

ABS Control Unit

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Despite various measures taken in recent years to reduce traffic accidents, there has been no decline in the number of injuries and deaths occurring on the road. This is, in part, due to the increase in traffic volume, and the rise in the numbers of aged and young drivers. As a result, automotive safety is a growing social concern. Drivers have become more aware of the importance of safety, and more motor vehicles are being equipped with safety devices such as air bags and antilock brake systems (ABS).

Given this changing outlook, we have developed jointly with Toyota Motor Corporation and Aisin Seiki Co., Ltd., the four-wheel ABS/ECU (antilock brake system with an electronic control unit) tailored for compact cars. This paper describes the fundamental design principles and performance of ABS, and outlines the hardware structure, and software evaluation equipment.

1. Introduction

The antilock brake system (ABS), first introduced by Mercedes Benz, is being used in the world's cars at a growing rate to meet increased user demand for greater safety. Originally an exclusive feature of luxury models, the ABS has recently begun expanding into less expensive models at an even greater rate. For this reason, Fujitsu Ten has developed a four-wheel ABS/ECU (antilock brake system electronic control unit) for compact cars jointly with Toyota Motor Corporation and Aisin Seiki Co., Ltd.

This paper begins with a brief review of the fundamental principles of the ABS and its benefits, then proceeds to describe its hardware configuration and the dedicated ICs recently developed to cut the number of parts required, to reduce the cost, and to achieve added reliability. Finally, the ABS simulator and the arbitrary waveform generator designed to improve software development efficiency are introduced.

2. Principles and effects of ABS

2.1 Fundamental principles of ABS

The fundamental principles of the ABS can be expressed in a graph showing the relationship among the slip rate, braking force, and cornering force (Figure 1).

Slip rate = $(\text{Vehicle velocity} - \text{Wheel velocity}) / \text{Vehicle velocity} \times 100 (\%)$

The continuous line in the graph represents the rela-

tionship between the slip rate and the braking force. It is commonly known as a $\mu - S$ curve, in which μ (coefficient of friction between the tires and the road surface) is used in place of the braking force. From this curve, it is apparent that the braking force is the largest when the slip rate is between 10 and 20% (with the wheels slipping by 10 to 20% of the wheel velocity). The braking distance is the shortest at this time. If the wheels are locked (100% slip rate) as a result of stepping on the brake with excessive force, the braking force is lessened, with the consequence of a longer braking distance.

The dotted line in the graph denotes the relationship

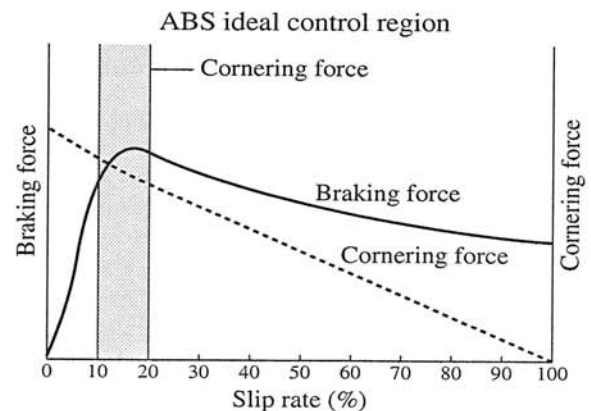


Figure 1. Relationship among braking force, cornering force, and slip rate

between the slip rate and the cornering force. The cornering force works on the front wheels as steering force and on the rear wheels as the force to keep the vehicle stable. The lower the slip rate, the higher the cornering force. The cornering force is reduced to 0 when the slip rate is 100%. This explains why steering is disabled when the wheels are locked, resulting in such poor stability that the slightest disturbance causes the vehicle to spin.

2.2 Effects and principle of ABS

Referring to Figure 1, the effects of the ABS are explained. When the driver steps on the brake, the braking force rises gradually, with a proportionate increase in the slip rate. The cornering force declines with increases in the slip rate. If the driver continues to step on the brake with more than the necessary force, the slip rate rises such that the braking force will exceed its peak, with the wheels quickly becoming locked.

The ABS monitors the slip rate and activates the actuator for reducing the wheel cylinder hydraulic pressure whenever the slip rate is found to exceed 10 to 20%. Consequently, the wheel velocity increases and the slip rate falls. Subsequently, the ABS raises the hydraulic pressure gradually to control the slip rate for a maximum braking force. The ABS iterates this control sequence to help obtain a high braking force without losing the cornering force. In other words, the ABS allows the vehicle to stop over the shortest possible distance without impairing steerability and stability during braking.

3. ECU configuration

3.1 Block configuration and function summaries

Figures 2 and 3 show the block diagram of the ABS/ECU and its exterior view. A summarized description of each of the functional blocks of the ABS follows.

- 1) Wheel velocity sensor processing circuit
The wheel velocity sensor processing circuit shapes the waveform of the sensor signal generated from rotation of the rotor attached to each of the four wheels, and also detects a failure in the sensor.
- 2) Switch input circuit
The switch input circuit converts the level of the ON/OFF signals from the stop lamp switch, parking brake switch, and so on, for the microprocessor.
- 3) Power supply circuit
The power supply circuit supplies power to the individual circuits and also generates start and stop signals for the microprocessor.
- 4) CPU monitoring circuit
The CPU monitoring circuit monitors the status of the microprocessor operation and the output operation, disabling the output system on detection of an alarm condition.
- 5) Wheel velocity signal output circuit (4ch)
The wheel velocity output circuit transmits wheel velocity signals to the traction control ECU.
- 6) Relay drive circuit
The relay drive circuit supplies a drive voltage to energize the pump motor drive relay and the hydraulic pressure control solenoid relay.

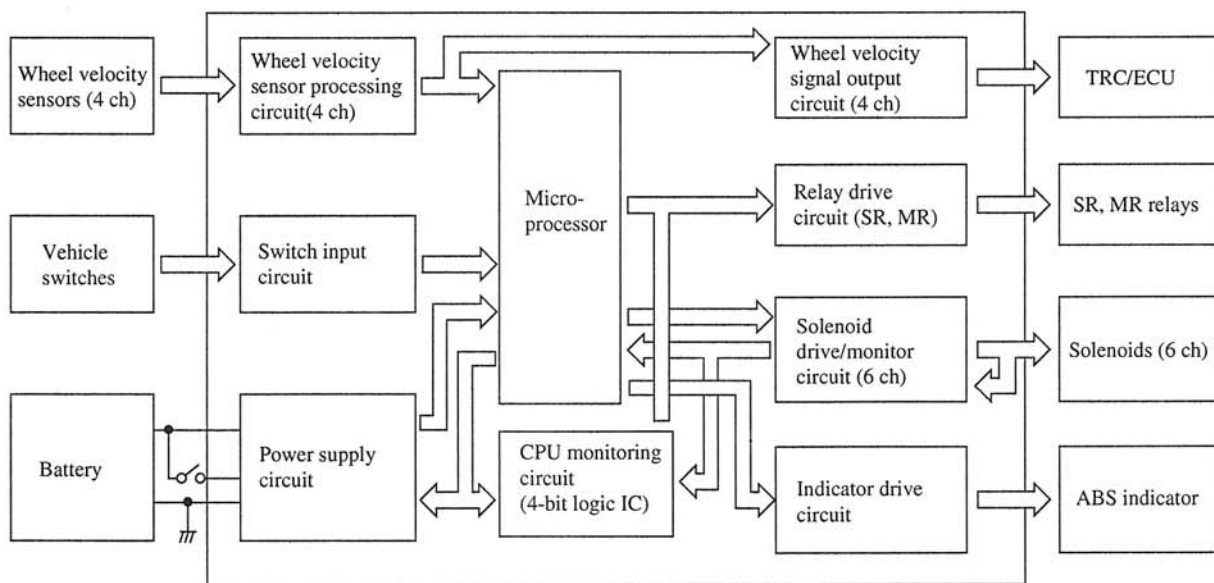


Figure 2. ABS block diagram

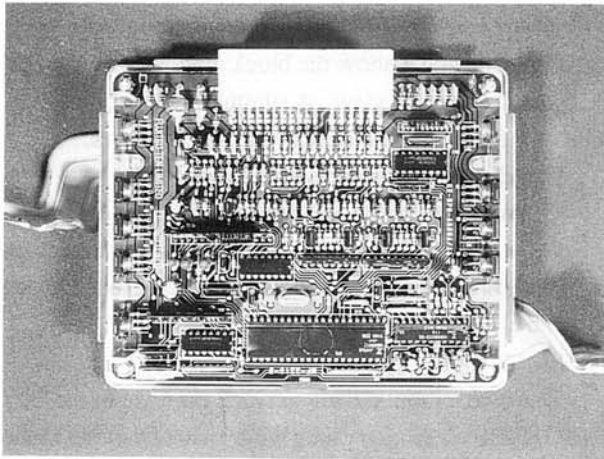


Figure 3. ECU

- 7) Solenoid drive/monitor circuit
The solenoid drive/monitor circuit supplies a drive voltage to the hydraulic pressure control solenoid and converts the level of the drive status for transmission to the microprocessor.
- 8) Indicator drive circuit
The indicator drive circuit is used to alert the driver to the normal or abnormal conditions of the ECU or to failures by turning on, turning off, or flashing the ABS indicator lamp.

3.2 Wheel velocity sensor waveform processing circuit

3.2.1 Processing circuit functions and configuration

The wheel velocity sensor waveform processing circuit provides mainly two functions. One is waveform shaping, whereby the sine waveform of the sensor signal generated from rotation of the rotor attached to each of the four wheels is shaped to form a square wave. The other is the detection of disconnections in the wheel velocity sensor, whereby disconnections in the harness, contact, coil or any other components between the ECU and the sensor are detected. To utilize the microprocessor input ports efficiently, the square wave signal and the sensor disconnection detection signal are transmitted to the microprocessor via a single line time sharingly on a time-division basis.

The wheel velocity sensor processing circuit is implemented in a dedicated IC to cut both the installation space and cost.

3.2.2 Waveform shaping function

Figure 4 shows the input sensitivity characteristics of

the waveform shaper. The input sensitivity characteristics are determined by the minimum sensor output voltage and the maximum value of the vehicle noise. Frequency characteristics provide for positively shaping the waveform of the minimum sensor output voltage across the frequency range of all the wheel velocities under ABS control, without shaping the waveform of the vehicle noise signal.

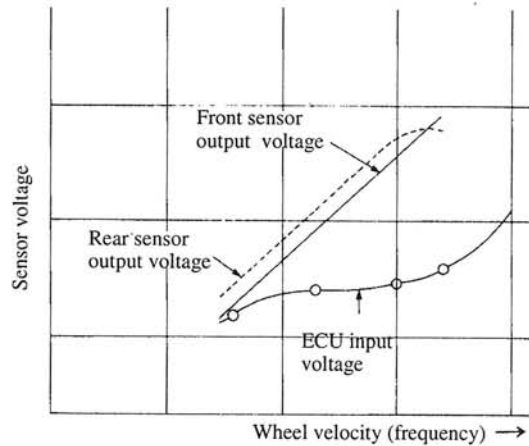


Figure 4. ECU input sensitivity characteristics

Figure 5 is a block diagram of the waveform shaping circuit. The frequency characteristics of this circuit are determined by r_1 to r_4 and C_1 to C_3 .

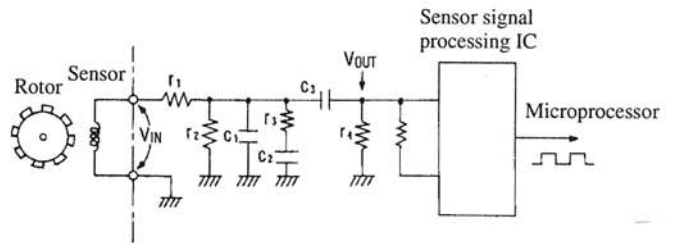


Figure 5. Sensor voltage waveform shaping circuit block diagram

The attenuation factor can be stated in an equation as:

$$\text{Attenuation factor } x = \frac{ABCD}{ABC + r_1(AB + AC + BC)}$$

$$A: \text{ Parallel impedance of } r_2 \text{ and } C_1 = \frac{r_2}{jr_2\omega C_1 + 1}$$

$$B: \text{ Serial impedance of } r_3 \text{ and } C_2 = \frac{jr_3\omega C_2 + 1}{j\omega C_2}$$

$$C: \text{ Serial impedance of } r_4 \text{ and } C_3 = \frac{jr_4\omega C_3 + 1}{j\omega C_3}$$

$$D: \text{ Ratio of division of } r_4 \text{ and } C_3 = \frac{jr_4\omega C_3}{jr_4\omega C_3 + 1}$$

The input sensitivity characteristics can be stated in an equation as:

$$V_{IN} = \frac{V_{OUT}}{x}$$

3.2.3 Disconnection detection function

Figure 6 shows an equivalent circuit of the sensor disconnection detection block. When Tr_1 is driven by a signal from the microprocessor, current I_0 flows through it so that a disconnection in the sensor is detected by monitoring the magnitude of I_0 . A disconnection in the sensor is detected during disconnection monitoring if I_0 falls due to high contact resistance in a connector elsewhere or a disconnection occurs in the harness, sensor internal coil, or elsewhere.

Figure 9 is a block diagram of the sensor signal process-

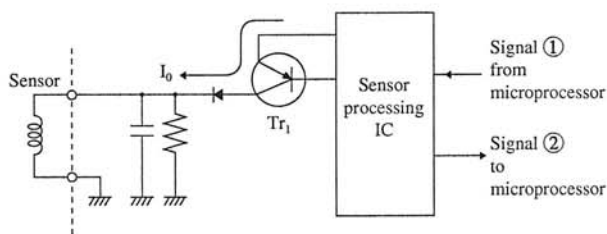


Figure 6. Equivalent circuit of the sensor disconnection detection block

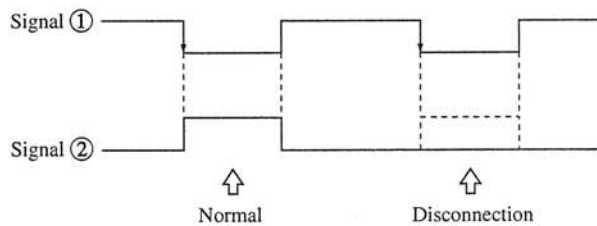


Figure 7. Signal logic for monitoring disconnections

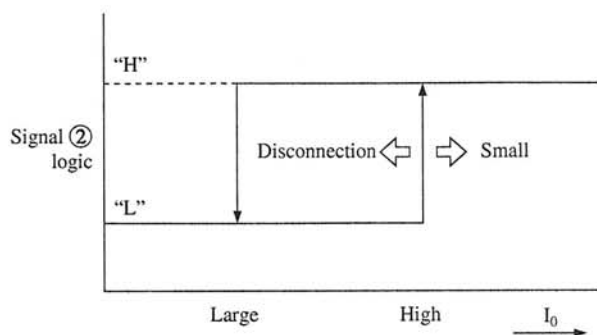


Figure 8. Disconnection detection characteristics

ing IC. The waveform shaper (block ①) has a low offset voltage and a low input bias current (30 nA or lower) in order to shape weak signals with high precision. The circuit is divided into four parts: an input signal clamping circuit for the input circuit protection, a bias voltage generating circuit, a comparator circuit with threshold voltages (Figure 10) depend on the bias voltage, and a constant-current circuit.

The disconnection detector (block ②) is made up of three parts: a disconnection detection start circuit, which drives the sensor current supply transistor Tr_1 and switches the send signal to the microprocessor from the waveform shaping signal to the disconnection detection signal, a comparator circuit, which compares the sensor current with a reference level, and a constant-current circuit. The disconnection detection current level is adjustable with an external resistor.

Figure 11 is an exterior view of the sensor processing IC, which is molded in a 17-pin ZIP package.

3.3 CPU monitoring circuit and logic IC

A 4-bit programmable logic IC which is specified for automotive applications was designed by Fujitsu Ten and manufactured by Fujitsu. It is used as a CPU monitoring circuit. This logic IC (CPU monitor) provides an instruction set which reduces 2-byte instructions and includes a reset instruction to prevent faulty operation caused by external disturbances.

It provides the following four major functions:

- 1) Monitoring CPU errors
- 2) Monitoring the relay output system
- 3) Monitoring the self-port facility
- 4) Enabling or disabling the system

On programming this IC, the following points were taken into consideration.

First, the following programming guidelines were used to increase reliability:

- 1) The use of 2-byte instructions is reduced to the minimum required. If the use of 2-byte instructions is unavoidable, their operands are chosen in order to prevent them from being mistaken for 1-byte instructions.
- 2) The use of interrupts and subroutines is prohibited.
- 3) The use of internal timers is prohibited, so that all time calculation is based on program step durations.

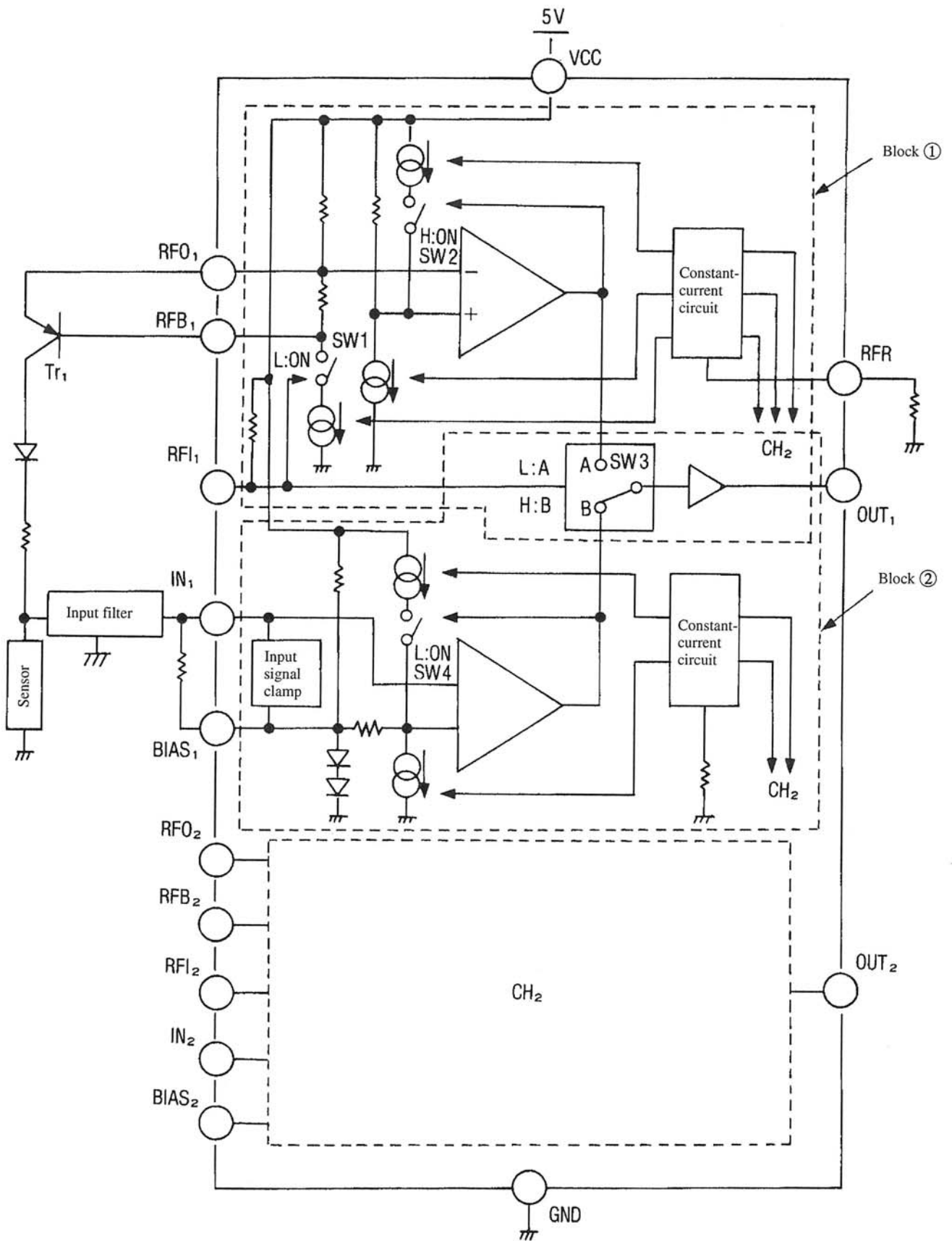


Figure 9. Sensor signal processing IC block diagram

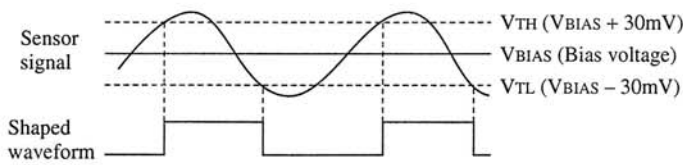


Figure 10. Waveform shaping logic

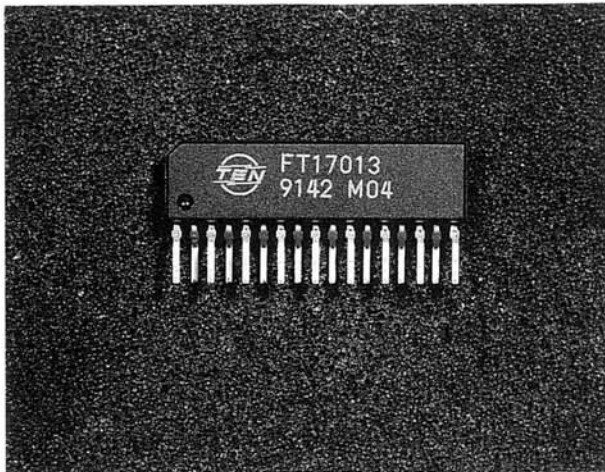


Figure 11. Sensor IC

- 4) The unused ROM space is filled with RESET instructions to ensure immediate return if it should be accessed as a result of errors in the program counter or elsewhere.

Second, the probability of detecting erroneous CPU operation has been increased. Errors in the CPU are monitored by measuring the period of pulses that are cyclically output from the CPU. Whenever the period of the pulses changes (suggesting an error), the system is disabled. The period of CPU monitor sampling is sufficiently shorter than that of the CPU output pulses. Since the pulses output from the CPU during erroneous operation are undefined, their period may become shorter than the sampling period. If the sampling period is synchronized with the pulses output from the CPU as shown in Figure 12, beats could arise, causing error pulses to be misrecognized as being normal. This problem has been solved by using different sampling periods to prevent the beat regions from overlapping each other. This has increased the probability of detecting CPU errors.

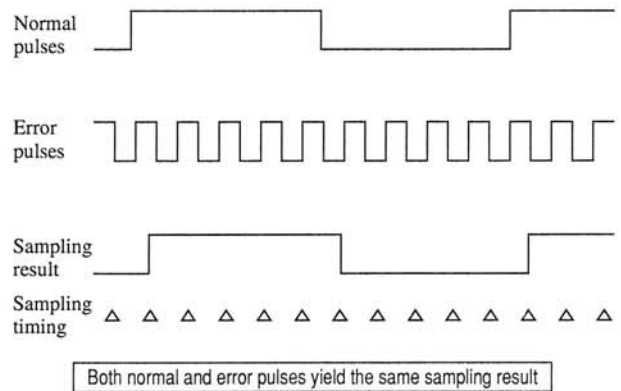


Figure 12. Pulse sampling and sampling result

4. Software evaluation apparatus

The developed ABS/ECU has been evaluated with an ABS simulator and an arbitrary waveform generator.

4.1 ABS simulator

Instead of designing a simulator that incorporates one large computer, the ABS simulator consists of a parallel array of multiple microprocessors (a multiprocessor system). It is linked to the ECU and actuators that are actually mounted on the vehicle to test the systems in real-time operation. The ABS simulator is shown in Figure 13.

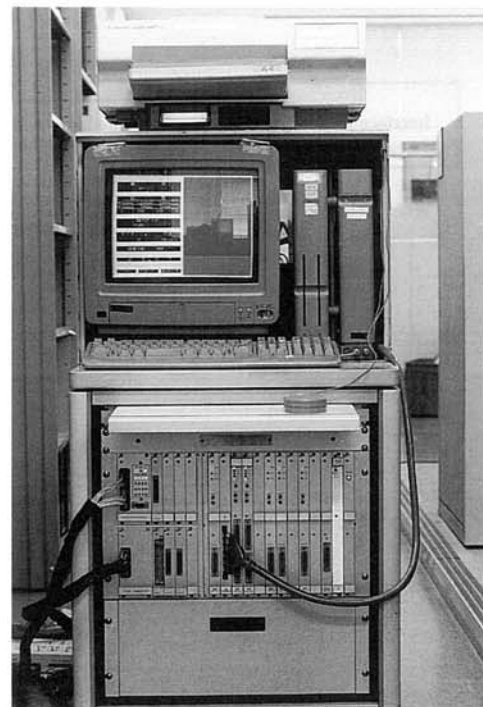


Figure 13. ABS simulator

4.1.1 Hardware configuration

The ABS simulator is broadly divided into a personal computer section, a simulator section, and an interface section (Figure 14).

1) Personal computer section

The personal computer section is made up of a personal computer, CRT, keyboard, mouse, and printer. The operator uses the mouse and keyboard to interactively set experimental conditions while viewing the CRT, representing simulation results in a graph. Figure 15 shows an example of a typical simulation output graph. The experimental conditions and results can be printed out as needed.

2) Simulator section

The simulator section is made up of four 16-bit microprocessor CPU boards, a memory board, an analog input board, an analog output board, and a pulse output board, connected together via a VME bus. The simulator section is connected to the personal computer with a bus, which transmits data via the memory board.

3) Interface section

The interface section consists of a level conversion circuit for linking the simulator to the ECU and actuators, an interface box housing the ABS peripheral circuitry, and a panel probe to allow the personal computer to read the ECU's internal RAM.

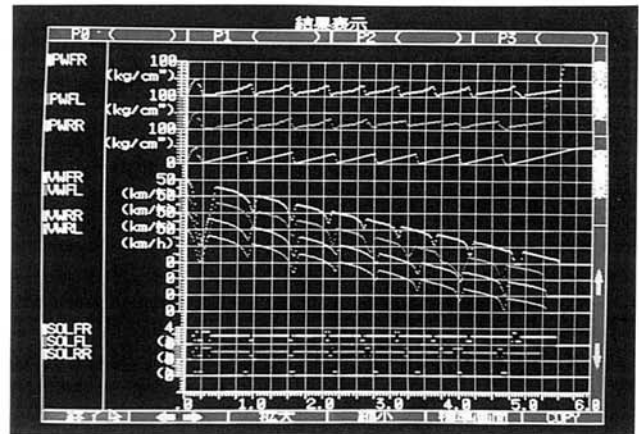


Figure 15. Simulation output waveforms

4.1.2 Software configuration

A simulation model of the ABS and environment is shown in Figure 16. To execute the vast amount of calculations in real time (in 1 ms intervals), the model has been divided into three blocks - braking, wheel motion, and vehicle motion/road surface characteristics. Three CPUs run in parallel handling the calculations of each block. A fourth CPU stores the result of the calculations from the three CPUs in time sequence and directs them to the CRT display or printer when the simulation is complete. Figure 17 is a flowchart of the ABS simulator operation.

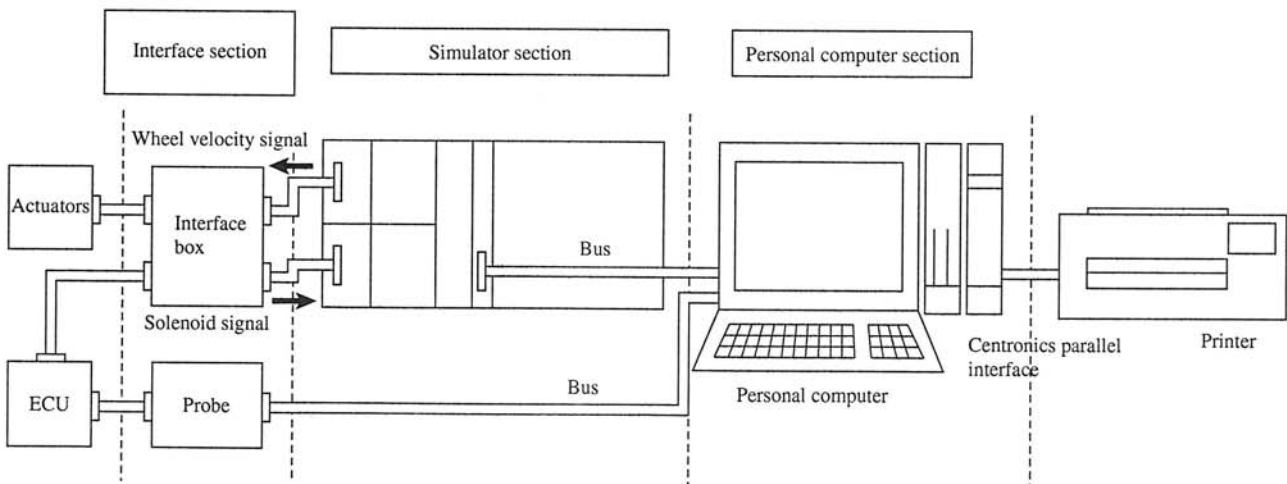


Figure 14. ABS simulator configuration

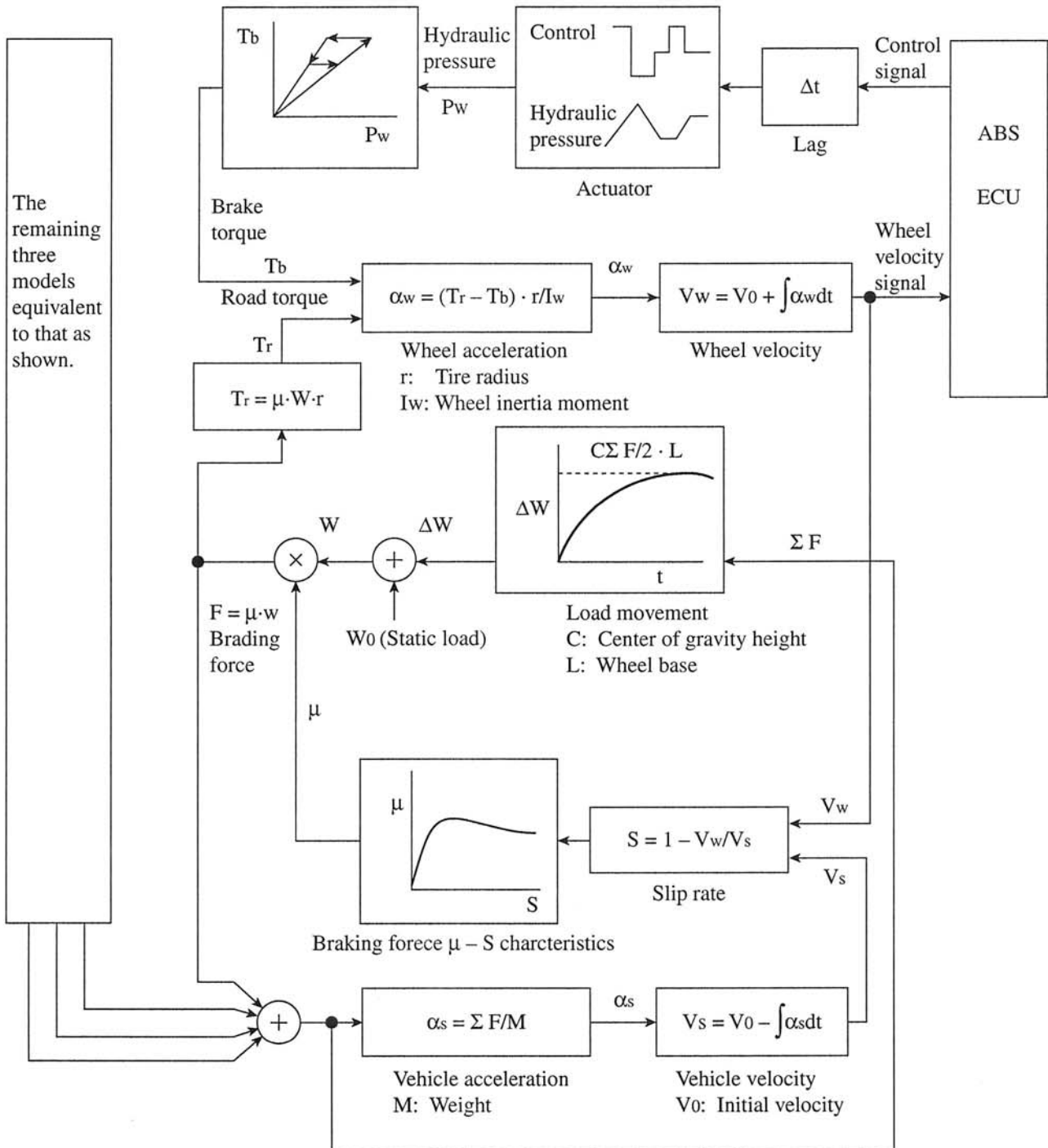


Figure 16. ABS simulation model

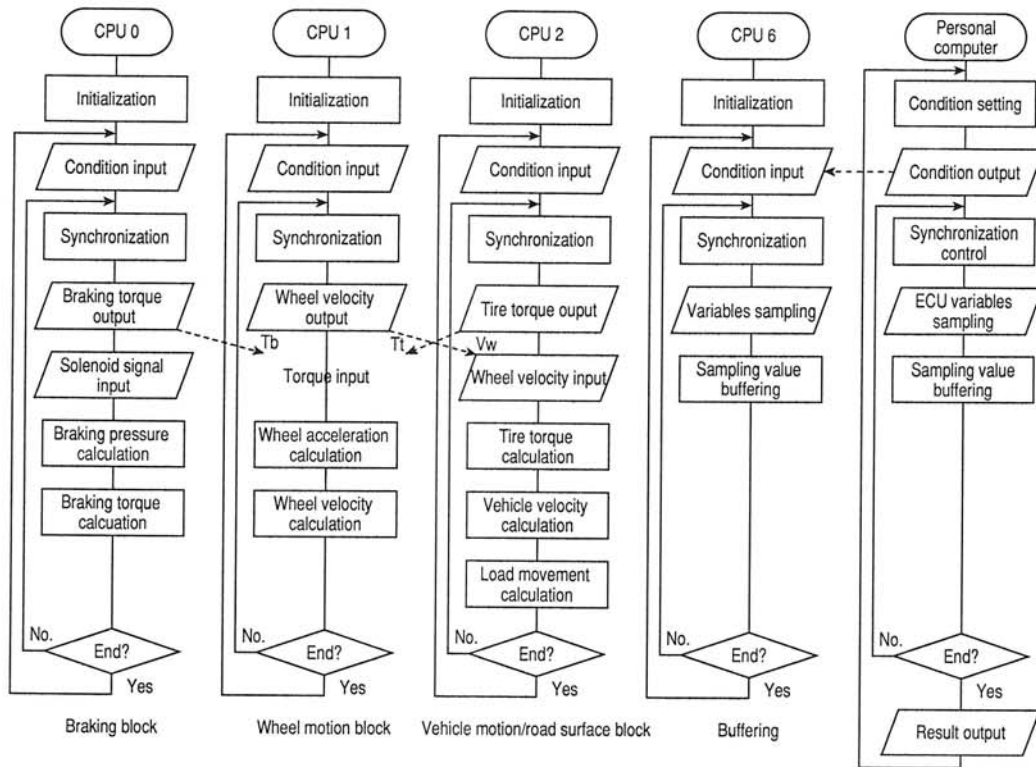


Figure 17. ABS simulator flowchart

4.1.3 Uses of the ABS simulator

The ABS simulator is used for the following purposes:

- 1) Verifying the ECU operation before starting field tests
- 2) Testing for reproduction of intermittent errors
- 3) Making comparisons with other manufacturers' ABSs and ECUs in similar terms
- 4) Analyzing the modes of ECU failures
- 5) Verifying correct ECU operations upon shipment

The ABS simulator is used in otherwise hazardous field tests and areas in which efficiency is important.

4.2 Arbitrary waveform generator

The arbitrary waveform generator uses the same hardware as the ABS simulator, with the difference that the software installed in the personal computer and simulator sections is modified. It issues arbitrarily changing wheel velocity signals to the personal computer and simulator sections to provide a detailed analysis of the responses from the ECU.

4.2.1 Software configuration

The personal computer generates arbitrary waveforms on the screen (Figure 18), assigns them to the wheels, and transmits the data to the simulator section. In the simulator section, CPU1 outputs data at 1 ms intervals as shown in the flowchart (Figure 19), based on the data generated by the personal computer, and CPU6, like the simulator, stores the data. The experimental results are output in the same way as the simulator.

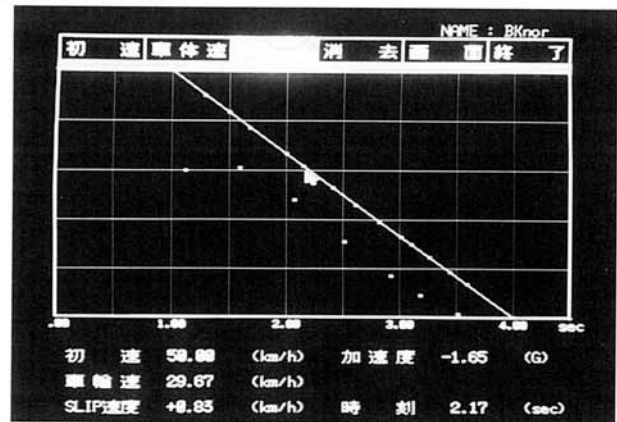


Figure 18. Arbitrary waveform generation screen

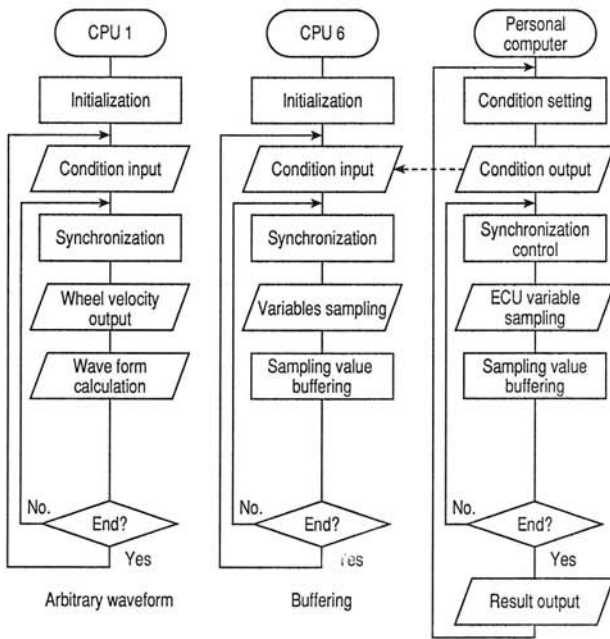


Figure 19. Waveform generator flowchart

4.2.2 Uses and effects

The arbitrary waveform generator is used for the following purposes:

- 1) Verifying correct operation of new control logic designed in the ABS development phase
 - 2) Reproducing and analyzing problems encountered in field tests
 - 3) Verifying design compliance with the specifications
- While the task of testing all possible variations and changes in parameters in field tests would entail many manhours, the arbitrary waveform generator allows waveforms to be generated for verifying the validity of the associated operations of the ECU, thereby speeding up the software development cycle.

5. Conclusions

A four-wheel ABS/ECU for compact cars has been developed jointly by three manufacturers. The authors are committed to continually developing and refining the mounting and evaluation technologies in order to develop ECUs better tailored to evolving customer needs. The authors extend their sincere thanks to the people concerned for their assistance in this development effort.



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