Lab 6: Non-linearity and its effects in communication systems

Wadhwani Electronics Lab

Department of Electrical Engineering
Indian Institute of Technology, Bombay

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?

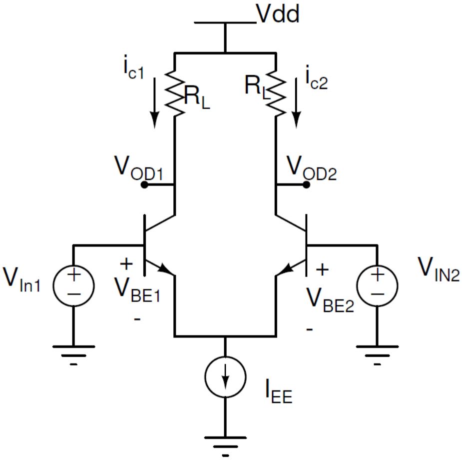

Figure: BJT Differential Amplifier

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(i.e., change the gain of v_{ID} using a slider). 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(i.e., change the gain of v_{ID} using a slider). Keep the default value $= 10^{-6}$ and maximum value $= 0.03$.

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 v_{ID} and apply this combined signal as an input to the 'Transcendental' block with the tanh(x) function (i.e., $tanh(v_{ID}/2v_T +$ interfere signal)).
- Ensure that the interferer is very close to the desired signal spectrum i.e., v_{ID}.
- 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)?

PART2b: Desensitization(h/w)

This part requires two IQ modulator boards and two AFGs and thus, two groups will work together. One group will transmit the interferer tone and the other group will transmit a DSB-FC signal (AM signal) as the message signal.

- Odd numbered group transmits the message signal and even numbered group transmits the interferer signal.
- Odd numbered group: message transmitting group
  <DIP Switch odd> = 2 x <Odd Numbered Group>
- Even numbered: interferer transmitting group
  <DIP Switch even> = 1 + 2 x <Odd Numbered Group>
- Reception has to be done by different groups by tuning the dongle to their frequencies
  f_C =1120.002MHz + 1.25MHz x <DIP Switch>
  (NOTE: 1120.002MHz is the f_{ref} and it varies from board to board. So change the equation accordingly if required.)

Make sure that the AFG output is set to HIGH IMPEDANCE mode.

...cont.: Desensitization(h/w)

- Odd numbered group can generate DSB-FC signal with 5kHz sinusoid by
  - Setting proper DC biases (around $500mV$) at both I and Q channels of AFG.
  - Add a 5kHz AC of amplitude say $20mV_{pp}$ at only one of the channels.
  - Compensating for input DC offsets so that the carrier is not suppressed.
  - This part is the same as what you have done in Lab 5 which has the generation of DSB-FC using an IQ modulator board.
- Even numbered group i.e. interferer group should only apply certain DC offset on I and Q input to initially keep interferer minimum. Ultimately, you have to increase the interferer power by EITHER
  - increasing interferer's power (by changing DC offset) OR
  - by reducing the distance between the interferer transmitter and receiver antenna.
- Observe message amplitude decreases as interference becomes stronger.
- Also observe that when the interferer channel number is increased to
  $<$DIP Switch even$>$ = 2 + 2 x $<$Odd Numbered Group$>$

  ✓How does separation of interferer frequency away from the signal spectrum affect the desensitization problem?