Digital Integrated Circuits – Logic Families (Pt. I)

Integrated circuits classified as

(i) Linear  (ii) Digital

Digital ICs classified as per level of integration.

These are like SSI, MSI, LSI, VLSI, ULSI and GSI as per the number of Gates.

SSI (<12), MSI (12 to 99), LSI (100 to 9999), VLSI (10,000 to 99,999), ULSI (100,000 to 999,999) & GSI (1 Million or more)

SSI    - Basic gates & FFs
MSI    - More complex like adders, comparators
LSI    - Small digital systems like digital clocks calculator
VLSI   - Digital system on chip like large memory chips
ULSI & GSI - Complex function – several boards of ICs
Logic Families

(i) Saturated (RTL, DCTL, DTL, TTL, I^2L)
    Bipolar
    Non Saturated (Schottky TTL & ECL)

(ii) MOS Families (P MOS, N MOS, C MOS)

Digital IC Characteristics

(1) Current and voltage parameters
They are: I_{IH}, I_{IL}, I_{OH}, I_{OL} And V_{IH}, V_{IL}, V_{OL} & V_{OH}
V_{IH} \rightarrow Minimum voltage level required for logic 1 at input. For TTL, it is 2.0V

(2) Propagation delay (t_{pd}); Delay time in going from low to high logic or high to low logic (t_{p LH} & t_{p HL})
\[ t_{pd} = (t_{p LH} + t_{p HL}) / 2 \]
In BJT \( t_{p LH} > t_{p HL} \) (Due to reverse recovery)
In FET \( t_{p LH} < t_{p HL} \) (Due to large capacitance)
Typical 15 ns (for TTL)
(3) **Power dissipation**
It is a measure of power consumed by logic gate when fully driven. Avg. power dissipated is product of DC supply voltage and mean current.
For TTL standard it is 10 mW

(4) **Fan in & Fan out**
Fan in – No. of inputs connected to gate without degradation
Fan out – Max number of similar gates that gate can drive
Typical, fan out 10 for TTL.

(Fan out)_H =I_{OH} / I_{IH} And (Fan out)_L =I_{OL} / I_{IL}
Overall Fan out is lowest of the two.

(5) **Noise immunity or Noise Margin** : It is the ability of the circuit to tolerate noise without causing spurious changes in the output
(6) Current Sourcing & Sinking

Current sourcing: Output supplies (sources) current to load circuit. For TTL it is 40 µA.
Current Sinking: Output receives (sinks) current from the input of the load gate. For TTL it is 1.6 mA

(7) **Speed Power Products or Figure of Merit (FOM):**

Speed power product $t_{pd} \times P_{Davg}$

$10 \text{ ns} \times 5 \text{ mw}$
50 pico – Joules (PJ)
When delay in ns & $P_{avg}$ in mw, speed power
Product in pico – Joules
Low value desirable.
For TTL (Std.) – 100 pico - Joules

Bipolar Logic Families
Bipolar ICs use resistors, BJT, and diodes. They are either saturated logic or non- saturated.
(1) Resistor Transistor Logic (RTL)

- Earliest, in use before development of ICs
- Low speed, High power dissipation and low Fan out
- Can be used in wired or connection

(2) Direct coupled Transistor Logic (DCTL)

- Base resistors $R_B$ not used
- Logic levels are $V_{BE(sat)} = 0.8$ V & $V_{CE(sat)} = 0.2$ V
- Simpler than RTL
- Poor noise margin
- Problem of current hogging

(3) Diode transistor Logic (DTL)

- First cct.config.to be designed as IC. Uses diode AND and BJT inverter.
• It has limitation of no low and constant output impedance in both the states.

(4) Transistor Transistor Logic (TTL)
Problem of DTL eliminated by totem pole output.
Q₁ – Multiple emitter transistor
Q₂ – Phase splitter
Q₃ & Q₄ – Totem pole output.

Diode D ensures that Q₄ cutoff when output low

A = B = 0 E – B Jns forward biased
Q₁ saturates
Q₂ base voltage ‘0’ so cutoff
Q₃ in cutoff & Q₄ acts like Emitter follower.

Output is high
Q₁ is in rev. active mode, current into base of Q₂, so saturates.
Voltage at collector of Q₂= 0.8V = 0.7 + 0.1 V, so Q₄ not turned ON,
Q₃ saturates **low output**

**Totem pole output:** Fast Switching speed and low power dissipation.

Large spike while switching from low to high.
**Open collector output**: Wired AND & OR operation.

**Tristate output**: Incorporates benefit of totem pole and open collector.

TTL sub families are in common use.

**Schottky TTL:**

- The main purpose is to increase speed.
- Four sub families that use Schottky diodes and transistors (74S, 74LS, 74ALS and 74AS).
- Schottky transistor use Schottky clamp diode across collector base junction of BJT to prevent its saturation.
- Schottky carrier diodes are also called hot carrier diodes.
## TTL sub families speed- power comparison

<table>
<thead>
<tr>
<th>Family</th>
<th>Minimizing Power</th>
<th>Minimizing delay time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Propagation Delay (ns)</td>
<td>Power Dissipation (mW)</td>
</tr>
<tr>
<td>TTL</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>L TTL</td>
<td>33</td>
<td>1</td>
</tr>
<tr>
<td>LS TTL</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>ALS</td>
<td>4</td>
<td>1.2</td>
</tr>
</tbody>
</table>

- Two approaches (i)Minimizing power (ii)minimizing delay time
- LTTL, LSTTL, ALS all have letter L for low power. ALS series has the best characteristics.
- HTTL, STTL, AS are high speed. **AS is the best.**
Separate tables help us to visualize.

## Comparison of TTL Subfamilies

<table>
<thead>
<tr>
<th>TTL Sub Families</th>
<th>Introduction</th>
<th>Features</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>TTL Std. (74)</td>
<td>Uses transistors in totem pole output configuration.</td>
<td>Most commonly used as SSI for lab expt.</td>
<td>Low speed &amp; high power dissipation (10ns,10mw)</td>
</tr>
<tr>
<td>Low Power TTL (74L)</td>
<td>Increased resistor values.</td>
<td>Reduced power dissipation (1mW) Batt. operated ccts.</td>
<td>High prop. delay Typically 33ns.</td>
</tr>
<tr>
<td>High speed TTL (74 H)</td>
<td>Smaller resistor values Emitter follower with Darling. pair</td>
<td>High speed Approx. Prop. Delay 6 ns</td>
<td>More power dissipation Approx. 22 mW</td>
</tr>
<tr>
<td>Schottky TTL (74S)</td>
<td>Unsaturated Schottky diode Darlington active pull up</td>
<td>Improved switching speed Approx. 3 ns</td>
<td>Average power dissipation approx.. 20 mW</td>
</tr>
<tr>
<td>--------------------</td>
<td>---------------------------------------------------</td>
<td>--------------------------------------</td>
<td>----------------------------------------</td>
</tr>
<tr>
<td>Low Power TTL (74LS)</td>
<td>Increasing internal resistance Uses Schott. diode</td>
<td>Low power = 2 mW Speed = 9.5 ns</td>
<td></td>
</tr>
<tr>
<td>Advanced Schottky TTL (74 AS)</td>
<td>Smaller device geometries reducing capacitance</td>
<td>Fastest logic family prop. delay 1.7 ns Suitable for high frequencies.</td>
<td>Moderate power dissipation about 8mW</td>
</tr>
<tr>
<td>Adv. Low power Schottky TTL(74ALS)</td>
<td>Uses complex circuit</td>
<td>Best for battery op. cct. Lowest speed power product 4.8pJ</td>
<td></td>
</tr>
</tbody>
</table>

**Integrated Injection Logic (I² L):**

- Also called merged transistor logic
- Uses both npn and pnp transistors
- Reduces number of metal interconnections
- High speed and less power dissipation. Best Figure of merit.
- Finds use in large computers

**Emitter Coupled Logic (ECL)**

- Current mode logic and non-saturated
- Fastest switching speed (Prop. Delay approx. 1 ns)
- High dissipation and takes large chip area
- Circuit consists of differential amplifier and emitter follower

Comparison of Bipolar Logic Families

<table>
<thead>
<tr>
<th>Name</th>
<th>Introduction</th>
<th>Features</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistor Transistor Logic (RTL)</td>
<td>In common use before development of ICs</td>
<td>First logic family</td>
<td>Low speed High power dissipation &amp; Low Fan out</td>
</tr>
<tr>
<td>Type</td>
<td>Description</td>
<td>Advantages</td>
<td>Disadvantages</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------</td>
</tr>
<tr>
<td>Direct coupled Transistor logic (DCTL)</td>
<td>Direct Coupled Base resistor of RTL omitted</td>
<td>Simpler than RTL</td>
<td>Small logic swing</td>
</tr>
<tr>
<td>Diode Transistor Logic (DTL)</td>
<td>Uses diode &amp; transistor</td>
<td>First circuit. Configuration Designed into IC.</td>
<td>No low and constant output impedance in both states</td>
</tr>
<tr>
<td>Transistor Transistor Logic (TTL)</td>
<td>Uses all transistors Totem pole output</td>
<td>Fast switching time Low power dissipation</td>
<td>Large current spike when switching from low to high</td>
</tr>
<tr>
<td>Integrated Injection Logic (I₂L)</td>
<td>Technology of merged transistor logic (MTL) Both p np &amp; n p n transistors are used. Low metal interconnections.</td>
<td>High component density Less power dissipation Used in large computers.</td>
<td>Low speed Poor noise immunity</td>
</tr>
</tbody>
</table>
| Emitter Coupled Logic (ECL) | Non saturated logic  
Complementary output  
Logic levels  
-0.8 logic 1  
-1.7 logic 0 | Fastest logic devices used in very high frequency applications  
No noise spikes | High power dissipation.  
Inconvenient voltage levels.  
Low noise margin |