Lecture #5
Sawtooth & Staircase Generators

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# Grading Strategy

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Agenda

- Non-Inverting Integrator
- Staircase Generator
- Sawtooth Generator
NON-INVERTING INTEGRATOR
Non Inverting Integrator

\[ V^+ = V^- \]

- **KCL @ \( V^- \):**
  \[ \frac{V_o - V^-}{R} = \frac{V^-}{R} \]
  So, \( V^- = \frac{V_o}{2} \)

- **KCL @ \( V^+ \):**
  \[ \frac{V_x - V^+}{R_3} + \frac{V_o - V^+}{R_3} = SC \times V^+ \]
  So, \( V^+ = \frac{V_x + V_o}{2 + SCR_3} \)

By equating \( V^+ \) & \( V^- \) we'll get:

\[ V_o = \left( \frac{2}{SCR_3} \right) V_x \quad \Rightarrow \text{non-inverting integrator.} \]

Or

\[ v_o(t) = \left( \frac{2}{CR_3} \right) \int_0^t v_x \, dt \]
Saturation time

Non Inverting Integrator

\[
\begin{align*}
V_o &= \frac{2}{sC} V \\
V_o &= \frac{2}{sC} V \int s \, dt \\
V_o &= \frac{2}{sC} \int s \, dv \\
V_o &= \frac{4}{sC} \int t \left(1 - \frac{t}{10^3 \times 10^{-6}}ight) \, dt \\
V_o &= 4V \\
\text{Saturation time at } V_o &= 5V \\
5 &= 4000 \, t_{sat} \\
t_{sat} &= \frac{5}{4000} = 1.25 \, ms \\
V_o &= 4000 \times 10^{-3} = 4V
\end{align*}
\]
Saturation time

Inverting Integrator

\[ V_o = \frac{-V}{C} t \]

What about \( v = 2v \) ?
STAIRCASE AND RAMP GENERATOR
Using BCD Counter

\[ V_0 = \frac{2^N t}{RC} \]
Staircase Example

\[ step = \frac{2}{10^3 \times 10^{-6}} \times 5t = 10^4 t \]

\[ = 10^4 \times \frac{5}{100 \times 10^{-3}} = 0.5V \]
SAWTOOTH GENERATOR CIRCUITS
Triangular vs. Sawtooth
Sawtooth circuit
Using non inverting Integrator

\[ v_o = \frac{2V}{RC} \cdot \frac{T}{R} \]
Duty Cycle of the Astable Waveform indicates the rise and fall time of the sawtooth waveform i.e. positive or negative ramp.
Sawtooth circuit...
Astable Multivibrator & Integrator

![Sawtooth wave generator circuit diagram]
Sawtooth circuit....
Integrator & rapid discharge element

\[ I_c = -\frac{V_{EE}}{R} \]

\[ V_{out} = -\frac{V_{EE}}{RC}T = -\frac{V_{EE}}{RCf} \]
Trapezoidal Generator circuit

If output voltage reaches $V_{cc}$ during time $T$, op-amp sawtooth generator goes to saturation, and output voltage is trapezoidal.
Sawtooth Voltage-Controlled Oscillator (VCO)

- VCO is a relaxation oscillator whose frequency can be changed by a variable dc control voltage.
- VCOs can be either sinusoidal or nonsinusoidal.
- One way to build a sawtooth VCO is with an op-amp integrator that uses a switching device (PUT) in parallel with the feedback capacitor to terminate each ramp at a prescribed level and effectively “reset” the circuit.
- The PUT is a programmable unijunction transistor with an anode, a cathode, and a gate terminal.

- Operation:

  ![Diagram of VCO circuit](a) Initially, the capacitor charges, the output ramp begins, and the PUT is off.

N.B. For more details regarding PUT, refer to ch. 11
Sawtooth VCO.

T, of the sawtooth waveform:

\[ T = \frac{V_p - V_F}{|V_{IN}|/R_iC} \]

\[ f = \frac{|V_{IN}|}{R_iC \left( \frac{1}{V_p - V_F} \right)} \]
Assignment

• Design a sawtooth generator to provide a sawtooth waveform with the following specs:
  • frequency from 1 KHz to 1 MHz
  • amplitude from 0.5 Vpp to 6Vpp.
• For more details, refer to:
  • Online tutorials on Sawtooth, Staircase generators.
• The lecture is available online at:
  • [http://bu.edu.eg/staff/ahmad.elbanna-courses/12884](http://bu.edu.eg/staff/ahmad.elbanna-courses/12884)
• For inquires, send to:
  • [ahmad.elbanna@feng.bu.edu.eg](mailto:ahmad.elbanna@feng.bu.edu.eg)