Lab #5: RF Front-end and Effect of Its Impairments on Communication Systems

Objective

The objective of this experiment is to introduce critical RF front-end components which are commonly used in wireless communication systems. Also, various RF front-end impairments and their effects on communications systems are explored. The students will be familiar with the following items:

- Learn about hardware components (low noise amplifier (LNA), filter, voltage-controlled oscillator (VCO), and etc.), and system analysis along with the measurements.
- Understand the functionality and characteristics of VCO, bandpass filters, mixers, and LNA.
- Learn how to model RF impairments including phase noise, nonlinearities due to PA and LNA in a simulation environment
- Learn how to interpret EVM, power spectrum, constellation diagram, eye diagram, and polar diagram.

Pre-Lab

Study and understand:

- Super heterodyne transmitters /receivers, the function of mixers and VCOs
- What is the maximum input power of the LNA that we will be using in the lab?
- What is the output power of the VCO?,
- Revise the following RF impairments, understand their cause and their impact on the system:
    - Harmonics
    - Intermodulation products
    - IQ impairments (IQ Gain imbalance, Quadrature offset, IQ offset, etc)
    - Frequency offset, phase noise
    - VCO tuning sensitivity, frequency pushing and pulling, stability, etc.

Procedure

I. Amplifiers and Nonlinearity

1) Use Keysight VSG and VSA directly for this part:

    a) Set the VSG to send a carrier signal at 470MHz frequency using a proper antenna with 0dBm transmission gain.

    b) Set the VSA accordingly to capture the transmitted signal. Plot the spectral density and measure its peak power.

2) Add an amplifier directly to the VSG output, then connect the antenna to its output. Set its supply voltage using a voltage supplier as instructed in the manual. (*Perform this step with the TA help*)

3) Capture the first harmonic at 930GHz and explain its existence. Why nonlinearity leads to harmonics at multiples of the fundamental frequency?

4) Modulate the carrier signal sent by the VSG with an arbitrary QPSK data sequence. Then, by VSA, receive the signal at its fundamental frequency and comment on the obtained power spectral density. Why there is a spectral growth?

5) Keep the same setup above but for each of the transmission gains -30dBm, -20dBm, -and 10dBm:

    a) Comment on spectral growth and harmonics.

    b) For the signal at its fundamental frequency, plot the CCDF for different gains and comment on the results.

6) Use a proper low-pass filter at the amplifier output to suppress harmonics.

II. Oscillators and Mixers

7) Connect a VCO to two power suppliers: one for supply and the other for control. Also, connect an antenna to its output. Make sure you keep the suppliers off before any connections. (*Do not turn on the suppliers during connection; ask the TA for help*)

8) Change the control voltage gradually and notice the change in center frequency. Make sure you sweep voltage within the VCO control range.

9) Choose an arbitrary center frequency. Instead of sweeping the control voltage, make changes to the supply voltage within 3 volts just below its typical value. Comment on the spectrum results obtained at VSA. Measure the VCO frequency pushing.

10) Set the supply voltage back to the right value. Over the control range, change voltage with a step size of 2 volts and record the center frequency. Using these recordings, plot the VCO tuning sensitivity. Is it linear?

11) Reduce the VSA span to have a closer look at the generated tone signal. Comment on the VCO stability.

12) Use a mixer to generate a carrier signal by VSG and VCO:

    a) Turn off the power suppliers.

    b) Connect the output of VCO to one mixer input and the output of VSG to another. Set the center frequencies of VSG and VCO to 720MHz and 715MHz, respectively. Connect an antenna to the mixer output.

    c) Start transmitting and notice the output at the VSA. You might need to adjust transmission gain at VSG. How do you compare intermodulation product with the harmonics seen before? Explain the difference between them.

III. IQ Imbalance

- Set the transmission parameters through the control panel as follows:
    - Amplitude: 0 dBm
    - Center frequency 2.4 GHz
    - Mode: Single carrier
    - Modulation: QPSK
    - Pulse-shaping filter: RRC (alpha = 0.5)

  Symbol rate: 1 Msps.

III.1 IQ gain imbalance

13) Using “I/Q hard key” on the front panel of VSG navigate to “I/Q Adjustement” and turn it On.

14) Select “Internal baseband adjustment” and then select on the “I/Q Gaian Balance” key. Set the Gain balance values to 0 dB, 0.5 dB, 1 dB. For each value observe constellation diagram and EVM on the VSA. Observe and provide your comments.

15) Repeat step (14) for 64 QAM modulation. Compare the results with QPSK.

16) Reset the Gain balance value back to 0 dB and the modulation type to QPSK.

III.2 Quadrature Offset

17) Under the "internal baseband adjustment" menu, select "Quadrature angle adjustment". Set the values of the Quadrature Adjust: to 0 deg, and 10 deg. In each case, observe Constellation diagram and EVM. Comments on your observation
18) Repeat step (17) above for 64 QAM Modulation and compare the result with QPSK.

IV. Time and Phase Errors

19) Generate a frame of QPSK symbols pulse shaped using a raised cosine filter. Use an over sampling ratio of 8 samples. For roll-off factors 0.0, 0.3 and 0.9:

    d) Down sample at all possible starting indices (i.e., the first 8 samples) to recover the transmitted symbols. Make sure you remove the zero symbols due filtering.

    e) Correlate recovered symbols with transmitted ones at each down sampling iteration.

    f) At each down sampling iteration, plot the constellation diagram.

    g) Comment on the results in (e) and (f).

20) Generate a frame of BPSK symbols pulse shaped using a raised cosine filter. Assuming a symbol rate of 25Ksps, add 320Hz frequency offset. Take FFT of the fame symbols raised to a power equal to the modulation order. With proper scaling for the frequency axis, comment on results.

21) In *"set_tf.mat"*, two sequences are given for the same sequence of symbols; however, one has additive noise, and the other has phase noise. Plot the constellation diagram of both and decide the type of noise in each one. Comment on the difference between these two types of noise.

V. Phase Noise (Optional)

Supported by references, give a brief explanation of the phase noise problem in mmWave hardware. Then, generate this noise using a proper model and use the spectrum analyzer method to calculate its value versus frequency offset in dBc (*ask the TA for references on this method*)