Embedded systems and the role of programmable logic devices in embedded systems

Embedded system: a combination of computer hardware and software, and perhaps additional mechanical or other parts, designed to perform a dedicated function. In some cases, embedded systems are part of a larger system or product, as in the case of an antilock braking system in a car.

Examples: microwave ovens, cell phones, calculators, digital watches, VCRs, cruise missiles, GPS receivers, heart monitors, laser printers, radar guns, engine controllers, digital cameras, traffic lights, remote controls, bread machines, fax machines, pagers, cash registers, treadmills, gas pumps, credit/debit card readers, thermostats, pacemakers, blood gas monitors, grain analyzers, and a gazillion others.

Contrast with general-purpose computer.

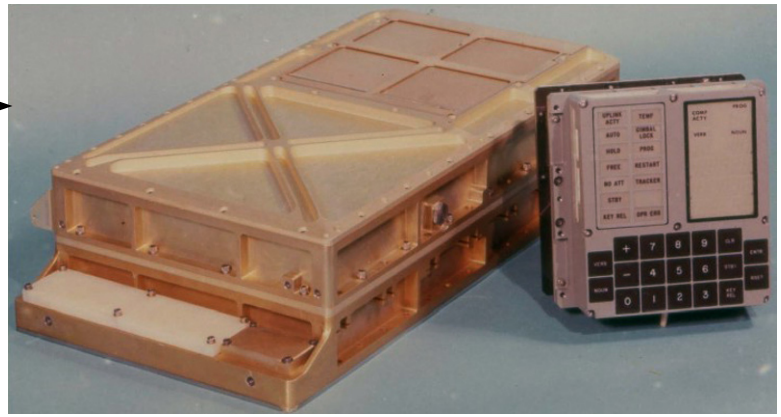
Source: https://barrgroup.com/Embedded-Systems/Glossary

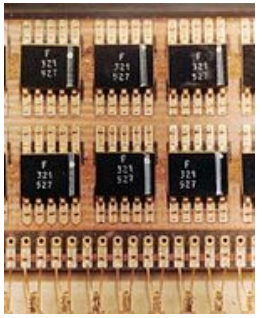
Embedded system: a historic perspective (hw)

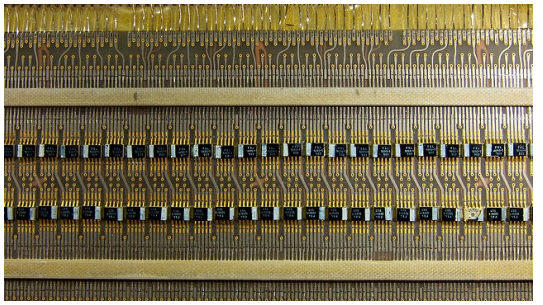
1960 1970 1980 1990 2000 2010 2020

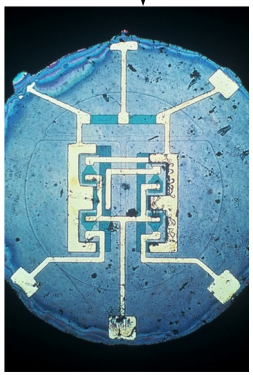
1961

1966 First notable emb. sys.: Apollo Guidance Computer (AGC)

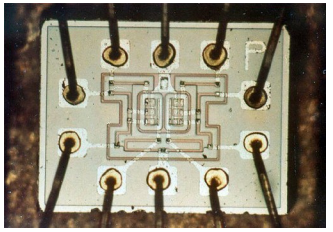


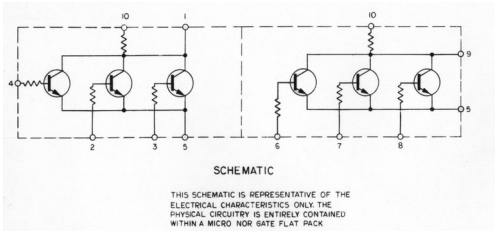






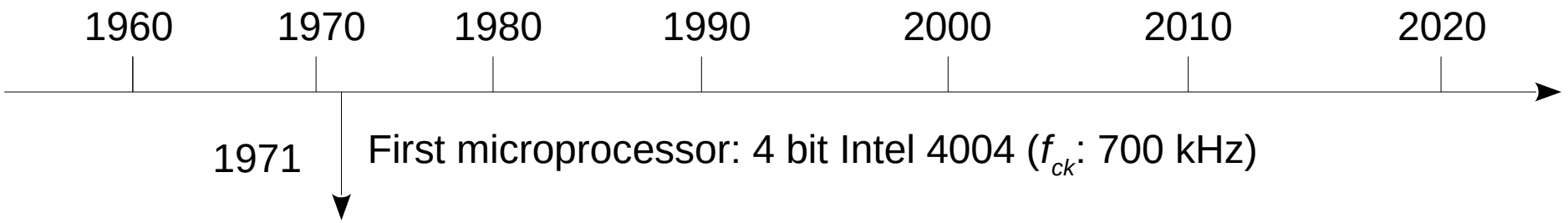
First Commercial IC (RTL)



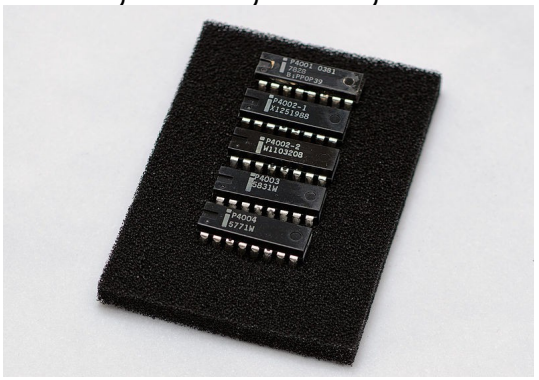


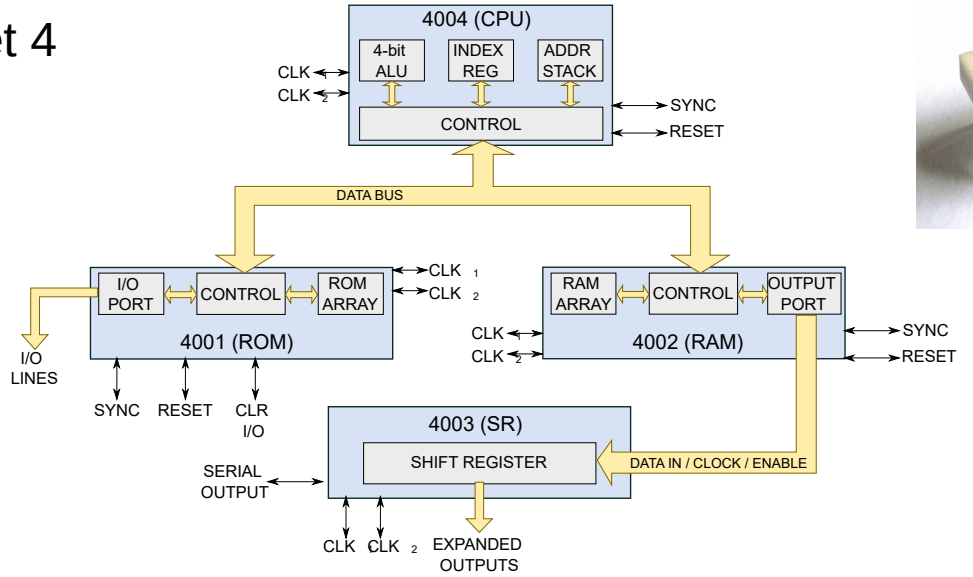
- Processor: 2800 dual 3-inputs RTL NOR ports;
- Word size: 16 bits
- Clock frequency 2.048 MHz
- RAM: 2 k-words (magnetic core)
- ROM: 36 k-words (core rope)
- Memory access time: 12 μs
- Weight: 32 kg
- Entire code for mission developed in assembler
- Processor power ~ Apple II
- Cost of each chip (end of Apollo program) 20 $

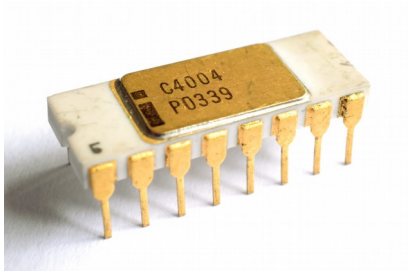
Embedded Systems: a historic perspective (hw)



MCS 4: Micro Computer Set 4
4001, 4002,4003, 4004

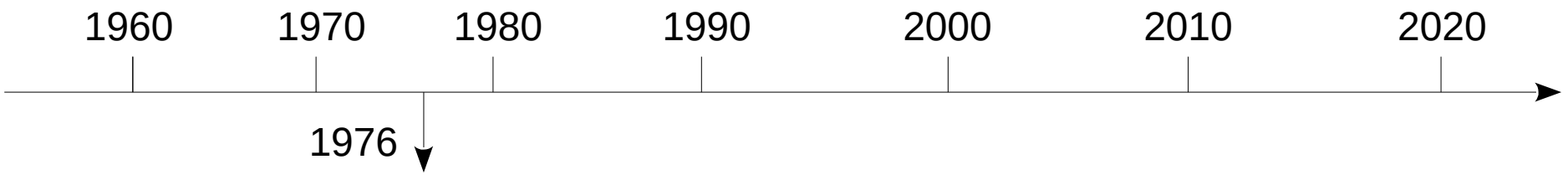






While the 4004 is recognized as the progenitor of microprocessors that paved the way for the diffusion of personal computers, it was develop for solving a typical embedded problem: reducing the production cost of a tabletop calculator.

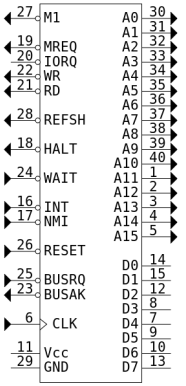
Embedded Systems: a historic perspective (hw)

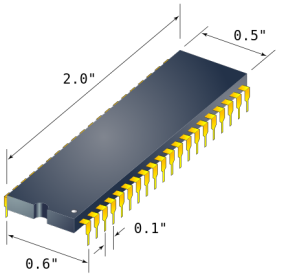


Zilog z80 is introduced (f_{CK}=4 MHz)

It was mainly aimed at embedded systems:

intelligent terminals; high end printers; advanced cash registers; telecom equipment; industrial robots; military applications; musical equipment (synthesizers); computerized coin operated video games (late 1970s and early 1980), arcade machines or video game arcade cabinets.





However, Z80 (together with Motorola 6502) was the basis for the diffusion of home computers.

Z80 based control board (still sold today)

Z80@ 3.5 MHz, 1982-1992

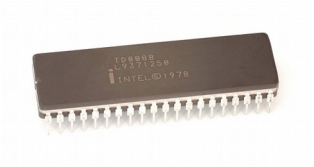
6510(6502+6 IO)@ 1 MHz (1982-1992)

Evolution of general purpose CPU

1960 1970 1980 1990 2000 2010 2020

z80

8088 (16 bit, 4 - 10 MHz, RAM 1MB)



P5

(32 bit, up to 33 MHz, RAM 4GB)

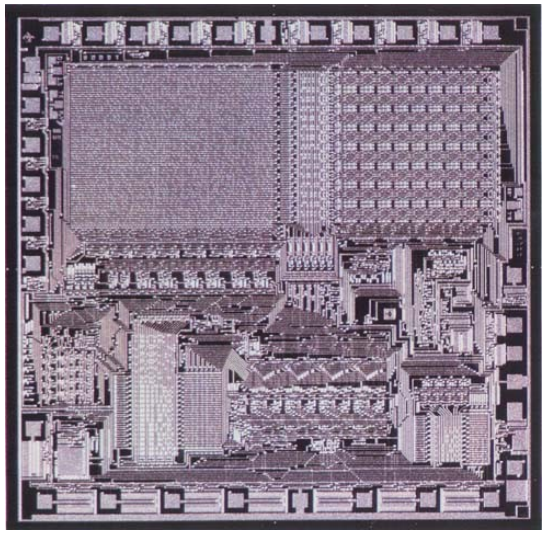
P55

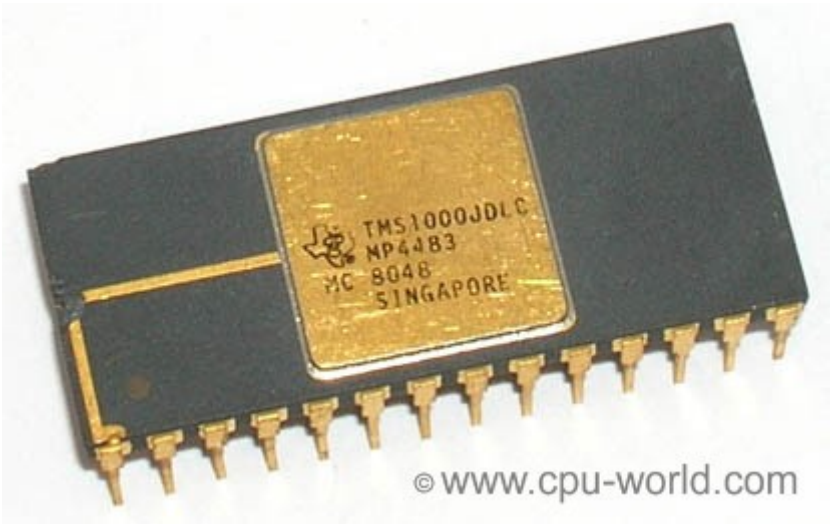
(32 bit, up to 300 MHz)

(64 bit, 6 cores 4 GHz)

Emb. Syst. design: CPU + gen. Purp. peripherals

Emb. Syst. design: Microcontrollers





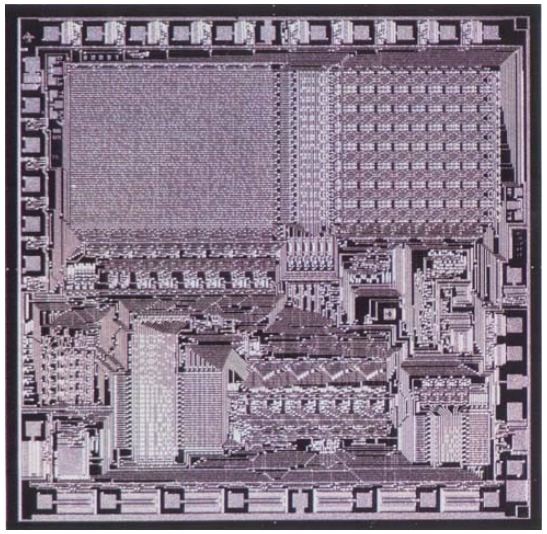
Ther first microcontroller: TMS1000

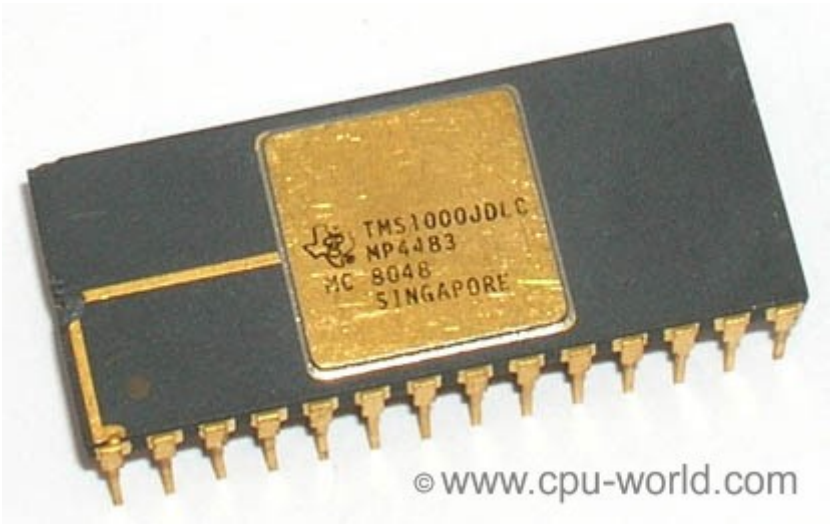
From www.cpu-world:

"Texas Instruments TMS1000 family of 4-bit microcontrollers was introduced in 1974.
The TMS 1000 microcontrollers had very simple design - only 2 4-bit general registers, 43 instructions, 1-level deep stack, shift-register program counter and no interrupts."

f_{CK}=200 kHz.

Emb. Syst. design: Microcontrollers





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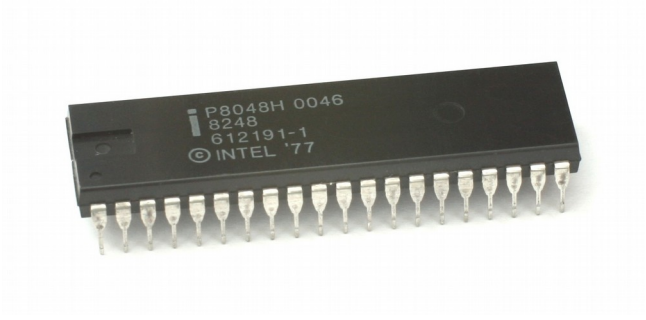
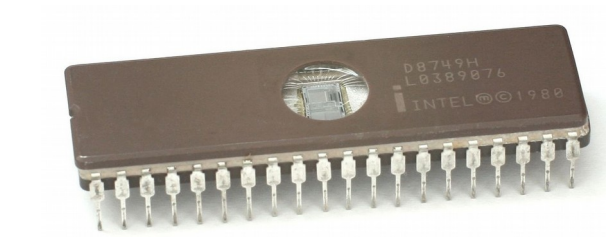




Intel MCS-48 (1976)

8 bit CPU (0.7 Mips)

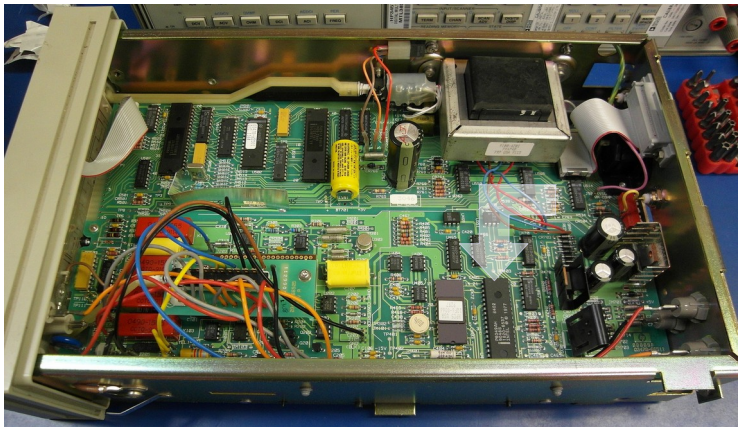
1 kbyte ROM (mask, OTP, EPROM)

64 bytes RAM

27 I/O lines

8 bit timer event counter

Sold in billions!



Emb. Syst. design: Microcontrollers

MCS-51 (1980)

intel®

PRELIMINARY

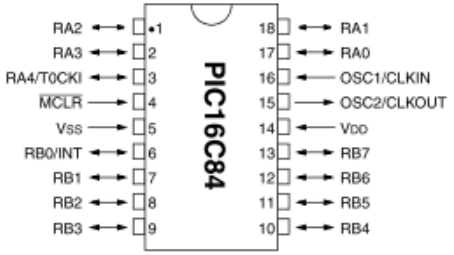
8XC51FX
CHMOS SINGLE-CHIP 8-BIT MICROCONTROLLERS

Commercial/Express

87C51FA/83C51FA/80C51FA/87C51FB/83C51FB/87C51FC/83C51FC
***See Table 1 for Proliferation Options**

- High Performance CHMOS EPROM/ROM/CPU
- 12/24/33 MHz Operation
- Three 16-Bit Timer/Counters
- Programmable Counter Array with:
  — High Speed Output,
  — Compare/Capture,
  — Pulse Width Modulator,
  — Watchdog Timer Capabilities
- Up/Down Timer/Counter
- Three Level Program Lock System
- 8K/16K/32K On-Chip Program Memory
- 256 Bytes of On-Chip Data RAM
- Improved Quick Pulse Programming Algorithm
- Boolean Processor
- 32 Programmable I/O Lines
- 7 Interrupt Sources
- Four Level Interrupt Priority
- Programmable Serial Channel with:
  — Framing Error Detection
  — Automatic Address Recognition
- TTL Compatible Logic Levels
- 64K External Program Memory Space
- 64K External Data Memory Space
- MCS® 51 Controller Compatible Instruction Set
- Power Saving Idle and Power Down Modes
- ONCE (On-Circuit Emulation) Mode
- Extended Temperature Range Except for 33 MHz Offering (−40°C to +85°C)

Emb. Syst. design: Microcontrollers



- Operating speed: DC - 10 MHz clock input
  DC - 400 ns instruction cycle
- 14-bit wide instructions
- 8-bit wide data path
- 1K x 14 EEPROM program memory
- 36 x 8 general purpose registers (SRAM)
- 64 x 8 on-chip EEPROM data memory
- 15 special function hardware registers
- Eight-level deep hardware stack

PIC 16C84 (1993): a game changer

Introducing serial programming and EEPROM memory: no UV erase needed during development.

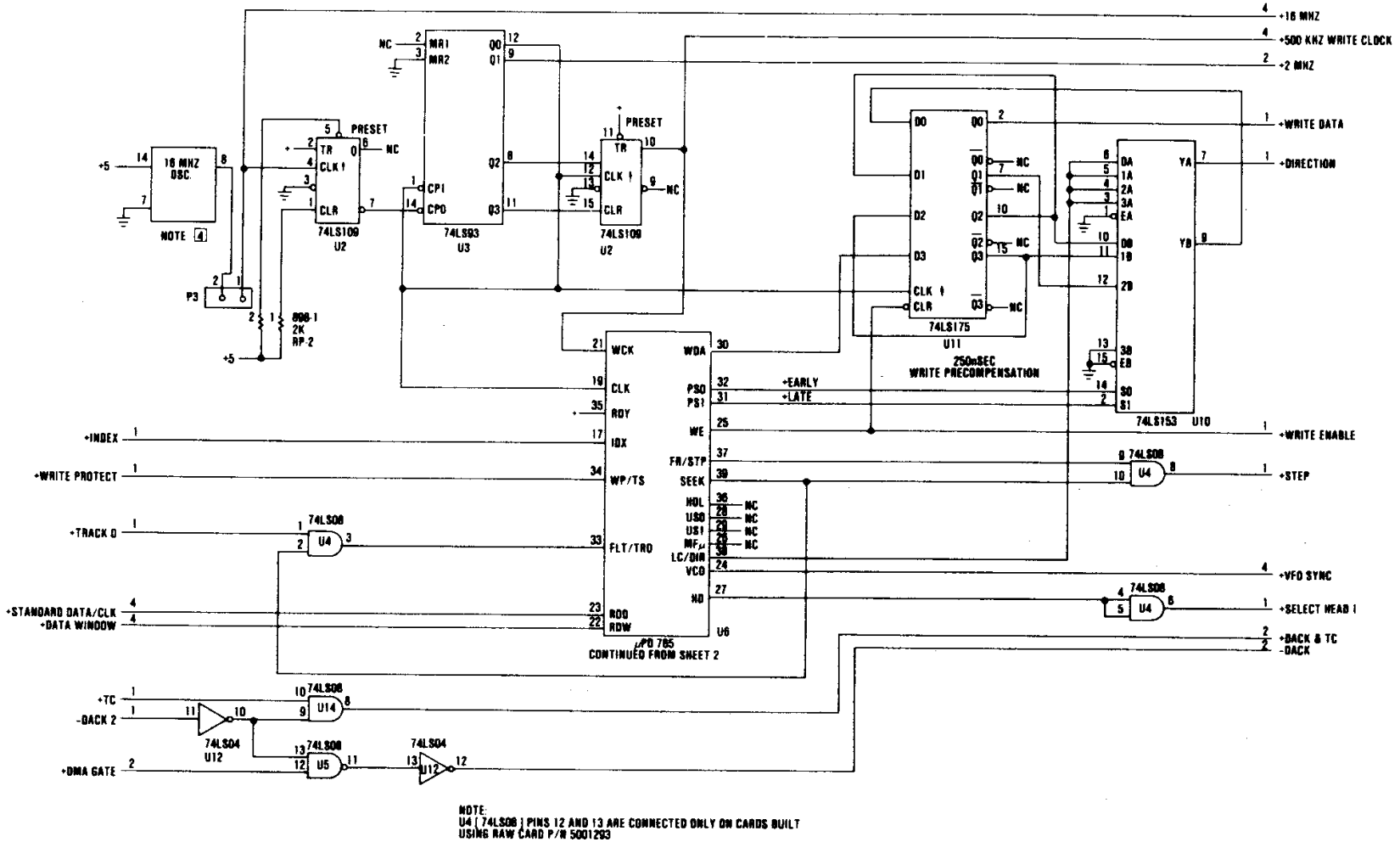
In the same year, ATMEL introduced Flash Memory based microcontrollers (AVR family).

In recent years Microchip (PIC producer) and ATMEL have joined after long competition.

Today microcontrollers (even low end ones) include advanced peripherals such as AD converters, PWM generators, USB, SPI, I2C and UARTs.

Glue logic

In the design of complex digital system (embedded systems, computer systems), a significant amount of effort and cost used to be taken by the need for glue-logic, i.e. a number of simple logic block need to connect complex blocks to one another.



5-1/4 Inch Diskette Drive Adapter (Sheet 3 of 4)

- Embedded systems and the role of programmable logic devices in embedded systems
- Embedded system: a historic perspective (hw)
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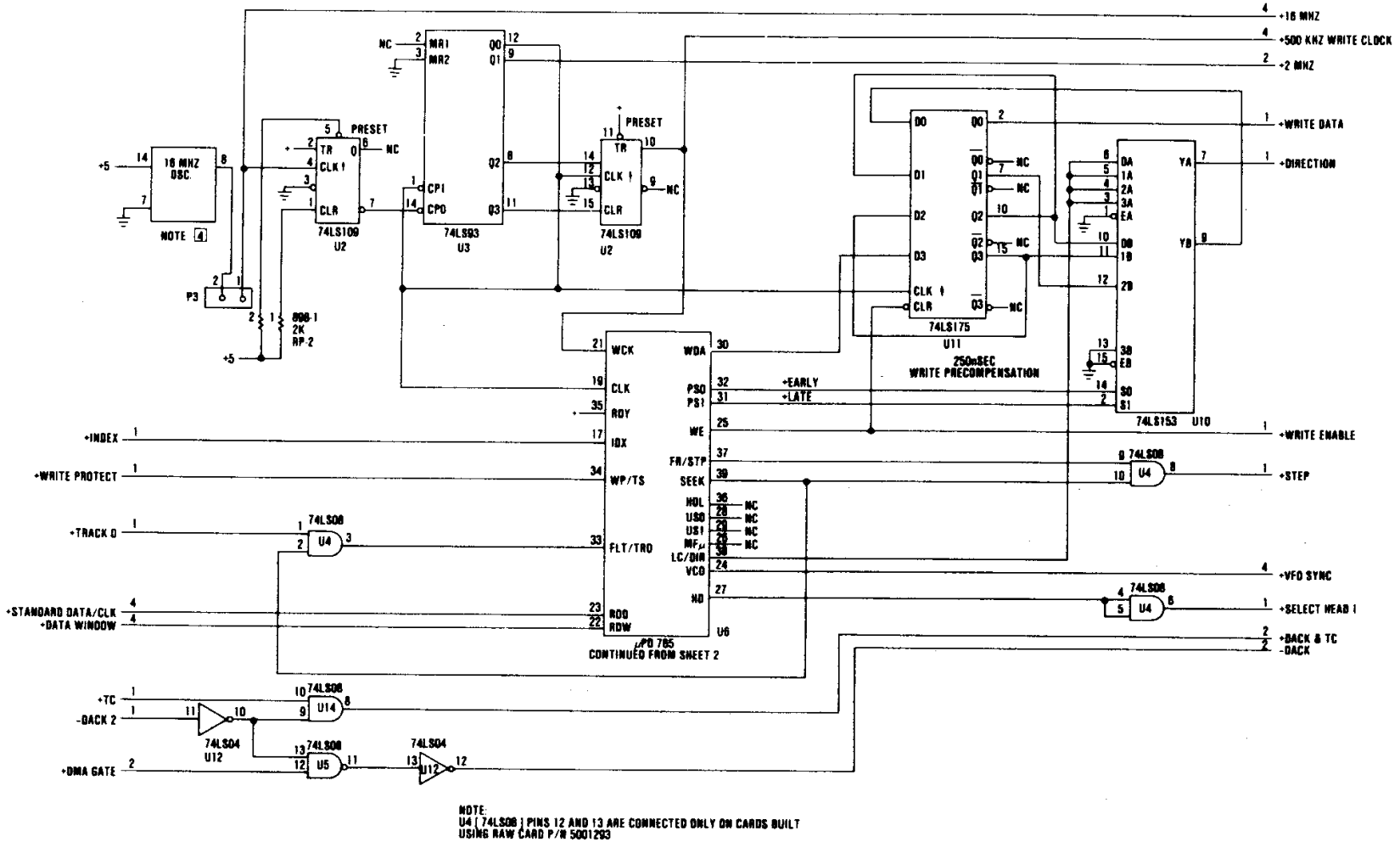
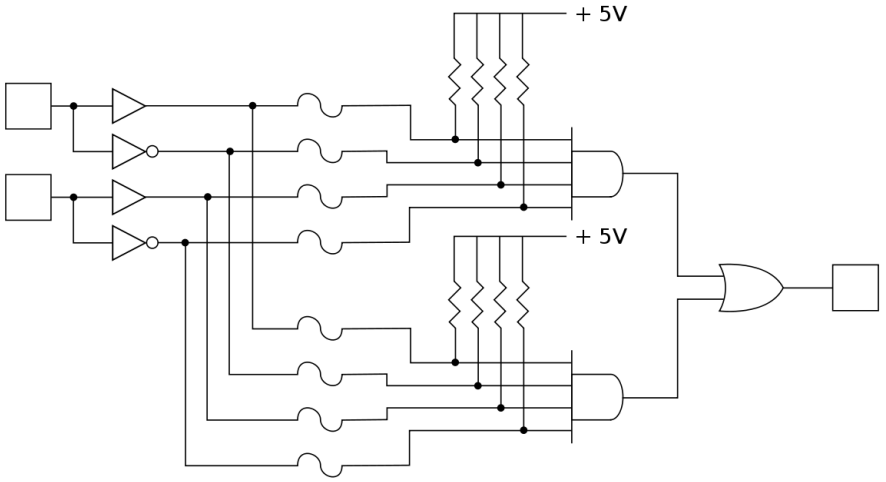


5-1/4 Inch Diskette Drive Adapter (Sheet 3 of 4)

Glue logic

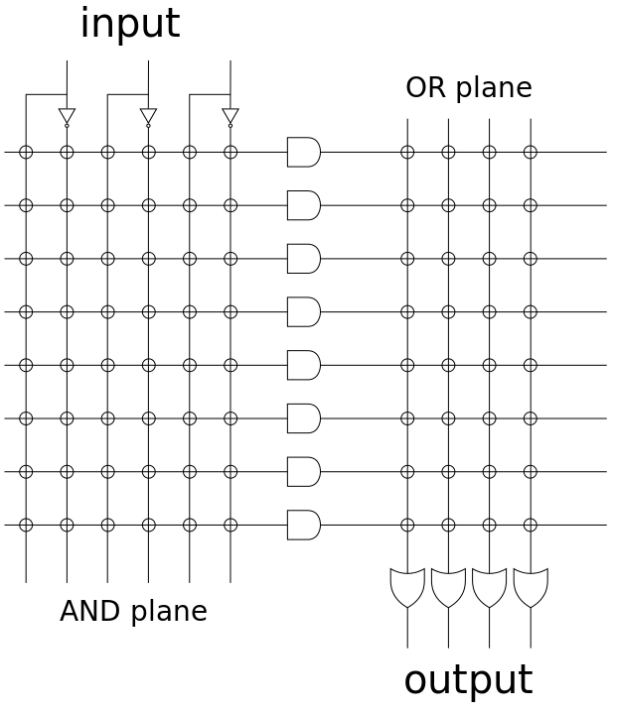
Since early embedded systems for consumer applications the need for reducing the cost and complexity coming form glue logic was strongly felt.

Note that a ROM can be regarded as a (conceptually) simple approach for realizing a programmable m-inputs, n-outputs arbitrary combinatorial functions.
The problem with ROM is that no minimization is possible: an 8 inputs – 8 outputs combinatorial function requires the implementations of 256 memory cells independently of the complexity of the functions. This limitation led to the development of dedicated programmable logic devices.



Simplified programmable logic device

One Time Programmable (OTP)

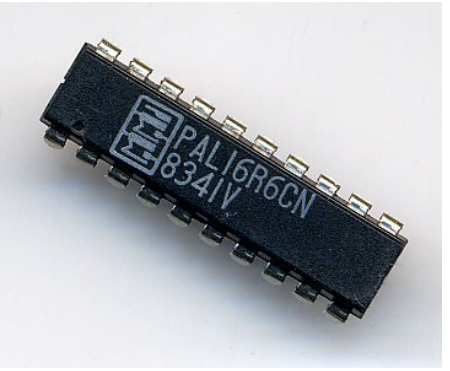


General structure of a PLA

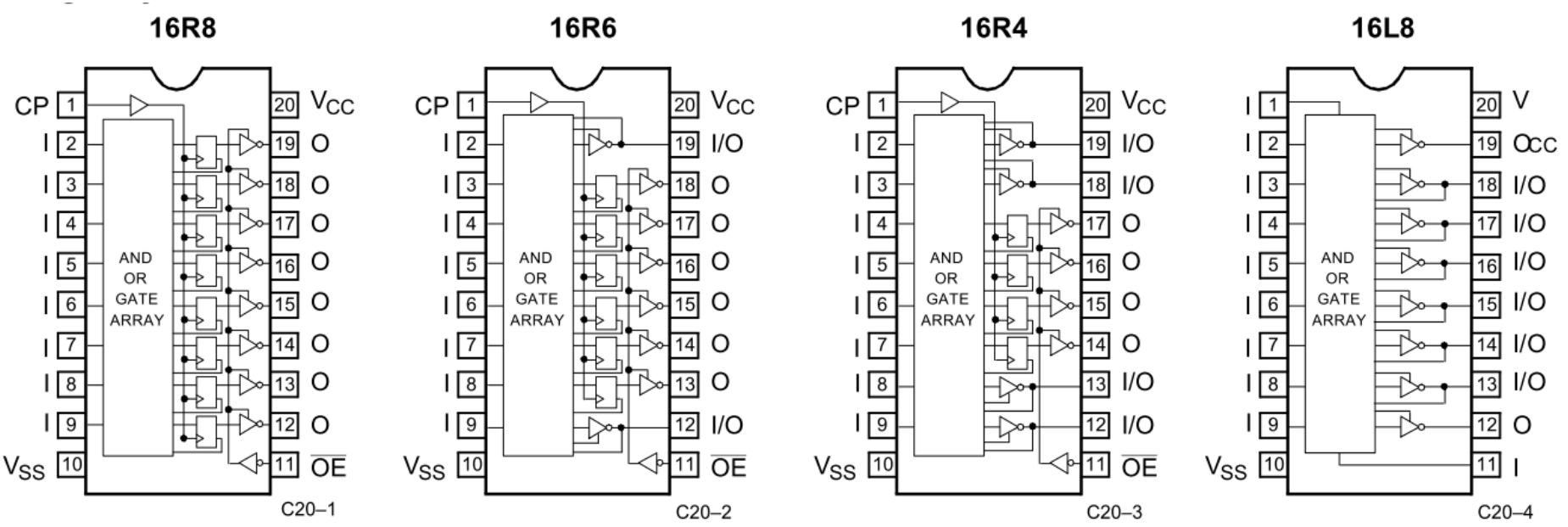
PLD evolution

First attempt at producing Field Programmable Logic Array (FPLA) were made by Signetics in 1975. Both AND and OR planes were programmable but the devices were slow and expensive.

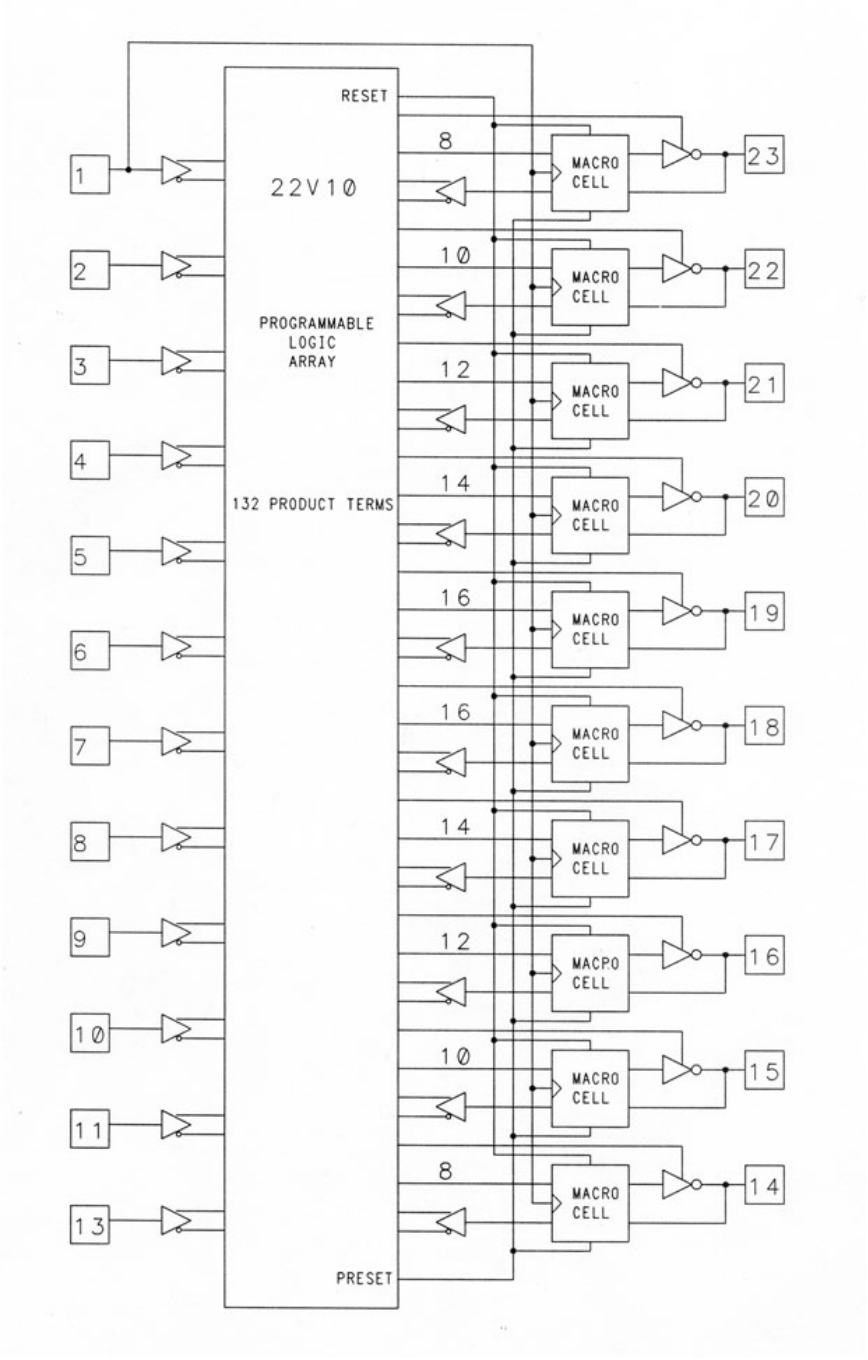
In 1978 MMI introduced the first widely used PLA (named PAL for commercial reasons): by having a fixed OR plane (only the AND plane was programmable) cost and propagation time could be considerably reduced.



MMI PAL 16R6 (OTP)

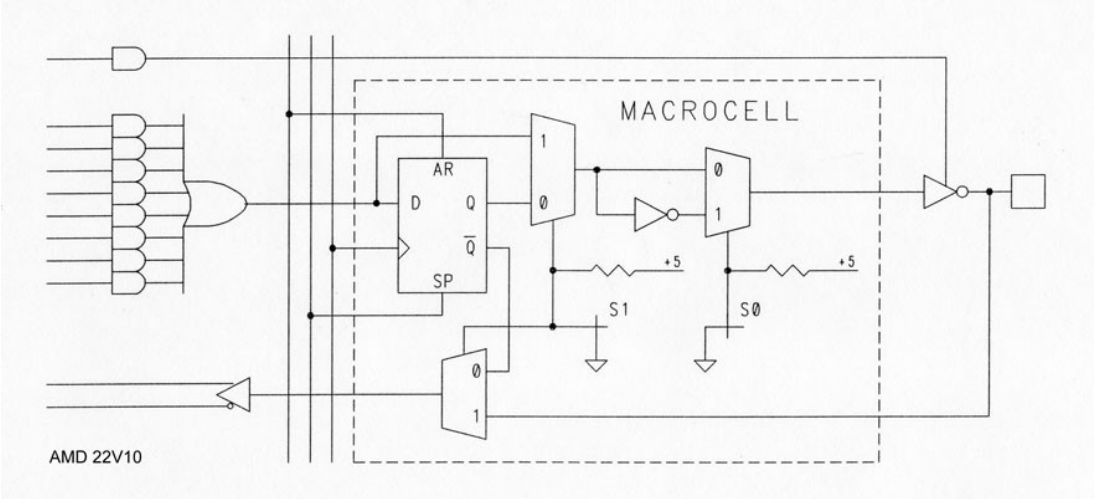


PLD evolution



In 1983 AMD introduced the "22V10" in which the output macro-cells could be individually programmed to operate as either a registered or a non-registered output.

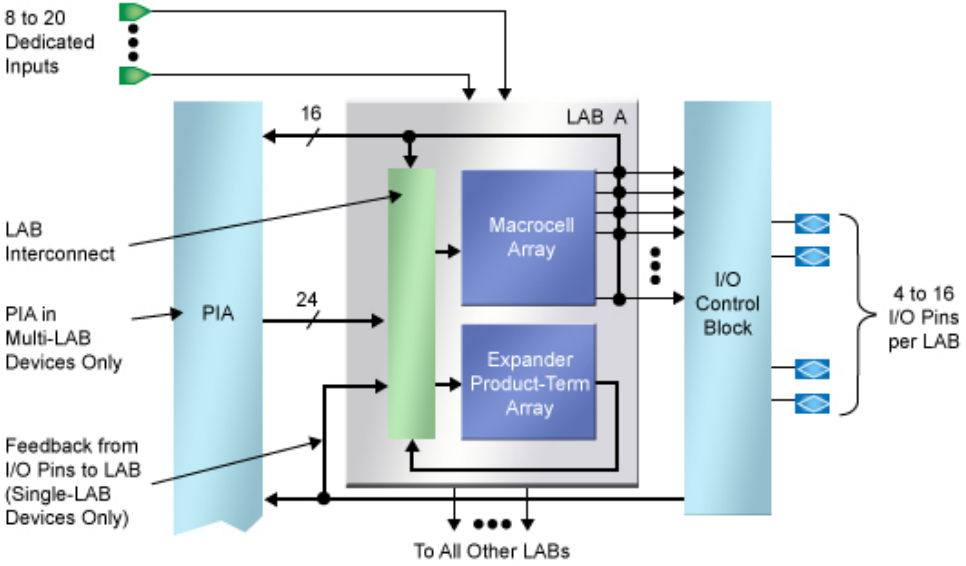
The PAL 22V10 was OTP only.

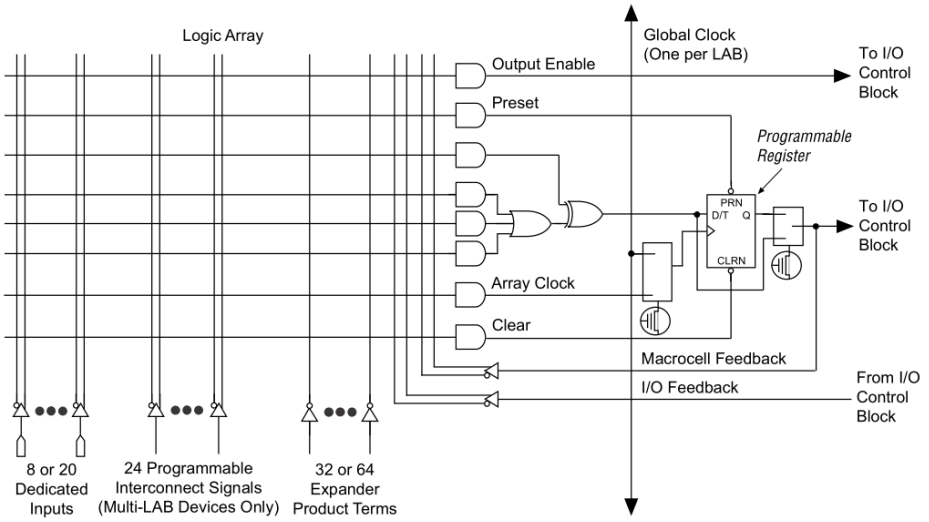


PLD evolution

In 1985 Lattice Semiconductors introduced the “GAL”: same functionality as the AMD PAL, but now the devices could be erased and reprogrammed: a huge advantage during development phase. Some devices had/have in-circuit programming capability.

In 1988 ALTERA introduced the first CPLD (MAX5000), that, to some extent, are an evolution of PAL.
Each LAB in MAX5000 contains 32 macrocells.

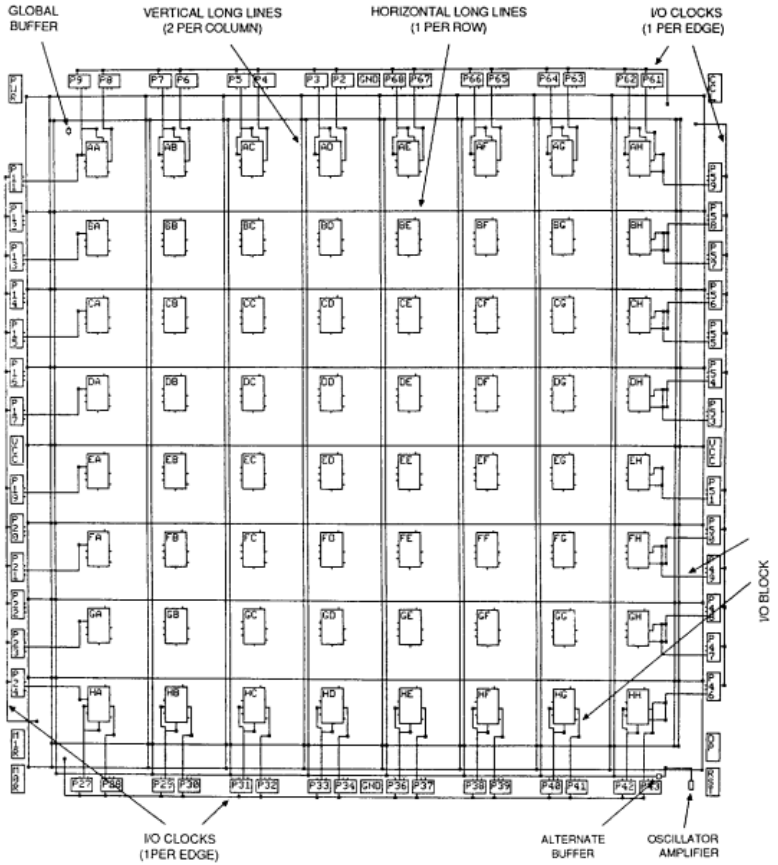


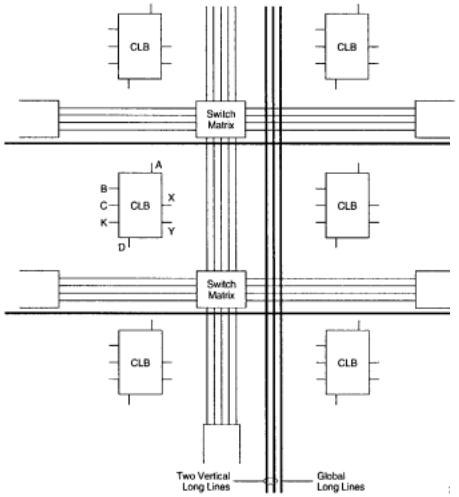


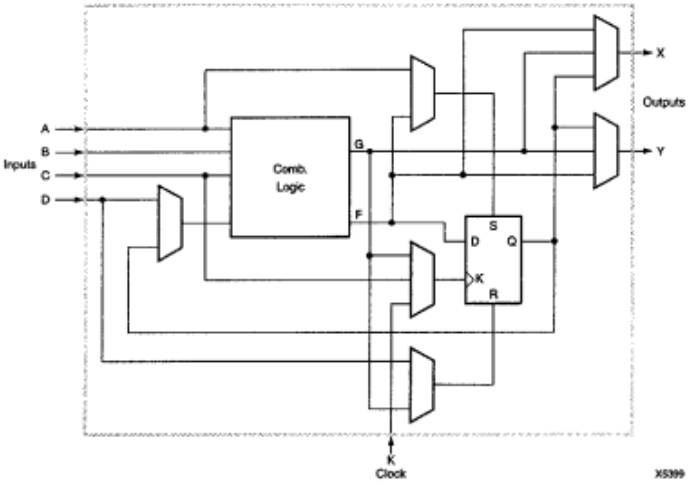
MAX 5000 were available with 1 to 12 LABs (32 to 192 macrocells). Each macrocell can resort to expander product term arrays. Clock frequency:50 MHz. Modern devices: up to 1700 macrocells.

FPGA

Born from a different approach with respect to PAL and CPLD: simpler blocks (logic functions based on LUTs) and interconnections.
The first FPGA (XC2464) was introduced by XILINX in 1985 (at the same time when the GALs were commercialized).



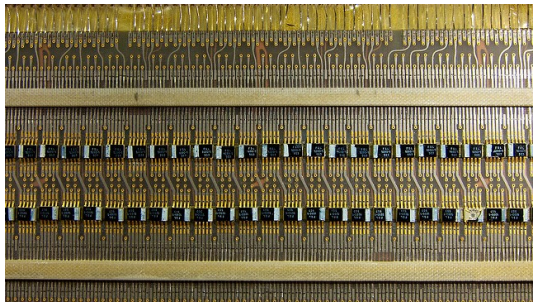




The XC2464 had 64 Logic Blocks.

Today high end FPGA have can have more than 5.000.000 elementary logic blocks combined with specialized blocks for RAM, fast multiplications, DSP elaborations, AD and DA conversion and more.

SoCs: a new, better, past!



- The CPU of the Apollo Guidance Computer was obtanied by hard wiring about 3000 dual NOR ICs.
- Imagine what can be done with millions of sophisticated logic blocks connected together and with specialized blocks on a single chip!

An entire system (including CPU, RAM, standard peripherals, AD and DA converters and non standard dedicated logic functions can be obtained on a single chip (System on Chip) and, what is more, you can design your own CPU as well as the entire system and change them at will!

Clearly sophisticated CAD tools are required:

- for the design, at the highest level possible, of the system (VHDL language)
- for the translation, with minimum effort, of the designed system into the proper interconnections within a given FPGA device (Quartus suite in the case of ALTERA).