EE 340: Communications Laboratory
Autumn 2017

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

Legends

Question/Observation: Show it to the TA and explain (carries marks)

Recall/think about something

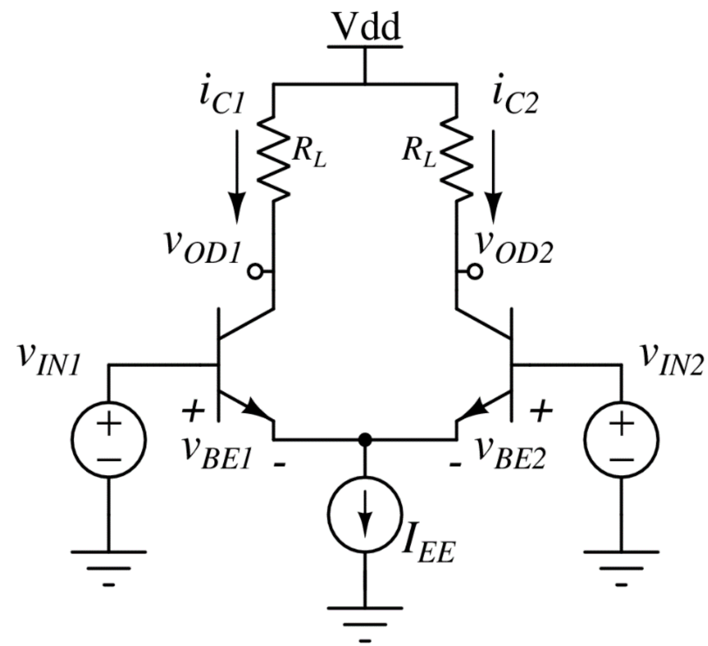
Caution

Additional information - weblink

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 strong interferer).
● To verify desensitization (or gain compression) of a RF receiver
caused by saturation.
● BONUS!!! Observing the behavior of 3rd order non-linearity using hardware experiments.

PART1: Large Signal Model



- Consider BJT differential amplifier, 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 ; v_{BE1}=v_{ID}/2)

- $v_{OD1} = i_{c1}R_L = \dfrac{A_v}{1+e^{(v_{BE2}-v_{BE1})/v_T}} = \dfrac{1}{1+ke^{-v_{ID}/2v_T}}$
- Plot the above input-output relation

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

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

What is the small signal differential gain of the system?

PART1a: 2nd Order Non-Linearity

For this part of lab, implement single ended output transfer function as shown in previous slide in GNU-Radio in 'transcendental' block keeping

- Apply the digital modulated data (as v_{ID}) from the given 'Input.bin' file using 'file_source' block at the input of this system with amplitude slider.
- Use exponential function in 'transcendental' block to mathematically model the single ended transfer function as discussed in last slide. (Assume $\boldsymbol{v_T}$ = 25mV)
- Keep k=0.9 and use slider to vary the signal power/amplitude. Keep default value = 10e-6 and maximum value = 100e-3.

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 narrowband signals (explain)?

Can you locate and justify out-of-band IM2 components the observed location of 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 signaling.

- So 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 *a*pply given modulated data from file with amplitude slider.
- Keeping $A_v = 1$ for the model, use slider to vary the signal power or amplitude. Keep default value = 10e-6 and maximum value = 30e-3.

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 nonlinearity 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 nonlinearity 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 so 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>=2x<Odd Numbered Group>
- Even numbered (interferer) group

  <DIP Switch even>=1 + 2x<Odd Numbered Group>
- Reception has to be done by different groups by tuning dongle to their frequencies

  f_C =1120.002MHz + 1.25MHz <DIP Switch odd>.

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

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

● Odd numbered group can generate DSB AM signal with 5 kHz sinusoid by
– Setting proper DC biases (around 500mV) at both I and Q channels of AFG
– Add a 5kHz AC of amplitude of say 20mV 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 + 2x<Odd Numbered Group.>,
  how does separation of interferer frequency away from the signal spectrum affect the desentization problem?

PART3: Two-tone test (h/w)

The goal of this experiment is to `generate' a two tone output from a single tone input using non-linearity.

- Set the DIP switch value:

  <DIP switch value>= 2x <Group Number>
- Your channel frequency becomes:

  f_C =1120.002MHz + <DIP Switch value>x 1.250MHz
- Make sure that the AFG outputs are in High-Impedance mode.
- Balance the DC bias across the I and Q channels to get optimal carrier suppression. Apply 5kHz signal with 20mV amplitude to I.
- Observe the spectrum of real part of the obtained signal.
- Set the gain of SDR dongle to maximum and adjust DC bias to remove the center tone (carrier)

✓ You should be able to explain why you got the resultant ”two-tones” separated by 10 kHz!

✓ Now bring your dongle antenna close to the IQ board antenna. Observe the relative change in amplitude of the two tones (f1 and f2)