Introduction to RF – Part I (Tut and Lab Notes)

- Aim: Learn how high-frequency signals are measured

- Part I – time-domain vs. frequency domain (RF Detectors and Mixers)
  - Bode plots, power and dB(m, c, uV) definitions,
  - AM vs. FM vs. PM modulation
  - RF (Schottky) Diodes → RF Detectors (homodyne detection)
  - RF Mixers (heterodyne detection)
  - Introduction to: oscilloscopes, spectrum analyser, vector network analyser

- Laboratory:
  - lab measurement with generator + spectrum analyser/oscilloscope
  - some simple simulations using QUCS – guided/student
  - “Play” with BPM mock-up
  - Repeat in || previous day experience now with some active elements

Laboratory Exercise – Overview

- Spectrum Analyzer test stand 1
  - Measurements of several types of modulation (AM FM PM) in the time and frequency domain.
  - Superposition of AM and FM spectrum (unequal carrier side bands).
  - RF-detectors: measure the square-law, sensitivity, loading, responses to FM&AM modulation
  - Concept of a spectrum analyzer: the superheterodyne method.
    - Practice all the different settings (video bandwidth, resolution bandwidth etc.). Advantage of FFT spectrum analyzers.

Exercise I – Getting Familiar

- Becoming familiar with oscilloscopes & spectrum analyzer
  – Pre-requisites: need signal generator (SiG), oscilloscope (OC), spectrum analyzer (SA), DC-block, RF mixer, Set the SA into '…' mode to observe spectra (i.e. factory default – depends on specific model) … other notes specific to equipment available/used at the Synchrotron.

- Display existing signals in lab using a short wire as an antenna.
  - Can you identify the sources?

- Measure the spectrum of an SiG output signal (CW mode, no modulation) and look for second and third harmonics.
  - How can you discriminate against SPA input mixer-related harmonics?
  - N.B. Do not exceed 0 dBm generator output power!

Exercise II – AM, FM & PM in Time-Domain

- Connect SiG output to the oscilloscope
  - Set proper input termination, proper scale, and trigger mode to normal and proper trigger level.
  - On generator set the carrier frequency to 0.1 MHz and amplitude to 0dBm.
  - Set oscilloscope to see sine waves.
- Play with AM modulation using internal 1 kHz and 400 Hz oscillator changing the modulation depth from 0% to 100%.
  - At 100% modulation depth change time bas of oscilloscope to 1ms/div to see nice AM envelopes (in Acquire menu set 'peak detection').
  - Change the modulation depth for 400 Hz and 1 kHz AM and observe the results.
- Change time base back to resolve carrier frequency and repeat last points for FM & PM changing the maximal peak deviation in the range 0-200kHz.
- Switch on AM and FM simultaneously and observe the results.

Exercise III – RF Detector

- Setup: Connect SiG → RF Detector (RFD) → oscilloscope
  - Set the OC's input termination to 50 Ohm, proper scale, and trigger mode to normal and proper trigger level.
  - On generator set the carrier frequency to 1 MHz and amplitude to 0dBm.
  - Split the SiG signal using a resistive 6dB divider and set-up the oscilloscope to see the unperturbed and RF detector signal.
- Compare the RFD signal for the different input impedance options.
  - Explain and record the differences (50Ω, 1MΩDC, 1MΩAC).
  - Which one would you prefer to detect small signals? What are the others for?
- Change the SiG output power and measure the RFD peak-voltage response (P_{in}=-60 … (max) dBm, respect RFD limts) .
  - Can you confirm the square-law dependence?
  - Variations between the available RFD?
  - Can you confirm the maximum bandwidth of the detector?
- Set the OC's input impedance to 1MΩAC and measure the RFD response to AM modulation changing the modulation depth from 0% to 100%.
- Repeat the measurement with FM and PM modulation.

Exercise IV – AM, FM & PM in Frequency-Domain

- Setup:
  - Set carrier frequency to 10 MHz. N.B. do not exceed 0 dBm generator output power!
  - Connect SiG to SA via DC-Block
  - Set the analyzer center frequency and span to adequate values.
- Change RBW and observe behaviour of the signal width and noise floor.
  - what is an influence on the measurement time?
  - What is advantageous in FFT analyzers?
- Measure AM and FM with 1 kHz internal source changing AM modulation depth and peak deviation for FM same way as before in time domain tests. (Set proper frequency span and RBW).
- Change the carrier frequency to 100 MHz (do not forget to change centre frequency on SPA). Compare the results with previous point.

Exercise V – Higher Frequenceis and ex. RF Mixer

- Setup:
  - Synchronize both SiG: Switch off all modulations, set signal carrier frequency to 10 MHz and connect them to the oscilloscope. Synchronize both generators using BNC time base I/O on the generators back plane.
  - Set one generator to 1 GHz and the other one to 1 MHz (do not exceed 0 dBm generator output power).
- Connect both generators to SPA via mixer connecting signals to appropriate mixer ports: what is your Local Oscillator, what is the signal you want to send and what is the resulting RF? Set properly the SA center frequency, span and RBW accordingly
- Change amplitude of modulation (do not exceed 0 dBm generator output power), change the carrier frequency, change modulation frequency and observe the results on SA. What might be a reason for the changes of the side-bands height when changing modulation frequency below 100 kHz?
- Now you can send your 1 GHz radio signal over 10 cm of air using two short wires as an antennas.

Exercise VI – Build your own Superheterodyne Receiver

- Setup:
  - Let us assume we have a system that allows us to measure only up to 100 MHz. But we want to measure signal with a frequency of 1 GHz . This expansion of our measurement bandwidth can be reached by applying superheterodyne principle. Pre-set SPA and set stop frequency to 100 MHz (let us assume it for a while as an upper limit for our system).
- Set one SiG to 1 GHz and an the other to 950 MHz (do not exceed 0 dBm generators output power)
- Connect generators via mixer to SPA.
  - What is now your LO, RF and IF?
- Tune LO to get your peak in the position you want.
- In the spectrum you see some higher harmonics. What could be a reason for that?
- Measure AM and FM modulation using internal SiG source

  (set proper span and RBW to be able to resolve close laying side bands for 1 kHz modulation).