Lab 6: 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 stronginterferer).
- To verify desensitization (or gain compression) of a 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 $v_{BE2} = -v_{ID}/2$)

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

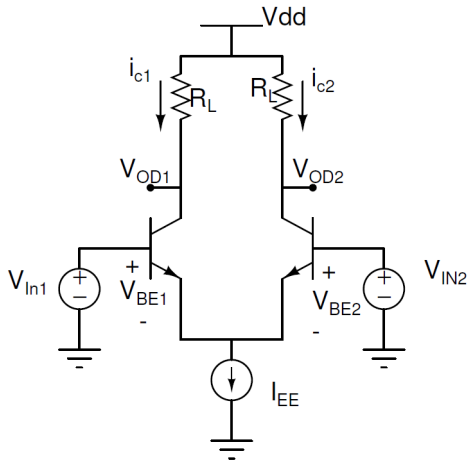✓What is the small signal differential gain of the system?

Figure: BJT Differential Amplifier

PART1a: 2nd Order Non-Linearity

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

- Apply the digital modulated data (as v_{ID}) from the given 'Input.bin' file using 'File Source' block at the input of his system with an amplitude slider. Keep the sampling rate as $4.3MHz$.
- Use the exponential function in 'Transcendental' block to mathematically model the single ended transfer function as discussed in last slide. (Assume $v_T = 25mV$).
- Keep k=0.9 and use slider to vary the signal power/amplitude. Keep the default value = 10e-06 and maximum value = 0.01.

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

✓ 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 do the unwanted spectral component change with respect to the desired component For example, if signal increases by 10 dB, how much is the change in 2nd order components (explain why?)

PART1b: 3rd Order Non-Linearity

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

- Implement the differential model to eliminate 2nd order non-linearity, so as to observe ONLY 3rd order non-linearity effect clearly.
- Use tanh(x) function in 'Transcendental' block to model this system and apply given modulated data from file with amplitude slider.
- Keep $A_v = 1$ for the model and use slider to vary the signal power/amplitude. Keep the default value = 10e-06 and maximum value = 30e-03.

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

✓Can these in-band components inside and in vicinity to 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 do the unwanted spectral component change with respect to the desired component (for some change in input power). Explain why?

PART2a: Desentization(s/w)

3rd ordered non-linearity leads to Desentization of receiver.

- So, we need to use the differential model (tanh(x) function) for this part of 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 signal and apply this to the input of the transcendental block with tanh(x) function.
- Make sure that interferer is very close to the desired signal spectrum.
- Increase 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 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: Desentization(h/w)

This part requires two boards and two AFG's and thus, two groups will work together. One group will transmit interferer tone and other group will transmit DSB signal (AM signal) as message.

- Odd numbered group transmits message and even numbered group transmits interferer.
- Odd numbered group – message transmitting group:
  <DIP Switch odd> = 2 x <Odd Numbered Group>
- Even numbered – interferer group:
  <DIP Switch even> = 1 + 2 x <Odd Numbered Group>
- Reception has to be done by different groups by tuning 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 AFG output is set to HIGH IMPEDANCE mode.

- Odd numbered group can generate DSB AM 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.
- Even numbered group i.e. interferer board 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 distance between 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 desentization problem?