

# **S-26.3120 Radio Engineering, laboratory course**

## **Lab 2: GSM Base Station Receiver**

### **Final report**

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# 1 Introduction

The second laboratory assignment was mainly about getting acquainted with the receiver part of the GSM base station (BS), understand the effect of noise and non-linearity in different parts of the heterodyne receiver, and to practice RF measurement with commonly used measurement equipment, including coaxial cables and attenuators, a vector network analyzer (VNA), a spectrum analyzer (SA), a signal generator and a noise diode. The measurement covered the pre-stage of the heterodyne receiver, consisting of the bias tee, the diplexer and the LNA, as shown in Fig. 1.

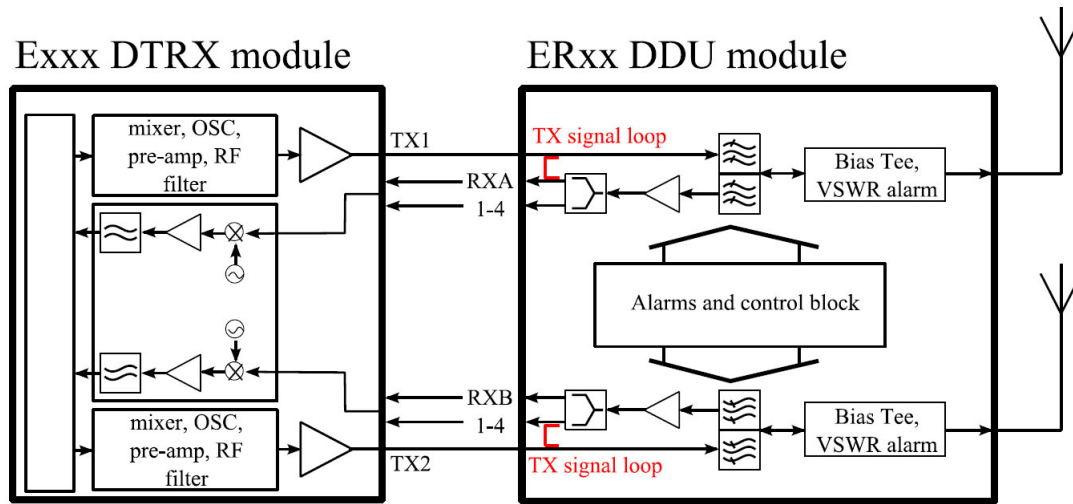


Figure 1: Receiver under study.

The laboratory consisted of four measurement tasks. In the first task, the 1 dB compression point of the RX pre-amp block was measured at 900 MHz using both the spectrum analyzer and the VNA. The 1 dB compression point sets the limit to maximum power level of the received signal at input of the pre-amp block. In the second task, the gain of the RX pre-amp block was determined by measuring the 3 dB RX bandwidth of the block. The approximated equivalent noise bandwidth of the block and the TX-band attenuation were also measured. This task was already covered in the first lab assignment as a part of the diplexer characteristics.

The third task is a noise measurement whose purpose was to determine the noise temperature of the RX pre-amplifier block using  $Y$ -coefficient method. Finally, the fourth task involving measuring the sensitivity of the RX pre-amplifier block, i.e., the minimum power level at input of the pre-amp block that can be detected with predefined  $BER$ .

This report is divided in five sections. After this introduction, general measurement procedures are discussed. The third section presents the measurement results while the fourth section includes the error estimates. In the second to last section, some conclusions are drawn. Finally, feedback is also given in the last section to further improve this laboratory assignment of the course.

## 2 Measurement steps

In this section, used measurement configurations are presented for each measurement task. Measurements in question may be divided into two distinct categories: power measurements with a spectrum analyzer (SA) and two-port transmission measurements ( $S_{21}$ ) with a vector network analyzer (VNA). There were no significant differences between the planned setups and those used in the actual measurements. The following measurement-specific subsections will elaborate.

### 2.1 1 dB compression point

To measure 1 dB compression point of a device, one needs a (manually) sweepable signal source and power detector. These may come separately or be incorporated in a single device. In both cases, the DDU module is connected the in between the source and the detector. We used both approaches, and made two measurements with equal power levels.

For separate signal generation and detection, we used *Rohde & Schwarz SML03* signal generator (SG) and *HP 8596E* spectrum analyzer. The measurement setup is shown in Figures 2 and 3. The setup employing *Rohde & Schwarz ZVL* VNA is shown in Figures 4 and 5. All equipment came precalibrated. In both measurements, the A-half of the base station was used.

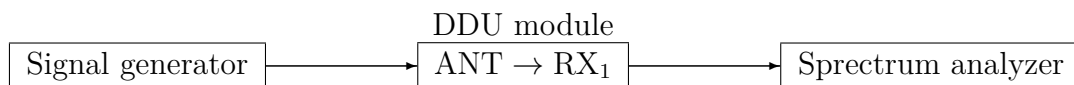


Figure 2: Measurement setup used in the first measurement task.

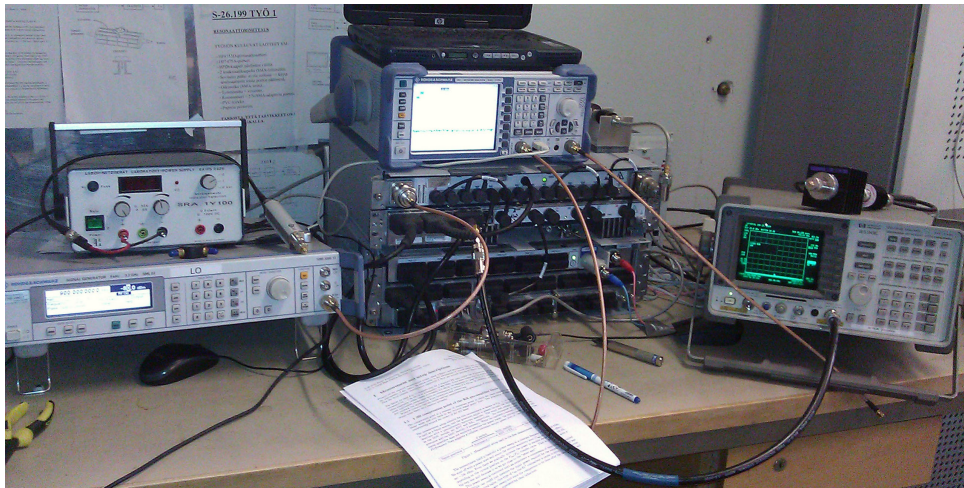


Figure 3: Using a signal generator and spectrum analyzer to characterize the DDU module.

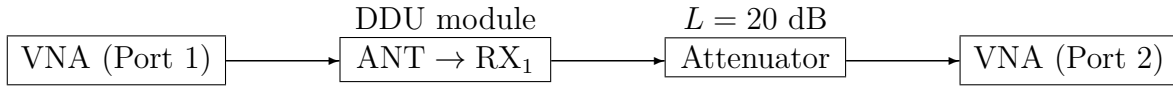


Figure 4: VNA measurements connections

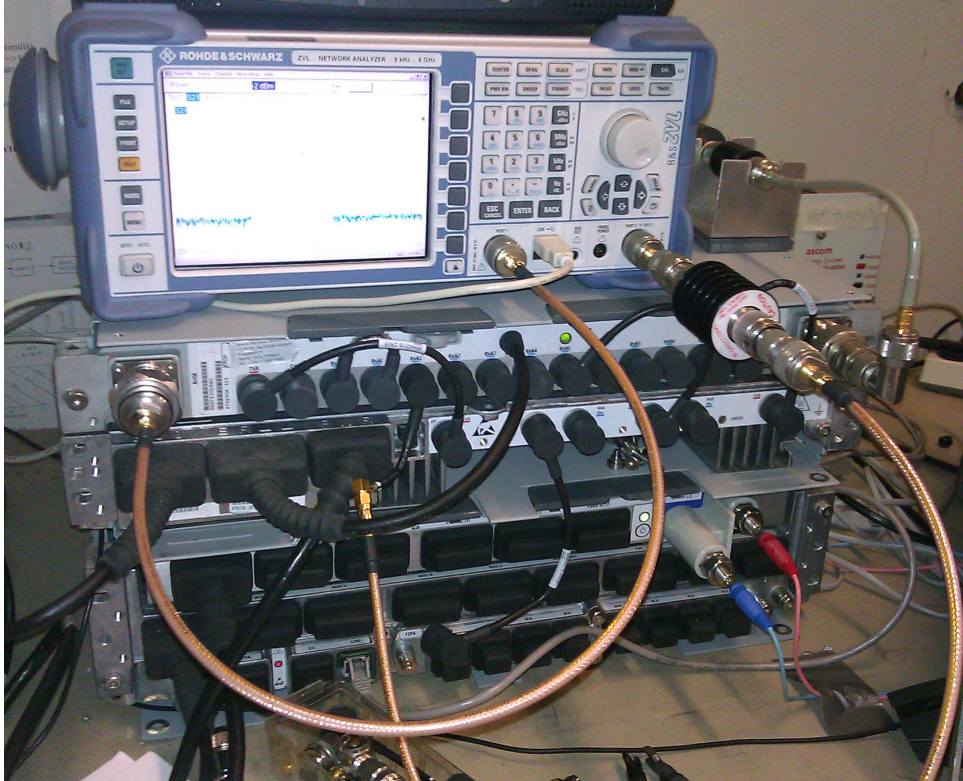


Figure 5: Measuring the DDU module with the VNA.

In essence, the measurement was a power sweep at a constant frequency of  $f = 900$  MHz; mapping detected power or gain against used input power. This raw data was later postprocessed using Matlab.

We started with a source power of  $-40$  dBm; a power level well below the 1 dB compression point. The power was gradually used in steps of first 10 dB, then 5 dB and finally 1 dB, until clear compression was observed. Compression may be seen in the lower than expected values of detected power (SG & SA), or equivalently as lower gain (VNA).

Since we were measuring a GSM receiver, we used settings found in the GSM specification for the spectrum analyzer with the exception of smaller averaging factor. The settings were as follows: an averaging factor of 100, zero span and 30 kHz video and resolution bandwidths. Input attenuation of the spectrum analyzer was increased from 10 dB all the way to 30 dB as we moved onto higher powers.

The two cables and attenuators were measured separately using a VNA. For the VNA, the measurement settings throughout this lab were as follows: 1601 points over a frequency range

of 800 . . . 1000 MHz, a measurement bandwidth of 10 kHz and averaging over 200 samples with a transmit power of  $-20$  dBm.

For more accurate and/or reliable SA measurements, even a larger attenuation factor could have been used to avoid the small, yet possible, compression in the SA. One should have also not trusted the quality of the SG as much than we did. The whole power sweep should have also been recorded without the DDU-module in between. Also, there was some oversigh in making the connections as can be seen in Fig. 5. As its only an attenuator in a transmission measurement, there is most likely no great an impact on the results as such. Nevertheless, it begs to question connector repeatability.

## 2.2 Frequency response

The frequency response was already measured in the first labs using a VNA. Thus we didn't need to measure the gain in these labs, as we used the results from the first labs. While the measurement procedure was given in the final report of the first labs, it is repeated here for completeness.

The measurement was carried out using a *Rohde & Schwarz ZVL* VNA, calibrated by the assistant prior to our arrival. The calibration settings were as follows: full two-port calibration with 1577 points within the 850 . . . 1000 MHz band,  $-20$  dBm reference power, and an averaging factor of 100. The reference plane was located at the non-VNA end of the used cables.

The actual measurement included connecting the VNA to the B-half of the DDU module in order to obtain the values of  $|S_{12}|$  over a set frequency range. In terms of physical connections, this would mean the following: VNA (Port 2)  $\rightarrow$  DDU module (in: ANT<sub>B</sub>, out: RX<sub>B1</sub>)  $\rightarrow$  VNA (Port 1). The raw data was stored onto a USB-memory as \*.s1p files for post processing using Matlab.

The theoretical noise bandwidth  $B_n$  for a device may be found as using the following formula

$$B_n = \frac{1}{G_{T, \max}} \int_0^\infty G_T(f) df, \quad (1)$$

where  $G_T(f)$  is the transducer gain at frequency  $f$ . In practice, one may only approximate this using numerical integration over the finite measurement bandwidth. Such approximation is bound to yield slightly optimistic values. Another possibility is to approximate the noise bandwidth as the 3 dB bandwidth, and applying a compensation factor based on the transition bands. Results obtained using both methods are shown and compared later in the text.

## 2.3 Noise temperature

In the noise measurement task, we used the  $Y$ -coefficient method. The setup is shown in Figures 6 and 7. A DC-voltage source is connected to a noise diode which is in turn connected by an SMA-cable to the ANT<sub>A</sub>-input in the pre-amplifier block (A-half). It would have been better to use desired direct connection, but that was not possible due to missing adapters.

The signal is led then from the RX<sub>A1</sub> output to the spectrum analyzer. We made another measurement where an amplifier was placed in between, as the noise power from the cold noise



source might've been masked by the SA noise. The parameters of the amplifier, made by Minicircuits, were as follows:  $B = 15 \dots 3000$  MHz,  $G = 19$  dB,  $T = 463$  K,  $F = 4.1$  dB and  $V_{CC} = +15$  V.

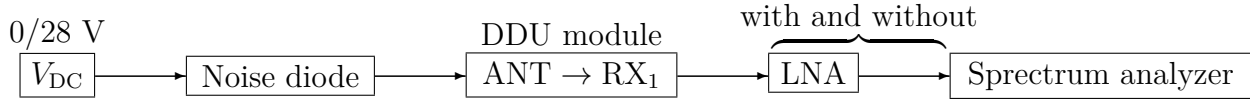


Figure 6: Noise temperature measurement setup

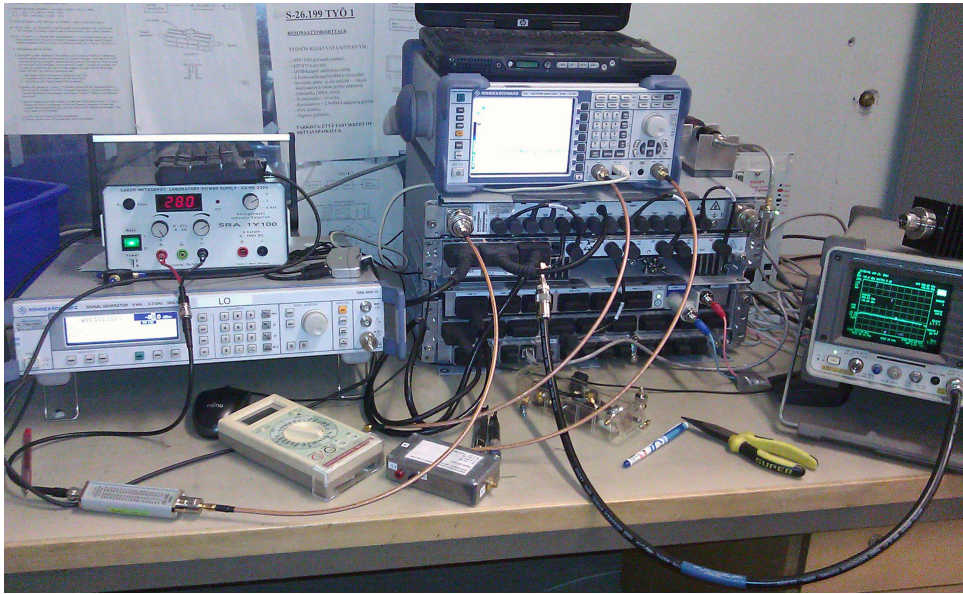


Figure 7: Noise temperature measurement setup without the additional amplifier.

The measurements themselves were carried out measuring two power levels required in the Y-parameter; when the DC-voltage is off/shorted (“cold”) and on (“hot”). We used *HP 346B* noise diode ( $ENR = 21.48$  dB when  $f = 1.00$  GHz) with a control voltage of  $28 V_{DC}$  taken from a laboratory-grade voltage source.

As for the SA settings, the settings we as follows: 0 dB input attenuation, zero span, 10 kHz resolution and video bandwidths and an averaging over 100 sweeps. For more accurate results, more time should have spent on this measurement. This would have allowed us to use smaller bandwidths and larger averaging factor.

The noise temperature, or equivalently noise factor/figure, may be found using the following formulae.  $Y$ -coefficient is given as

$$Y = \frac{P_H}{P_C} = \frac{T_H + T_e}{T_C + T_e} \Rightarrow T_e = \frac{T_H + YT_C}{Y - 1}, \quad (2)$$

where  $P_{H/C}$  is the measured power for hot and cold loads at equivalent noise temperatures  $T_{H/C}$ , and  $T_e$  is the noise temperature of the measured device.  $T_C = 290$  K is the physical

temperature of the noise diode, and  $T_H$  may be solved from the definition of  $ENR$ :

$$ENR = 10 \lg \left( \frac{T_H}{T_0} - 1 \right) \Rightarrow T_H = T_0 \left( 10^{\frac{ENR}{10}} + 1 \right). \quad (3)$$

Obtained noise temperature  $T_e$  may be converted to noise factor  $F$  or figure  $F_{dB}$  using the following relationship:

$$F_{dB} = 10 \lg (F) \text{ dB} = 10 \lg \left( 1 + \frac{T_e}{T_0} \right) \text{ dB}. \quad (4)$$

One should notice that the  $T_e$  given by Eq. 2 is actually the noise temperature of the whole chain. This chain is a cascaded system, consisting of a SMA-cable, the DDU module, the optional amplifier, another SMA-cable and the spectrum analyzer, in this order. The contribution of the DDU module may be determined by reverse calculating Friis' noise equation:

$$F_{\text{total}} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \dots \Leftrightarrow T_{\text{total}} = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1 G_2} + \dots, \quad (5)$$

where  $G_i$  is the available power gain of the  $i$ th stage. Similar indexing is also used for both of the noise quantities  $F$  and  $T$ . This simplified formula assumes equal noise bandwidths between the stages.

The parameters required by the formula may be obtained through calculation, or are provided by the manufacturer. For example the noise contribution of the cables can be obtained from their attenuation  $L$  and physical temperature  $T_{\text{phys}}$  through formula  $F = (L - 1)T_{\text{phys}}$ . The amplifier specifications were given already in the text. For the spectrum analyzer, its noise characteristics eluded us. Luckily, there is significant gain earlier in the chain, thus minimizing the effect of the noise originating in the SA.

## 2.4 Sensitivity

In the sensitivity measurement, we measured the minimum input power at the ANT<sub>A</sub>-input that results in a reliably detectable signal above the noise floor in the output of the DDU module. In GSM-systems, a signal with  $SNR > 10$  dB is detected with an acceptable  $BER$ . For this, a measurement setup identical to the one used in the first task may be used. The setup used there is shown in Figures 2 and 3. An attenuator may be used between the signal generator and the DDU module.

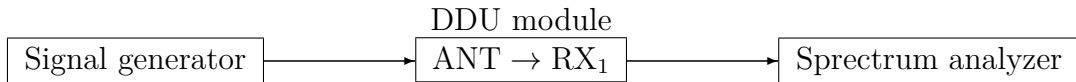


Figure 8: Measurement setup used in the sensitivity measurement.

The first step was to measure the noise floor at 900 MHz without any signal we're hoping to detect. That is, the RF power was switched off at the generator. Then we turned on an

input signal that's some dBs below the reported sensitivity level of  $-112.5$  dBm. We gradually increased the power until the signal-to-noise ratio was no less than the 10 dB required by the standard. The corresponding power level was recorded. Also powers corresponding to an *SNR* of 12.5 and 7.5 dB we measured.

One could have also measure the power required to beat the noise just barely, and add the SNR later on. This approach is, however, less accurate and more painful. It also assumes  $P_{\text{out}}(P_{\text{in}})$  relationship to be ideal in the range.

Since it's a GSM system, we use the measurement settings as they are defined in the standard with the exception of averaging. The standard 500-sweep averaging was used in when measuring the noise floor, but 100 was used when RF power was enabled. The final settings were as follows: an averaging factor of 500/100, zero span and 30 kHz video and resolution bandwidths. The input attenuator was disabled in the SA settings.



## 3 Results

The results are described in detail in the following subsections. The four measurement data were post-processed either by Matlab or by means of calculation to find wanted parameters of the pre-amp block under test.

The attenuation of cables and attenuator used in the measurements were determined using the VNA, and were taken into account when post-processing the measurement data. The attenuations are 19.95 dB, 0.2 dB and 0.3 dB, for the attenuator, thin cable and thick cable, respectively. The parameters of the additional amplifier used in the noise measurement were specified as follows:  $G = 19$  dB,  $T = 463$  K,  $F = 4.1$  dB.

### 3.1 1 dB compression point

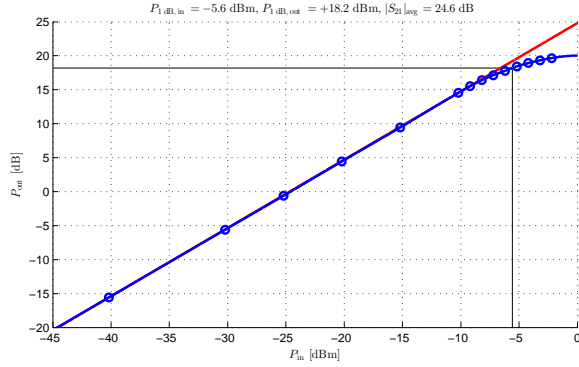
1 dB compression point arises from the nonlinearities of the receiver LNA. At high enough powers, the gain of the LNA for a certain frequency starts to drop with increasing power. The input power at which the LNA gain is compressed by 1 dB was measured using two different measurement setups. The results are presented here.

The first measurement setup consisted of a signal generator and a spectrum analyser. A single frequency of 900 MHz sent from the signal generator was measured with the spectrum analyser. The signal generator power was increased gradually, until a 1 dB drop in the gain was achieved. The measurement results for the first setup are presented in Fig. 9(a, c and e). The attenuations of the cables are corrected from the results.

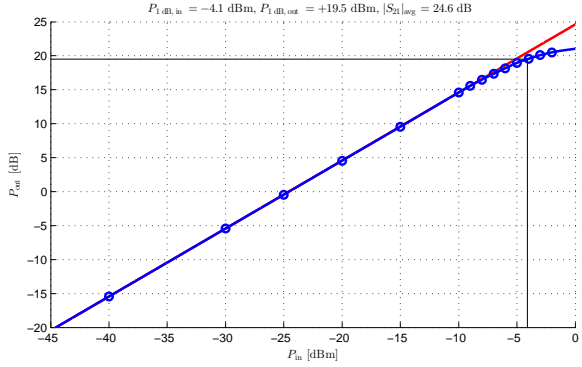
The second measurement setup consisted of a vector network analyser. The VNA was measuring the  $|S_{21}|$  as the input power was increased gradually, until a 1 dB drop was visible on the screen. An attenuator was required in between the base station and VNA port 2 to protect the device from the amplified signal. The measurement results for the second setup are presented in Fig. 9(b, d and f). The vector network analyser was calibrated before use.

All the sub figures are plotted from one data set for spectrum analyser setup and VNA setup each. The data sets are post processed using Matlab. Both data sets are visualised with three different figures, so that it is easier to compare the two measurements. Matlab '*phcip*' interpolation with additional extrapolation was used for completeness. The Extrapolated data should not thus be taken into account when analysing the DDU performance.

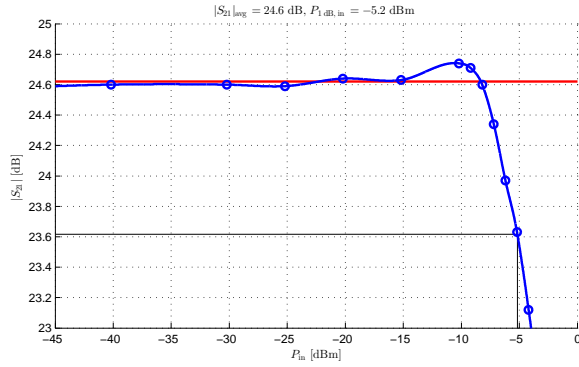
The compression point derived from the spectrum analyser measurement is  $CP_a = -5.6$  dBm. Fig. 9(c) shows how the measured gain fluctuates around the average gain of 24.6 dB, however, with a small amplitude. The compression point derived from the VNA measurement is  $CP_b = -4.1$  dBm without any gain fluctuation. One could assume the “actual” compression point to be found within these limits.



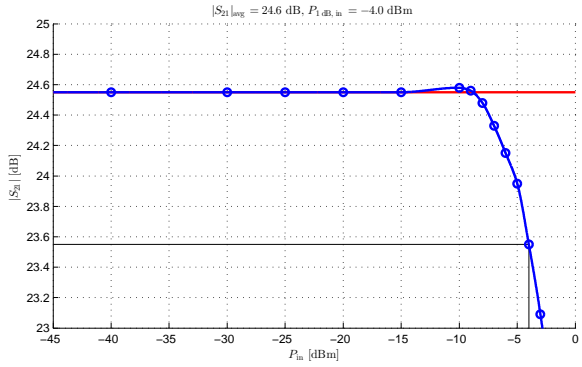
(a)  $P_{\text{out}}(P_{\text{in}})$  using SG & SA



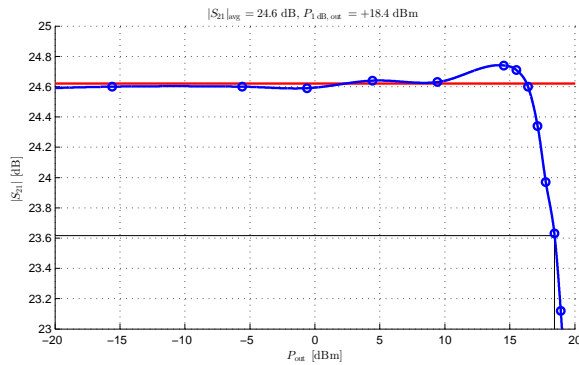
(b)  $P_{\text{out}}(P_{\text{in}})$  using VNA



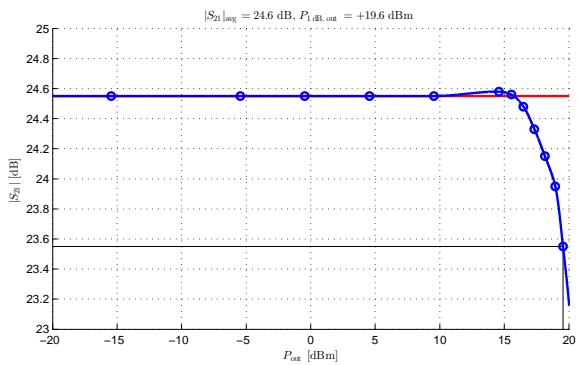
(c)  $G(P_{\text{in}})$  using SG & SA



(d)  $G(P_{\text{in}})$  using VNA



(e)  $G(P_{\text{out}})$  using SG & SA



(f)  $G(P_{\text{out}})$  using VNA

Figure 9: Results from the 1 dB compression point measurements. Ideal behaviour is shown with red straights, measurements with blue markers and Matlab 'pchip' interpolant in blue.

### 3.2 Frequency response

The  $|S_{12}|$  response of the DDU module (B-half) within the 850...1000 MHz band is shown in the following figure (Fig. 10). In the figure, in addition to the actual response (in black), additional information is shown. GSM RX and TX band limits (in red), both 3 dB (in blue) and noise (in green) bandwidth of the pre-amp block are also visualized. Visualization of the noise bandwidth is somewhat questionable as it's a purely theoretical concept, but is nevertheless shown for scale.

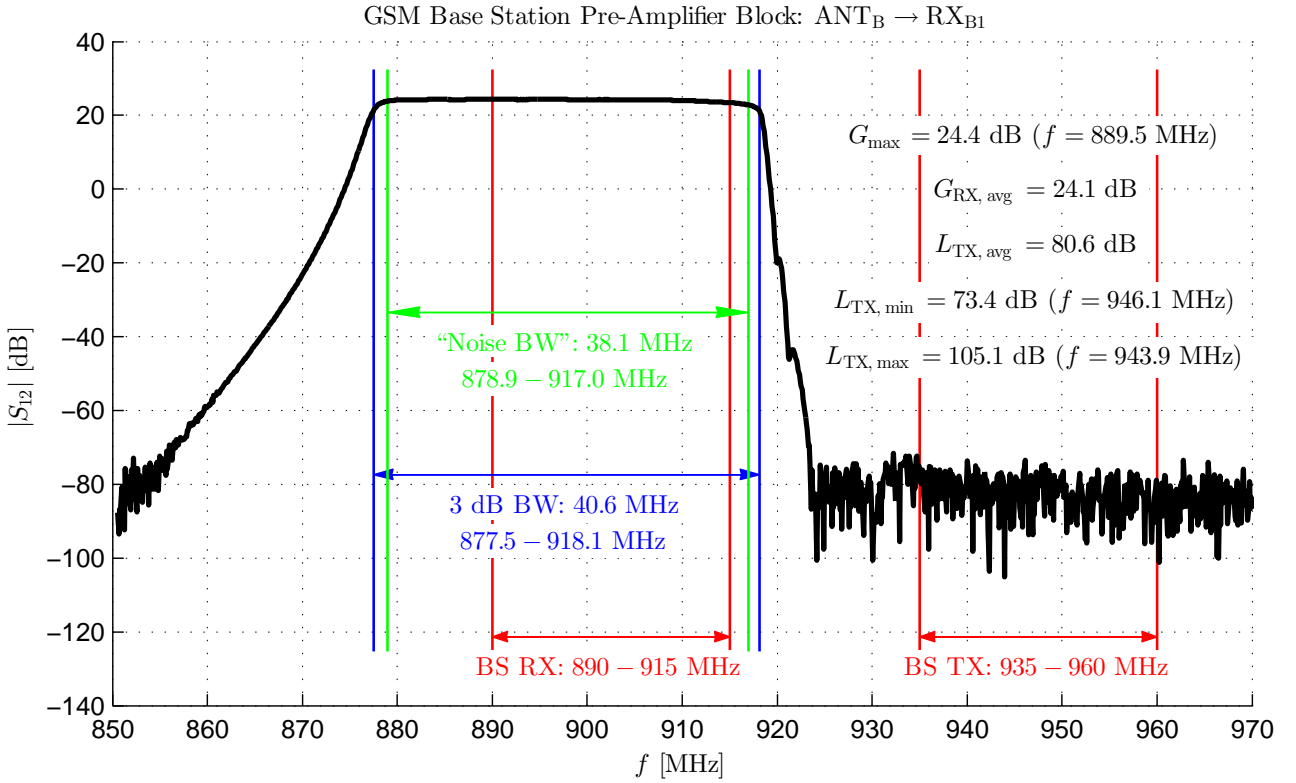


Figure 10:  $S_{12}$  of the DDU module as was measured in the first labs.

The noise bandwidth shown, obtained from Eq. 1 is less than the actual band since we cannot use infinite frequency range. Frequency range of 850...1000 MHz with  $G_{\text{T, max}} = |S_{12}|_{\max} = 24.4$  dB was used instead. The obtained value (38.1 MHz) is roughly 6 % shy of the 3 dB bandwidth (40.6 MHz), as one might expect. The 3 dB bandwidth may thus be used to avoid being overly optimistic.

In the graphical approximation method we need to investigate the effect of frequency roll-off speed. From Fig. 10 the transition bands are approx. 30 MHz (3.4 %) and 5 MHz (0.55 %) for lower and upper bands, respectively. During this transition, the  $S_{12}$  drops roughly 100 dB from +20 dB to -80 dB. This corresponds to a slope of 3.3 dB/MHz (29 dB/%) and -20 dB/MHz (-180 dB/%), respectively. The effect of such steep slopes are neglectable, and thus the 3 dB bandwidth may be used as the noise bandwidth.

### 3.3 Noise Temperature

The noise of the RX block was measured two times using the Y coefficient method, the noise diode working as a hot load and a short circuit as a cold load in room temperature (290 K). The first measurement was done without an extra LNA in between the spectrum analyser and the RX block, and the second measurement was done with the LNA in between.

The noise temperature of the hot load can be calculated from the *ENR* using Eq. 3, which gives  $T_H = 41065$  K. The equivalent noise temperature of the chain in between the diode and the spectrum analyser can be calculated from this temperature, room temperature and the measured noise powers. This is done using the Y-coefficient method, which gives  $T_{\text{total, w/}} = 162.1$  K and  $T_{\text{total, w/o}} = 643.8$  K for the setups with and without the LNA, respectively.

The previous noise temperature values still include the noise powers from the other parts of the chain, i.e., cables, the LNA and the SA. The RX block noise temperature can be obtained from Eq. 5, which is for example for the LNA setup

$$T_{\text{total, w/}} = T_{C1} + L_{C1}T_{\text{DDU, w/}} + \frac{L_{C1}T_{\text{LNA}}}{G_{\text{DDU}}} + \frac{L_{C1}T_{C2}}{G_{\text{DDU}}G_{\text{LNA}}}, \quad (6)$$

and yields  $T_{\text{DDU, w/}} = 139.7$  K and  $T_{\text{DDU, w/o}} = 601.4$  K for the setups with and without the LNA, respectively. Subscript  $Ci$  refers to the  $i$ th cable.

Table 1: Results from the noise measurement.

LNA?	$P_C$ [dBm]	$P_H$ [dBm]	$T_{\text{total}}$ [K]	$T_{\text{DDU}}$ [K]	$F_{\text{DDU}}$ [dB]
No	−107.3	−90.8	643.8	601.4	4.9
Yes	−91.3	−71.7	162.1	139.7	1.7

The final results are presented in Table 1. The results differ significantly. The noise temperature calculated from the LNA setup is clearly closer to reality than the result obtained without the LNA. The reason for this is that the cold noise power is does not exceed the noise floor of the SA with a large enough margin. The LNA is required in the setup to rise the noise level high enough, so that it can be defined more precisely with the spectrum analyser.

### 3.4 Sensitivity

In this measurement, the sensitivity or the minimum detectable input power of the RX pre-amp block was measured using SA. The noise level at the output of the block was measured, when the RF power from SG was completely turned off, to be at −101.89 dBm. Three different output SNR values of the block, the minimum *SNR* from GSM standard, below GSM minimum standard and above GSM minimum standard, were used to calculate desired power level at the output side. Input power levels from SG were written down when the desired output powers were reached. Table 2 below summarizes the measurement data for the minimum detectable input power at different values of *SNR*.

Table 2: Results from the sensitivity measurement.

$SNR$ [dB]	$P_{\text{transmit}}$ [dBm]
7.5	−118.0
10	−115.6
12.5	−113.0

It can be seen that at the minimum SNR required from GSM standard (around 10 dB) the measured sensitivity of the RX pre-amp block is −115.6 dBm. Taking into account the attenuations caused by SMA-cables, which were measured in the first task, the actual sensitivity is −116.1 dBm ( $= -115.6 \text{ dBm} - 0.2 \text{ dBm} - 0.3 \text{ dBm}$ ).

These results assume the SA recognizes its measuring noise and applies internal correction. Most likely this correction must be done manually by adding 2.5 dB to the noise floor. [2] The same effect may be achieved by using an SNR of 12.5 dB, resulting in a sensitivity level of −113.6 dBm.

### 3.5 Dynamic range

The dynamic range of a radio receiver is a range of received signal levels over which the receiver can operate. The dynamic range of the DDU under test can be determined as a ratio of the 1 dB compression point and the sensitivity or the minimum detectable power (MDP) of the pre-amp block. In decibels, the dynamic range is simply a difference between these two power limits:

$$DR = P_{1 \text{ dB}} - P_{\text{MDP}} \quad (7)$$

Using the values of the 1 dB compression point and the sensitivity obtained from measurement, the measured dynamic range of the RX pre-amp block is:

$$DR_{\text{measured}} = -5.6 \text{ dBm} - (-116.1 \text{ dBm}) = 110.5 \text{ dB} \quad (8)$$

The theoretical value of dynamic range is calculated with the provided sensitivity from producer as following:

$$DR_{\text{theoretical}} = -5.6 \text{ dBm} - (-112.5 \text{ dBm}) = 106.9 \text{ dB} \quad (9)$$

The measured 1 dB compression point value was applied in the theoretical dynamic range calculation above, since there is no such value given by producer. Therefore, the theoretical and measured dynamic ranges differ by −3.6 dB due to different sensitivity values as discussed in the previous subsection.

These measurements we obtained using the 1 dB compression point from the SG & SA measurement along with the assumption that the spectrum analyzer makes the noise correction. Using 1 dB compression point obtained from the VNA measurements increases both dynamic ranges by 1.5 dB. Correcting for the noise decreases  $DR_{\text{measured}}$  by 2.5 dB.



## 4 Error estimates

In this section, error estimates for the two types of measurements are presented. The values presented here are only rough estimates based on literature (with more or less general cases) and their soundness in this case is somewhat questionable. In this section, we do not take human errors (see previous section) into account. It is just stated that systematic errors arising from the cables and connections are possible in measurement all measurements. Thus they are valid only for “correct” measurements, and are more of the “provided for completeness” nature. Probabilities are not given due to the nature/basis of the estimation.

### 4.1 Spectrum analyzer

Each of the components inside the spectrum analyzer contributes to the total uncertainty, depending for example on the signal frequencies, amplitudes, and measurement settings. The Agilent (former HP, manufacturer of the used SA) has made available a document that specifies the different error sources, giving also rough estimates for some spectrum analyzers. According to the document [3], the error estimates vary broadly among different analyzer models, giving worst case uncertainties exceeding  $\pm 6$  dB. On the other hand, the document gives also representative values of amplitude uncertainties, which in our case yields about  $\pm 1$  dB.

The second error source for the spectrum analyzer is the power marker reading. In each of the tasks, the spectrum analyzer was set to average 500 measurement points, which should average out most of the random errors. However, reading the power marker in the screen, there was a noticeable fluctuation in the shown power value. Based on the experience obtained during the measurements, the power marker error is estimated to be approximately  $\pm 0.5$  dB.

In conclusion, the error estimates that can be taken into account numerically are the manufacturers representative value of approx.  $\pm 1$  dB, and the power marker fluctuation of roughly  $\pm 0.5$  dB. These uncorrelated errors may be summed to achieve the total uncertainty of the SA measurements of approx.  $\pm 1.5$  dB.

There is also the question of calibrating the spectrum analyzer properly with the time interval defined by the manufacturer. Agilent suggests to have the spectrum analyzer calibrated thoroughly once in a year, and quick-calibrated if there are changes operating environment [4]. If the spectrum analyzer used in the measurements is not calibrated correctly, it is possible that the measurements are not reliable. In this case, the calibration is the most important error source, and the device should be calibrated correctly before estimating any other errors.

### 4.2 Vector network analyzer

For the VNA, different error sources and ways to cope with them are listed in the lecture slides discussing VNA measurements. The different sources are noise, cabling/connector repeatability, directivity, isolation, mismatch and environment induced drift.

Noise and cabling/connector repeatability are random errors, which can be averaged out. In our case, only the noise was averaged, since we did not touch the cabling. Systematic errors arising directivity, isolation, and mismatch in this task were for the most part neglected

with a calibration. Before conducting measurements, the VNA is always calibrated using a standard calibration module. The calibration moves the reference planes to the connectors of the test cables, and somewhat cancels the systematic errors from the connectors and cables used in a specific measurement. Finally, the environment induced drift is not relevant, since the measurement was done inside a short time interval.

Rohde & Schwarz provides specifications that describe the measurement uncertainty of the VNA in question in different frequency bands. For transmission measurements in the frequency range of 50 MHz to 3 GHz, accuracy for signal powers of  $-50 \dots 0$  dB is better than 0.2 dB (0.3 dB for powers of  $-50 \dots -70$  dB) with 0 dBm transmit power. [5] The reader should note that these ranges was exceeded from both ends during the measurements (the measurement power range was roughly  $-100 \dots +4$  dBm).

In conclusion, two things are assumed. First, calibration is assumed to cancel the systematic errors arising from cables and connectors to a negligible level. Second, random errors are cancelled with averaging almost entirely. The manufacturer provides error estimates for the device itself, giving an error estimate of under 0.3 dB that is mostly applicable in our case. The topics discussed in the last paragraph of the last subsection apply here to some extent to here as well.

### 4.3 Noise diode

According to the lecture supplement handout [2], error sources in noise measurements can be divided into four categories. First error source is the noise diode calibration error, second error source arises from  $Y$ -factor method, third from mismatches and fourth from the attenuations. Also the physical operating temperatures might have been some kelvins above  $T_0 = 290$  K.

The noise diode calibration uncertainty is about  $\pm 0.1$  dB. The noise diode ENR varies 0.01 dB/ $^{\circ}$ C, and 0.1 dB/% for variations in the operating voltage. In the  $Y$ -factor method, the hot and cold temperatures should be suitable for the noise temperature that is to be defined. Also mismatch and cable temperatures (see [2], p. 89-90) should be taken into account if top-notch accuracy is wanted. Finally, attenuations have to be taken carefully into account when calculating the noise temperature using the Frii's formula.

For our laboratory assignment it is assumed, that the chain is perfectly matched, attenuations precisely measured, and the  $ENR$  variations due to temperature and voltage source fluctuations are small. Therefore, only the effect of the  $\pm 0.1$  dB calibration uncertainty is to be taken into account. This corresponds to about  $\pm 900$  K in hot source temperature, and  $\pm 20$  K in the final equivalent noise temperature.

### 4.4 Signal generator

For the sensitivity measurement, also the uncertainty of the signal generator should be taken into account. The signal generator amplitude error and amplitude flatness are relevant parameters. For more thorough discussion, the reader is advised to refer to [2, 6].

## 5 Conclusions

In this laboratory assignment, the receiver part of a GSM base station was measured. The measurements covered the most important performance parameters of a receiver part, including 1-dB compression point, frequency response, noise temperature, and sensitivity. The most important learning outcome was to understand high and low power measurements, and how a power level affects measurements. Sensitivity and noise measurements require very low power measurements, whereas 1 dB compression point demonstrates the effects of high powers. This report presented the measurement setups and their corresponding results.

The main measurement instruments included a spectrum analyser, a vector network analyser, and a signal generator, which all were pre calibrated and ready to use. An attenuator and a low noise amplifier were used to transform the measured signals to proper levels. In addition, different connecting cables were used, and their attenuations defined with the VNA. Measurement uncertainties for the spectrum analyser and VNA are estimated to be approximately  $\pm 1.5$  dB and  $\pm 0.3$  dB, respectively.

The 1-dB compression point was measured with two different measurements. The first was done using a signal generator and a spectrum analyser, and the second was done using only a VNA. In a nutshell, the input power was gradually increased, and the output power measured. In this report, figures are presented from which it is possible to define the 1-dB compression point. The compression point defined with the first setup is  $CP_a = -5.6 \pm 1.5$  dBm and the second setup gives a compression point of  $CP_b = -4.1 \pm 0.3$  dBm, with the given error estimations.

The frequency response was already defined in the previous laboratory assignment. The  $S_{21}$  parameter of the RX block was measured with a VNA. The 3 dB and noise bandwidths were defined from the obtained graph, yielding 40.6 MHz and 38.1 MHz, respectively. However, the difference between these two values is small, and the band edges are steep. Therefore, it is concluded that the 3 dB bandwidth may be used as the noise bandwidth as well, thus avoiding too optimistic measurement results.

The DDU noise power was measured with and without a low noise amplifier in between the signal generator and the spectrum analyser. The noise power was then calculated using Y coefficient method, which requires a hot/cold noise source. The noise temperature results for the DDU are  $T_{\text{DDU,w/}} = 140 \pm 20$  K and  $T_{\text{DDU,w/o}} = 612 \pm 20$  K, with and without the LNA, respectively. It is concluded that the measurement setup requires an amplifier, as the cold source noise power is too low to be measured precisely without. Therefore, the DDU noise temperature is  $140 \pm 20$  K. The result seems realistic.

The minimum detectable power of the RX pre-amp block was measured using the spectrum amplifier, and compared to the GSM standard. The GSM standard specifies a signal to noise ratio of 10 dB for sensitivity measurements. With the specified signal to noise ratio, the sensitivity is defined to be  $-116.1 \pm 1.5$  dBm. In comparison with the sensitivity specified by producer ( $-112.5$  dBm), the measured value is about  $-3.6$  dBm lower.

The dynamic range can be calculated from the minimum detectable power and 1 dB compression point given above. It is the range in between these two values, and is the range of received signal levels over which the receiver can operate. The measured dynamic range

is therefore  $110.5 \pm 3.0$  dBm (add +2.5 dB for noise correction). The theoretical dynamic range calculated using the manufacturers *MDP* is  $106.9 \pm 1.5$  dBm. The measured dynamic range is therefore about 3.6 dB (1.1 dB for noise-corrected) higher than the range given by the manufacturer.

In conclusion, the receiver block parameters were measured, and a good deal of new things learned. It was especially interesting to measure low powers and to estimate how it effects the measurements. It was also fun to measure the same parameters using different devices/setups, and see how they affect the results.

## 6 Feedback

The second laboratory assignment was a good practical example of how power levels affect measurements. In addition, it was interesting to learn how noise measurements may be conducted. However, there were some drawbacks as well.

When writing the preliminary report, we were left wondering if all the needed devices were really listed in the instructions sheet. In the noise measurements, the LNA was definitely required, but not listed. Feedback for all the reports would also be welcome, as a grade does not tell the pluses and minuses of a report. What was especially good? What could have been better? Any wrong thoughts or deductions? After all, learning process depends very much on “learning from mistakes.” Also, there was the question on sweep time. Not the assistant nor the lecturer could not thoroughly explain for example how it affects measurements.

The assistant was very helpful and ready to answer questions. For example, when we asked for some equipment that would not normally be used in the lab, he brought them immediately. In addition, the assistant had taken our feedback from the previous lab into account, and improved the measurement setup.



## References

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