Bipolar Digital Circuits

17 Chapter

Chapter 17
Bipolar Digital Circuits

Analysis and Design of Bipolar Logic Circuit Technologies

Overview

- Historical context: First logic circuit technology in digital systems
- Three main bipolar logic families covered:
- • Emitter-Coupled Logic (ECL)
- • Transistor-Transistor Logic (TTL)
- • BiCMOS Digital Circuits
- Focus on circuit analysis, design principles, and performance characteristics
- Current status: Less frequently used due to

Overview

- Bipolar circuits: historically significant but now specialized applications only
- Each logic family offers specific advantages:
- • ECL: Highest speed for time-critical applications
- • TTL: General-purpose logic (historically dominant)
- • BiCMOS: Best of both bipolar and CMOS technologies

Emitter-Coupled Logic (ECL): Fundamentals

- Based on differential amplifier circuit configuration
- Key operating principle: Transistors switch between cutoff and active region
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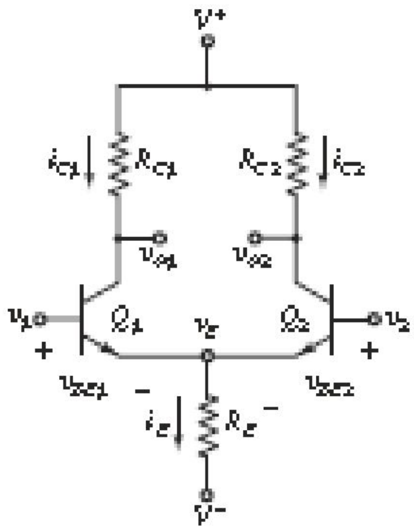

Figure 17.1 Basic differential amplifier circuit

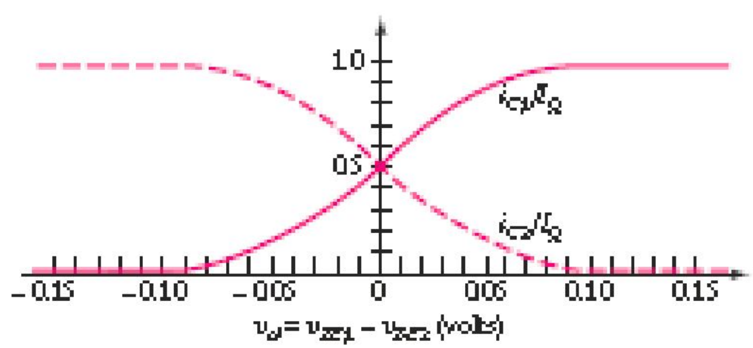

Figure 17.2 Normalized dc transfer characteristics, BJT differential amplifier

- Visual: Differential amplifier forms the core

ECL Circuit Architecture

- Classical ECL gate components:
- • Differential amplifier configuration (core logic)
- • Emitter-follower output stages (high current drive)
- • Reference able switching threshold)
- Unique featu NOR and OR outputs avail
- Modified ECL peed for reduced power dissipation

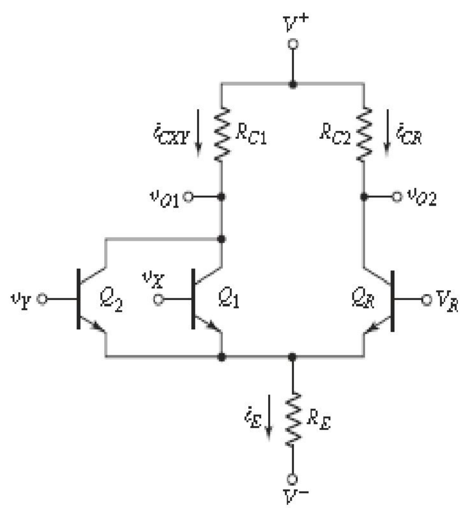

Figure 17.3 Basic two-input ECL OR/NOR logic circuit

Transistor-Transistor Logic (TTL)

- Evolution: Developed from Diode-Transistor Logic (DTL)
- Operating mode: Transistors driven between cutoff and saturation
- Input tra … turation and inve …
- Key innc … ed charge f …
- Totem-p … witching speed si …
- Transist … β =

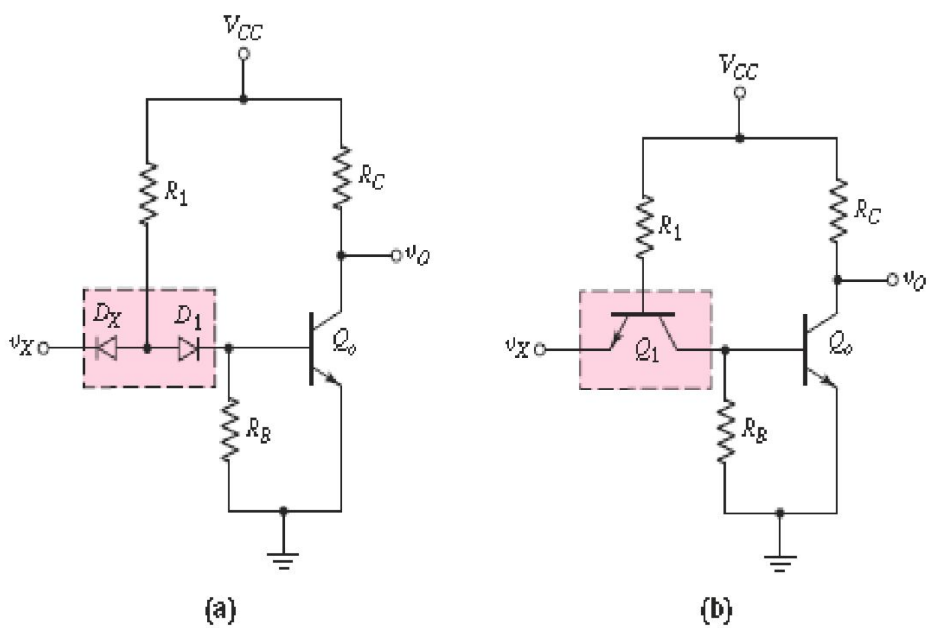

Figure 17.21 (a) Basic DTL gate and (b) basic TTL gate

Schottky Transistor-Transistor Logic

- Key innovation: Schottky diode clamped between base and collector
- Function: Prevents transistor from entering deep saturation
- Result: S   han standard
- Low-Pow   resistor values r
- Advance   ieves lowest s

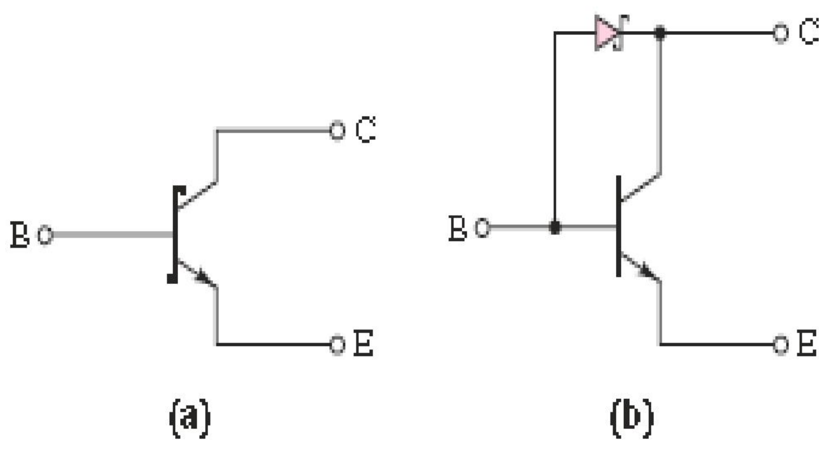

Figure 17.30 (a) Schottky clamped transistor symbol and (b) Schottky clamped transistor equivalent circuit

- Trade-off optimization: Balance between

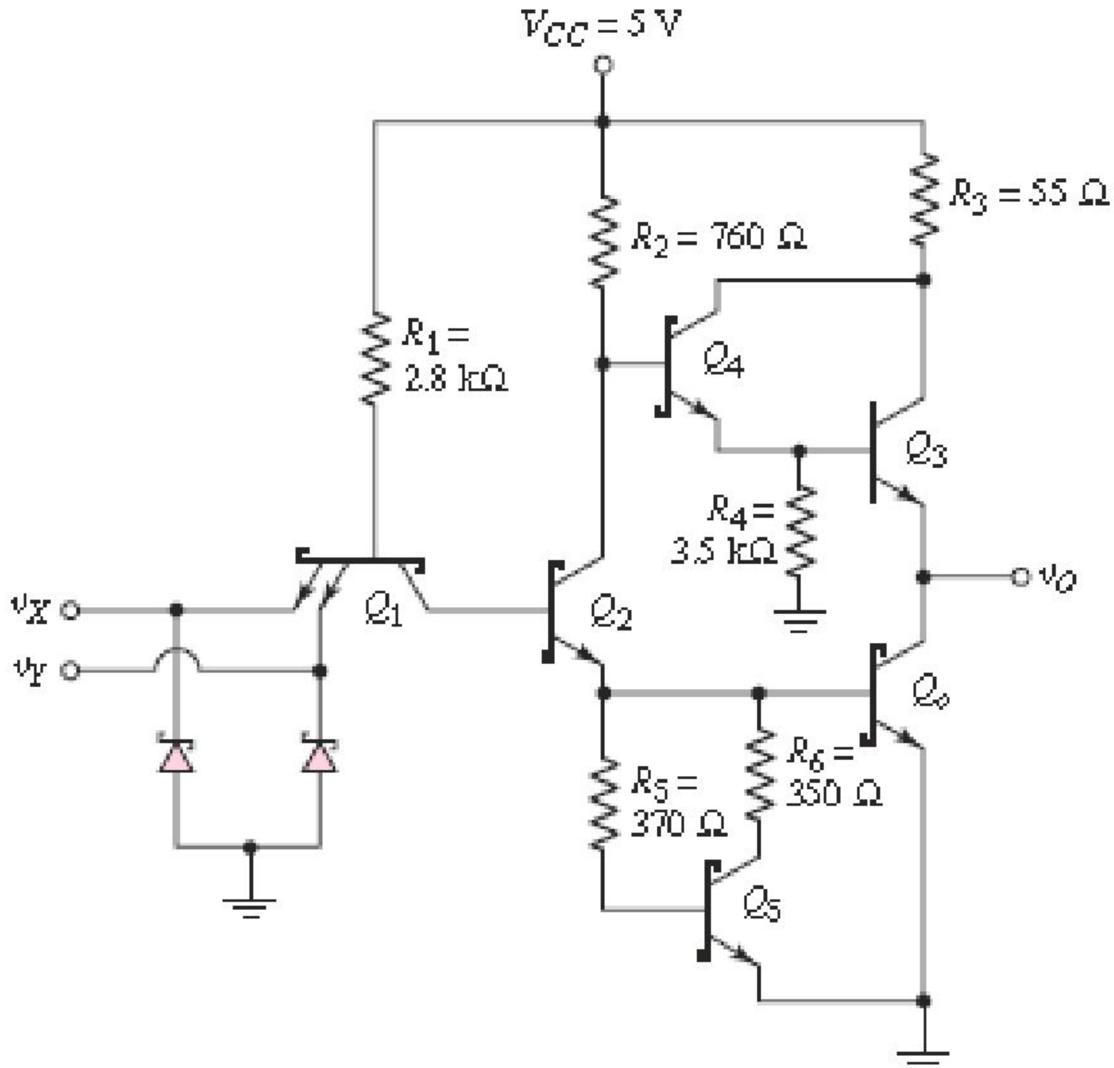

Figure 17.33 Schottky TTL NAND logic circuit

BiCMOS Digital Circuits

- Technology integration: Combines bipolar and CMOS on single IC chip
- Advantages from CMOS: High input impedance and low power dissipation
- Adv ... ive and
- Idea ... loac
- Typi ... npn bipc
- Outp...

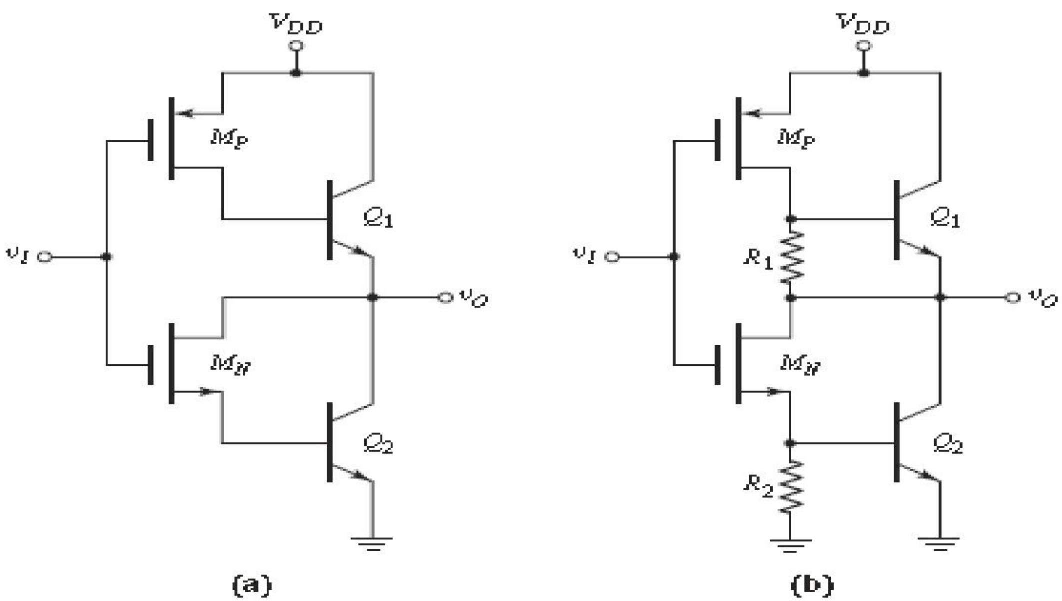

Figure 17.36 (a) Basic BiCMOS inverter. (b) Improved version of BiCMOS inverter.

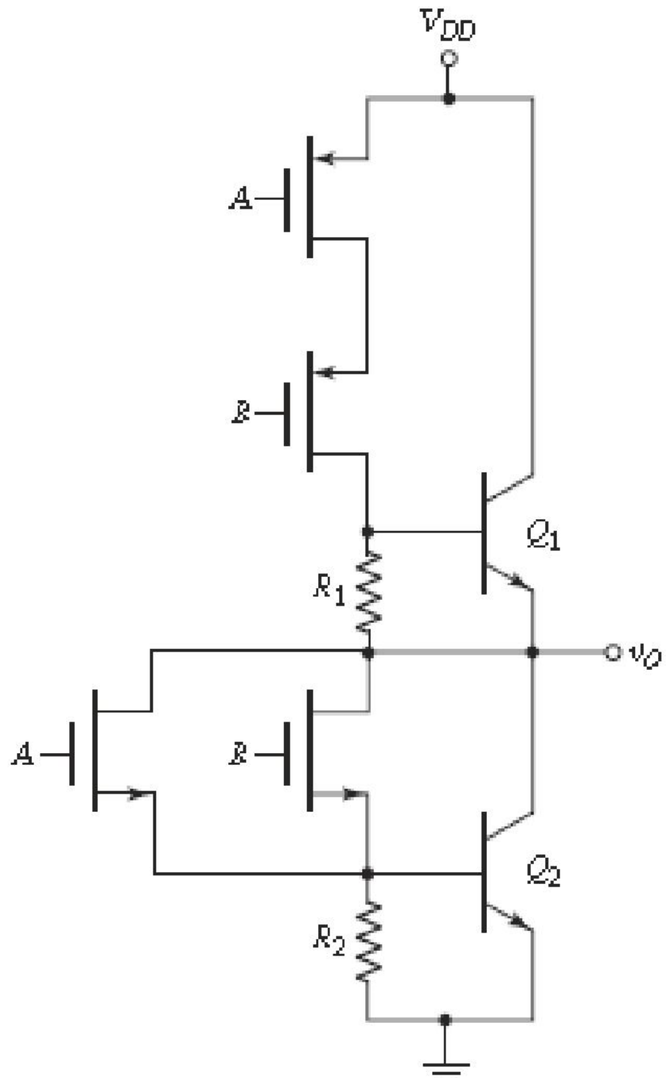

Figure 17.37 Two-input BiCMOS NOR circuit

Critical Performance Metrics

- 1. Propagation Delay Time (tpd):
- • Time for signal to propagate through logic gate
- • ECL: Fastest | TTL: Moderate | Schottky TTL: Improved
- 2. Power Dissipation (P):
- • Power consumed per gate during operation
- • Major limitation of bipolar technologies
- 3. Fanout:

Comparative Analysis of Logic Families

- ECL: Non-saturating operation → Fastest speed, highest power
- Standard TTL: Saturating operation → Moderate speed, moderate power
- Schottky TTL: Prevents deep saturation → Improved speed, similar power
- Low-Power Schottky: Higher resistances → Reduced power, acceptable speed
- BiCMOS: Hybrid approach → Balanced

Comparative Analysis of Logic Families

- Differential amplifier transfer characteristics (ECL foundation)
- Multi-emitter input transistor operation (TTL innovation)
- Schottky barrier diode clamping mechanism (saturation prevention)
- Totem-pole output stage configuration (rapid switching)
- Reference voltage circuit design (stable logic thresholds)
- Series gating for complex logic functions (performance optimization)

Comparative Analysis of Logic Families

- Fundamental trade-off: Speed vs. Power cannot be eliminated
- Each technology represents optimization for specific applications
- Saturation avoidance (ECL) vs. saturation management (TTL/Schottky)
- Technology evolution driven by: switching speed, power efficiency, manufacturing cost
- BiCMOS attempts to transcend single-technology limitations
- Historical lesson: No single 'best' technology—context determines choice

Summary

- Bipolar logic families were foundational to early digital systems
- ECL: Fastest bipolar technology through saturation avoidance
- TTL: Balanced performance made it historically dominant for general use
- Schottky clamping: Elegant solution to saturation delay problem
- BiCMOS: Strategic technology integration for

Summary

- Historical significance: First practical digital logic circuit technology
- Current status: Specialized applications only (high-speed, legacy systems)
- Replaced by CMOS due to superior power efficiency
- Enduring principles:
-   • Circuit design involves fundamental trade-offs
-   • Performance optimization requires understanding device physics
-   • Technology selection depends on application requirements
- Foundation for understanding modern high-speed digital design

17.7 SUMMARY

- This chapter presented the analysis and design of bipolar digital logic circuits, which were historically the first logic circuit technology used in digital systems.
- Emitter-coupled logic (ECL) is used in specialized high-speed applications. The basic ECL gate has the same configuration as the differential amplifier, but transistors are switched between cutoff and the active region. Avoiding driving transistors into saturation keeps the propagation delay time to a minimum.
- The classical ECL gate uses the diff-amp configuration in conjunction with emitter-follower output stages and a reference voltage circuit. Both NOR and OR outputs are available.
- Modified ECL logic gates can be designed with reduced power dissipation.
- The analysis of diode-transistor logic (DTL) circuits introduced saturating bipolar logic circuits and their characteristics.
- The input transistor of the transistor–transistor logic (TTL) circuit is driven between saturation and the inverse active mode. This transistor reduces the switching time by quickly pulling charge out of the base of a saturated transistor. The totem-pole output stage was introduced in order to increase the switching speed of the output stage.
- The Schottky clamped transistor has a Schottky diode between the base and collector of an npn transistor, thus preventing the transistor from being driven deep into saturation. The propagation delay time of Schottky TTL, then, is shorter than that of regular TTL.
- Low-power Schottky TTL has the same basic configuration as the DTL circuit. Resistor values are increased so as to reduce the currents, which in turn reduce the power dissipated per circuit.
- BiCMOS circuits incorporate the best characteristics of both the CMOS and bipolar technologies. One example is a basic CMOS inverter that drives a bipolar output stage. The high input impedance and low power dissipation of the CMOS design is coupled with the high current drive capability of a bipolar output stage. An example of a BiCMOS NOR logic circuit was considered.
- As an application, a static ECL logic gate to implement a specific logic function was designed.