EEE225: Analogue and Digital Electronics

Lecture VIII

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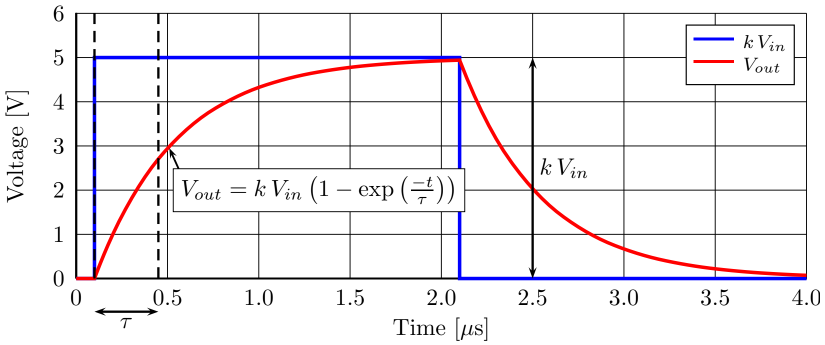
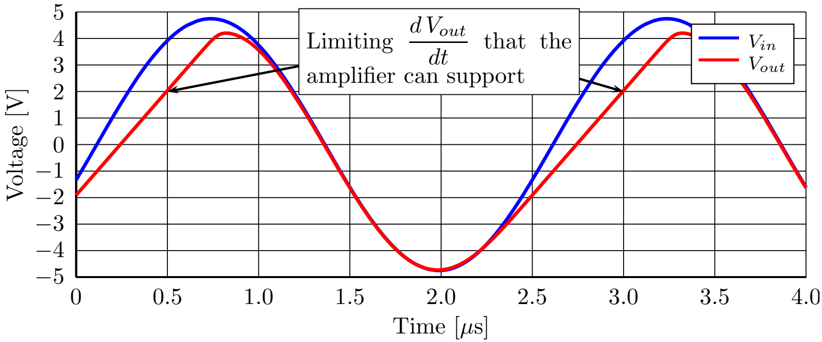
This Lecture

Slew Rate Limiting

- Slew rate limiting is *non-linear*, the ratio of v_o and v_i *depends on the magnitude of* v_i. It is a limit on the maximum rate of change of output voltage.
- It is particularly prevalent in problems where large signals and high frequencies are in use.
- It is often caused by the differential pair and VAS current source's inability to charge or discharge the compensation capacitor sufficiently quickly.
- Manufacturers specify in $V/\mu s$. (TL081 8 $V/\mu s$). Specific opamps can manage 5000 $V/\mu s$.
- Opamp manufacturers artificially increase the value of c_{cb} to obtain stability and a first order response. But increasing c_{cb} increases the current needed from the differential stage and VAS current source. It's a *compromise*, greater stability (esp. at lower closed loop gain) comes at the expense of lower slew rate.



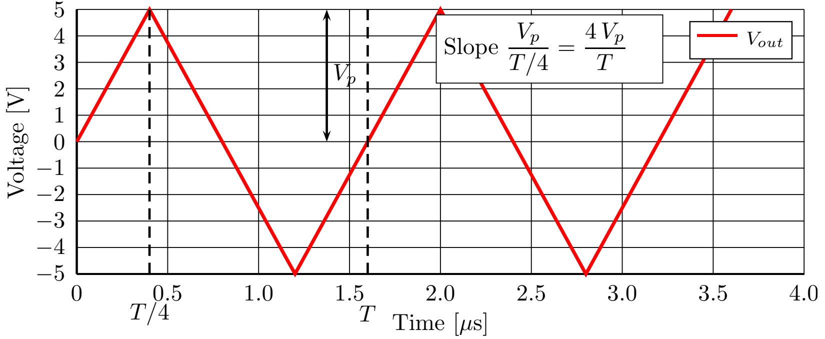
The square input signal interacts with the (low pass) opamp as if the opamp was an RC network. The result is an exponential rise to maximum of the form $V_o = k\,V_{in}\,(1 - \exp t/\tau)$ where $t = 0$ is the rising edge of the square signal, k is the system gain and τ is the time-constant of the opamp. Max rate of change $= (k\,V_{in})/\tau$. If the initial rate of change was maintained the output waveform would cross the setpoint at τ.



Max rate of change of a sinusoid,

$$V_{in}\sin(\omega t) = \left.\frac{d\left(V_{in}\sin(\omega t)\right)}{dt}\right|_{max} = \left.V_{in}\,\omega\cos(\omega t)\right|_{max} \qquad (1)$$

Max when $cos(\omega\, t) = 1$. Max dV/dt for sinusoid is $V_{in}\,\omega$.



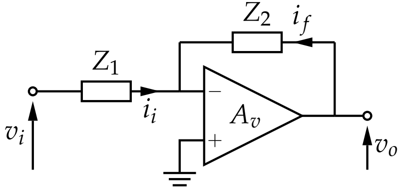
For the triangle the rate of change of voltage is constant. In the graph above the amplifier must change it's output voltage by V_p in a time, $T/4$ where T is the period. For example if $V_p = 5\ V$ and $T = 1.6\ \mu$s the slew rate must be $\geq \frac{4 \times 5}{1.6 \times 10^{-6}}\mathrm{V/s}$ or 12.5 $\mathrm{V}/\mu\mathrm{s}$

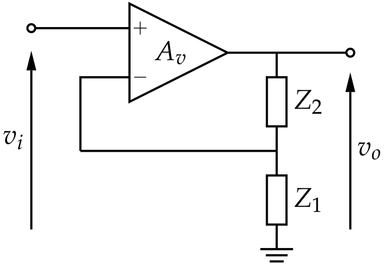
Opamps with Frequency Dependent Feedback

Part II of the second section of the course...

- Introduction of simple general opamp amplifier (Z_1, Z_2, not R_1, R_2)
- An analogue integrator
  - Freq domain analysis
  - Time domain analysis
  - Problems with integrators
  - Analogue circuit to solve 1st order differential equation (printed notes)
- An analogue differentiator
  - Freq domain analysis
  - Time domain analysis
  - Problems with differentiators
- Pole-Zero Circuits.
  - Description of first order circuits (HP, LP, PZ)
  - Example with defined components
  - Example of intrinsic freq response type problem

Some Standard opamp circuits





Inverting design gain...

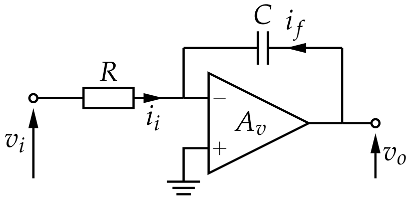
$$\frac{v_o}{v_i} = -\frac{Z_2}{Z_1} \qquad (2)$$

Non-inverting design gain...

$$\frac{v_o}{v_i} = \frac{Z_1 + Z_2}{Z_1} \qquad (3)$$

Provided closed loop gain is not dependent on open loop gain (i.e. if $A_v \to \infty$). Z_n is an arbitrary impedance (could be R, L and C).

Opamp Integrator

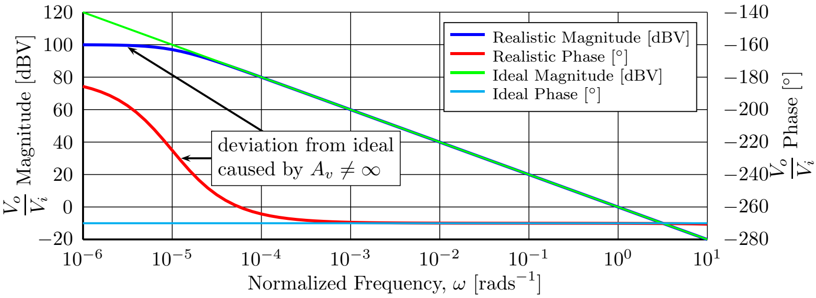


In the frequency domain.

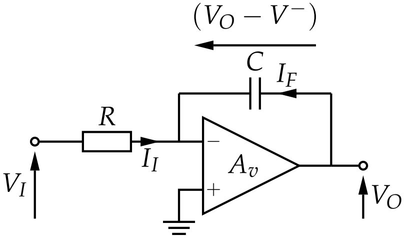
$$\frac{v_o}{v_i} = -\frac{Z_2}{Z_1} \tag{4}$$

$$\frac{v_o}{v_i} = -\frac{\left(\frac{1}{j\,\omega\,C}\right)}{R} = -\frac{1}{j\,\omega\,C\,R} \tag{5}$$

- Integrators used in filters, instrumentation circuits and in control systems, but not often implemented using an opamp.
- Often $j\,\omega = s$ where 's' is the same as appears in the Laplace transform. So (5) becomes $1/(s\,C\,R)$.
- As ω approached 0 (i.e. DC) the gain $\rightarrow \infty$. This can not actually happen as the gain can not rise above A_v



The finite A_v affects performance by moving the pole up from zero frequency to some finite frequency. The graph above is normalised i.e. $C\,R = 10^0$. The usable range of the integrator is about $10^{-3} \rightarrow 10^1$ Hz normalised but it depends on the value of A_v to some extent. Care should be taken to avoid phase errors as well as magnitude errors.



In the time domain (notice upper case letters)

$$I_I + I_F = \frac{V_I - V^-}{R} + C\frac{d\left(V_O - V^-\right)}{dt} = 0 \quad (6)$$

Assuming $V^- \approx 0$

$$\frac{V_I}{R\,C} = -\frac{dV_O}{dt} \qquad (7)$$

integrating both sides,

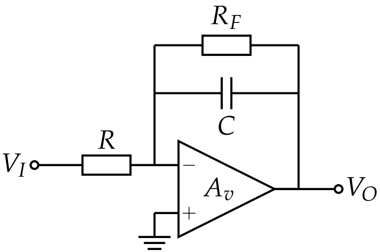
$$V_O = -\frac{1}{R\,C}\int V_I\,dt + A \quad (8)$$

A is a constant proportional to the voltage across the capacitor prior to the start of the integration.

Integrators have a major problem however, called “wind-up”.

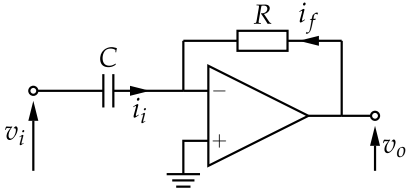
- There is no DC feedback between output and input.
- Any small voltage (offset of the opamp or offset of the signal source) is integrated over time.
- Eventually the integrator output will saturate against one of the power supply rails.

This can be avoided by providing DC feedback either as part of a larger system or more directly using a resistor.



The result of the DC pathway (R_F) is to change the gain of the circuit from $-A_0$ at DC to $-R_F/R$. This moves the pole up in frequency, decreasing the useful frequency range of the integrator.

Opamp Differentiator



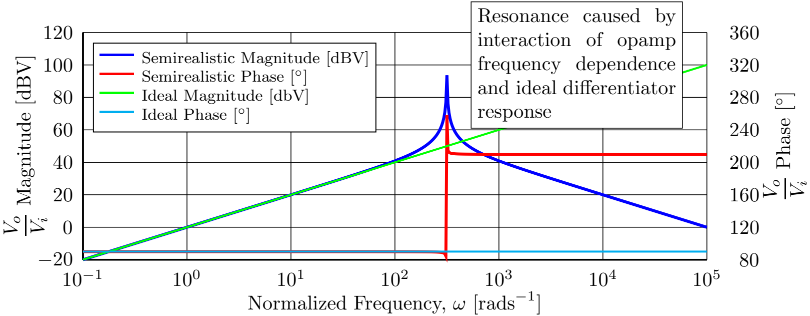
In the frequency domain.

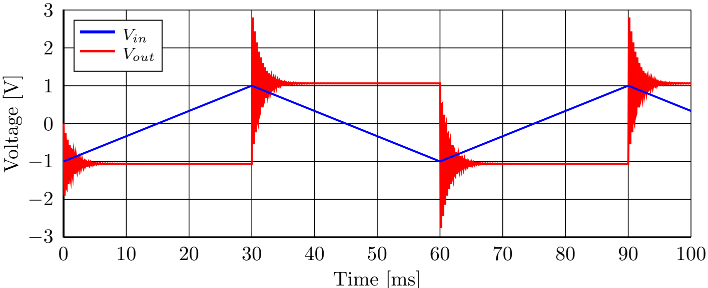
$$\frac{v_o}{v_i} = -j\,\omega\,C\,R = -s\,C\,R \quad (9)$$

In the time domain,

$$V_O = C\,R\,\frac{dV_I}{dt} \quad (10)$$

- Key components interchanged. Same assumptions as for integrator. Same style of analysis.
- The capacitance and intrinsic frequency response of the opamp (A_v) interact with each-other forming (in the case of first order opamp assumptions) a second order circuit. This makes the differentiator unusable for a few decades of frequency around resonance.


Semirealistic Magnitude [dBV]
Semirealistic Phase [°]
Ideal Magnitude [dbV]
Ideal Phase [°]
Resonance caused by interaction of opamp frequency dependence and ideal differentiator response
$\frac{V_o}{V_i}$ Magnitude [dBV]
$\frac{V_o}{V_i}$ Phase [°]
Normalized Frequency, ω [rads^{-1}]
120
100
80
60
40
20
0
−20
360
320
280
240
200
160
120
80
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}


V_{in}
V_{out}
Voltage [V]
Time [ms]
3
2
1
0
−1
−2
−3
0
10
20
30
40
50
60
70
80
90
100

Review

- Discussed slew rate limiting, a non-linear effect which depends on signal magnitude. Examples for square, sine and triangle given.
- Introduced two opamp circuits for integration and differentiation of signals using resistors and capacitors as gain setting components.
- Considered some limitations and impracticalities of both circuits including the interaction between the intrinsic frequency response of the opamp and the frequency dependent feedback.