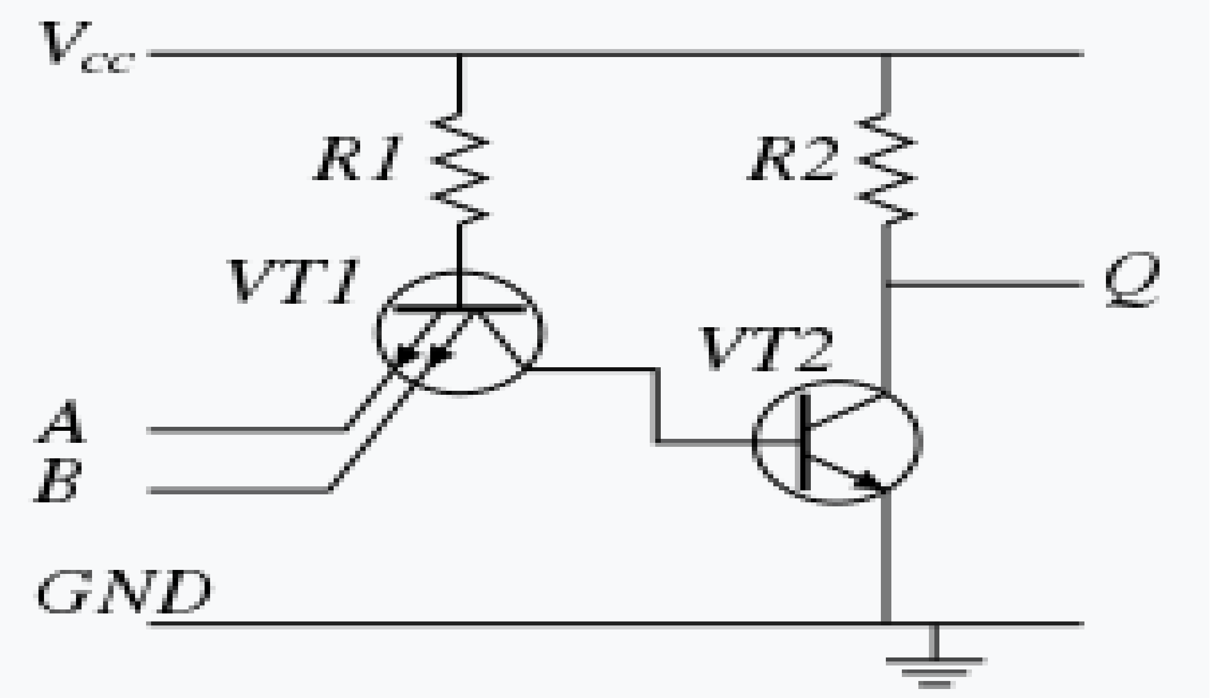
Unit 3: Transistor-Transistor-Logic (TTL)

TTL was invented in 1961 by James L. Buie of TRW, which declared it, "particularly suited to the newly developing integrated circuit design technology." The original name for TTL was *transistor-coupled transistor logic* (TCTL). The first commercial integrated-circuit TTL devices were manufactured by Sylvania in 1963, called the Sylvania Universal High-Level Logic family (SUHL). The Sylvania parts were used in the controls of the Phoenix missile. TTL became popular with electronic systems designers after Texas Instruments introduced the 5400 series of ICs, with military temperature range, in 1964 and the later 7400 series, specified over a narrower range and with inexpensive plastic packages, in 1966. The Texas Instruments 7400 family became an industry standard. Compatible parts were made by Motorola, AMD, Fairchild, Intel, Intersil, Signetics, Mullard, Siemens, SGS-Thomson, Rifa, National Semiconductor, and many other companies, even in the Eastern Bloc (Soviet Union, GDR, Poland, Czechoslovakia, Hungary, Romania - for details see 7400 series). Not only did others make compatible TTL parts, but compatible parts were made using many other circuit technologies as well. At least one manufacturer, IBM, produced non-compatible TTL circuits for its own use; IBM used the technology in the IBM System/38, IBM 4300, and IBM 3081.

The term "TTL" is applied to many successive generations of bipolar logic, with gradual improvements in speed and power consumption over about two decades. The most recently introduced family 74Fxx is still sold today (as of 2019), and was widely used into the late 90s. 74AS/ALS Advanced Schottky was introduced in 1985. As of 2008, Texas Instruments continues to supply the more general-purpose chips in numerous obsolete technology families, albeit at increased prices. Typically, TTL chips integrate no more than a few hundred transistors each. Functions within a single package generally range from a few logic gates to a microprocessor bit-slice. TTL also became important because its low cost made digital techniques economically practical for tasks previously done by analog methods.

The Kenbak-1, ancestor of the first personal computers, used TTL for its CPU instead of a microprocessor chip, which was not available in 1971. The Datapoint 2200 from 1970 used TTL components for its CPU and was the basis for the 8008 and later the x86 instruction set. The 1973 Xerox Alto and 1981 Star workstations, which introduced the graphical user interface, used TTL circuits integrated at the level of arithmetic logic units (ALUs) and bitslices, respectively. Most computers used TTL-compatible "glue logic" between larger chips well into the 1990s. Until the advent of programmable logic, discrete bipolar logic was used to prototype and emulate microarchitectures under development.

Fundamental TTL gate:



Two-input TTL NAND gate with a simple output stage (simplified)

TTL inputs are the emitters of bipolar transistors. In the case of NAND inputs, the inputs are the emitters of multiple-emitter transistors, functionally equivalent to multiple transistors where the bases and collectors are tied together. The output is buffered by a common emitter amplifier.

Inputs both logical ones:

When all the inputs are held at high voltage, the base–emitter junctions of the multiple-emitter transistor are reverse-biased. Unlike DTL, a small “collector” current (approximately 10μA) is drawn by each of the inputs. This is because the transistor is in reverse-active mode. An approximately constant current flows from the positive rail, through the resistor and into the base of the multiple emitter transistor. This current passes through the base–emitter junction of the output transistor, allowing it to conduct and pulling the output voltage low (logical zero).

An input logical zero:

Note that the base–collector junction of the multiple-emitter transistor and the base–emitter junction of the output transistor are in series between the bottom of the resistor and ground. If one input voltage becomes zero, the corresponding base–emitter junction of the multiple-emitter transistor is in parallel with these two junctions. A phenomenon called current steering means that when two voltage-stable elements with different threshold voltages are connected in parallel, the current flows through the path with the smaller threshold voltage. That is, current flows out of this input and into the zero (low) voltage source. As a result, no current flows through the base of the output transistor, causing it to stop conducting and the output voltage becomes high (logical one). During the transition the input transistor is briefly in its active region; so it draws a large current away from the base of the output transistor and thus quickly discharges its base. This is a critical advantage of TTL over DTL that speeds up the transition over a diode input structure.

The main disadvantage of TTL with a simple output stage is the relatively high output resistance at output logical "1" that is completely determined by the output collector resistor. It limits the number of inputs that can be connected (the fanout). Some advantage of the simple output stage is the high voltage level (up to V_{CC}) of the output logical "1" when the output is not loaded.

A common variation omits the collector resistor of the output transistor, making an open-collector output. This allows the designer to fabricate logic by connecting the open-collector outputs of several logic gates together and providing a single external pull-up resistor. If any of the logic gates becomes logic low (transistor conducting), the combined output will be low. Examples of this type of gate are the 7401 and 7403 series. Open-collector outputs of some gates have a higher maximum voltage, such as 15 V for the 7426, useful when driving other than TTL loads.