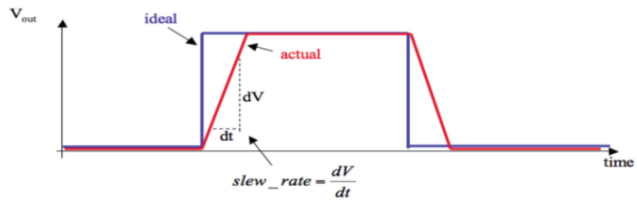
Summary of lecture 3 (5th December 2019)

Real operational amplifiers, comparators, stability & oscillations

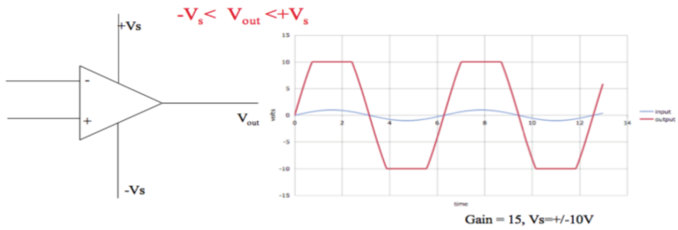
Slew rate:



The output of an ideal op-amp responds instantaneously; in a real op-amp the output response is limited by the 'slew-rate' – the maximum rate-of-change of output voltage.

As input frequency increases, the output voltage waveform begins to deviate from the input waveform when dV/dt approaches the slew-rate.

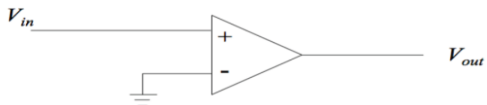
Saturation:



The output of an ideal op-amp is not voltage-limited; in a real op-amp the output voltage is limited to the supply-rail voltages powering the op-amp.

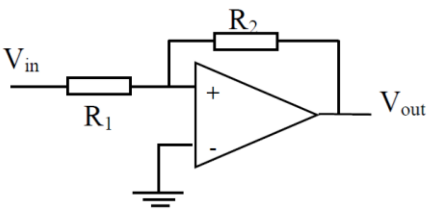
Saturation (or 'clipping') gives rise to additional harmonics in the output waveform, and ambiguity about the shape of the input waveform: information is lost as a result. However, saturation may also be used as a means to derive a square (digital) waveform from a non-square input waveform.

Comparator:



A basic comparator is very simple: an op-amp without feedback to limit the gain; a very small input signal results in a saturated output. Comparators act as a polarity or zero-crossing detector. The basic comparator is useful, but can result in unwanted zero-crossing detections in the presence of noise. The hysteretic 'Schmitt-Trigger' configuration is often used.

Schmitt-Trigger looks superficially similar to inverting-amplifier (be careful!), but uses positive instead of negative feedback to produce hysteresis.



Hysteresis is the property that the output of a system depends not only on the input, but also on the current state (and potentially on the past state) of the system. In this case, hysteresis gives rise to a 'dead-band' around the zero-volt point;

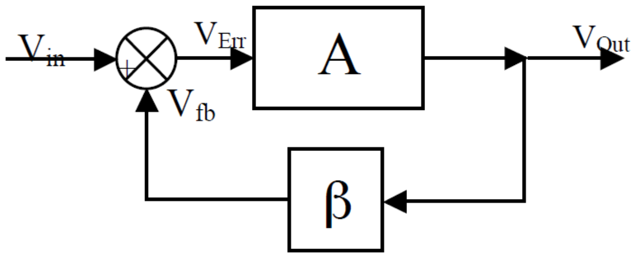
- If the output is **low**, the input must exceed a **positive** threshold to trigger output to go **high**
- If the output is **high** the input must drop below a **negative** threshold to trigger the output to go **low**

The dead-band is equal to sum of positive and negative threshold magnitudes; any fluctuations in signal smaller than the dead-band (e.g. noise) won't cause false triggers of output.

For a Schmitt-trigger, the threshold voltage is given by: $V_{\text{threshold}} = \mp V_{\text{supply}}\left(\frac{R_1}{R_2}\right)$

Stability:

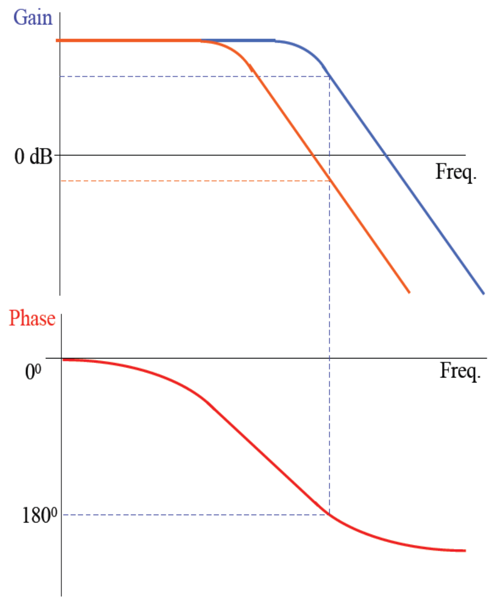
A control system will be stable if it meets the Barkhausen criteria for stability:



- Loop gain, $|A\beta| < 1$ and
- Total loop phase shift is not n.360°

Otherwise, the system will oscillate. You may find these expressed differently, depending on whether the criteria are for stability or oscillation, and how the loop phase shift is defined.

To check of a system will be stable, we need to inspect the Bode plot:



- Find frequency at which total phase-shift is 360°, e.g. phase-shift across β = 180°
- Map frequency onto gain plot to determine the loop gain at that point
- If loop gain < 0 dB then system will be stable
- If loop gain = 0 dB then system will oscillate at that frequency
- If loop gain > 0 dB then system will oscillate at that frequency and saturate

One can design an oscillator to provide a sinusoidal (or square) wave output using these criteria: this is useful e.g. as a timing (clock) signal, and is used to produce the output of a function generator.