An Introduction to Wireless Systems EITF50
Laboratory Experiments 2

SPECTRUM ANALYSER, AMPLIFIER and MIXER MEASUREMENTS

Göran Jönsson 2017

Objectives:

Part 1 (2 hours):

- Get familiar with the possibilities and limitations of the spectrum analyser.
- Understand the concepts:
  1. resolution bandwidth (RES BW)
  2. sweep time (SWP)
  3. video bandwidth (VIDEO BW)
  4. reference level (REF LVL)
  5. attenuation (RF ATT)

  and how these functions affects the measurement result.

- Measurements on AM and FM signals.
- “Look at” radio signals received by an antenna.

Part 2 (2 hours):

- Amplifier measurements: power gain, 1-dB compression point and third-order intercept point.
- Mixer measurements.

Note! Safety instructions for the spectrum analyser:

1. Some analysers doesn’t allow DC at the input.
2. Never exceed the maximum allowed RF input power.

A good habit is to read the specification and the safety instructions for the instruments.

Good luck!
1. The Spectrum Analyser

Preparation Exercise 1:
- Draw a block diagram showing the RF spectrum analyser.
- Explain the concepts: (1) resolution bandwidth (RES BW), (2) reference level (REF LVL), (3) attenuation (RF ATT) and (4) video bandwidth (VIDEO BW).
- How does the concepts above affect the sensitivity and the large-signal handling in the spectrum analyser?
- What electrical quantity (voltage, current or power) does the analyser measure?
- What is the advantage by using logarithmic amplifiers in the spectrum analyser?
- Express the modulation index for AM ($m_a$) by using the ratio $P_{1sb}/P_c$.

1.1 Input Attenuator (RF ATT)
Connect the signal generator and make the following signal generator settings:
- carrier frequency $f_c = 200$ MHz
- output power $P = -30$ dBm

Make the necessary settings at the spectrum analyser to display the signal and measure the signal-to-noise ratio. Now change manually the RF ATT and study the change of the signal-to-noise ratio. Explain the behaviour by referring to the theory of noise figure.

Turn RF ATT back to auto mode.

1.2 Resolution Bandwidth (RES BW)
Change manually the RES BW. What is the ratio between the displayed level of the noise floor and the RES BW for different settings. Explain by referring to the theory of thermal noise.

How and why does the change of RES BW affect the sweep time (SWT)?

Turn RES BW back to auto mode.

1.3 CW Signal (only carrier)
Change the generator settings to:
- carrier frequency $f_c = 500$ MHz
- output power $P = -70$ dBm

Use the RES BW, REF LVL and VIDEO BW settings to clearly display the signal. Sketch the curve and explain the shape for different RES BW settings.

1.4 Amplitude Modulated Signal
Set the signal generator for AM modulation:
- $f_c = 100$ MHz
- $P = -60$ dBm
- $m_a = 100%$
- $f_m = 3$ kHz

Measure the carrier and baseband frequencies. Measure the level ratio between the carrier and sidebands and calculate the modulation index ($m_a$). Choose arbitrary values for $m_a$ and $f_m$ and verify the result by the spectrum analyser.
1.5 Frequency Modulated Signal

Preparation Exercise 2:

- The general expression for the FM signal is \( s(t) = A \cos(\omega_c t + 2\pi k_0 \int v_m(t)dt) \).
  Derive the modulation index \( m_f \) if \( v_m(t) \) is: \( v_m(t) = E_m \cos\omega_m t \).
- Explain the concept of deviation.
- Calculate the FM channel bandwidth by using Carson’s rule for
  1) the NBFM signal according to measurement a) below
  2) the WBFM signal according to measurement e) below.

a) Start with narrow band FM (NBFM) and set the signal generator to:

- \( f_c = 100 \text{ MHz} \) FREQ \( \rightarrow 100 \rightarrow \text{ MHz} \)
- \( P = -60 \text{ dBm} \) LEVEL \( \rightarrow -60 \rightarrow \text{ dBm} \)
- \( \Delta f = 0.75 \text{ kHz} \) MODULATION \( \rightarrow \text{ FM} \rightarrow \text{ FM1 DEVIATION} \rightarrow 0.75 \rightarrow \text{ kHz} \rightarrow \text{ SELECT} \)
- \( f_m = 3 \text{ kHz} \) MODULATION \( \rightarrow \text{ FM} \rightarrow \text{ FM1 SOURCE} \rightarrow \text{ LFGEN1} \rightarrow \text{ SELECT} \)

MODULATION \( \rightarrow \text{ FM} \rightarrow \text{ LFGEN1 FREQ} \rightarrow 3\text{kHz} \rightarrow \text{ SELECT} \)

What is the modulation index \( m_f \) for this signal?

Adjust the analyser settings to display the signal clearly.
Compare with AM and explain the result.
There is however one difference between the NBFM and AM spectrum that can’t be displayed by the spectrum analyser, what is that?

b) You will get some wider FM by increasing the generator \( \Delta f \) to 3 kHz. Explain the shape of the spectrum referring to the Bessel function. Estimate the 99%-bandwidth from the measurement and compare with Carson’s rule.

c) At what modulation index is the carrier rejected for the first time?

d) At what modulation index does the first pair of sidebands disappear?
  Compare with the Bessel function.

e) Increase the \( \Delta f \) to 75 kHz (as in broadcast FM transmissions) and examine the spectrum.
  Draw spectrum sketches for some ratings of \( f_m \).

1.6 Spectrum Analysis of a Received Radio Signal

Connect a wire that will work as an antenna to the analyser input.

a) Tune the analyser centre frequency to a broadcast station (e.g. 107 MHz). Why does the spectrum not look like the previous measurement? Try to demodulate the signal with the built-in demodulator and listen. How does the setting of RES BW (= IF bandwidth) affect the sound quality? Explain.

b) GSM (Global System for Mobile Communication) is a digital communication system that uses both FDMA (Frequency Division Multiple Access) and TDMA (Time Division Multiple Access).

Find a GSM channel in frequency band 935-960 MHz and examine the spectrum. Compare the shape of the spectrum to the previous measurements on analogue signals.
2. RF Amplifier Characteristics

Preparation Exercise 3:
- Define the concepts of 1-dB compression point ($CP_{1dB}$) and intercept point ($IP$).
- Describe how you can use a signal generator and a spectrum analyser to measure $CP_{1dB}$, $IP_2$ and $IP_3$.
- What is a two-tone test and what is the advantage of this method when you measure $IP_3$?

2.1 Measurements on the Amplifier MAR-1

from the data sheet:

**MONOLITHIC AMPLIFIERS 50 Ω Flat-Pack**

**BROADBAND DC to 2 GHz**

<table>
<thead>
<tr>
<th>MODEL NO.</th>
<th>FREQ. MHz</th>
<th>GAIN, dB Typical (at MHz)</th>
<th>MAXIMUM POWER, dBm</th>
<th>DYNAMIC RANGE, dBm Typ.</th>
<th>VSWR Typ. (1)</th>
<th>ABSOLUTE MAXIMUM RATING (25 °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$f_l$, $f_u$</td>
<td>100 500 1000 2000 MIN.</td>
<td>($P_{out}$ [dBm])</td>
<td>($P_{in}$ [dBm])</td>
<td>In</td>
<td>Out</td>
</tr>
<tr>
<td>MAR-1</td>
<td>DC-1000</td>
<td>18.5 17.5 15.5 6 13.0</td>
<td>+1.5 +13 +14.0</td>
<td>1.3 1.3 1.4 0.1 140 200</td>
<td>17 5.00</td>
<td></td>
</tr>
<tr>
<td>MAR-2</td>
<td>DC-2000</td>
<td>12.5 12.3 12.0 11.0 8.5</td>
<td>+4.5 +13 +17.0</td>
<td>1.3 1.4 60 325 25 5.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAR-3</td>
<td>DC-2000</td>
<td>12.5 12.2 12.0 10.5 8.0</td>
<td>+10.0 +13 +23.0</td>
<td>1.5 1.7 70 400 35 5.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAR-4</td>
<td>DC-1000</td>
<td>8.3 8.2 8.0 6 7.0</td>
<td>+12.5 +13 +25.5</td>
<td>1.6 2.0 85 500 50 5.25</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a) Turn off any modulation in the signal generator and measure the power gain of the amplifier at 200 MHz. How should you choose the generator level in order to get an accurate measurement of the linear gain?

b) Keep the generator frequency (200 MHz) and change the generator level from -60 to 0 dBm in 5 or 10 dB steps and measure at each step the level at the amplifier output at 200, 400 and 600 MHz.

Plot the results in a diagram ($P_{out}$ [dBm] as a function of $P_{in}$ [dBm]) and read the 1-dB compression point and the intercept points $IP_2$ and $IP_3$.

Describe the measurement method and show the result.

c) Optional experiment: Use the two-tone method to measure $IP_3$. Compare with the previous result.

2.2 Measurements on the Mixer ZFM-2 (Optional)

a) Connect the mixer to two signal generators, appropriate levels are stated in the data sheet. Explore how sum and difference frequencies will arise at the output.

b) Measure the conversion gain of the mixer.
An Introduction to Wireless Systems EITF50
Laboratory Experiments 3:

VECTOR NETWORK ANALYSER, ANTENNA and RECEIVER MEASUREMENTS

Göran Jönsson 2017

Objectives:

Part 1 (2 hours):

- Get acquainted with the vector network analyser (VNA),
- Calibration of the VNA,
- Basic VNA measurements,
- By simple antenna measurements get a sense of:
  1. radiation pattern,
  2. polarization,
  3. propagation loss etc.

Part 2 (2 hours):

- Get familiar with the radio test instrument,
- Understand the concepts:
  1. receiver sensitivity and,
  2. selectivity.

Note that all the preparation exercises should be solved before the laboratory practice starts!

Good luck!
1. Vector Network Analyser and antennas

Preparation Exercise 1:
- What is the reflection coefficient \( \Gamma \) for the impedances \( \infty, 0 \) and 50 \( \Omega \)?
- How do you read impedance and reflection coefficient in the Smith chart?
- Mark the impedances \( \infty \Omega, 0 \Omega \) and 50 \( \Omega \) in the Smith chart.

1.1 Vector Network Analyser (VNA)
Before each new measurement the set-up needs to be calibrated in order to define the reference planes.

a) Choose the frequency range 50 -500 MHz and set the VNA for \( s_{11} \) measurement.
   
   Connect a test cable (approx. 30 cm) at port 1. Note how the result looks like before the calibration.

b) Perform the calibration:
   
   CAL->START NEW CAL->FULL ONE PORT->PORT 1->PC7->
   
   leave the port disconnected ->OPEN PORT 1->
   
   connect a short-circuit plug->SHORT PORT 1->
   
   connect a 50\( \Omega \) terminator->MATCH PORT 1->APPLY CAL

   Explore where the three impedances \( \infty \) (open circuit), 0 \( \Omega \) and 50 \( \Omega \) end up in the Smith chart and in the polar chart (LIN POLAR) that shows the reflection coefficient.

c) Connect a straight adaptor at the calibrated reference plane. How does the adaptor affect the measurement result at 50 MHz and at 500 MHz?

   What are the wavelengths corresponding to the start- and stop frequencies. Compare the length of the adaptor to the wavelengths.

   Connect a short cable (approx. 20 cm) at the adaptor and evaluate the result.

d) Remove the adaptor and the additional cable and change the stop frequency to 1 GHz. Perform a new calibration, this time by using professional calibration standards.

   Evaluate the calibration by connecting the short cable.

   Connect the “secret box” at the calibrated reference plane and try to explore the circuits. What kind of component are hidden in the box (capacitor, coil, short circuit line, open line or an attenuator)?

1.2 Ground Plane Antenna
In this experiment you will design a ground plane (GP) antenna. You will compare the theoretical to the physical length (when the antenna is at resonance). You will also explore how the antenna is affected the shape of the ground plane and by objects in the environment.

Preparation Exercise 2:
- Calculate the theoretical length of a ground plane antenna intended for use at 900 MHz.
- What is the theoretical load impedance of a GP antenna?
a) Build a GP antenna by cutting a piece of wire. Make the antenna a couple of cm longer than the calculated length.

Connect both chassis to the VNA ports. Set the sweep range to 400 -1400 MHz and calibrate at the BNC connectors for $s_{11}$ and $s_{22}$ measurements.

CAL->START NEW CAL->FULL ONE PORT->BOTH->PC7->
Set the VNA for standing-wave measurement (SWR).

Apply the antenna at the large chassis. Study the SWR and adjust the length by cutting the wire until it shows a resonance at 900 MHz. Measure the physical length and compare with the calculated value.

b) Read the frequencies where the SWR has increased to 2. The difference between these frequencies may be called the antenna bandwidth.

c) Measure the impedance of the antenna at the resonant frequency.

d) Move the antenna element to the smaller chassis and compare the antenna properties.

e) Explore the behaviour when the antenna is disturbed in various ways:
   - hold the chassis in your hand,
   - touch the antenna element,
   - keep the antenna close to a metal sheet,
   - etc....

1.3 Dipole Antenna

Preparation Exercise 3:
   - Sketch the radiation pattern of a dipole antenna.
   - How is the antenna polarization defined?

a) While the antennas have fixed cables we have to perform a normalization instead of a conventional calibration.

Set the sweep range to 1400 -1800 MHz, set the VNA to measure $s_{21}$ and connect the antennas to the test ports. Keep the dipoles as close as possible and perform the normalization:

CAL->START NEW CAL->TRANSM NORM->FORWARD->THROUGH->APPLY CAL

b) Put the antennas at a close distance (approx. 10 cm) and turn the receiver antenna in the horizontal plane. Compare the behaviour to the theoretical radiation pattern.

Repeat the experiment at a larger distance. Discuss the result.

c) Put the antennas at a close distance (approx. 10 cm) and turn the receiver antenna in the vertical plane and study the linear polarization. Try to find a minimum.

Repeat the experiment at a larger distance. Why is the minimum not that distinct at this time?

d) Measure how the propagation loss increases when the antenna distance is increased from approx. 1 cm to 1 m. Plot a chart and discuss the result.
2. Receiver Measurements

In this section you will use a radio test instrument that provides all the necessary signal sources and instruments that are needed to perform receiver measurements. The receiver belonged to the early mobile phone system MTD which was manually operated. The uses 80 duplex radio channels in the 450 MHz band. Technical specifications are found on the next page. (Tekniska data för SRA CN-605MTD).

The usable frequencies are:

- \( f_{\text{transmit}} = 453,000 – 454,975 \text{ MHz} \),
- \( f_{\text{receive}} = 463,000 – 464,975 \text{ MHz} \).

**Preparation Exercise 4:**

- Draw a block diagram showing a superheterodyne receiver.
- What is SINAD?
- How do you define and measure the sensitivity of a receiver?
- Which block in the receiver determines the sensitivity?
- How do you define and measure the channel selectivity?
- Which block in the receiver determines the selectivity?
- What is the difference between the voltage unit \([V]\) compared to \([V_{\text{EMF}}]\)?
  (in swedish \([V_{\text{EMK}}]\))

2.1 Sensitivity

Set the receiver at channel 01 and the RF-generator in the instrument at 463 MHz (that corresponds to channel 01), the test tone frequency \( f_m = 1 \text{ kHz} \) and the deviation \( \Delta f = 3.5 \text{ kHz} \).

Find the minimum RF level that is needed to provide a received signal quality of 12 dB SINAD. Compare with the specification in the data sheet.

Repeat the measurement at a mid-band channel (for example channel 41 = 464 MHz). Is the sensitivity equally good at both channels? Explain any difference that may occur.

2.2 Channel Selectivity

Connect by a combiner an external signal generator that adds an interfering signal at the neighbouring channel. Note that the insertion loss of the combiner is 3 dB.

The channel selectivity is measured at 12 dB SINAD and a signal level of \(1 \mu V_{\text{EMF}}\). Compare with the specification in the data sheet.

- Draw a diagram showing the measurement setup.

Make the following settings:

- signal frequency 463,000 MHz, level -110 dBm (what is the corresponding voltage at the receiver input?), test tone frequency \( f_m = 1 \text{ kHz} \) and deviation \( \Delta f = 3.5 \text{ kHz} \),
- the interfering signal 25 kHz above the wanted signal (= the neighbouring channel), level -50 dBm, \( f_m = 400 \text{ Hz} \) and \( \Delta f = 3.5 \text{ kHz} \),
- adjust the level of the interfering signal until the SINAD value is 12 dB and determine the selectivity.

2.3 Optional: Measurements at a GSM Telephone

By using a radio test instrument CMU200 from Rohde&Schwarz you will get a glimpse of how function tests of GSM phones can be performed.
Tekniska data

ALLMÄNT
Frekvensområde, sändaren
Frekvensområde, mottagaren
Antal MTD-kanaler
Antal sidokanaler

Kanalavstånd
Frekvensnoggrannhet
Modulering
Nominell spannning
Nominell antennimpedans
Tompassning

SANDARE
(data vid nominell spannning 13,2 V och +25°C)
Uteffekt (vid 50 ohm belastning)
Max frekvensdeviation
LF-område
LF- karakteristik

Icke önskad stränng
Stromförbrukning

MOTTAGARE
(data vid nominell spannning 13,2 V och +25°C)
Känslighet (1/2 EMK vid 12 dB SINAD)
Selektivitet (enligt SEN)
Max LF-uteffekt (vid max deviation och 1000 Hz)
Dämpning av falska frekvenser
Störstränng
Bruksplåt
Stromförbrukning

ÖVRIGT
Kraftförsörjning

Täthet mot omgivningstemperatur
Vikt station (utan kassett)
Vikt duplexfilter
Vikt kassett

KORREKTIONSTANGENT
Vald siffra raderas. Stationen återgår till mottagnings-/passningsläge.

ANROPSTANGENT
För utsändning av anropssignal på vald kanal.

KONTROLLLAMPA
Tänd lampor = tillslagen station.

STROMBYTARE
Kontrolla lampor och bakgrundsbelysning tänds när stationen släcks till.

VOLYMVRED/YTRE LARM
Vidrör med tummen för att släcka volym

PLATS FÖR EGET ARONNENTUMMER

LYSSNA TANGENT
Vidrör med tummen för att lyssna på öppna mottagar kan

GUL LAMPA
Släckt vid selektiv mottagning och lyser vid öppen mottagning. Blinkande sken visar att anrop kommer in.

ROD LAMPA
Visar när vald kanal är upptagen.

KANALVALSTANGENTER
För val av anrop- och traffickanal. Kanal 1-9 väljs som 01-09.