Oscilloscope waveform
Types and interpretation

Prepared for
WIRE & GAS 2012 Training Convention

Long Reef Garage

Sam Nazarian

All captured waveforms are relative to ground
unless otherwise stated

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

Jack Stepanian

Acknowledgement and references

Authors wish to acknowledge that information gathered and collated for the purpose of research and development of this is 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, Rellim, 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.

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The Automotive Technician (TAT)

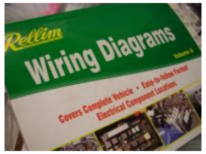
Repco Auto Tech Encyclopedia

Auto Data PC Based DATA Base

Hanatech G-Scan Mount Auto EQ

Autel MaxDas InterEquip

Automotive Service Solution

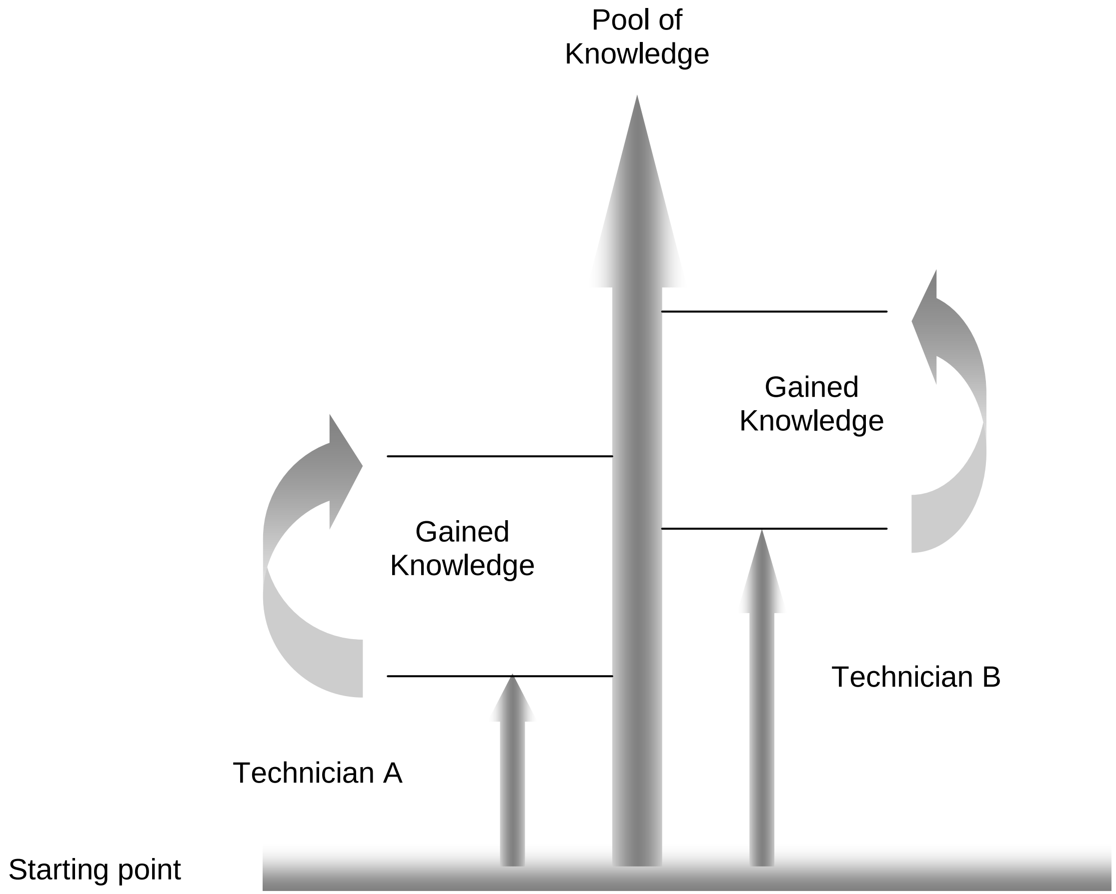


Relim Bookworks Wiring Diagrams

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

PRE

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

POST

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

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

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

Y Axis

Voltage Axis

+ Volts

0.0 Volts

- Volts

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

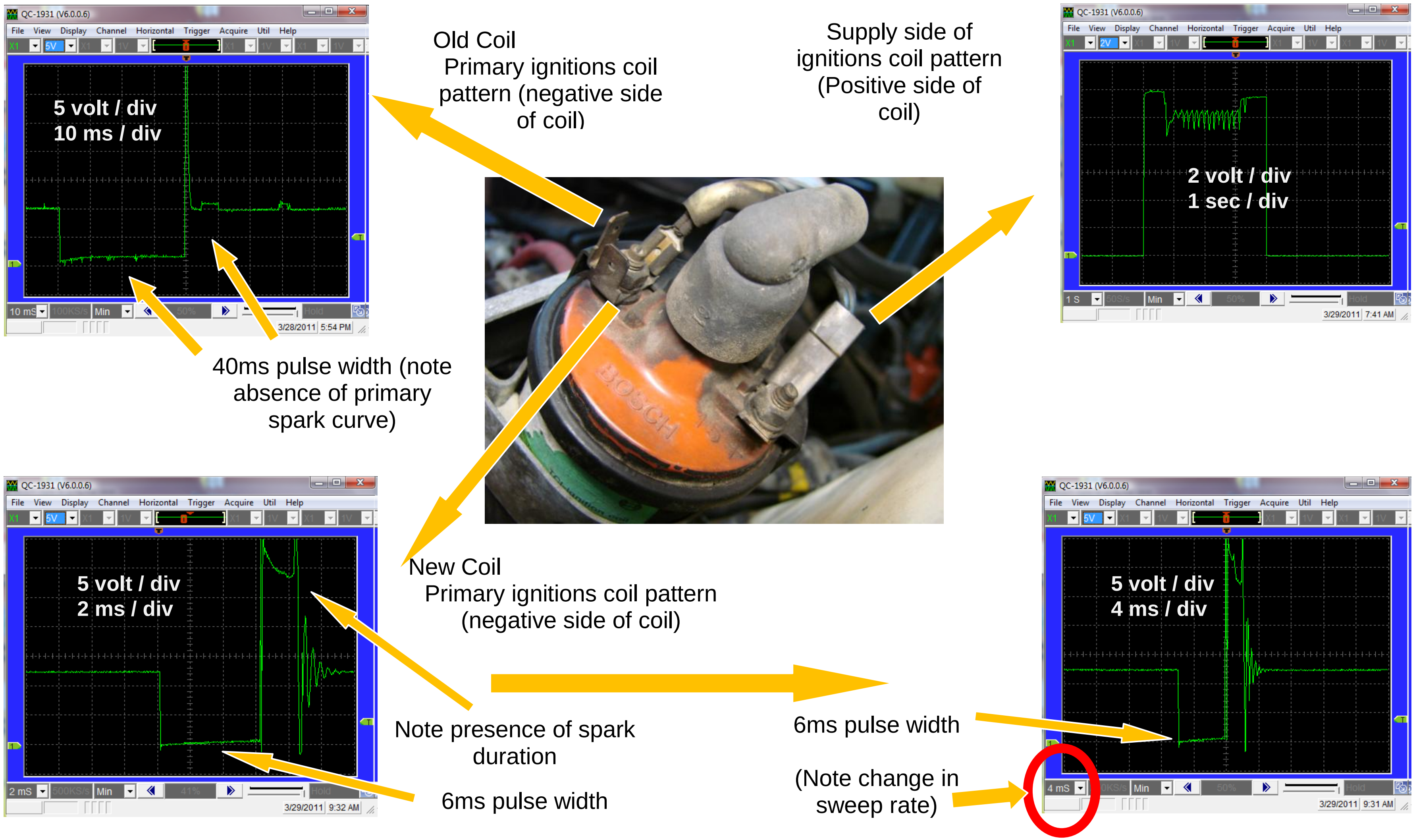
X Axis

Time base Axis

1 second per division

Jeep Cherokee – Manifold Air Pressure Sensor (MAP)

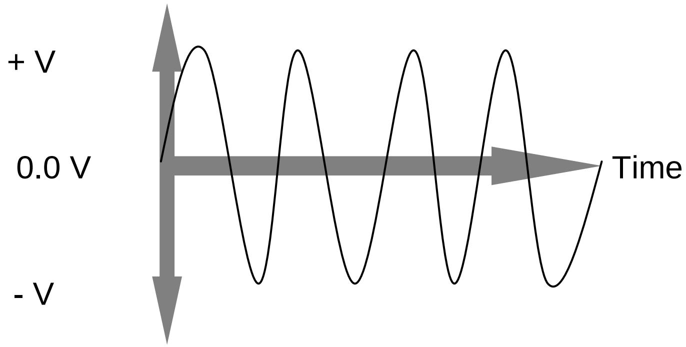
Instant Diagnosis of symptom (car cranks but does not start) - absence of spark duration



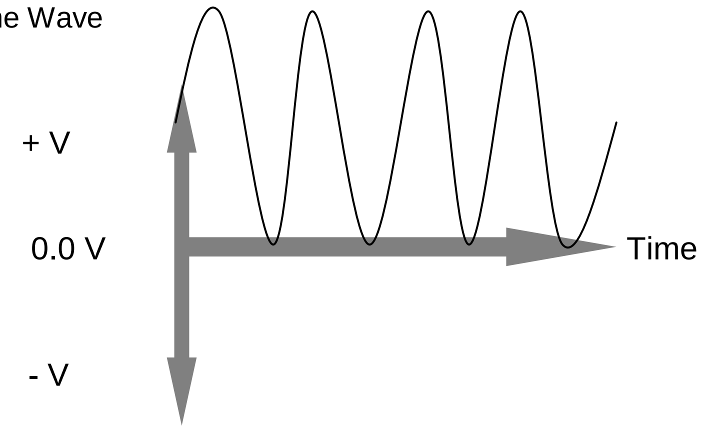
Volvo 240GL (primary ignition coil pattern)

Types of Waveforms Alternating Current (AC) and Direct Current (DC)

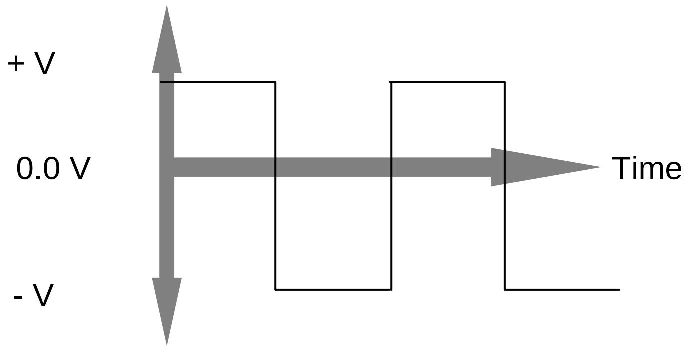
AC Sine Wave



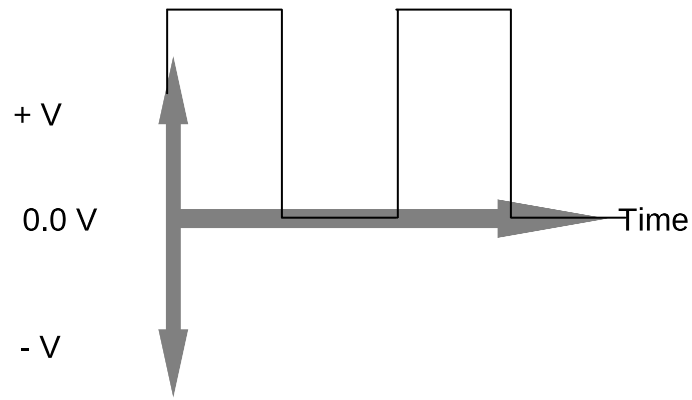
DC Sine Wave

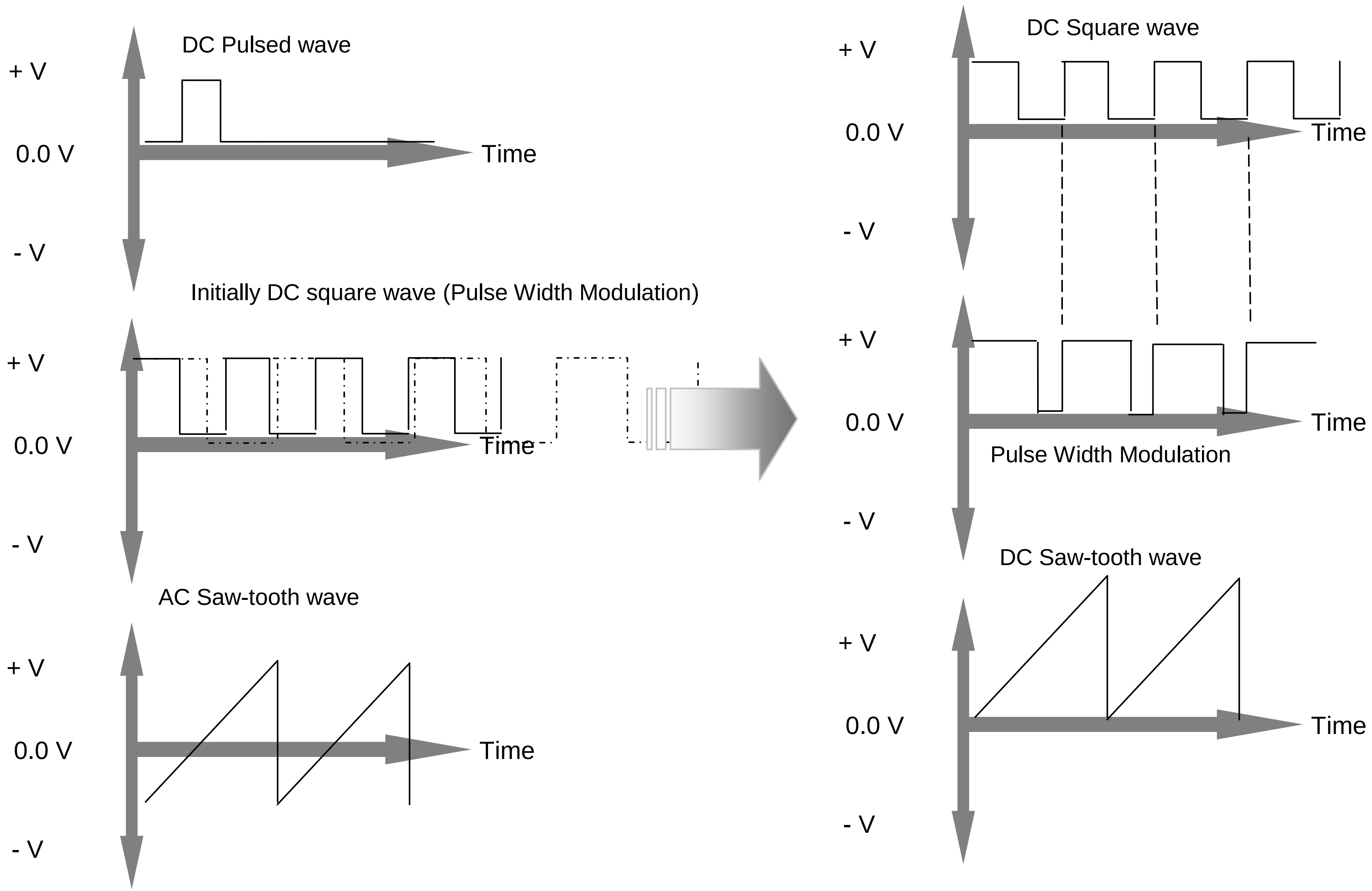


AC Square Wave

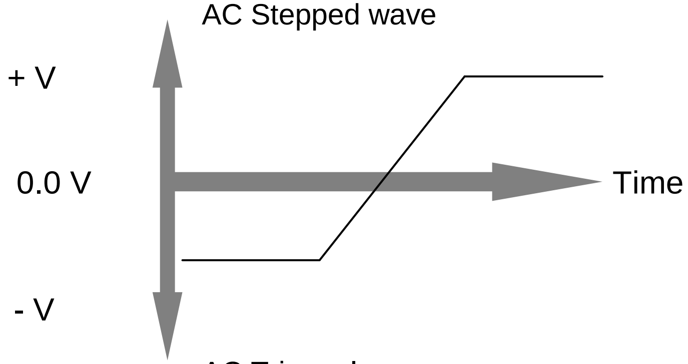


DC Square Wave

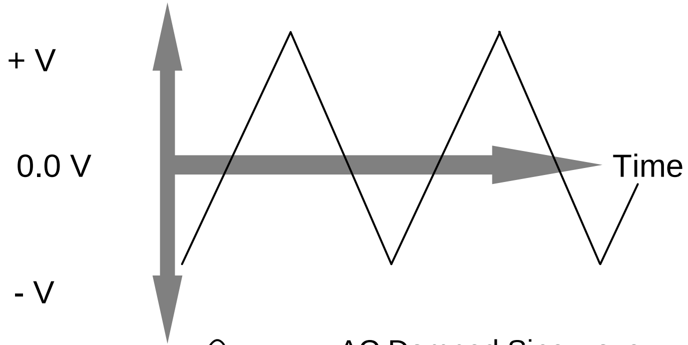



DC Pulsed wave
+ V
0.0 V
Time
- V
Initially DC square wave (Pulse Width Modulation)
+ V
0.0 V
Time
- V
AC Saw-tooth wave
+ V
0.0 V
Time
- V
DC Square wave
+ V
0.0 V
Time
- V
+ V
0.0 V
Time
Pulse Width Modulation
- V
DC Saw-tooth wave
+ V
0.0 V
Time
- V

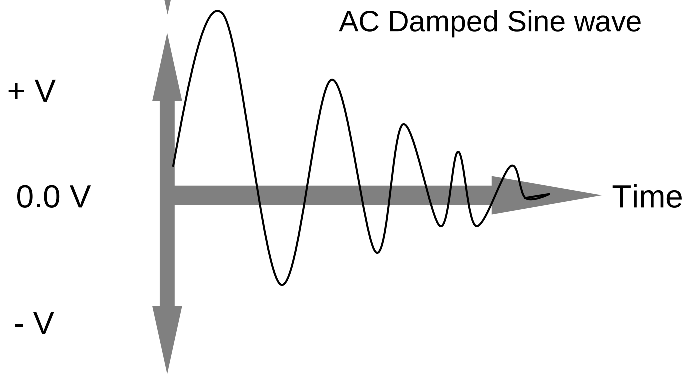
AC Stepped wave



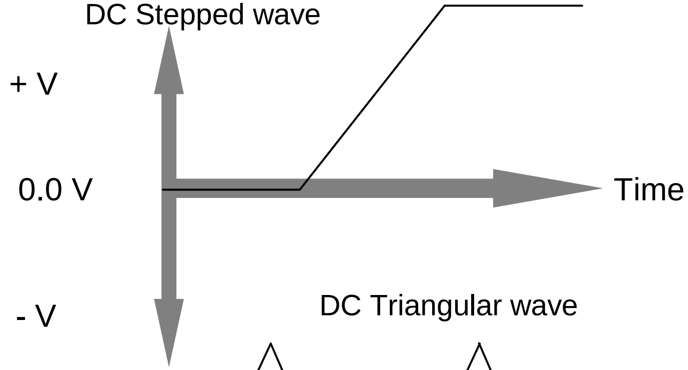
AC Triangular wave



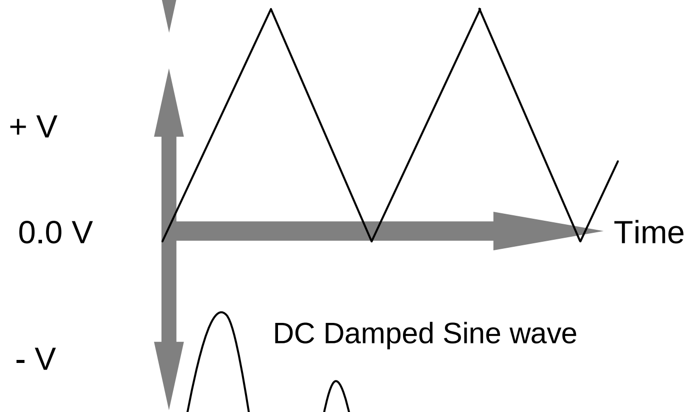
AC Damped Sine wave



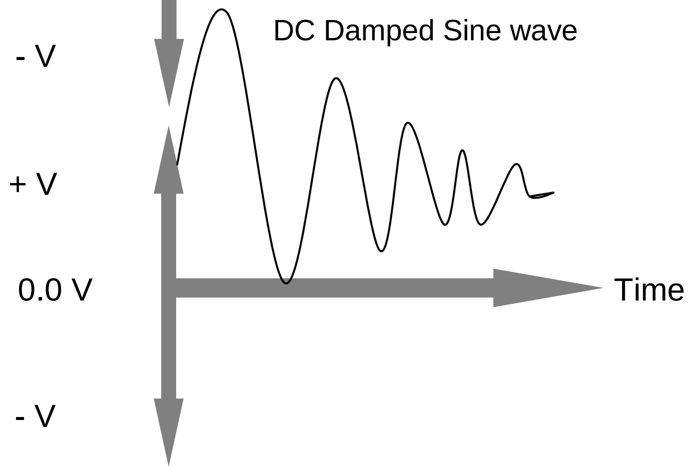
DC Stepped wave



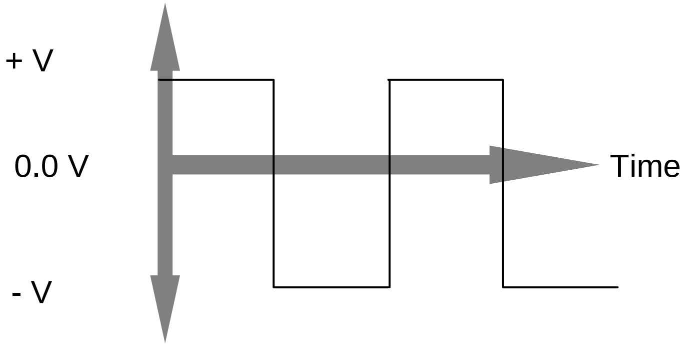
DC Triangular wave

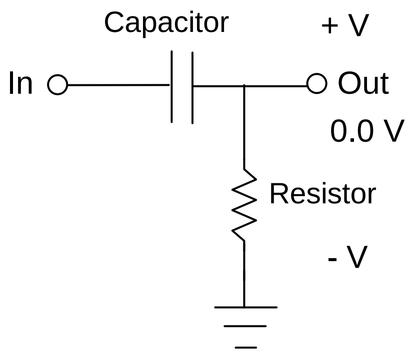


DC Damped Sine wave

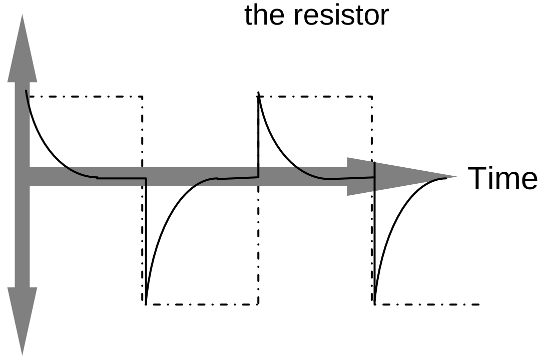


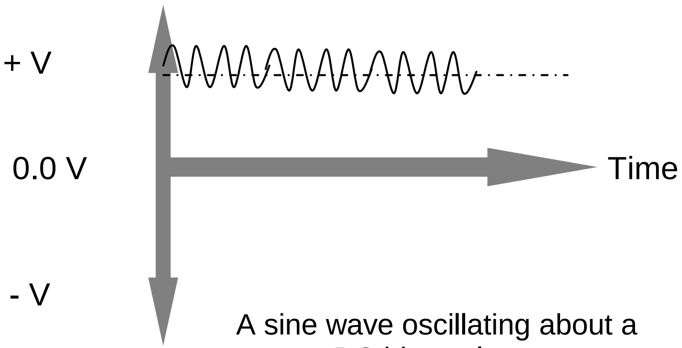
AC Square Wave signal oscillating above and below zero volts



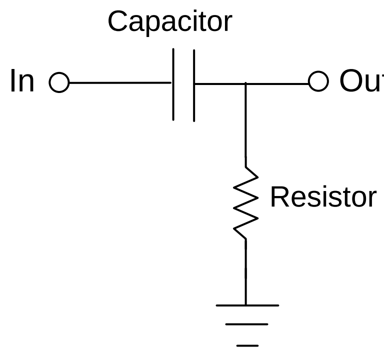


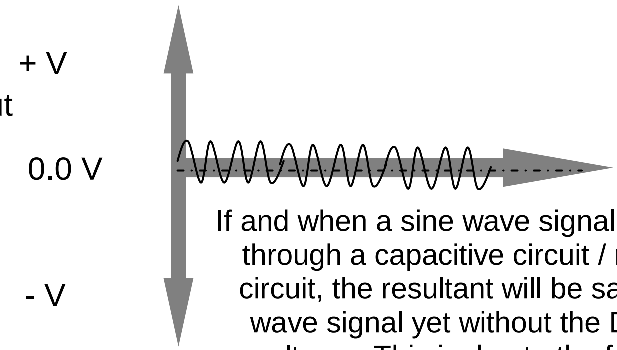
If and when a square wave signal is passed through a capacitive circuit the resultant will be ‘spiked’ due to the capacitor charging and discharging via the resistor





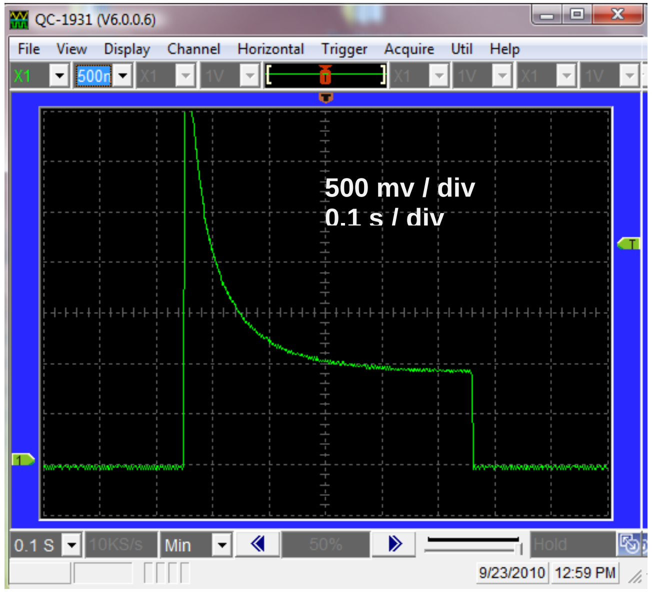
A sine wave oscillating about a DC bias voltage



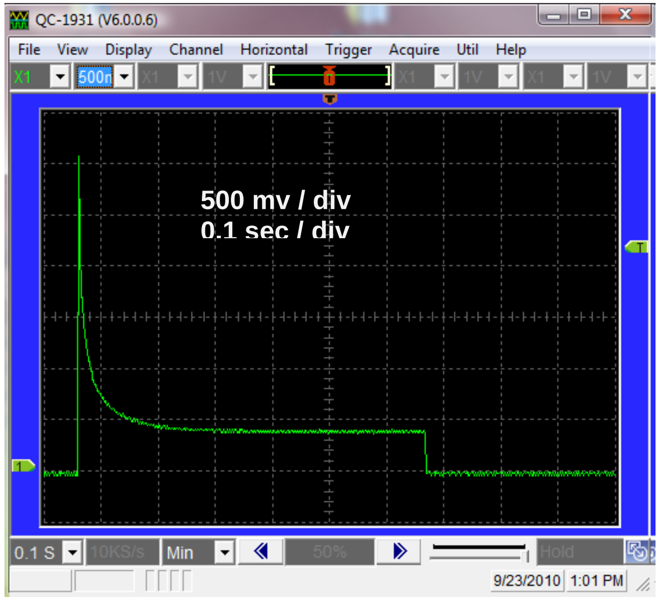


If and when a sine wave signal is passed through a capacitive circuit / resistive circuit, the resultant will be same sine wave signal yet without the DC bias voltage. This is due to the fact that capacitors act as a short circuit for AC and yet open circuit for DC. Hence, A sine wave oscillating about (above and below) zero volts

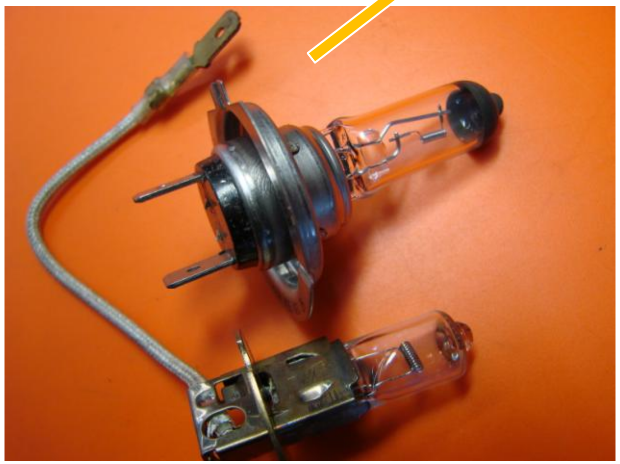
Scope pattern- depicting characteristics of positive temperature co-efficient current draw of a tungsten filament.



H3 – 100W - 5A per division and 0.1s

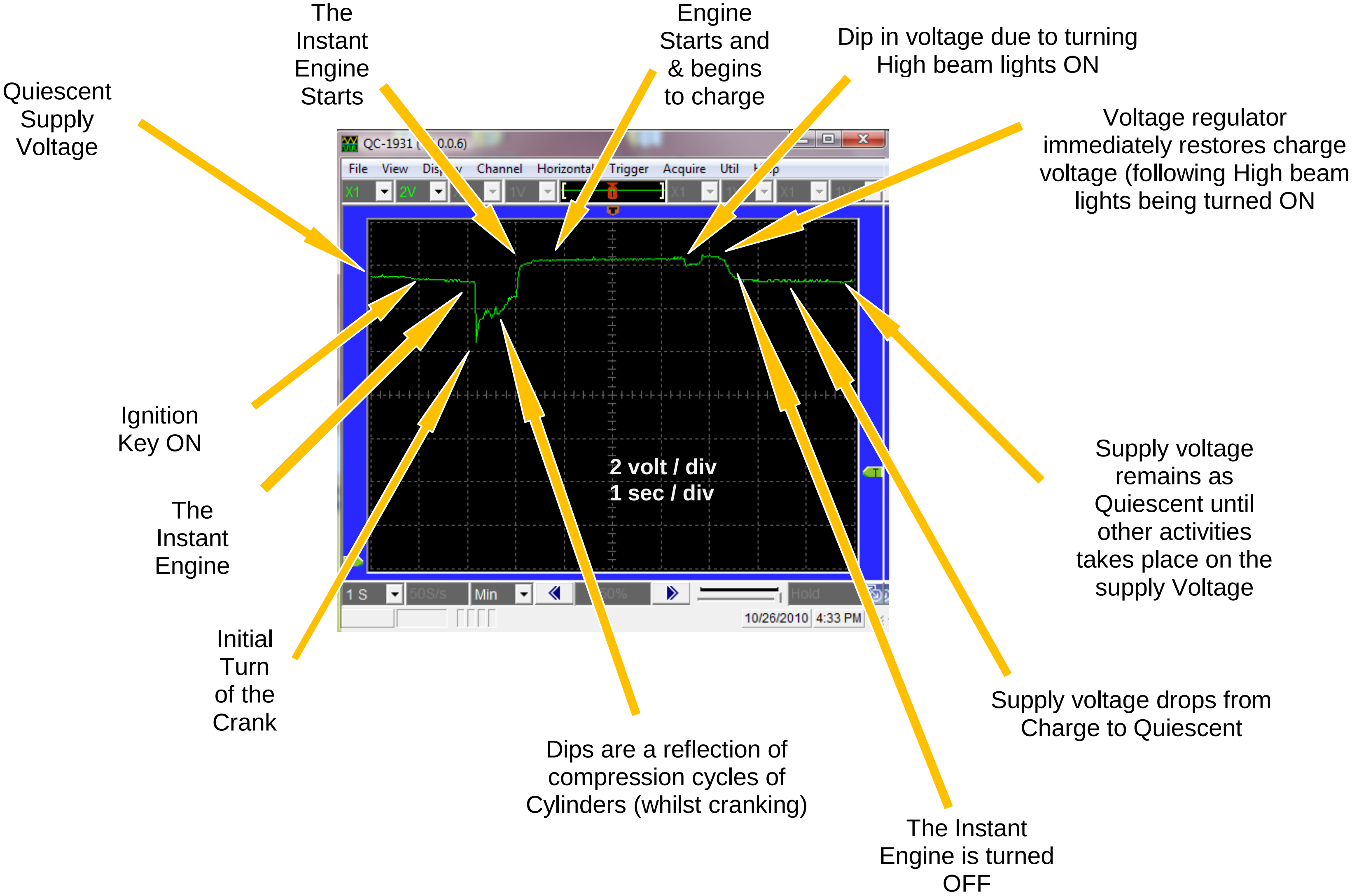


H7 – 55W -5A per division and 0.1s



Good scope pattern,(H3 – 100W & H7 – 55W)

Anatomy of waveform analysis - Typical Battery Supply voltage measured post to post (good scope pattern)



Nissan Pathfinder

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 Engine Starts

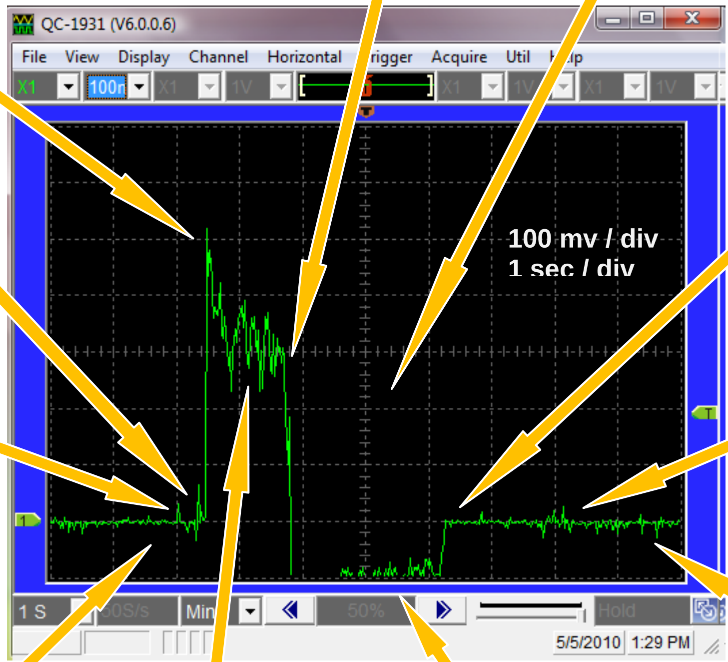
Engine Starts and whilst running is drawing current (hence voltage drop)

The Instant of Engine Cranking

The Instant Engine is turned OFF

Ignition Key ON

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



Quiescent zero base ground voltage

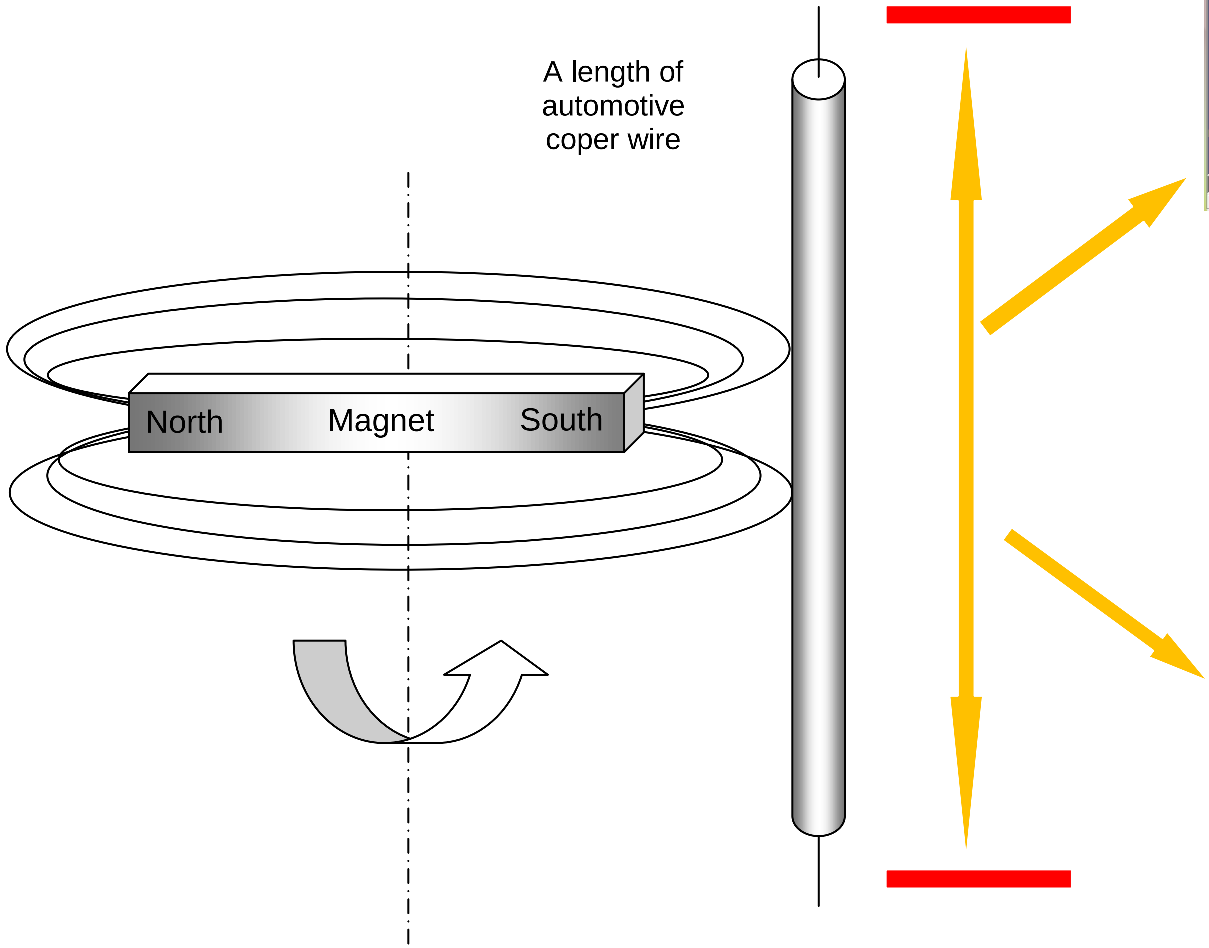
Dips signifying compression of Cylinders (whilst cranking)

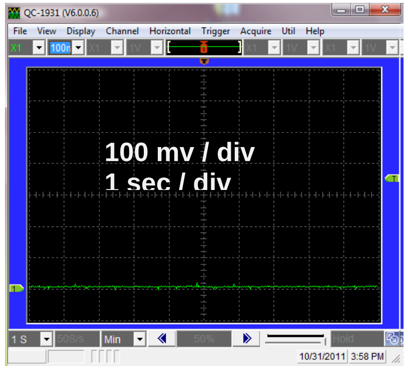
Voltage drop below Zero volts base line (negative value) signifies Electrolysis

Current draw minimal (voltage drop minimal)

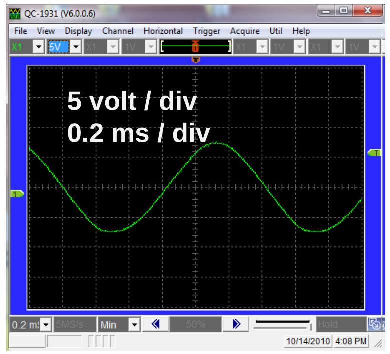
Subaru Outback

Effect of a magnetic field on an inductor



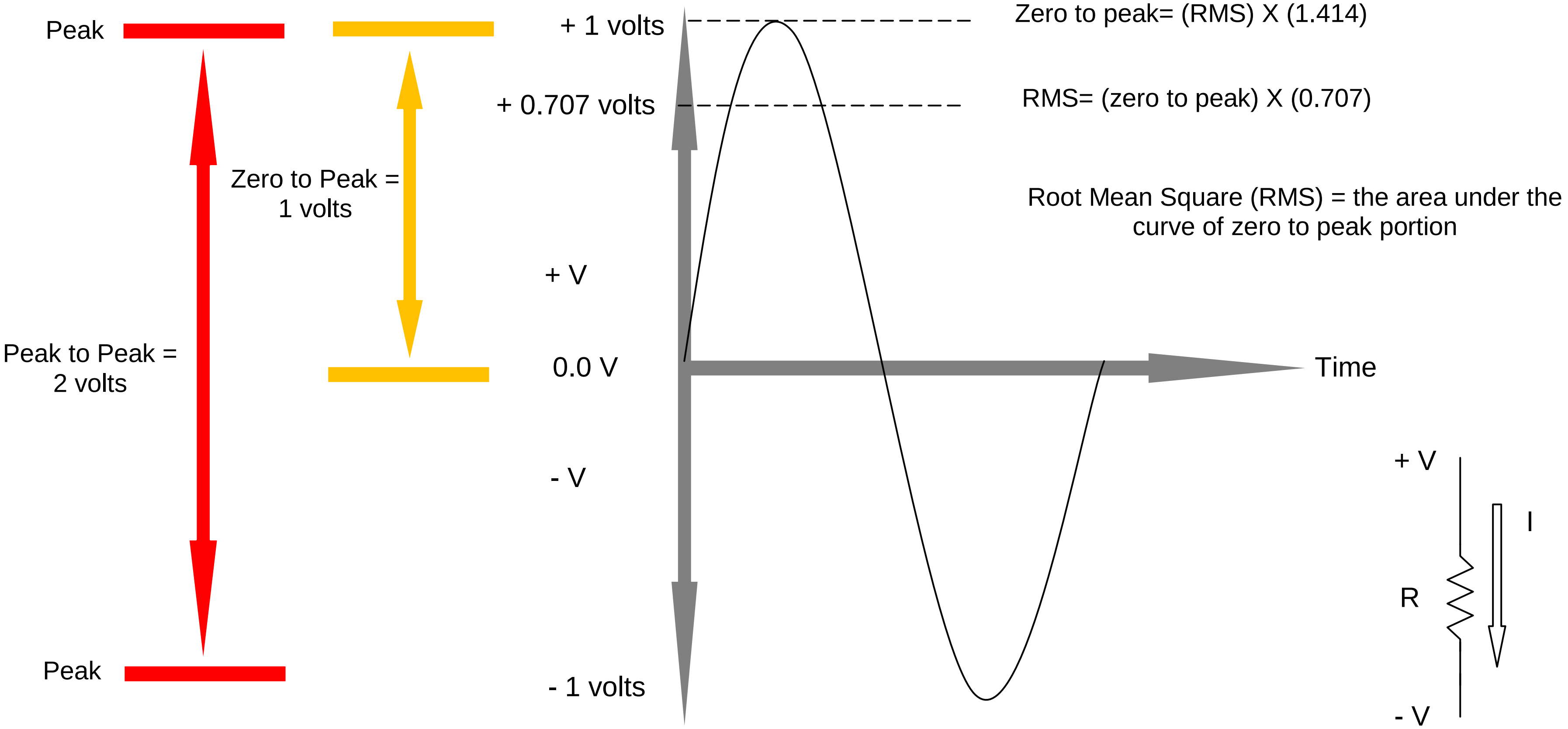


There will be no potential difference (voltage) between two ends of the wire whilst magnet is STATIONARY



However as the magnet rotates the generated AC signal will be proportional to rate at which the magnetic field cuts the copper wire

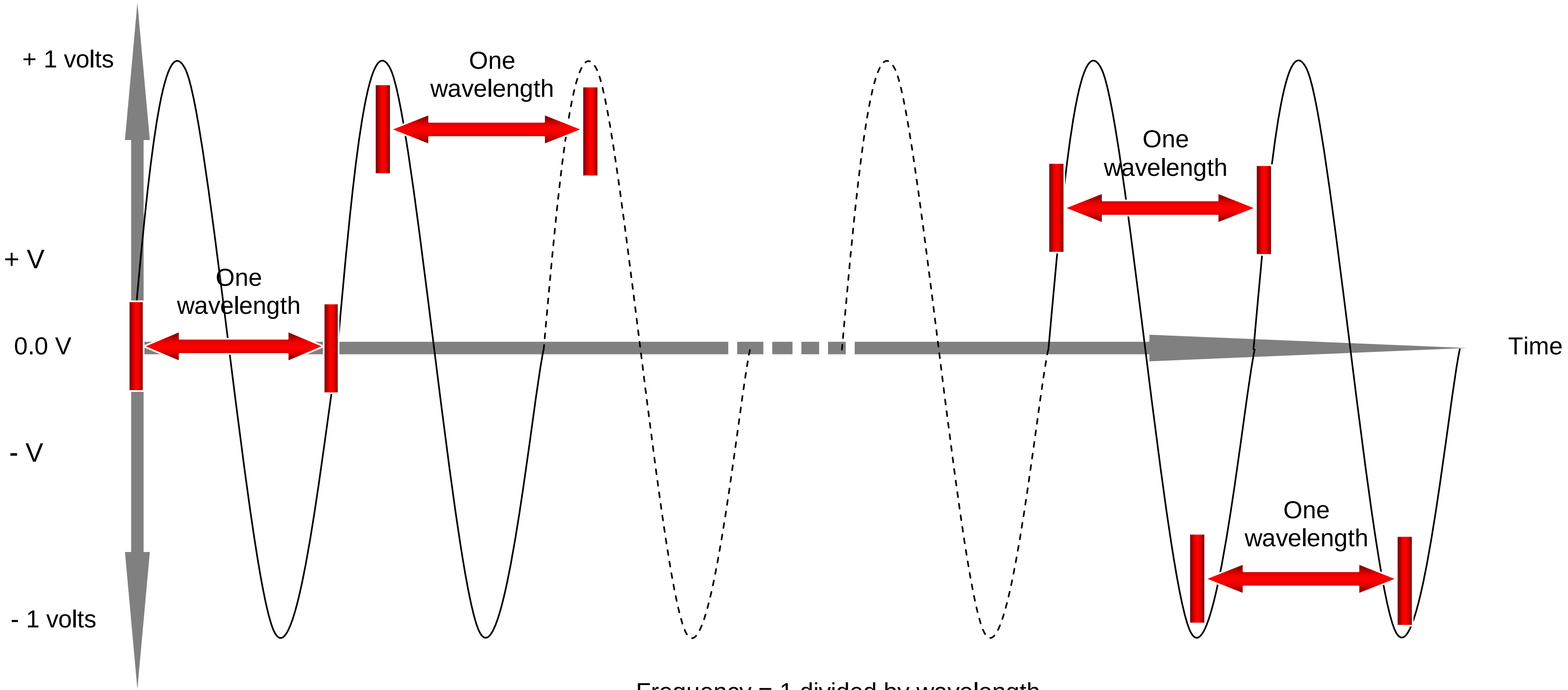
Anatomy of a Sine Wave (Y Axis – voltage scale)



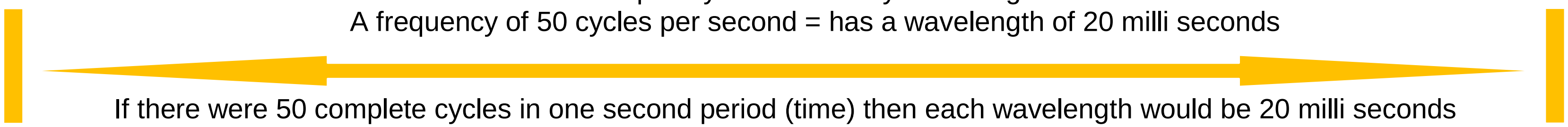
Ohms Law
Volts (RMS) = I (Amps) X R (Ohms)
Power = Volts (RMS) X I (Amps)

Anatomy of a Sine Wave (X Axis – time base)

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

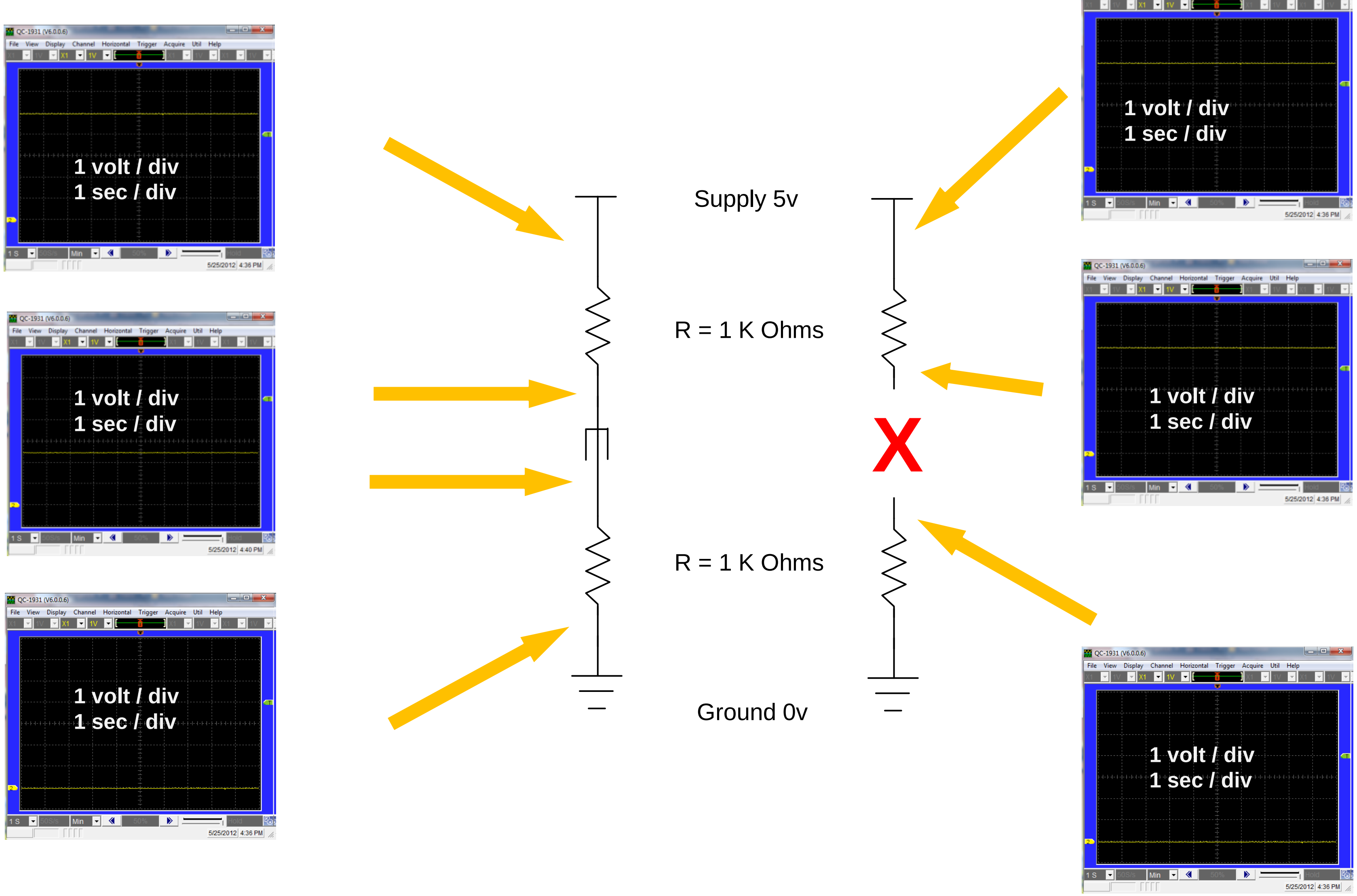


Frequency = 1 divided by wavelength
A frequency of 50 cycles per second = has a wavelength of 20 milli seconds



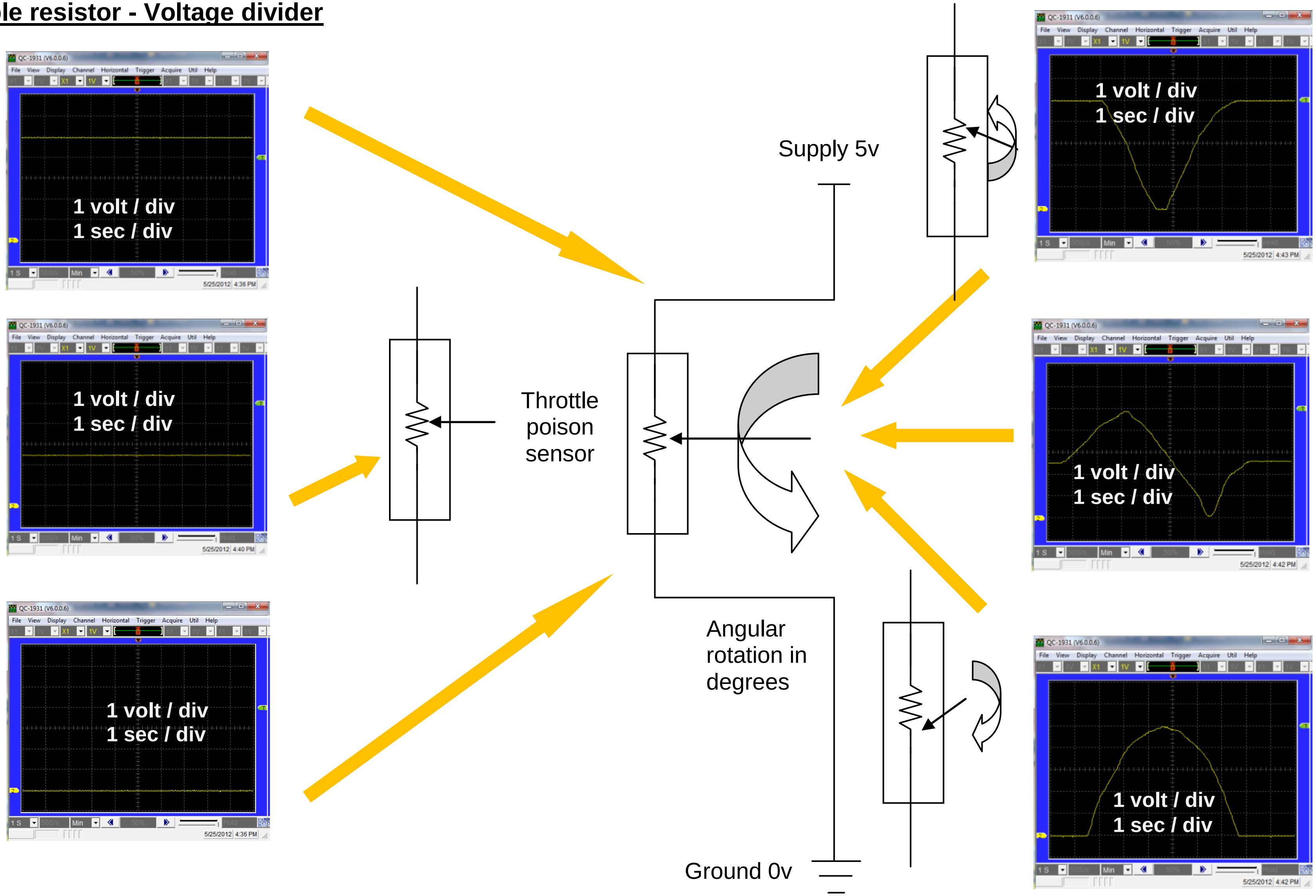
If there were 50 complete cycles in one second period (time) then each wavelength would be 20 milli seconds

Voltage divider - Resistor circuit



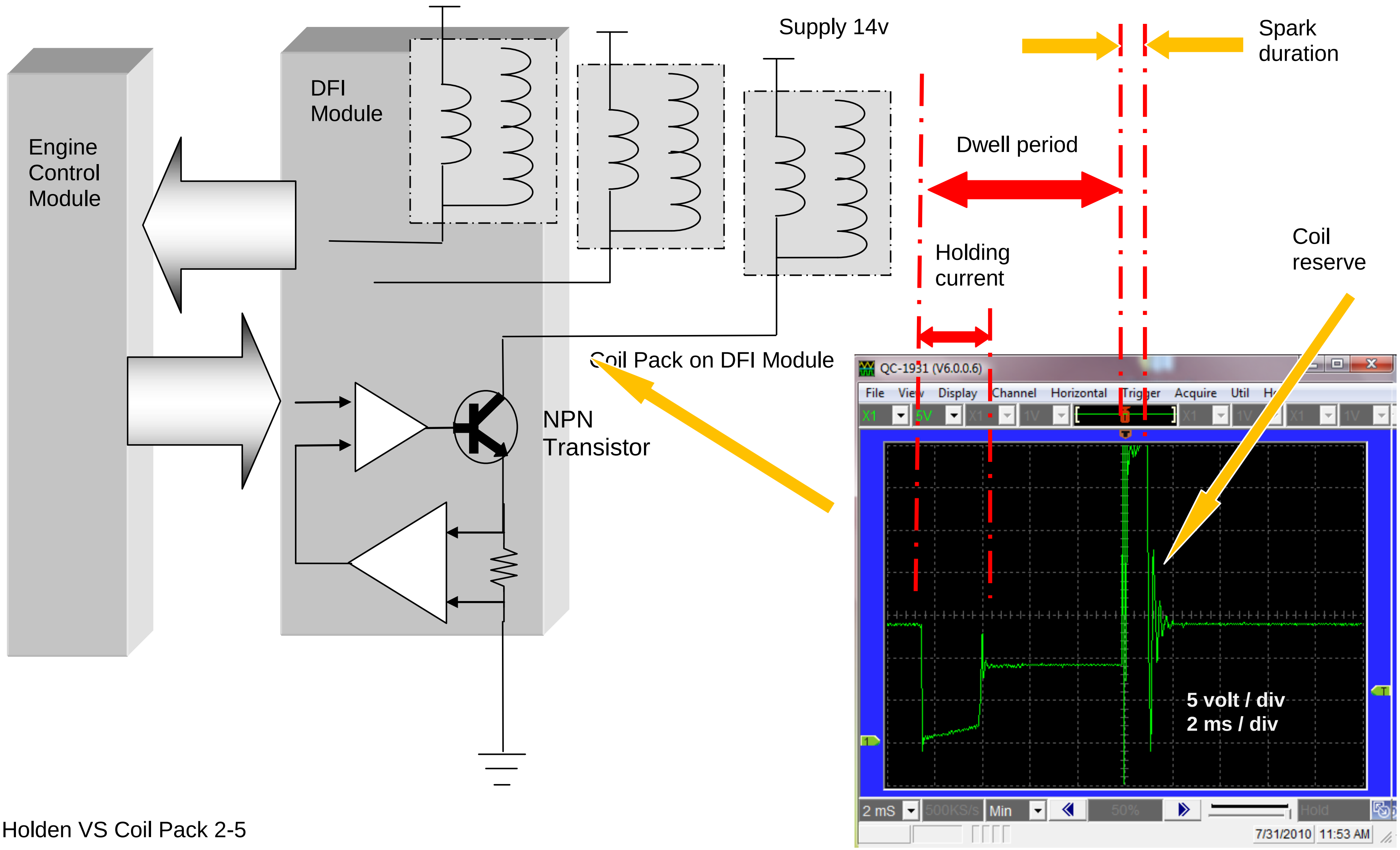
Generic automotive voltage divider circuit

Variable resistor - Voltage divider



Generic automotive voltage divider variable resistor

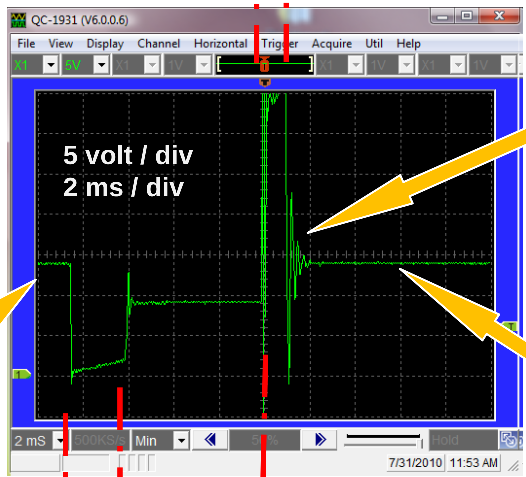
Direct Fire Ignition Module (DFI) – with primary current limiter control



Holden VS Coil Pack 2-5

Direct Fire Ignition Module (DFI) – with primary current limiter control

Spark duration



Coil reserve

Supply charge voltage prior to ignition trigger signal

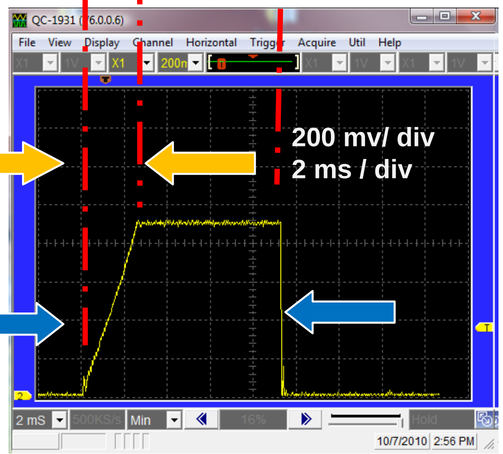
Supply charge voltage at end of ignition period

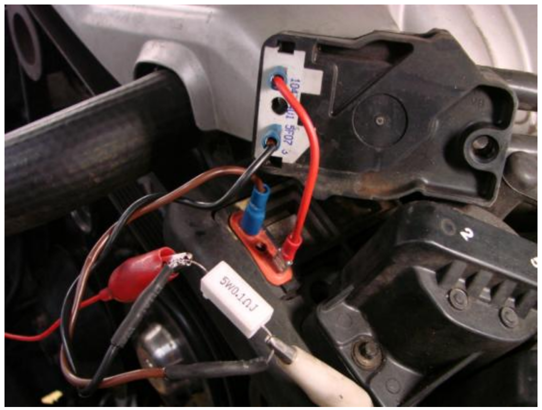
Holding current

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.

Ramping current

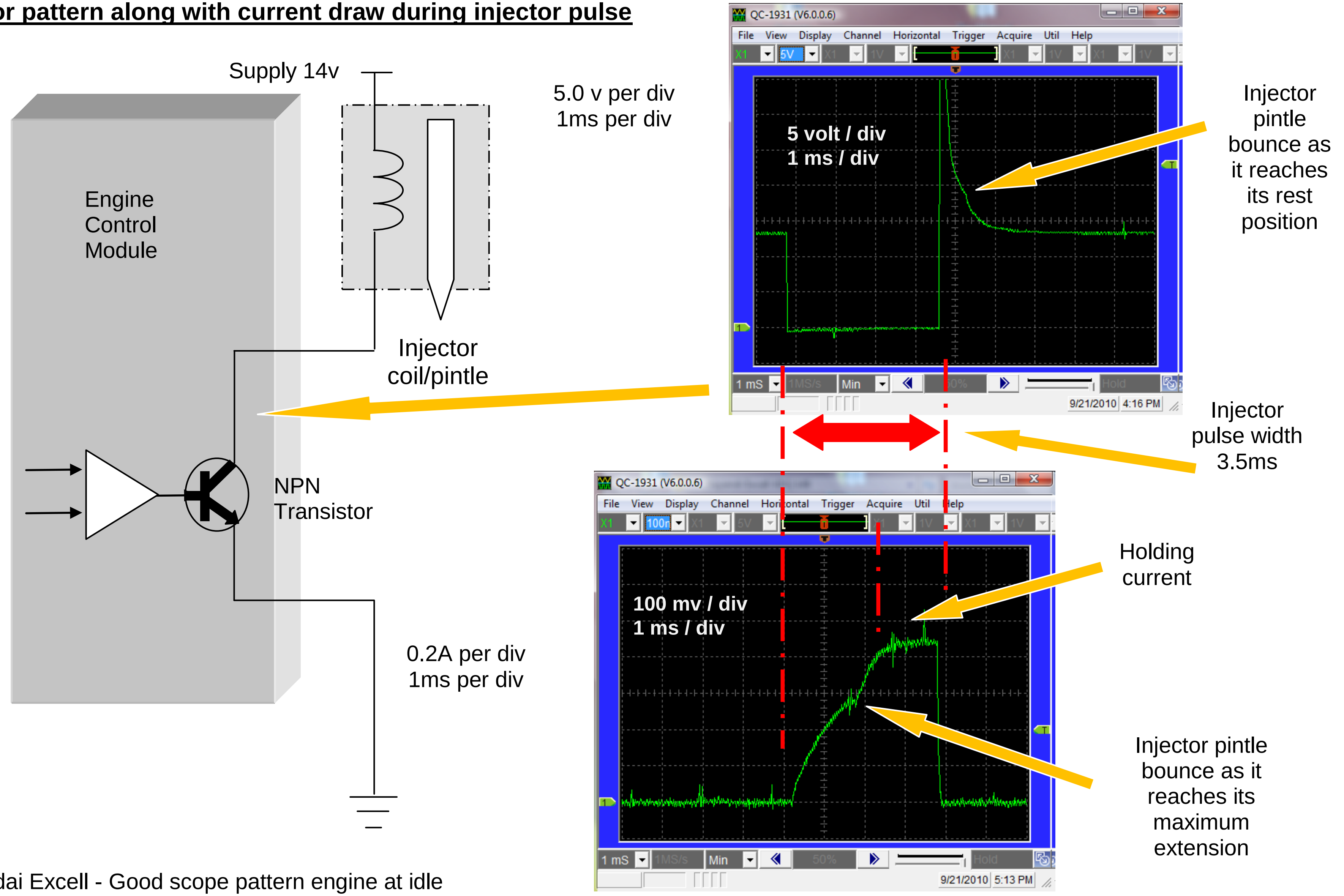
Dwell period





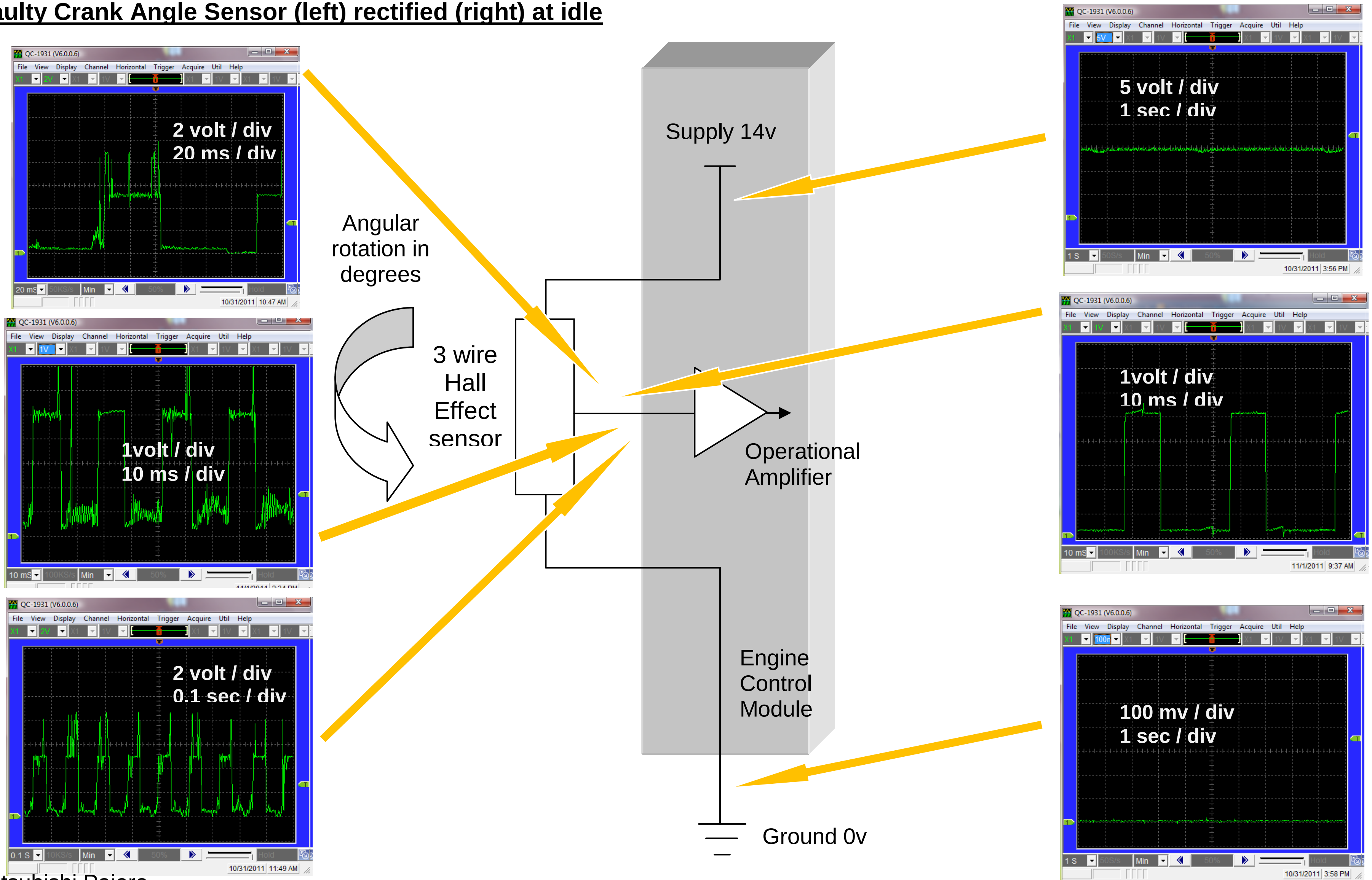
Holden VS Coil Pack 2-5

Injector pattern along with current draw during injector pulse



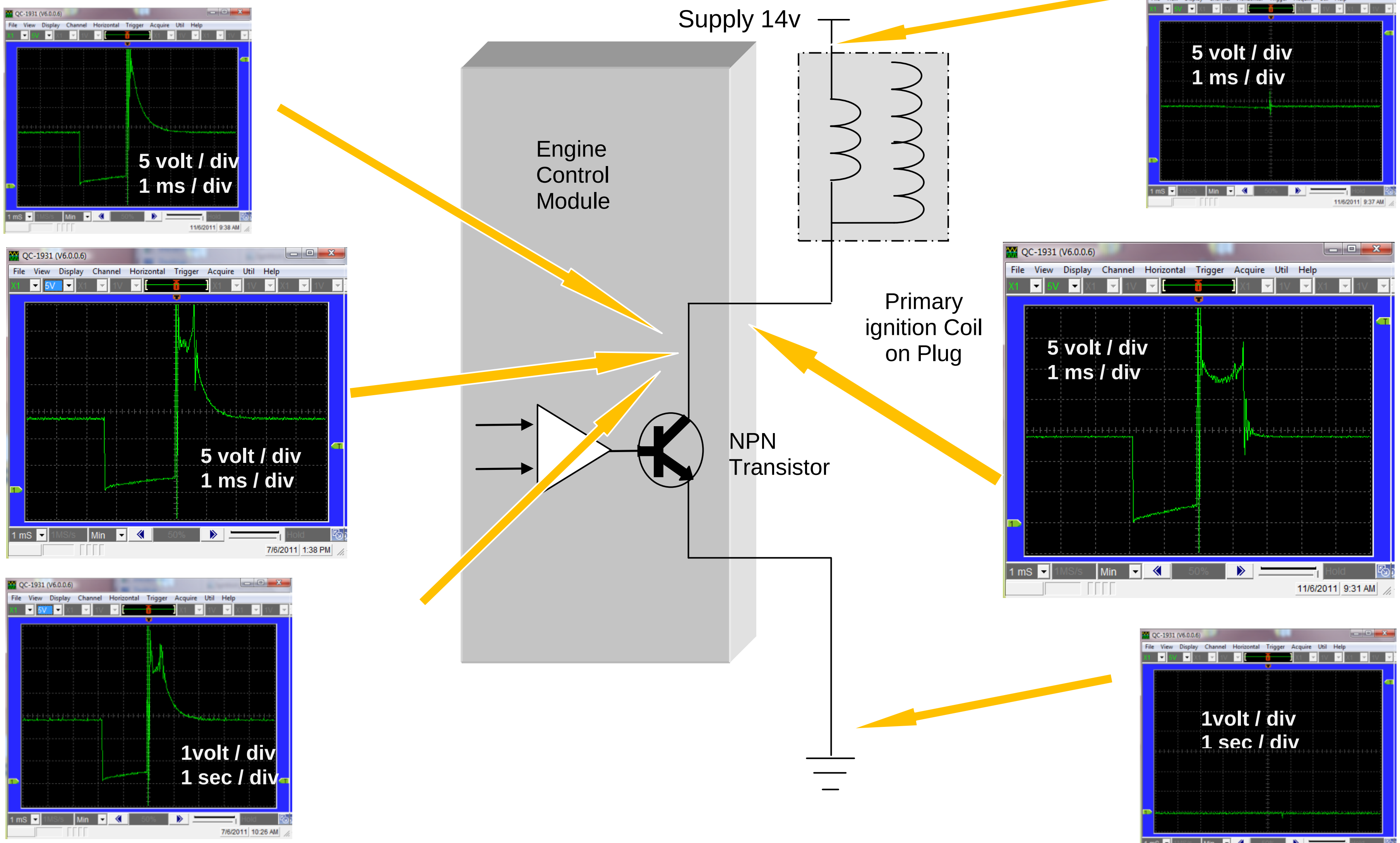
Hyuandai Excell - Good scope pattern engine at idle

Faulty Crank Angle Sensor (left) rectified (right) at idle



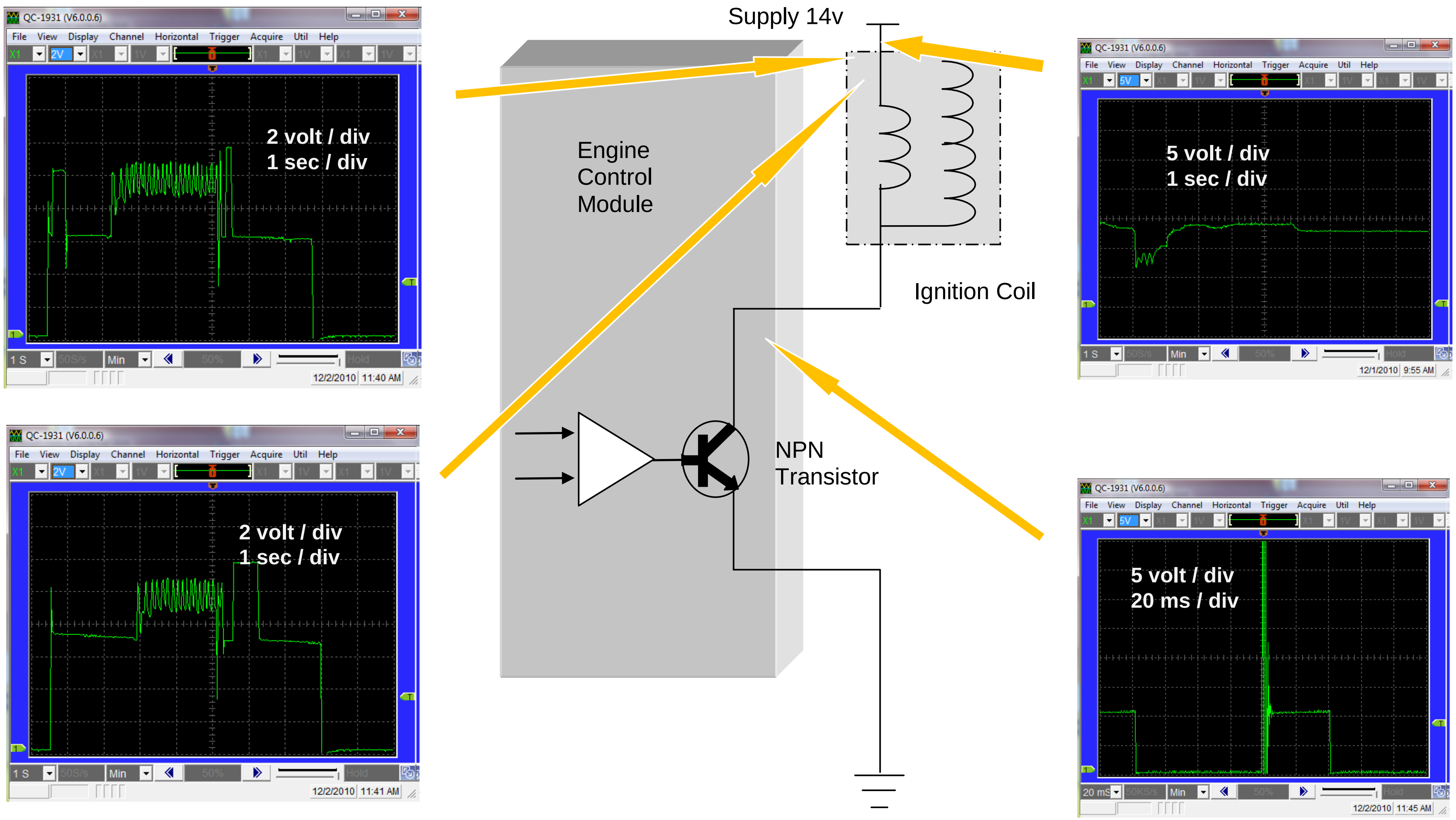
Mitsubishi Pajero

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



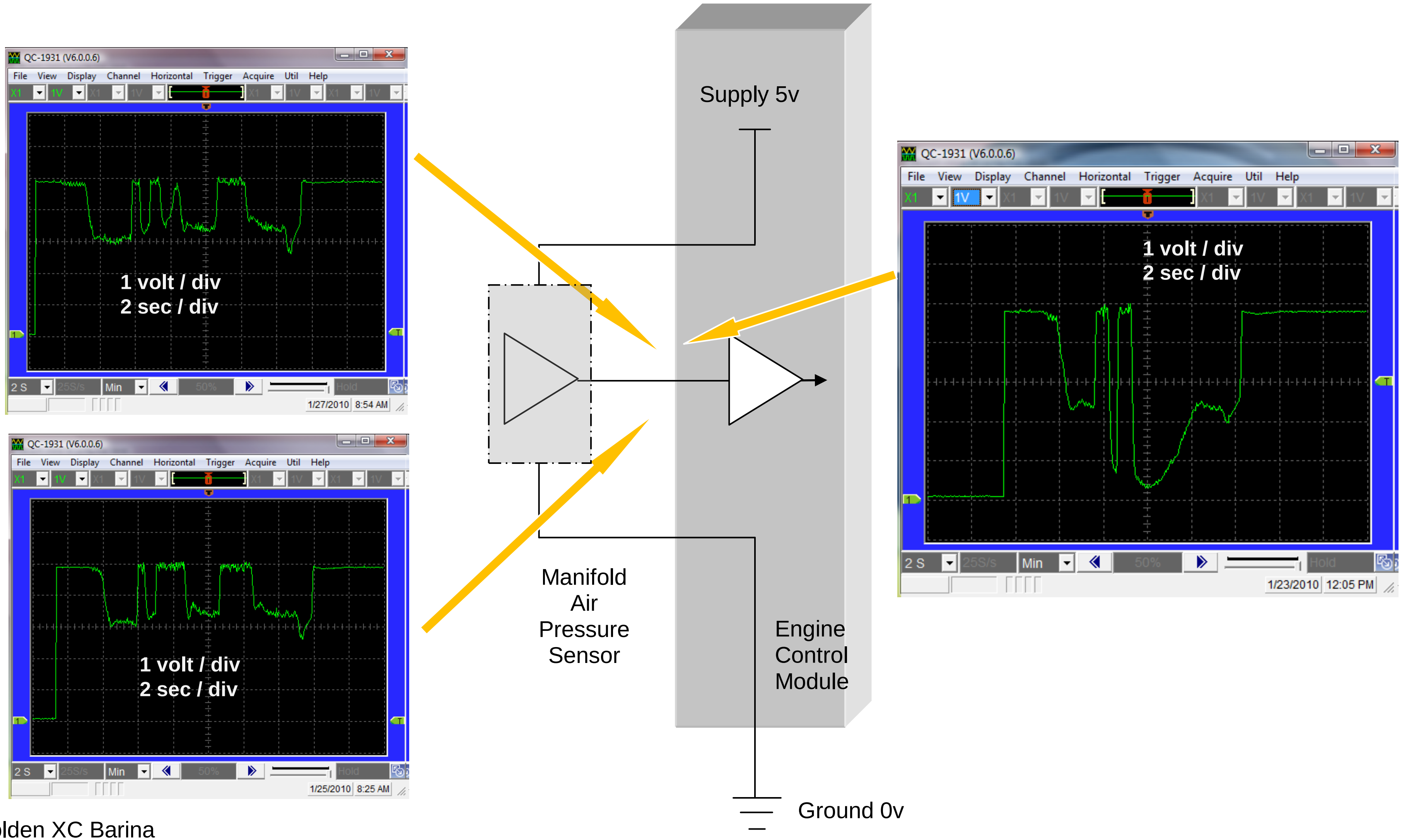
Holden XC Barina

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



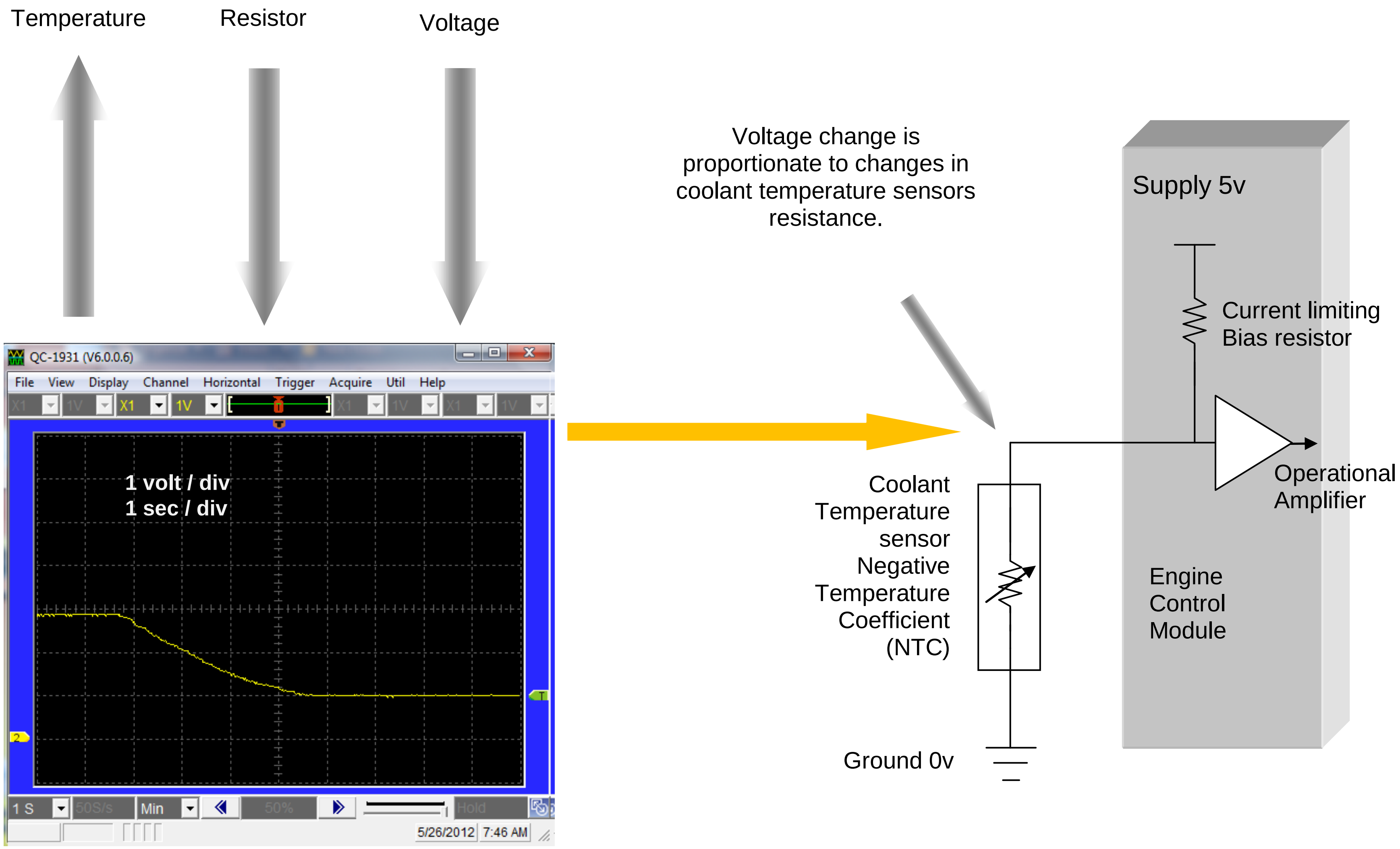
Susuki Vitara

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



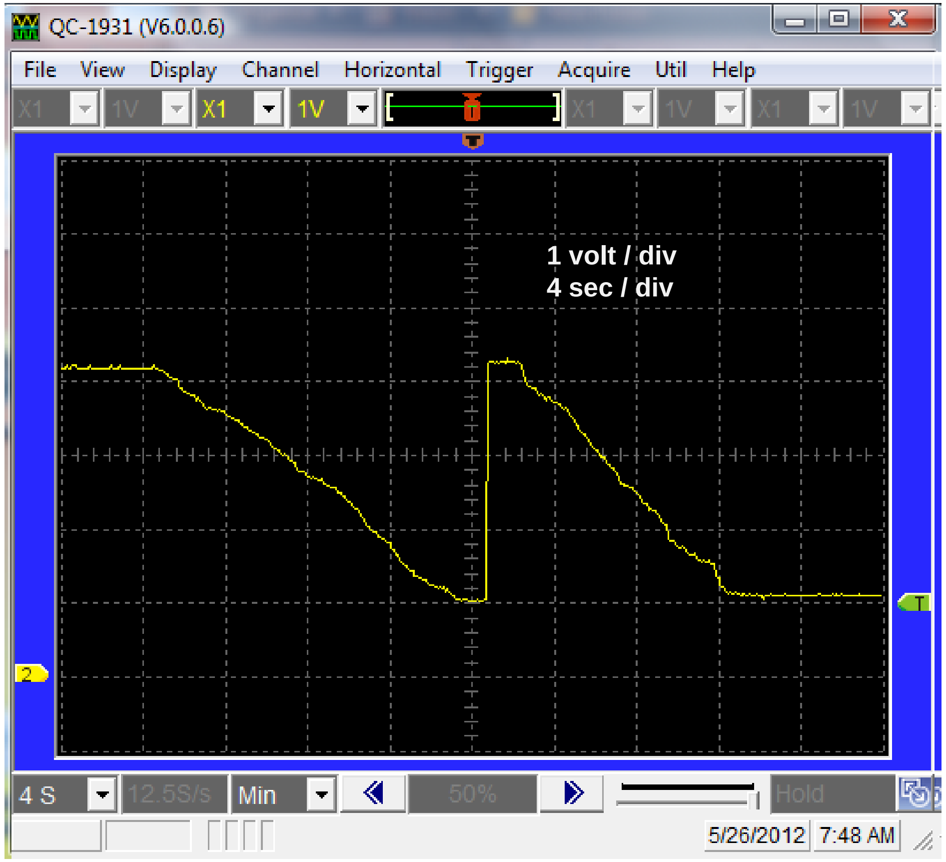
Holden XC Barina

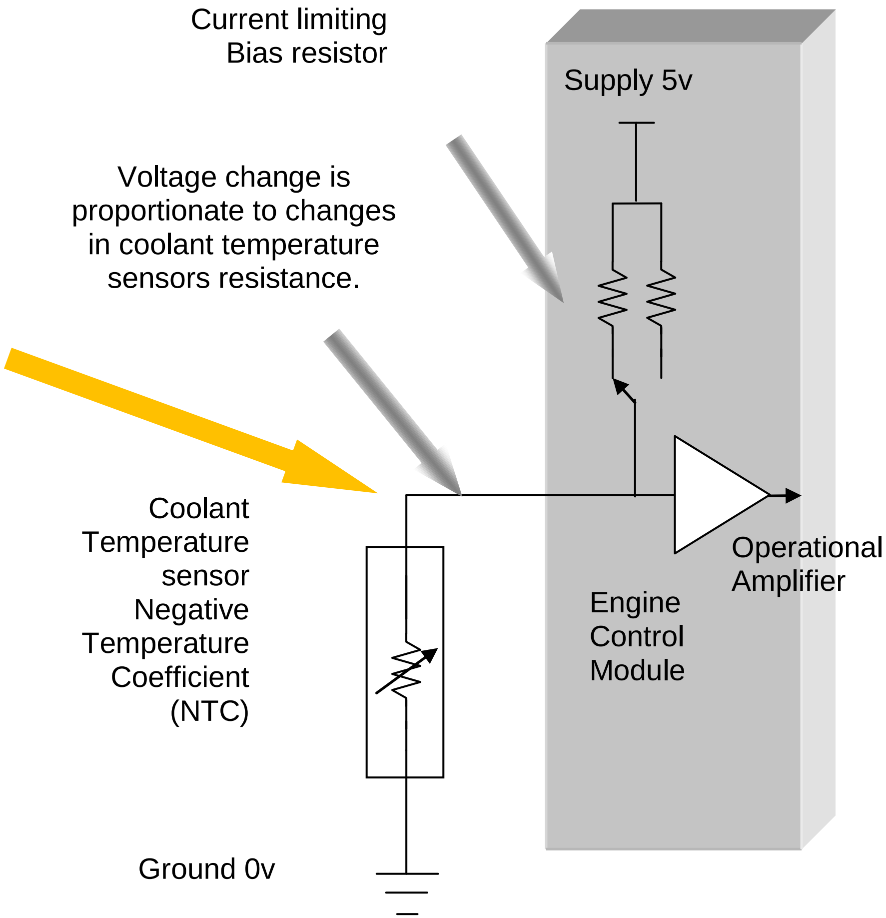
Single step Coolant temp sensor, as block temperature increases whilst engine running voltage will drop proportionately



Generic good automotive scope pattern

Two step Coolant temp sensor, as block temperature increases whilst engine running voltage will drop proportionately

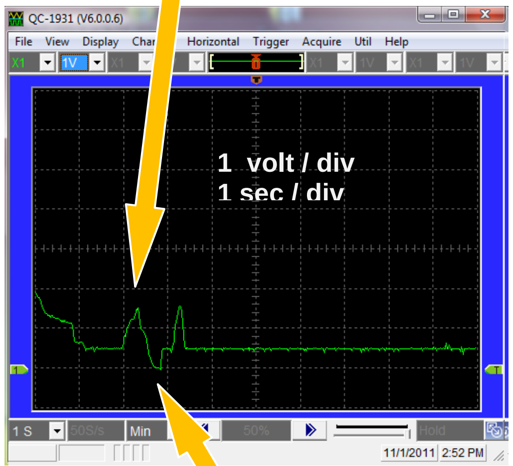




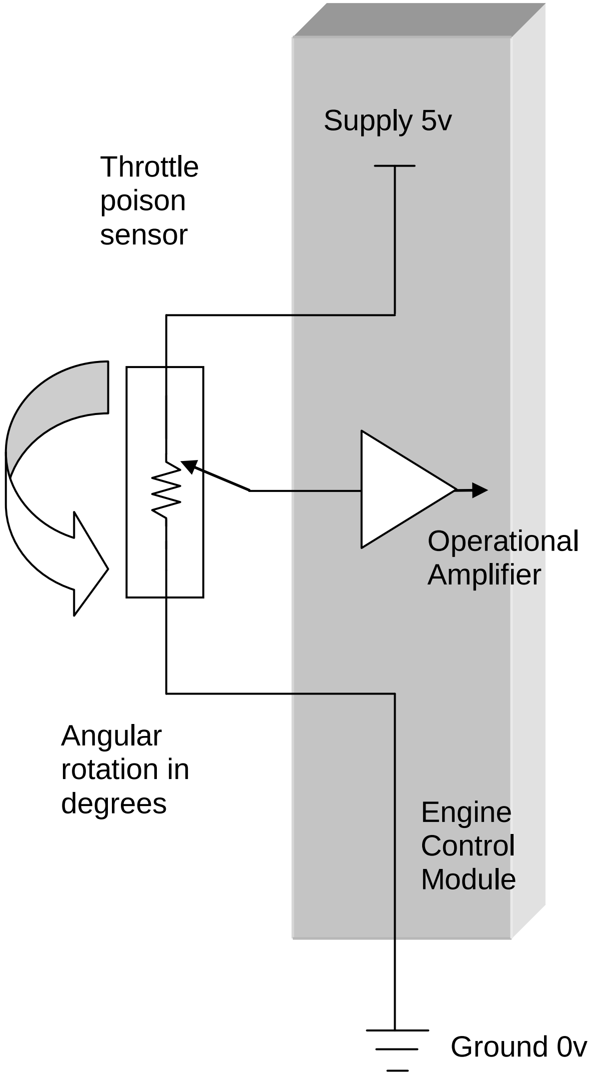
Generic good automotive scope pattern

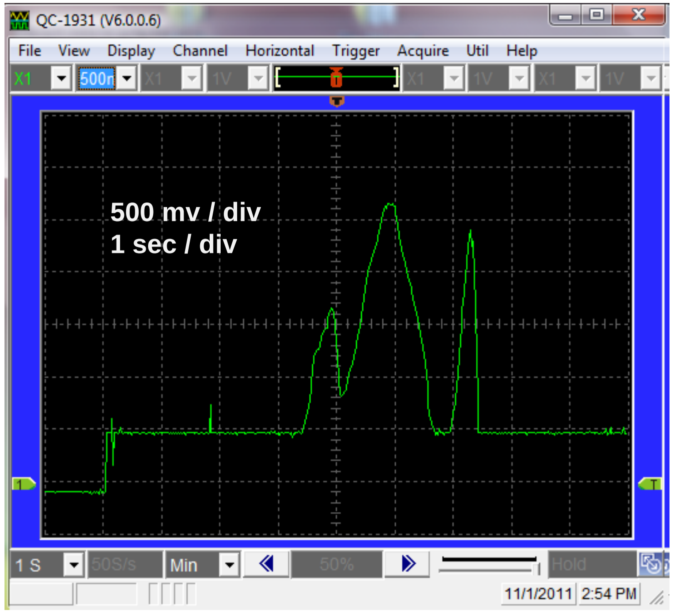
Faulty Throttle Position Sensor – note 'drop-out' to zero volts, (left) new Throttle Position Sensor signal (right)

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

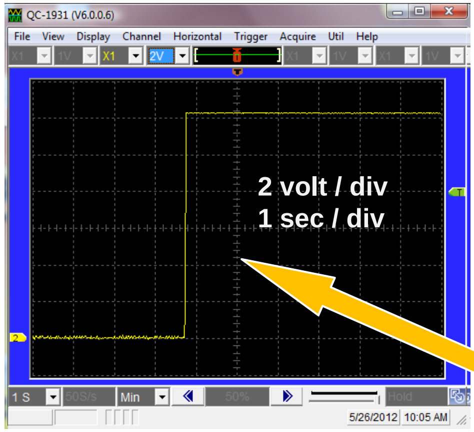


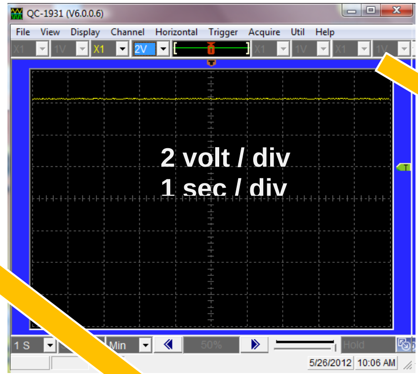


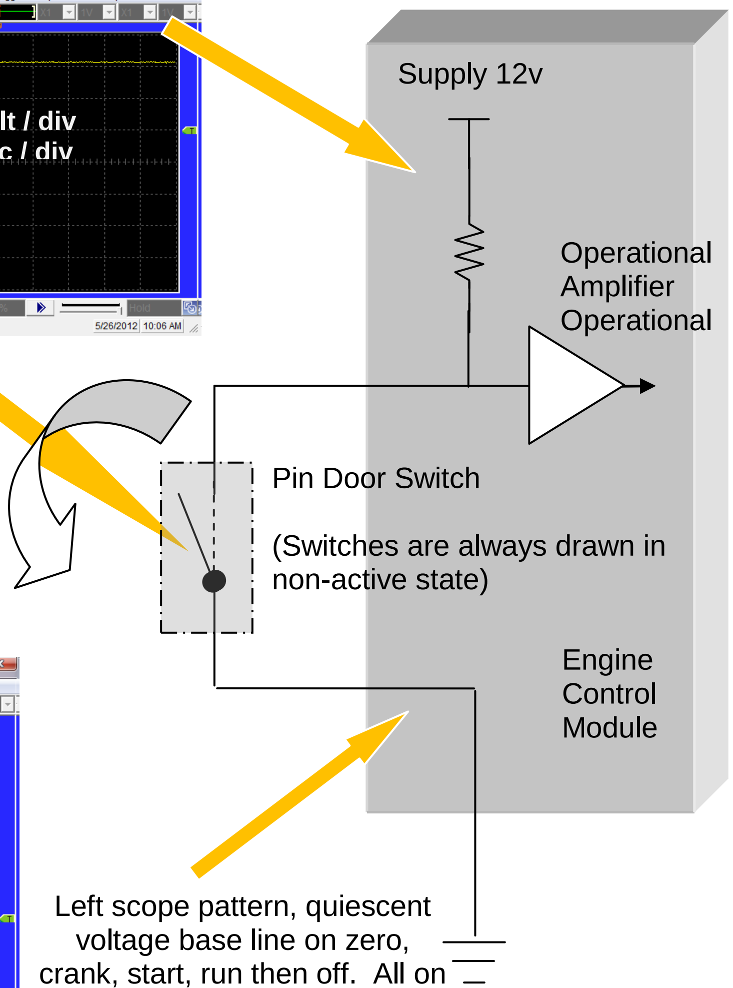
Note, **Absence** of 'drop-out' (short) to ground – Above trace is – Ignition off then On then crank then start, run, rev engine then allow to idle

Toyota Prado Landcruiser

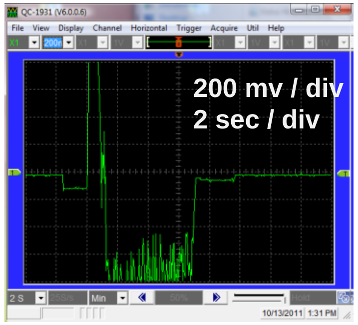
Bad earth – Electrolysis (bottom left scope), Flush cooling system, clean earth strap, re-test (bottom/middle right scope)



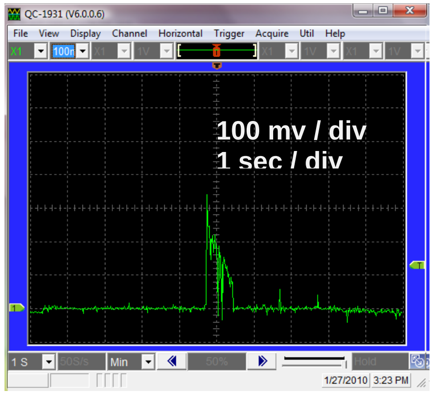




Initially, switch in closed position, and as the switch is open circuited, the voltage is pulled up to supply voltage due to the 'pull-up' resistor.



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



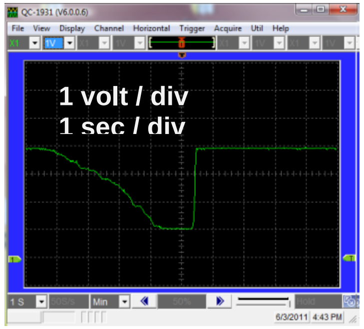
Left scope pattern, quiescent voltage base line on zero, crank, start, run then off. All on same quiescent base line. Good earth

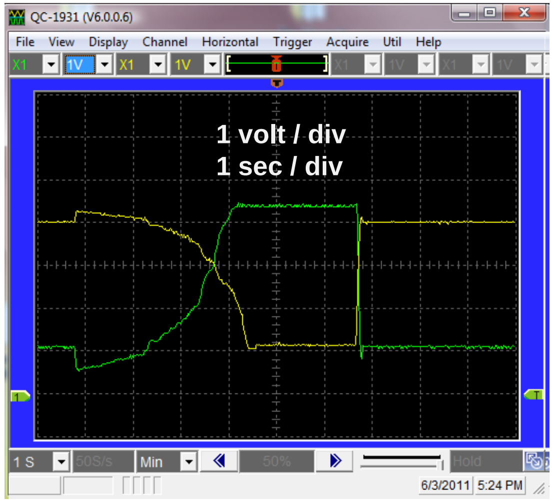
Generic, automotive earth scope pattern.

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

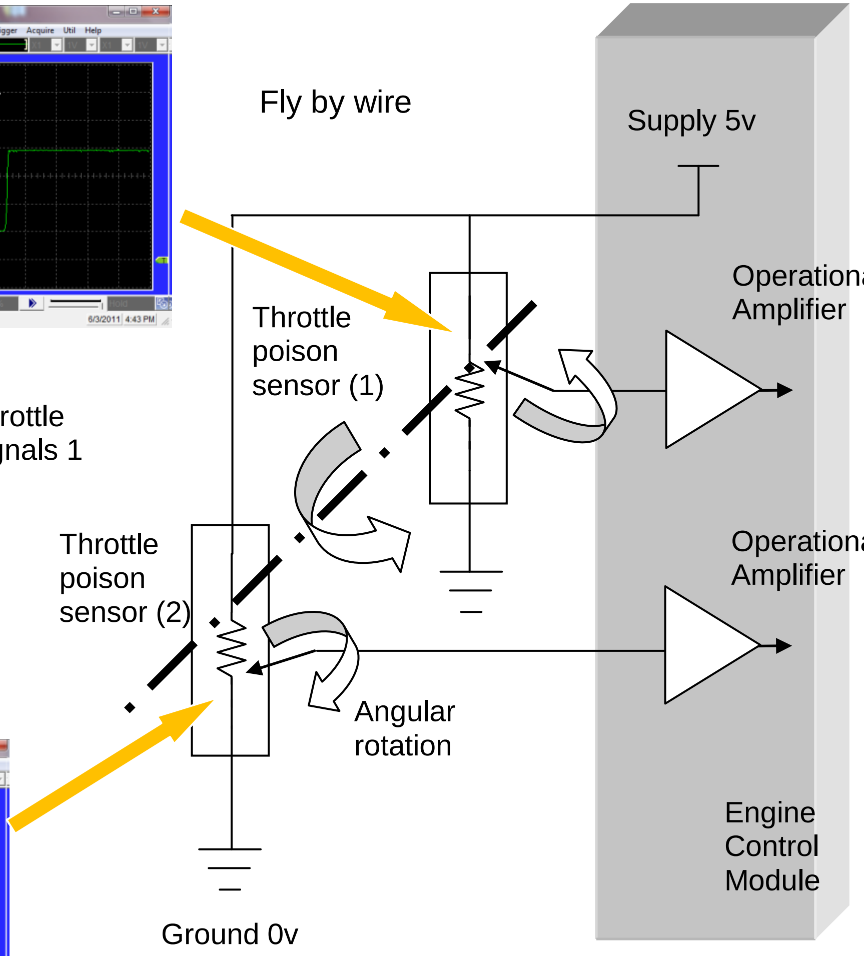
Fly By Wire – Throttle position sensor – Good scope patterns

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

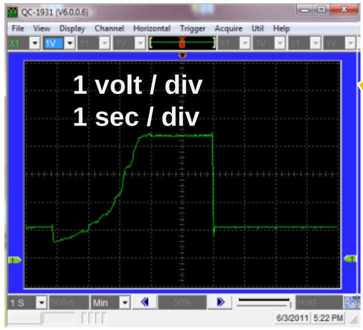




Superimposed Throttle poison sensor signals 1 and 2

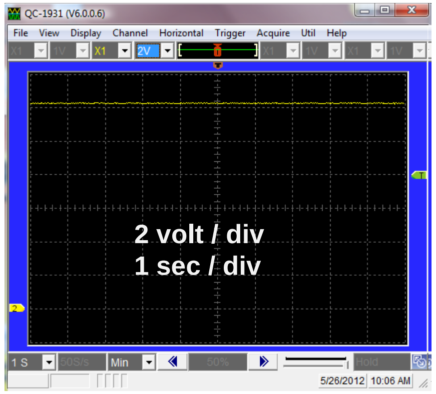


Throttle poison sensor (2) – as butterfly rotates clockwise voltage decreases proportionally.

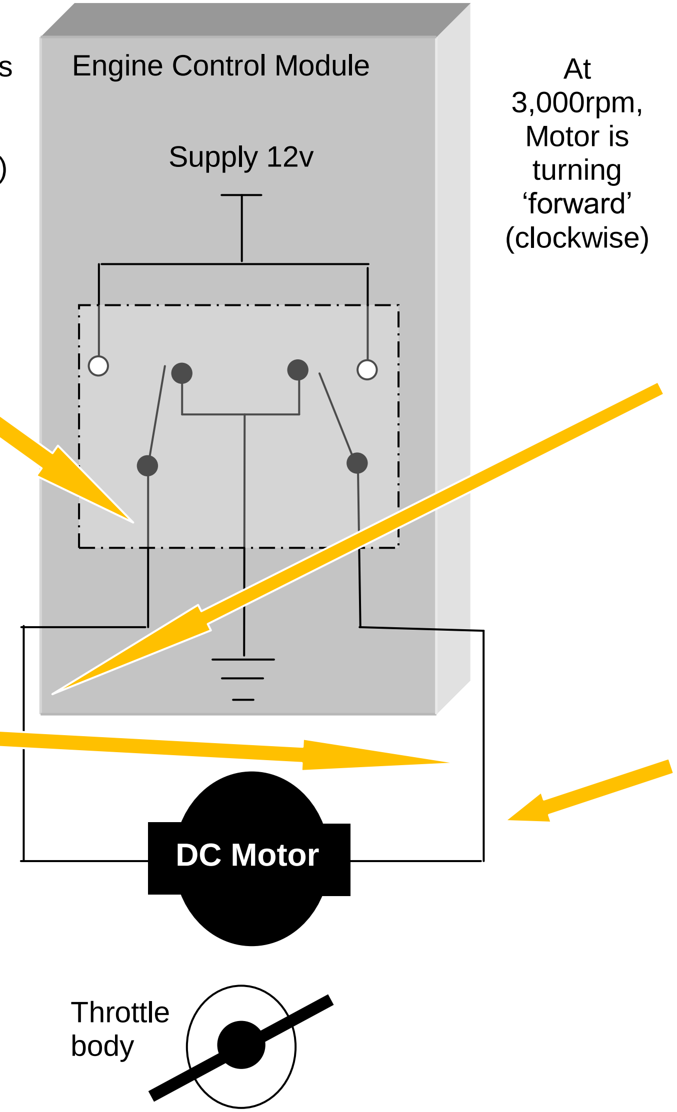


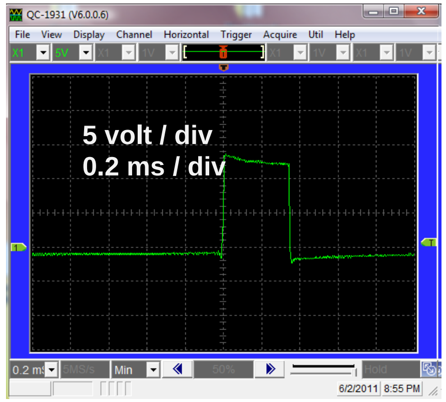
BA Ford – good scope pattern

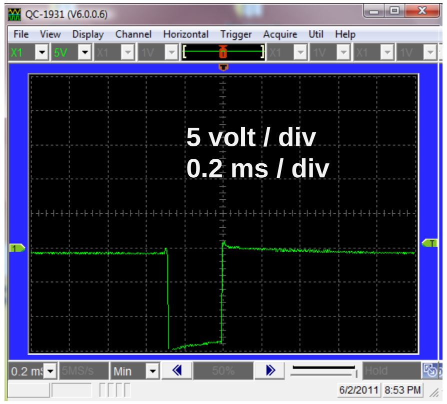
Throttle Body Actuator control

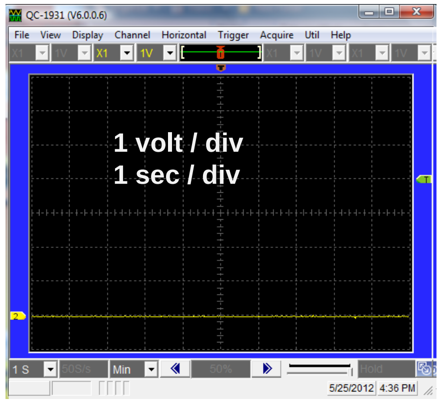


At idle, Motor is turning 'backward' (anticlockwise)





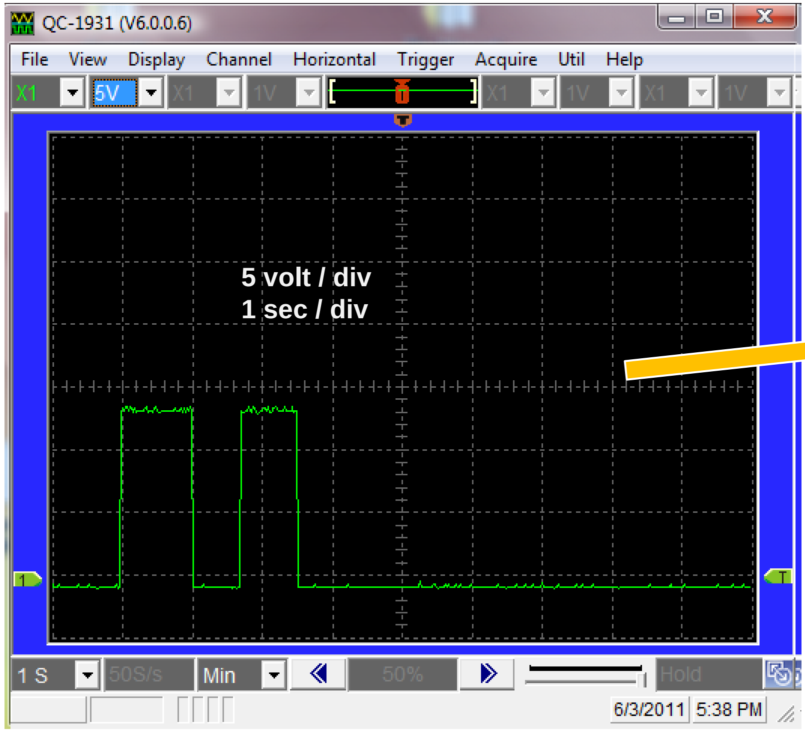




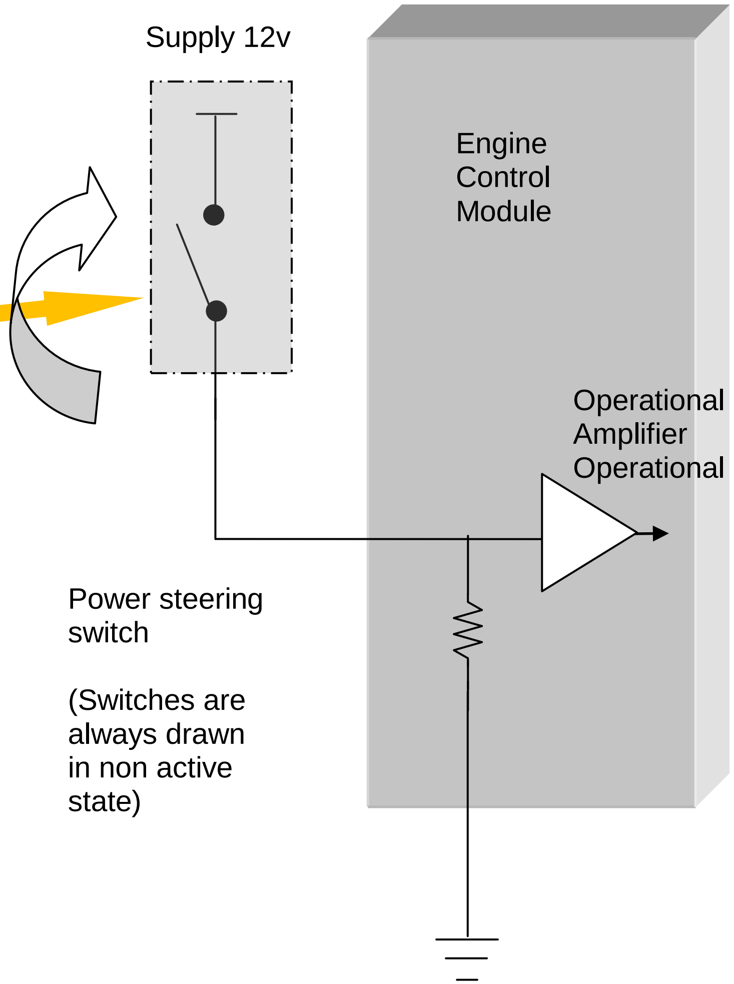
Throttle body butterfly is spring loaded and is held at rest position of 15% butterfly opening (1,800 rpm). Therefore, at 15% butterfly opening, the voltage across the two terminals of the actuator motor is ZERO volts

BA Ford – good scope pattern

Power steering switch – engine at idle

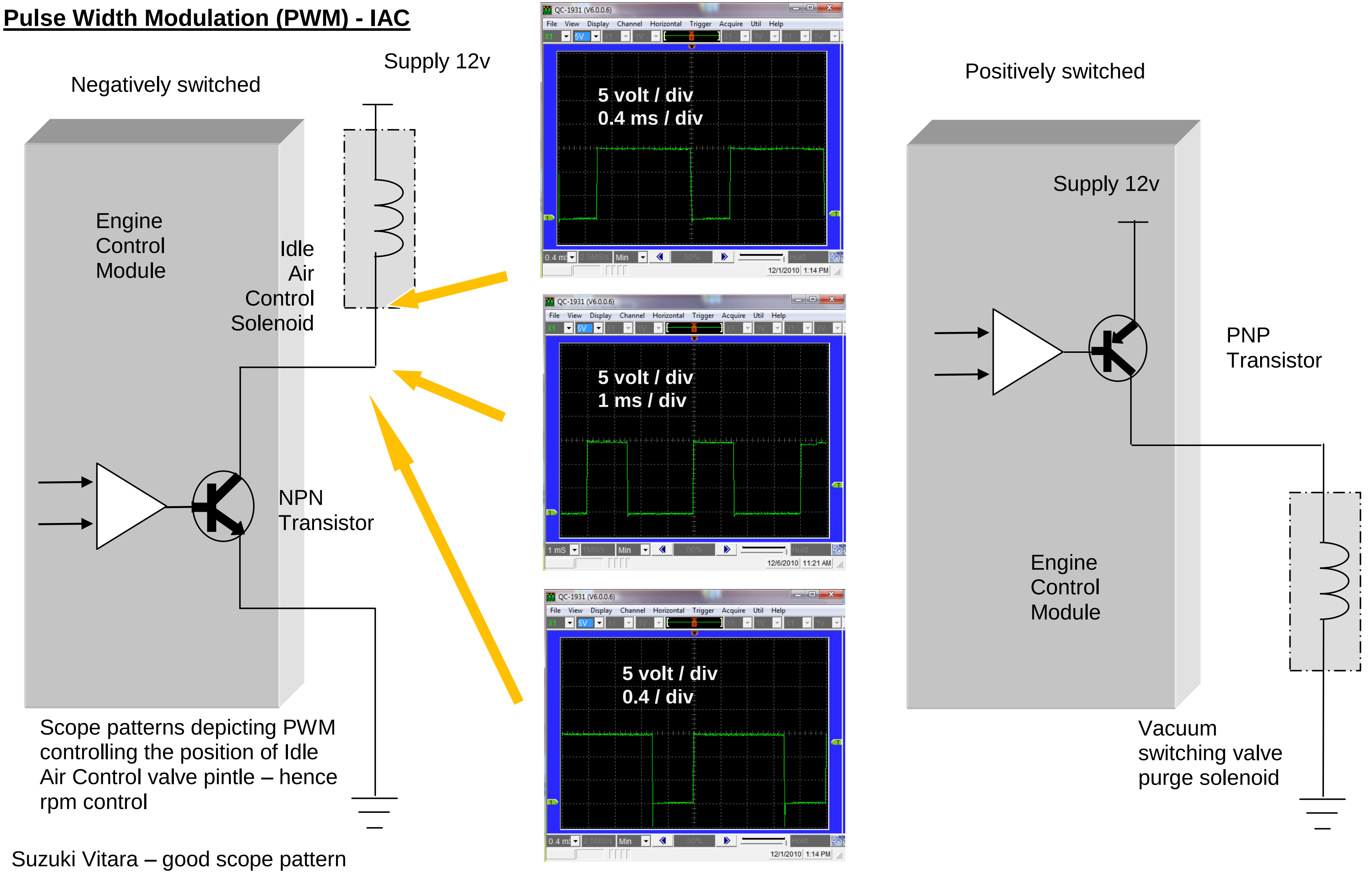


Power steering switch- Engine at idle, then as power assist is required, the switch is closed. The voltage is pulled up - to supply voltage. And as assist is no longer required, the switch is reverted to open position. The pull down resistor will then pull the voltage down to ground.



BA Ford – good scope pattern

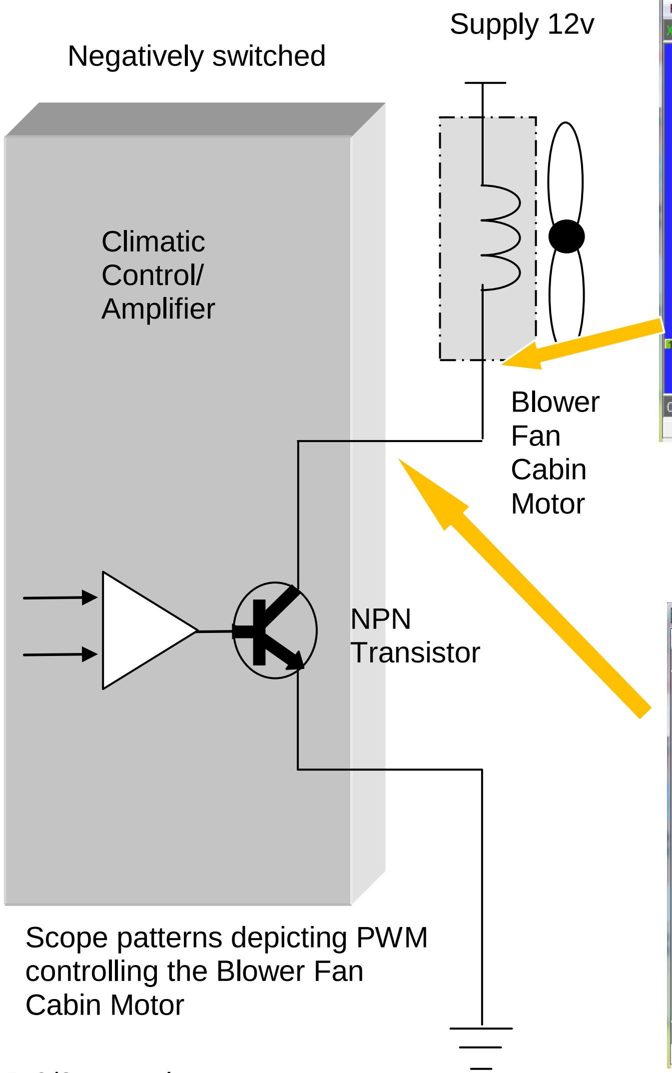
Pulse Width Modulation (PWM) - IAC

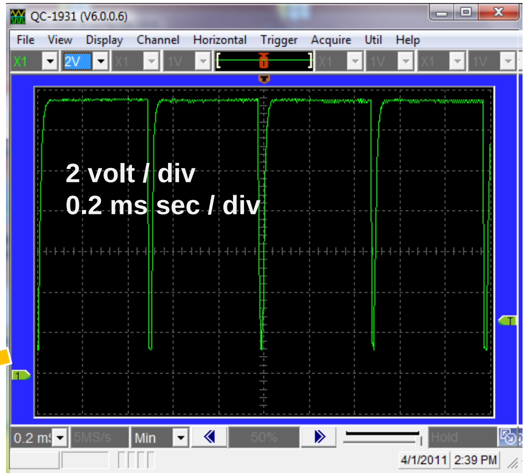


Scope patterns depicting PWM controlling the position of Idle Air Control valve pintle – hence rpm control

Suzuki Vitara – good scope pattern

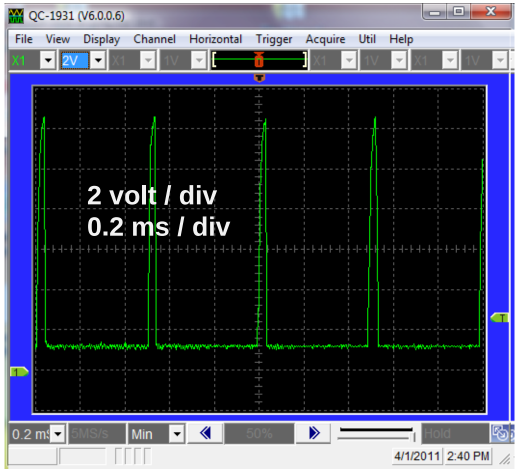
Pulse Width Modulation (PWM) – Blower motor



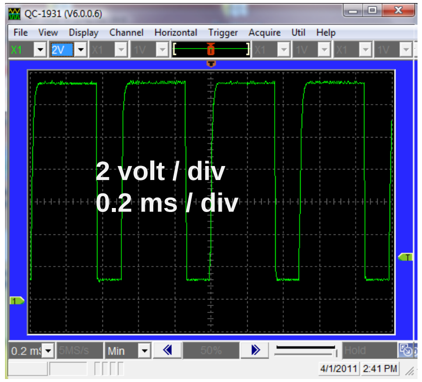


At lowest speed

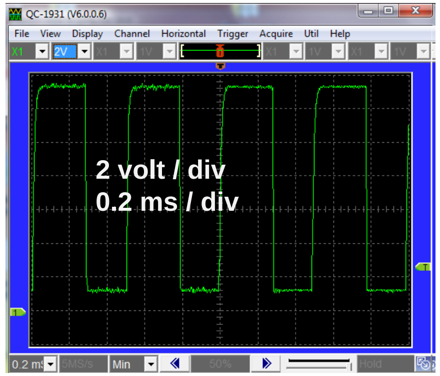
At highest speed



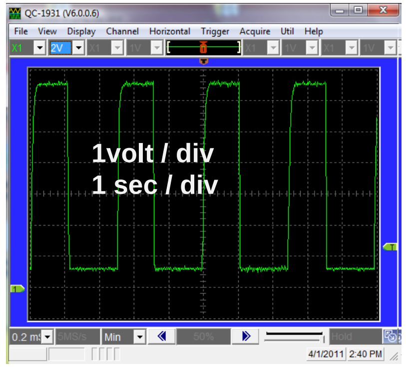
At 25%



At 50%



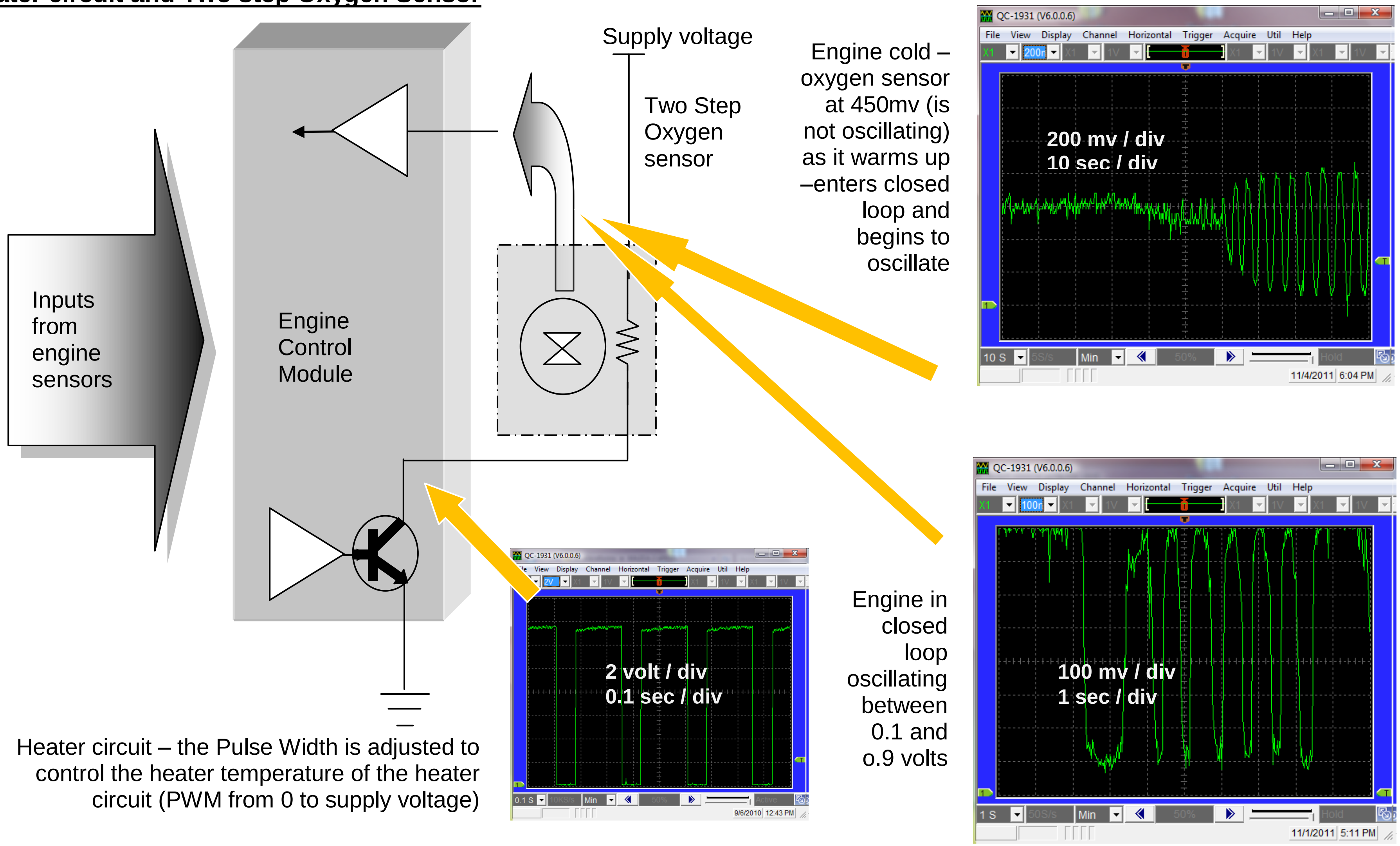
At 75%



Scope patterns depicting PWM controlling the Blower Fan Cabin Motor

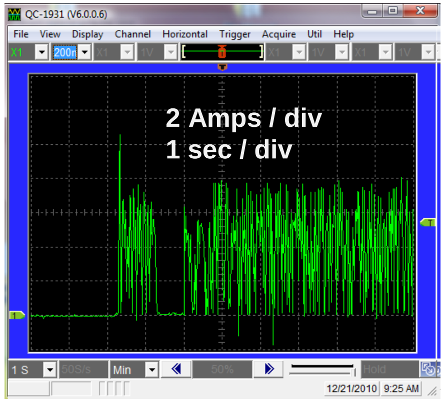
SAAB 9/3 – good scope pattern

Heater circuit and Two step Oxygen Sensor

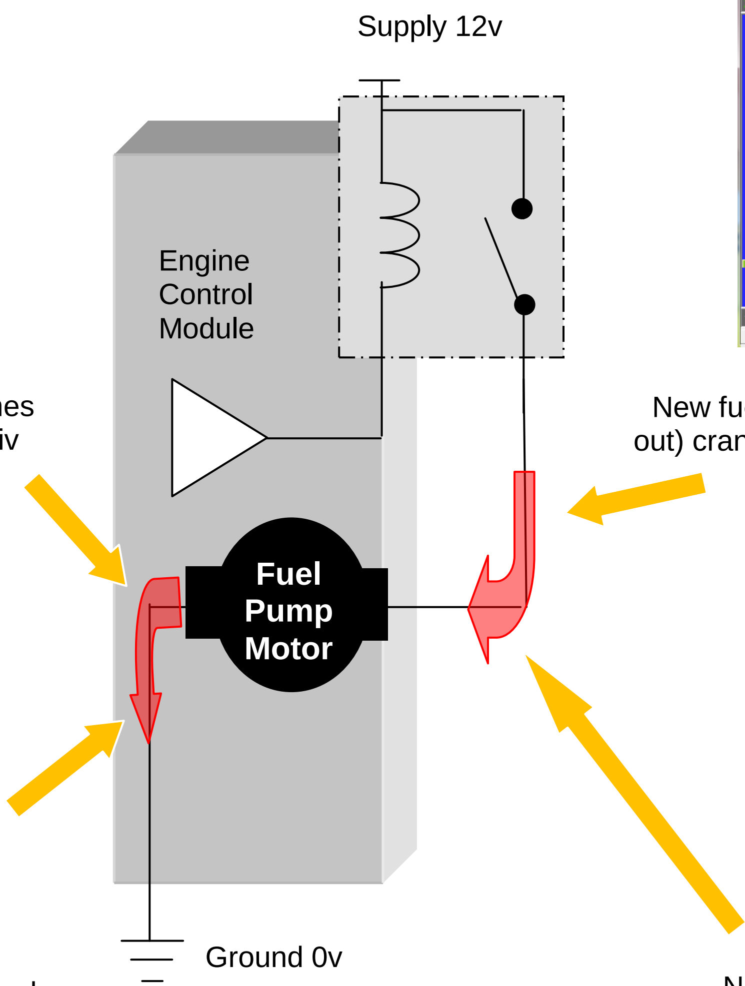


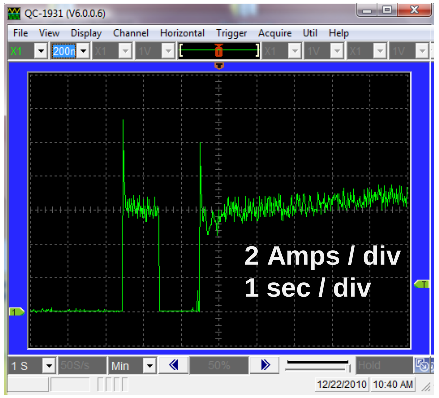
Mazda 2 - good scope pattern

Fuel pump current draw scope pattern – left depicting a faulty fuel pump. Right of a new pump

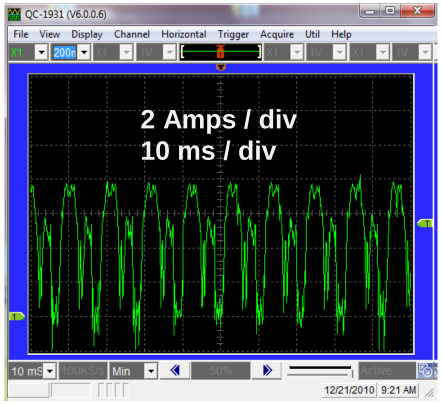


Old fuel pump – ignition off, then on (times out) crank run then ignition of 2A per div and 1 sec per div.

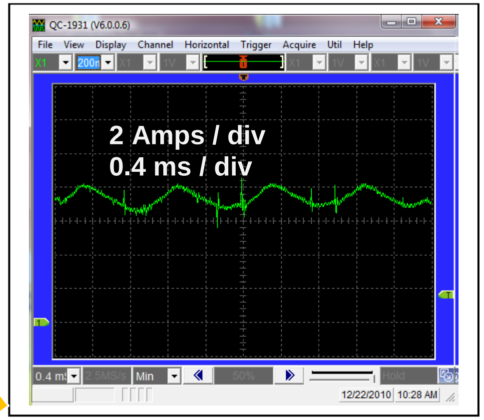




New fuel pump – ignition off, then on (times out) crank run then ignition of 2A per div and 1 sec per div.



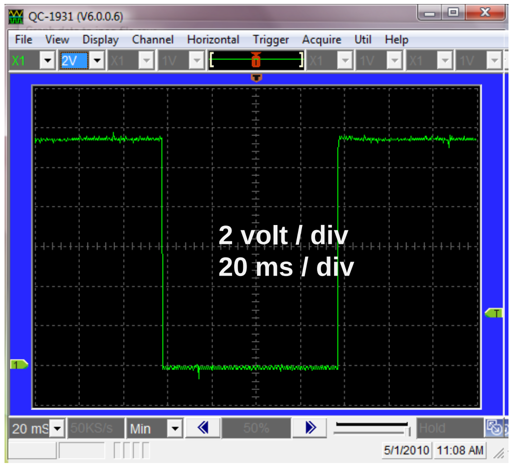
Old Pump – engine at idle 2A per div and 0.4ms per div



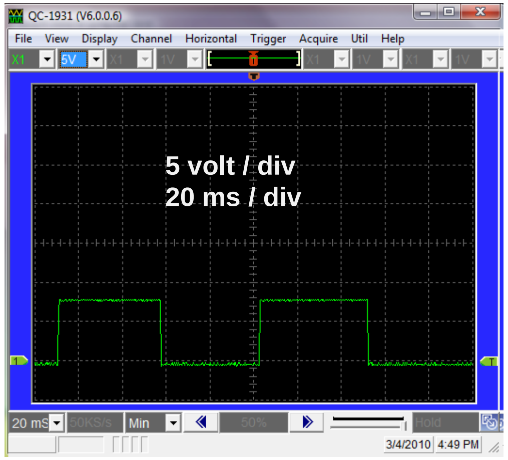
New Pump – engine at idle 2A per div and 0.4ms per div

Mazda 6

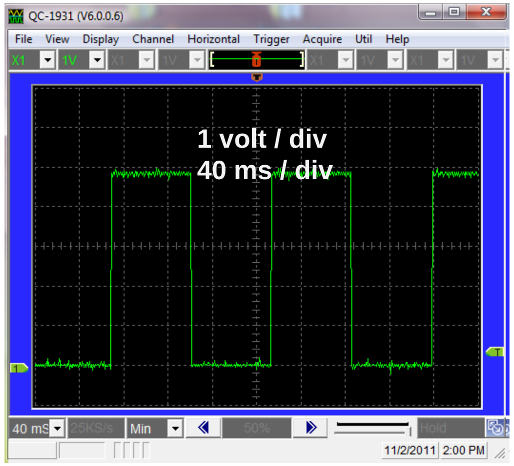
Variety of Hall Effect sensor signal waveforms – good scope patterns



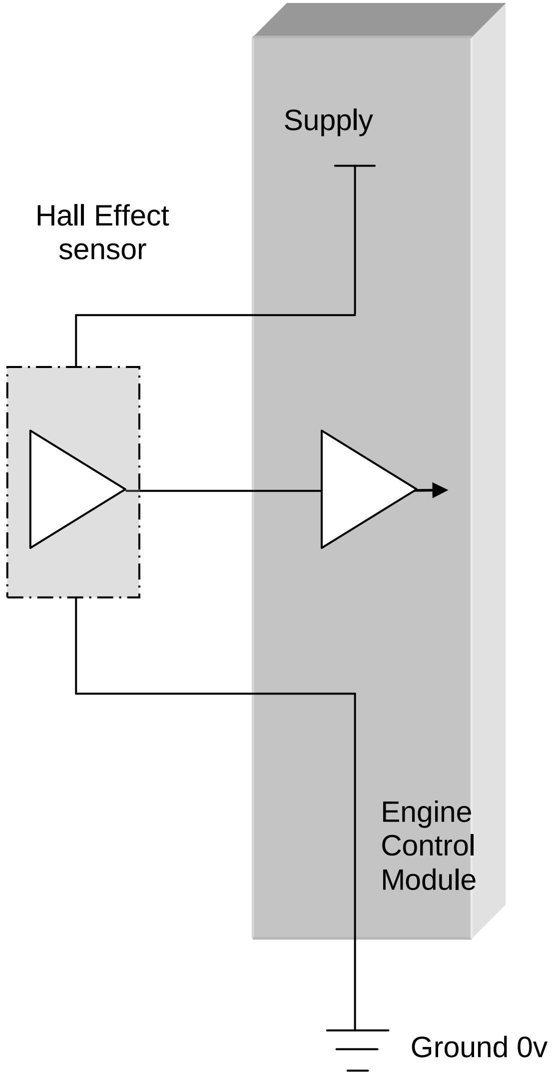
Mercedes Benz C180 – CAM lobe



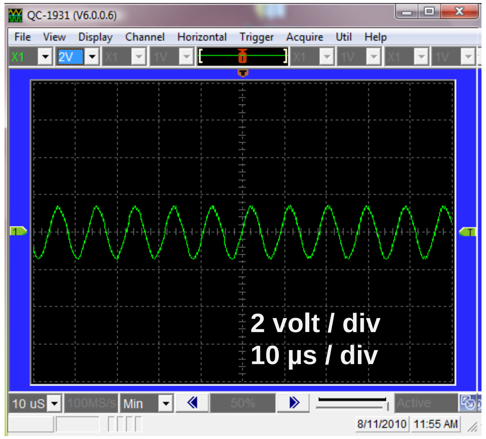
Ford AU – transmission output



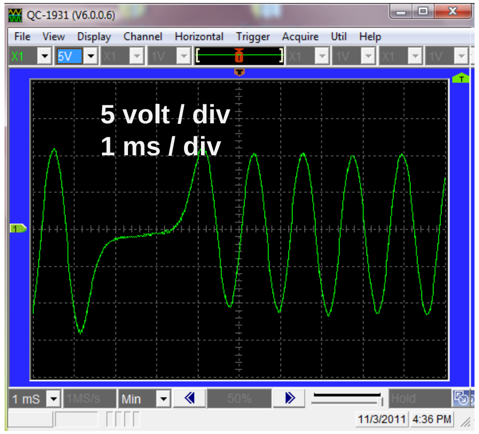
Holden TS Astra – Cam Shaft



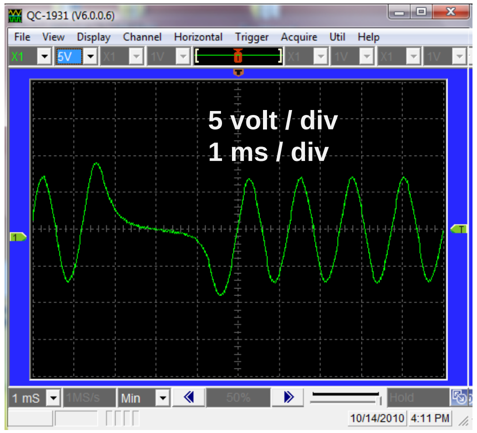
Variety of magnetic sensor signal waveforms – good scope patterns



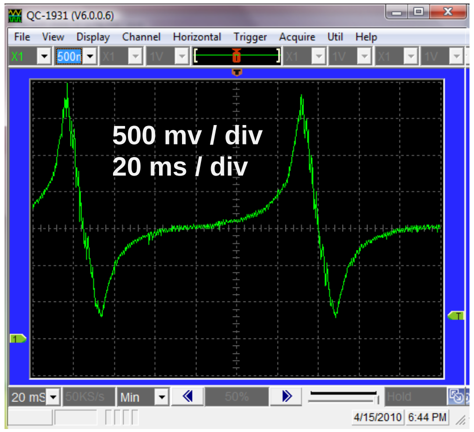
Holden Vectra JS – Cam shaft



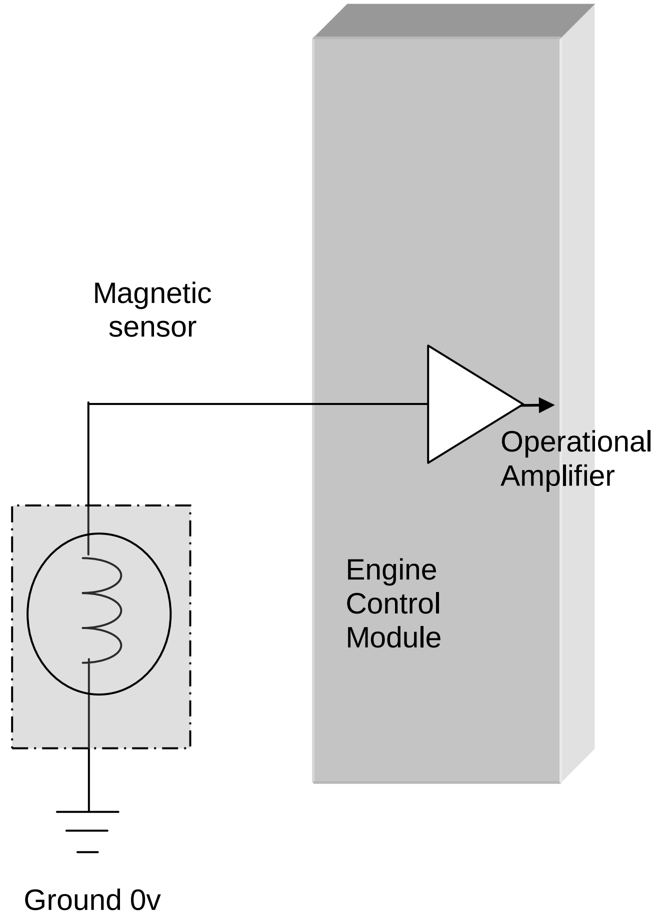
Hyundai Excel – crank angle



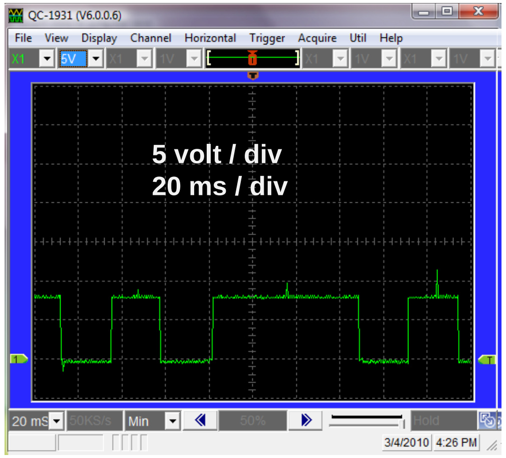
VW Golf – crank angle sensor



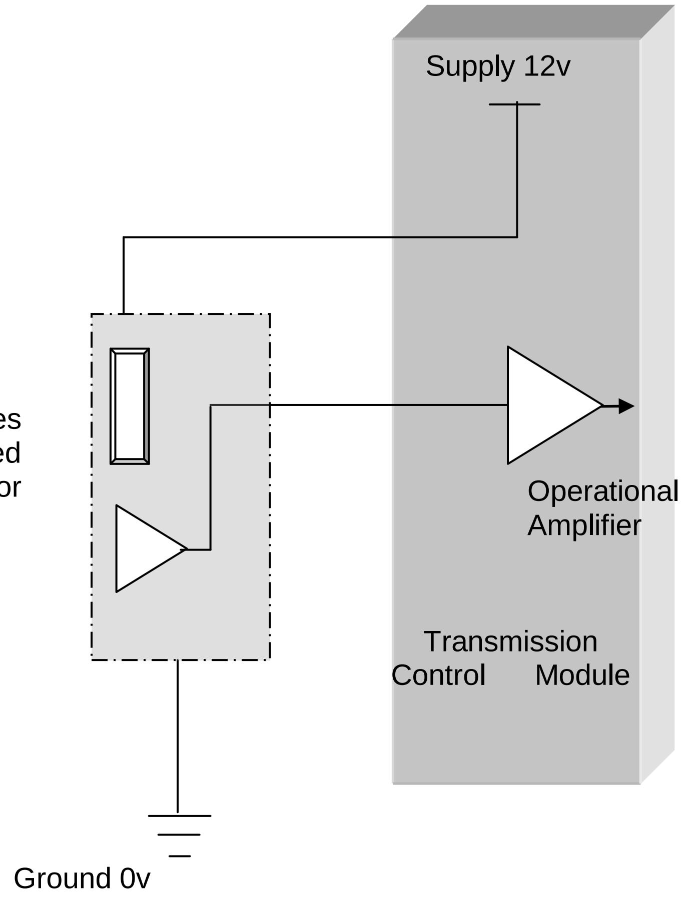
Ford KH Laser – pick up in distributor

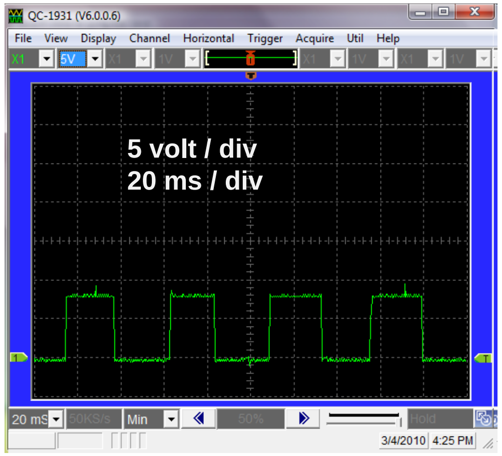


Transmission output speed sensor – upper scope pattern faulty, lower scope pattern Good



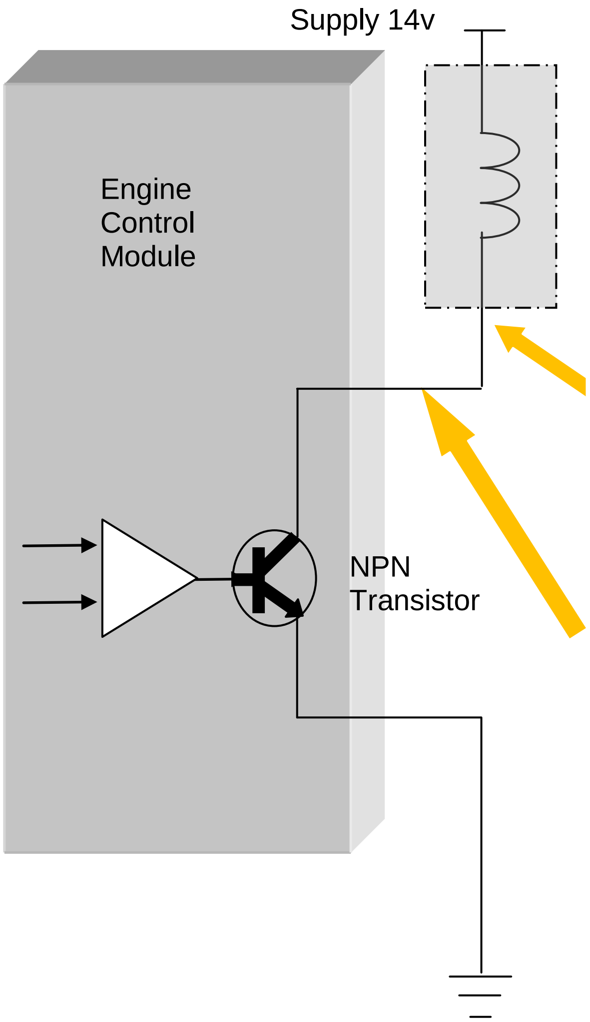
3 Wires
Hall Effect output speed
sensor



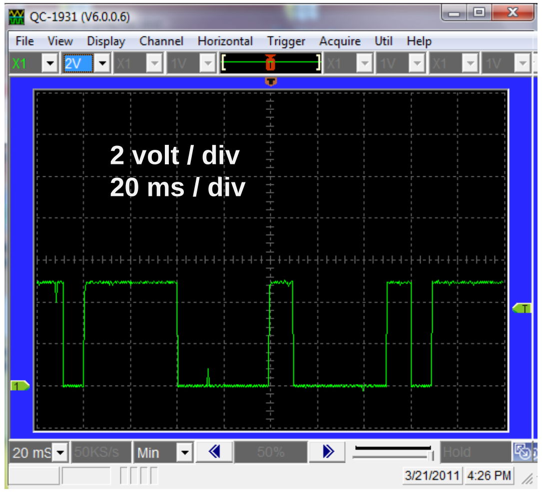


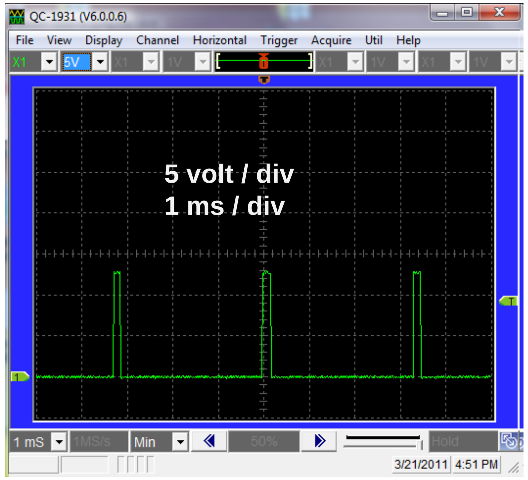
Ford AU - lower scope pattern - good

Variable Valve Timing Control (VVT control)

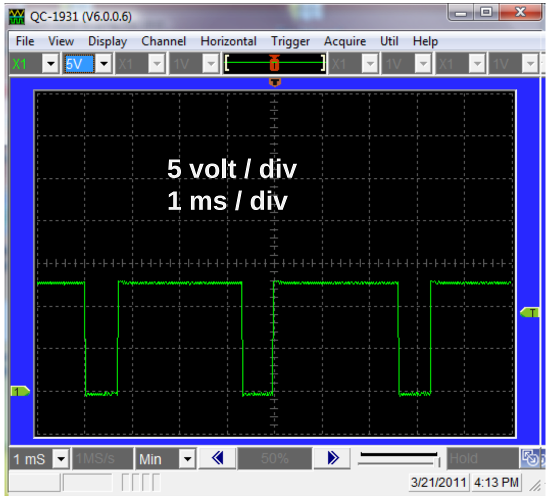


Engine crank and run – at idle





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

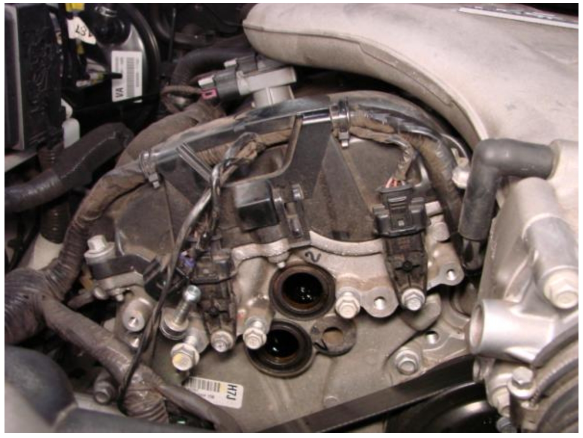


Engine at 2,000rpm

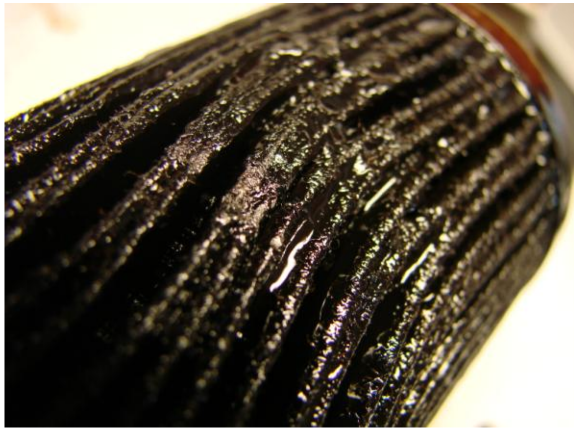
VE Ute – Good scope patterns

Variable Valve Timing Control (VVT control)

DTC – Implausible variable cam shaft timing control



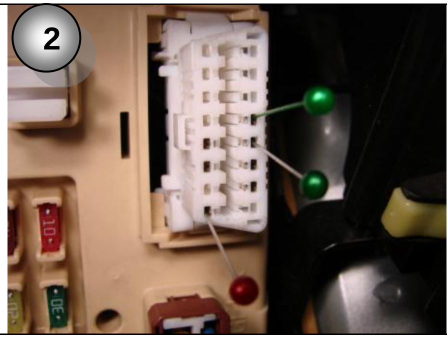


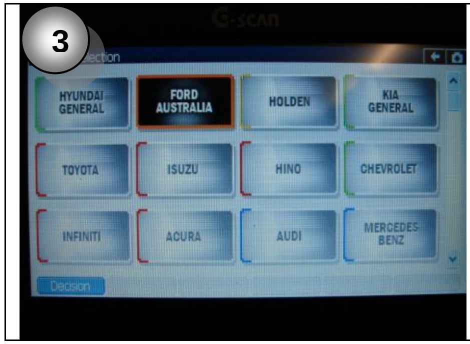
VE Ute

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

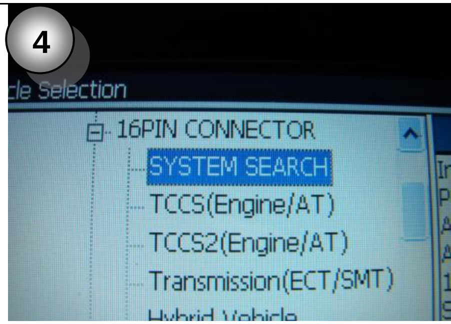
Plug scan tool, turn ignition ON and power up scan tool. Does it power up! Then go to step 3, if NOT go to step 2



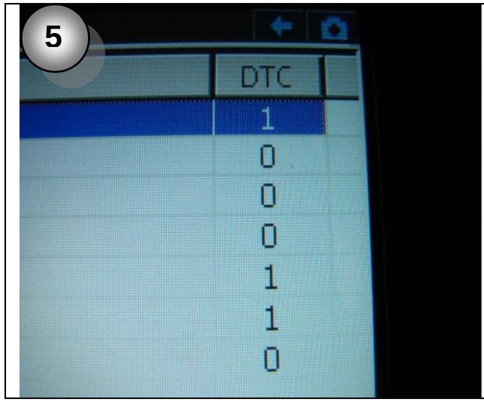
Check DLC Supply and grounds (pin 16 for supply and pins 4 & 5 for grounds)



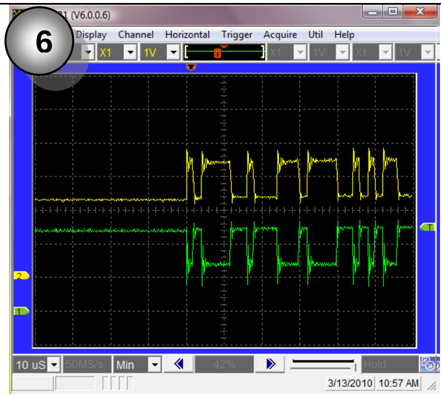
Select Make, year, model and follow prompts. Should there be communication error then check DLC pin 6 and 14 for CAN BUS communication signals. If NOT go to step 4



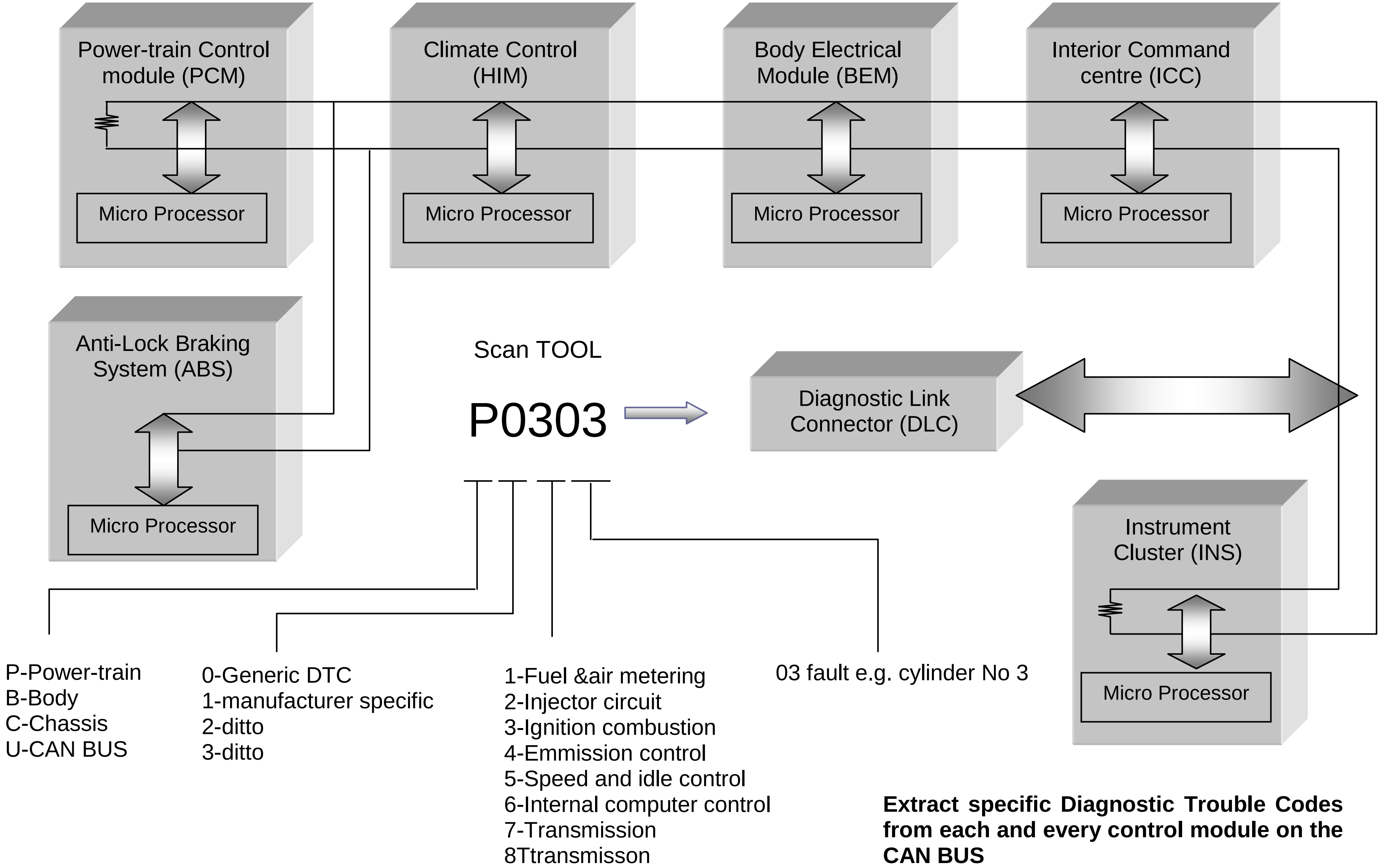
Carry out system search - and decipher as to which control units (on the BUS) are able to communicate with the scan tool. Should all control units be present then go to step 5, if NOT then go to step 6



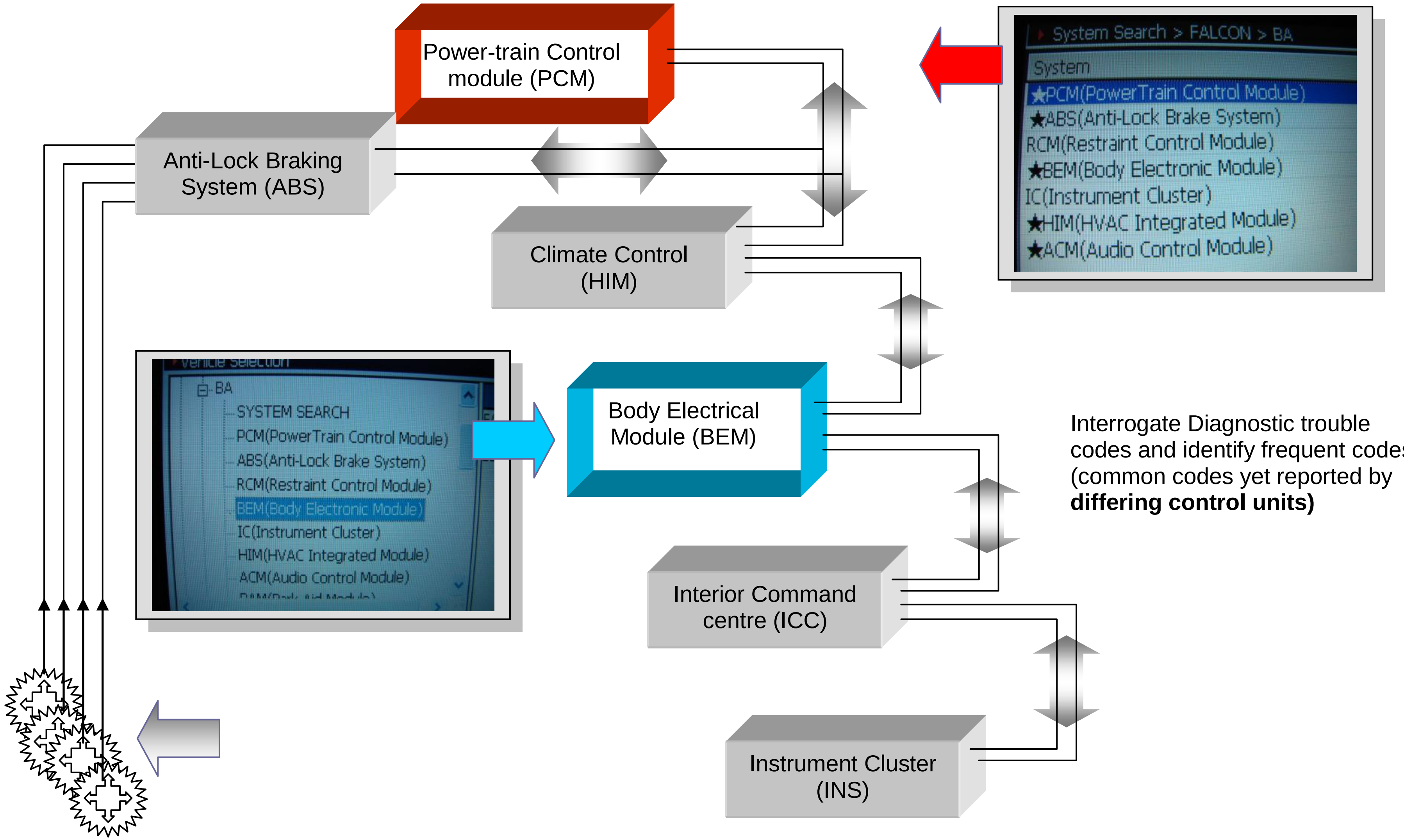
Extract specific Diagnostic Trouble Codes from each and every control module on the CAN BUS and determine whether it is CAN BUS issue and or specific sensor to a control module



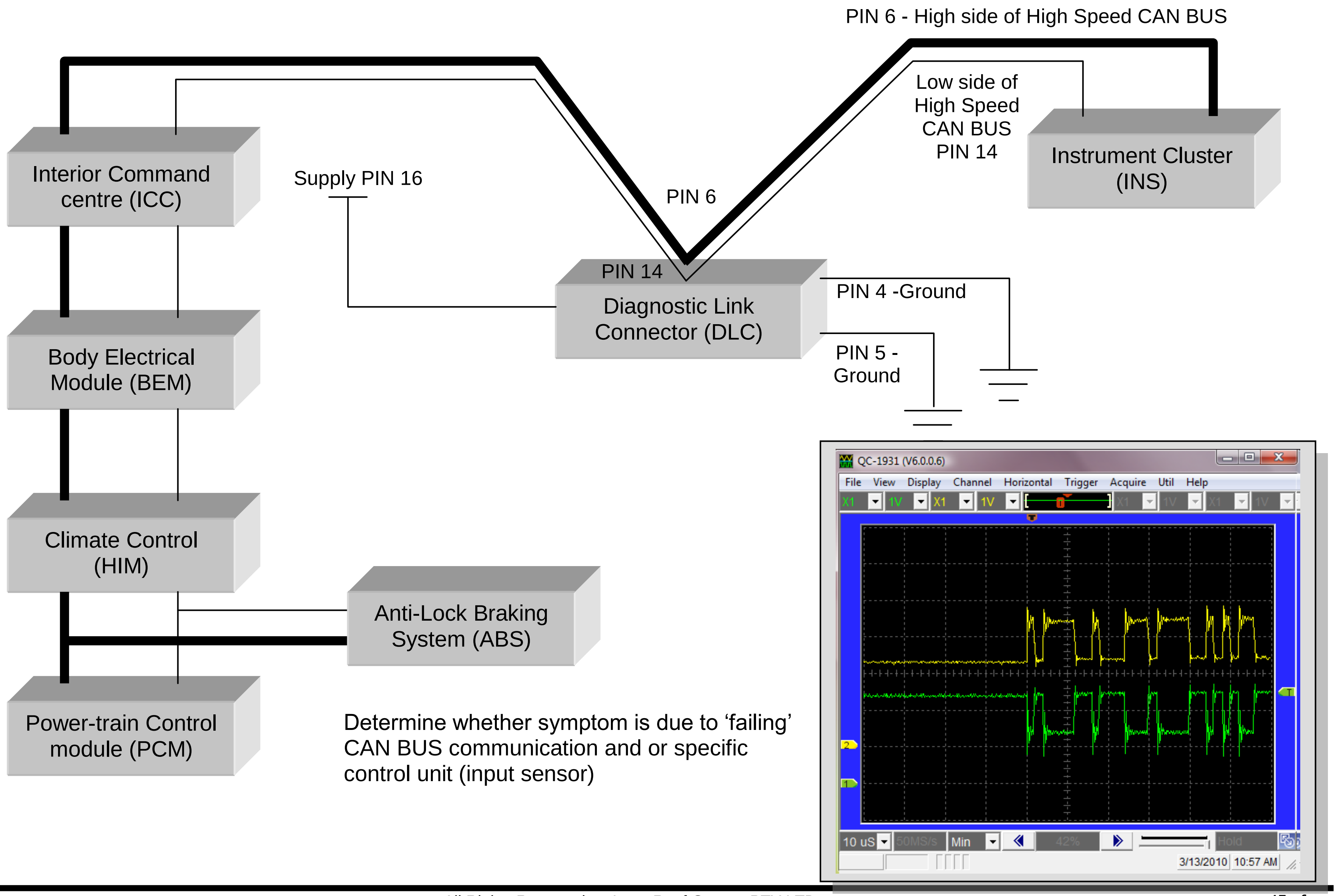
Identify control unit that has failed to communicate and check supplies grounds. Then communication signal wires/terminals



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



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%203%20-%202009.pdf
http://www.hobbyprojects.com/oscilloscope_tutorial/measurement_terms.html
http://cp.literature.agilent.com/litweb/pdf/5989-8064EN.pdf
http://courses.washington.edu/phys431/scope_ex/scope_ex.pdf
http://www.picoauto.com/waveforms/Ignition/Secondary/wave85.html
http://www.flashcardmachine.com/automotive-waveforms.html
http://ecee.colorado.edu/~mcclurel/txyzscopes.pdf
http://www.picotech.com/education/oscilloscopes/advanced-triggering.html
http://autoclub.atilim.edu.tr/dokuman/Automotive%20Electrical%20and%20Electronic%20Systems/Chapter11.pdf
http://www.dtec.net.au/Multi%20Spark%20Ignition.htm

Notes: