

LOGIC FAMILY

In computer engineering, a logic family of monolithic digital integrated circuit devices is a group of electronic logic gates constructed using one of several different designs, usually with compatible logic levels and power supply characteristics within a family. Many logic families were produced as individual components, each containing one or a few related basic logical functions, which could be used as "building-blocks" to create systems or as so-called "glue" to interconnect more complex integrated circuits. Other logic families were essentially only used to produce large scale integrated circuits such as a central processor, memory, or other complex function. The list of logic families can be divided into ten main categories, listed here in rough chronological order of introduction along with their usual abbreviations:

- Diode logic (DL)
- Resistor-transistor logic (RTL)
- Diode-transistor logic (DTL)
- Emitter coupled logic (ECL)
- Transistor-transistor logic (TTL) and variants
- P-type Metal Oxide Semiconductor logic (PMOS)
- N-type Metal Oxide Semiconductor logic (NMOS)
- Complementary Metal-Oxide Semiconductor logic (CMOS)
- Bipolar Complementary Metal-Oxide Semiconductor logic (BiCMOS)
- Integrated injection logic (I²L)

The first four families (DL, RTL, DTL, and ECL) were originally implemented using discrete components, in circuits derived from the vacuum tube based logic of early computers. Diode logic was never implemented in integrated circuits, as DTL was far more practical.

The PMOS and I²L logic families were used for relatively short periods, mostly in special purpose custom LSI (Large Scale Integrated Circuits) devices and are generally considered obsolete. For example, early digital clocks or electronic calculators may have used one or more PMOS devices to provide most of the logic for the finished product.

Of these ten families, only five (ECL, TTL, CMOS, NMOS, and BiCMOS) are currently still in widespread use. ECL is used for special very high speed applications because of its price and power demands, while NMOS logic is mainly used in VLSI (Very Large Scale Integrated Circuits) applications such as CPUs and memory chips which fall outside of the scope of this article. Simple "building block" logic gate ICs are based on the TTL, CMOS, and BiCMOS families.

ECL

The first logic family to be available in integrated circuits was emitter coupled logic, introduced by Motorola as *MECL* in 1962.

RTL

A family of simple resistor-transistor logic integrated circuits was developed for the Minuteman II Guidance Computer and Apollo Guidance Computer in 1962, but these devices were not available to the public. Both Texas Instruments and Fairchild Semiconductor soon introduced their own families of RTL.

DTL

The first diode-transistor logic family of integrated circuits was introduced by Signetics in 1962.

TTL

The first transistor-transistor logic family of integrated circuits was introduced by Sylvania as *Sylvania Universal High-Level Logic* (SUHL) in 1963. Texas Instruments introduced 5400 Series TTL family in 1964. Transistor-Transistor Logic uses bipolar transistors to form its integrated circuits. TTL has changed significantly over the years, with newer versions replacing the older types. Here is a list of TTL logic, again in rough chronological order:

- Transistor-transistor logic (TTL - no letter code)
- High Threshold TTL logic (H)

- Low Power TTL logic (L)
- Schottky TTL logic (S)
- Low Power Schottky TTL logic (LS)
- Fast TTL logic (F)
- Advanced Low Power Schottky TTL logic (ALS)

The part numbers for TTL logic devices often use the following naming convention, though specifics vary between manufacturers: First a two or three letter prefix which indicates the manufacturer of the device, immediately followed by a two figure secondary prefix, of which the two most common are '74', indicating a commercial temperature range device and '54', indicating an extended (often military) temperature range. Then up to three letters describing the logic family (for example ALS for 'Advanced Low Power Schottky TTL').

Then a number of figures arbitrarily assigned for each device. There are hundreds of different devices in each family but when this number is the same, the function and pin-out of the chip is nearly always the same regardless of manufacturer -- exceptions include some flat-pack devices, surface-mount devices, and at least one low-power TTL device has a different pin-out than the regular series part. Additional suffix letters and numbers may be attached to indicate the package type, quality grade, or other information but this varies widely by manufacturer.

For example SN74ALS245 means this is a device made by Texas Instruments, it is a commercial (not a military) temperature range TTL device, and it is a *bi-directional eight bit buffer*.

Since the transistors of a standard TTL gate are saturated switches, minority carrier storage time in each junction limits the switching speed of the device. Since current must flow to maintain devices in a defined state, power is consumed at all times. Variations on the basic TTL design are intended to reduce these effects and improve speed, switching time, or both.

LSTTL

The German physicist Walter H. Schottky formulated a theory predicting the Schottky effect, which led to the Schottky diode and later Schottky transistors. Schottky transistors have a much higher switching speed than conventional transistors because the Schottky junction does not promote charge storage, leading to faster switching gates. The only problem is that gates built with Schottky transistors use more power than normal TTL. This was later alleviated somewhat with the low power Schottky (LS) version, which draws much less power than the original Schottky logic, but still more than regular TTL, in addition to being slightly slower. But with the introduction of Advanced Low Power (ALS) most of these problems were overcome. A faster logic family called 'Fast TTL' (F) was also introduced that was faster than normal Schottky TTL.

CMOS

Meanwhile, because of the still relatively large power demand of LS-TTL, another technology gained acceptance as a low power alternative. This technology does not use regular bipolar transistors, but employs Field effect transistors instead. Because the technology used a complementary pair of FET's (a N-MOS and a P-MOS FET) it was called CMOS (Complementary Metal Oxide Semiconductor logic). The first CMOS logic family of integrated circuits was introduced by RCA as *CD4000 COS/MOS* in 1968.

In contrast to TTL logic, CMOS uses almost no power in the static state (i.e. when inputs are not changing). When the gate switches states, current is drawn from the power supply to charge the stray capacitance at the output of the gate. This means that current draw of CMOS devices increases with clock speed.

The first family of CMOS logic carried the prefix 'CD' followed by four digits beginning with a 4, leading to its description as the 4000 series of logic gates, also known as the CD4K logic family.

The initial family of CMOS logic was slower than LS-TTL; however, because the logic thresholds of CMOS were proportional to the power supply voltage, CMOS devices were well-adapted to battery-operated systems with simple power supplies. CMOS gates can also tolerate much wider voltage ranges than TTL gates.

Lowering the power supply voltage

One very important feature of CMOS chips is that they work with a broader range of power supply voltages. While TTL ICs all require a power supply voltage of 5V (+/- 0.5V), CMOS works with a wider range of power supply voltage -- usually anywhere from 3 to 15V. This trait was also shared with the NMOS and PMOS logic used in VLSI devices such as microprocessors. Lowering the supply voltage reduces the current required to charge stray capacitance, and so reduces the current drawn by complex microprocessors. This in turn reduces the heat dissipation of the processor. By lowering the power supply from 5V to 3.3V, they could cut the dissipated power by almost 60 percent (power dissipation is proportional to the square of the supply voltage). Newer CPUs have lowered their power supply voltages further.

HC Logic

Because of the incompatibility of the CD4000 series of chips with the previous TTL family, a new standard emerged which combined the best of the TTL family with the advantages of the CD4000 family. It was known as the 74HC (High performance silicon gate) family of devices and used the pinout of the 74LS family with an improved version of CMOS technology inside the chip. And it could be used together with other logic devices which used 3.3V power supplies (and thus 3.3V logic levels), and in designs that used 5V power supplies and devices that used TTL logic levels.

The logic level problem

There was however a problem when combining CMOS and TTL logic. CMOS inputs inherently recognize other electrical voltages as a valid '0' (low voltage) and a valid '1' (high voltage) than TTL does. Where TTL needs to see a voltage lower than 0.8 volt to recognize a valid '0' and voltages above 2.0 volts to recognize a valid '1' (all voltages in-between 0.8 and 2.0 are 'forbidden' as logic levels) CMOS devices (working with a 5 V power supply) recognize all voltages below 1.5 V as '0' and all voltages above 3.5 V as '1'. Additionally, a TTL output pin does not rise above about 2.4 V for a logic '1' (it drops below 0.4 V for a logic '0'). This causes a problem when a TTL device tries to drive a CMOS device that works with a 5 V power supply. The output level of the TTL chip when outputting a logic '1' level does not reach a level that the CMOS device recognize as a valid '1'.

This was solved by the invention of the 74HCT family of devices that uses CMOS technology but TTL logic levels. These devices only work with a 5V power supply. They form a perfect drop-in replacement for TTL logic, although HCT is slower than original TTL (HC logic has about the same speed as original TTL).

Improved versions

With HC and HCT logic and LS-TTL logic competing in the market it became clear that further improvements were needed to create the 'ideal' logic device that combined high speed, with low power dissipation and compatibility with older logic families. A whole range of newer families has emerged that use CMOS technology. A short list of the most important family designators of these newer devices includes:

- LV logic (lower supply voltage)
- LVT logic (lower supply voltage while retaining TTL logic levels)
- ALVT logic (an 'advanced' version of LVT logic)

But there are many others including AC/ACT logic, AHC/AHCT logic, ALVC logic, AUC logic, AVC logic, CBT logic, CBTLV logic, FCT logic, LVC logic and LVC logic.

BiCMOS

One major improvement was to combine CMOS inputs and TTL drivers to form of a new type of logic devices called BiCMOS logic, of which the LVT and ALVT logic families are the most important. The BiCMOS family has many members, including ABT logic, ALB logic, ALVT logic, BCT logic and LVT logic.

Other families

Other circuit families include:

- Complementary Pass-transistor Logic (CPL)
- Cascode Voltage Switch Logic (CVSL)

Conclusion

At the moment the most important families still are the LS-TTL and the HC and HCT families, although BCT logic also is starting to become popular. There is no consensus yet which low voltage logic family is 'winning' although AHC logic seems to gain some popularity. But the 'race is still on', especially because not every manufacturer supports every logic family, and some logic families only support a small subset of the complete list of LS-TTL devices available.