



DATAMATH CALCULATOR MUSEUM

Intel and TI: Microprocessors and Microcontrollers

Two famous companies, Intel and Texas Instruments started about the same time the development of higher integrated microprocessors. Intel continued this development to today's Pentium processors. Texas Instruments stopped the development of pure single-chip microprocessors and added the program and data memories plus the I/O-functions on the chip. The microcontroller was born.

The story is based on the book:

Computer Structures: Principles and Examples

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• Intel: The birth of the Microprocessor

"In the beginning Intel created the 4004 and the 8008."

• The Prophecy

Intel introduced the microprocessor in November 1971 with the advertisement, "Announcing a New Era in Integrated Electronics." The fulfillment of this prophecy has already occurred with the delivery of the 8008 in 1972, the 8080 in 1974, the 8085 in 1976, and the 8086 in 1978. During this time, throughput has improved 100-fold, the price of a CPU chip has declined from \$300 to \$3, and microcomputers have revolutionized design concepts in countless applications. They are now entering our homes and cars.

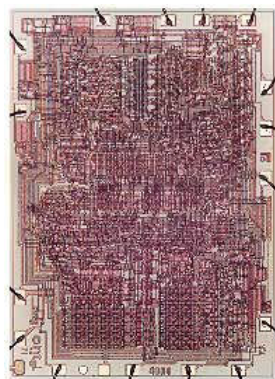
Each successive product implementation depended on semiconductor process innovation, improved architecture, better circuit design, and more sophisticated software, yet upward compatibility not envisioned by the first designers was maintained.

• Historical Setting

In the late 1960s it became clear that the practical use of large-scale integrated circuits (LSI) depended on defining chips having

- High gate-to-pin ratio
- Regular cell structure
- Large standard-part markets

In 1968, Intel Corporation was founded to exploit the semiconductor memory market, which uniquely fulfilled these criteria. Early semiconductor RAMs, ROMs, and shift registers were welcomed wherever small memories were needed, especially in calculators and CRT terminals. In 1969, Intel engineers began to study ways of integrating and partitioning the control logic functions of these systems into LSI chips. At this time other companies (notably Texas Instruments) were exploring ways to reduce the design time to develop custom integrated circuits usable in a customer's application. Computer-aided design of custom ICs was a hot issue then. Custom ICs are making a comeback today, this time in high-volume applications which typify the low end of the microprocessor market. An alternate approach was to think of a customer's application as a computer system requiring a control program, I/O monitoring, and arithmetic routines, rather than as a collection of special-purpose logic chips. Focusing on its strength in memory, Intel partitioned systems into RAM, ROM, and a single controller chip, the central processor unit (CPU).



Intel embarked on the design of two customer-sponsored microprocessors, the 4004 for a calculator (Intel receives a request from Japan's ETI/Busicom to develop integrated circuits for a line of calculators - the design becomes the 4004 microprocessor) and the 8008 for a CRT terminal (developed for Computer Terminal Corporation - later called DataPoint). The 4004, in particular, replaced what would otherwise have been six customized chips, usable by only one customer. Because the first microcomputer applications were known, tangible, and easy to understand, instruction sets and architectures were defined in a matter of weeks. Since they were programmable computers, their uses could be extended indefinitely.



Both of these first microprocessors were complete CPUs-on-a-chip and had similar characteristics. But because the 4004 was designed for serial BCD arithmetic while the 8008 was made for 8-bit character handling, their instruction sets were quite different.

• Texas Instruments: They invented the Microcontroller

U.S. Patent Office Rules TI Engineer Invented Computer-On-A-Chip

The U.S. Patent and Trademark Office has affirmed that Texas Instruments engineer Gary W. Boone is the inventor of the single-chip microcontroller, a device that revolutionized electronics by putting all the functions of a computer on one piece of silicon.

The Patent Office ruling, which was just released, is the outcome of a five-year proceeding to determine whether a highly publicized patent awarded in the summer of 1990 to Gilbert P. Hyatt, covered an invention made first by Mr. Boone at TI. The patent office proceeding, known

as an interference, focused on who was first to invent the single-chip microcontroller.

"This ruling rightfully establishes Gary Boone and TI as the inventor of the single-chip microcontroller, settling the broad speculation that followed after Mr. Hyatt received a patent. Gilbert Hyatt has absolutely no claim on the invention," said Richard Donaldson, senior vice president and general patent counsel for TI.

The Patent Office also granted TI's request for a statutory invention registration (SIR), which will officially recognize Gary Boone and TI as the inventor of the single-chip microcontroller. TI holds several patents covering the commercial implementation of the computer-on-a-chip, based on work done by Mr. Boone and other TI inventors, resulting from TI's effort in the late 1960s and 1970s on TI's [TMS100](#) and TMS1000 microcontroller families.

"TI has nothing to gain financially now from receiving another patent on Boone's basic invention of the computer-on-a-chip," explained Mr. Donaldson. "What is important is the Patent Office's confirmation that Gary Boone and TI were first to invent the computer-on-a-chip."

A notice will be attached to Mr. Hyatt's U.S. Patent No. 4,942,516 (Single chip integrated circuit computer architecture) explaining that his claims for invention of the single-chip microcontroller have been canceled.

This ruling will have no effect on TI royalties or its intellectual property licensing program.

The computer-on-a-chip, also known as the single-chip microcontroller, is a tiny sliver of silicon containing all the essential parts of a computer. Single-chip microcontrollers are widely used in computer keyboards, automatic ignition systems, television and videocassette recorder controls, and other household and industrial applications. Unlike microprocessor chips, single-chip microcontrollers contain on-chip permanent computer programs that direct the chip to perform predetermined functions. Microprocessor chips rely on external program storage devices, such as memory chips or disk drives.

Boone invented the computer-on-a-chip while working on the TMS100 microcontroller chip, which TI introduced commercially in late 1971 (read the original press release [here](#)). Unlike the microprocessor chip, which TI and Intel Corporation had each successfully built earlier in 1971, and which is used as the central computing chip in present-day personal computers, the computer-on-a-chip is especially suited to appliance and industrial control applications because it contains a permanent on-chip program that directs the chip to perform a dedicated function, such as controlling a microwave oven or tuning a television.

After months of work, Boone and his coworkers completed building the first working computer-on-a-chip in the early morning hours of July 4, 1971. Two weeks later, TI filed a patent application, which resulted in the series of patents issued, beginning in 1978, naming Boone as the inventor.

Hyatt never actually built a computer-on-a-chip, but based his claim to the invention on a series of patent applications he filed with the Patent Office in the 1970s and 1980s. In the Patent Office interference proceeding, he claimed he filed the first patent application describing a computer-on-a-chip in December 1970. After a review of tens of thousands of pages of Hyatt's patent filings, however, the Patent Office determined that Hyatt first mentioned the invention in an application that was not filed until December 1977--six years after TI introduced the product.

In 1994, TI requested that the Patent Office publish Boone's patent application as an SIR rather than as an additional patent. An SIR gives official recognition to an invention, but does not entitle the inventor to collect royalties.

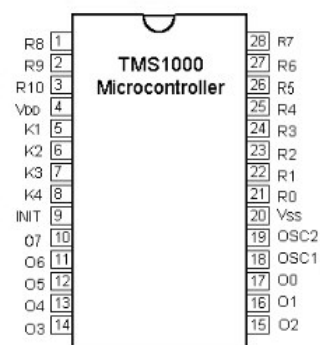
Texas Instruments Incorporated. Dallas, Texas (June 19, 1996)

• TMS1000: The first available Microcontroller

The TMS1000 is actually a series of 4-bit Microcontrollers containing ROM, RAM, I/O, & CPU on one chip produced by Texas Instruments. Find the original press release [here](#). The units are not capable of expansion in any way. The highest clock frequency attainable by the series is 0.4MHz. This results in a 2.5 microsecond clock cycle. All instructions execute in 6 clock cycles. The devices were fabricated using PMOS and required a single -15V supply.



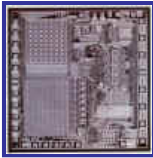
The only data input available is through the 4 bit K input lines. Input instructions collect whatever signals are available on the input lines at the time. Output data exist as 8 O lines and 11, 13, or 16 control, or R lines. The accumulator and the status flag determine the bit pattern of the O lines. This information has to be requested when the chip is produced. What this means is that only 32 distinct patterns can be generated by the O lines. The Y register determines which individual R control line is being set or reset. All of these units have internal clock logic which can be connected to an RC circuit with one end of the capacitor connected to Vss, one end of the resistor connected to Vdd and the opposite ends of the components connected to both OSC1 and OSC2. If an externally generated signal is to be used, it must be connected to OSC1 while OSC2 is grounded. The INIT (reset signal) should be held high for at least 6 clock cycles after power is applied. Reset causes the Page Address and Page Buffer registers to be loaded with binary ones. The O and R outputs as well as the program counter are zeroed.



• The TMS1000 Single Chip Calculators

Because of their limited requirements, hand-held calculators were one of the first consumer-oriented products to take advantage of the emerging LSI technology. After the initial, ad hoc designs, calculators have been implemented as stored-program computers. Today, most calculators consist of a single LSI computer chip plus a display. And the adoption of LSI technology was very rapid. For example, the [TI-2500](#) Datamath calculator introduced in 1973, had 119 parts, of which 82 were electronic in nature. By 1976, the [TI-1200](#) consisted of only 22 parts, of which only the calculator chip (a complete computer with programs) and display were electronic. This single-chip integration is made possible by the tightly specified user environment. Input (e.g., keyboard or magnetic card) and output (e.g., LED display, printer, or magnetic card) options are limited. Further, the input language (i.e., function per key) is also fixed.

The TMS1001 was the first LSI MOS chip of the TMS1000 family used in the Texas Instruments [SR-16](#) calculator. The chip contains a microcomputer complete with a program ROM having 1,024 eight-bit words; a temporary storage RAM; input (from keypad); output (to control keypad scan and LED display); and an oscillator (clock). The TMS1000 chip was designed to span a range of hand-held calculator



products (from four-function up through simple memory calculators). Since the chip had to be customized with the ROM program appropriate to a product, other programmable features were included to improve the chip's flexibility. This programmability was provided by two programmable logic arrays (PLAs). The output PLA converts five bits into twenty 8-bit output patterns in order to conserve program space. These patterns are specified by the calculator designer and represent different output patterns on a seven-segment display. The second PLA is for instruction decoding. The chip provides 16 microinstructions, such as "gate register Y to ALU." Twelve of these microinstructions form the fixed instruction set. The remaining instructions can be formed by combining any of the 16 microinstructions. Thus the instruction set can be specialized to improve ROM efficiency and execution speed for a particular application. Several special features of the microcomputer are aimed at the calculator application. The data paths are 4 bits wide to allow serial processing of binary-code decimal (BCD) digits. The arithmetic functions assume 2's complement integers, special instructions can be formed to facilitate BCD arithmetic (e.g., add six to accumulator for adjustment to legal BCD digits). Another BCD-oriented feature is the RAM addressing, which provides for four words of sixteen 4-bit fields. While the SR-16 only displays eight digits, the extra can be used as "guard" digits to maintain numerical precision or as expansion space for future products with larger displays or exponent displays. (Note that the BCD digit-serial data path allows for this expansion by increasing the loop count on variable-length-dependent operations.) The TMS 1000 applicability is primarily limited by ROM (program), RAM (user-accessible internals and temporaries), speed, and number of I/O pins. All the calculator functions are done by program. Two time-consuming functions are display refreshing and keypad scanning. The monolithic microcomputer must serially refresh the digits of the current display value at a sufficiently high frequency to achieve "persistence." The monolithic microcomputer must also serially examine keypad rows to see if any keys have been depressed. Even simple functions, such as Add, can take several instructions to execute, since BCD digits are addressed sequentially. Due to limitations on the LSI chip density, certain architectural features add to programming complexity:

RAM addressing: Since instruction size is limited to 8 bits, there is not enough room to specify an address in the instruction. Thus, a preloaded register pair (X,Y) is assumed to contain the currently valid address when executing the memory-reference instruction. The register can be updated by using instructions with immediate operands or by incrementing.

Program Counter (PC) incrementing: In order to save a separate incrementer for the PC or trips through the ALU for updating, the PC update is implemented by a pseudo-random sequence to go through all 64 states produced by a feedback shift register such as is used in cyclic redundancy codes. Thus only a shifter and several logic gates are required.

Instructions with side effects: Certain instruction op codes have been selected so that they can apply appropriate constants to the ALU and RAM. While this saves ROM space for frequently used constants, it seems to make op code selection difficult and add non-symmetry to the instruction format.

• All TMS1000 chips

The TMS1000 was introduced in 1974 and used in the SR-16 calculator. The following table summarizes the 15 different chips used in TI single-chip calculators.

Chip Series	TMS1000	TMS1070	TMS1100	TMS1170	TMS1200	TMS1270	TMS1300	TMS1370	TMS1400	TMS1470	TMS1600	TMS1670	TMS1700
Technology	PMOS	PMOS	PMOS	PMOS	PMOS	PMOS	PMOS	PMOS	PMOS	PMOS	PMOS	PMOS	PMOS
Pins per package	28	28	28	28	40	40	40	40	28	28	40	40	28
Data operand size	4 bits	4 bits	4 bits	4 bits	4 bits	4 bits	4 bits	4 bits	4 bits	4 bits	4 bits	4 bits	4 bits
Instruction ROM	1024*8	1024*8	2048*8	2048*8	1024*8	1024*8	2048*8	2048*8	4096*8	4096*8	4096*8	4096*8	512*8
Data storage RAM	64*4	64*4	128*4	128*4	64*4	64*4	128*4	128*4	128*4	128*4	128*4	128*4	32*4
Fixed instructions	11	11	11	11	11	11	11	11	11	11	11	11	11
Microprogrammable instructions	32	32	42	42	32	32	42	42	42	42	42	42	32
Display drive	none	VFD	none	VFD	none	VFD	none	VFD	none	VFD	none	VFD	none
First calculator	SR-16	TI-2550-II	(SR-40P) TI-5050M	Kosmos2	TI-5050	TI-5200	TI-5220	Canon L1632		Astro			
Introduction date	11/74	10/75	(never) 06/76	1978	03/75	01/77	06/77	01/77		1979			
Type designation	TMS1001	TMS1071	TMS1111 TMS1115	TMC1172	TMS1214	TMS1278	TMS1309	ZA0543		TMS1470			

The following two tables summarizes other - mainly chip-size optimized - architectures found in TI calculators. The TP0320 is a CMOS version of the TMS1000 with live memory. The TP0455, TP0456, TP0458 are 4 bit CMOS microcomputers with a gate-programmable architecture. They are based on the original TMS1000 microcomputer series and added timekeeping capability. They also includes onboard Instruction ROM, Data storage RAM, ALU, and assorted I/O capabilities. The TP0470, TP0475, TP0480, and TP0485 (CD2901, CD2902, CD2903) mark the eclipse of Texas Instruments' 4-bit calculator chip development.

Chip Series	TMS0950	TMS1040	TMS0970	TMC0980	TMC0920	TMC1500	TMC1980	TMC1990	TMC0260	TMC0270
Technology	PMOS	PMOS	PMOS	PMOS	PMOS	PMOS	PMOS	PMOS	PMOS	PMOS
Pins per package	28	28	28	28	28	28	28	28	40	40
Data operand size	4 bits	4 bits	4 bits	4 bits	40 bits serially	64 bits serially	4 bits	4 bits	4 bits	4 bits
Instruction ROM	1024*8	1024*8	1024*8	2048*9	511*9	2048*13	2048*9	1024*8	2048*9	2048*9
Data storage RAM	64*4	64*4	64*4	9*16*4	5*10*4	20*16*4	9*16*4	4*16*4	9*16*4	9*16*4
Fixed instructions	11	11	11	9	30	165	10	12	9	9
Microprogrammable instructions	32	32	32	46	---	---	47	31	46	46

Display drive	LED	VFD	LED	LED	VFD	LED	VFD	LED	VFD	VFD
First calculator	TI-1200	TI-2550-III	TI-1200	TI-30	TI-1050	TI-57	Dataman	TI-1000	TI-5040	Speak & Spell
Introduction date	03/75	01/76	03/76	06/76	05/77	05/77	06/77	06/77	06/78	06/78
Type designation	TMS0952	TMS1043	TMC0972	TMC0981	TMC0921	TMC1501	TMC1982	TMC1991	TMC0261	TMC0271

Chip Series	TP0310	TP0320	TP0455	TP0456	TP0458	TP0470 TP0475	TP0480 TP0485
Technology	CMOS	CMOS	CMOS	CMOS	CMOS	CMOS	CMOS
Pins per package	28	28	28/40	28/40	40	28/40	28/40
Data operand size	40 bits serially	4 bits	4 bits	4 bits	4 bits	4 bits	4 bits
Instruction ROM	511*9	2048*9	2048*9	2048*9	3072*9	3072*13 +128*13	3072*13 +128*13
Data storage RAM	5*10*4	12*16*4	8*16*4	8*16*4	12*16*4	22*16*4	22*16*4
Fixed instructions	30	11					
Microprogrammable instructions	---	46					
Display drive	LCD	LCD	LCD	LCD	LCD	none	LCD
First calculator	TI-1030	TI-50	Time Card	TI-54	BA-III	(Project X)	TI-88
Introduction date	06/78	08/78	1981	1981	1982	(1981)	02/82
Type designation	TP0311	TP0321	CD4501	CD4551	CD4812	CD290x	CD290x

These chips (w/o the failed TP0470/0475/0480/0485 devices) vary in implementation technology, number of I/O lines, display drive, amount of ROM (up to 26.6K Bits) and amount of RAM (up to 1,280 Bits). Calculator applications range from simple four-function calculators to the 50-step programmable TI-57. As of mid 1979, over 35 million TMS1000 chips were used in both calculator and non-calculator applications, establishing the TMS1000 as the computer architecture with the largest installed base. The internal clock rate varies from 200 to 450 kHz, depending on technology.

Find all the other calculators using the TMS1000 Single Chip Architecture in the Datamath Calculator Museum [IC-List](#).

• The TMS7000 Single Chip Microcomputers

A follow-on to the TMS1000 is the TMS7000 series announced in 1981 [Hayn, McDonogh, and Bellay, 1981]. The TMS7000 is an 8-bit monolithic microcomputer without on-chip ROM, with 2k Bytes, or with 4k Bytes on-chip ROM, 128 Bytes of RAM and up to 32 I/O lines in a 40 pin package. The TMS7000, TMS7020 and TMS7040 were the first members of the series and manufactured in a 5 Volt NMOS technology. Compared to similar designs from Intel, Motorola, and Zilog, the TMS7000 architecture had two outstanding features: A user-definable instruction set and a novel on-chip interconnection technology called "Strip Chip Architecture Topology (SCAT)", allowing customized variations of the hardware features.

Texas Instruments introduced in 1983 the second generation of the TMS7000 manufactured in a low-power CMOS process with the first devices TMS70C00, TMS70C20 and TMS70C40 and in later years massively expanded into larger on-chip ROM and ROM, serial interface, package options and even EPROM technology. The TMS70C20 can be located in the [CC-40](#) Compact Computer introduced in 1983.

The next step in the evolution of the TMS7000 family was in 1989 the TMS370 family.

Texas Instruments made in 1986 use of the flexibility of the "strip architecture" introduced with the original TMS7000 and developed the TMS70C46 for their [TI-74 BASICALC](#) and [TI-95 PROCALC](#) systems labeled TMC70009 and TMC70011, respectively. The [PC-324](#) printer used the TMC70016 while the [FIA-10](#) calculator and its stablemate [FIS](#) are powered by the TMC70035 chip. The TMS70C46 added to the TMS70C40 a variety of features to lower the manufacturing costs and complexity of the system:

- Clock divide logic
- Wake-up interrupt on key press
- Dock-Bus Logic
- Address decoder for 4 devices
- Address latch for C-Port
- Logic for additional E-Port

TMS7000 Family (as of January 1989 without piggy-back package options and prototyping devices SE77C42, SE70P161, SE70P162, SE70CP160, and SE70CP162):

Chip Series	TMS7000 TMS7001 TMS7002	TMS7020	TMS7040 TMS7041 TMS7042	TMS7742	TMS70C00 TMS70C02	TMS70C20	TMS70C40 TMS70C42	TMS70C46	TMS70C82 TMS77C82	TMS70CT20	TMS70CT40
Technology	NMOS	NMOS	NMOS	NMOS	CMOS	CMOS	CMOS	CMOS	CMOS	CMOS	CMOS
Voltage max. Frequency	4.5 - 5.5 V 5/8 MHz	4.5 - 5.5 V 5 MHz	4.5 - 5.5 V 5/8 MHz	4.5 - 5.5 V 5 MHz	2.5 - 6.0 V 5/6 MHz	2.5 - 6.0 V 5 MHz	2.5 - 6.0 V 5/6 MHz	2.5 - 6.0 V 5 MHz	2.5 - 6.0 V 5 MHz	4.5 - 5.5 V 5 MHz	4.5 - 5.5 V 5 MHz

Pins per package	40	40	40	40	40/44	40/44	40/44	54	40/44	28	28
Instruction ROM Instruction EPROM	0k*8	2k*8	4k*8	4k*8	0k*8	2k*8	4k*8	4k*8	8k*8 8k*8	2k*8;	4k*8;
Data storage RAM	128*8 128*8 256*8	128*8	128*8 128*8 256*8	256*8	128*8 256*8	128*8	128*8 256*8	128*8	256*8	128*8	128*8
I/O Ports	32	32	32	32	32	32	32	40	32	20	20
Timer	1 1 3	1	1 1 3	3	1 3	1	1 3	1	3	1	1
Serial Interface	0 1 1	0	0 0 1	1	0 1	0	0 1	0	1	0	0
First System						(HX-2000) CC-40		TI-74			
Comments						TMX70C20		TMC70009			
Introduction date						03/83		02/86			
Type designations						L11001 C11002 C11202 C14018 C14020 C71003		TMC70011 TMC70016 TMC70035			

Find here the original press release from 1974:

TMS 1000 One-Chip Microcomputers

Lowest cost. Broadest support. PMOS, NMOS, CMOS.

You're to market faster, and more economically, using TI's Series TMS1000 microcomputers. They carry today's lowest price. Versions are available for less than \$3.00 in volume quantities. And nobody matches the depth and breadth of TI's total support that speeds design-in.

Proven Microcomputer Family specific application requires flexibility. Which is what you get with TI's TMS1000 Series. All in the table are P-channel MOS/LSI circuits. A mature technology of proven reliability. In fact, TI has more than six years of experience in building millions of PMOS devices.

Reliability is enhanced by single-chip construction that cuts component count as much as 75% - which helps hold total system costs down.

Soon to come: NMOS circuits for faster throughput and CMOS microcomputers for applications requiring low-voltage, low-power operation.

All are software and architecturally compatible.

Preprogrammed Microcomputers

Speed your product introduction by eliminating software development. TI's Series TMS1000 now includes two preprogrammed microcomputers for specific applications. The TMS1117 is a microwave oven controller that's also useful as an industrial timer. And the TMS1018 is a number cruncher.

Special Support Circuits

Certain applications will require special support circuits. And these TI has:

TMS1976 Capacitive Touch Input is a single-package circuit which accepts inputs directly from a capacitive touch panel for direct input to all TMS 1000 devices.

TMS1024 and TMS1025 Input/Output Expanders provide an inexpensive means for expanding the number of inputs and outputs (up to 28) with one device.

TL505 Analog-to-Digital Converter permits up to 10 bit or 0.1% accuracy.

TL497 Switching Regulator converts TTL +5 volts to -15 volts for use in mixed systems.

Hardware Design Aids...

TI's start-to-finish support substantially reduces development time and costs. And it's support that's compatible with all present TMS1000 Series microcomputers. Readily accessible are hardware design aids that allow you to

check out your design thoroughly...field test it and even test market before committing to volume production.

The SE-1 System Evaluators are microprocessor-based with off-chip memory for prototyping, program checkout, and field testing. HE/2 and EP/1 Hardware Evaluators provide real-time checkout and debugging.

and Software Design Aids

Software generation can be accomplished with minimum effort and expense. TI makes available Assemblers and Simulators on three nationwide timesharing networks (GE, NCSS, TYMSHARE).

Also 16-bit ANSI Fortran for installation on your in-house 16-bit minicomputer.

And TIML High Level Design Language specifically formulated for the TMS1100 which significantly shortens software development time.

Training and Backup

TI's total support goes further. To include Customer Training Courses held regularly in Houston. TI software development and applications engineering staff in Houston. Field-located applications specialists. And automated systems for generating parts tooling and tests for prototypes and production parts. (For training information call 713-776-6511, Ext. 501).

Lowest cost and support options to meet your needs are good reasons to use TI's TMS 1000 microcomputers in appliance controls. Communications systems. Electronic games. Vending machines and cash registers. Terminals and peripherals. Industrial controls. Gas pumps. Credit card verifiers. Auto and telephone controls. Printers. Test instruments. Multiple timers. Traffic light systems. Any place you need the cost and the performance capability of TI's microcomputers.

Call your local TI sales office, or for a brochure about the TMS1000 microcomputer family, write Texas Instruments Incorporated, P.O. Box

If you have additions to the above article please email: joerg@datamath.org.

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