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Microprocessors in automotive electronics

Automatic Placement and Routing allows the customer to design engine-control logic based on standard cells while reducing development time.

Abstract: *Emission and fuel efficiency requirements have accelerated the use of electronics in engine control. Analog vs. digital, and NMOS vs. CMOS devices are compared for use in engine-control systems. The RCA integrated-circuit layout, Automatic Placement and Routing (APAR), which interconnects standard logic cells by a computer to provide a custom design, is discussed. The use of microprocessors in two system examples is demonstrated. The conclusion points out the future expanded usage of microprocessors in automotive electronics.*

Electronic-based systems are becoming increasingly important in automobiles. The requirements for better fuel efficiency, mandated emission standards, and the demand for more sophisticated driver information and display systems have all led to a rapid increase in solid state device usage. The most powerful systems are based on microprocessors.

Solid state devices were first successfully used in radios, followed by power control applications such as breakerless ignition, alternator diodes and electronic voltage regulators. Integrated circuits got their start in seat belt interlock circuits and automotive clocks. These early applications showed that solid state devices are reliable and cost-effective solutions to automotive problems. The emission and fuel efficiency requirements in effect in the United States have accelerated the use of electronics in engine control. All of the major manufacturers in the United States will have microcomputers in at least some models in the 1980 model year. Much more extensive use is planned in the 1981 model year.

Engine control systems—analog or digital

Many of the earlier solid state designs for engine control used analog techniques. This was a natural starting place due to the successful experience in entertainment applications and the analog nature of many of the signals needed for the engine to control the combustion process. Some analog-based systems for spark timing control were put into production; however, most newer systems use digital techniques. This evolution toward digital is due to a number of factors:

- Digital LSI technology is evolving rapidly;
- Digital systems are less sensitive to supply voltage and temperature variation;
- Precision adjustment and timing are not required; and
- Broader system design tolerances are possible.

This trend to digital has led to two system approaches: standard, or more usually custom, integrated circuits for a specific well-defined function; and microprocessor-based systems for more complex systems.

The basis for use of a microprocessor is its flexibility. The system capability is easy to expand by increasing the memory and occasionally adding additional input/output capability. Different engine needs can be met by software and Read-Only Memory (ROM) changes; hardware changes are not usually needed. In some systems, the required modifications for different engine parameters can be done with Programmable Read-Only Memory (PROM).

NMOS vs. CMOS

There are a number of different applications for microprocessors in the automobile, each with its own special requirements. The largest usage in the United States will be in engine control applications. To the usual microprocessor selection criteria of architecture, support parts and developmental aids, must be added the difficult environmental and reliability needs of automotive applications. Today's automotive processors are built using either NMOS or CMOS technology. Figure 1 shows the relative LSI capability of the two technologies; note that NMOS has had a significant lead in transistor count but the advent of SOS technology has narrowed the gap.

The advantages of CMOS

CMOS has several important performance advantages over NMOS. Table I summarizes the differences. Of particular significance is that it has the best noise immunity of any LSI technology, low power consumption and wide operating voltage range as well as the ability to operate from −65 to +125°C. These factors contribute to improved system reliability. The noise immunity and operating voltage range make CMOS more tolerant of

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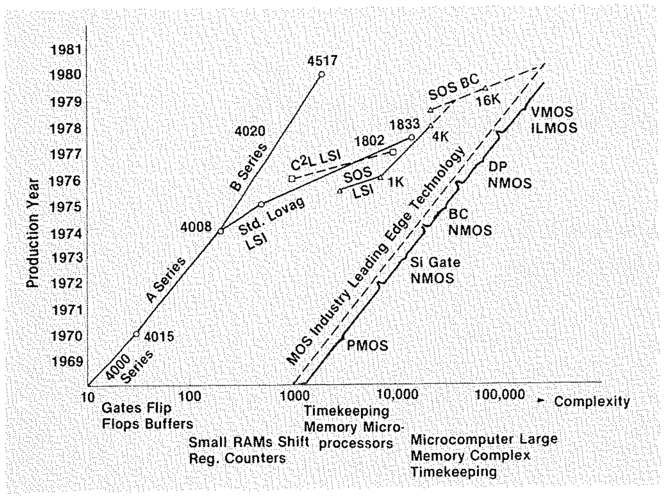


Fig. 1. NMOS leads in transistor count, but SOS technology narrows the gap.

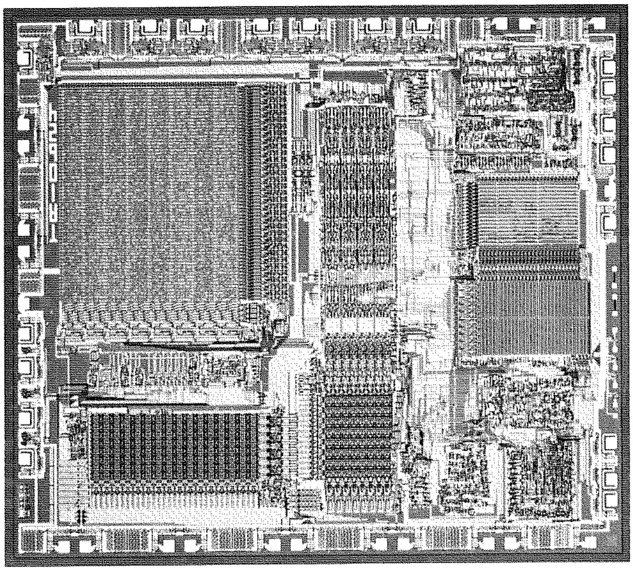


Fig. 2. The CDP 1804 is the most advanced CMOS microcomputer developed by RCA.

automotive voltage transients and low voltage during cold start and make it resistant to noise pulses. The low power consumption and high maximum operating temperature make CMOS devices cooler and typical operation is further away from the maximum permissible temperature for any ambient temperature. This reduction in maximum junction temperature contributes directly to improved long term reliability; it also allows location of CMOS systems in the engine compartment rather than the passenger compartment or somewhere in a body cavity. This alleviates problems with ground loops and simplifies connector construction as well as minimizing lead lengths. Mounting the electronic packages in the engine compartment also minimizes packing redesign due to body styling changes.

A second order advantage of the wide temperature and voltage range is the capability to operate devices during life testing and burn-in at accelerated conditions. Acceleration factors of 50-100 times can be obtained by the combination of increased voltage and temperatures. This acceleration allows quick reliability evaluation of new processes and designs.

A CMOS microcomputer

The most advanced CMOS microcomputer developed by RCA is the 1804 microcomputer. It is an 8-bit CMOS/SOS device that has a powerful instruction set, 2-K bytes of ROM and 64-bytes of RAM; the total transistor count is approximately 32,000 (Fig. 2). For most engine control systems only two LSI circuits will be needed, the 1804 microcomputer and a custom I/O circuit. Expansion is easily accomplished since additional memory may be added with no interface circuits (Fig. 3).

Custom I/O development

For most engine control systems it will be necessary to develop a special purpose interface circuit for added logic capability and to provide adequate real-time response and an interface to the various sensors and outputs. In general, this interface circuit is different for each customer and incorporates special features and circuitry that are proprietary to each user. RCA has developed an automated integrated circuit layout capability that has proven to be very successful in producing custom LSI circuits.

APAR layout

This technique, called Automatic Placement and Routing (APAR), is based on a large number of standard logic cells that are placed and interconnected by a computer. The advantages of this technique are: (1) the customer can design the logic based on the standard cells much the way he would produce a breadboard with packaged ICs; and (2) the total development time is significantly reduced with a high probability of working samples on the first pass.

The present standard cell library consists of over 60 cells of logic functions, layout geometries such as interconnecting tunnels, bond pads, high current drivers and some special cells for automotive applications such as voltage comparators and analog switches. Each logic cell has a

Table I. Comparison of NMOS and CMOS performance.

Characteristic	*CMOS*	*NMOS*
1. Quiescent power	1 — 100 μwatts SSI to LSI	100 — 1500 milliwatts MSI — LSI
2. Operating power @ 1 MHz	1 — 100 milliwatts SSI — LSI	100 — 1500 milliwatts MSI — LSI
3. Noise immunity	30% of supply voltage	10% of supply voltage
4. Supply voltage range	5 ± 20% 8 ± 50% 3 — 20	5 ± 5% 5 ± 10%
5. Temperature range	−55°C to 125°C	0 — 70°C −55° to 125°C special selection

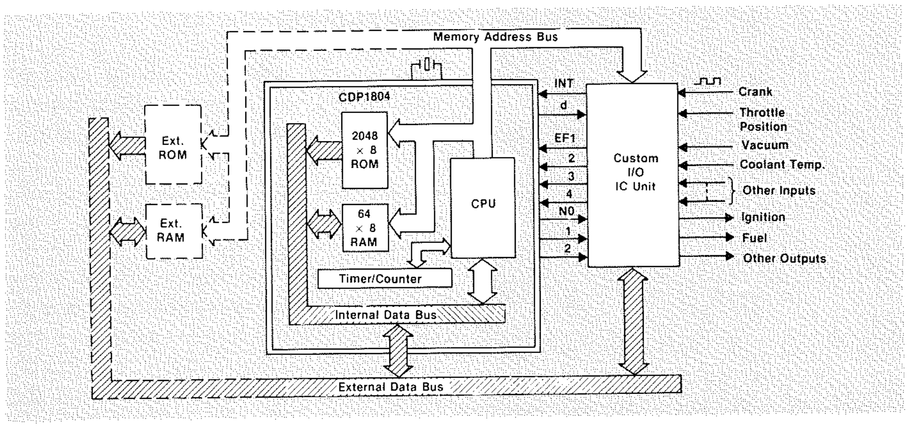


Fig. 3. Expansion of the 1804 microcomputer-based engine control system is accomplished easily.

fixed height of 315 microns, the width of the cell depends on the complexity of the logic function and varies from 60 to 400 microns. The connections to the cell are made at the top and bottom of each cell. Figure 4 shows a typical cell layout.

APAR design process

The design process, using the library, is straightforward. There is a data sheet for each cell (Fig. 5) that gives the logic function, cell interconnection data, and basic performance. The integrated circuit is then configured using the cell library by the logic designer. The next step in the process is to enter information defining the cells and their interconnections into the computer data base. This common data base is used for logic simulation, cell placement and interconnection and generation of the test program.

The output of the APAR run is checked for design rule violations and a check plot is prepared. There are generally some manual modifications made to reduce the overall die size using interactive graphic equipment. The final file is used to drive electron beam mask-making equipment to produce the required photomasks. Following conventional wafer processing, the test program generated via the data base is used to check functionality.

Since the process is fully computerized after generation of the logic diagram, the process is fast and error-free. The throughput time is largely determined by queuing and is approximately 1/4 of the time required for a layout using conventional drafting procedures.

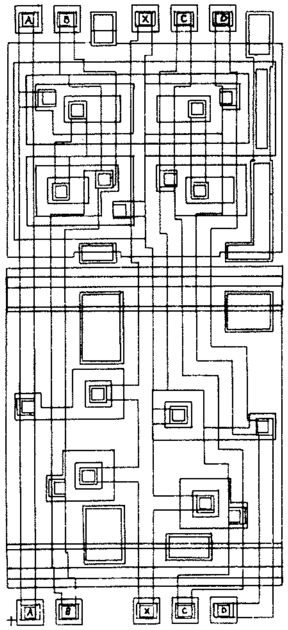
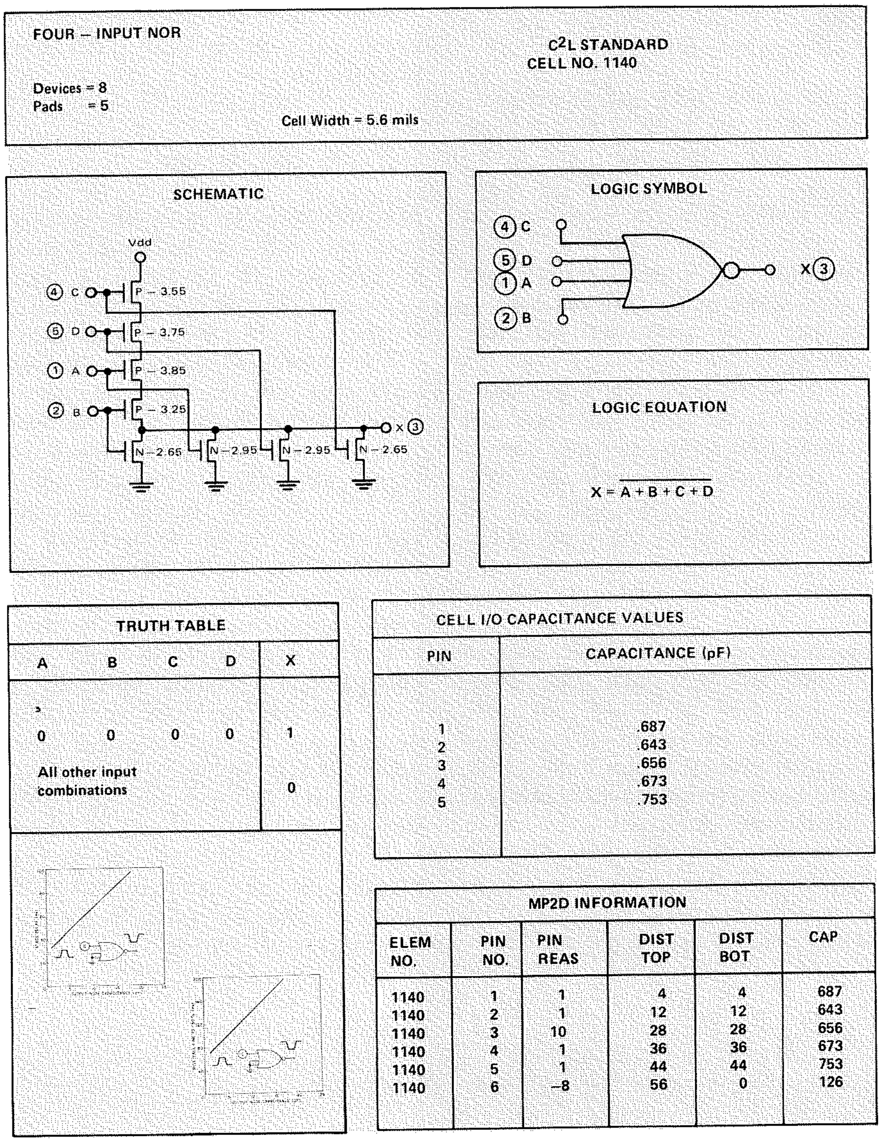


Fig. 4. The connections to the APAR logic cell are made at the top and bottom.



FOUR – INPUT NOR

C²L STANDARD
CELL NO. 1140

Devices = 8
Pads = 5

Cell Width = 5.6 mils

SCHEMATIC

LOGIC SYMBOL

LOGIC EQUATION

$$X = \overline{A + B + C + D}$$

TRUTH TABLE				
A	B	C	D	X
0	0	0	0	1
All other input combinations				0

CELL I/O CAPACITANCE VALUES	
PIN	CAPACITANCE (pF)
1	.687
2	.643
3	.656
4	.673
5	.753

MP2D INFORMATION					
ELEM NO.	PIN NO.	PIN REAS	DIST TOP	DIST BOT	CAP
1140	1	1	4	4	687
1140	2	1	12	12	643
1140	3	10	28	28	656
1140	4	1	36	36	673
1140	5	1	44	44	753
1140	6	−8	56	0	126

Fig. 5. A data sheet, for each APAR cell, gives the logic function, cell interconnection, and basic performance.

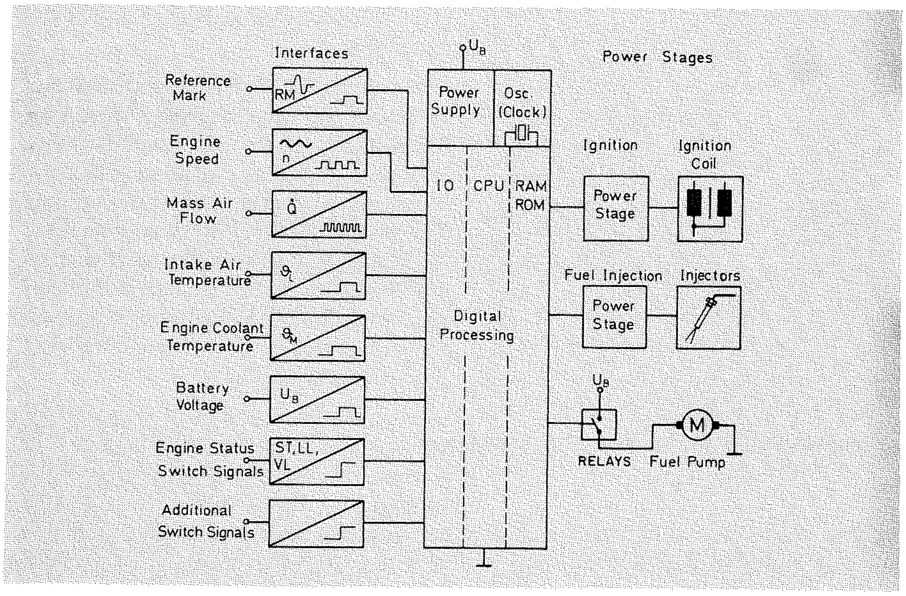


Fig. 6. Block diagram of Bosch engine-control system.

APAR device simplicity

CMOS is an ideal technology for computer layout. All static circuitry is used; dynamic clocking and multiphase logic design procedures usually used in NMOS are not necessary. The current levels are low, and race conditions are avoided so that cell placement and node loading do not affect the logic functionality. Maximum clock frequencies of approximately 5 MHz may be used at 5 volts.

The upper limit of device complexity using this technique is currently approximately 3000 transistors in a random logic configuration. The size consumed per transistor is approximately 10,000 microns, about 1.6 times that needed in a hand-packed layout in the same technology. Thus, the die cost is somewhat higher.

Completed circuits are then used to check out the design in the automobile. Generally, there is substantial time between design verification and the start of production; however, if there is not, APAR circuits can be produced in substantial quantities for production.

If time allows, the fully proven APAR circuit may be redone using manual techniques to achieve smaller die size. This manual layout is done using the APAR circuit as a guide and is, therefore, simplified.

System examples

Microprocessors are now used in several production engine control systems. Figure 6 shows a block diagram of a system developed by Robert Bosch GmbH used by Bayrische Motoren Werke AG (BMW).

This system controls both fuel injection and the ignition. It is based on the RCA 1802 microprocessor with standard program and read/write memories, and an APAR input/output chip designed jointly by RCA and Bosch. The precise amount of fuel and the correct spark timing are determined by the information received from the sensors.

A second example is a system developed by Chrysler Corporation to control spark timing based on six different inputs. The system uses only four LSI parts, the 1802, a standard RAM and ROM and a custom APAR chip. An interesting feature of this system is that it contains a small PROM that can handle 4, 6 and 8 cylinder applications as well as allowing for some change in engine control constants. The system is mounted in the air intake to the air cleaner under the hood.

Conclusion

The present needs of engine control systems vary from 25,000 to 50,000 devices which are usually contained in several packages. As more functions are added, for instance anti-knock, cruise control, idle speed and transmission control, the number of transistors needed will be increased toward 100,000. In such systems most of the transistor count is concentrated in the memory with one transistor per bit in the program memory and five or six per bit in the read/write memory. As an example, with program memory of 7-K words and 256 bytes of read/write memory, a total memory transistor count of about 70-K transistors would be needed.

The continual improvement in LSI technology will be used to increase the reliability of the system. Automotive users will not continue to be at the leading edge of LSI complexity in terms of number of transistors.

Don Carley joined RCA in 1957 and initially had responsibility in rf power transistor development. In 1971, he moved into integrated-circuit operations and subsequently held a number of positions in that area, including Manager, CMOS Engineering and Manager, Microprocessor Applications. He is presently involved in automotive IC development.

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