Waveshaping Circuits and Data Converters

Lesson #17
Comparators and Schmitt Triggers
Section 12.1
Waveshaping Circuits and Data Converters

• Comparators and Schmitt Triggers
• Astable Multivibrators and Timers
• Rectifiers, Peak Detectors, Sample-and-Hold
• A/D and D/A Converters
Comparators

- Circuits which compare two input voltages, \( v_1 \) and \( v_2 \), and produces a logic output
  - E.g.
    - High if \( v_1 > v_2 \)
    - Low if \( v_1 < v_2 \)
  - Inputs:
    - Inverted and non-inverted
    - \( v_i = v_1 - v_2 \)
  - Ideal Transfer Characteristics
    - Symmetrical or Unsymmetrical
Real Comparators

- Real Comparators have a gradual transition
- $|v_i| > 0.2\ mV$ to cause a change in state.

- Interface Analog to Digital signals and may have different voltage ranges
  - +15 to −15 V on the analog side
  - +5 to 0 V on the digital side
**Schmitt Triggers**

- Noise on the input can cause undesirable transitions in the output of a comparator.
  - Example: comparing a noisy signal to a reference voltage.

  ![Schmitt Trigger Diagram](image)

- Through the use of positive feedback to the comparator, this problem can be eliminated - The Schmitt Trigger
Effects of Positive Feedback

- From this circuit: \( v_o = Av_i \) and \( v_i = v_f - v_{in} = \beta v_o - v_{in} \)
- Because of the positive feedback, \( v_i \) is no longer equal to zero (not a virtual ground)
- So as \( v_i \) increases in the positive (negative) direction, increases in the positive (negative) direction.
- Because of the positive feedback, this will increase \( v_i \) in the positive direction (negative) which will further increase \( v_o \) which further increase \( v_i \) and so on.
- When will this stop?

If we had infinite power, then never.
However, we have limited power which is given by the amplifier’s DC voltage supplies: +A, -A.

- If \( v_i \) goes positive, then \( v_o \) “instantaneously” grows to +A volts
- And if \( v_i \) goes negative, then \( v_o \) “instantaneously” grows to -A volts
Hysteresis

- Assume that $\beta = \frac{R_2}{R_1 + R_2} = 0.1$ and $v_o$ levels are $+10$ (for $v_i > 0$) and $-10$ V (for $v_i < 0$).

- First, note that $v_i = v_f - v_{in}$. Now, let’s assume $v_o = +10$ V and therefore $v_f = 1$ V then as long as $v_{in}$ is less than $1$ V, then $v_o = +10$ V (it’s high state) since $v_i$, the input to the comparator, will be $> 0$. Once $v_{in}$ surpasses 1, $v_i < 0$, and the output will switch to $-10$ V.

- At this point, $v_f = -1$ V and as long as the $v_{in} > -1$ V, the output will stay in its low state, $-10$ V.

- Note that has the characteristic of being a flip-flop. If one pulses it with high (>1), then the output switches to a low and visa versa.

This is characteristic is called hysteresis
Inverter

\[ v_{in} + v_i = v_f \]
\[ v_i = v_f - v_{in} \]
\[ v_f = \beta v_o \]
\[ v_i = \beta v_o - v_{in} \]

For \( v_i > 0; v_o = A \)
\[ v_i = \beta v_o - v_{in} > 0 \Rightarrow \beta A - v_{in} > 0 \Rightarrow \beta A > v_{in} \]
\[ v_{in} < \beta A \]

For \( v_i < 0; v_o = -A \)
\[ v_i = \beta v_o - v_{in} < 0 \Rightarrow -\beta A - v_{in} < 0 \Rightarrow -\beta A < v_{in} \]
\[ v_{in} > -\beta A \]

Note that \( \pm \beta A \) volts are the thresholds for when the circuit switches states.
Other Forms of Schmitt Triggers

- Non-inverting types

- Specified Thresholds
**Specific Thresholds**

\[ v_i = v_i - v_{in} \]
\[ v_i > 0; v_o = +A \]
\[ v_i < 0; v_o = -A \]

From node at noninvering input:

\[ \frac{v_i + v_o - v_{t}}{R_2} + \frac{v_o - v_{SS}}{R_3} + \frac{v_t}{R_1} = 0 \]

\[ v_i = \frac{v_o + \frac{V_{SS}}{R_3}}{\frac{R_3}{R_1}} = \frac{v_o + \frac{V_{SS}}{R_1}}{\frac{G_T}{R_3}} = \frac{v_o + \frac{V_{SS}}{G_T R_1}}{G_T R_3} \]

\[ v_i = \frac{v_o}{G_T R_3} + \frac{V_{SS}}{G_T R_1} - v_{in} \]

\[ v_i = \frac{A}{G_T R_3} + \frac{V_{SS}}{G_T R_1} - v_{in} > 0; v_{in} < V_{t1} = \frac{A}{G_T R_3} + \frac{V_{SS}}{G_T R_1} \]

\[ v_i = -\frac{A}{G_T R_3} + \frac{V_{SS}}{G_T R_1} - v_{in} < 0; v_{in} > V_{t2} = -\frac{A}{G_T R_3} + \frac{V_{SS}}{G_T R_1} \]
An Example

- Choose the 3 resistors to provide thresholds of $5 \pm 0.1 \, V$ for output levels of $\pm 14.6 \, V$.

![Circuit Diagram]

At the non-inverting mode, we have:

$$\frac{V_t}{R_2} + \frac{V_i - V_{SS}}{R_1} + \frac{V_t - v_o}{R_3} = 0$$

Using $15 \, V$ for $V_{SS}$ and $V_t = 5.1$ for $v_o = +14.6$, we have

$$\frac{5.1}{R_2} + \frac{5.1 - 15}{R_1} + \frac{5.1 - 14.6}{R_3} = \frac{5.1}{R_2} + \frac{9.9}{R_1} + \frac{9.5}{R_3} = 0$$

Using $V_t = 4.9$ for $v_o = -14.6$, we have

$$\frac{4.9}{R_2} + \frac{4.9 - 15}{R_1} + \frac{4.9 + 14.6}{R_3} = \frac{4.9}{R_2} + \frac{10.1}{R_1} + \frac{19.5}{R_3} = 0$$

- We need to chose one of the 3 resistors. If we choose $R_3 = 1 \, M$, then $R_1 = 20.55 \, k$ and $R_2 = 10.38 \, k$. If we chose resistors too small then may draw excessive amounts of current from our $15 \, V$ supply and create a large power drain on the circuit.
Example continued

\[ v_i = v_t - v_{in} \]

when \( v_i > 0; \) \( v_o = +14.6v \)
therefore,
\[ v_i = v_t - v_{in} > 0 \]
\[ v_t > v_{in}; \text{ or } v_{in} < 5.1 \]

\[ v_i = v_t - v_{in} \]
when \( v_i < 0; \) \( v_o = -14.6v \)
therefore,
\[ v_i = v_t - v_{in} < 0 \]
\[ v_t < v_{in}; \text{ or } v_{in} > 4.9 \]
Another Example

- What are the transfer characteristics for this circuit if $R_1=1k$ and $R_2=2k$ and the thresholds levels are $\pm10\,V$.

\[
V_{in} = i(R_1 + R_2) + v_o
\]
\[
V_t = iR_1 = \frac{V_{in} - v_o}{R_1 + R_2} R_1
\]
\[
v_i = V_{in} - V_t = V_{in} - \frac{V_{in} - v_o}{R_1 + R_2} R_1
\]
\[
v_i = V_{in} - \frac{V_{in} - v_o}{3} = \frac{2}{3} V_{in} + \frac{v_o}{3}
\]

For $v_o = +10\,V$, $v_i > 0$

\[
v_i = \frac{2}{3} V_{in} + \frac{v_o}{3} > 0; \frac{2}{3} V_{in} < -\frac{v_o}{3}; V_{in} < -5
\]

For $v_o = -10\,V$, $v_i < 0$

\[
v_i = \frac{2}{3} V_{in} + \frac{v_o}{3} < 0; \frac{2}{3} V_{in} < -\frac{v_o}{3}; V_{in} < 5
\]
Homework

• Comparators and Schmitt Trigger Circuits
  – Problems: 12.8-9