Introduction to RF – Part II (Tut & Lab Notes)

- Aim: learn how high-frequency signals are transmitted

- Part II – RF Transmission, S-Parameter & Noise
  - Signal transmission and reflection → S-parameters
  - Low-, band- and high-pass filters
  - Amplification and noise figure

- Laboratory:
  - In || lab measurements with VNA and various RF components (hair-pin filter, strip-lines, diplexer, attenuator, low-pass, etc.)
  - Measure cable response (terminated, open,short) – see defects
  - Cantenna + VNA → building their own radar
  - demonstrate equivalence between 'scope+pulse generator' and VNA
  - RF mixer (DIY radar or FM modulation generation, check with SA and RFD)

Laboratory Exercise – Overview

- Vector Network Analyser
  - Calibration of the VNA
  - N-port measurement for various reciprocal and non-reciprocal components
  - Beam transfer impedance measurements with the wire (button, stripline PU.)
  - coaxial line characteristic impedance.
  - Time Domain Reflectomentry using synthetic pulse: direct measurement of
  - Self-made RF-components: calculate, build and test you own (i.e. attenuator, high-pass, low-pass)
  - Invent your own experiment

- Spectrum Analyzer
  - Concept of noise figure and noise temperature measurements
  - Noise figure measurements on amplifiers and also attenuators.
  - The concept and meaning of noise-figure numbers.
  - *… to be elaborated*

Exercise I – Getting familiar with a VNA

- Setup:
  - VNA, N-type (SMA-type?) calibration kit, different Tees, various to-be-tested RF objects (strip-line BPM, button-type BPM, micro-strip filter/coupler, attenuators, ...)
  - Initialise the VNA pressing 'PRESET'
- Calibrate the VNA:
  - Dial a frequency span from minimum to maximum possible.
  - Define the calibration kit (it has to be redone each time you press PRESET)
  - In sweep menu select the number of point to 1601.
  - Calibrate S11 and S 21 using *(missing: description of specific procedure for available VNA...)*.
  - Typical RF cables are equipped with N-connectors type M (male) on either side. Thus the calibration kit elements to be attached at the end of such a cable are N-connectors type F (female).
  - At the screen of the instrument during the calibration procedure you will be asked, which type of calibration kit element you are using.
  - Keep in mind that the type of calibration is defined for the type of connector you are doing the calibration on (i.e. the end of the cable), but NOT for the calibration kit element itself!

Exercise I – Getting familiar with a VNA cont'd

N.B. The term N for the type of cable connector we are using here has its historical roots in the word **N**avy since this kind of connector was first used by the US–Navy more than 50 years ago. The frequently applied competitor, the BNC connector comes from the same shop (**B**ajonnet **N**avy **C**onnector). The BNC has much lower performance compared to the N-connector.

- Calibration continued ...
  - Now follow the menu on the calibration page and attach the open, short load as requested by the system. For the through use I-connector. Don't forget to confirm that the calibration is done –otherwise it will be not stored and whole procedure has to be repeated.
  - For very critical and accurate measurements you may calibrate the system using the trace average function, but this rather time–consuming. However, you may reduce the IF bandwidth from 3 KHz (standard setting) to 100 Hz and watch the difference.
  - As a next step select in the **display** menu select the number of traces 2. For trace 2 we are measuring now in transmission from part 1 to port 2 i.e. S21 .
  - Connect the end of the cable where you just did the S11 calibration to port 2 of the VNA.
- Done, you may now measure simultaneously some DUT in reflection and transmission knowing that your system has been calibrated!

Exercise II – VNA Frequency-Domain Measurements

- Confirm Calibration effectiveness:
  - Use another reference termination (from another calibration kit or what is given to you) and connect it port 1 (the one for which the S11 has been calibrated).
  - What is the difference between the previously used reference standard?

- Measure (/document) the S11 and S21 of the passive components that are lying around – can you confirm their purpose?
  - Start with passive components and measure one active one (i.e. amplifier).
  - N.B. Whenever you measure medium or high power amplifiers, be sure that the power level cannot destroy the input of the VNA. For example, even measuring the input impedance of an amplifier may destroy the VNA, when the amplifier produces parasitic (self) oscillations. You can protect the VNA by either lowering its output power or adding some attenuators to the input/outputs.

Exercise III – Coaxial RF Cables

- Introduction:
  - Oscilloscopes are a priori are optimised for time-domain measurements but can also compute the corresponding frequency-domain signal – with the caveat of having a lower vertical dynamic range, resolution and higher noise.
  - Similarly, VNA – being designed for frequency-domain analysis – can also be used to simulate the time-domain response for time-invariant linear systems.

- Connect "a long cable" to the VNA and measure the S11, with the other end of the cable being either left open, being terminated or shorted.
  - What is the approximate bandwidth of the cable?
  - Compare with other RF cables you can find (i.e. 7/8" & 3/8" corrugated, some Succoflex & standard lab-grade BNC cable). Normalise your results to 100 m.
  - Which one would you use for which application? Does it matter?
  - Why does one still use BNC and related cables?

Exercise IV – VNA Time-Domain Measurements

Transpose the displayed S11 data to 'synthetic time domain' data.

- Re-do the open/short/terminated analysis. Do the results correspond to expectations?
- Extend the cable using Ts, N/BNC-barrels (VNA-cable-T-cable-VNA) with the second end being either open or connected to a short (1-2 m cable).
- Extend two cables with regular barrel (i.e. N-type) and with a 'I-don't-care-how-RF-signals-are-transmitted' solution that consists of multiple adapters (i.e. N-SMA-BNC-SMA-N). Can you identify and locate the fault? Redo this with an already installed cable going to the accelerator tunnel.

- If you like/have the time, you could:
  - re-do the measurements in time-domain using a fast pulse generator, signal splitter and oscilloscope
  - Build your own radar, connecting two Cantennas to Port 1 and 2.
  - Feel free to experiment around and invent your own experiment

Exercise V – Noise Figure

- Go back to your SiG, OC, and SA setup from the day before.
  - Set SiG to 200 MHz and -50 dBm output power.
  - Connect to amplifier (mind which end is input/output) and then SA.
- Set the SA centre frequency around 200 MHz and RBW to visualise the central peaks.
  - Can you observe 2nd or 3rd harmonics of the amplifier?
  - Do they change with input amplitude? Important: do not exceed -20 dBm generator output power!
- Disconnect first the SiG from the amplifier, and then the amplifier from the SA.
  - Do you observe a change of noise floor? (N.B. You may need to adjust RBW to observe the noise floor in the first place).
  - Reconnect the amplifier. Put a 50 ohm load and then short on its imput? Does the noise-floor change? Why?
  - Calculate the corresponding noise figure of the amplifier.