Agilent TS-5000 Family of Automotive Electronics Functional Test Systems

Antilock Brakes and Traction Control

Application Note

Agilent Technologies TS-5400 Series II Automotive Electronics Functional Test System

Antilock brake system/traction control electronic control module testing

Smarter cars are here; they warm your seats, set your radio station, tell you where to turn next and drive over icy patches and wet roads. The latter of these features is of particular concern for most drivers weathering the changing seasons and terrain of their everyday driving route. Antilock brake and traction control systems (ABS/TC) are considered necessary car safety features today. As a result, ABS/TC electronic control module (ECM) manufacturers are pressured to make safer, more reliable systems. For this reason, functional testing of ABS/TC ECMs becomes paramount and extensive monitoring of the system components is done in its normal course of operation.

ABS/TC ECM functionality relies on variable reluctance sensors (VRS), solenoids, pump motors and fail lamp outputs, which all have "recapture" monitor lines that allow it to determine the state of each input/output. What follows is a sampling of manufacturing functional tests on the ABS/TC ECM that lend to increased reliability and system integrity using the Agilent Technologies TS-5400 Series II electronics functional test platform.

Serial Link

The backbone of UUT-assisted testing (manipulation and verification of ECM functionality via the serial link) lies in the ability of the ECM to communicate with the test and measurement instrumentation. The common serial interfaces include UART-based ISO-9141, J1850 (pulse width modulated and variable pulse width), and J1939 (controller area network).

I/O Check
An input/output check may be easily accomplished by verifying that the ECM correctly reads the states of a given input or output.

Testing
Typically, the ECM designer determines the algorithm for setting the module in either a TEST or RUN mode. This algorithm, a specific handshake for example, is often executed in a given window of time just after the system is powered up (~500 ms for example), which is determined by the serial interface chosen. Therefore, testing the serial communication of the ECM can be accomplished using one of several methodologiesbased on specific ECM design.

Agilent TS-5400 Series II testing solution
In an effort to meet the needs of the most common serial interfaces, this system features an optional serial port adapter that supports ISO-9141, J1850, and J1939 serial communication. In addition, the Test Executive software provided with the platform has built-in action sets to facilitate serial communication to set the ECM in either test or run mode. The software envelope supporting this hardware feature set includes easy-to-use commands for test plan development.

A few Agilent TestExec SL actions related to serial port communication follow. Aside from the expected Read/Write/Configure software capabilities for serial communication provided, the test executive streamlines common process steps used in ECM functional testing. For example, sending the ECM a periodic "keep alive" message (referred to as a group message below) to maintain TEST mode (rather than RUN mode) is made significantly easier with the following actions:

mComConfigGroup: Configures any of the support serial interfaces for a group message

mComStartGroup: Specifies the time between groups, between group elements, group repeat count and the group message itself. GroupRepeatCount = 0 represents indefinite repetition of a keep alive message

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Variable Reluctance Sensors

A variable reluctance sensor (VRS) at each wheel provides wheel speed signals to four receivers located in the ECM. Occasionally, the rear wheels share a sensor, but this is seen less frequently in the industry today. The frequency generated by these sensors is directly proportional to velocity. Voltage levels on each VRS may range from 50 mV_{pp} (at 20 Hz) to 200 V_{pp} (at 5000 Hz).

Wheel slippage detection
Since the frequency generated by the signals is proportional to velocity, frequency changes relative to each of the sensors indicate that slippage on one or more of the wheels have occurred. It is paramount, therefore, that the test platform provides up to four independent, isolated frequency signals if all four wheels are to be simulated at once. Additionally, these signals need to sweep along different ramp profiles, which traditional frequency generators are incapable of doing.

Testing
Three of the wheel sensor inputs are routed to three wheel inputs and are held at constant amplitude and frequency representing constant velocity (1V_{pp} at 1kHz for example). The fourth wheel sensor input is applied with a swept waveform in both an upward and downward ramp; see Figure 1. The test verifies that at a certain frequency difference between the wheels, or at a certain change in frequency for a given wheel, the correct isolation or purge solenoids are activated.

Agilent TS-5400 Series II testing solution
This system can be configured to include the E6173A arbitrary waveform generator for use in this test. Ramp times can be programmed with the E6173A ARB to be symmetric or asymmetric, depending on the desired input. Frequency generators cannot provide this type of complex swept waveform. The platform's software includes built-in actions allowing ease of programming for ramp up times, duration and ramp down times. The E6173A has two isolated channels. Therefore, if simulation of four simultaneous wheel speeds is desired, using two generators is advised.

Supporting this hardware solution is the test executive software envelope with action routines and test plan examples for the E6173A arbitrary waveform generator. A sampling of TestExec SL actions for the E6173A ARB include the following:

arbConfOut: Configures the ARB's output circuitry

arbSet: Programs the ARB by transferring all settings specified in the configuration

Arb_Dl_Swept_: Downloads a basic swept waveform of specified frequency, amplitude and offset

Arb_Dl_Std_Waveform: Downloads a sine, square/ pulse, or triangle waveform of a specified frequency, amplitude, and offset.

Arb_Dl_Custom_Waveform: Downloads a custom, user-defined waveform consisting of up to ten sequences with fifty segments per sequence to the ARB.

Cross Talk
Testing the ABS/TC module's handling of cross talk is important when assessing the system's ability to properly interpret the incoming VRS wheel signals. Misinterpretation due to channel-to-channel cross talk may cause the system to react incorrectly.

Testing
One channel is set to high voltage AC and the others are set to either low-level AC values (less than 100 mV) or to DC. If cross talk due to the high-input voltage channel exists, the low-level channels will respond, despite the fact that their own voltage levels do not warrant action. Speed status is requested via the serial link and no speed should be present on the non-driven inputs.

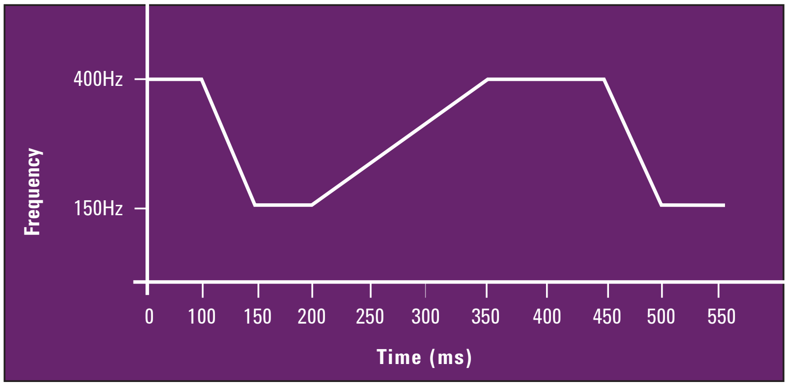

Figure 1: Swept waveform for fourth wheel sensor input (other three held constant)

Wheel Speed Threshold

The required response of the VRS receiver located at the ECM is illustrated in Figure 2. Verifying this expected behavior requires testing at multiple frequencies to characterize the wheel speed threshold.

Testing

This test would require the ability to apply various discrete input voltage and frequency values. The test might include input frequencies of 18 Hz, 400 Hz, and 1800 Hz at voltage levels just above and below the threshold at each frequency.

Agilent TS-5400 Series II testing solution

To perform the cross talk test, the E6173A Arbitrary Waveform Generator will generate up to 32 V_{pp}, requiring a step-up transformer in order to generate the required testing voltage levels. The optional E6171B Measurement Control Module (MCM) has an on-board transformer that can deliver 160 V_{pp}.

When testing the wheel speed threshold, the generated waveform does not require additional signal processing since the stimulus is no more than 2 to 3 volts for high-frequency testing. In both tests, the system supports common serial communication, including ISO–9141, J1850, and CAN/J1939 for response verification from the ECM.

Short/open sensor

In the vehicle, the ECM monitors shorts and opens on the VRS sensors. A VRS sensor includes a ferromagnetic disk and sensing coil. This sensor may be represented in an overall circuit as a 1.5kΩ resistor in series with an AC voltage source. The ECM passes current through the sensor, which should be floating with respect to chassis for noise rejection. Therefore, monitoring the sensors for shorts or opens becomes crucial to maintaining system integrity. The sensors may be compromised, for example, when salt deposits cause leakage current to pass from the sensor to chassis ground. This results in decreased noise rejection, which leads to improper event determination by the ECM. Similarly, if the sensor were opened, current would not pass and event determination would once again be inaccurate.

Testing

In the vehicle, the ECM monitors the shorts and opens. In production testing, the VRS open, short, and short-to-chassis detection feature is accomplished via relay-induced faults. The fault is verified by interrogating the ECM via the serial link and/or by the ECM turning on the display failure lamp.

Agilent TS-5400 Series II testing solution

This test system can be configured to include several different load cards for this application. In particular, E6175A 8-Channel Load Card, E6176A 16-Channel Load Card, and the E6177A 24-Channel Load Card would be appropriate choices. Since VRS testing involves current levels no greater than a few milliamps, users typically select the E6177A 24-Channel Load Card due to its bridge load capabilities. Serial communication with the ECM may be accomplished via one of the common interfaces supported by the platform: ISO-9141, J1850, or J1939.

The test executive software supports the comprehensive signal and load routing architecture. The TestExec SL switch path editor provides a less cryptic, easily read path description. In addition, for test plans where relay actions are repeated in various sections, relay state tracking streamlines redundant commands by recognizing the existing state of the relay, thereby speeding the time of test.

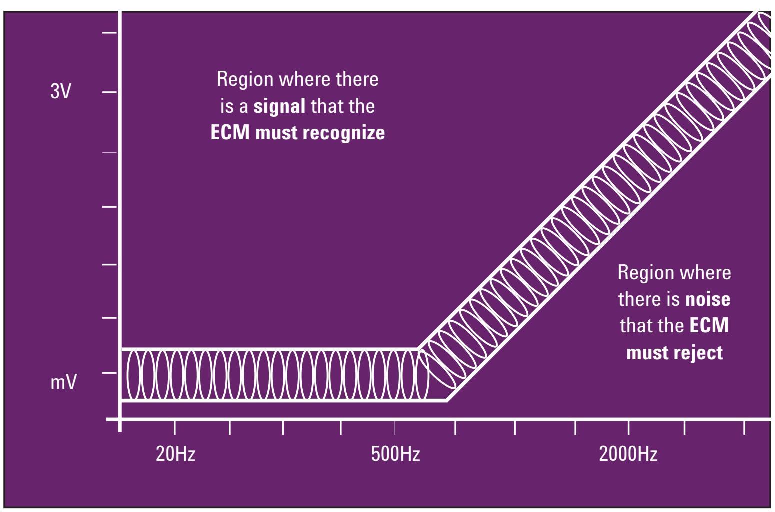

Figure 2: ABS/TC ECM response to VRS input

Solenoid Drivers

In order to control the wheel from slipping during an ABS event, braking pressure is modulated by the control of solenoid drivers (see Figure 3). ABS/TC response abilities ultimately rest with the ECM's ability to control the state of the solenoid-driven valves. Typical measurements of interest include the saturation and flyback voltage, driver leakage current and the ECM microcontroller ADC input recapture accuracy.

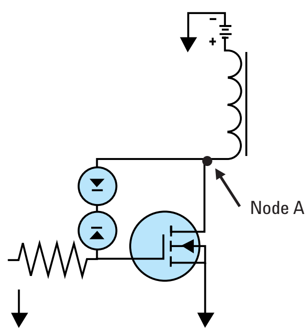

Figure 3: Typical lowside solenoid driver

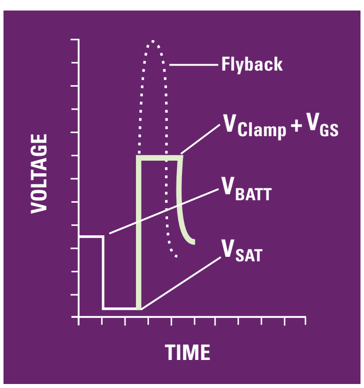

Figure 4: Voltage profile of solenoid deactivation

Saturation voltage
Saturation voltage (see Figure 4) is important for characterizing the health of the solenoid driver electronics. Typical saturation voltage values range from 0.5–1V.

Testing
Saturation voltage, as seen in Figure 4, is measured at the solenoid output (node A in Figure 3) just after turning on the solenoid driver. This voltage is easily measured with a DMM or by using a digitizer (ADC) and maybe followed by serial interrogation of the ECM to determine the voltage it measured.

Agilent TS-5400 Series II testing solution
This system includes a digital multimeter and/or a digitizer. In addition, the E6175A 8-channel load card, E6176A 16-channel load card, and the E6178B 8-channel 30A load card can handle transient voltages up to 500V while protecting the output relays. Common serial communication interfaces supported by this platform include ISO-9141, J1850, and J1939.

Multiple measurements, including saturation voltage, are greatly facilitated through use of TestExec SL software actions including:

ADC_Config_1_Chan: Configures E1563A or E1564A Digitizer for capturing a waveform for later analysis on Channel 1.

ADC_Analyze_Wave: Measures a waveform using the E1563A or E1564A Digitizer to analyze it for Vmin, Vmax, high pulsewidth, low pulsewidth, and period values. Measures Vmax and Vmin at the "offset" parameter's sample count after edges.

ADC_Min_Max_: Returns Vmin or Vmax DC voltage values from the E1563A or E1564A Digitizer in a window defined by the "start" and "stop" parameter times from the trigger point.

Flyback voltage
The inductive nature of the solenoids causes considerable voltage flyback when the solenoid is turned off (see Figure 4). If left unclamped, the flyback voltage can reach levels as high as 200 to 300 V, which must be limited to protect the solenoid driver. Typical clamp voltages are in the 40 to 60 V range.

Testing

There are two readily recognized ways to test flyback voltage: a static measurement that uses a voltage source and resistor (see Figure 5) and a dynamic measurement with the solenoid load in place. The dynamic test is often considered a more credible method of test. In the case of the static measurement, a voltage source of ~100 V and a resistor of ~10 kΩ may be used. The voltage is applied and the output, V_{out}, is measured to verify that the protective clamping circuit on the solenoid driver is functioning correctly (see Figure 5).

In dynamic testing, an Analog to digital converter (ADC) may be used to process the signal for use by the ECM microcontroller. The benefit of dynamic testing lies in its ability to capture multiple characteristics of solenoid driver behavior in a single test, such as saturation and *flyback voltage. Typically, capturing the saturation* and *flyback voltage simultaneously is difficult because the first is 0.5 to 1V, while the latter may be several hundred volts. The disparity in these voltage levels prohibits good resolution of their values. However, by employing a dual slope attenuator, high voltages are attenuated within a range that captures both (saturation* and *flyback) to be captured with good resolution. Figure 6 illustrates a typical voltage profile resulting from a dual slope attenuator.*

Agilent TS-5400 Series II testing solution

For static testing of the flyback voltage, the platform's E6171B measurement control module (MCM) can be programmed to apply a 100 V-compliance voltage with a current source limit of 1 mA. The output is then measured with a DMM to verify clamping levels of 40 to 60V. The TestExec SL software support for these actions include the following:

ForceVMeasI: MCM used as voltage source then measures the current flow using the DMM

In addition, the following parameters will define the test and qualify its results:

Vapply: Applied DC voltage
Iexpect: Expected current (milliamps)
Iactual: Actual current (milliamps) read by the DMM

For dynamic testing of flyback voltage, the system may be configured to include a digitizer (ADC) to simplify the test. Once the solenoid driver is turned on and off, the resulting output voltage waveform is captured and saved to a waveform data type file using built-in software actions. The MCM's onboard, programmable dual slope attenuator can be set to scale high input voltage values as desired.

Next, a comprehensive list of information may be extracted from the waveform, including flyback and saturation voltage, solenoid driver on/off time and duration of the flyback pulse. Using this platform with the optional digitizer allows this extensive data set to be acquired in just one setup.

Software support for this sophisticated test methodology includes the following TestExec SL action:

ADC_Transform: Transform E1563A or E1564A digitizer returned data with the MCM attenuator gain and offset terms. This action converts digitizer readings through the attenuator to the values at the input of the attenuator.

Parameters to define the test action and qualify the results are as follows:

trigfirst: 1=Reads data from digitizer before running analysis routines
atten: Configures the attenuator;
1 = adjust for MCM attenuator,
0 = do not adjust
store: 1 = Write to file, 0 = Do not write to file

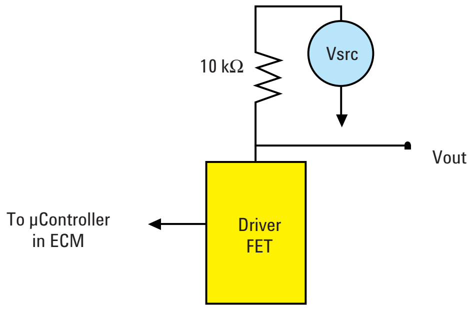

Figure 5: Static measurement of flyback voltage

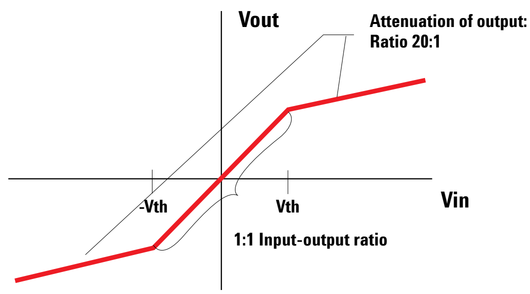

Figure 6: Input-output voltage profile of dual-slope attenuator

Driver leakage current

Information on the driver leakage current verifies the health of the driver FET (see Figure 3). Excessive leakage current is indicative of possible electrostatic damage (ESD).

Testing

To measure driver leakage current, disconnect the load and measure the current flowing to the solenoid driver while it is in the "off" state at node A in Figure 3.

ECM microcontroller (µC) ADC recapture accuracy

When the solenoid driver initiates, the µC ADC input must accurately capture the "on" voltage level and likewise, when the driver turns off, it must accurately capture the resting voltage level to determine the condition of the driver and solenoid load. Ultimately, in order for the ABS/TC ECM to behave appropriately and run its own self-diagnostics of the output solenoid, the µC ADC recapture must be accurate. For example, during operation of the vehicle, a test pulse is continuously generated every few milliseconds with a short duration of ~300 µs such that the driver is not activated (see Figure 7).

Testing

Disconnect the solenoid load and apply a DC voltage supply to turn on the driver. Determine the voltage value seen by the µC ADC recapture path by serial interrogation of the ECM. The voltage seen at the input to the µC should reflect the applied voltage giving consideration to the circuit design of the recapture path.

Agilent TS-5400 Series II testing solution

The platform's MCM contains a VI function that applies a low fixed voltage and measures the resulting current. This functionality greatly simplifies the solenoid driver's leakage current measurement.

The TestExec SL software support for this action includes the following:

ForceVMeasI: MCM used as voltage source then measures the current flow using the DMM

For testing the µC ADC recapture accuracy, the MCM can be used as a dc source voltage to the solenoid driver. Through serial interrogation, several sections of the resulting voltage profile may be tested for accuracy. Generally, the "on" voltage of a few hundred millivolts, the resting voltage of V_{batt} and one other voltage level are used for verification. Serial communication with the ECM may be tested on any of the supported common interfaces: ISO-9141, J1850, or J1939.

Smart Drivers

Today, ABS/TC systems often employ smart drivers that sense the condition of the solenoid and turn themselves off if the situation warrants, such as a short on the solenoid load.

Testing

Verifying that the smart driver responds appropriately to a short detection may require analog to digital conversion. Two facts should be verified: (1) the µC registers an over current condition when the solenoid load is shorted; (2) the smart driver reacted appropriately by shutting down to prevent damage. Verifying these facts requires knowledge of the peak and duration of the solenoid current profile, as seen in Figure 8. Finally, interrogation via the serial link will determine if the ECM was informed of an over current condition.

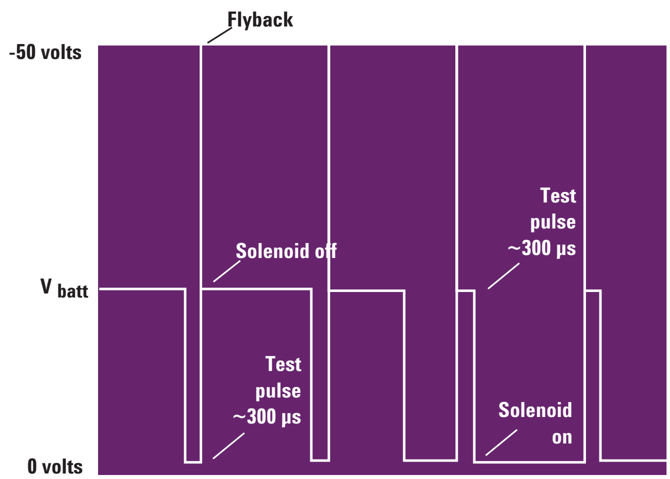

Figure 7: Test pulses applied regularly as a diagnostic input for determining ABS system integrity

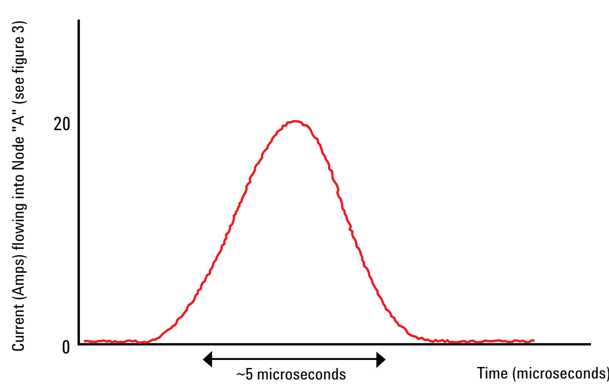

Figure 8: Solenoid current profile with working smart driver when load is shorted

Agilent TS-5400 Series II testing solution
Using TestExec SL, this waveform may be saved with the needed characteristics, such as peak and duration of the solenoid current extracted from the results. In addition, if the driver fails to shut down, protective fuses are built-in to several of the load cards.

Relay induced faults, such as a short across the solenoid load, can be created with the available load card switching for this platform. Load cards featuring 50 mΩ-sense resistors for current sensing should be placed in series with the shorted solenoid load. Then, the voltage drop across the resistor can be measured by use of a digitizer or digital multimeter (also configurable with the platform). The results will determine if the driver shut down when the over current condition was induced.

The E6178B 8-channel heavy duty load card is typically selected for its high current capabilities. Other load cards are generally equipped with fuses to protect the card in the event of prolonged, high current applications. This test could potentially result in a prolonged high current scenario if the smart driver fails.

Serial interrogation via any one of the supported interfaces, including ISO-9141, J1850, and J1939, will verify that the ECM was prompted with an over current condition.

Pump Motor Driver

Since hydraulic fluid is diverted to the dump accumulator during an ABS event, the fluid must be returned to the master cylinder/high pressure side of the hydraulic system. After each DUMP cycle, the pump motor is used to recycle hydraulic fluid to the high side of the ISO valve. The pump motor requires significant current with start-up surge currents as high as 200 Amps (for ~20 ms) and steady state currents of 10 to 30 Amps.

Testing
Testing the pump motor drivers closely resembles the previously outlined algorithms for testing solenoid drivers. The distinguishing characteristic of pump motor driver testing is the potentially high current levels the test and measurement instrumentation must tolerate.

Agilent TS-5400 Series II testing solution
The load card switching capability of the E6178B 8-channel heavy-duty load card option with this platform has the current ratings to effectively test the pump motor driver despite the increased current levels. In addition, the loads are protected with 30 A fuses in the event that the pump motor driver fails to shut down.

Antilock Brake System Test Solution

Optional throughput multiplier
The Agilent TS-5400 Series II automotive electronics functional test system may be configured to include an optional throughput multiplier, which is often used when testing low pin-count/complexity ECMs. The throughput multipler facilitates multiple up UUT (unit under test) testing. Multiple up UUT testing results in decreased set up time of the instrumentation per UUT, consolidating delays in relay closures and overlapping time delays due to inherent UUT latencies. The TestExec SL software tool provides comprehensive support for this test strategy.

Automotive electronics manufacturing environment
The TS-5400 family of automotive electronics functional test systems offers support for factory automation. From a more basic automation scheme to the use of PLC (programmable logic controllers), the TS-5400 Series II has comprehensive serial communication support and digital I/O capabilities allow the platform to be integrated as part of an existing manufacturing environment.

Overall solution
The test needs for antilock brake system ECMs as generally outlined in this application note may be satisfied by the following instrumentation.*

- Arbitrary waveform generator
- Digitizer
- Digital multimeter
- Serial port adapter
- Power supply
- Measurement control module
- Select load cards

*Note: This instrumentation list is presented as a general test solution profile, and is not for use as a direct ordering guide. For information on the detailed platform profile, please refer to the Product Note.

References
Jurgen, Ronald. *Automotive Electronics Handbook.* McGraw Hill Inc, 1999.
Mizutani, Shuji. *Car Electronics.* Sankaido Co, Ltd., 1992.

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