Oscilloscope waveform
Types and interpretation

Prepared for
WIRE & GAS 2012 Training Convention

Long Reef Garage

All captured waveforms are relative to ground unless otherwise stated.

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For Circuit diagrams, connector Location/end views and pin configurations please see TAT, Rellim Bookworks, Repco Auto Tech Encyclopedia, Auto Data, and Automotive Service Solution.
Acknowledgement and references

Authors wish to acknowledge that information gathered and collated for the purpose of research and development of this training manual was based on actual measurements from a BA Ford Falcon vehicle.

For Circuit diagrams, connector Location/end views and pin configurations please see TAT, Relim, Bookworks, Repco Auto Tech Encyclopedia, Auto Data and Automotive Service Solution.

Information contained herewith is limited to Engine management and CAN BUS. For more information regarding Pin configuration, Circuit Diagrams and location of connectors please kindly contact above mentioned organizations.

Information contained within is NOT intended to be used as a ‘stand alone’ training manual and or a reference material– rather as a reference material (an adjunct) to be used during training session.

Websites accessed to gain information regarding Engine management and CAN BUS Operation, Configuration and Topology please, see ‘References’ at end of this training manual.

Special thanks to Jeff Smit (Technical editor TAT) and Ken Newton (TAT) for their implausible editorial assistance, encouragement and moral support.

Authors would also like to thank the following organization for their unparalleled support and assistance in providing information, access to data and use of their scan tools (herewith contained in this training manual):

The Automotive Technician (TAT)  Repco Auto Tech Encyclopedia  Auto Data PC Based DATA Base  Hanatech G-Scan Mount Auto EQ  Autel MaxDas InterEquip  Automotive Service Solution  Relim Bookworks Wiring Diagrams  Pico-Scope PC USB Mount Auto EQ
The essence of diagnostics is to apply gathered knowledge to maximize honing-in skills and minimize guess-work, thus avoiding unnecessary replacement of components.

After all, it isn’t what you know but rather it is the application of knowledge that makes the difference in diagnosing symptomatic vehicles.
Basic steps of Diagnosis

Initial BASIC checks

1. Listen to customer's complaint
2. Listen to car's complaint
3. Carry out basic checks
4. Check battery supply, charge voltage (AC, DC waveform)
5. Check battery Grounds (disable car from start – Post to block, chassis, terminal)
6. Carry out basic Wiggle test (wiggle connectors and electrical cables for possible bad connectivity)
7. Listen for Vacuum leaks
8. observe possible restriction (inlet, exhaust)
9. Extract OBD generic diagnostic Trouble codes

In-Depth Diagnostics

1. Inform Customer
2. Obtain budget commitment
3. Extract specific diagnostic Trouble codes from each and every control module on the CAN BUS
4. Interrogate Diagnostic trouble codes and identify frequent codes (common codes yet reported by differing control units)
5. Determine whether symptom is due to ‘failing’ CAN BUS communication and or specific control unit (input sensor)
6. If symptom is CAN BUS related: Obtain Block diagram of CAN BUS Topology
7. If symptom is specific control unit (input sensor) related: obtain circuit diagram
8. Measure supply and ground voltages of that specific ECM and Capture waveforms (of suspect component)
9. Keep customer informed of progress
10. Prepare Invoice (Diagnosis / Remove and replace)
11. Inform customer of final costing
12. Hand over (show photos, captured waveforms colored circuit diagrams and other supporting material)
What is an Oscilloscope - Good scope pattern

1 volt per division

1 volt = 1,000 mv
mv = milli volt
1 milli = one thousandth
µ = micro
1 micro = one millionth

Y Axis

+ Volts

0.0 Volts

- Volts

Voltage Axis

X Axis

Time base Axis

1 second per division

1 volt / div
1 sec / div

Jeep Cherokee – Manifold Air Pressure Sensor (MAP)

IMPORTANT
MUST, make sure that oscilloscope is ‘floating’. That there is no part of the oscilloscope earthed unless connected by operator.

All captured waveforms are relative to ground, unless otherwise stated

1 second = 1,000 ms
ms = milli second
1 milli = one thousandth
µ = micro
1 micro = one millionth
Instant Diagnosis of symptom (car cranks but does not start) - absence of spark duration

Volvo 240GL (primary ignition coil pattern)
Types of Waveforms Alternating Current (AC) and Direct Current (DC)

**AC Sine Wave**

- + V
- 0.0 V
- - V

**DC Sine Wave**

- + V
- 0.0 V
- - V

**AC Square Wave**

- + V
- 0.0 V
- - V

**DC Square Wave**

- + V
- 0.0 V
- - V
Oscilloscope waveform types and interpretation

Authors: Sam Nazarian & Jack Stepanian

- **DC Pulsed wave**
  - + V
  - 0.0 V
  - - V

- **Initially DC square wave (Pulse Width Modulation)**
  - + V
  - 0.0 V
  - - V

- **AC Saw-tooth wave**
  - + V
  - 0.0 V
  - - V

- **DC Square wave**
  - + V
  - 0.0 V
  - - V

- **Pulse Width Modulation**
  - + V
  - 0.0 V
  - - V

- **DC Saw-tooth wave**
  - + V
  - 0.0 V
  - - V
AC Stepped wave

AC Triangular wave

AC Damped Sine wave

DC Stepped wave

DC Triangular wave

DC Damped Sine wave
AC Square Wave signal oscillating above and below zero volts

If and when a square wave signal is passed through a capacitive circuit the resultant will be 'spiked' due to the capacitor charging and discharging via the resistor

A sine wave oscillating about a DC bias voltage

If and when a sine wave signal is passed through a capacitive circuit / resistive circuit, the resultant will be same sine wave signal yet without the DC bias voltage. This is due to the fact that capacitors act as a short circuit for AC and yet open circuit for DC. Hence, A sine wave oscillating about (above and below) zero volts
Scope pattern- depicting characteristics of positive temperature co-efficient current draw of a tungsten filament.

H3 – 100W - 5A per division and 0.1s

H7 – 55W -5A per division and 0.1s

Good scope pattern,(H3 – 100W & H7 – 55W)
Anatomy of waveform analysis - Typical Battery Supply voltage measured post to post (good scope pattern)

- **Quiescent Supply Voltage**
- **Ignition Key ON**
- **The Instant Engine Starts**
- **Initial Turn of the Crank**
- **Dips are a reflection of compression cycles of Cylinders (whilst cranking)**
- **Engine Starts and begins to charge**
- **Dip in voltage due to turning High beam lights ON**
- **Voltage regulator immediately restores charge voltage (following High beam lights being turned ON)**
- **Supply voltage remains as Quiescent until other activities take place on the supply Voltage**
- **Supply voltage drops from Charge to Quiescent**
- **The Instant Engine is turned OFF**

For Circuit diagrams, connector Location/end views and pin configurations please see TAT, Relim Bookworks, Repco Auto Tech Encyclopedia, Auto Data, Automotive Service Solution
Typical Negative Battery Post to Block voltage measurement (it would be ideal if there were no voltage drop below zero base line)

Initial Turn of the Crank – Maximum current draw (maximum voltage drop)

The Instant of Engine Cranking

Quiescent zero base ground voltage

Ignition Key ON

Dips signifying compression of Cylinders (whilst cranking)

Voltage drop below Zero volts base line (negative value) signifies Electrolysis

The Instant Engine Starts

Engine Starts and whilst running is drawing current (hence voltage drop)

The Instant Engine is turned OFF

Base ground voltage drop remains same (minimal) as the remainder of control units go to ‘sleep’

Current draw minimal (voltage drop minimal)

Subaru Outback

Voltage drop below Zero volts base line

100 mv / div
1 sec / div

1 S

5/5/2010 1:29 PM
Effect of a magnetic field on an inductor

A length of automotive copper wire

There will be no potential difference (voltage) between two ends of the wire whilst magnet is STATIONARY.

However as the magnet rotates the generated AC signal will be proportional to the rate at which the magnetic field cuts the copper wire.
Anatomy of a Sine Wave (Y Axis – voltage scale)

Peak

Zero to Peak = 1 volts

Peak to Peak = 2 volts

Zero to peak = (RMS) X (1.414)

RMS = (zero to peak) X (0.707)

Root Mean Square (RMS) = the area under the curve of zero to peak portion

R\hspace{1mm}I

Ohms Law

Volts (RMS) = I (Amps) X R (Ohms)

Power = Volts (RMS) X I (Amps)
Anatomy of a Sine Wave (X Axis – time base)

One wavelength = One cycle of Peak to peak, or zero to zero

Frequency = 1 divided by wavelength
A frequency of 50 cycles per second = has a wavelength of 20 milli seconds

If there were 50 complete cycles in one second period (time) then each wavelength would be 20 milli seconds
Voltage divider - Resistor circuit

Generic automotive voltage divider circuit
Variable resistor - Voltage divider

Generic automotive voltage divider variable resistor
Direct Fire Ignition Module (DFI) – with primary current limiter control

- Engine Control Module
- DFI Module
- Supply 14v
- NPN Transistor
- Coil Pack on DFI Module
- Spark duration
- Dwell period
- Holding current
- Coil reserve

Holden VS Coil Pack 2-5

5 volt / div
2 ms / div
Direct Fire Ignition Module (DFI) – with primary current limiter control

This type of current control is often referred to as a 'linear current control' - reflecting the manner the current is ramped-up. Unlike switching current where it is continuously switched to control the amount of current flowing through the primary ignition coil.

Holden VS Coil Pack 2-5

Spark duration
Coil reserve
Supply charge voltage at end of ignition period
Supply charge voltage prior to ignition trigger signal
Holding current
Ramping current
Dwell period

5 volt / div
2 ms / div

200 mv / div
2 ms / div
Injector pattern along with current draw during injector pulse

Hyundai Excel - Good scope pattern engine at idle

Supply 14v

Engine Control Module

NPN Transistor

Injector coil/pintle

5.0 v per div
1 ms per div

0.2A per div
1 ms per div

Injector pulse width 3.5ms

Injector pintle bounce as it reaches its rest position

Holding current

Injector pintle bounce as it reaches its maximum extension
Faulty Crank Angle Sensor (left) rectified (right) at idle

Angular rotation in degrees

3 wire Hall Effect sensor

Operational Amplifier

Engine Control Module

Ground 0v

Mitsubishi Pajero
Faulty Coil on plug – Primary ignition pattern (left) rectified (right) idle

Holden XC Barina
Faulty supply to Ignition coil pattern (left) rectified (right) Ignition On, crank, run then ignition OFF

Susuki Vitara
Faulty / semi blocked catalytic converter back pressure reflected on MAP (left) new cat converter MAP signal (right)
Ignition Off, then ignition ON, crank, run and rev engine number of times
Single step Coolant temp sensor, as block temperature increases whilst engine running voltage will drop proportionately

Voltage change is proportionate to changes in coolant temperature sensors resistance.

![Generic good automotive scope pattern](image_url)

**Coolant Temperature sensor**

**Negative Temperature Coefficient (NTC)**

**Supply 5v**

**Current limiting Bias resistor**

**Engine Control Module**

**Operational Amplifier**

**Resistor**

**Voltage**

**Temperature**

**Ground 0v**

1 volt / div

1 sec / div

For Circuit diagrams, connector location/end views and pin configurations please see TAT, Relim Bookworks, Repco Auto Tech Encyclopedia, Auto Data, Automotive Service Solution
Two step Coolant temp sensor, as block temperature increases whilst engine running voltage will drop proportionately.

1 volt / div
4 sec / div

Current limiting Bias resistor
Supply 5v
Operational Amplifier

Voltage change is proportionate to changes in coolant temperature sensors resistance.

Coolant Temperature sensor
Negative Temperature Coefficient (NTC)
Engine Control Module

Ground 0v

Generic good automotive scope pattern

For Circuit diagrams, connector Location/end views and pin configurations please see TAT, Relim Bookworks, Repco Auto Tech Encyclopedia, Auto Data, Automotive Service Solution.
Faulty Throttle Position Sensor – note ‘drop-out’ to zero volts, (left) new Throttle Position Sensor signal (right)

As the engine was revved, Throttle Position Sensor followed the voltage yet at times would exhibit a ‘drop-out’ (short) to a zero volts

Note - ‘drop-out’ (short) to a zero volts

Toyota Prado Landcruiser
Bad earth – Electrolysis (bottom left scope), Flush cooling system, clean earth strap, re-test (bottom/middle right scope)

Initially, switch in closed position, and as the switch is open circuited, the voltage is pulled up to supply voltage due to the ‘pull-up’ resistor.

Above scope pattern is of battery negative post to block. Ignition OFF, then ignition ON, then crank, then run then allow idling then switching OFF. Excessive electrolysis

Left scope pattern, quiescent voltage base line on zero, crank, start, run then off. All on same quiescent base line. Good earth

Generic, automotive earth scope pattern.
Fly By Wire – Throttle position sensor – Good scope patterns

Throttle poison sensor (1) – as butterfly rotates clockwise voltage increases proportionally.

Superimposed Throttle poison sensor signals 1 and 2

Throttle poison sensor (2) – as butterfly rotates clockwise voltage decreases proportionally.

BA Ford – good scope pattern
Throttle Body Actuator control

At idle, Motor is turning ‘backward’ (anticlockwise)

At 3,000rpm, Motor is turning ‘forward’ (clockwise)

Throttle body butterfly is spring loaded and is held at rest position of 15% butterfly opening (1,800 rpm). Therefore, at 15% butterfly opening, the voltage across the two terminals of the actuator motor is ZERO volts.

BA Ford – good scope pattern
**Power steering switch – engine at idle**

Power steering switch-   Engine at idle, then as power assist is required, the switch is closed. The voltage is pulled up - to supply voltage. And as assist is no longer required, the switch is reverted to open position. The pull down resistor will then pull the voltage down to ground.

BA Ford – good scope pattern
**Pulse Width Modulation (PWM) - IAC**

Negatively switched

Supply 12v

Engine Control Module

Idle Air Control Solenoid

NPN Transistor

Scope patterns depicting PWM controlling the position of Idle Air Control valve pintle – hence rpm control

Suzuki Vitara – good scope pattern

Positively switched

Supply 12v

PNP Transistor

Engine Control Module

Vacuum switching valve purge solenoid

Negatively switched devices:
- Engine Control Module
- Idle Air Control Solenoid
- NPN Transistor

Positively switched devices:
- Engine Control Module
- Vacuum switching valve purge solenoid

For Circuit diagrams, connector Location/end views and pin configurations please see TAT, Relim Bookworks, Repco Auto Tech Encyclopedia, Auto Data, Automotive Service Solution
Pulse Width Modulation (PWM) – Blower motor

Negatively switched
Supply 12v

Climatic Control/Amplifier

NPN Transistor

Blower Fan Cabin Motor

Scope patterns depicting PWM controlling the Blower Fan Cabin Motor

SAAB 9/3 – good scope pattern

At lowest speed

At highest speed

At 25%

At 50%

At 75%

2 volt / div 0.2 ms / div

2 volt / div 0.2 ms / div

2 volt / div 0.2 ms / div

1 volt / div 1 sec / div

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Heater circuit and Two step Oxygen Sensor

Engine Control Module

Inputs from engine sensors

Engine cold – oxygen sensor at 450mv (is not oscillating) as it warms up – enters closed loop and begins to oscillate

Two Step Oxygen sensor

Supply voltage

Engine in closed loop oscillating between 0.1 and 0.9 volts

200 mv / div
10 sec / div

Engine cold – oxygen sensor at 450mv (is not oscillating) as it warms up – enters closed loop and begins to oscillate

Mazda 2 - good scope pattern

2 volt / div
0.1 sec / div

100 mv / div
1 sec / div

Heater circuit – the Pulse Width is adjusted to control the heater temperature of the heater circuit (PWM from 0 to supply voltage)
Fuel pump current draw scope pattern – left depicting a faulty fuel pump. Right of a new pump

Old fuel pump – ignition off, then on (times out) crank run then ignition of 2A per div and 1 sec per div.

New fuel pump – ignition off, then on (times out) crank run then ignition of 2A per div and 1 sec per div.

Old Pump – engine at idle 2A per div and 0.4ms per div

New Pump – engine at idle 2A per div and 0.4ms per div
Variety of Hall Effect sensor signal waveforms – good scope patterns

Mercedes Benz C180 – CAM lobe

Ford AU – transmission output

Holden TS Astra – Cam Shaft
Variety of magnetic sensor signal waveforms – good scope patterns

Holden Vectra JS – Cam shaft

Hyundai Excel – crank angle

VW Golf – crank angle sensor

Ford KH Laser – pick up in distributor
Transmission output speed sensor – upper scope pattern faulty, lower scope pattern Good

Ford AU - lower scope pattern - good
Variable Valve Timing Control (VVT control)

**VE Ute – Good scope patterns**

- Engine crank and run – at idle
  - Engine at 2,000rpm
  - Engine at idle - yet with the aid of scan tool, VVT control activated to its maximum advance setting – as can be seen the engine control module is 'electronically' commanding the solenoid to adjust appropriately

- Engine at 2,000rpm
Variable Valve Timing Control (VVT control)
DTC – Implausible variable cam shaft timing control
### Oscilloscope waveform types and interpretation

#### Authors: Sam Nazarian & Jack Stepanian

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<table>
<thead>
<tr>
<th>Step</th>
<th>Instruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Plug scan tool, turn ignition ON and power up scan tool. Does it power up! Then go to step 3, if NOT go to step 2</td>
</tr>
<tr>
<td>2</td>
<td>Check DLC Supply and grounds (pin 16 for supply and pins 4 &amp; 5 for grounds)</td>
</tr>
<tr>
<td>3</td>
<td>Select Make, year, model and follow prompts. Should there be communication error then check DLC pin 6 and 14 for CAN BUS communication signals. If NOT go to step 4</td>
</tr>
<tr>
<td>4</td>
<td>Carry out system search - and decipher as to which control units (on the BUS) are able to communicate with the scan tool. Should all control units be present then go to step 5, if NOT then go to step 6</td>
</tr>
<tr>
<td>5</td>
<td>Extract specific Diagnostic Trouble Codes from each and every control module on the CAN BUS and determine whether it is CAN BUS issue and or specific sensor to a control module</td>
</tr>
<tr>
<td>6</td>
<td>Identify control unit that has failed to communicate and check supplies grounds. Then communication signal wires/terminals</td>
</tr>
</tbody>
</table>

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Extract specific Diagnostic Trouble Codes from each and every control module on the CAN BUS

- Power-train Control module (PCM)
- Climate Control (HIM)
- Body Electrical Module (BEM)
- Interior Command centre (ICC)
- Anti-Lock Braking System (ABS)
- Scan TOOL

Diagnostic Link Connector (DLC)

- P0303

- P-Power-train
- B-Body
- C-Chassis
- U-CAN BUS

- 0-Generic DTC
- 1-manufacturer specific
- 2-ditto
- 3-ditto

- 1-Fuel & air metering
- 2-Injector circuit
- 3-Ignition combustion
- 4-Emmission control
- 5-Speed and idle control
- 6-Internal computer control
- 7-Transmission
- 8-Transmission

03 fault e.g. cylinder No 3
Interrogate Diagnostic trouble codes and identify frequent codes (common codes yet reported by differing control units)
Determine whether symptom is due to 'failing' CAN BUS communication and or specific control unit (input sensor)
Abbreviation, acronyms and references:

Abbreviations:

DFI – Direct fire Ignition
CAN BUS – Controlled Area Network Bidirectional Universal System
BEM – Body Electrical Module
PCM – Power Control Module
HIM – Heater and air conditioning Integrated Module
SRS – Supplementary Restraint System
INS – Instrument Cluster Panel
ICC – Interior Command Centre
DMM – Digital Multi meter
OSC – Oscilloscope
ICU – Immobilizer Control Unit
YRS – Yaw Rate Sensor
SAS – Steering Angle sensor
APPS – Accelerator Pedal Position sensor
TPS – Throttle position Sensor
ECTS – Engine coolant temperature Sensor
CKPS – Crankshaft position Sensor

Web sites: (these are only a few of sites visited)
References:

http://my.ece.ucsb.edu/bobsclass/2A/Labs/2A%20Lab%20-%202009.pdf
http://www.flashcardmachine.com/automotive-waveforms.html
http://eceee.colorado.edu/~mcclurel/txyzscopes.pdf
http://www.picotech.com/education/oscilloscopes/advanced-triggering.html
http://www.dtec.net.au/Multi%20Spark%20Ignition.htm

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