

Emission Control and Diagnostics

Anti-Lock Braking System Diagnostics

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Abstract

Most vehicle systems have many different computer systems to control the operation of the vehicle. These systems may inherit a verity of problems and system diagnostics are required to understand the fundamental problem of the system. In this case a team identifies the function of two different ABS systems to identify the operation and diagnose any existing and occurring problems. A series of tests are conducted to initially identify the operation of the ABS system and discover any underlining issues that may cause future problems.

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2. Literature review

Wu, M. and Shih, M. (2003). "Simulated and experimental study of hydraulic anti-lock braking system using sliding-mode PWM control." Published in the *Mechatronics*, 13(4), pp.331-351. "Anti-lock braking systems (ABS) are well known in the automotive industry as one of the most critical active safety systems. ABS improves vehicle safety by reducing longitudinal breaking distance. This occurs by the control of the wheel slip."

3. Introduction

ABS or anti-lock braking system is used in almost all modern vehicles. ABS is a vital to reduce stopping distances and assist the vehicle in turning when the brakes are applied. ABS was first developed in 1929 for use on aircraft to ensure maximum friction between the tires and the runway (Kritzinger, 2017). Adopting the idea of ABS to motorists happened in 1966 on the Jensen Ferguson Formula which was a primitive version but still effective (Driving-safety systems, 1999). This idea was then developed over the years by different companies, deviating in design solutions but achieving the same goal of wheel braking intervention.

The modern version of ABS affects many different aspects of the vehicle like the steering, braking and the stability of the vehicle. The Main goal of ABS is to ensure that under braking the wheel doesn't lock up. If a tire locks up, then the coefficient of friction is reduced between the road surface and the tire causing the vehicle to skid and lose its ability to react to driver input like steering. To ensure that the wheel continues to rotate while under heavy braking a ABS modulator unit pulses the brakes to allow the tire to grip onto the road surface. To detect a slipping wheel, wheel sensors are mounted to the hub of the wheel to detect if a wheel is about to lock up. Each wheel has its own sensor and can be modulated accordingly depending on what side the skid is occurring. (Tavares, 2009)

The wheel sensors can also be used for Traction control or stability control. As well as detecting a locked wheel, it can also detect if the wheel is spinning too fast meaning that the wheel is slipping. Traction control and the ABS module can communicate with each other to ensure maximum friction in accelerating and braking ensuring maximum control. If the wheel is detected to be spinning too fast, the traction control module tells the ABS module to break the particular wheel. This is to allow the tire to grip the road surface.

The action of intermittently releasing the brakes reduces the braking distances. This is due to the fact that the coefficient of friction between the tire and the road varies in respect to slip. In perfect rolling condition the value of the frictional coefficient is nearly zero. But when the wheel is skidding then sliding friction comes into play. Because the tire deforms, the ideal slip ratio is 12% to ensure maximum amount of friction is used. Anything more than 12% slip ratio then the tire reduces the coefficient of friction dramatically. But in ABS braking, the module adjusts the brake pressure to ensure that the slip ratio is at the ideal 12%. (Driving-safety systems, 1999).

With all of these systems, Driver control is increased in all weather and situations. ABS alone has saved many lives by allowing the vehicle to maintain maximum grip when conducting an emergency stop and swerves.

Two types of ABS systems are going to be researched to understand the fundamental differences between the two systems.

4. ABS Systems

Teves Mk IV ABS

The Teves Mk IV is used between 1991 to 1993 and is mainly used on the Ford Fiesta mk5 and the Ford Puma. This particular system uses reluctance sensor on each wheel hub and incorporates an the Electronic Brake Control Module (EBCM) in the modulator itself. This system also incorporates 10 individual solenoid vales to control each wheel as well as using additional solenoids to achieve additional stages of intervention. As well as multiple interventions, the unit incorporates isolation solenoid to isolate the front brake hydraulic circuits from the master cylinder and rear circuits. Incorporated in the ABS module is a electric hydraulic pump. The main purpose of a pump is to generate pressure after the pressure reduction phase. Combining the hydraulic pump with a traction control system the pump may also be used to reduce a spinning wheel by pressurising certain brake callipers reducing a wheel spin.

Wheel reluctance sensors are used on each wheel hub and are paired with a sprocket with sensing teeth. The system can detect a change in speed due to the sensor detecting the sprocket teeth causing a waveform. The ECU module can distinguish if a wheel has reduced it rotational speed, allowing the system to know what wheel has locked up.

The Teves system has two main phases of ABS operation. This only occurs when the system detects a wheel slippage. The first phase of operation is pressure maintain. This phase prevents the pressure in the brake calliper to increase. This is caused by blocking the pipe between the master cylinder and the brake calliper via one of the solenoids. If the Teves ABS system detects that stage 1 is insufficient to prevent the wheel locking up then phase 2 activates which is pressure reduction. The pressure in the brake calliper is reduced by reducing the hydraulic pressure to the brake calliper. If the system doesn't detect any slippage, then the system would act as if there isn't ABS fitted to the vehicle which is known as passive mode.

If the Teves system detects a fault in the system then the ABS warning light will illumine on the dashboard. This it to alert the driver that the ABS system is non functional and would need to be serviced. The ABS warning light also signals a when the system first started. This is to enable the driver to know that the system is conducting a pre test before vehicle use.

Bosch ABS 2EH

The Bosch 2EH ABS system was mainly used between the years 1993 to 1998 and mainly used on the Vauxhall Calibra. The system is a nonintegral meaning that it's an add-on to the existing master cylinder and booster. This system utilizes a three channel setup composing of three dual position solenoids. Two of the solenoids are directed to each front wheel and the remainder solenoid is sent to the rear where it shares a common channel. This is because the front wheels can be controlled independently from each other where the majority of the vehicle control inputs are located. The rear wheels are not as important to have independent ABS control due to the fact that the rear wheels have less braking

influence. This system has three different intervention states. These states are passive, pressure hold and pressure decrease. This system utilizes three integral sensors located on both fronts and on rear. This is due to the three channel setup not needing the additional wheel speed sensor.

The triple position solenoid valve is controlled by the EBCM by varying the amount of amps to the solenoid. This allows the solenoid to move to different levels allowing different valves to open. For example under normal driving passive mode, the solenoid is not energised and allows fluid to pass through. If the EBCM detects the wheel slowing down then it will activate intervention one which is pressure hold. The EBCM outputs 2.5 amps to set it to the first position. If the third position is needed which is pressure decrease mode, then the EBCM sends 5 amps to the solenoid to open the third valve. This system allows for a smaller compact design because it uses less solenoid valves to operate the system. The valves also incorporate a low pressure accumulator which is a temporary storage vessel for the released fluid.

Once the pressure is released and is back to normal and the speed sensor indicates that the wheel is spinning, the ABS system will reset and standby. The system has a duty cycle rate of 10 times per second.

When the system is turned on, it will perform self checks to ensure that all components are operational. Examples of these checks are; battery voltage, wheel speed sensor circuits, fluid levels and pressure differential switch. If it is found to have an issue with any components then the system will turn on the ABS light, store a fault code and disable ABS. The advantage to this system is that the EBCM module communicates and sends data through the OBD 2 port which allows for easier diagnostics.

5. ABS Systems Operational Tests

When conducting testing on the ABS systems, roles were assigned to ensure accuracy in each aspect of the system. These roles are as follows:

Testers Name	Role Assigned
Ashleigh	Read Voltages and Analyze Waveforms
Toby	Key Positions
Dion	Test Scribe
Harrison	Terminal Prober
Richard	Control System Operation

Safety notice

All safety precaution was set in place to ensure that safe working practices were followed. PPE was worn in all testing environments. The equipment involved has a combination of 12 volts DC and 240 Volts AC so particular precaution was taken to ensure equipment passed PAT testing and all grounding points were attached. Rotational components for the toothed gear is also a hazard but is covered by a metal grill to ensure so nobody get caught in the equipment causing harm. Additionally to rotating parts, any loose clothing was tied back or covered to avoid injury. Lastly the system used hydraulic pressure so which can cause harm if a line is fractured or leaking so particular attention was undertaken to ensure that all lines are in exceptional condition.

Teves Mk IV ABS

To understand the operation of the Teves system, tests were conducted on several aspects of the module. The main objective is to gain a understanding on how the module is triggered and the effects on adjacent components like the motor and solenoids.

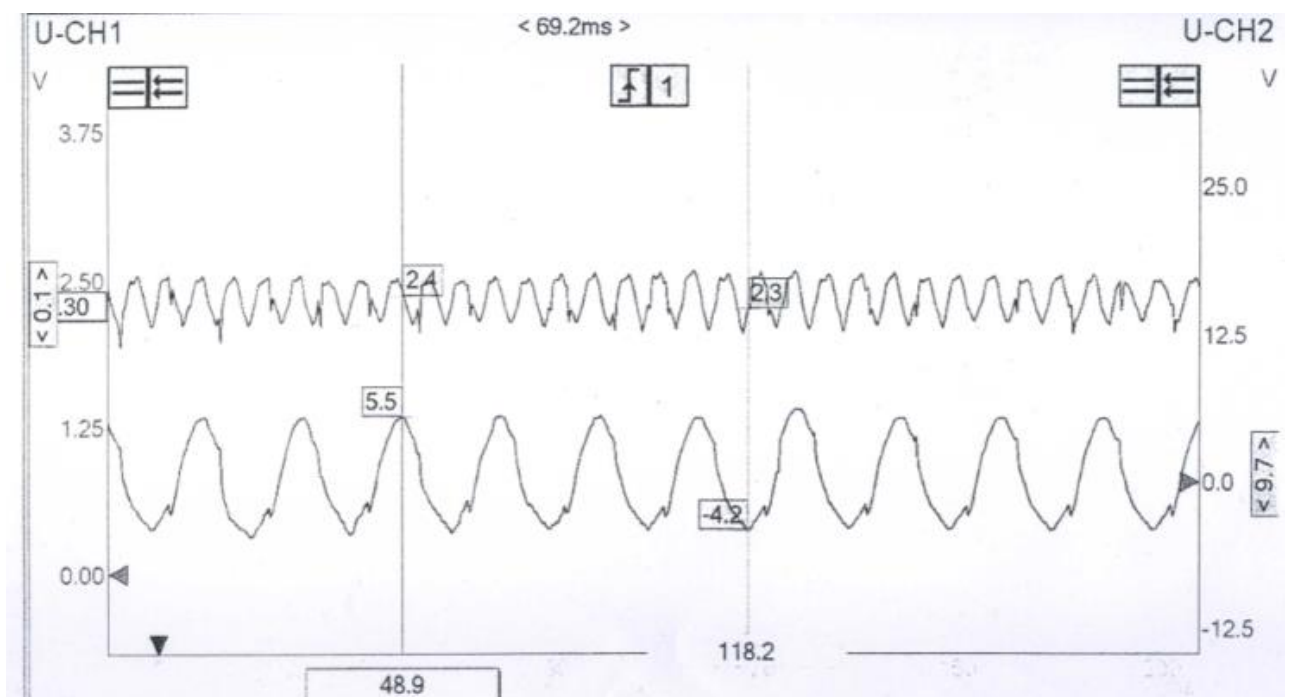
Firstly the 25 pin multi-plug is examined to gain access to the back of the connector. This is to allow a multi-meter to be used on different pins to identify the voltages at different operational states. Start the series of tests by leaving the “ignition on” and using the multi-meter to probe each pin starting from pin 1 down to pin 25. Repeat this procedure but for “ignition off” and in a “running” state ensuring that all results are noted down. By identifying the voltages of each pin can help understand the voltage requirements of the systems. For example pins 7, 9 and 25 are constant 12 volts live while pins 8 and 24 are constant ground (Fig 1). In addition the wheel speed sensors positives (pins 17, 18, 19 and 20) give a peak of 1.25 volts meaning that the reluctance sensor is generating a voltage from the wheel.

Fig 1: Table of the Teves MK IV ABS Multi-plug voltages

Teves MkIV ABS Multi-plug voltages				
Note	Pin No.	Ignition on (v)	Igniton off (v)	Running (v)
Wheel speed sensor ground	1	0	0	0.25
Wheel speed sensor ground	2	0	0	0.25
	3			
	4			
	5			
	6			
12v Live	7	12.2	12.2	12.2
Ground	8	0	0	0
12v Live	9	12.2	12.2	12.2
Wheel speed sensor ground	10	0	0	0.25
Wheel speed sensor ground	11	0	0	0.25
Ignition Live	12	11.99	0	11.99
DATA	13	9.28	9.28	9.28
	14			
	15			
Ignition Live	16	11.9	0	11.99
Wheel speed sensor positive	17	0	0	1.25
Wheel speed sensor positive	18	0	0	1.25
Wheel speed sensor positive	19	0	0	1.25
Wheel speed sensor positive	20	0	0	1.25
	21			
	22			
	23			
Ground	24	0	0	0
12v Live	25	12.2	12.2	12.2

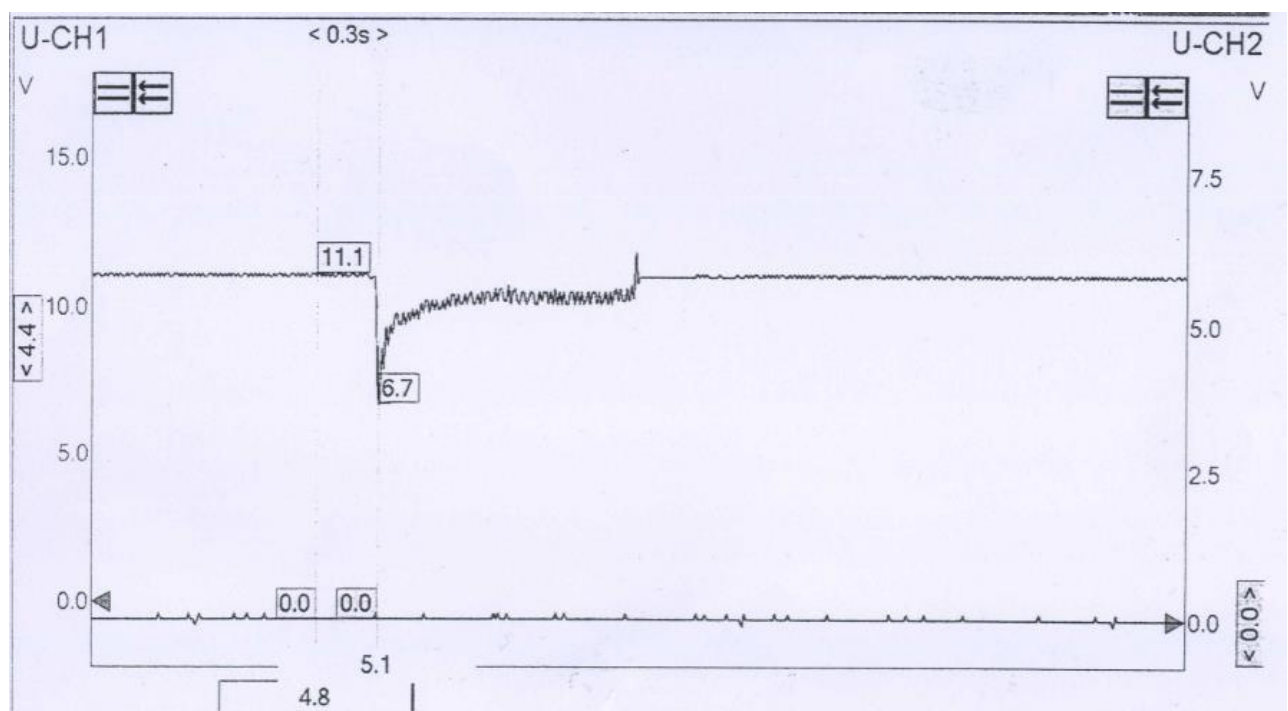
Once all voltages are taken of the 25 pin multi-plug the wheel speed sensor can be tested to identify how the ABS module understands how to activate. An Bosch BEA tester is used to on it universal oscilloscope setting to identify the wheel sensor wavelength. By attaching the sensor terminals to pins 2 and 9 (Wheel speed sensor ground and wheel speed sensor positive) and setting the oscilloscope to the correct scale. An AC wave form is present for both positive and negative terminals of the sensor. On the graph (Fig 2) shows the two waveforms. Both waveforms show an antilog signal. Looking at the upper wave from which is ground of the wheel sensor shows a small peak voltage of 0.30 volts. The lower waveform shows the positive side of the wheel sensor. This is also a AC waveform with a peak voltage of 1.25 volts. This voltage is generated by the reluctance wheel speed sensor by the teeth passing the sensor tip causing a spike in voltage allowing the abs module to detect the rotation of the wheel. If the waveform peaks are more spread apart then the wheel is spinning at a slow rate. If there isn't a waveform generated at all then the wheel is stopped. The Teves ABS system monitors the waveform for any discrepancies like a flat line or spread out peaks to determine the speed of the wheel and to understand when to activate ABS intervention.

Fig 2: Teves Mk IV ABS wheel sensor waveform



An additional test is to investigate the parasitic draw on module and power supply when the solenoids activate. By using the universal oscilloscope pin 9 is probed on the multi-port. The ABS system is then run and pressure sustain is activated to simulate a skidding wheel. On the graph (Fig 3) illustrates the supply voltage to the module running at 12.2 volts but spikes down to 6.7 volts when pressure maintain is activated. There is a reduced parasitic draw until the system resets to passive mode. This is due to the high loads exerted onto the system.

Fig 3: Teves Mk IV ABS Solenoid activation affecting battery voltage



Bosch ABS 2EH

To understand the operation of the Bosch system, tests were conducted on several aspects of the module. The main objective is to gain a understanding on how the module is triggered and the effects on adjacent components like the motor and solenoids.

Firstly this system has two main plugs which both carry different voltages and signals. The objective is to uncover the back of these plugs to expose the terminals to probe off. The purpose of gathering voltages of the system is the gain an understand of what each pin dose and what goltrages are being outputted. Starting with the 4 pin connector, this operates the main module supply voltages and warning signals if there is a issue. This is evident in the table (Fig 4) where pin 2 shows ignition live to power the module and pin 4 where there is voltage sent to the light but is waiting to be grounded by the EBCM if there is a fault.

Fig 4: Bosch 2EH ABS 4 Pin Supply Connector

Bosch 2EH ABS 4 Pin Supply Connector				
Note	Pin No.	Ignition on (v)	Ignition off (v)	Running (v)
Control Relay	1	11.75	0	11.75
Ignition Live	2	12.04	0	12
Ground	3	0	0	0
Warning Light	4	11.75	0	11.75

Next the Solenoid plug can be checked to understand the voltages at different operating conditions. On the table (Fig 5) clearly identifies the solenoids wire bunches and the voltages supplied. When the ignition is off no voltages is going to the solenoids but when the ignition is on, the solenoids receive battery voltages on all pins. This is due to how the solenoid is actuated. The solenoids receive constant supply voltage but when in use, the EBCM ground the coil causing the electromagnet to energise and as a result the valve moves. To further understand the operation, the oscilloscope can be used to identify the exact time and operation length.

Fig 5: Bosch 2EH ABS Solenoid voltages

Bosch 2EH ABS Solenoid voltages					
Note	Pin No.	Ignition on (v)	Ignition off (v)	Colour wire	
Solenoid 1	1	12.08	0	12.04	green
Solenoid 1	2	12.08	0	11.96	Black
Solenoid 2	3	12.08	0	11.96	Yellow
Solenoid 2	4	12	0	11.96	Black
Solenoid 3	5	12	0	11.96	Yellow
Solenoid 3	6	12	0	11.96	Black

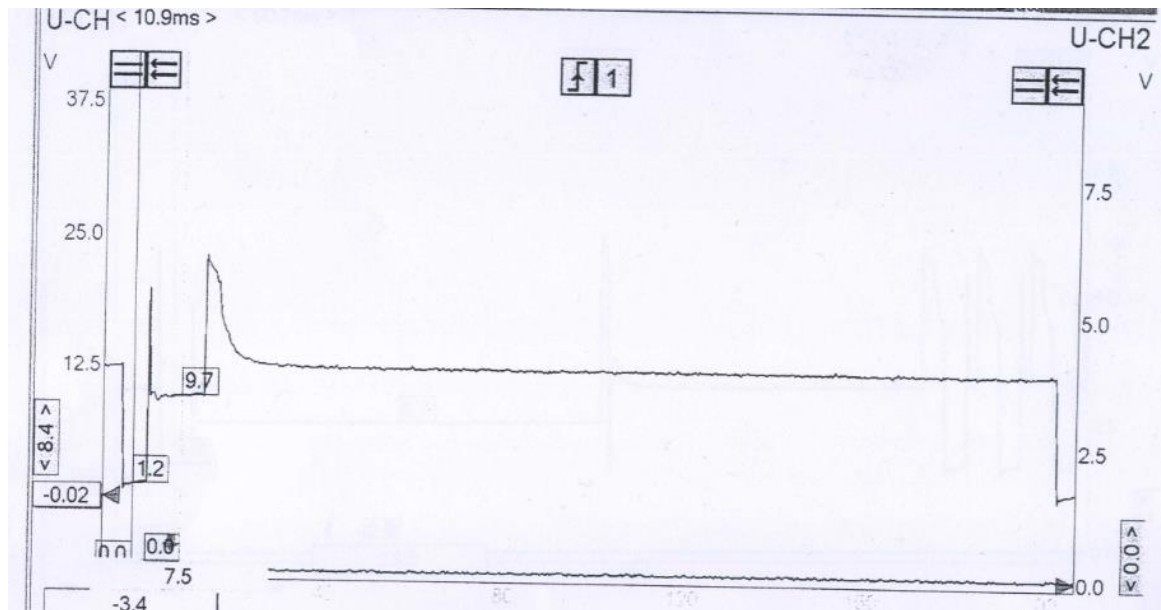
The 15 pin multi-plug can be tested using the same method of probing the pins using a multi-meter to understand the what the different pins are out putting. On the table (Fig 6) identifies the wheel sensor voltages as well as the warning systems for the EBCM. Looking at pin 2, which is the ground side of the wheel sensor, shows a residual voltage of 0.2 volts when the ignition is on. This to verify that the there is no open circuit in the sensor ensuring that it is fully operational. 0.2 volts is also seen on the positive side but is the return signal from the continuity check. When the system is running, pin 4 which is the positive side of the wheel sensor is showing 1.25 volts. This voltage increase is from the sensor and the toothed sprocket generating a peak output voltage. This would more apparent when the oscilloscope is used on the sensor.

Fig 6: Bosch 2EH ABS 15 Pin Multi-plug Voltages

Bosch 2EH ABS 15 Pin Multi-plug Voltages				
Note	Pin No.	Ignition on (v)	Ignition off (v)	Running (v)
Warning Light	1	11.88	0	11.75
Wheel sensor Ground	2	0.2	0	0.25
	3			
Wheel sensor Positive	4	0.29	0	1.25
Wheel sensor Ground	5	0.2	0	0.25
Wheel sensor Positive	6	0.2	0	1.25
Wheel sensor Ground	7	0.2	0	0.25
	8			
Brake switch	9	11.88	0	11.75
Wheel sensor Positive	10	0.2	0	1.25
	11	0		
	12	10.68	0	10.51
Wheel sensor Positive	13	0.2	0	1.25
Wheel sensor Ground	14	0.2	0	0.25
	15	0.2	0	0.25

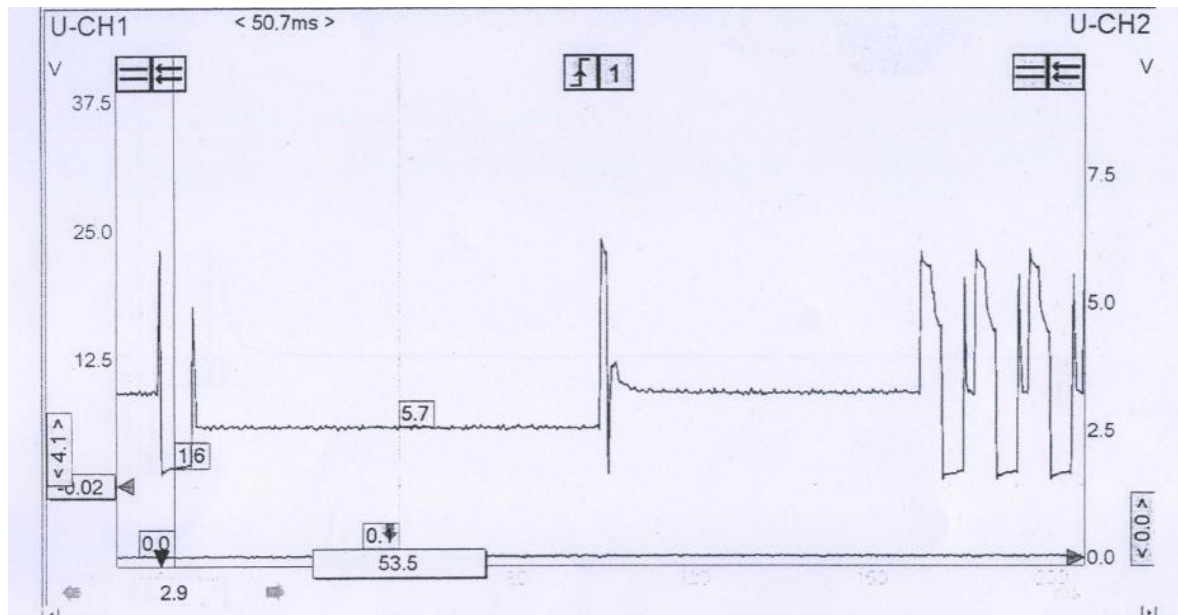
The universal oscilloscope is very useful when identify small wave forms. The scaling can be adjusted to ensure a clear image can be caught a understood. In this case the oscilloscope will be used to identify the first and second stages of solenoid operation. The rear solenoid is hooked up to pin 5 on the solenoid plug and the test rig activated. By slowing down the toothed sprocket, the wheel sensor detects a reduction in speed. This causes the EBCM to activate the first stage of intervention which is "Pressure hold" sending out 2.5 amp to ensure that the valve only moves half way. This causes the voltage to drop from 12 volts to 9.7 volts. In the oscilloscope reading (Fig 7) clearly shows the solenoid being activating for a millisecond and causes a tail EMF spike. If the system detects more slippage, there would be more frequent waveforms because the system has a duty cycle of 10 pulses per second.

Fig 7: Bosch 2EH ABS first stage Pressure holds 2.5 amps



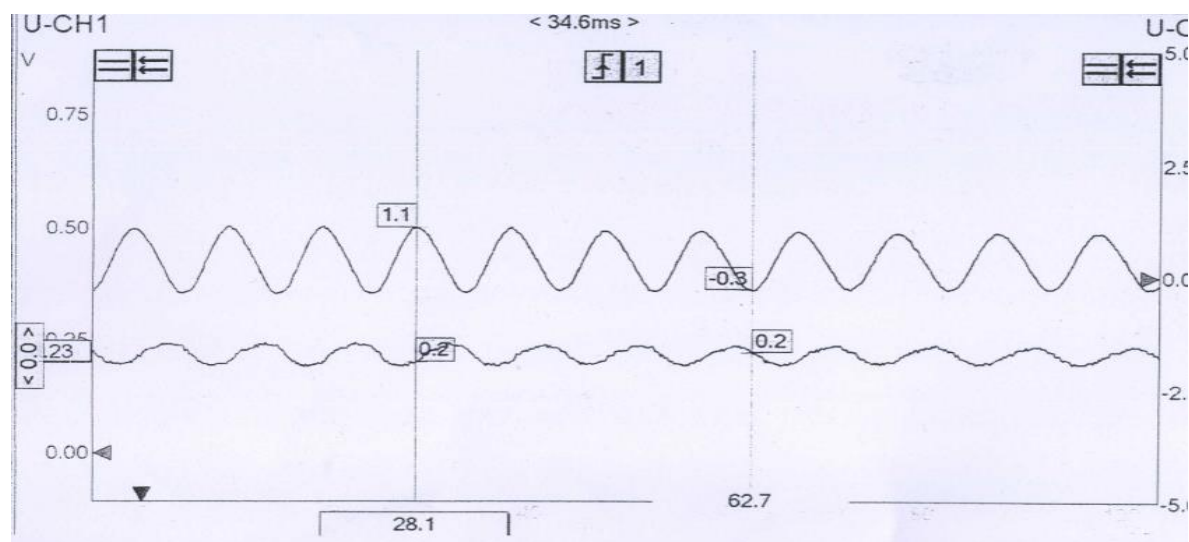
The second stage of the ABS intervention is “pressure Release”. This stage is where the EBCM detects that the wheel is still skidding and to release the pressure to ensure the wheel can continue to rotate. In the graph (Fig 8) shows similar characteristics as stage one, replicating the same tail EMF but the pulse much shorter. This is due to the systems duty cycle trying to re apply the brakes as quickly as possible. To achieve maximum solenoid valve lift, more amps is supplied by the EBCM. As a result, the voltage is much lower at 5.7 volts.

Fig 8: Bosch 2EH ABS Second stage pressure Release 5 amps



The wheel sensor creates a similar pattern as the Teves system because the sensors are virtually the same. Utilizing a toothed sprocket generates a AC output to let the EBCM know the wheel speed. Looking at the graph (Fig 9), the upper waveform is the positive side of the sensor creating a peak voltage of 1.1 volts. The bottom waveform is the ground side but still has a sort of waveform with a peak of 0.2 volts. Because of the interference from the positive side, gives the unwanted waveform but is irrelevant due to the minimal voltages involved.

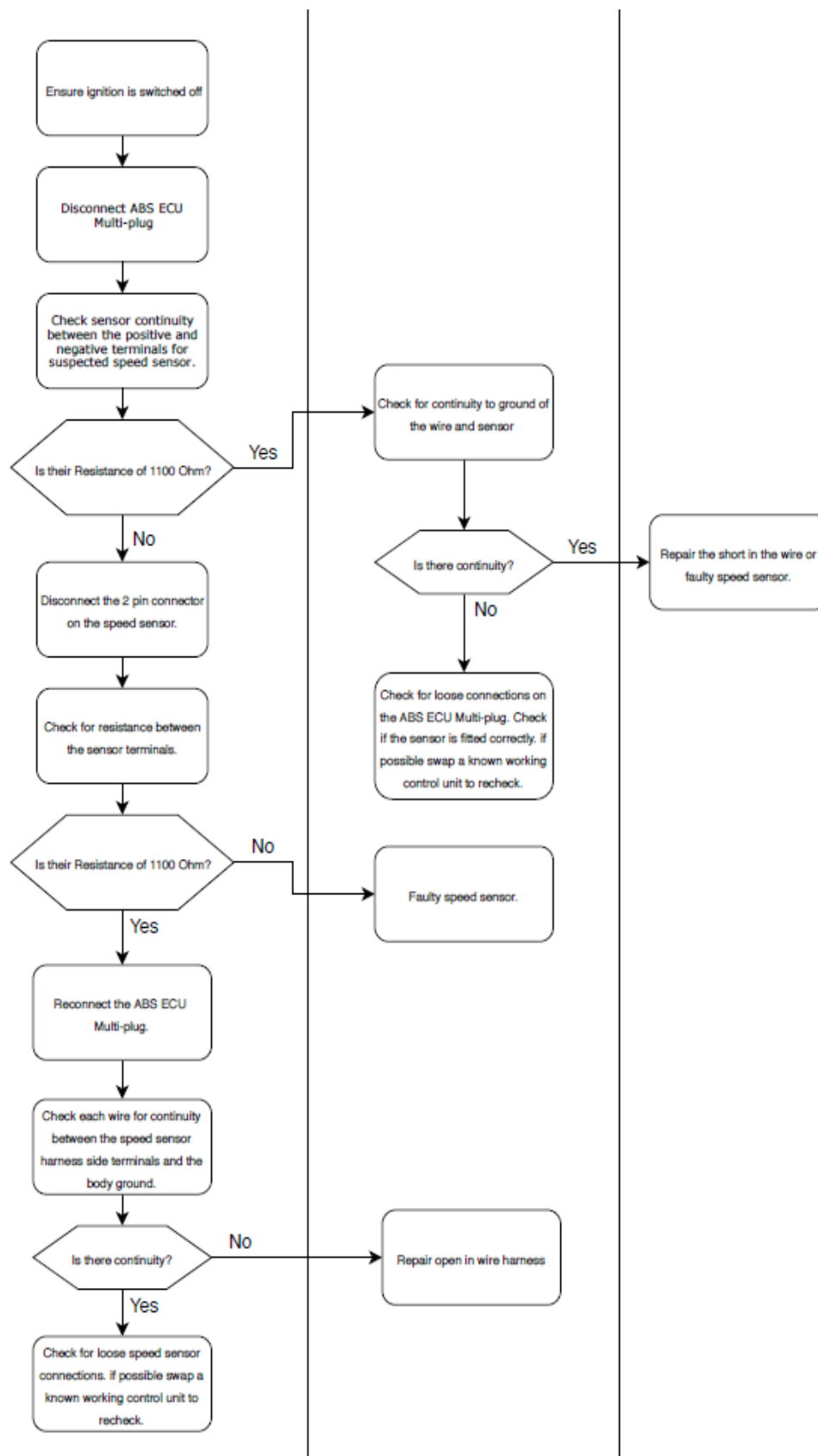
Fig 9: Bosch 2EH ABS Wheel speed sensor waveform



6. Fault Diagnostic chart

Below is a flow diagnostic chart giving a understanding on how to diagnose and solve and faulty wheel sensor. This chart can be applies to both systems. The systems have OBD equipped which will give a P code supplying the reason for the system fault. These codes can be read using a reader. An example of a wheel sensor code is: "P1394 – wheel speed sensor 1 – sensor circuit intermittent". Once the reason for the fault is identified, the diagnostic route (Fig 10) can be used to isolate and solve the issue. Once solved, the diagnostic equipment can clear the code so that the system can operate once again.

Fig 10: Fault Diagnostic chart for diagnosing a faulty wheel speed sensor.



7. Strengths and Weakness of the two systems

Teves Mk IV ABS

Strength

- Three main intervention modes: passive, pressure maintain and Pressure reduce.
- Has individual solenoid valves to ensure system redundancy
- Integrated ECU module
- Nonintegral (remote) ABS system

Weakness

- Specialist scan diagnostic equipment is required to read any problem codes if the ABS warning light is illuminated.
- Solenoids are not serviceable

Bosch ABS 2EH

Strength

- Three position solenoids
- OBD support
- Less complicated
- Smaller compact design
- Solenoids can be dismantled
- Nonintegral (remote) ABS system

Weakness

- More to go wrong in the solenoids

8. Conclusion

In conclusion both Teves and the Bosch systems are adequate at creating a reliable system to ensure maximum safety in passenger vehicles. Both systems are very similar in many different ways for example the wheel sensor system of having a sensor on the hub of the wheel with a toothed sprocket. They both create the same waveform meaning that the detection systems is the same if not similar. The only difference in terms of the sensor side is the

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