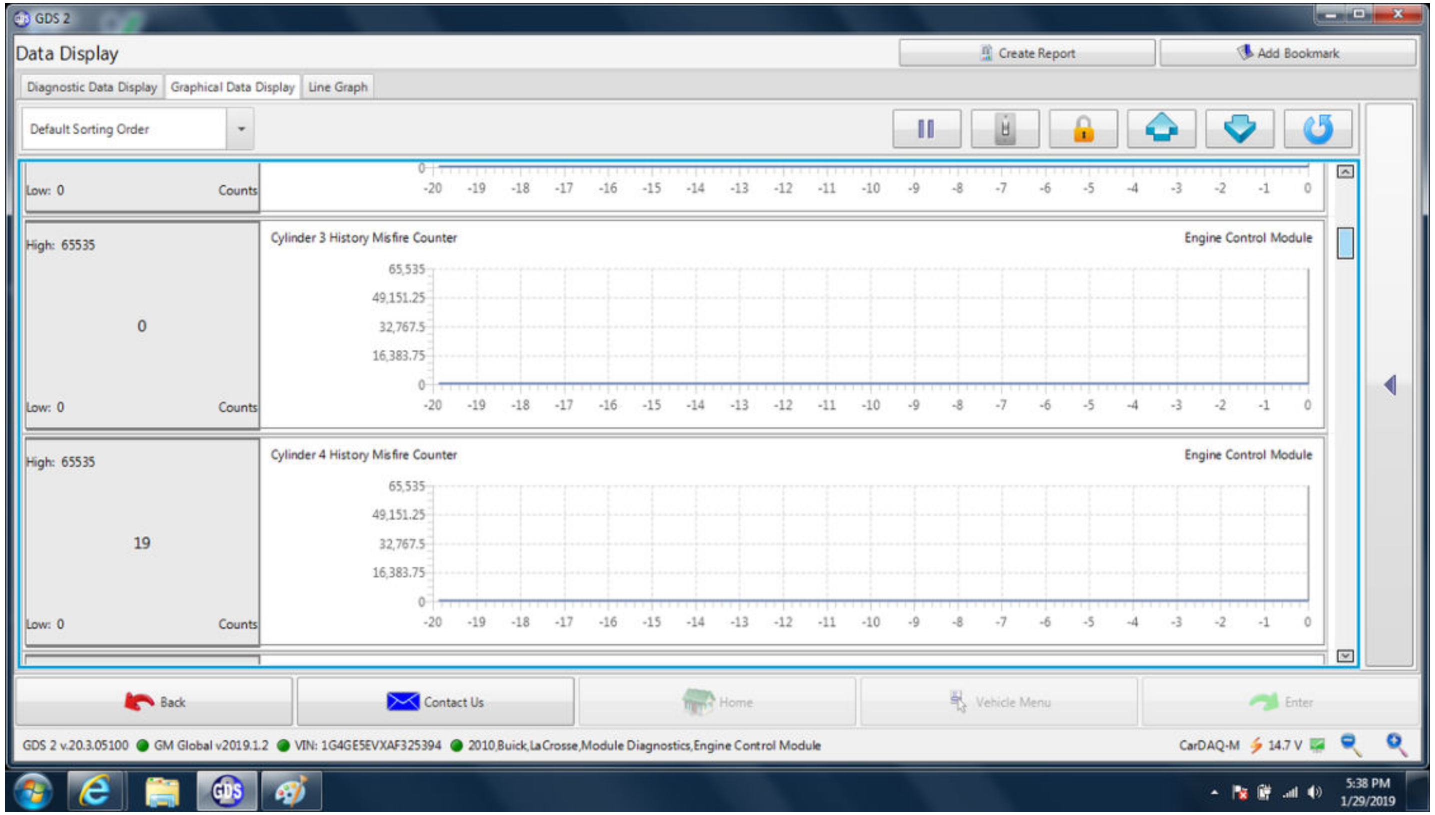
History Cylinder Misfires…



22 = Historic cylinder 1 misfires

0 = Historic cylinder 2 misfires

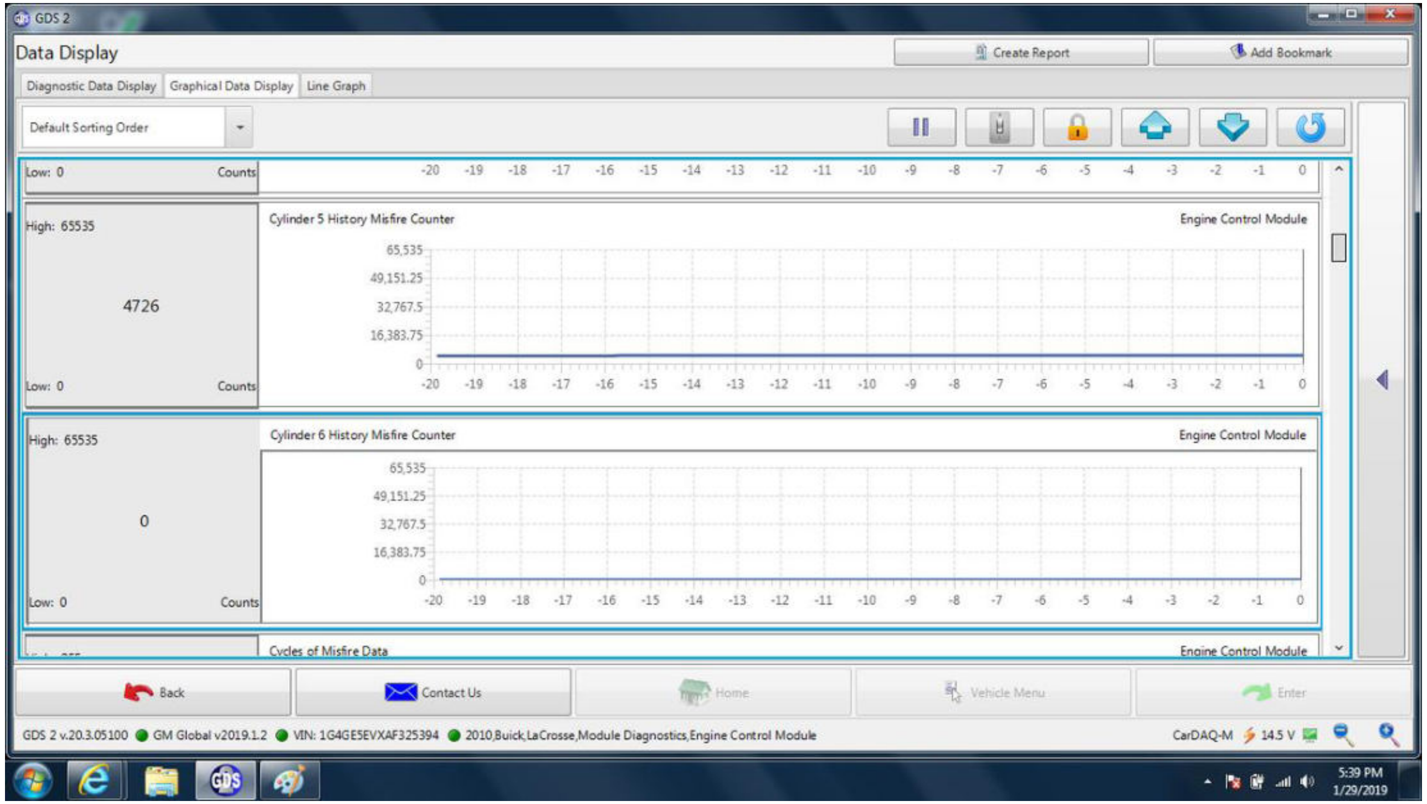
History Cylinder Misfires…



0 = Historic cylinder 3 misfires

19 = Historic cylinder 4 misfires

History Cylinder Misfires

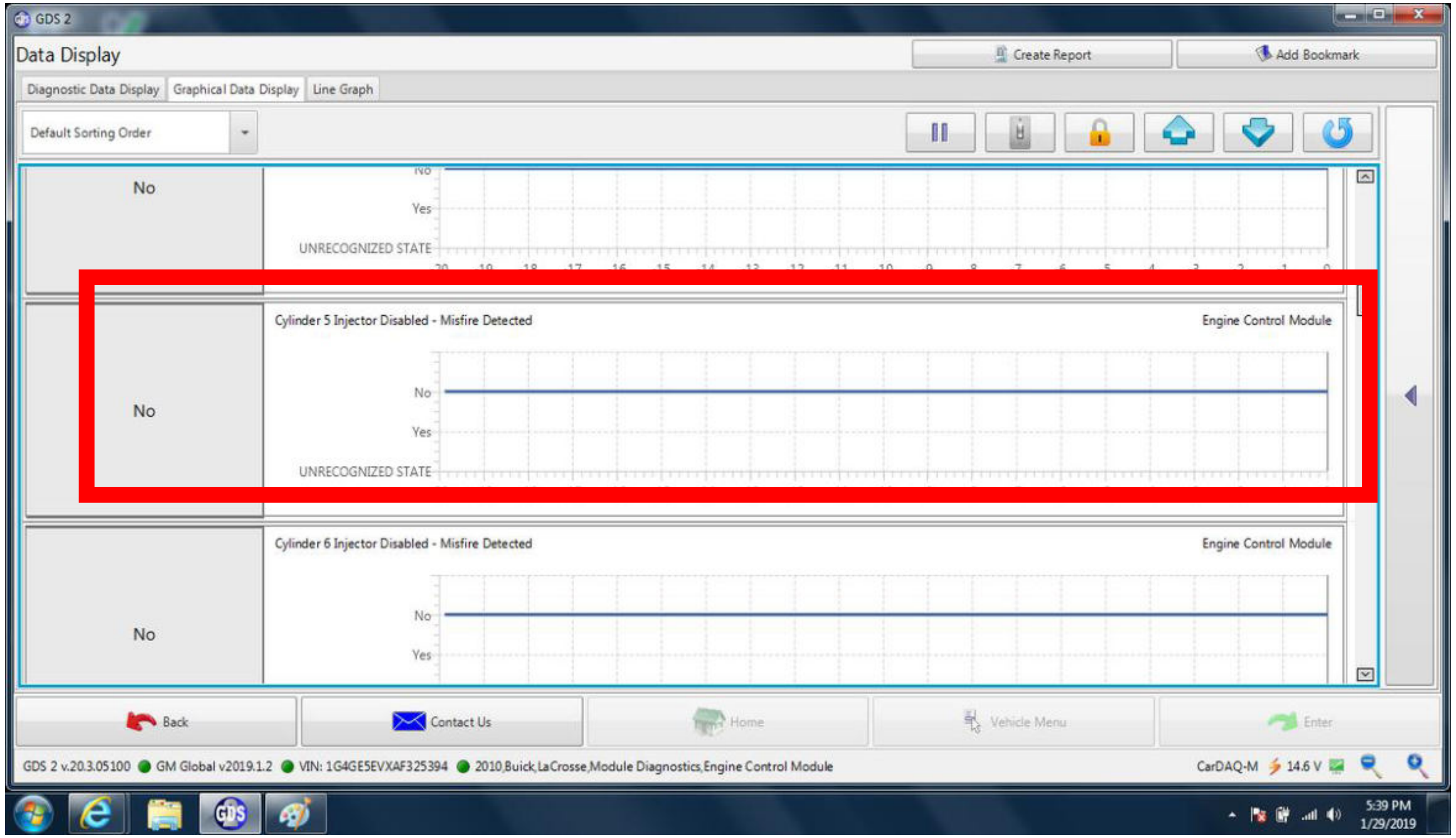


4700 = Historic cylinder 5 misfires

0 = Historic cylinder 6 misfires

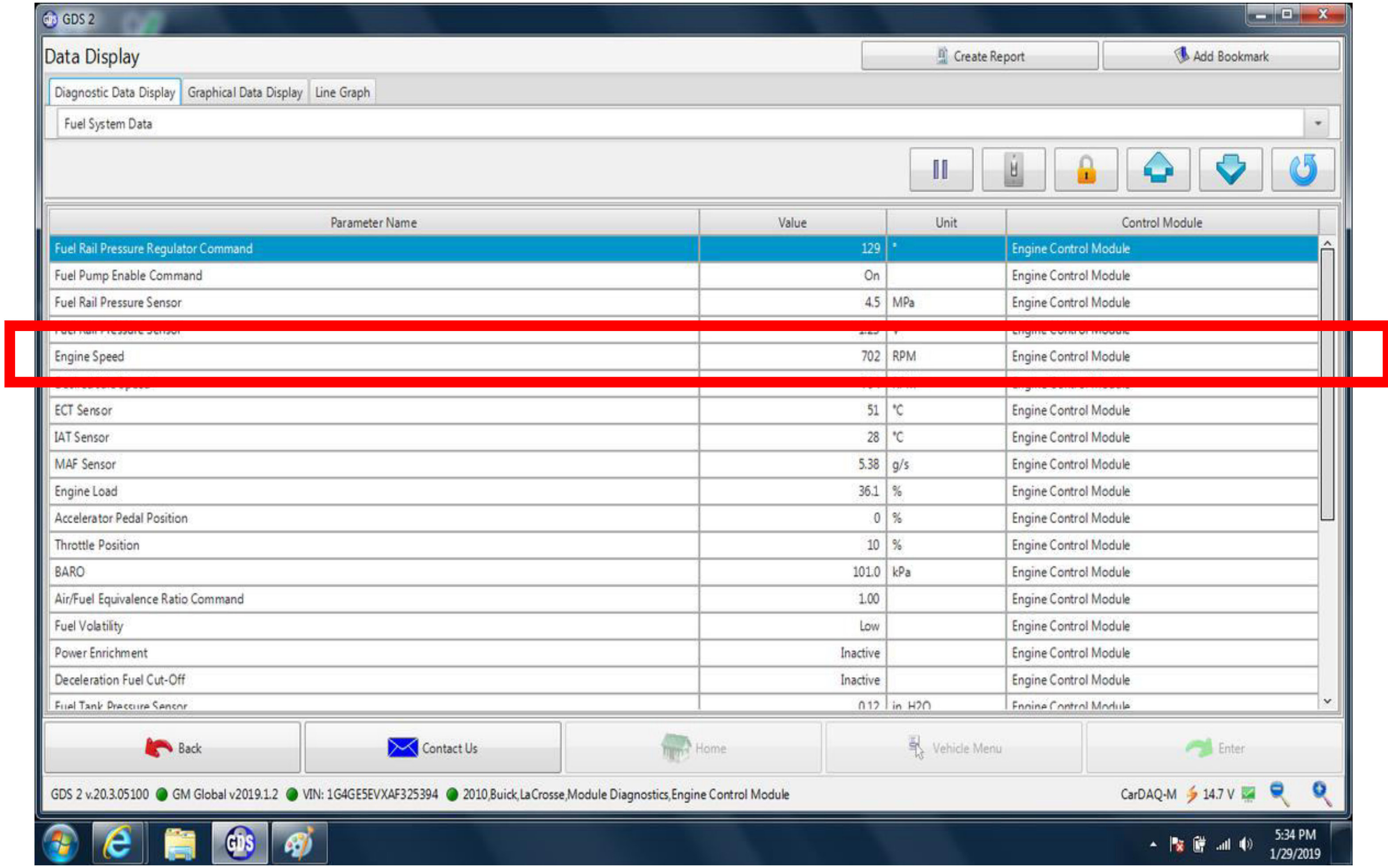
This Seat Is Comfortable… I Think I'll Stay For a While

- Start pinpoint test or analyze?
- Strategy or a legitimate
- Very helpful data parameter



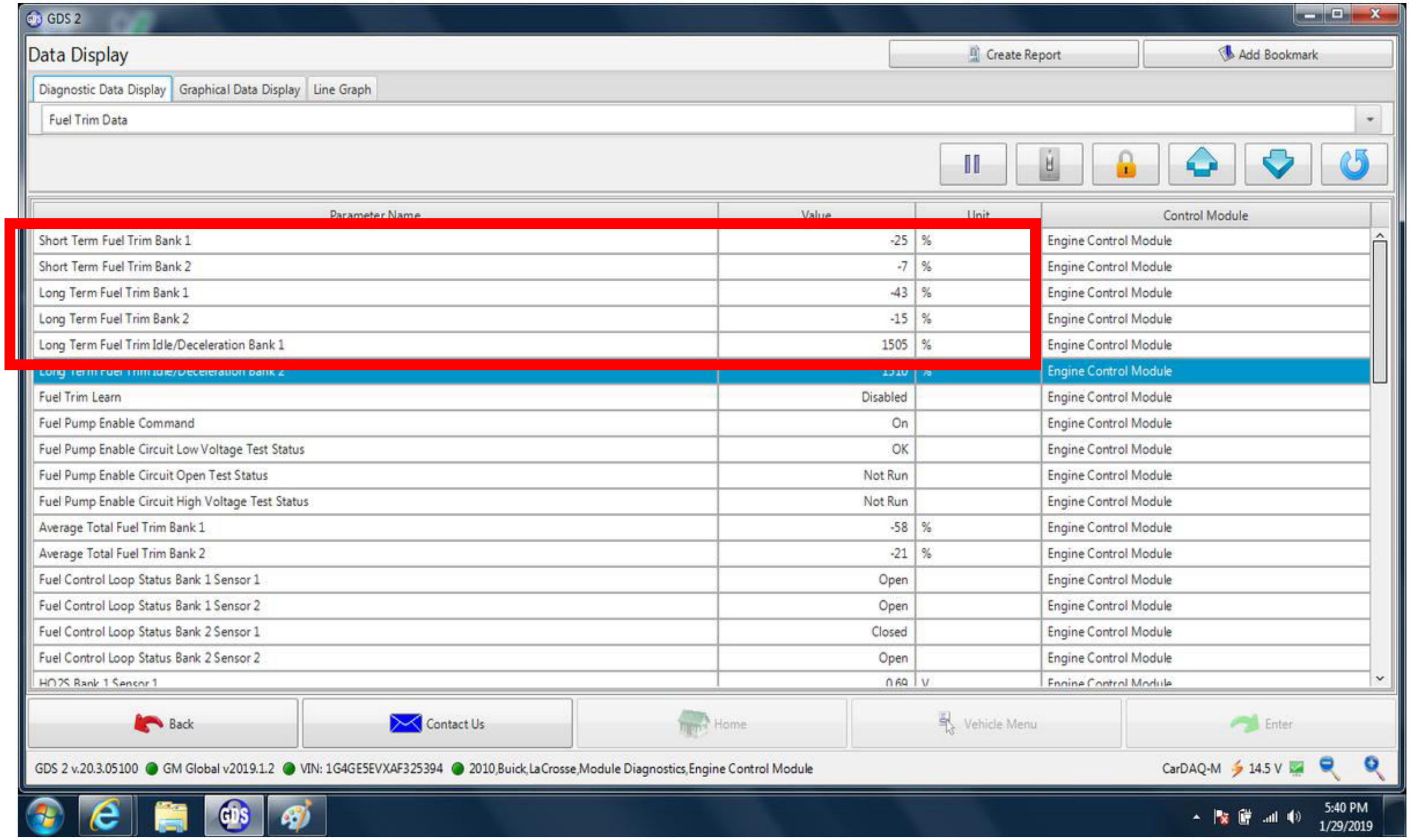
Engine Data…

- Idle speed
  - *Fuel rail pressure 4.5 MPa = 652 PSI*
  - *5.38 gram/second*
  - *CEQ_ratio = 1.00*



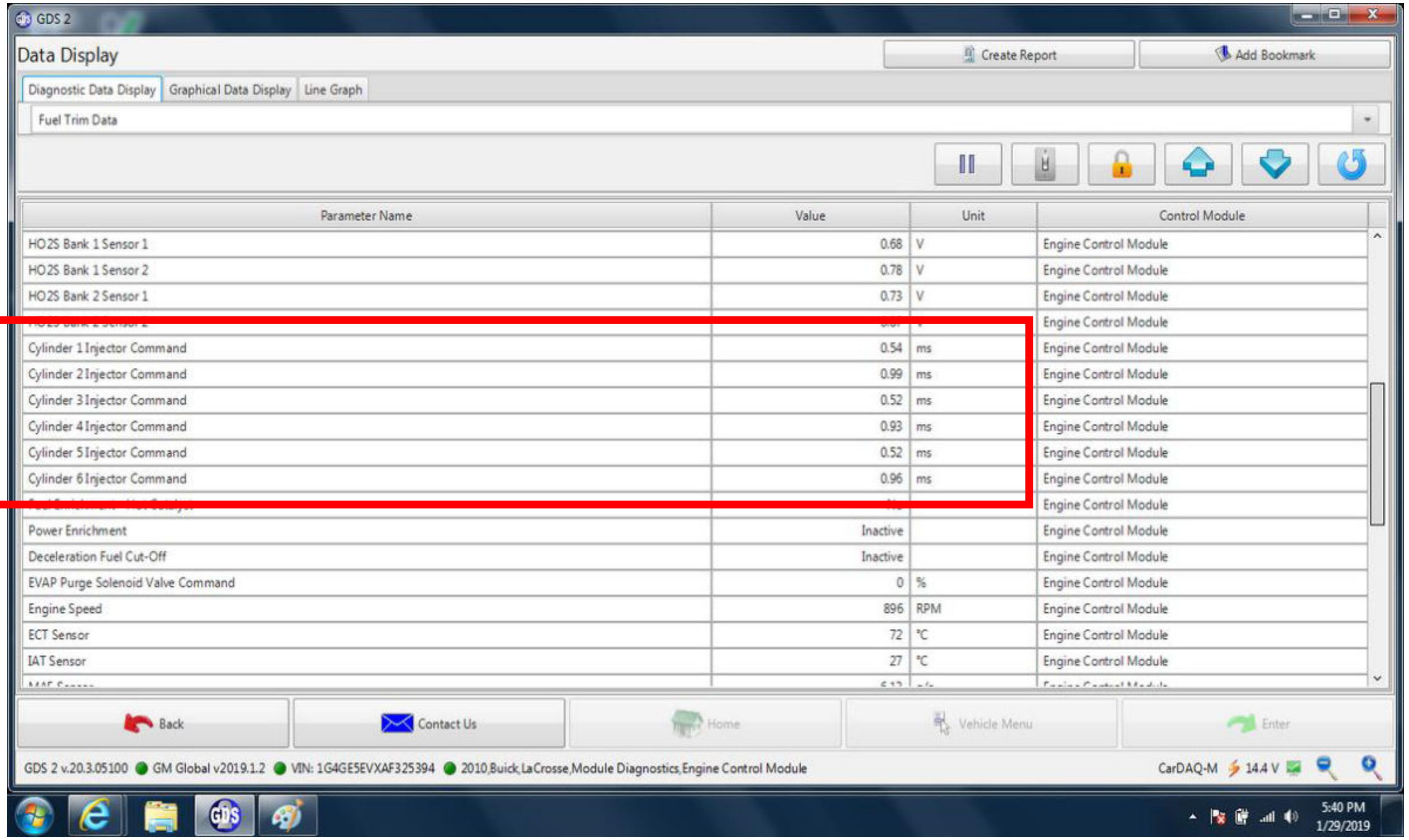
Engine Data…

- Bank 1 STFT: -25
- Bank 1 LTFT: -43%
- Total Bank 1 fuel trim: -68%
- Bank 2 STFT: -7
- Bank 2 LTFT: -15%
- Total Bank 2 fuel trim: -22%
  - *Massive correction*
  - *Generally, fuel-side failure*



What Does The Data Show Us?

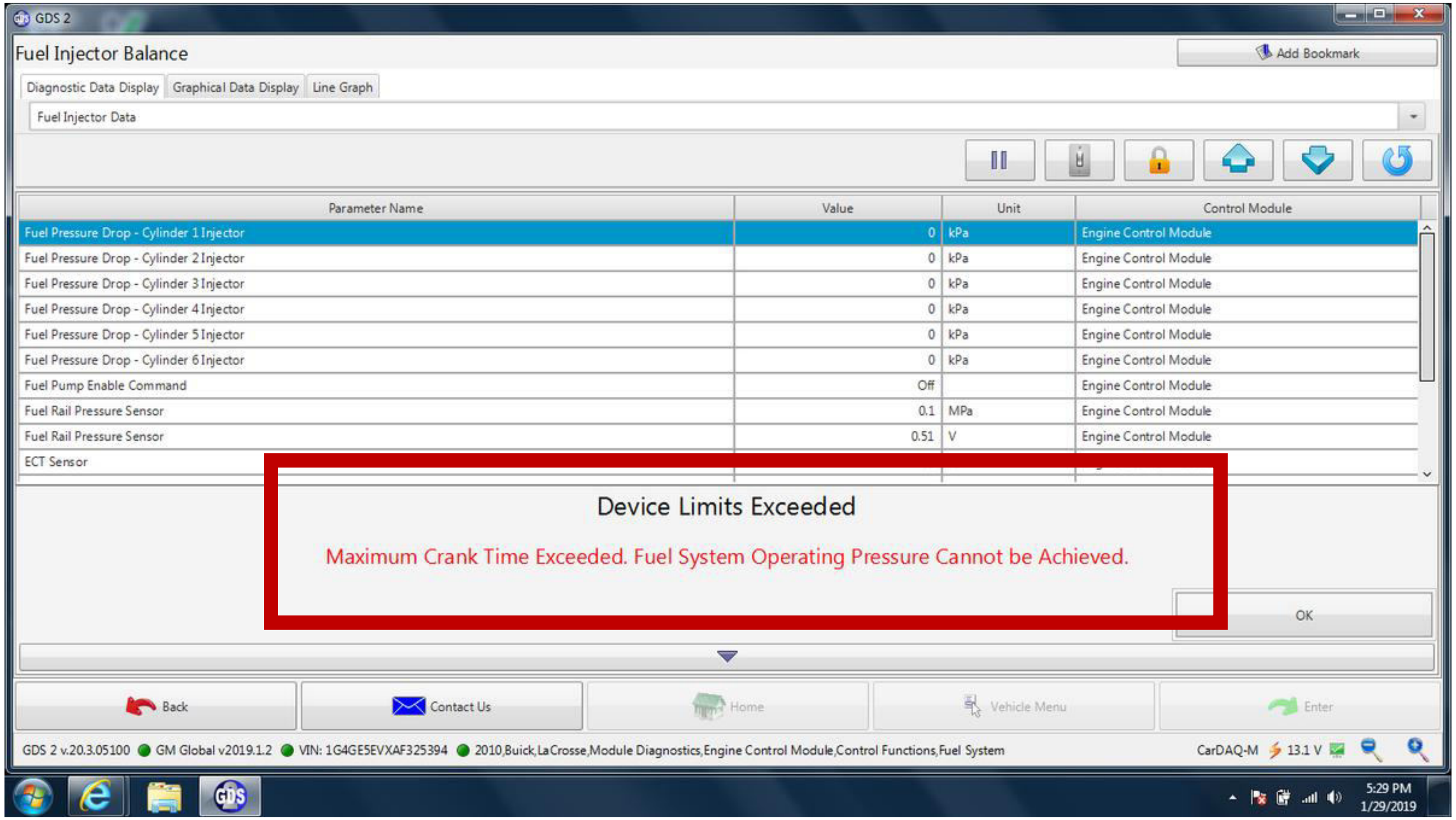
- HO2S = "Rich"
- Bank 1 injectors on-time = 0.53 mS
- Bank 2 injectors on-time = 0.96 mS
  - *Result of negative fuel trim*
  - *Cylinder-to-Cylinder differences*
  - *Transient or A/F-imbalance compensation*



Dribbling Injectors?

Justified Fuel Injector Balance Test

- Cranking test
- Test incomplete
- Insufficient rail pressure



Ready to Make a Call

- Active cylinder 5 misfire
- No ECM-disabled injector
- Fuel odor present
- Substantial negative fuel trims
- Can't run injector balance
    - *Can't build rail pressure*
    - *Rail pressure dives with Engine "off"*

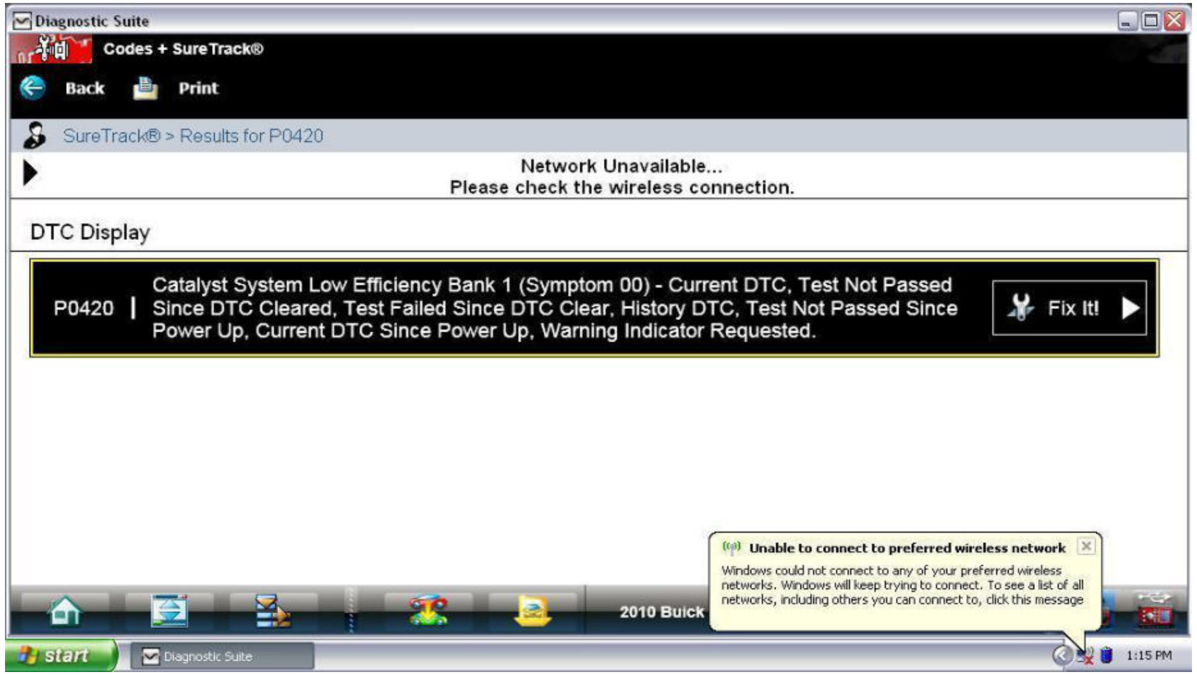

#1
#3
#5

Verification of Repair

- Injector Replacement
- Engine Runs Good
- Fuel Trims Good
- Engine Light Re-Illuminated

Post-Fix Scan

- P0420
- Suspect catalyst damage from leaking injector
  - *Client was warned before injector replacement*
  - *Declined additional testing*



2009 Mini Cooper
1.6L Turbo

Cranks / No Start

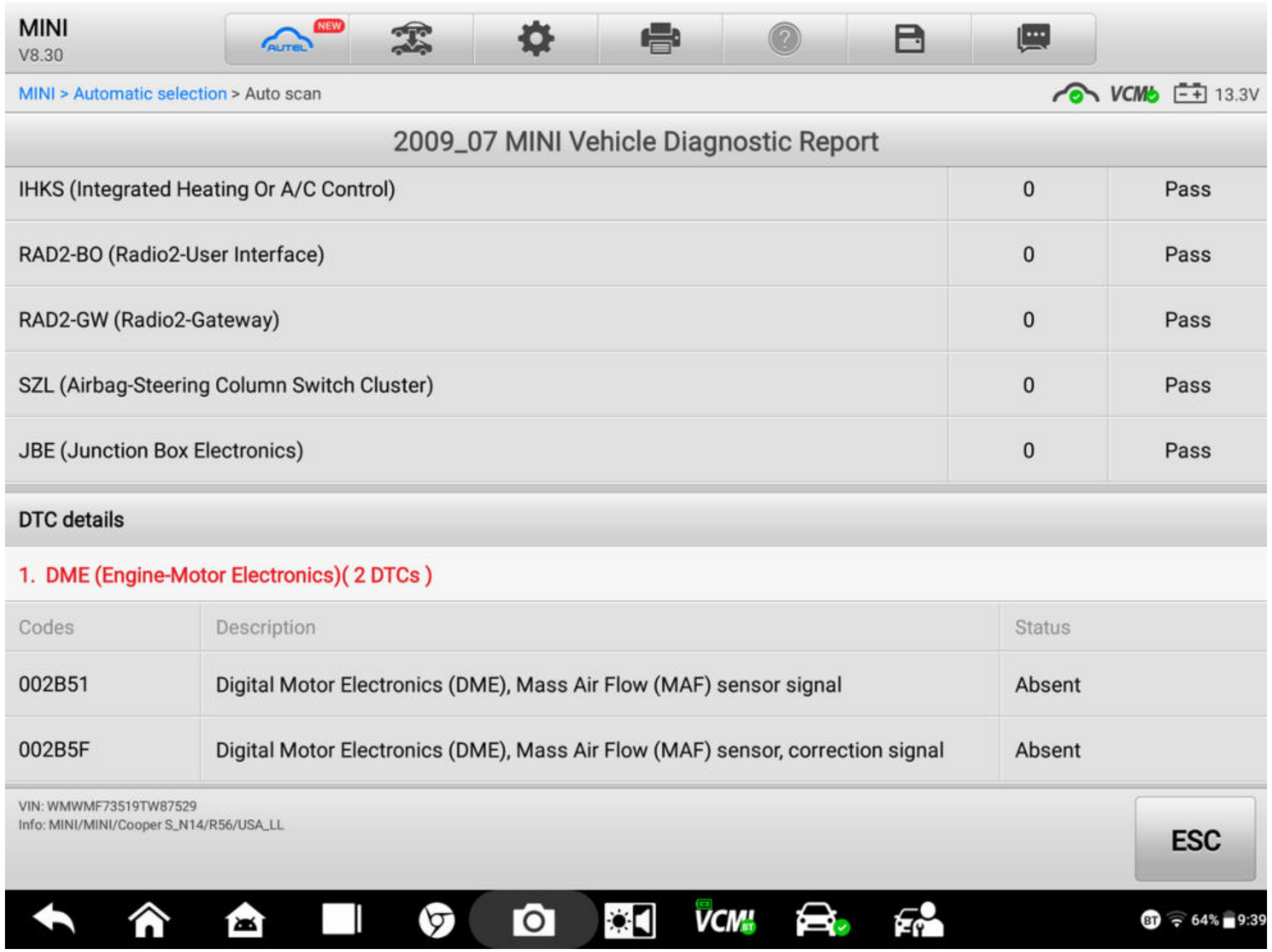
VIN: WMWMF73519TW87529
Mileage: 89,514
Diagnosed: March 2022

Back Story

- Injectors replaced recently
- Not recent enough to assume faulty
- Ran well for months
  - *Shop replaced dead battery*
  - *Shop replaced spark plugs (no change)*
  - *Shop determined no injector control*

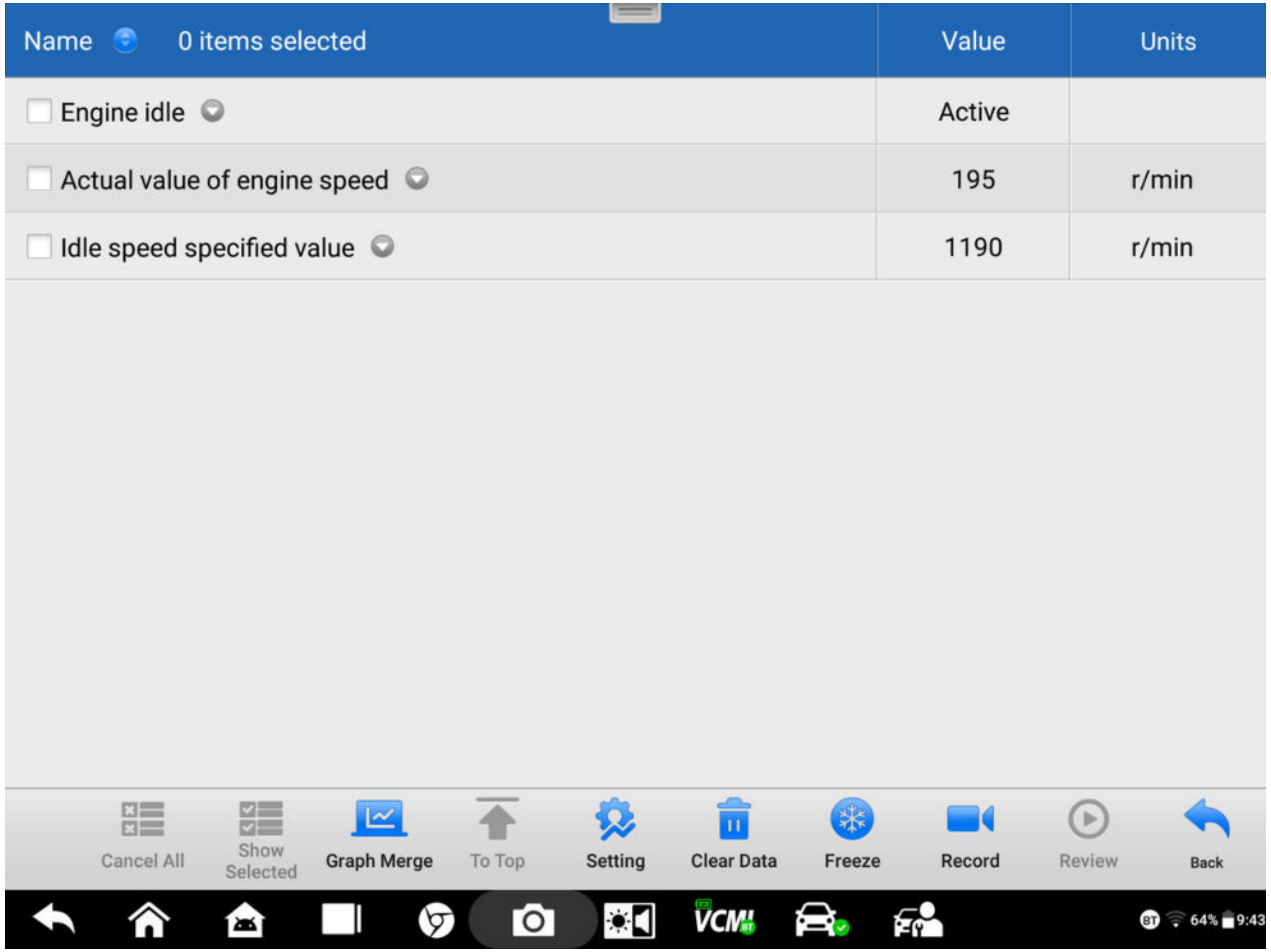
DTCs Retrieved

- MAF DTCs
- Appears intermittent (not current)
    - *Could be self-induced*
    - *No obvious diagnostic direction*
    - *Remember, battery was replaced*



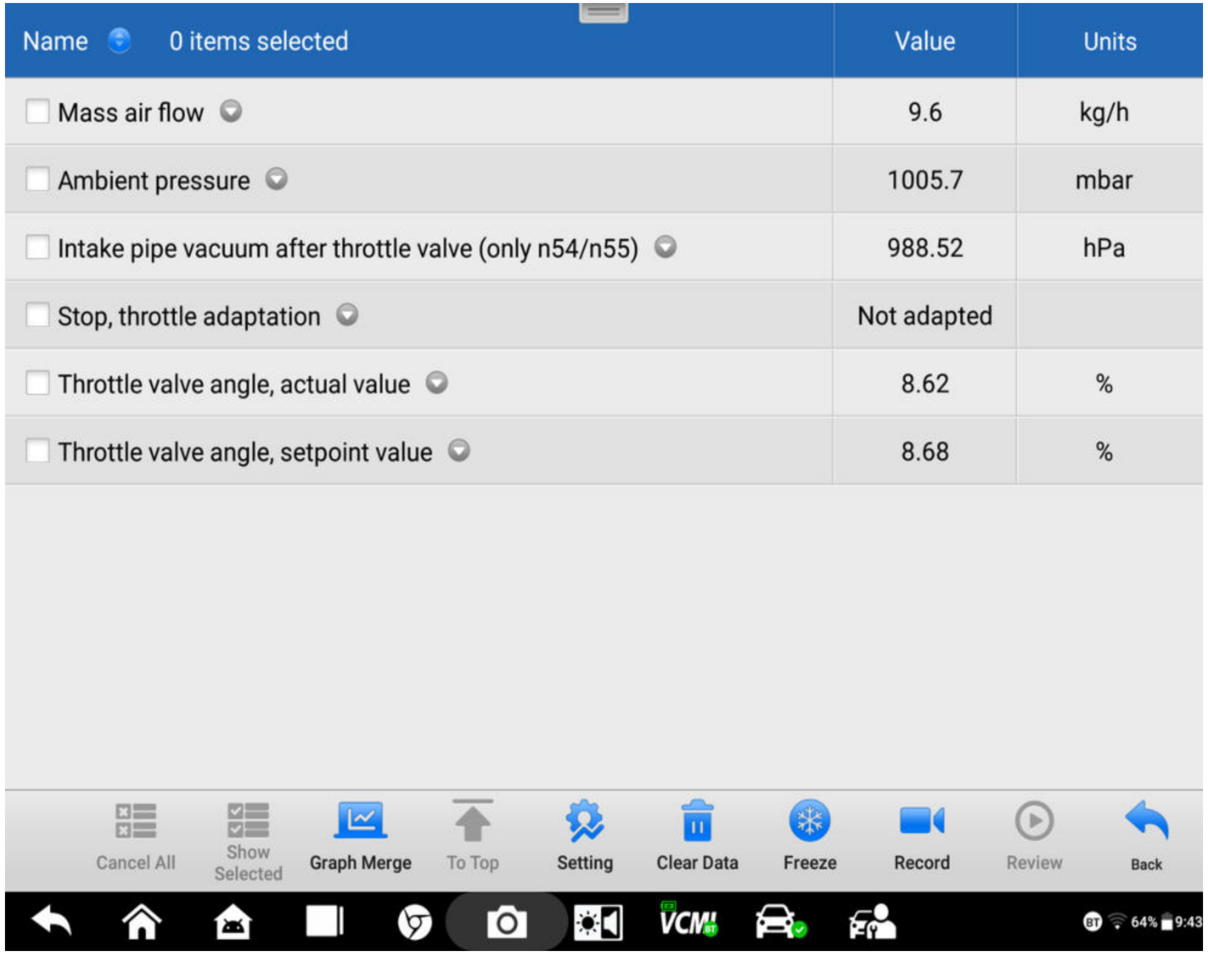
Start-Attempt Data…

- Engine Speed visible
  - *Crank Signal Likely Recognized*



Start Attempt (*Cranking*) Data…

- MAF: 9.6kg/h = 2.5 grams/second
- Seems close enough to start
- Barometric = 1005 mbar (29.67 inHg)
- Intake pressure after throttle = 988 kPa = 29.17 inHg



Start Attempt (*Cranking*) Data

- Requested rail pressure = 725 psi
- Actual rail pressure = 47 psi
- Injector on-time 22mS
- Service info discrepancies
  - *A little low*
  - *Can we trust rail pressure values that low?*
  - *Maybe it's 72 psi & reporting 47 psi*

Name 0 items selected	Value	Units
Adaptation value of fuel delivery control	0.98	
Cylinder 1 fuel injection timing	22.37	ms
Cylinder 2 fuel injection timing	22.3	ms
Cylinder 3 fuel injection timing	22.14	ms
Cylinder 4 fuel injection timing	22.3	ms
Actual value of rail pressure	47.86	psi
Rail pressure setpoint value	725.19	psi
Duty factor of fuel quantity control valve	62.89	%

13 31 Fuel Pump with Drive and Pipe N14

with ignition "ON" and fuel pump running	bar	5.0

VS

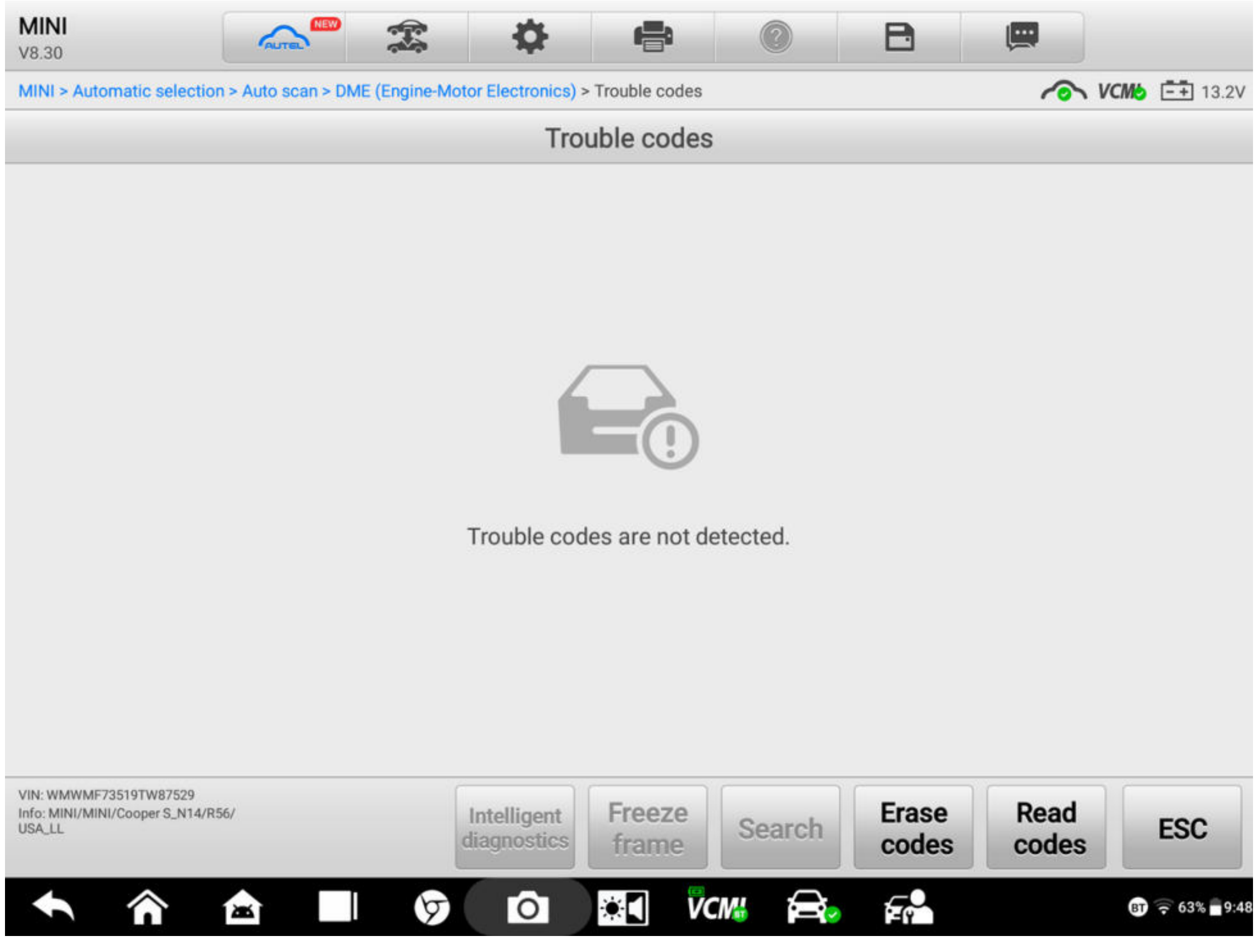
Fuel Pressure

Pressure 1 (PSI)		Pressure 2 (PSI)
Range	Note	Note
50.0	Y331	Y332

Y331: System pressure with engine idling.
Y332: Fuel pump pressure.

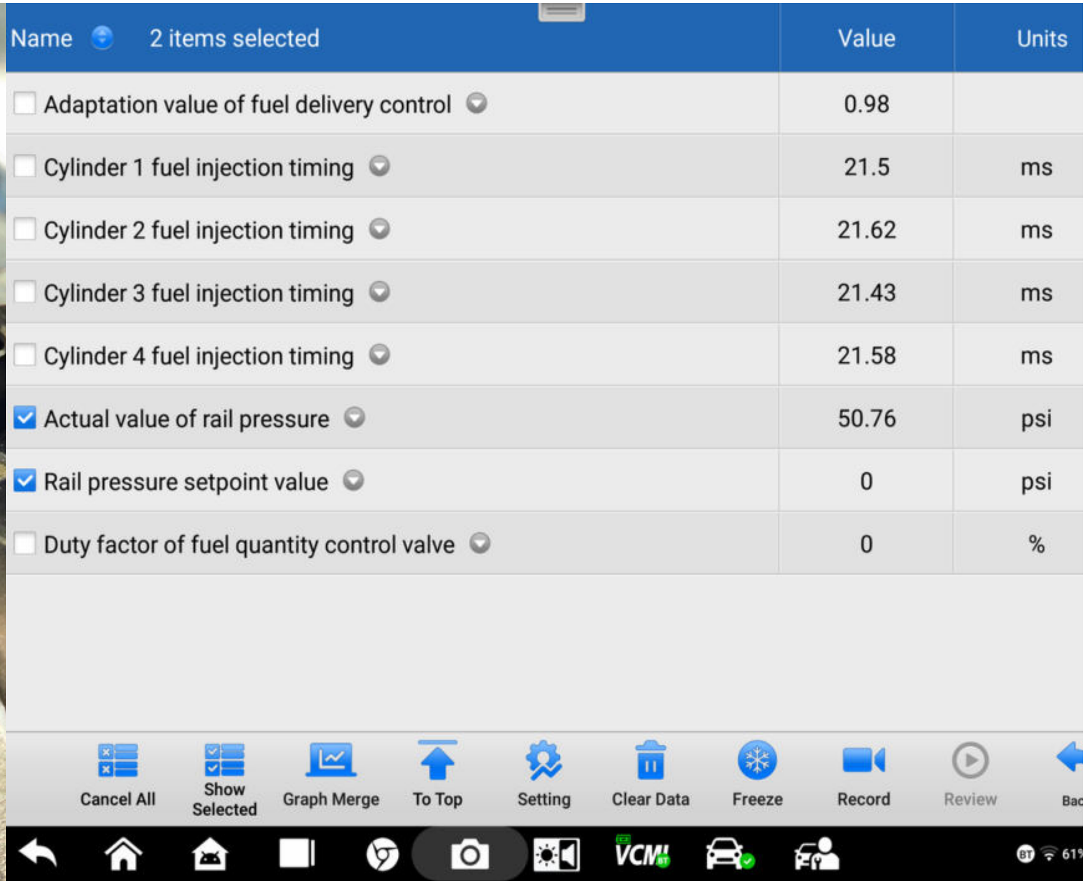
Code Scan: *Hoping For Clues*

- Low rail pressure issues?
- Hoping for a circuit fault
    - *No DTCs detected*



Experiment: *HPFP Open Circuit/Pressure Change*

- Default to high- or low pressure?
- Quick test
- Results could flush out fault
- Results might be inconclusive
- No change exhibited

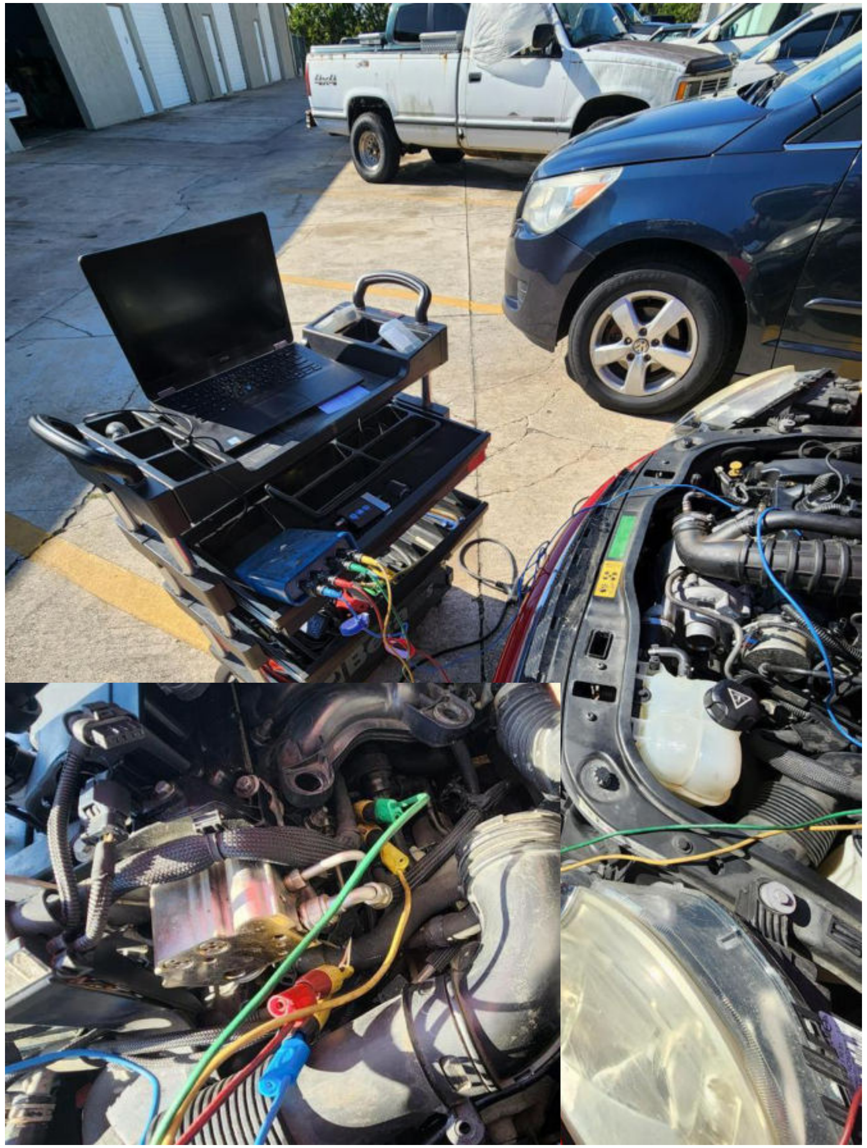


Name 2 items selected	Value	Units
Adaptation value of fuel delivery control	0.98	
Cylinder 1 fuel injection timing	21.5	ms
Cylinder 2 fuel injection timing	21.62	ms
Cylinder 3 fuel injection timing	21.43	ms
Cylinder 4 fuel injection timing	21.58	ms
Actual value of rail pressure	50.76	psi
Rail pressure setpoint value	0	psi
Duty factor of fuel quantity control valve	0	%

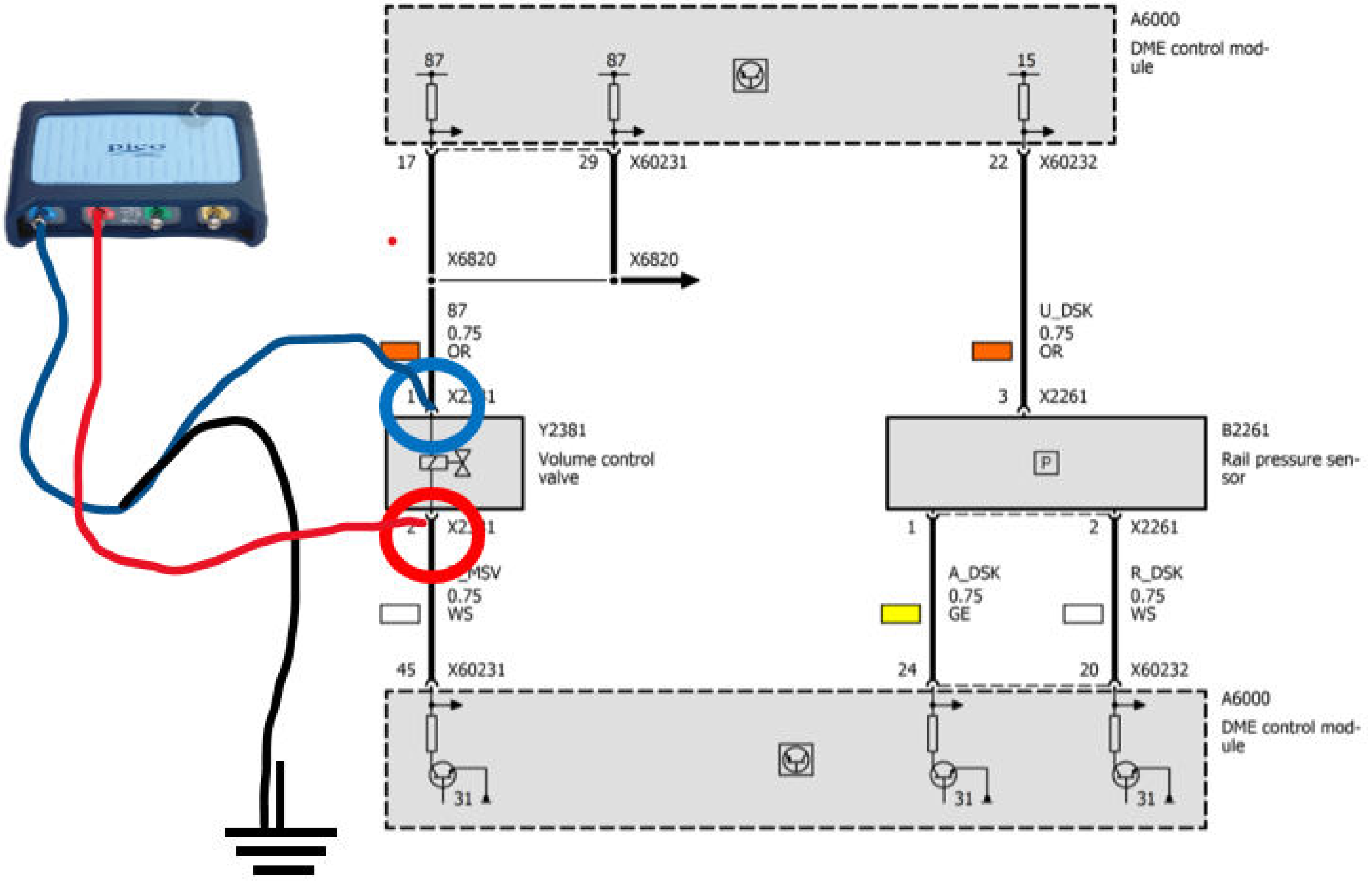
Does low-pressure system appear to be working?

Pinpoint Test: *Measuring HPFP Control Circuits*

- High pressure system diagnostics
- Process of elimination
- No HPFP regulator circuit codes
    - *Circuit & control verification still critical*



Test Lead Placement

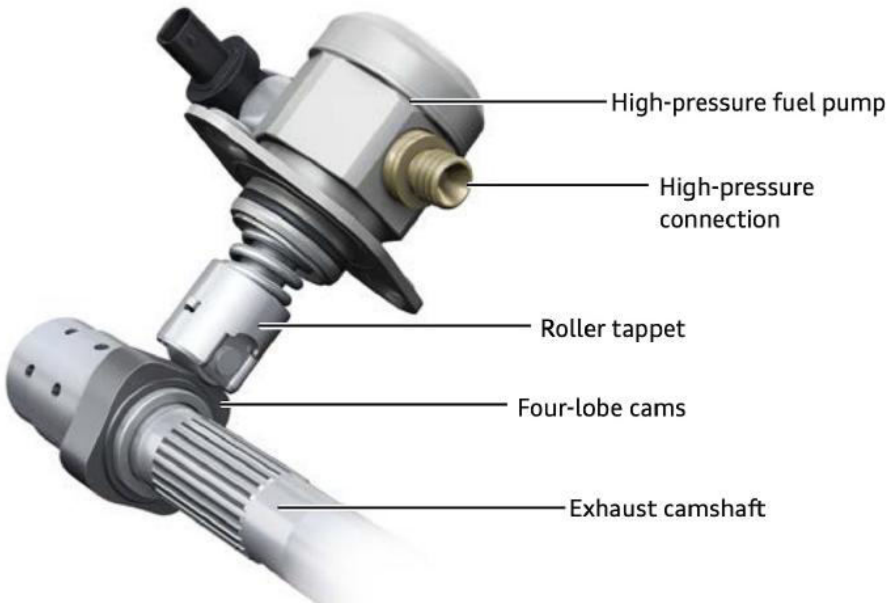


The Waveform – *The Result*

- Blue trace: HPFP regulator voltage control
- Red trace: HPFP regulator ground control
- Green trace: #4 injector high-side control
- Gold Trace: #4 injector low-side control
  - *Initial control activity stops*
  - *To build peak pressure?*
  - *Control & circuits appear okay*

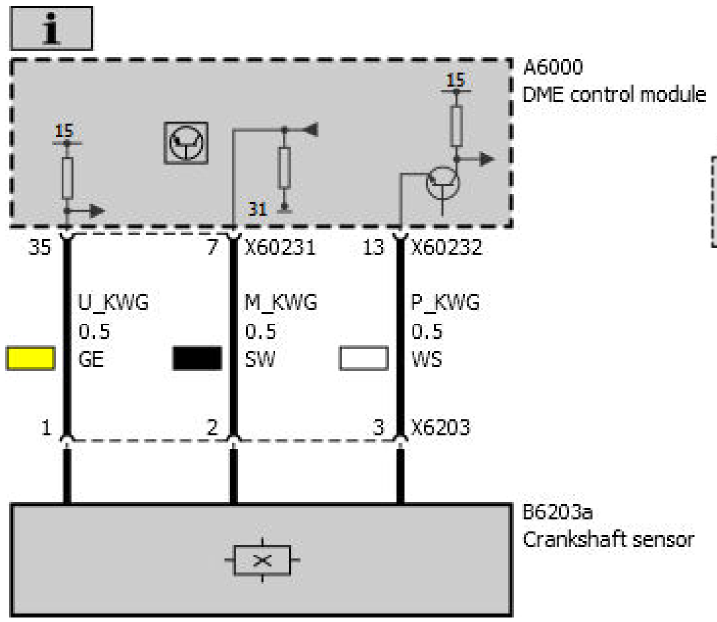
Significance of Cam Timing

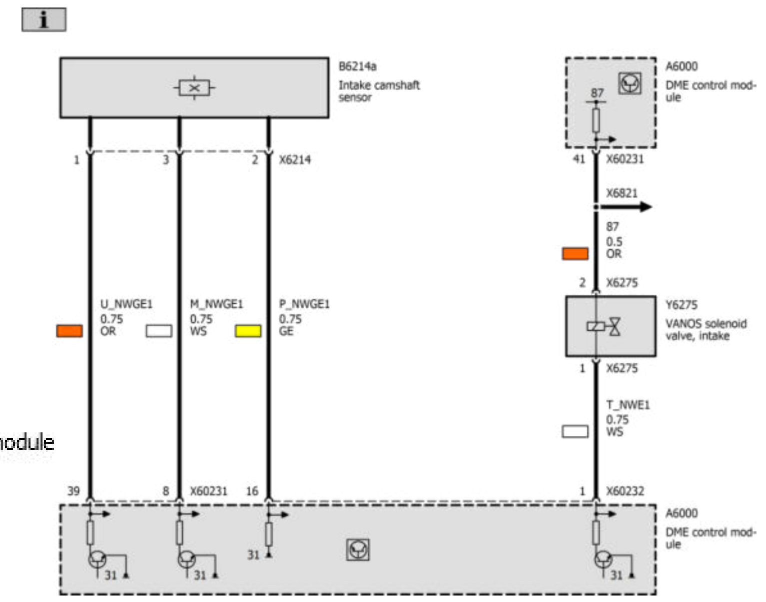
- Camshaft timing is critical
  - *ECM (DME) uses cam sensor signal for pressure control*
  - *Incorrect cam timing = Wrong pressure control timing*



Checking Camshaft Timing

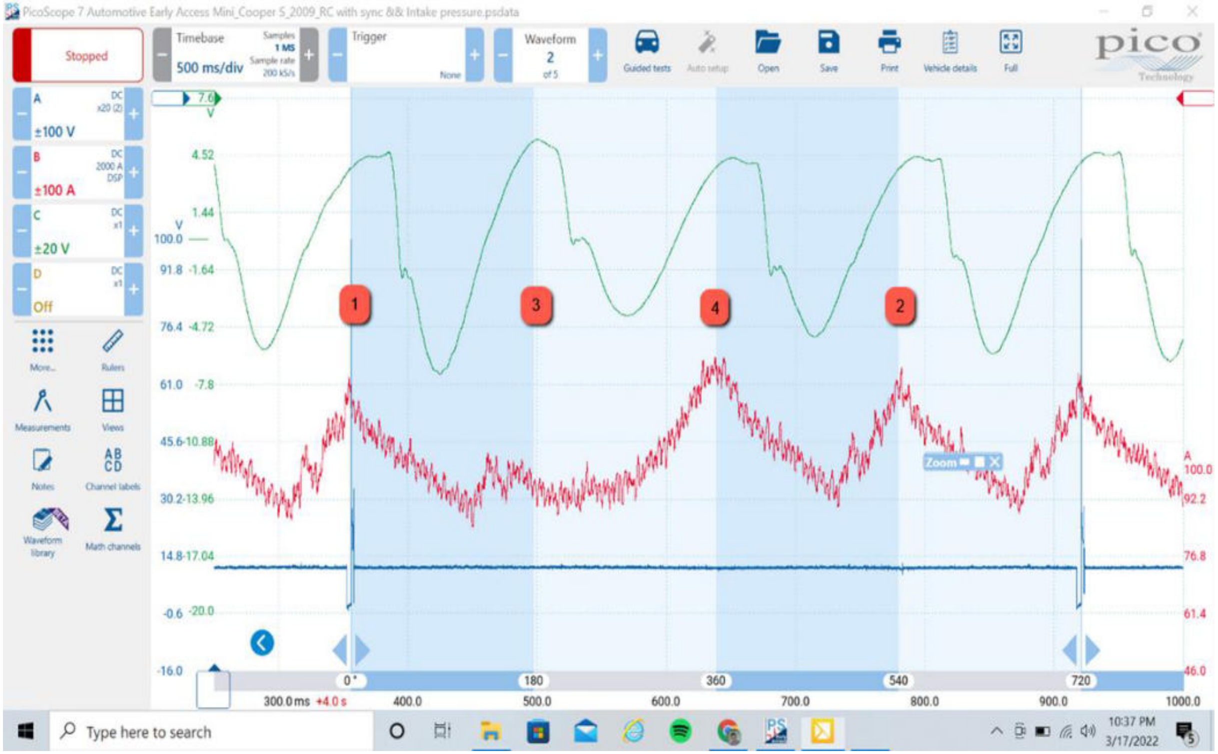
- No DTCs
- Oscilloscope waveform
- Crankshaft signal vs camshaft signal
- Compare to known-good reference
    - *Initially Not Available*
    - *Moving On For Now*





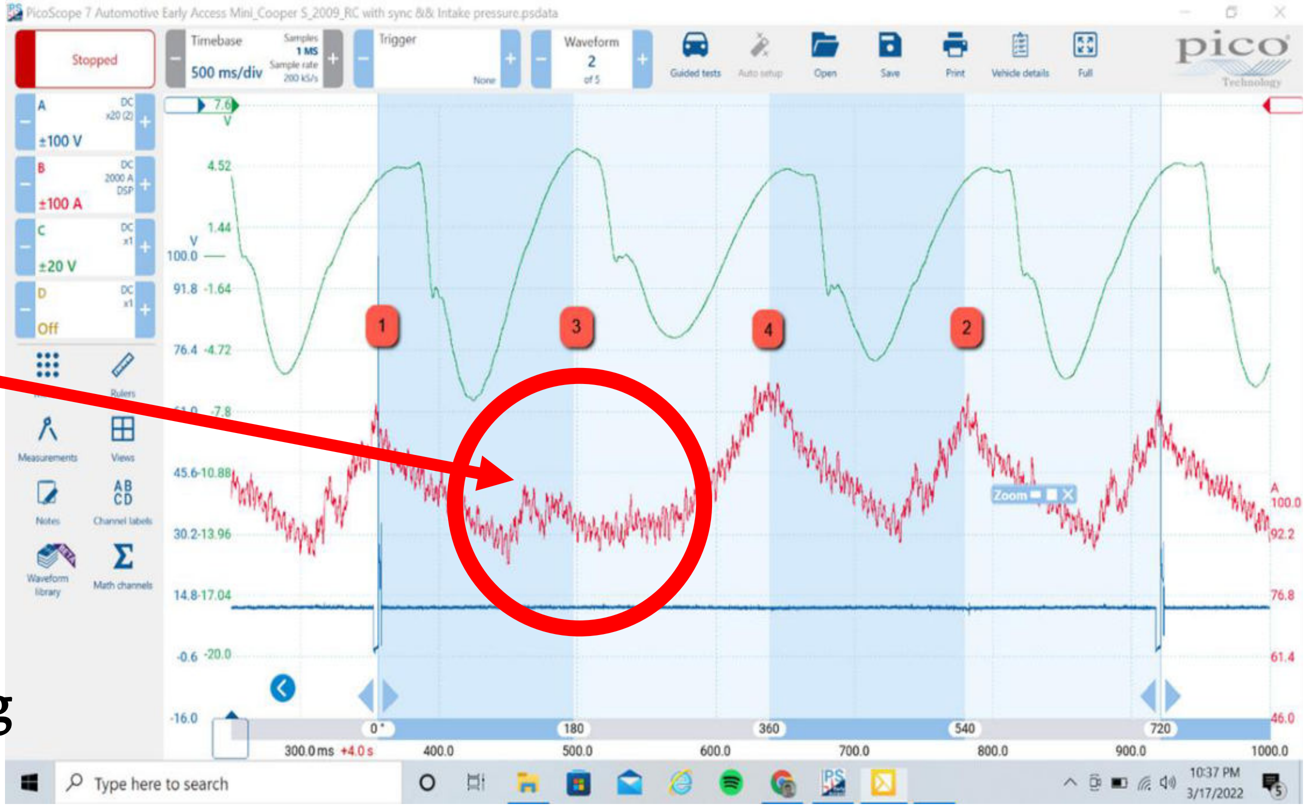
Relative Compression with Sync…

- Using starter current to compare
- General engine mechanical test
  - *Incorrect Cam Timing = Incorrect Ignition Timing?*



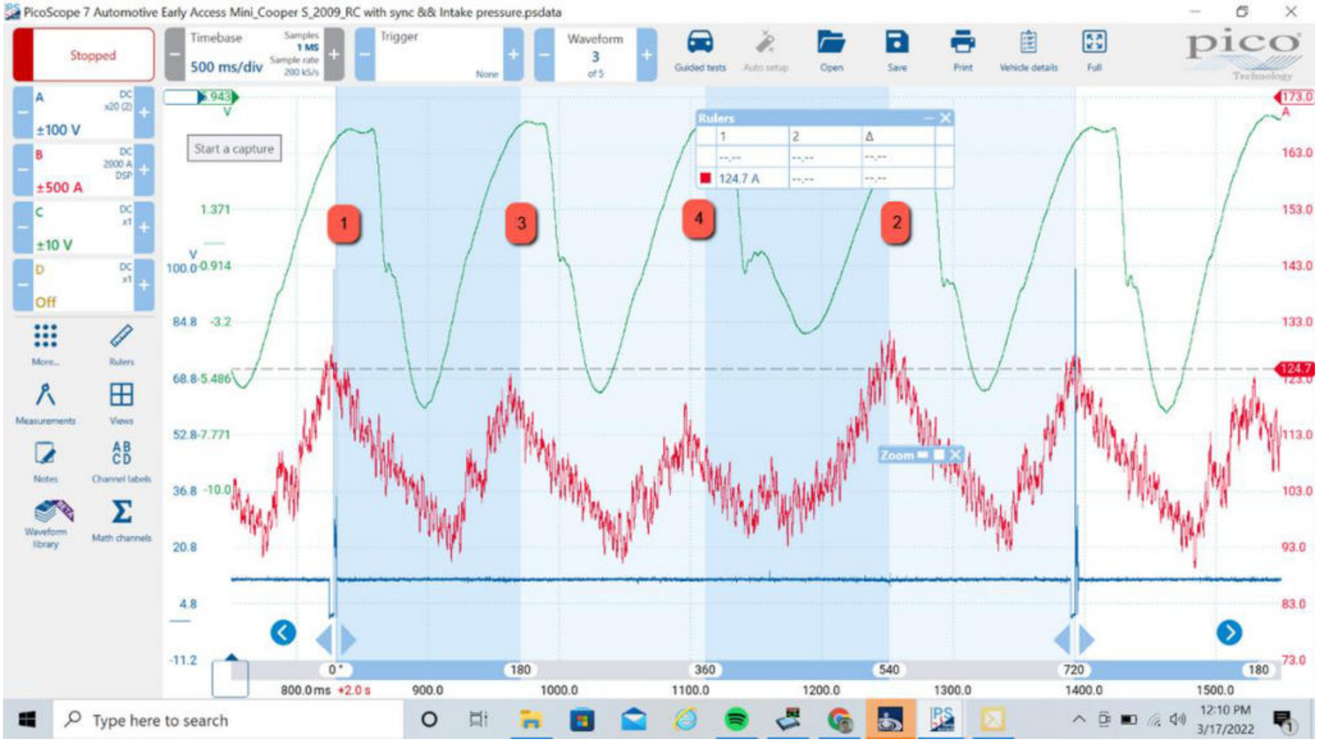
Relative Compression with Sync

- Inline engine, camshaft timing will affect all
- Cylinder 3 starter current low
- Indicates weak cylinder 3 mechanical contribution
- Followed by weak intake pull due to slowed crankshaft
- Ignition timing close to TDC, indicates sufficient timing



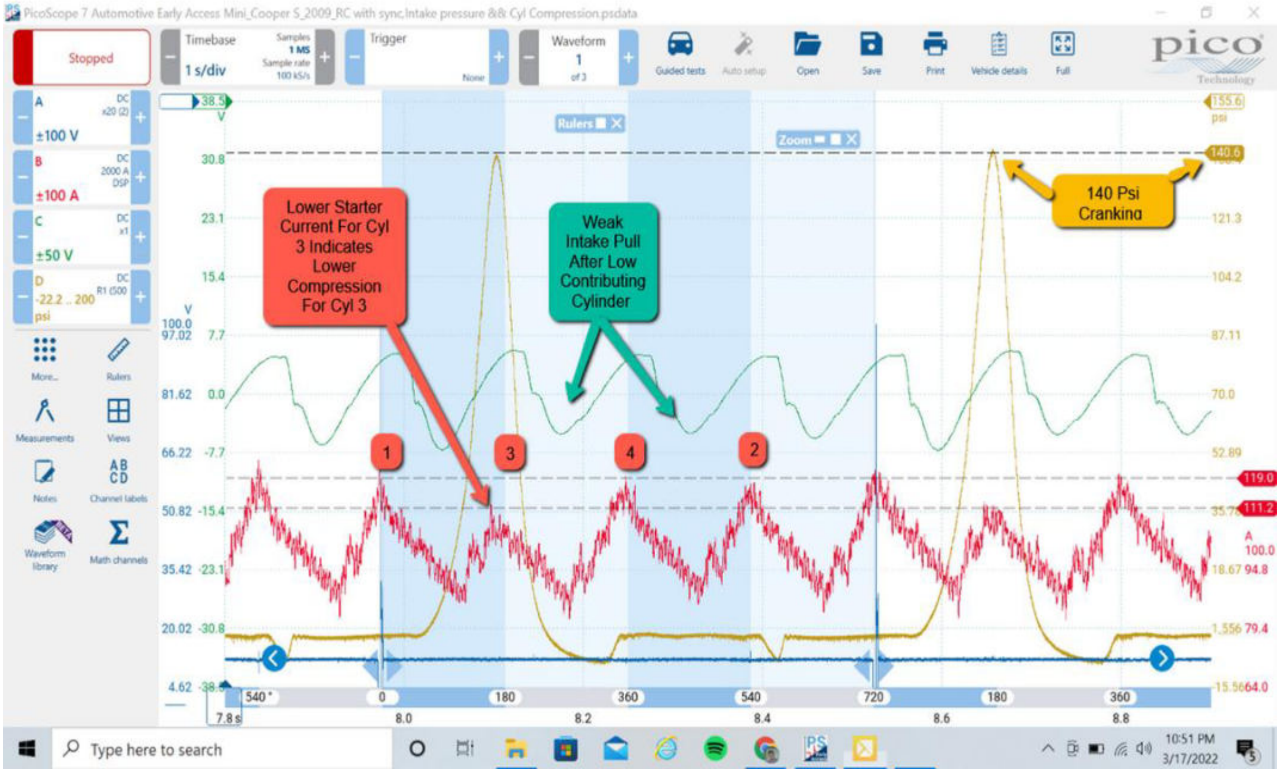
Relative Compression with Sync…

- Now cylinder #4!
  - *Weak intake pull*
  - *Due to slowed crankshaft speed*



Relative Compression with Sync…

- Cylinder pressure added
- Cylinder #3, again!
  - *Could be added volume from compression hose*
  - *Weak intake pull due to slowed crankshaft speed*

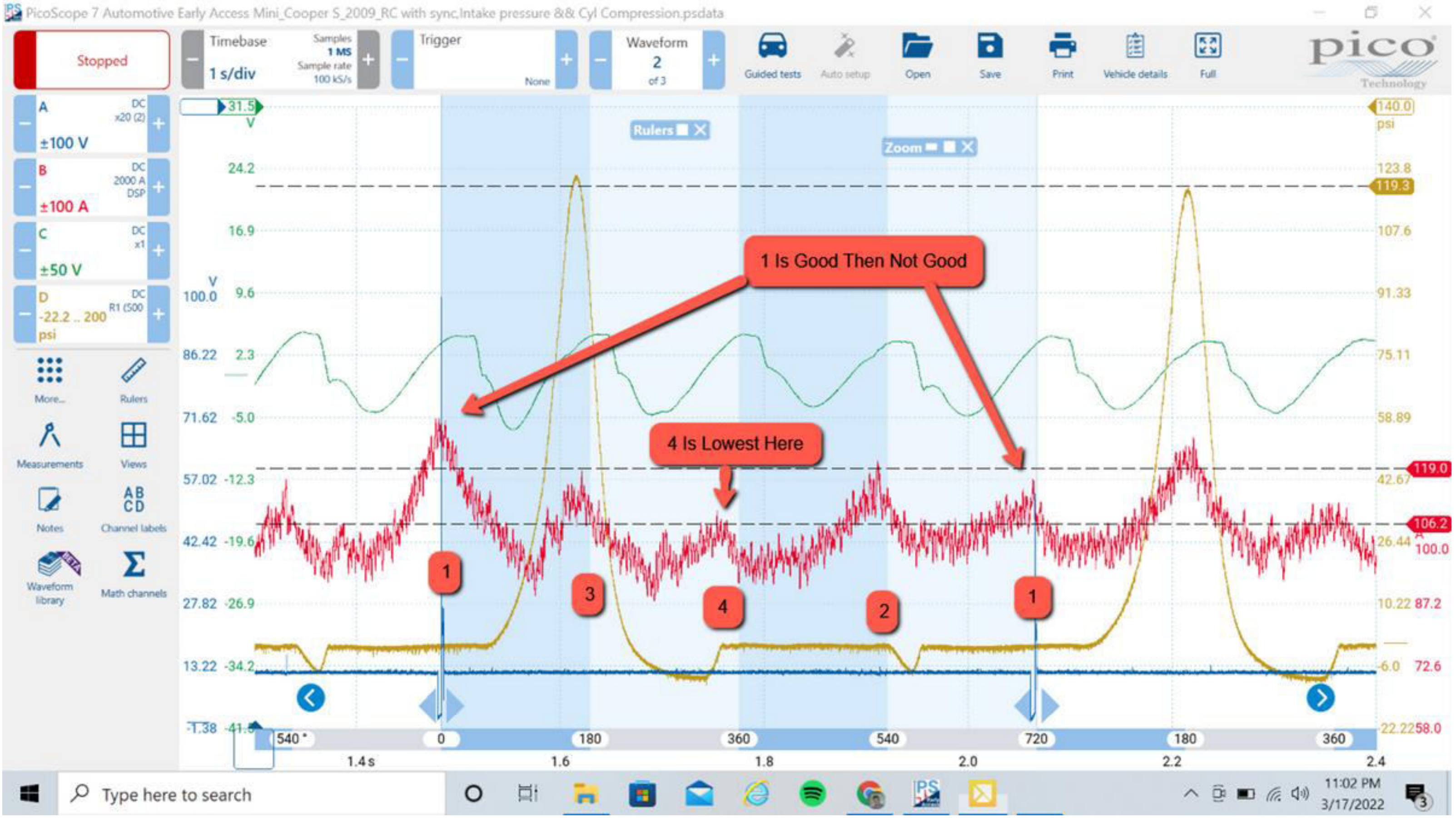


Relative Compression with Sync…

Now Cylinder #2!

Relative Compression with Sync…

- **Very Erratic**
  - *Cylinder #1 is good*
  - *Then not good*

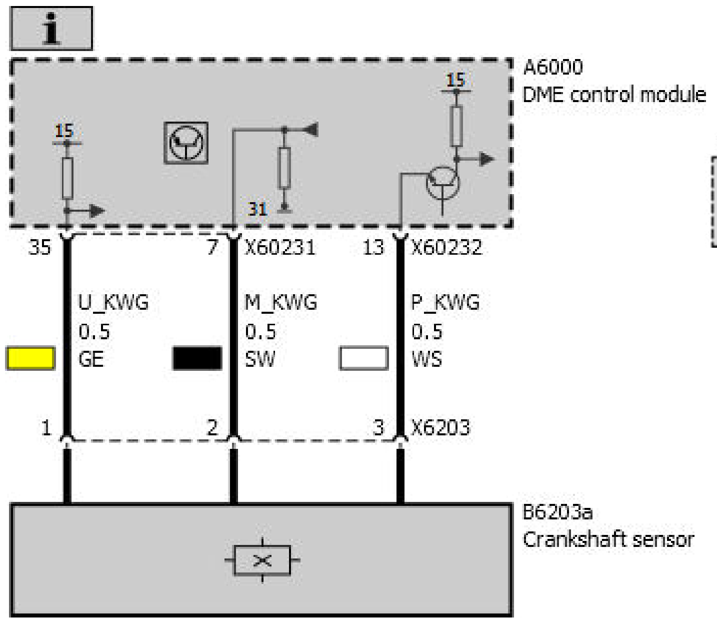


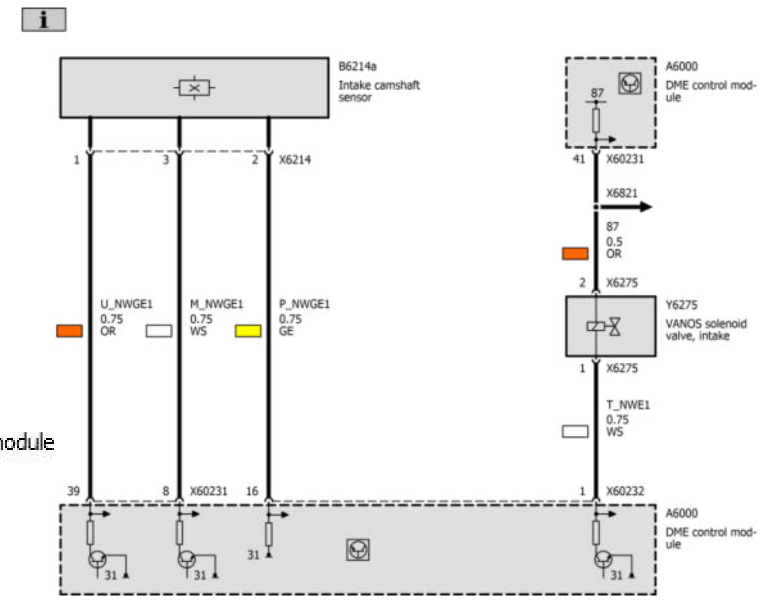
Relative Compression with Sync…

- **Erratic Cylinder Integrity?**
  - *Cylinder #3 not good*
  - *Then good, within 720 degrees*

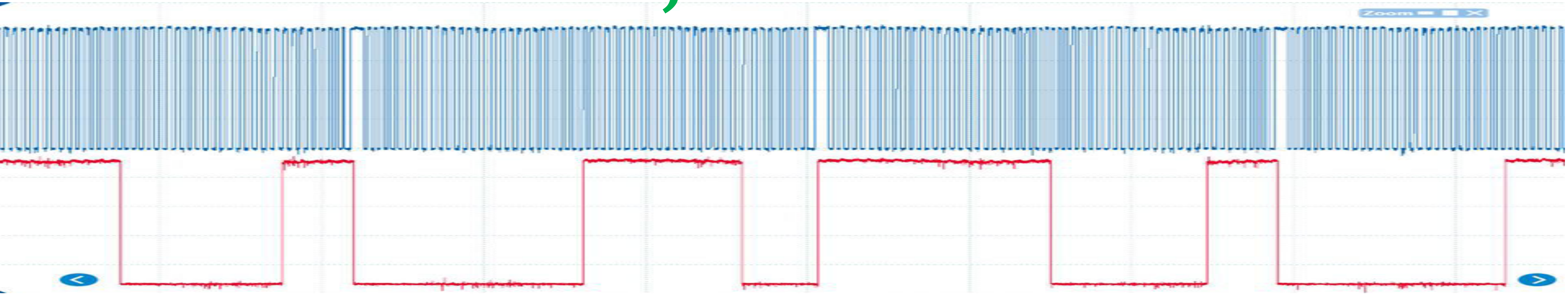
Justified Checking Camshaft Timing…

- No DTCs
- Oscilloscope waveform
- Crankshaft Vs Camshaft Signal
- Reference Known Good & Compare
    - *Now Available*





Subject-Vehicle

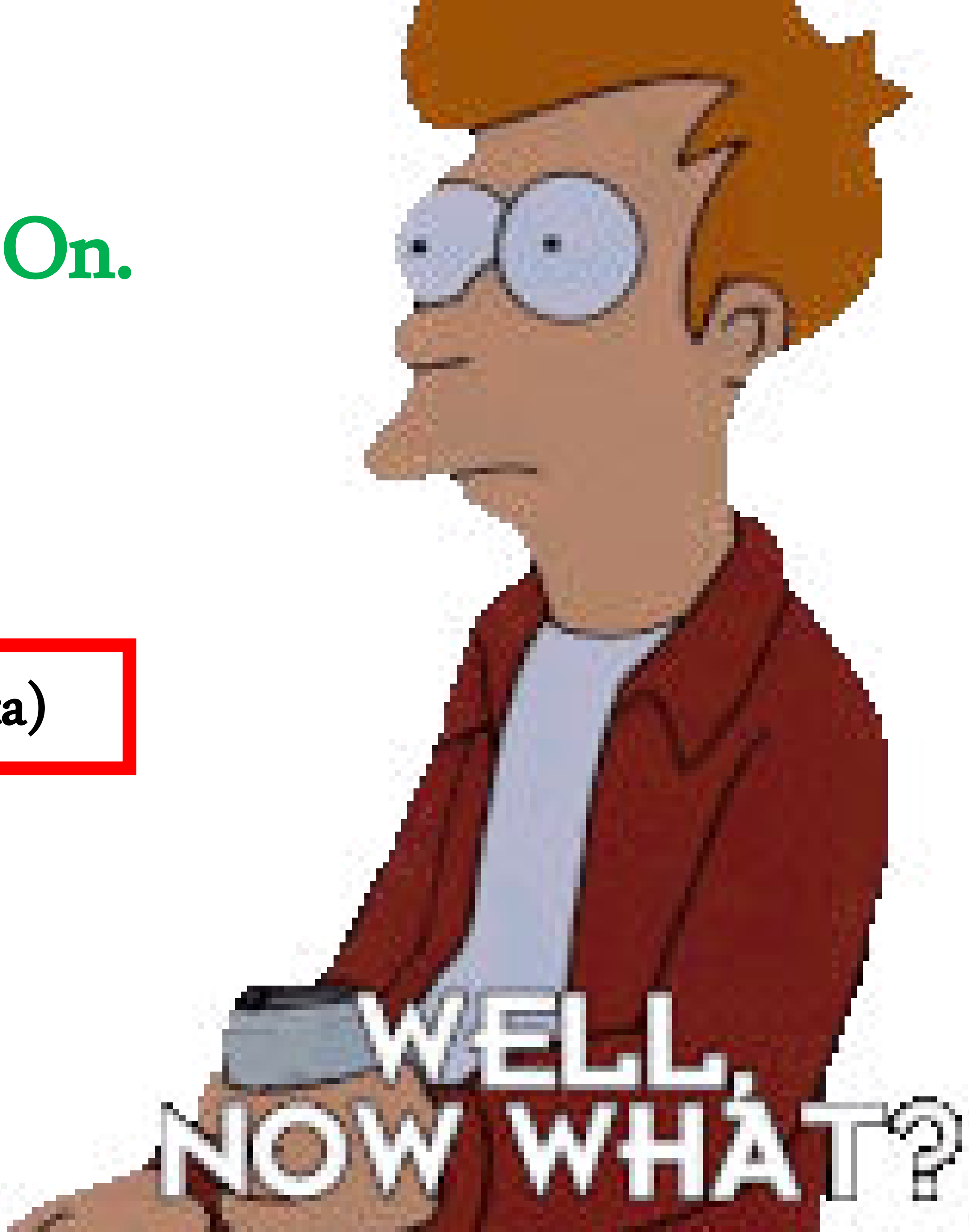


Known Good

...Match Or Not?

An Assumption Was Made Early On.
What Was It?

- Rail pressure low
- Supply pressure seemed close enough (scan data)
- Erratic cylinder contribution – Not the cause
- Camshaft timing appears good



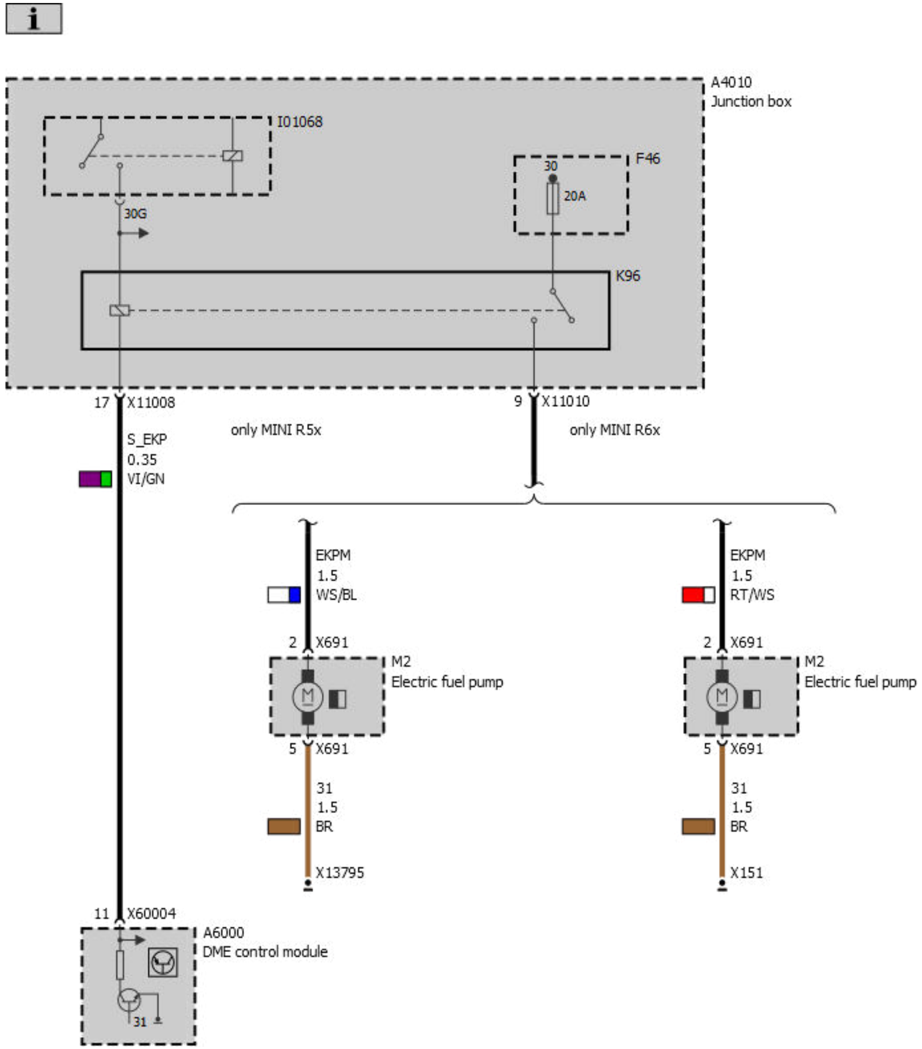
Checking Supply Pressure

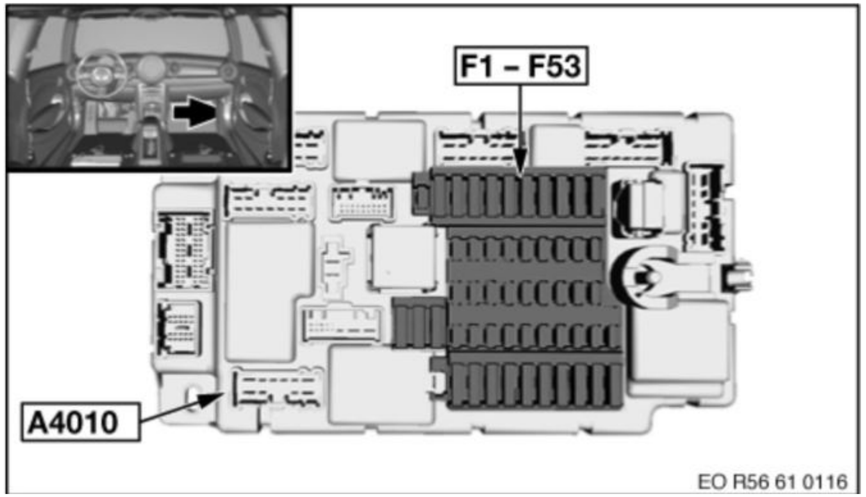
- A costly assumption
- We thought understood the limitations
  - *"50 psi is close enough"*
  - *"It's not accurate"*
  - *"I bet it's actually closer to 70 psi"*
- 50 psi scan data = 0 psi actual pressure

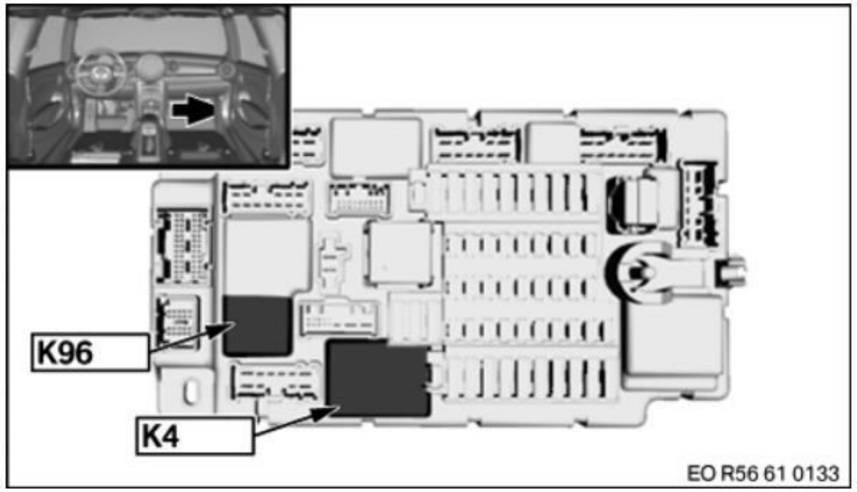
Supply Pump Circuit Test

- Alternate-load test
- High current test light did not illuminate light
    - *Missing voltage supply or ground*
    - *Testing each independently*
    - *Revealed no voltage present*

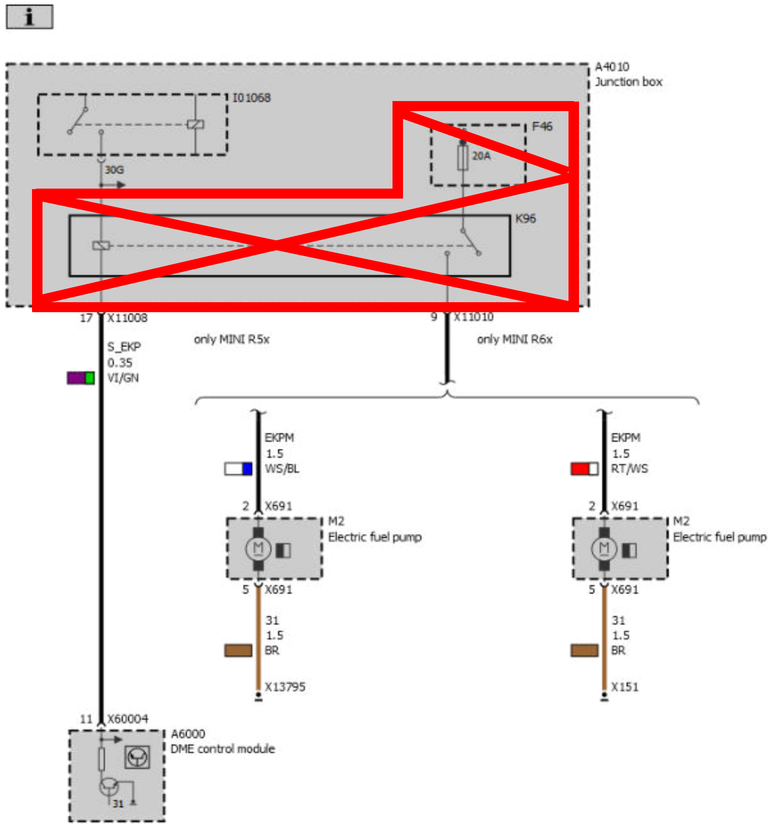
Supply Pump Schematic & Component Location



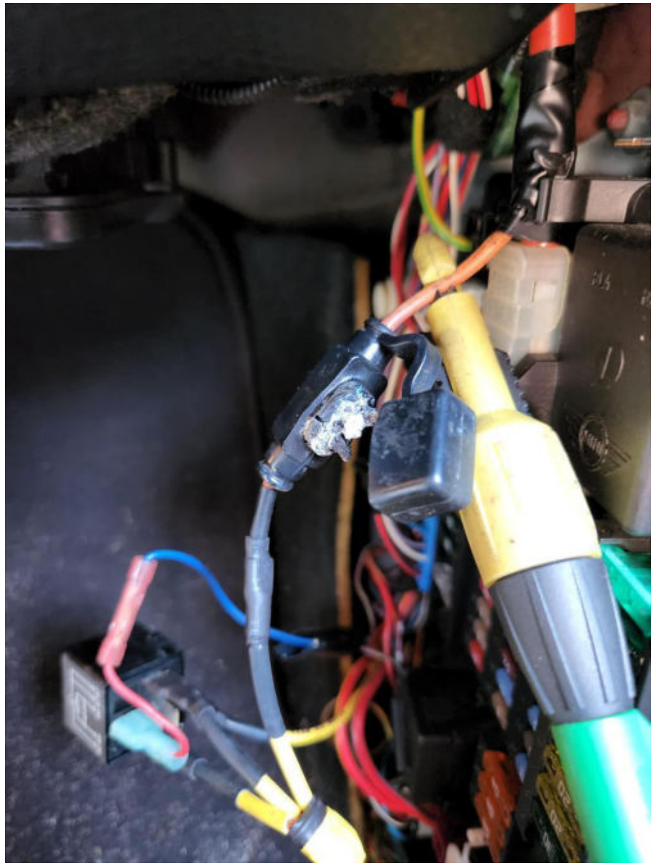




Circuit Has Been *Bypassed!*

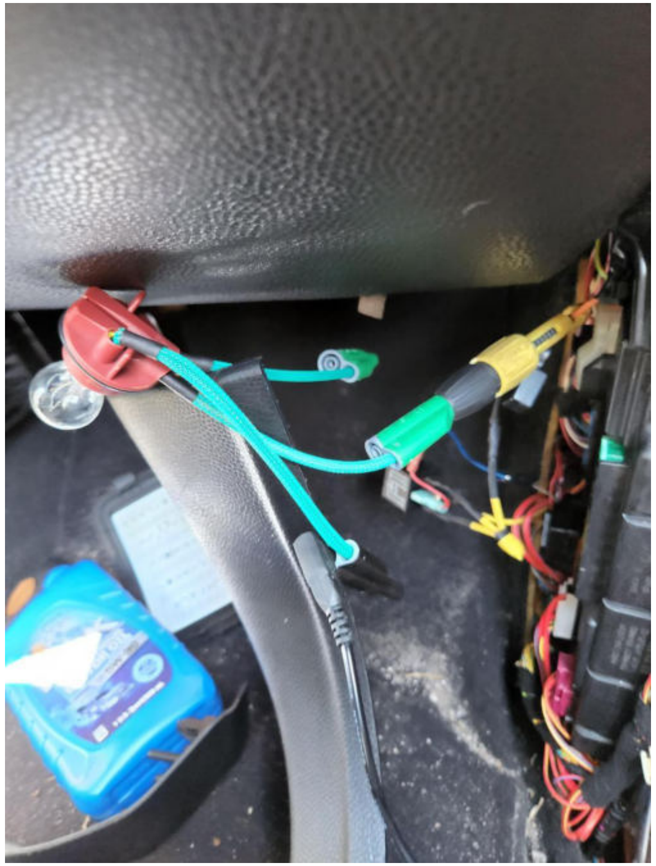


Junction Box Relay & Fuse Bypassed



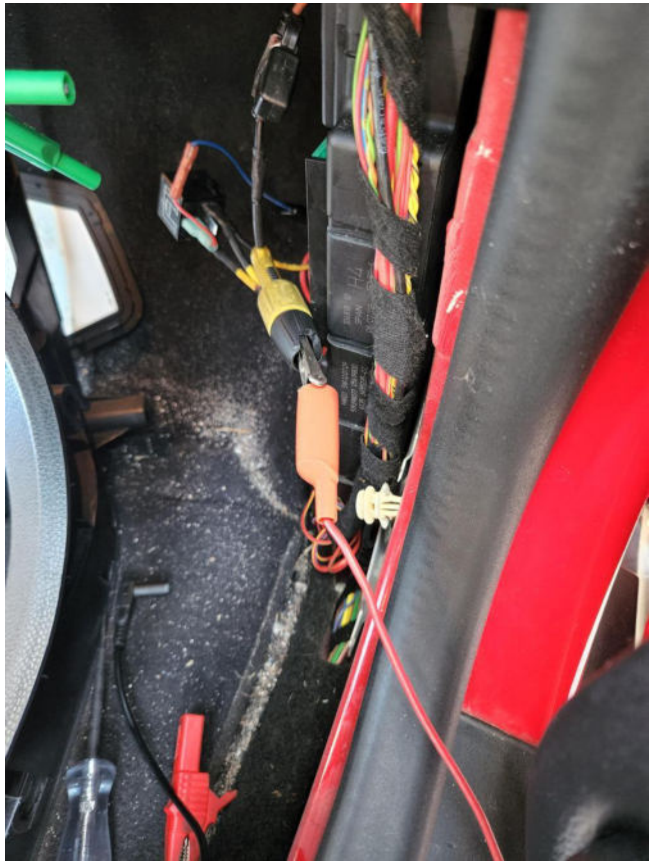
External Inline Fuse & Relay Installed

Corroded & Crusty

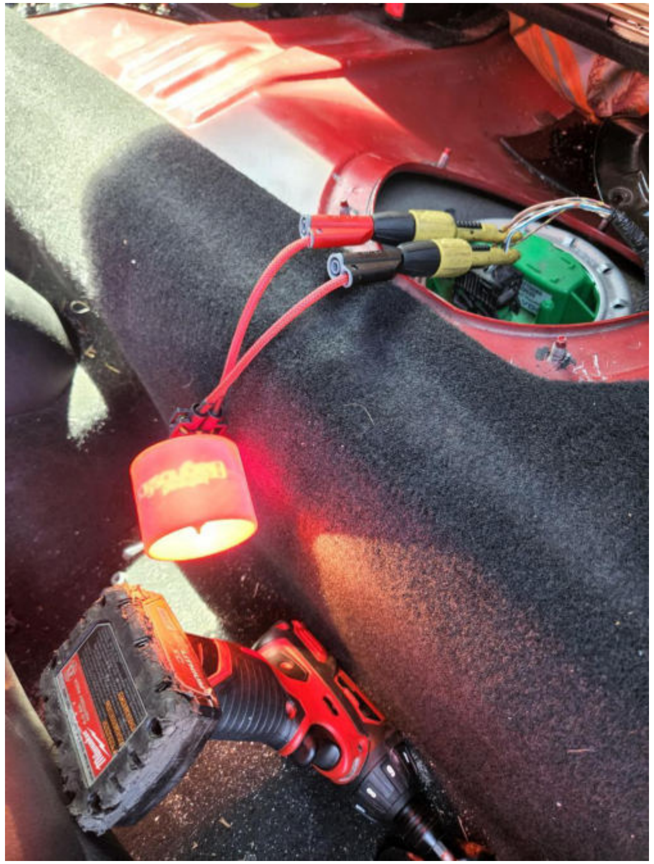


No Voltage Upstream of Inline Fuse

Supply Pump Circuit Tests



Jump Voltage To Under Dash Circuit



Voltage Now Present @ Pump

It's Alive, Building Pressure

& Moving Fuel

It's Alive!

What About The Erratic Relative Compression?

- Cranking cadence smoothed out
- May still have intermittent mechanical issue
- *Not fuel-washed*
- *Possible valvetrain hydraulics*
- Not the cause of our concern
- Our client was advised

It's *Science* ...Not Magic

- Appears to be *wizardry*
- Understand the science of Computerized Fuel Injection
- Strategy to achieve a goal
- Tools/Limitations, Fundamental knowledge, Information

Training Must Always Continue

- Standards will change
- Strategies will change
- Systems and components will change
- Need for intelligent analysis will never change
- Master that which applies to everything
- Most important tool is a Technician's mind

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