ELEC 3106
Study Notes

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Semester 1 2013 – Electrical Engineering
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NOTES - Week 2 : Noise, distortion, saturation & dynamic range.

Noise : unwanted signals that obscure the desired signal.

- Johnson noise : a component generates a flat frequency noise voltage across its terminals. (white noise) (thermal noise)
- Shot noise : stems from fluctuating electric current, as discrete electric charges don't flow perfectly. Defined by formula: I_{noise} (rms) = $I_{nR} = (2q I_{dc} B)^{\frac{1}{2}}$ (B = bandwidth). Smaller currents have (relatively) larger fluctuations. It is Gaussian & white.
- $1/f$ noise : Oh, but there's more. Resistors suffer from fluctuations in resistance generating a 'pink' noise voltage and has a $\frac{1}{f}$ spectrum.
- Interference : many circuits are 'microphonic' they are sensitive to vibration and sound. May be controllable by shielding & filtering.

SIGNAL-TO-NOISE RATIO: $SNR = 10 \log_{10} \left(\frac{V_s^2}{V_n^2} \right)$ dB

If the signal is narrow-band the amp keeps adding noise power while signal power remains constant.

NOISE FIGURE : $NF = 10 \log_{10} \left(1 + \frac{V_n^2}{4kTR_s} \right)$

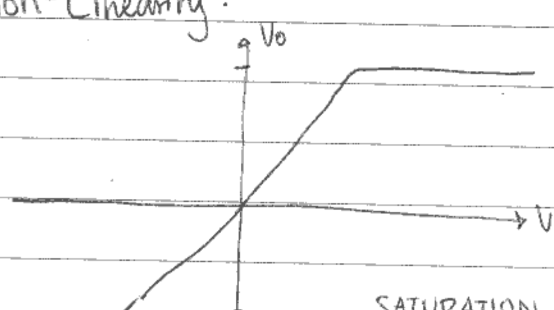
Ratio of output of the real amplifier to the output of an ideal amplifier of the same gain, with a R_s connected across the input terminals.
V_n^2 = mean squared noise voltage contributed by amplifier.

Dynamic Range: $DR = 20 \log \frac{\sqrt{\overline{V_s^2}_{max}}}{\sqrt{\overline{V_n^2}}}$

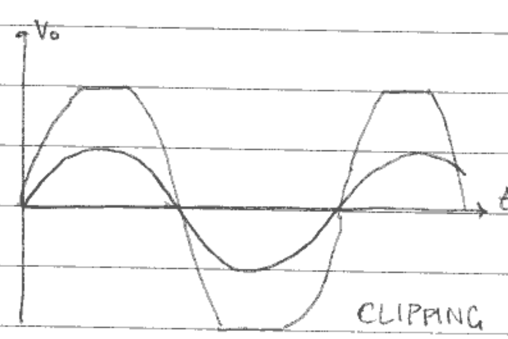
- upper limit - nonlinearity
- lower limit - noise.

Analogue equivalent to # bits. Ratio of max input level to min input level at which the system can sustain reasonable signal quality.

Non-Linearity :



SATURATION



CLIPPING

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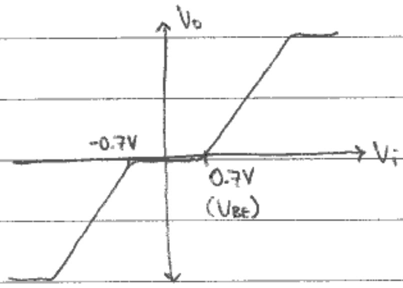
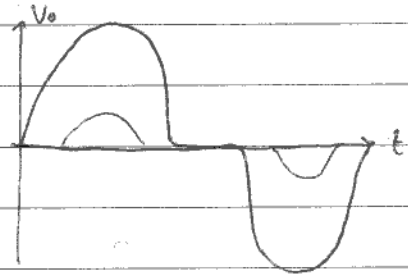
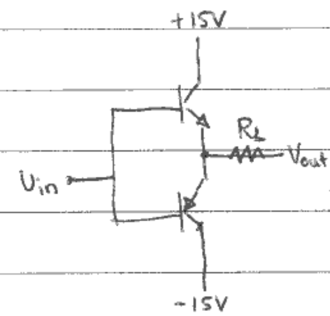
Clipping is a form of waveform distortion generally occurring when overdriving an amplifier.

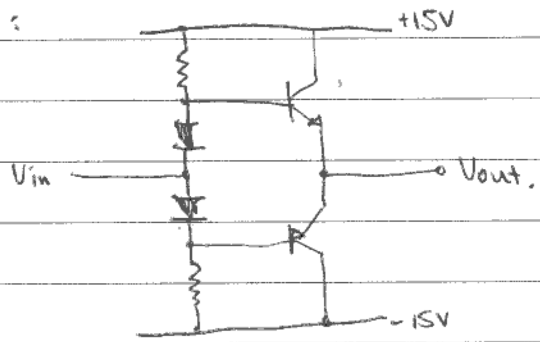
Crossover distortion - caused by switching between matched devices (transistors). The output trails the input with a drop of V_{BE}.





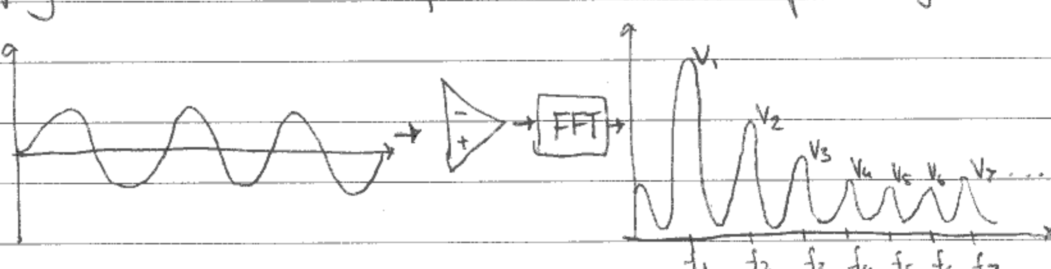


It can be alleviated with FEEDBACK (op-amp) or biasing the push-pull follower with diodes & resistors:



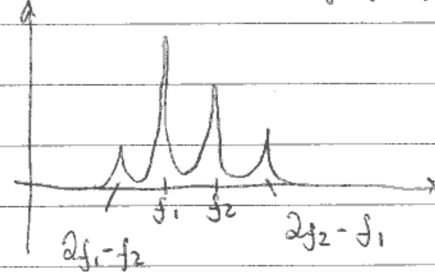
Measures of non-linearity: Total Harmonic Distortion.

- Apply a Fast Fourier Transform to a sine wave put through a broadband amp.



$$THD = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 \cdots}}{V_1} \%$$

Third order intermodulation: after FFT



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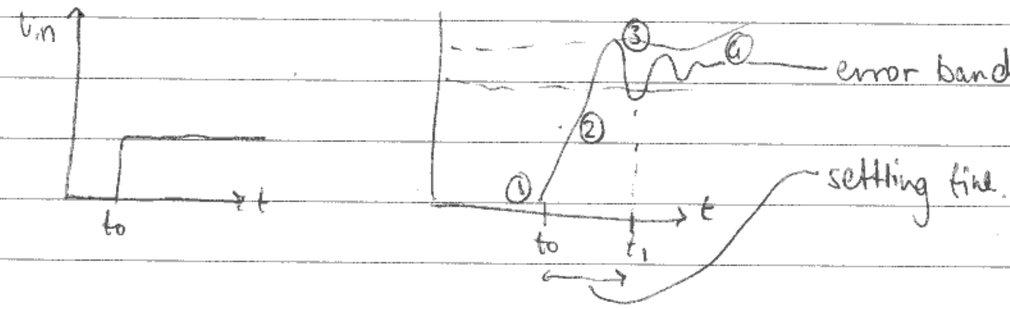
Settling time : Time elapsed from the application of a step input to the point where the output settle to within a specified error band → approaches the end.

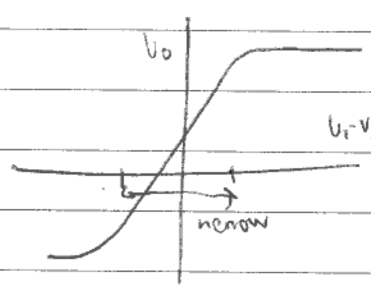


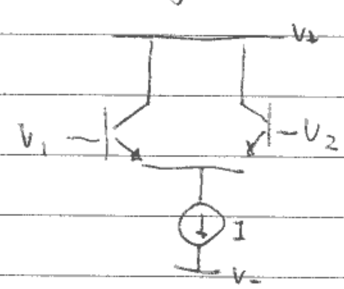
Settling time includes delay to the onset of output slewing ① and slewing time ② and recovery time from slew overload ③ and finally settling in the error band

Consider ① Sample-hold circuits, and ② A/D convertors.

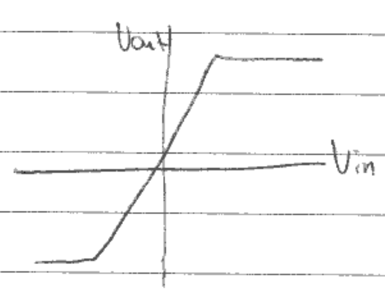
Where are amplifiers non-linear?

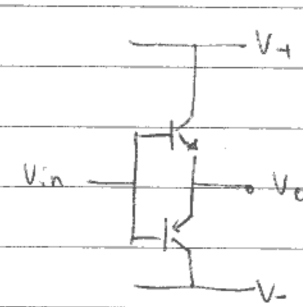
1, Voltage transfer curve of input stage, typically differential.





2, Output stage VTC.





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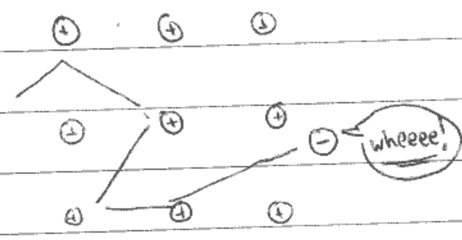
Noise is often shown in 'spectral density'.
characterise noise by average, rms or mean square. expressed in terms of spectral noise density. function of f..

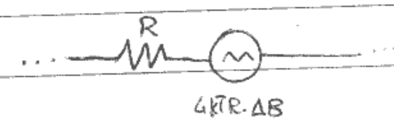
- Thermal noise :
  caused by randomness in motion.
  independent of frequency.



Noise models:

- Resistors $e_n^2 = 4kTR \cdot \Delta B$

  (Boltzmann; absolute temp; V^2/Hz; bandwidth)



↳ No dependence on f
↳ Proportional to temperature & resistance.
↳ White (Johnson) noise

Nonlinear amplifiers: linear : $V_o = A_v V_{in}$

nonlinear : $V_o = A_1 V_{in} + A_2 V_{in}^2 + A_3 V_{in}^3 + \ldots$

If V_{in} is a pure sinusoid, what would V_o look like?

- Let $V_{in} = a\cos(\omega t)$

$$\therefore V_o = A_1 a\cos(\omega t) + A_2 a^2 \cos^2(\omega t) + A_3 a^3 \cos^3(\omega t)$$

$$= \frac{A_2 a^2}{2} + \left(A_1 a + \frac{3A_3 a^3}{4}\right)\cos(\omega t) + \frac{A_2 a^2}{2}\cos(2\omega t) - \frac{A_3 a^3}{4}\cos(3\omega t)$$

- These are n^{th} order harmonics generated by the non-linearity.

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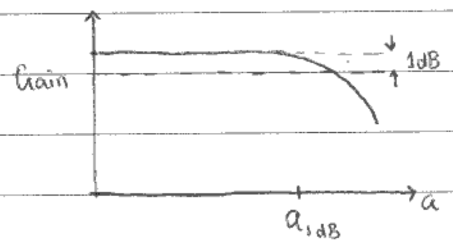
1dB Compression Point : the fundamental frequency component at output, that is the point where the device is outputting 1dB less power (say, 80%) is the 1dB compression point.



As amplitude increases, gain will surely decrease.

3rd order intermodulation:

- consider $V_{in} = a_1 \cos(\omega_1 t) + a_2 \cos(\omega_2 t)$, where ω_1 is close to ω_2.
- consider amplifier with VTC : $V_0 = A_1 V_{in} + A_2 (V_{in})^2$
- all kinds of frequency components are generated, including intermodulation.

(i) Fundamental components

$$\left(A_1 a_1 + \tfrac{3}{4} A_3 a_1^3 + \tfrac{3}{2} A_3 a_1 a_2^2\right) \cos(\omega_1 t)$$
$$\left(A_1 a_2 + \tfrac{3}{4} A_3 a_2^3 + \tfrac{3}{2} A_3 a_2 a_1^2\right) \cos(\omega_2 t)$$

(ii) Intermodulation products

@ $\omega_1 \pm \omega_2$ → $A_2 a_1 a_2 \cos(\omega_1 + \omega_2)t + A_2 a_1 a_2 \cos(\omega_1 - \omega_2)t$

@ $2\omega_1 \pm \omega_2$ → $\frac{3A_3}{4} a_1^2 a_2 \cos(2\omega_1 \pm \omega_2)t + \frac{3}{4} A_3 a_1^2 a_2 \cos(2\omega_1 \mp \omega_2)t$

@ $2\omega_2 \pm \omega_1$ → $\frac{3A_3 a_1 a_2^2}{4} \cos(2\omega_2 \pm \omega_1)t + \frac{3}{4} A_3 a_1 a_2^2 \cos(2\omega_2 \mp \omega_1)t$

The 3rd order intermodulation products are $2\omega_1 - \omega_2$ and $2\omega_2 - \omega_1$ since ω_1 & ω_2 are very close to each other.