The 555 timer IC

- **Threshold**
- **Trigger**
- **Discharge**
- **Ground**
- **$V_{CC}$**
- **Comparator 1**
- **Comparator 2**
- **Flip-flop**
- **Out**
- **$R_1$**
- **$V_{TH}$**
- **$V_{TL}$**
- **$Q_1$**
- **100 $\Omega$**
R-S Flip flop

<table>
<thead>
<tr>
<th>S</th>
<th>R</th>
<th>Q_n</th>
<th>Q_n^-</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>Q_{n-1}</td>
<td>Q_{n-1}^-</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>undefined</td>
<td>undefined</td>
</tr>
</tbody>
</table>
R-S Flip flop

![Diagram of R-S Flip flop]
555 as a monostable multivibrator
555 as an astable multivibrator
Non-linear wave shaping
Diode shaping networks
Output Stages and Power Amplifiers

Ch 11
Multistage amplifiers - rationale

High input Z for minimal loading

(differential input for noise immunity)

High gain (in multiple stages)

High power output

Low output Z for minimal impact from load
Multistage amplifiers - rationale

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High power output
General considerations in (output) power amplifiers
General considerations in (output) power amplifiers

Linearity
General considerations in (output) power amplifiers

DC power in

Signal power out

Efficiency

Linearity

in

out

out

in
General considerations in (output) power amplifiers

- DC power in
- Heat (and cooling)
- Signal power out
- Efficiency

Graph: Linearity

\( \text{Efficiency} \)
General amplifier tradeoffs

360° conduction angle | Best linearity | Lowest efficiency

180° conduction angle | Moderate linearity | Moderate efficiency

<180° conduction angle | Poor linearity | Best efficiency
General amplifier tradeoffs

- **360° conduction angle**: Best linearity, Class A, Lowest efficiency
- **180° conduction angle**: Moderate linearity, Class B, Moderate efficiency
- **<180° conduction angle**: Poor linearity, Class C, Best efficiency
Class A amplifier
Class A amplifier

Bias circuit
Class A amplifier
Class A amplifier

\[ v_o = v_i - v_{BE1} \]
Class A amplifier

\[ v_O = (V_{CC} - V_{CE1sat}) \]

\[ v_I = \]

\[ V_{BE1} \]

\[ -IR_L \]

\[ (-V_{CC} + V_{CE2sat}) \]
Class A amplifier

\[ (V_{CC} - V_{CE1\text{sat}}) \]

Large linear range

\[ V_{BE1} \]

\[ IR_L \]

\[ (-V_{CC} + V_{CE2\text{sat}}) \]

Q \(_1\) turns off
Class A efficiency

Output voltage
Class A efficiency

Output voltage

Collector-emitter voltage

468
Class A efficiency

Output voltage

Collector-emitter voltage

Collector current
Class A efficiency

Output voltage

Collector-emitter voltage

Collector current
Class A efficiency

Output voltage

Collector-emitter voltage

Collector current

Power dissipation
Class A efficiency

\[ \eta \equiv \frac{P_L}{P_S} = \frac{\text{Power delivered to load}}{\text{Power supplied to circuit}} \]
Class A efficiency

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For a sinusoidal signal with peak voltage \( \hat{V}_o \)

\[ P_L = \frac{\left( \frac{\hat{V}_o}{\sqrt{2}} \right)^2}{R_L} = \frac{\hat{V}_o^2}{2R_L} \]
Class A efficiency

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Supply power is

\[ P_S = 2V_{CC}I \]
Class A efficiency

\[ \eta \equiv \frac{P_L}{P_S} = \frac{\text{Power delivered to load}}{\text{Power supplied to circuit}} \]

For a sinusoidal signal with peak voltage \( \tilde{V}_o \)

\[ P_L = \frac{\left( \frac{\tilde{V}_o}{\sqrt{2}} \right)^2}{R_L} = \frac{\tilde{V}_o^2}{2R_L} \]

Supply power is

\[ P_S = 2V_{cc}I \]

Efficiency is

\[ \eta \equiv \frac{P_L}{P_S} = \frac{2R_L}{2V_{cc}I} = \frac{1}{4} \left( \frac{\tilde{V}_o}{IR_L} \right) \left( \frac{\tilde{V}_o}{V_{cc}} \right) \]
Class A efficiency

\[ \eta \equiv \frac{P_L}{P_S} = \frac{\frac{\hat{V}_o^2}{2R_L}}{2V_{CC}I} = \frac{1}{4} \left( \frac{\hat{V}_o}{IR_L} \right) \left( \frac{\hat{V}_o}{V_{CC}} \right) \]

But

\[ \hat{V}_o \leq V_{CC} \quad \text{and} \quad \hat{V}_o \leq IR_L \]

So

\[ \eta \leq \frac{1}{4} \]

Best efficiency when

\[ \hat{V}_o = V_{CC} = IR_L \]
Class A efficiency

\[ \eta = \frac{P_L}{P_S} = \frac{\frac{\hat{V}_o^2}{2R_L}}{2V_{CC}I} = \frac{1}{4} \left( \frac{\hat{V}_o}{IR_L} \right) \left( \frac{\hat{V}_o}{V_{CC}} \right) \]

But

\[ \hat{V}_o \leq V_{CC} \]  and  \[ \hat{V}_o \leq IR_L \]

So

\[ \eta \leq \frac{1}{4} \]

Class A isn’t practical for stages that develop any appreciable amount of power

Best efficiency when

\[ \hat{V}_o = V_{CC} = IR_L \]
Class B output stage
Class B output stage

\[ +V_{CC} \]

\[ Q_N \]

\[ Q_P \]

\[ v_I \]

\[ i_L \]

\[ v_O \]

\[ -V_{CC} \]

\[ R_L \]

Push

Pull
Class B transfer characteristic

\[ v_O = \begin{cases} 
(V_C - V_{CEN_{sat}}) & \text{Slope} = 1 \\
(-V_C + V_{ECP_{sat}} - V_{EBP}) & +0.5 \text{ V} \\
(V_C - V_{CEN_{sat}} + V_{BEN}) & \text{Slope} = 1 \\
(-V_C + V_{ECP_{sat}}) & -0.5 \text{ V}
\end{cases} \]
Class B “dead band”
Class B operation

ClassB(x)

h(t)

20 \cdot \log(A_j)
Class B operation

ClassB(x)

h(t)

20 \cdot \log(A_j)
Class B efficiency

\[ P_{D_{\text{max}}} = \frac{2V_{CC}^2}{\pi^2 R_L} \]

\[ \eta = 50\% \]

\[ \eta = 78.5\% \]
Reducing Class B crossover distortion
Class AB – conceptual model

Class B push-pull amplifier
Class AB – conceptual model

Crossover compensation

\[
\frac{V_{BB}}{2}
\]

\[+V_{CC}\]

\[Q_N\]

\[i_N\]

\[Q_P\]

\[i_P\]

\[i_L\]

\[R_L\]

\[v_I\]

\[v_O\]

\[-V_{CC}\]
Class AB

\[ +V_{CC} \]
\[ 1 \text{ mA} \]
\[ Q_1 \]
\[ -V_{CC} \]
\[ +V_{CC} \]
\[ Q_2 \]
\[ 1 \text{ mA} \]
\[ -V_{CC} \]
\[ Q_3 \]
\[ Q_4 \]
\[ v_i \]
\[ v_o \]
\[ i_i \]
\[ R_L = 100 \Omega \]
Class AB transfer function

\[ v_O = \begin{cases} 
(V_{CC} - V_{CE\text{sat}}) & \text{for } v_I > 0 \\
0 & \text{for } -V_{CC} + V_{EC\text{psat}} < v_I < 0 \\
-V_{CC} + V_{EC\text{psat}} & \text{for } v_I < -V_{CC} + V_{EC\text{psat}} 
\end{cases} \]

Slope = 1
Class AB transfer function

\[ v_O = \begin{cases} 
V_{CC} - V_{CEN_{sat}} & \text{for } v_I > 0 \\
-V_{CC} + V_{ECP_{sat}} & \text{for } v_I < 0
\end{cases} \]

Slope = 1
Class C operation

\[ h(t) \]

\[ \log A_j \cdot j \]

\[ \text{Cconduction\_angle} \equiv \frac{\pi}{3} \]
Class C operation

$h(t)$

$t$

$20 \cdot \log(A_j)$

$j$

$C_{\text{conduction\_angle}} \equiv \frac{\pi}{8}$
Power BJTs

• Collector currents in the multi-ampere range

• Multi-watt power dissipation

Achieved by:

• High temperature tolerant designs ($T_J$ up to 200 °C)

• Effective heat dissipation design
Thermal resistance model

\[ T_J - T_A = \theta_{JA} P_D \]
Power derating curve

- Power dissipation at ambient
- Reduced power rating at increased temperature
- Slope: \( \frac{-1}{\theta_{JA}} \)
- Maximum allowable junction temperature

\( P_{D_{\text{max}}} \)
\( P_{D0} \)
\( T_{A0} \)
\( T_{J_{\text{max}}} \)
\( T_A \)
Achieving efficient heat dissipation

“TO3” package

- Maximum heat dissipation surface
- Mounting holes to allow bolting to heat sink