

Anti-Lock Braking Systems



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1. Introduction:

Anti-lock braking system is a combination of hydromechanical braking components with switching solenoids and relays that operate the brakes based on wheel and vehicle speed information. This paper will define the operation of ABS and its components and describe the diagnostic techniques and troubleshooting of this system, this will be achieved by investigating 2 abs rigs (i.e. Bosch 2EH and Teves Mark IV) located at the university engine Laboratory. Both systems have been tested using oscilloscope where multiple waveforms have been recorded for further investigation and fault detection. Furthermore, this assignment will discuss a systematic procedure to trouble-shoot a Teves Mark IV abs that has indicated a malfunction as the abs warning light stays on. Briefly at the end, the report will highlight the main differences between bosch 2EH and Teves Mark IV systems and also the strength and weaknesses of both Anti-lock braking systems.

2. ABS overview and troubleshooting:

Anti-lock braking system prevent the wheels from locking during panic or emergency braking or heavy braking situations in general, therefore it enables the driver to keep steerability of the vehicle. (Hillier, 2014). The components of an abs are, wheel-speed sensor which reads the rotation of the wheel and sends back a voltage to the ecu, the ecu will convert that voltage to a corresponding speed and subsequently, use it to determine wheel lock-up; ABS modulator unit which controls the amount of pressure going to the brake calipers of each wheel; Valves and Pump and its purpose is to control the fluid movement; ABS electronic control unit (ECU) which controls the system by making constant calculations and commanding the modulator unit to increase/decrease/maintain the braking pressure. When the ECU detects that wheels locking may occur, it activates the modulator unit to operate one of its valves, when the valve is activated it releases the pressure on the brakes of the wheel which are about to lock, the ecu will then calculate precisely the barking force this wheel needs and send a signal to the modulator to reopen the valve to allow pressure to be applied again until the maximum traction point is exceeded. This cycle will keep happening over and over to keep the grip and stability with the pressure release-apply-release-apply sequence happening at up to 16 times per second.(Josh Smith. 2014).

A vehicle fitted with an abs system is designed to notify the driver with a warning lamp if there is a malfunction in the system, the system rarely detects a fault on the abs Module or electronic control unit. It is often sensors or wiring problems, commonly the sensors as they become contaminated with debris or metal shavings. This also has been mentioned by Allan Bonnick 'Fortunately ECUs are normally very reliable and most of the testing that need to be done is on components that rely on conventional technology for their operation.' If the sensor wiring becomes damaged it will also activate the malfunction light as that will results intermittent or no continuity between the sensor and the ECU. Therefore, it is advised to physically check all wiring and abs sensors first when the malfunction occur. A damaged tooth on the abs reluctor will also cause a fault on the abs system because this will result misreading of wheel speed which is information that is critical in order for the abs system to operate effectively.

3. Methodology and test outcomes:

3.1 Safe work procedures:

Health and safety within engineering workshop is a legal requirement for any engineering company or university, this is subjected to a number of multiple risk assessments and safe codes of working practices which have to be enforced by the responsible authorities and constantly followed by the employees/students when working inside workshop areas. Therefore, due to the high-risk activities taking place in the workshops, all students at university are restricted from performing any type of work until they have successfully completed the workshop induction course online, thus, to ensure all students are aware of the safe work procedures such as wearing the appropriate personal protective equipment (PPE).

The primary legislation and policies in Great Britain are set by the government in the Health and Safety at Work etc Act 1974 (HSWA) and published online by the health and safety executive (HSE) for each organisation to review and follow. (hse.gov.uk[online]). This Act is set as introduced in the book, to make further provision for securing the health, safety and welfare of employees, for protecting others against risks to health and safety while performing their job, and to control certain emissions into the atmosphere.(Health and Safety at Work etc Act 1974). Every company (small or large) and university is required to have a specific health and safety policy and this must be easily accessible to all employee/students.

3.2 Investigation process:

A group of 5 students carried out a system operation test of two antilock braking systems (ABS), first abs included Bosch 2EH and the second system consisted of Teves Mk IV, precisely the investigation was performed on the electronic control unit. The testing session lasted for 90 minutes at the engine laboratory utilising a high-performance oscilloscope (Bosch FSA-740), which can provide accurate reading during deep interpretation. This system is aided with a measurement module and a PC system in trolley that is capable of displaying coloured waveforms on a VGA monitor and can be frozen or recalled looking for intermittent faults. Furthermore, the station also linked to a standard printer which was used in this investigation to obtain hard copies of abs waveforms from the testing performed on both Bosch and Teves systems. (Denton. 2000).

The testing of both Bosch ABS 2EH and Teves Mk IV ABS started with the systems under non-dynamic condition (Ignition-off) where all the pins have been tested using the oscilloscope probes to ensure the systems have no faults prior to the live dynamic testing. Next phase was to test the systems with Ignition-on and under dynamic condition (system-running) respectively in order to observe the change in voltage that occur between those two conditions. During the dynamic testing and while probing on the bosch solenoid pins, the system was set to cause an abs intervention by changing the speed of one wheel and that to investigate the drop in voltage which happen in the solenoid during the two phases of abs intervention. However, the Teves abs solenoids could not be tested as they were inaccessible (internally installed) but the principle is the same as demonstrated in the bosch system which is a drop in voltage within the solenoid at every abs intervention.

3.3 Results interpretation:

When carrying out the testing of electronic control units of both antilock braking systems, voltages of all pins was recorder during three conditions: Ignition-off; Ignition-on; System-running. Furthermore, multiples waveforms were printed for deep investigation concerning wheel speed sensors signal and ground, brake light switch, and abs solenoids voltages.

- Bosch ABS 2EH:

the table below contains all pins identification, that information has been handed-in during the testing session along with the ECU diagram to aid on the investigation procedures (Appendix 1).

Pin N	Identification
1	ABS warning lamp
2	Wheel speed ground
4	Wheel speed signal
5	Wheel speed ground
6	Wheel speed signal
7	Wheel speed ground
9	Brake light switch
10	Wheel speed signal
12	Serial data wire
13	Wheel speed signal
14	Wheel speed ground
15	Diagnostic lead
4 Pins Pack	
1	Ignition key
2	Over arch relay
3	Earth
4	Light
Solenoids	Pins
Black	Front solenoid
Yellow	//
Black	Front solenoid
Yellow	//
Black	Rear solenoid
Green	//

Figure 1 Bosch Pins identification table

Pin Number	(ignition-off)	(ignition-on)	(system-running)
1	0v	12.5v	12.25v
2	0v	0.22v	0.23v
4	0v	0.35v	0.35v
5	0v	0.22v	0.23v
6	0v	0.35v	0.35v
7	0v	0.22v	0.23v
9	0v	12.3v	12.3v
10	0v	0.35v	0.35v
12	0v	11.13v	11.09v
13	0v	0.35v	0.35
14	0v	0.22v	0.23v
15	0v	0.25v	0.36v

4 Pins Pack			
1	0v	12.37v	12.37v
2	0v	12.6v	12.6v
3	0v	0.04v	0.04v
4	0v	12.3v	12.3v
Solenoids	Pins		
Black	0v	12.5v	12.5v
Yellow	0v	12.5v	12.5v
Black	0v	12.5v	12.5v
Yellow	0v	12.5v	12.5v
Black	0v	12.5v	12.5v
Green	0v	12.5v	12.5v

Figure 2 Bosch Testing voltages Table

After checking all ECU pins at ignition-off and ensuring there was no faults in the circuit as the results show zero voltage in the hall system, the ignition turned on and a permillage testing was conducted when more than 12volts (battery voltage) was confirmed in pins such as ignition key; brake light switch; abs warning lamp; and other pins as presented on the table above, also a potential voltage between 0.2v and 0.4v was verified in wheel speed signal and wheel speed ground (AC signal output).

Abs warning lamp voltage is not changing (12.5v) in both static and dynamic conditions, but it is grounded in case faults occurs. If the voltage of wheel speed signal (0.35v) change that will cause the abs intervention as this will read as a wheel speed change in the control unit. Under abs intervention the voltage in brake light switch will drops from 12.3v to 8.9v. The increase of voltage in diagnostic lead from static (0.25v) to dynamic (0.36) represent the data. During abs intervention, solenoid voltage drops from 12.5v to 9.5v at stage one of the intervention and to 5.5v at stage two.

- Teves Mk IV ABS:

same with the Teves ABS, the pins identification table is presented below and also a ford puma ECU diagram which can be found in Appendix 2.

Pin N	Identification
1	Wheel speed ground
2	Wheel speed ground
7	Memory permanent live
8	Earth
9	Ignition live
10	Wheel speed ground
11	Wheel speed ground
12	Ignition live

13	Data link
16	Lamp
17	Wheel speed signal
18	Wheel speed signal
19	Wheel speed signal
20	Wheel speed signal
24	Earth
25	Permanent live

Figure 3 Teves Pins identification table

Pin Number	(ignition-off)	(ignition-on)	(system-running)
1	0v	2.3v	2.6v
2	0v	2.3v	2.6v
7	12.6v	12.6v	12.6v
8	0v	0v	0v
9	0v	12.6v	12.6v
10	0v	2.3v	2.6v
11	0v	2.3v	2.6v
12	0v	12.6v	12.6v
13	9.86v	9.86v	9.7v
16	0v	12.6v	12.6v
17	0v	2.3v	2.6v
18	0v	2.3v	2.6v
19	0v	2.3v	2.6v
20	0v	2.3v	2.6v
24	0v	0v	0v
25	12.6v	12.6v	12.6v

Figure 4 Teves Testing voltages Table

The testing procedures conducted on Teves Mk IV abs are same as the bosch abs. However, during ignition-off pin13 and pin25 shows battery voltage, that because both of the pins represent the permanent live which is used to keep the memory alive at all conditions. Data link (pin13) also shows 9.86v during ignition-off and that to power the reader unit (this also can be found in the EOBD systems).

3.4 Waveforms Analysis:

Below is a technical investigation of the waveforms obtained during the abs testing using Bosch FSA-740 diagnostic system.

○ Appendix 3:

The waveform in this appendix represents the wheel speed sensor (WSS) signal and WSS ground, those outputs has been obtained by measuring from the two terminals of bosch 2EH abs wheel sensor (located in the ECU plug). The sensor is made of coil

and a permanent magnet, the rotation of the pinion (reluctor ring with teeth) which is fitted at each wheel induce this AC voltage (varying voltage or emf) due to the variation of the magnetic force picked-up by the sensor coil. A voltage of 1.1v/-0.3v is shown in this testing as captured by the oscilloscope during a certain speed, this voltage and frequency will increase as the wheel speed increases. (Allan, 1998). Based on functionality, wheel speed sensors are divided into two types (Active and passive sensors), the WSS used in the abs tested was 'Passive' sensor, the sensor signal is transmitted to the Control Unit via power supply wire in a form of a current signal using pulse width modulation, and based on the wheel speed information the ECU will then decide if an ABS intervention is required and the best course of action for the hydraulic modulator through the calculation of brake slip and the acceleration or deceleration of each individual wheel. (Hella. 2018,'Wheel speed sensors in motor vehicles').

The wave pattern will indicate problems that may be on the abs reluctor (wear on teeth), this will be identified by observing the voltages and the frequency of the signal. In a test performed during this investigation, the abs reluctor was found to operate perfectly with no damages and that have been achieved by comparing the signal obtained to the signal presented on Ditetex article of anti-lock braking system. The article explains how to exactly detect mechanical failure if any of

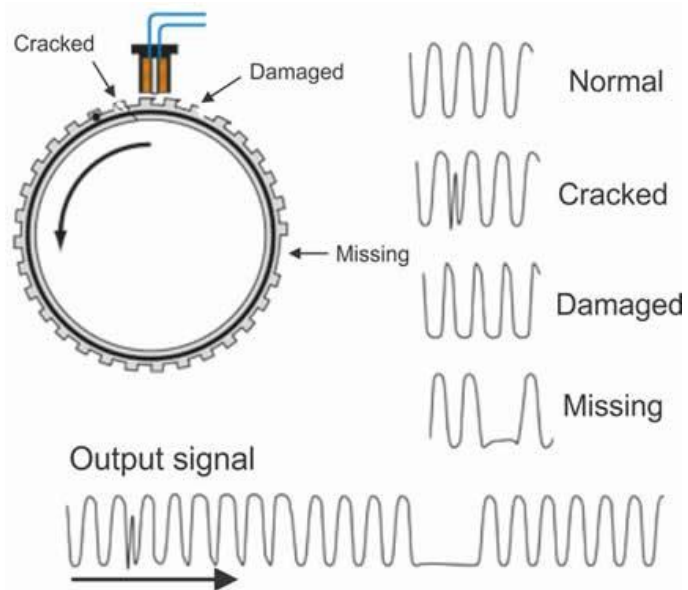


Figure 5: Reluctor teeth problems (autoditex.com)

the teeth is missing, damaged or cracked, the image presented here demonstrate how the issue can be investigated. (Ditex, [Online]).

○ Appendix 4:

The waveform on this appendix represents the brake light switch voltage which is measured to be 11.1v (should be battery supply voltage but due to the system being operating without alternator, the voltage drops in the battery during the investigation period). The switch shows supply voltage when the brakes are applied. However, it can be noticed that the voltage drops to 6.7v after brake was applied, that drop-in

voltage occurs due to the abs intervention because when the pump motor is energized to operate during the last phase of abs intervention, a substantial amount of energy was consumed to turn-on the pump motor system which then effected the circuit voltage, even if the testing was performed in a complete vehicle, all circuitry will be effected due to the amount of loading on the pump motor.

The brake light switch has two major functions, the first includes turning on the brake light when the brakes are applied, and the second encompasses sending a signal to the electronic brake control module (EBCM), which monitors the speed of each wheel, the input signal of the brake switch is one of the major inputs received on the EBCM system to aid on identifying when the wheel is about to lock. (Jones & Bartlett. 2014).

○ Appendix 5:

The waveform in appendix5 represents the drop in voltage from 12.5v (Battery) to 9.7v which happens within the solenoid circuit during the first phase of abs intervention.

Specifically, when the inlet valve inside the solenoid is closed as the degree of brake slip increase and that to maintain the pressure at the brakes and stop any additional pressure coming from the master cylinder toward the brakes 'the solenoid valves is switched to the maintain pressure (pressure-holding phase) setting. The connection between the master cylinder and the brakes is shut off as the inlet valve is closed so that any increase of pressure in the master cylinder does not lead to a pressure increase at the brakes.'(Heinz-Jurgen, 2014).

In order to interrupt the connection between

the brake master cylinder and the wheel brake cylinder, the system applies 50% of current (holding current) to winding at the wheel and the armature then responds by shifting until the input valve is closed.(A.Stegmaier. 1995).

○ Appendix 6:

The waveform represents the second drop in voltage occurs at the rear solenoid, voltage drops to 5.7v due to the second phase of abs intervention. At this stage the

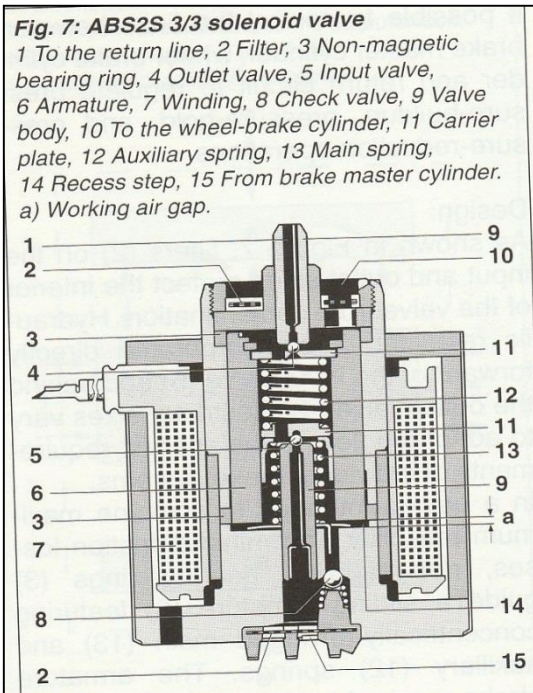


Figure 6 ABS solenoid valve (Bosch Automotive brake systems. 1995)

electronic control unit detect that the degree of slip at any of the wheels increases more and that even after the first stage of abs intervention, therefore the ecu must react further by reducing the pressure at the concerned wheel. To achieve this, the hydraulic modulator controls the outlet valve by switching it to the 'pressure release' setting, the outlet valve will be open at this stage to enable the return pump to release the fluid from the brake concerned in a controlled manner. (Heinz-Jurgen, 2014).

The significant drops in voltage happened during this final phase of abs intervention is related to the operation described above, to successfully switch the outlet valve to open position, the winding (refer to the previous solenoid valve picture) receive a maximum current in order to allow the armature's force to surpass the spring's force and open the outlet valve. (A.Stegmaier. 1995).

- Appendix 7:

Same as appendix 3, however, this waveform was obtained from testing the Teves Mark IV ABS.

4. ABS fault diagnostic chart:

The Warning lamp is the first point of reference for diagnosis on abs, the ECU will activate the abs malfunction indicator lamp at vehicle start-up while checking the abs essential components (all functional circuit, solenoid valves,...etc) for proper operation. (Allan, 1998). if no problems are found during that self-check, the abs malfunction indicator lamp will turn-off (immediately after the end of the operation). On earlier systems the lamp would not turn-off until the vehicle speed reached approximately 5mph.

This section of the report will cover a trouble-shooting of Teves Mk IV abs system, the system detected a fault on the abs and activated the warning lamp. Therefore, a systematic testing procedure has been followed to define the fault and the flowchart bellow represent the troubleshooting guide created to solve the problem.

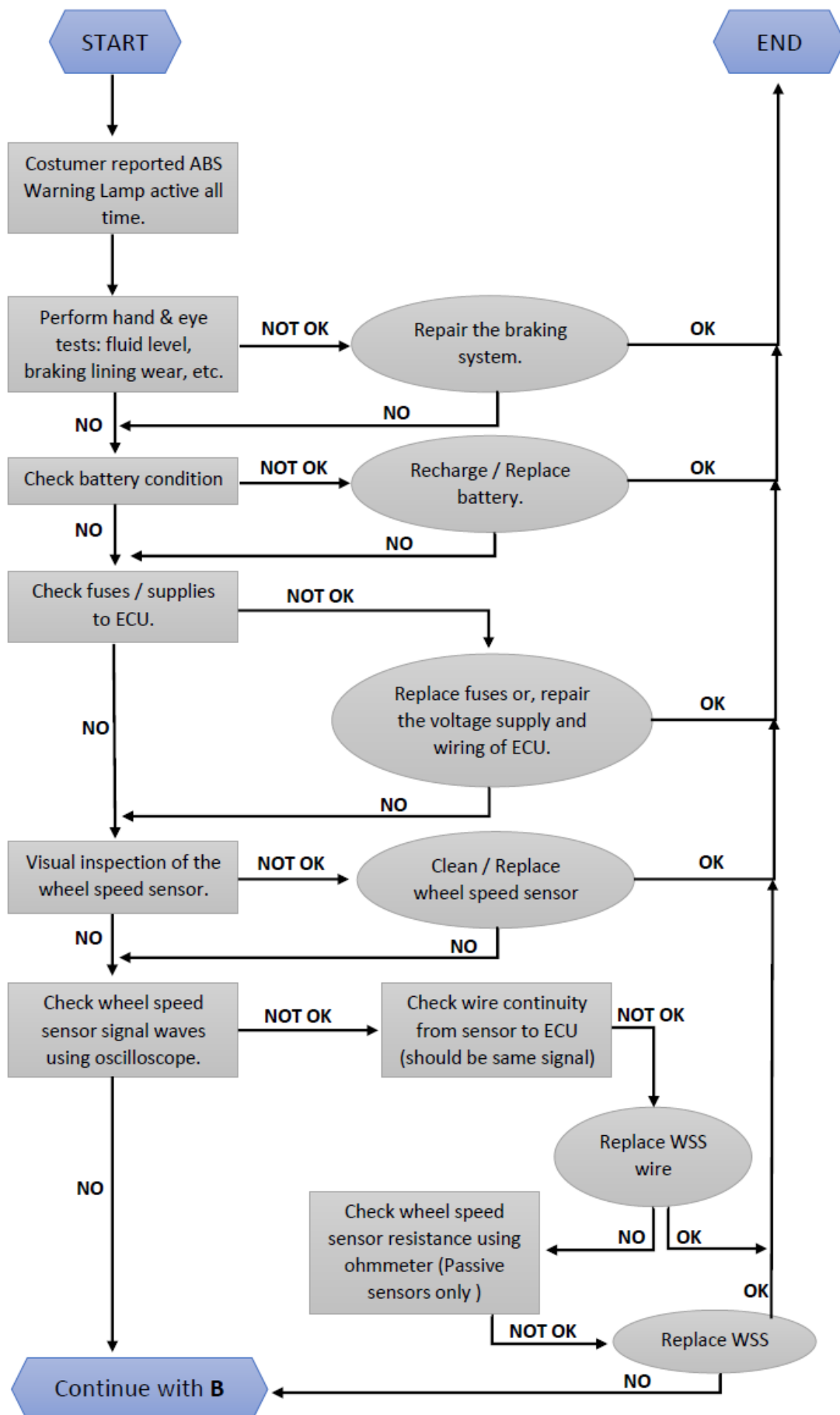


Figure 7 Flowchart first section

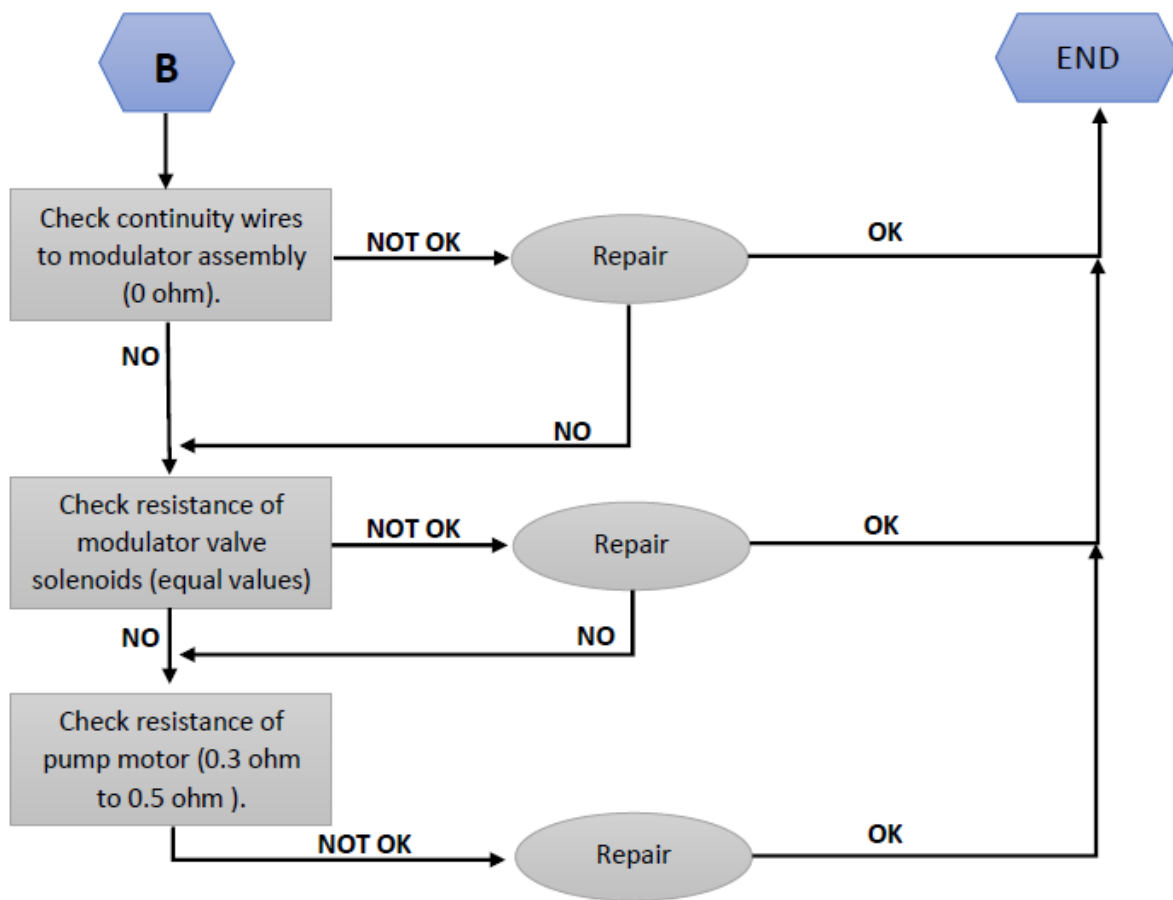


Figure 8 Flowchart second section

Flowchart technical information:

To check the reliability of a passive wheel speed sensor, disconnect the sensor connector, and measure the active resistance between the terminals of the sensor using an ohmmeter. If it shows high resistance, the sensor is damaged. Zero or close to zero indicate that the sensor coil is in a short circuit. (Ditex, [Online]).

When checking the wire continuity for the sensor to ECU, the signal must be the same at the ECU. Continuity of wire to modulator assembly must be 0 ohm, and resistance of pump motor must range between 0.3 to 0.5 ohm. (Denton. 2000).

5. Bosch 2EH abs and Teves (ATE) abs:

5.1 Systems Comparison:

The table below highlights the main difference found on Bosch 2EH and Teves Mark IV systems.

Bosch 2EH ABS	Teves Mark IV ABS
Used between 1986 and late 1990s.	Used in 1993 and later. (Clifton. 2004).
Non-integrated system. (Clifton. 2004).	Non-integrated system. (Clifton. 2004).
3 input channels and 3 output channels.	4 input channels and 4 output channels.
No traction control system on Bosch 2EH ABS.	Aided with low-speed traction control (LSTC).(Clifton. 2004).
3 Hydraulic channels (2 for the frond and one for the rear). (Bosch. 2014).	4 hydraulic channels (one for each wheel).
3 solenoids (2 for the frond and one for the rear, solenoids are multiphase operation).	10 solenoids (2 solenoids for each wheel and 2 for aiding the system, solenoids are single-phase operation).
Diagnostic capability through OBD1	Diagnostic capability through OBD2

5.2 Systems Strengths:

The antilock braking system in general provides the driver with the ability to keep the vehicle under control and that will minimise the risk of accident, abs also maximise the traction, which refers to the friction between road surface and tyres (Josh Smith. 2014), thus increasing the efficiency of tyres up to 30%. Vehicle fitted with abs can be steered smoothly during braking and also decrease braking distance.

Teves Mark IV abs system utilise a conventional master cylinder and power booster, plus it has a separate solenoid system for each wheel and a pump assembly to control the abs hydraulic action (Clifton. 2004), this system uses four input channels based on its four sensors placed at each wheel, thus allows the electronic control unit to calculate precisely the slip angle of each wheel and prevent it from locking. Another factor that contribute to the strength of this abs version is the low-speed traction control system (LTCS) which aid the abs when it detects wheel spin.

Bosch 2 systems uses three channels, two at the front and one at the rear (Clifton. 2004), this set-up helps to optimise steerability as each of the front wheels have separate hydraulic channels for maximum control. The rear wheels share one hydraulic channel and consequently, make the whole system cost effective.

5.3 Systems Weaknesses:

The main drawback of anti-lock braking system is the maintenance issues as the whole braking system is controlled by electronic engine control unit. Therefore, when it comes to fault detecting, communication to the ECU and extracting information from the memory is critical. The Teves Mark IV abs uses on-board diagnostic system version 2 (OBD2) which is not the latest version as currently the communication through EOBD is much more advanced and useful when it comes to diagnostics and abs troubleshooting. Bosch 2 system is not very effective when it comes to braking distance because it uses only one hydraulic channel to control both of the rear wheels, plus the 3/3-way solenoids valves fitted inside that system is not as effective in comparison to the new bosch 2/2-way valves set-up which use one pair of solenoid valves for each wheel. (Bosch. 2014).

6. Conclusion:

The aim of this paper is to discuss the function of an anti-lock braking system and the diagnostic procedures of a faulty system. Except from the brief abs overview, the function of each abs component has been covered in detail while discussing the waveforms obtained from the systems experimented at the university workshop, and by interpreting the signal waveforms of each abs part make it easier to detect and trace the fault source. Furthermore, the trouble-shooting of the Teves Mark IV abs explain one of the various systematic process when approaching faulty abs and attempting to repair it. The essay also discussed bosch 2EH and Teves Mark IV ABS differences as well as system's strength and weaknesses at the end.

The practical work conducted in order to complete this essay has a great effect on the learning process concerning investigating and trouble-shooting abs system or any similar electronically controlled part on a vehicle, that because of the experience obtained when using diagnostic tools and specifically advanced tools such as the bosch oscilloscope unit. Understanding and knowing how to utilise such tools is vital when it comes to emissions control and diagnosis within the automotive industry.

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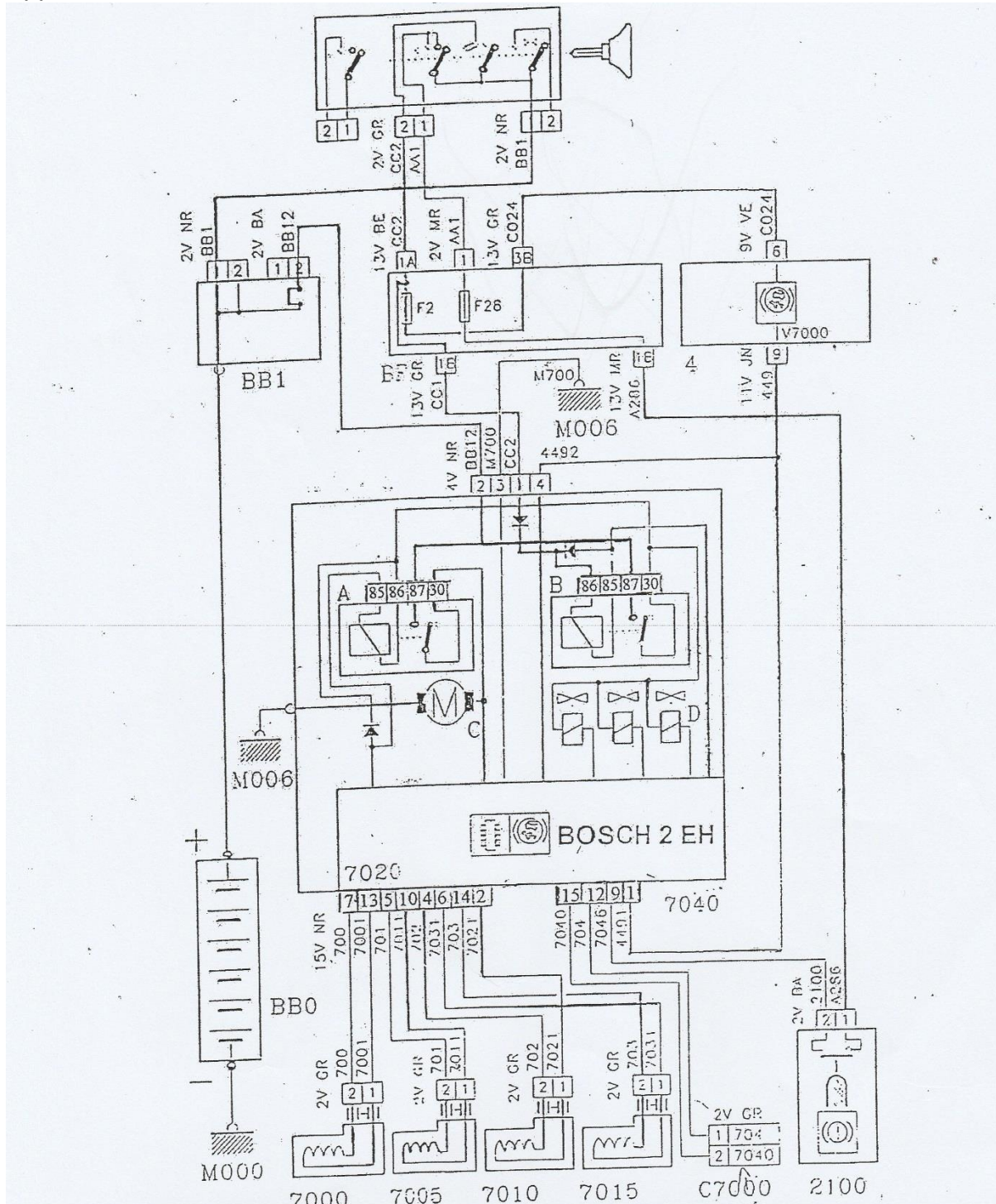
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Appendices

Appendix 1:



Appendix 2:

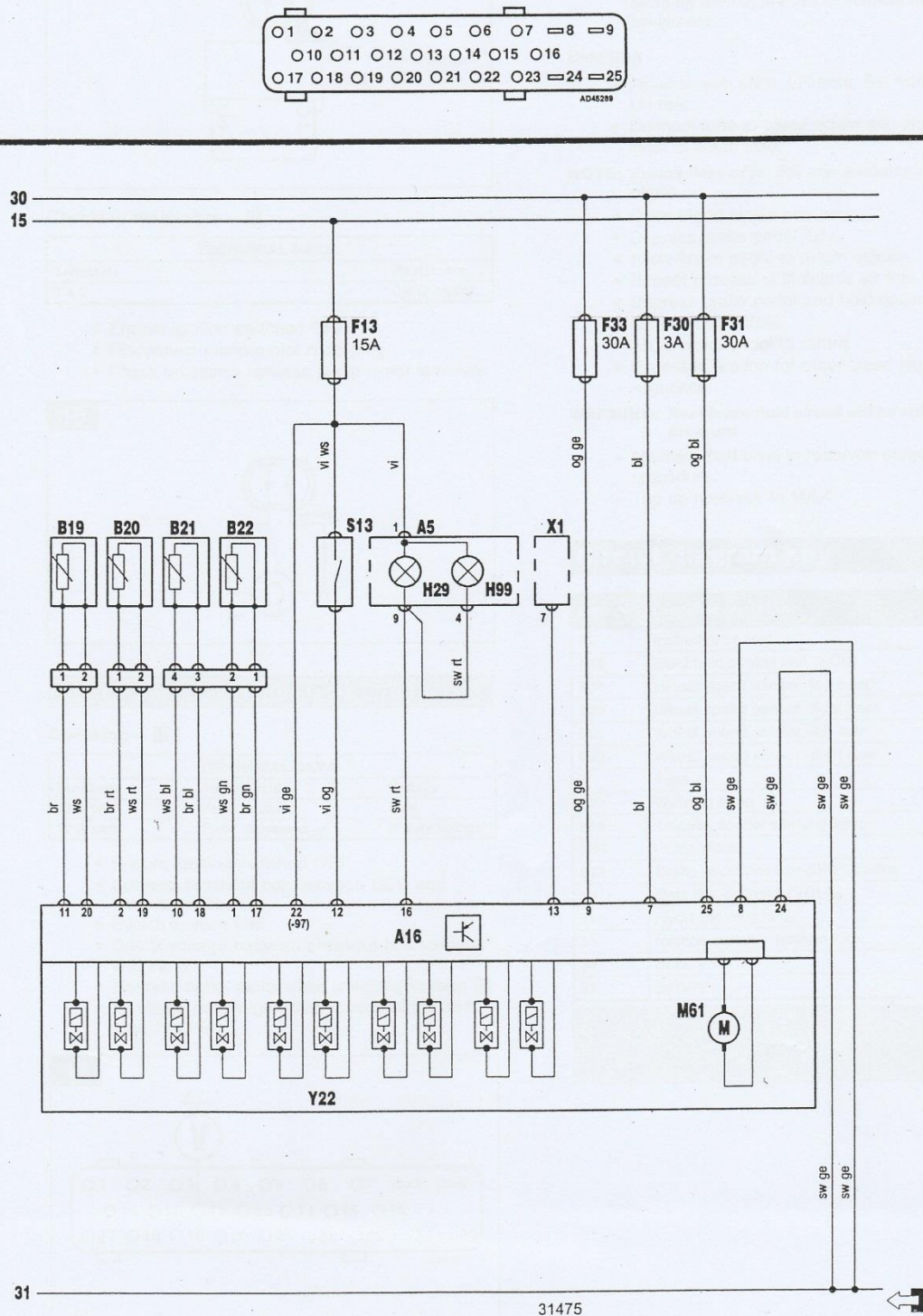
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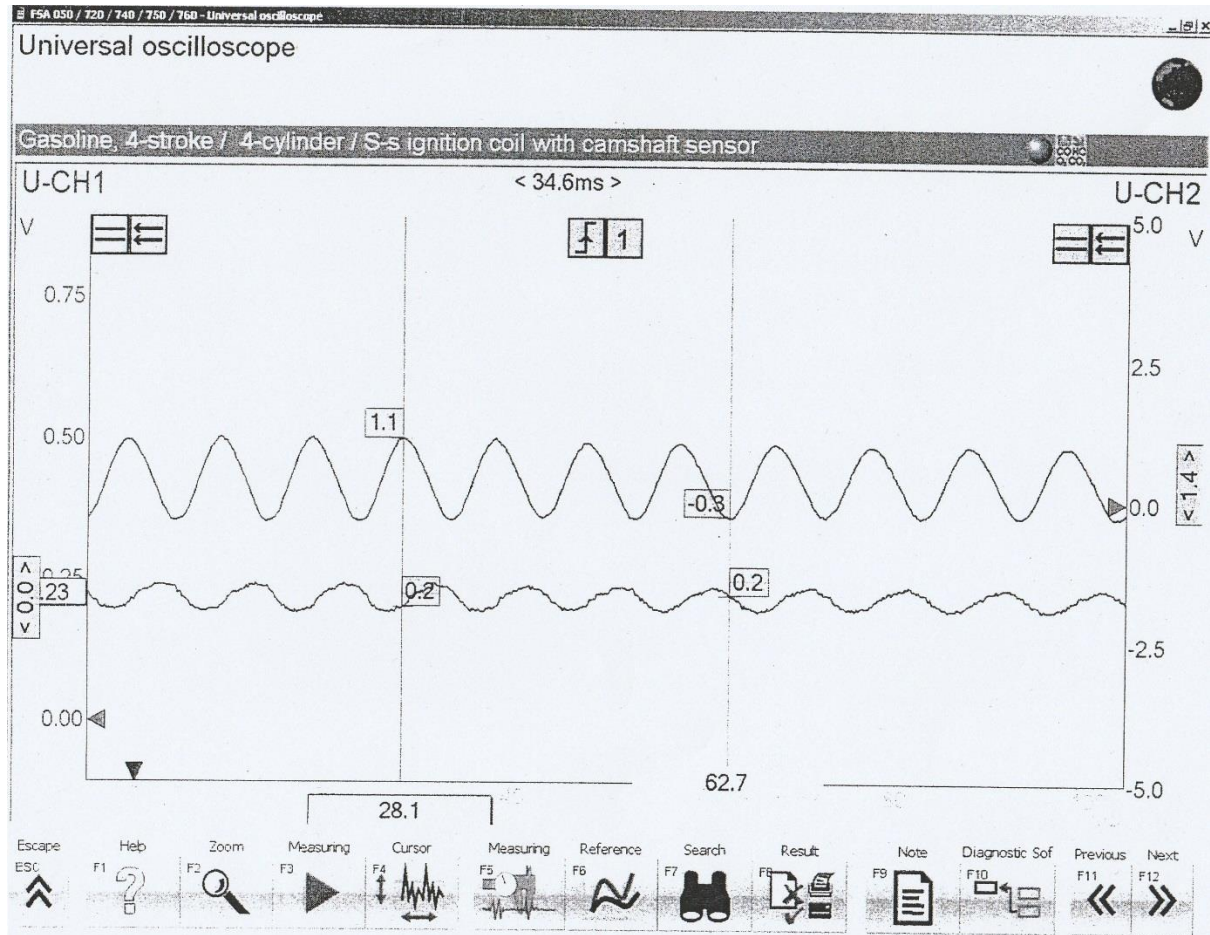
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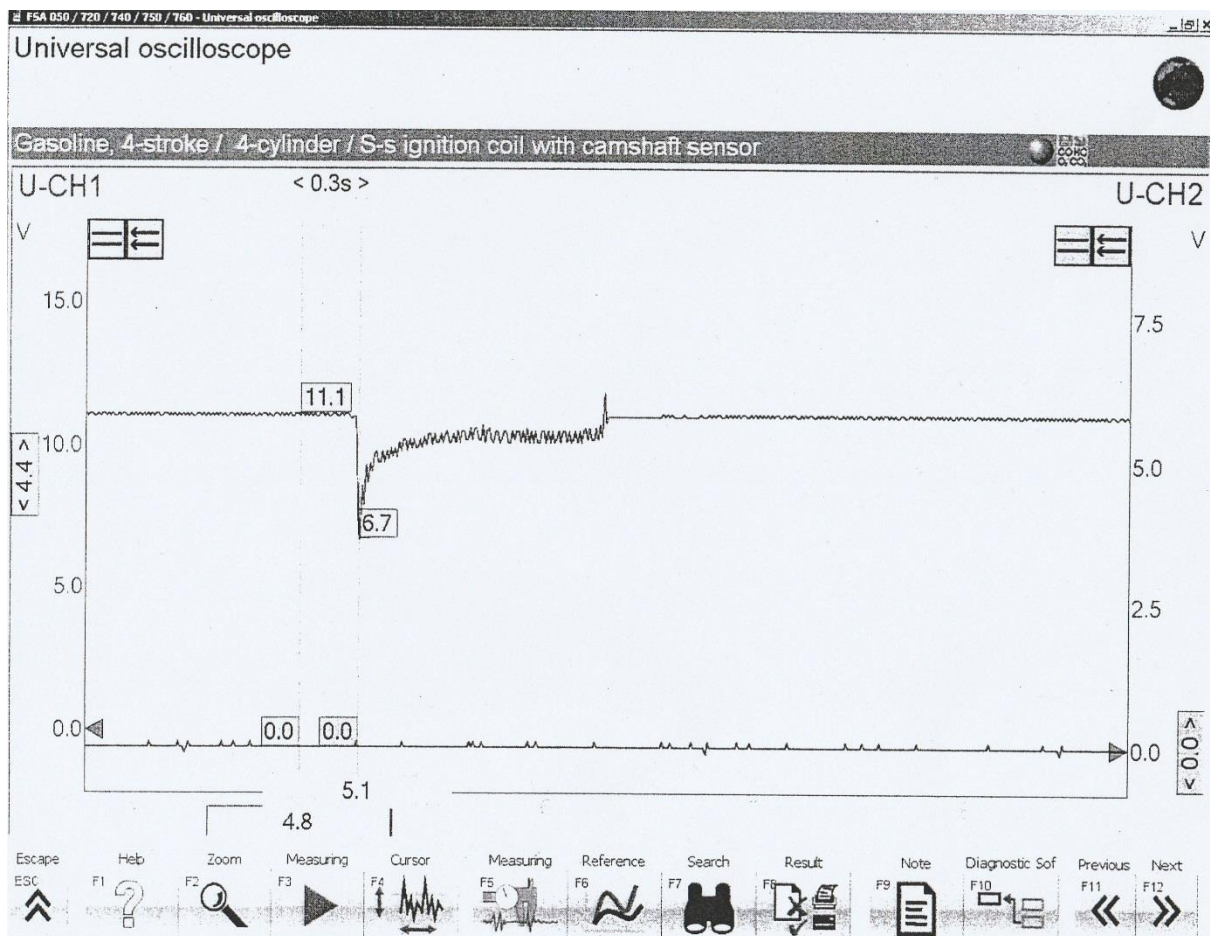
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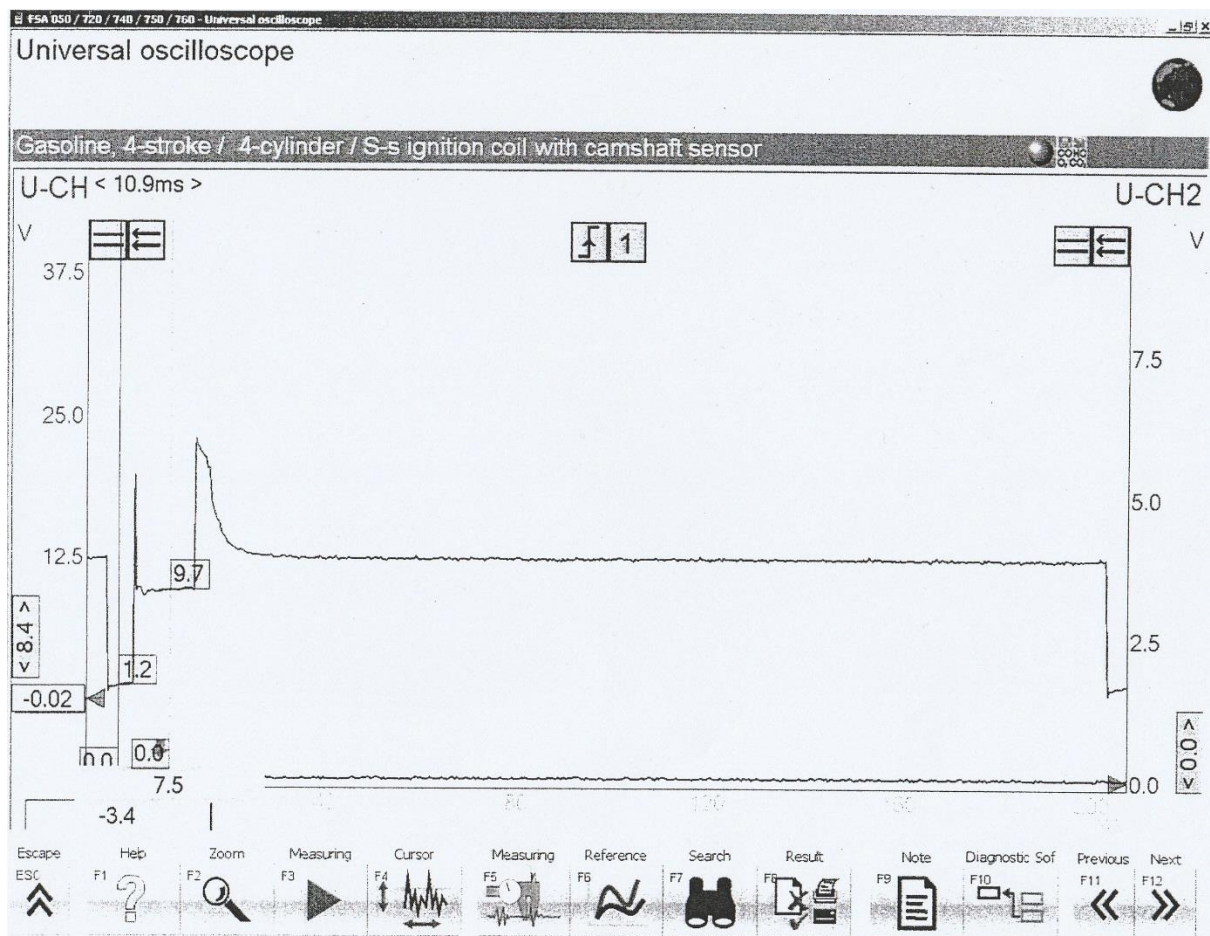
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ECU harness multi-plug and circuit diagram

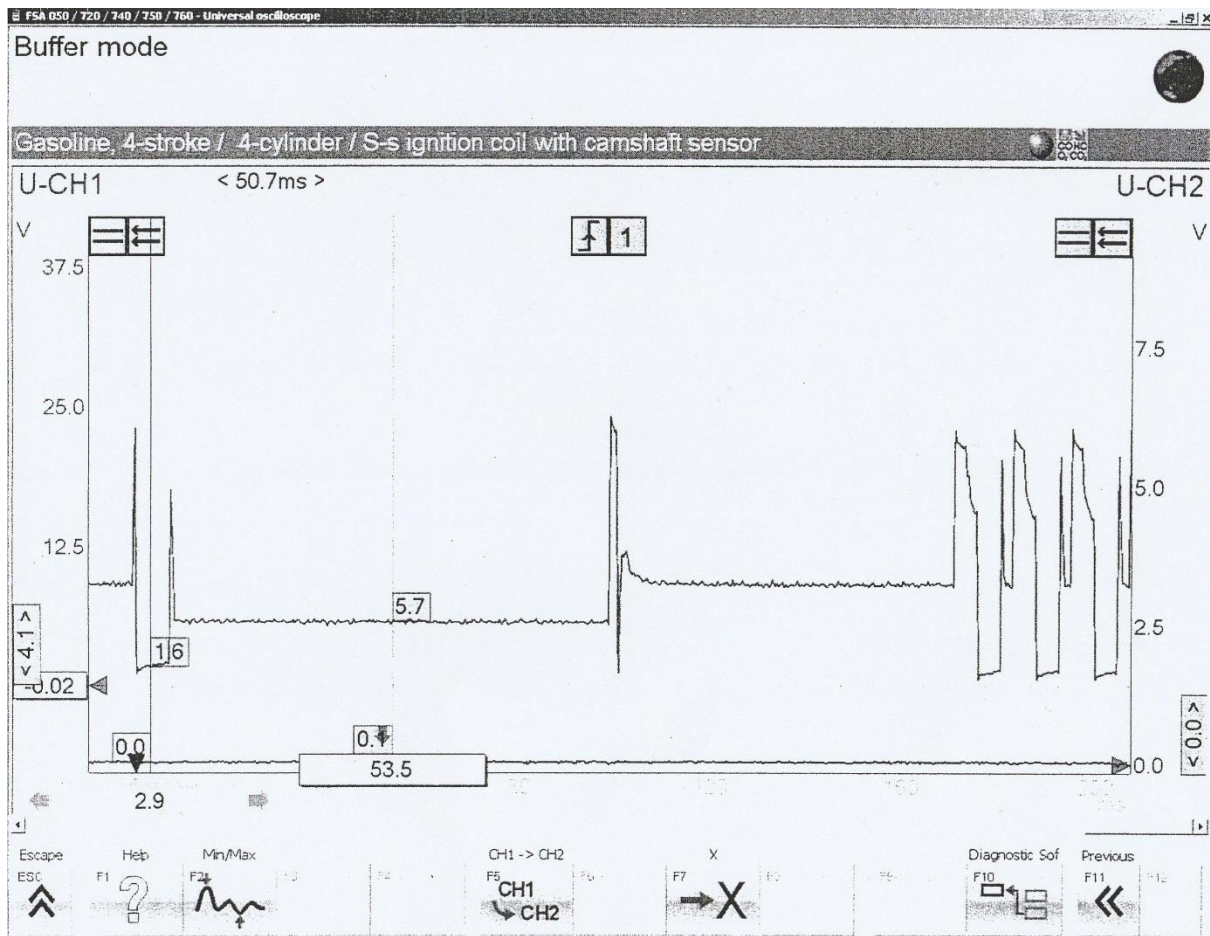
Appendix 3:



Appendix 4:

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