S-26.3120 Radio Engineering, laboratory course

Lab 2: GSM Base Station Receiver

Final report

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Group 3:

Sampo Salo	79543L
Tuomas Leinonen	84695P
Huy Nguyen	411330

Sampo Salo, 79543L
Tuomas Leinonen, 84695P
Huy Nguyen, 411330

1 Introduction

TODO: Huy and Sampo (1st paragraph: general intro, 2nd: the measuremets, 3rd: structure of this report)

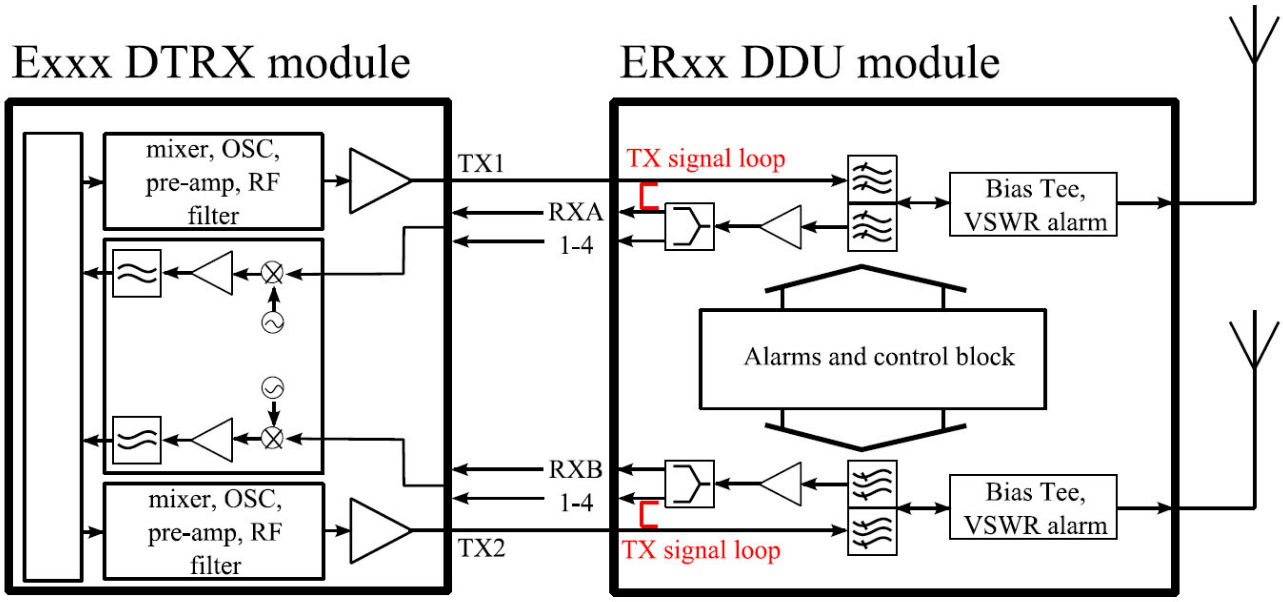


Figure 1: Receiver under study.

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 measurememt 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.

DDU module

Signal generator → ANT → RX_1 → Sprectrum analyzer

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

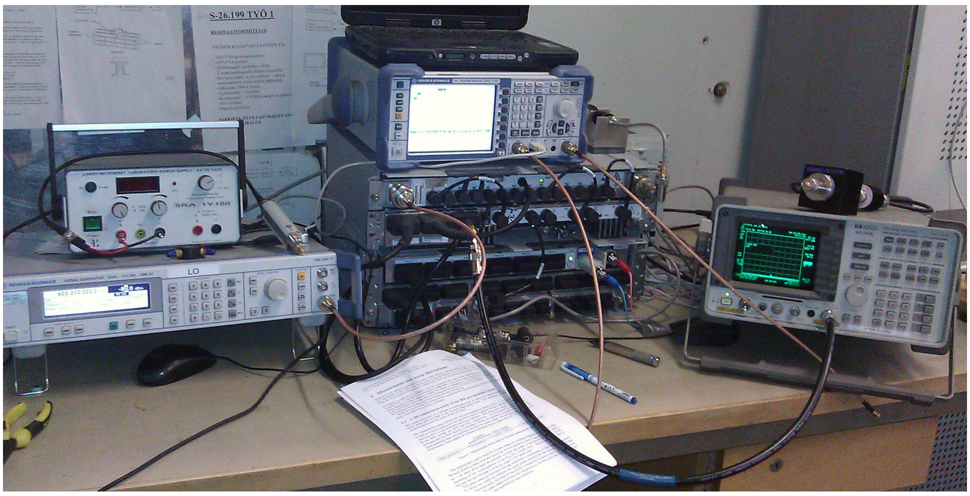


Figure 3: Using a signal generator and spectrum analyzer to characterize the DDU module.

VNA (Port 1) $\longrightarrow$ DDU module ANT $\rightarrow$ RX_1 $\longrightarrow$ $L = 20$ dB Attenuator $\longrightarrow$ VNA (Port 2)

Figure 4: VNA measurements connections

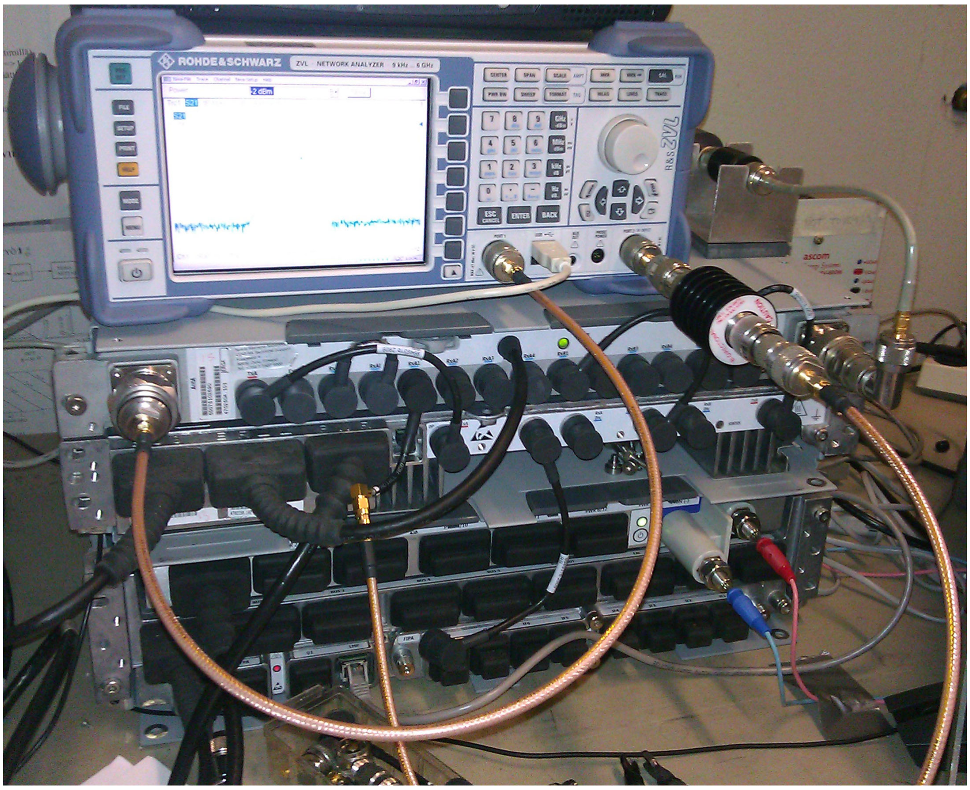


Figure 5: Measuring the DDU module with the VNA.

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 expeception of smaller averaging factor. They 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

Sampo Salo, 79543L
Tuomas Leinonen, 84695P
Huy Nguyen, 411330

of 800 . . . 1000 MHz, a measurement bandwidth of 10 kHz and averaging over 200 samples.

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 chould 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 oversigth 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 used the cables.

The actual measurement included connecting the VNA the port pairs in order to obtain the absolute values of S_{12} parameter over a set frequency range. In terms of physical connections, this would mean the following: VNA (Port 2) → DDU modul → VNA (Port 1). The raw data was stored onto a USB-memory as `*.s1p` files for post processing using Matlab.

2.3 Noise temperature

ENR = 21.48 dB

In the third measurement task, we'll use a setup shown in Fig. 6. A DC-voltage source is connected to a noise diode connected directly to the ANT-input in the pre-amplifier block. This direct connection is desirable as attenuation changes the noise temperature. The signal is led from the RX_1 output to a spectrum analyzer. An LNA may be needed in between the DDU output and the spectrum analyzer, as the spectrum analyzer might not be sensitive enough for the cold noise source.

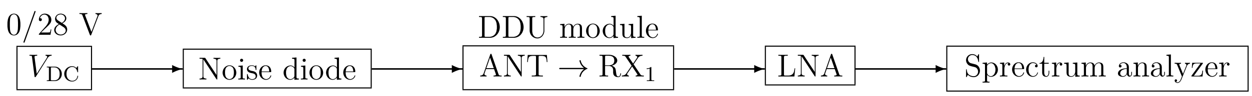


Figure 6: Noise temperature measurement setup

The measurement itself is carried out measuring two power levels required in the Y-parameter; when the DC-voltage is off/shorted ("cold") and on ("hot"). As for the SA settings, we are measuring noise at a single frequency (using zero-span): a very weak, random signal.

Sampo Salo, 79543L
Tuomas Leinonen, 84695P
Huy Nguyen, 411330

Thus, input attenuator should be disabled, and minimum resolution bandwith used. A large averaging factor, say a thousand, is also beneficial. The measurement may take a few minutes, and it's OK; there are only two measurements to be made.

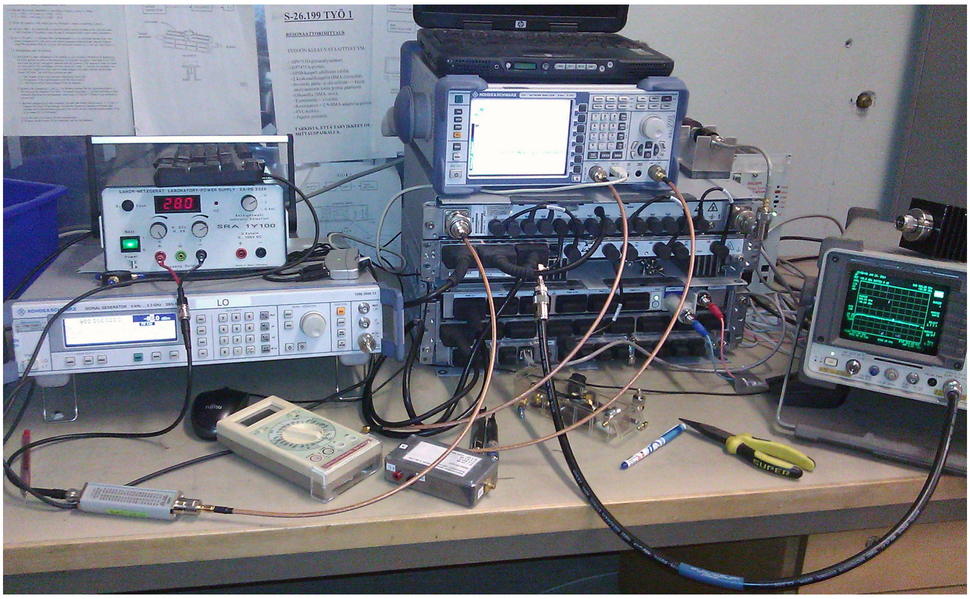


Figure 7: Receiver under study.

2.4 Sensitivity

In the sensitivity measurement, we're trying to measure the minimum input power at ANT input that results in a detectable signal above the noise floor in the ouput of the DDU module. For this, a measurement setup identical to the one used in the first task may be used, as is shown in the following figure (Fig 8). This time though it's more than likely that an attenuator is required.

DDU module

Signal generator → ANT $\rightarrow$ RX$_1$ → Sprectrum analyzer

Figure 8: Measurement setup used in the sensitivity measurement.

The measurement starts by measuring the noise floor at 900 MHz without any signal we're hoping to detect. That is, the RF power is switched off at the generator. Then we turn on an input signal that's some dBs sensitivity of -112.5 dBm. We gradually increase the power until the signal-to-noise ratio is no less than the 10 dB required by the standard. One could also measure the power required to beat the noise just barely, and add the SNR later on if $P_{\mathrm{out}}(P_{\mathrm{in}})$ relation is assumed to be ideal.

Sampo Salo, 79543L
Tuomas Leinonen, 84695P
Huy Nguyen, 411330

Since it's a GSM system, we use the measurement settings as they are defined in the standard. They are as follows: an averaging factor of 500, zero span and 30 Hz video and resolution bandwidths. As the spectrum analyzer input power is expected to be less than -80 dBm ($P_{\mathrm{SA}} \approx P_{\mathrm{DDU,\,min}} + G_{\mathrm{DDU}} = -112.5\ \mathrm{dBm} + 24.4\ \mathrm{dB} = -88.1\ \mathrm{dBm}$), it's best to disable the input attenuator.

3 Results

TODO: Huy and Sampo (general results and intro to more specific results)

3.1 1 dB compression point

3.2 Frequency response

Wasn't this already covered in the first laboratory assignment as a part of the diplexer characterization? Fig. 10 presents the measurement setup used there. The DDU module is simply connected between the two ports of a precalibrated VNA; ANT and RX_1 connectors of the DDU module are connected to ports 1 and 2 of the VNA, respectively. In the VNA, measurement power shoud be as high as possible due the stop band-attenuation, yet simultaneously small enough not to cause compression in the pass-band (in neither the VNA nor in the pre-amp itself).

The following figure (Fig. 11) shows the results obtained in the first lab works with a transmit power of -20 dBm in the VNA (using the B-half of the BS and connecting the ports vice versa). In the figure, in addition to GSM RX and TX bands (in red), both 3 dB (in blue) and noise (in green) bandwidth of the pre-amp block are visualized. This noise bandwidth visualization is somewhat questionable as it's a purely theoretical concept, but is nevertheless shown for scale. The shown noise bandwidth is found using a numerical approximation with $|S_{12}|$ of the formula given in the lecture supplement handout:

$$B_\mathrm{n} = \frac{1}{G_\mathrm{T,\,max}} \int_0^\infty G_\mathrm{T}(f)\, df. \tag{1}$$

The noise bandwidth shown is less than the actual band since we cannot use infinite frequency range. Frequency range of $850 \ldots 1000$ MHz with $|S_{12}|_\mathrm{max} = 24.4$ 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. 11 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.

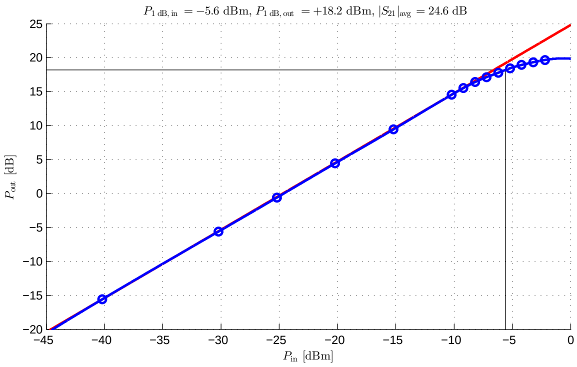
3.3 Noise Temperature

TODO: Huy and Sampo

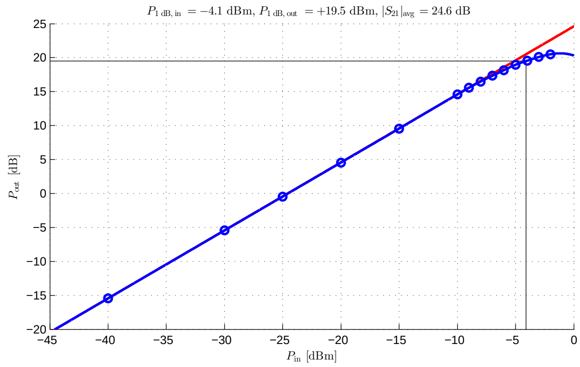
3.4 Sensitivity

TODO: Huy and Sampo

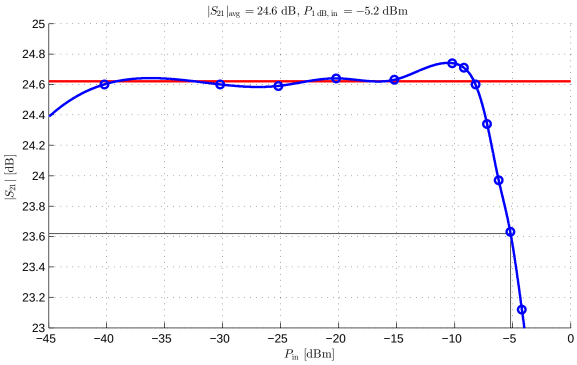
Sampo Salo, 79543L
Tuomas Leinonen, 84695P
Huy Nguyen, 411330



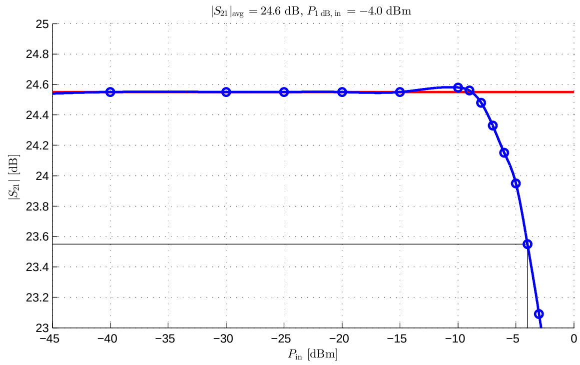
(a) $P_{\mathrm{out}}(P_{\mathrm{in}})$ using SG & SA



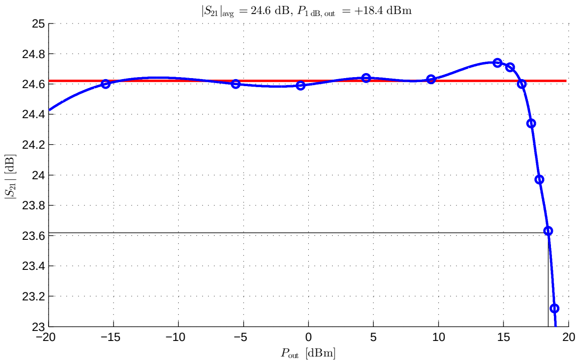
(b) $P_{\mathrm{out}}(P_{\mathrm{in}})$ using VNA



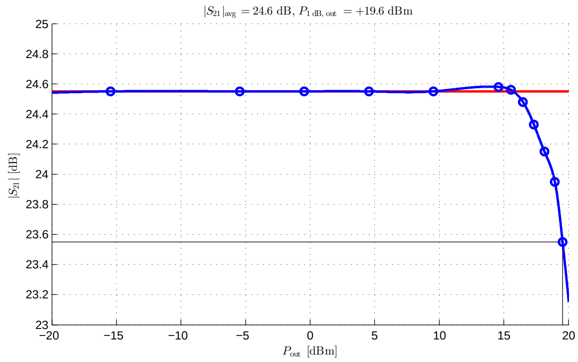
(c) $G(P_{\mathrm{in}})$ using SG & SA



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



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



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

Figure 9: Results from the 1 dB compression point measurements. Ideal behaviour is shown with red straights, measuremets with blue markers and spline inter-/extrapolant in blue.

Sampo Salo, 79543L
Tuomas Leinonen, 84695P
Huy Nguyen, 411330

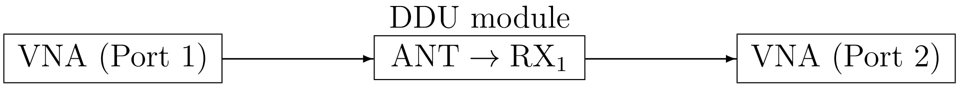


Figure 10: Measurement setup used when determining the gain of the pre-amplifier block.

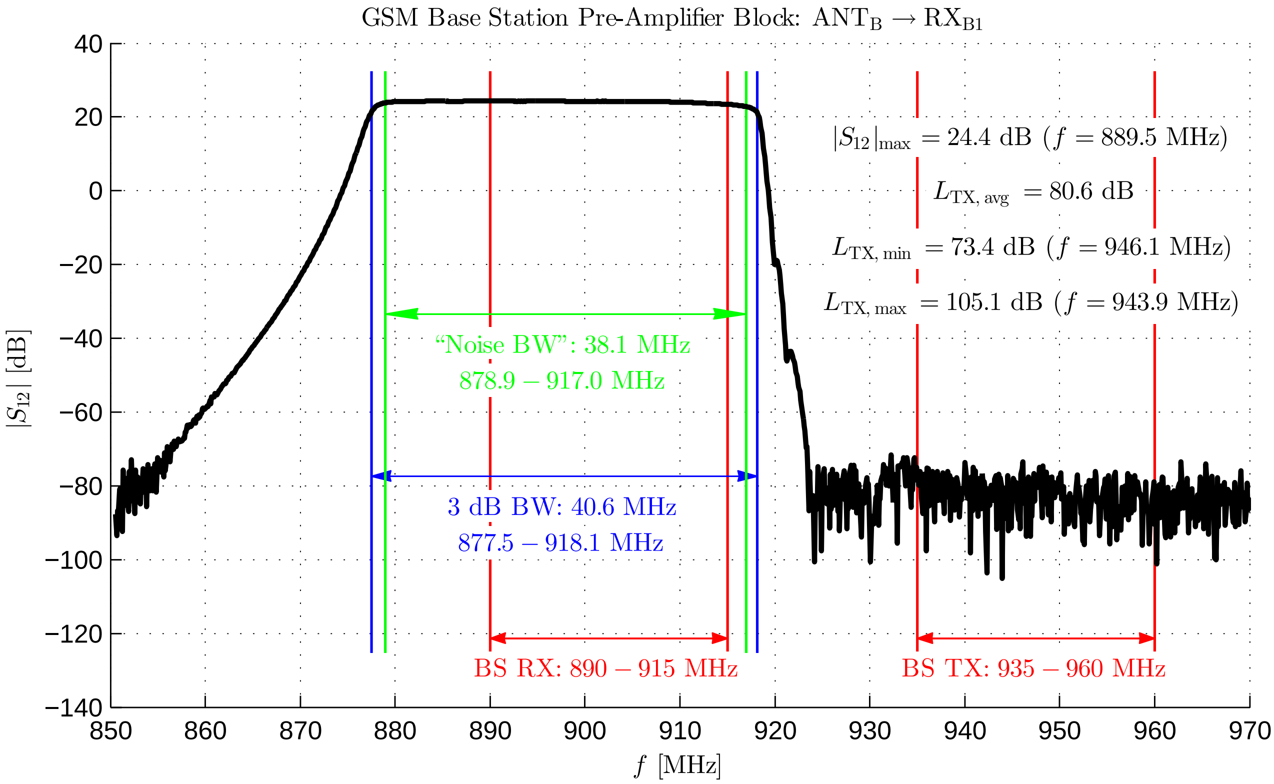


Figure 11: Results from the diplexer characterization.

3.5 Dynamic range

TODO: Huy and Sampo

Sampo Salo, 79543L
Tuomas Leinonen, 84695P
Huy Nguyen, 411330

4 Error estimates

TODO: Huy and Sampo (make additions, corrections, change the style to avoid excess repetition etc.)

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 ±6 dB. On the other hand, the document gives also representative values of amplitude uncertainties, which in our case yields about ±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 ±0.5 dB.

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

Sampo Salo, 79543L
Tuomas Leinonen, 84695P
Huy Nguyen, 411330

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 $-50 \ldots 0$ dB is better than 0.2 dB (0.3 dB for powers of $-50 \ldots -70$ 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 $-100 \ldots +4$ dBm).

In conclusion, two things are assumed. First, calibration is assumed to cancel the systematic errors arising from cables and connectors. Second, random errors are cancelled with averaging. 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

See lecture handout supplement.

Sampo Salo, 79543L
Tuomas Leinonen, 84695P
Huy Nguyen, 411330

5 Conclusions

TODO: Huy and Sampo

Sampo Salo, 79543L
Tuomas Leinonen, 84695P
Huy Nguyen, 411330

6 Feedback

TODO: Huy and Sampo (not all devices are listed in the instructions sheet, learning from feedback)

Sampo Salo, 79543L
Tuomas Leinonen, 84695P
Huy Nguyen, 411330

References

[1] C. Icheln, S. Khanal, *GSM Receiver laboratory assignment instructions*, S-26.3120 Laboratory course in Radio Engineering course material.

[2] C. Icheln (edited), *Lecture supplement handout*, S-26.3120 Laboratory course in Radio Engineering course material.

[3] Agilent, Spectrum Analysis Basics, Application Note 150. Available online at `http://cp.literature.agilent.com/litweb/pdf/5952-0292.pdf` [Retrieved: Jan 2nd, 2014].

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[5] R&S ZVL Vector Network Analyzer Specifications, Version 06.00, Dec 2008. Available online at `http://www.upc.edu/pct/documents_equipament/d_160_id-655-2.pdf` [Retrieved: Jan 2nd, 2014].