# Lab 4: Non-linearity and its effects in communication systems

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# Aim of the experiment

To study non-linearity and its effects on communication systems.

- To observe 2nd order (or even order) non-linearity.
  - Generation of undesired DC components and
  - Unwanted out-of-band spectral components.
- To observe the effect of 3rd order (or odd order) non-linearity
  - In band spurious signal generation (and signal distortion) at the transmitter.
  - Desensitization of the receiver (in the presence of a strong interferer).
- To verify desensitization (or gain compression) of an RF receiver caused by saturation.

# Large Signal Model

Consider BJT differential amplifier as shown in the Figure below with

$$v_{ID} = v_{BE1} - v_{BE2}$$

- Using large signal BJT model, prove that

$$i_{C1} = \frac{\alpha I_{EE}}{1+e^{-v_{ID}/v_T}};\ i_{C2} = \frac{\alpha I_{EE}}{1+e^{+v_{ID}/v_T}}$$

- **Single ended output** ($v_{BE2} =$ constant and $v_{BE1} = v_{ID}/2$)

$$v_{OD1} = i_{c1} R_L = \frac{A_v}{1+e^{(v_{BE2}-v_{BE1})/v_T}} = \frac{1}{1+ke^{-v_{ID}/2v_T}}$$

  Plot the above input output relation.

- **Differential output** (with $v_{BE1} = +v_{ID}/2$ and $v_{BE2} = -v_{ID}/2$)

$$v_{OD} = (i_{c1} - i_{c2})R_L = \alpha I_{EE} R_L \frac{e^{v_{ID}/2v_T} - e^{-v_{ID}/2v_T}}{e^{v_{ID}/2v_T} + e^{-v_{ID}/2v_T}} = A_v tanh(v_{ID}/2v_T)$$

✓What is the small signal differential gain of the system?

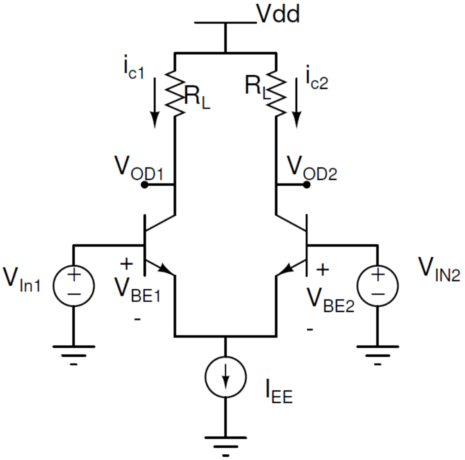


Figure: BJT Differential Amplifier

# PART1a: 2nd-Order Non-Linearity

For this part of the lab, implement a single-ended output transfer function as shown in the previous slide in GNU Radio as follows:

- Apply the digitally modulated data (as $v_{ID}$) from the given 'Input.bin' file using the 'File Source' block at the input of this system with an amplitude slider. Keep the sampling rate at $4.3MHz$.
- Use the exponential function in the 'Transcendental' block to mathematically model the single-ended transfer function as discussed in the last slide. (Assume $v_T = 25mV$).
- Keep k=0.9 and use a slider to vary the signal power/amplitude. Keep the default value $= 10^{-6}$ and maximum value $= 0.01$.

By varying the slider, observe the unwanted in-band and undesired components in the band adjacent to the desired signal band.

✓Is it possible to remove these unwanted out-of-band spectral components for narrow band signals (explain)?
✓Can you locate and justify the out-of-band IM2 components and observe the unwanted spectral components?
✓How fast does the unwanted spectral component change with respect to the desired component For example, if the signal increases by 10 dB, how much is the change in 2nd-order components (explain why?)

# PART1b: 3rd-Order Non-Linearity

2nd-order non-linearity, can be eliminated with Differential_signalling.

- Implement the differential model to eliminate 2nd-order non-linearity, so as to observe ONLY the 3rd-order non-linearity effect clearly.
- Use the tanh(x) function in the 'Transcendental' block to model this system and apply given digitally modulated data from the 'Input.bin' file with an amplitude slider.
- Keep $A_v = 1$ for the model and use slider to vary the signal power/amplitude. Keep the default value $= 10^{-6}$ and maximum value $= 30^{-3}$.

By varying the slider, observe the unwanted in-band and undesired components in the band adjacent to the desired signal band. But this time effects of 2nd-order non-linearity like DC component are eliminated.

✓Can these in-band components inside and in the vicinity of the desired signal spectrum be removed easily as compared to previously seen out-of-band?
✓Can you justify the observed location of unwanted spectral components?
✓How fast does the unwanted spectral component change with respect to the desired component (for some change in input power)? Explain why?

# PART2a: Desensitization(s/w)

3rd ordered non-linearity leads to Desensitization of the receiver.

- We need to use the differential model for this part of the experiment.
- This time fix the amplitude of the desired modulated signal from the file.
- Add a sinewave tone representing an interferer to the output of the signal and apply this to input of the 'Transcendental' block with the tanh(x) function.
- Ensure that the interferer is very close to the desired signal spectrum.
- Increase the interferer amplitude from 0.01 to 1 by a separate slider.
- You should observe that the desired signal amplitude decreases as you increase the interferer amplitude. This saturation of the receiver is called **desensitization** and is the basic principle behind jamming of the receiver.

  ✓Can 2nd order non-linearity also cause desensitization of the receiver(use small signal polynomial approximation to analyze this)?