S-26.3120 Radio Engineering, laboratory course

Lab 2: GSM Base Station Receiver

Final report

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1 Introduction

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

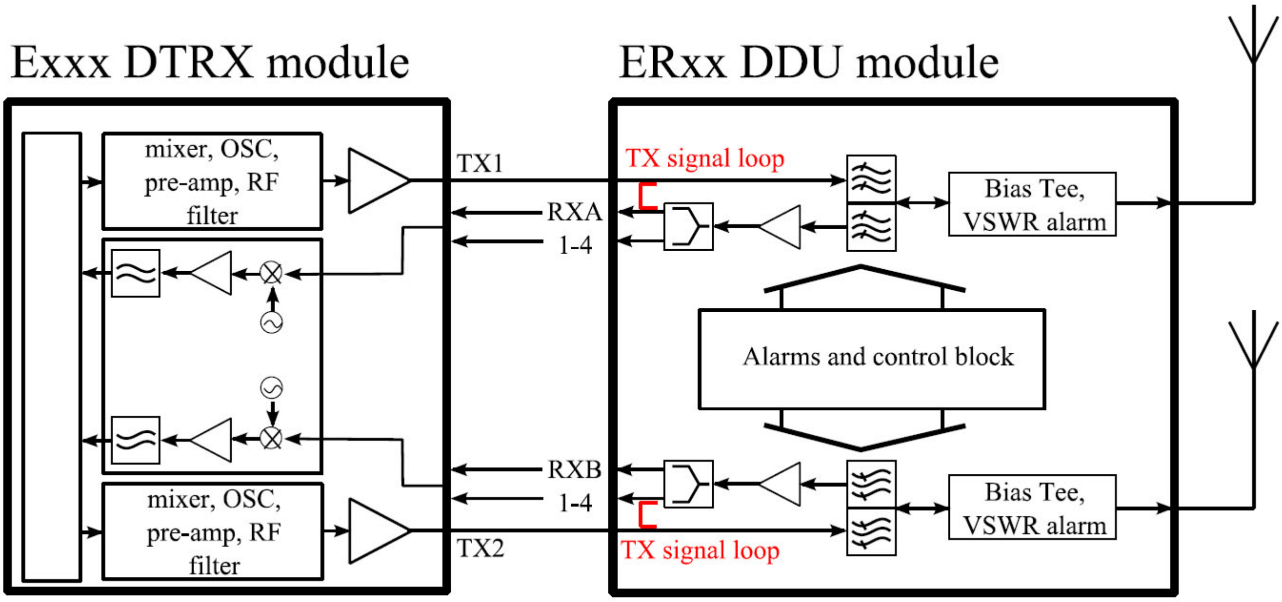

Figure 1: Receiver under study.

2 Measurement steps

TODO: Tuomas (corrections etc.)

2.1 1 dB compression point

The measurement setup suitable for this measurement is shown in Fig. 2. A signal generator is used as a signal source, and the generated signal is passed through the DDU module before detection with a (precalibrated) spectrum analyzer. The input and output connections used in the DDU module are ANT and RX_1, respectively. An attenuator is used between the generator and the DDU module, if necessary. While the operator's manual of the R&S SML03 signal generator does not explicitly mention the power range, the testing range defined in the *Performance Tests* suggests a (reliable) minimum output power level of -80 dBm.

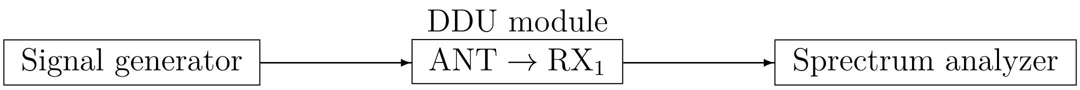

Figure 2: Measurement setup used in the first measurement task.

The measurement itself is basically a power sweep at a constant frequency of $f = 900$ MHz. We start off with a power level well above the receiver sensitivity level ($P_{\text{min, BS}} \approx -112.5$ dBm), say -100 dBm. From there we gradually increase the power in suitable steps of $0.1 \ldots 10$ dB, depending on the current position on the $P_{\text{out}}(P_{\text{in}})$ transfer curve. That is, we'll start with a big step size and decrease it as we get close to the "sweet spot".

This power sweep is continued until we experience a compression of more than the required 1 dB. While one could just measure the input power required for the output to be 1 dB less than the expected value, this type of "on-the-fly" comparison is prone to error. Thus it's better to measure a full power sweep and leave the comparison to be done after the measurement and against a fitted straight representing ideal behaviour.

Since we are dealing with a GSM receiver, we may use the same settings for the spectrum analyzer as we did in the first labs – except for the averaging factor. They were as follows: an averaging factor of 500, zero span and 30 Hz video and resolution bandwidths. An averaing factor of 500 would make the measurement quite lengthy, especially if dense power "grid" is used. Averaging over 100 measurements will most likely be more than adequate. Depending on the 1 dB compression point, we might need to watch out for compression in the spectrum analyzer. This is taken care of by altering the input attenuation.

The effect of the cables and the attenuator may be measured using a VNA (could be used for the entire measurement aswell), or using the SA by making the whole measurement relative. In a relative measurement, the power is measured again when the DDU module is by-passed to account only for the cables and the possible attenuator. This also required to know the real input power.

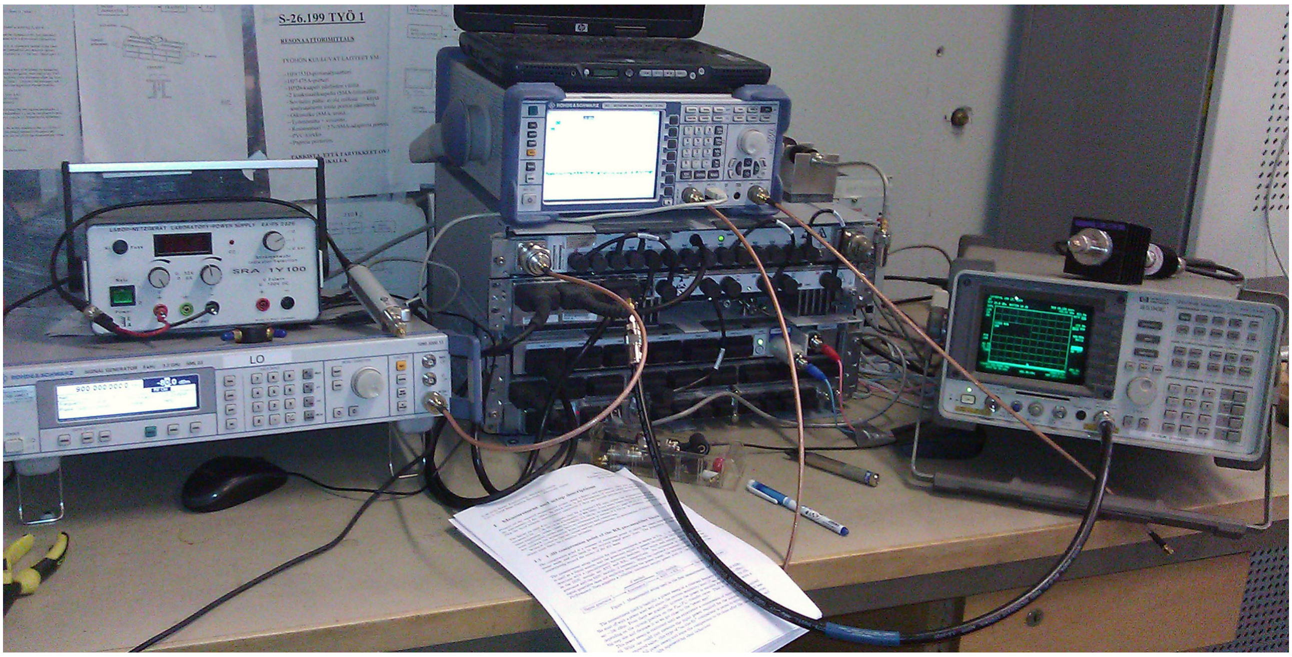

Figure 3: Receiver under study.

2.2 Frequency response

Wasn't this already covered in the first laboratory assignment as a part of the diplexer characterization? Fig. 5 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. 6) 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 $|S_{12}|_{\max} = 24.4$ 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.

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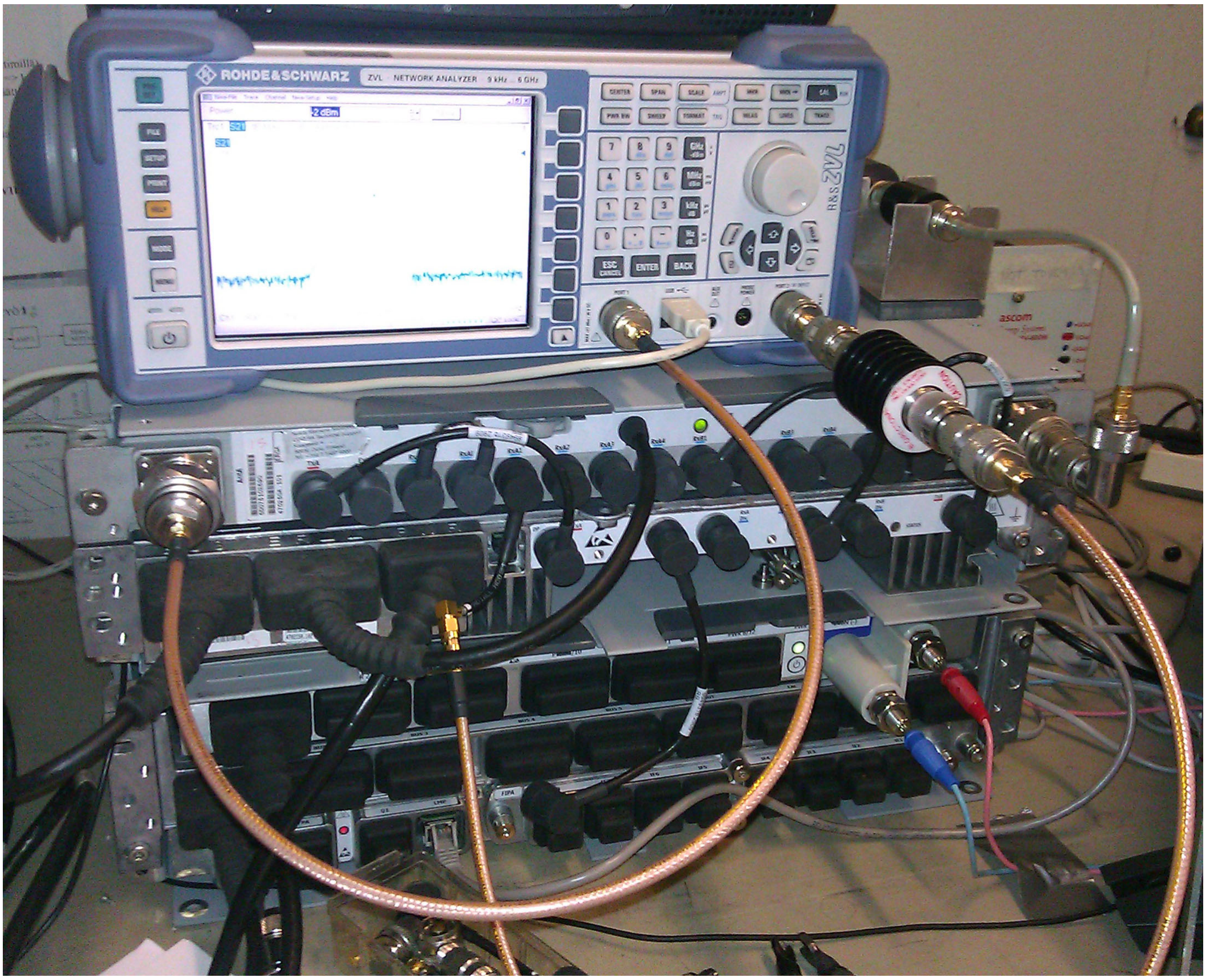

Figure 4: Receiver under study.

DDU module

VNA (Port 1) ⟶ ANT → RX_1 ⟶ VNA (Port 2)

Figure 5: Measurement setup used when determining the gain of the pre-amplifier block.

In the graphical approximation method we need to investigate the effect of frequency roll-off speed. From Fig. 6 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.

If a VNA is not available as the instructions suggest, the task is quite laborious and absurd, just to be honest. Nevertheless, the procedure is listed here for completeness. We would need

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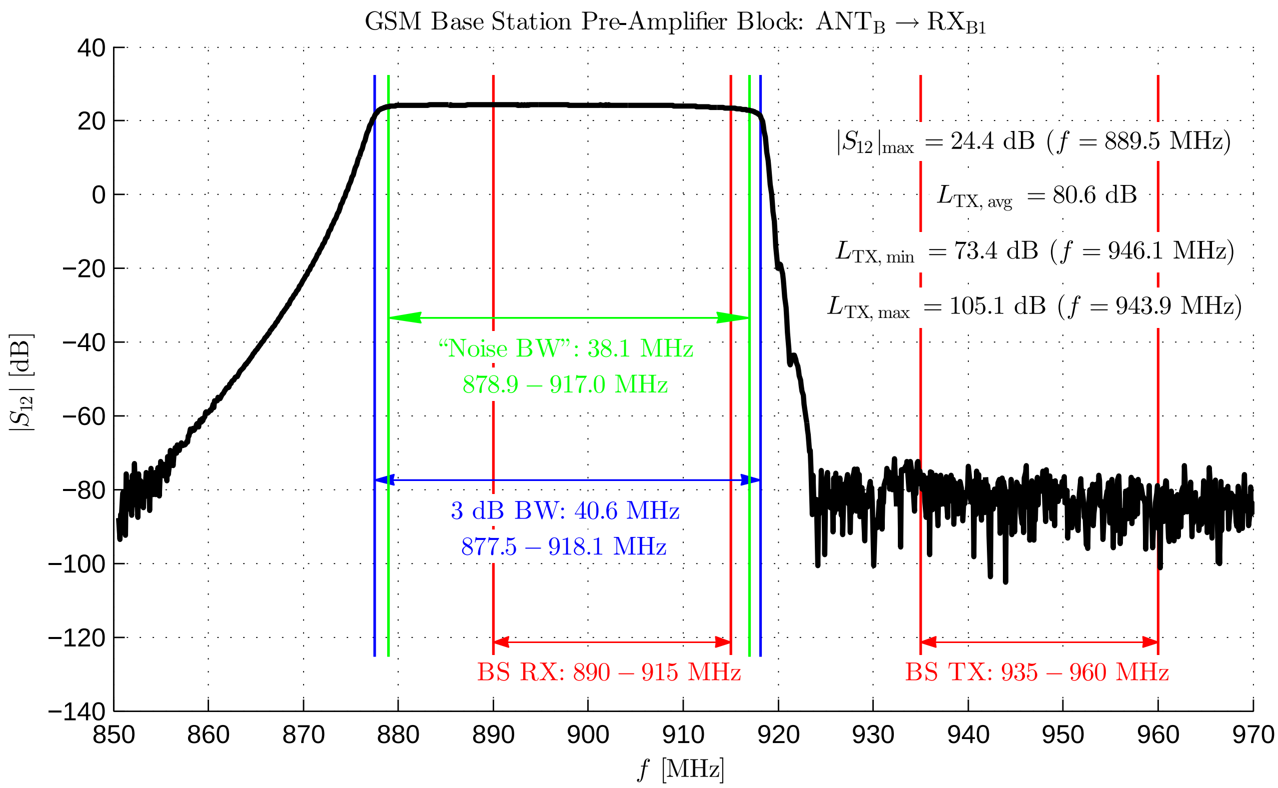

Figure 6: Results from the diplexer characterization.

to simulate the VNA function manually using a signal generator and a power meter or a signal analyzer, leading to a setup like the one shown in Fig. 2. The output power is kept constant while frequency is swept over the range, taking notes on the relative power levels observed in the detector.

2.3 Noise temperature

ENR = 21.48 dB

In the third measurement task, we'll use a setup shown in Fig. 7. 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.

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. 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,

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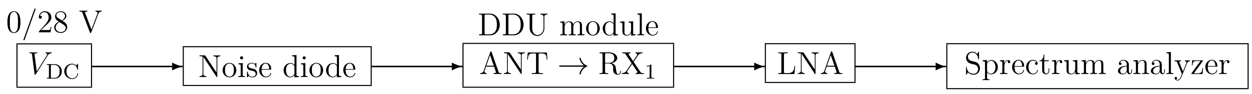

Figure 7: Noise temperature measurement setup

and it's OK; there are only two measurements to be made.

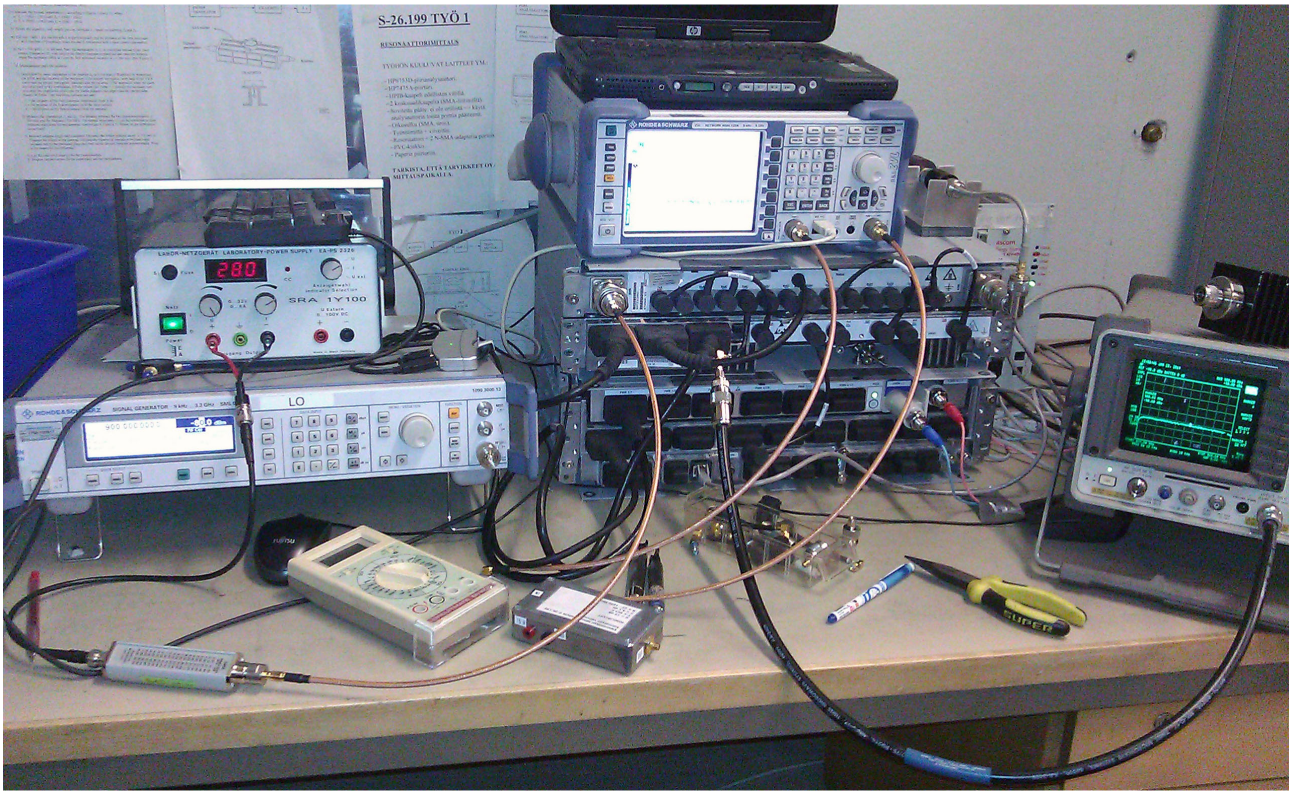

Figure 8: Receiver under study.

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 9). This time though it's more than likely that an attenuator is required.

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

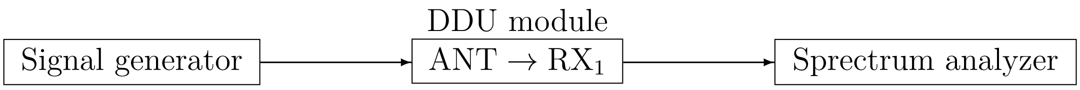

Figure 9: Measurement setup used in the sensitivity measurement.

measure the power required to beat the noise just barely, and add the SNR later on if $P_{\text{out}}(P_{\text{in}})$ relation is assumed to be ideal.

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 ($P_{\text{SA}} \approx P_{\text{DDU, min}} + G_{\text{DDU}} = -112.5\ \text{dBm} + 24.4\ \text{dB} = -88.1\ \text{dBm}$), it's best to disable the input attenuator.

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3 Results

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

3.1 1 dB compression point

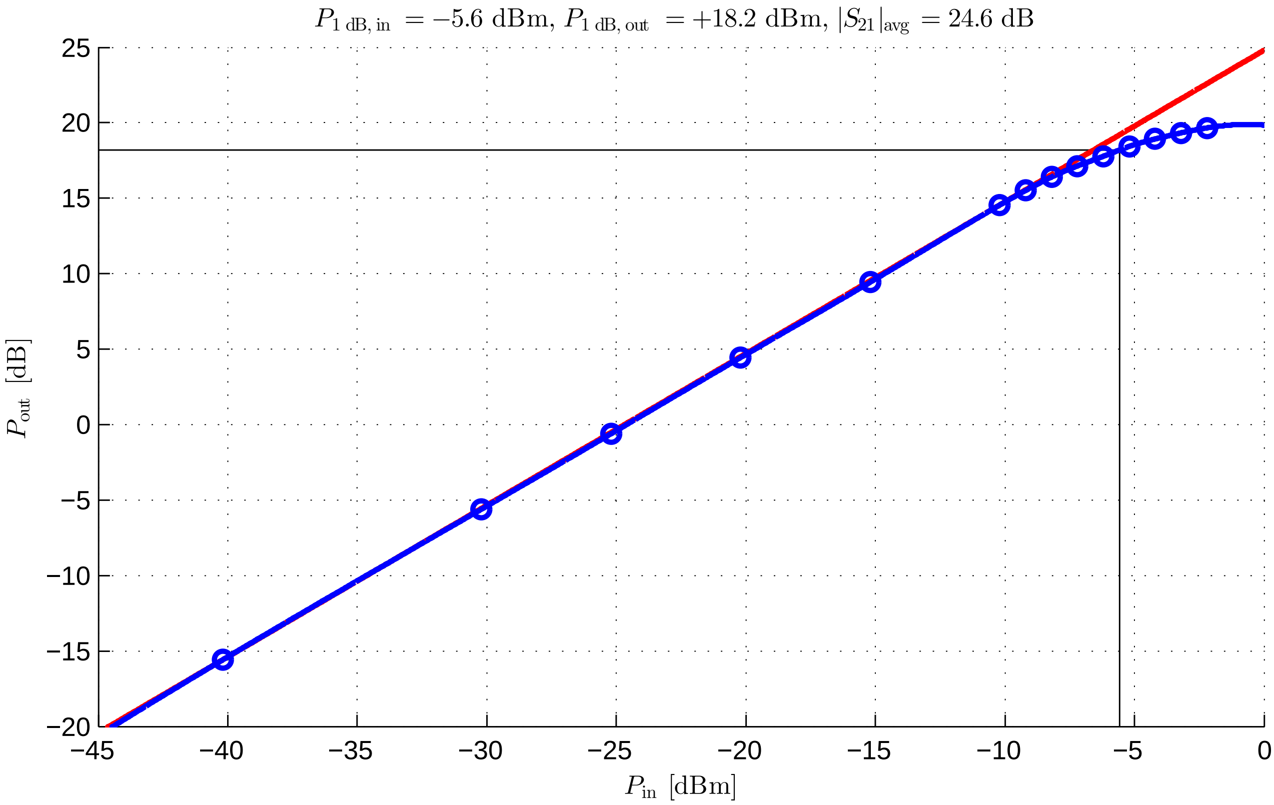

Figure 10: Results from the diplexer characterization.

3.2 Frequency response

3.3 Noise Temperature

TODO: Huy and Sampo

3.4 Sensitivity

TODO: Huy and Sampo

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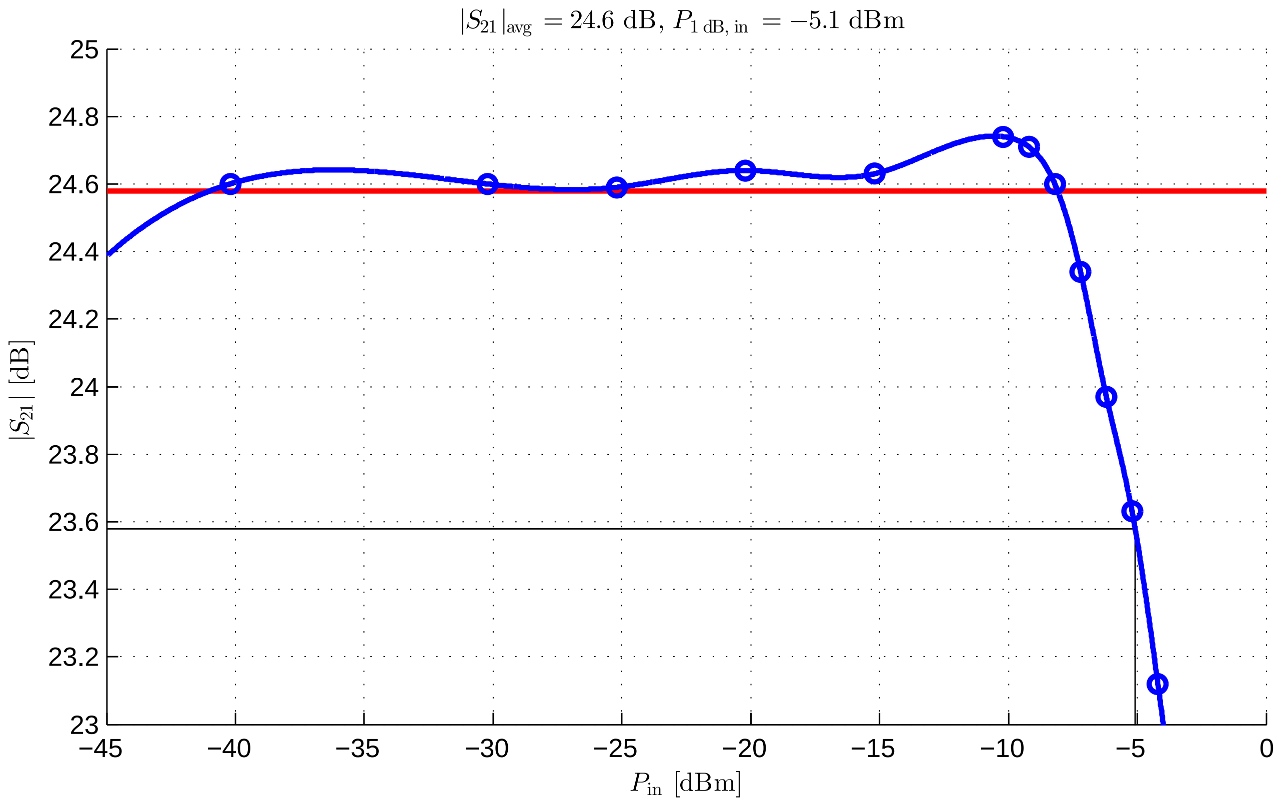

Figure 11: Results from the diplexer characterization.

3.5 Dynamic range

TODO: Huy and Sampo

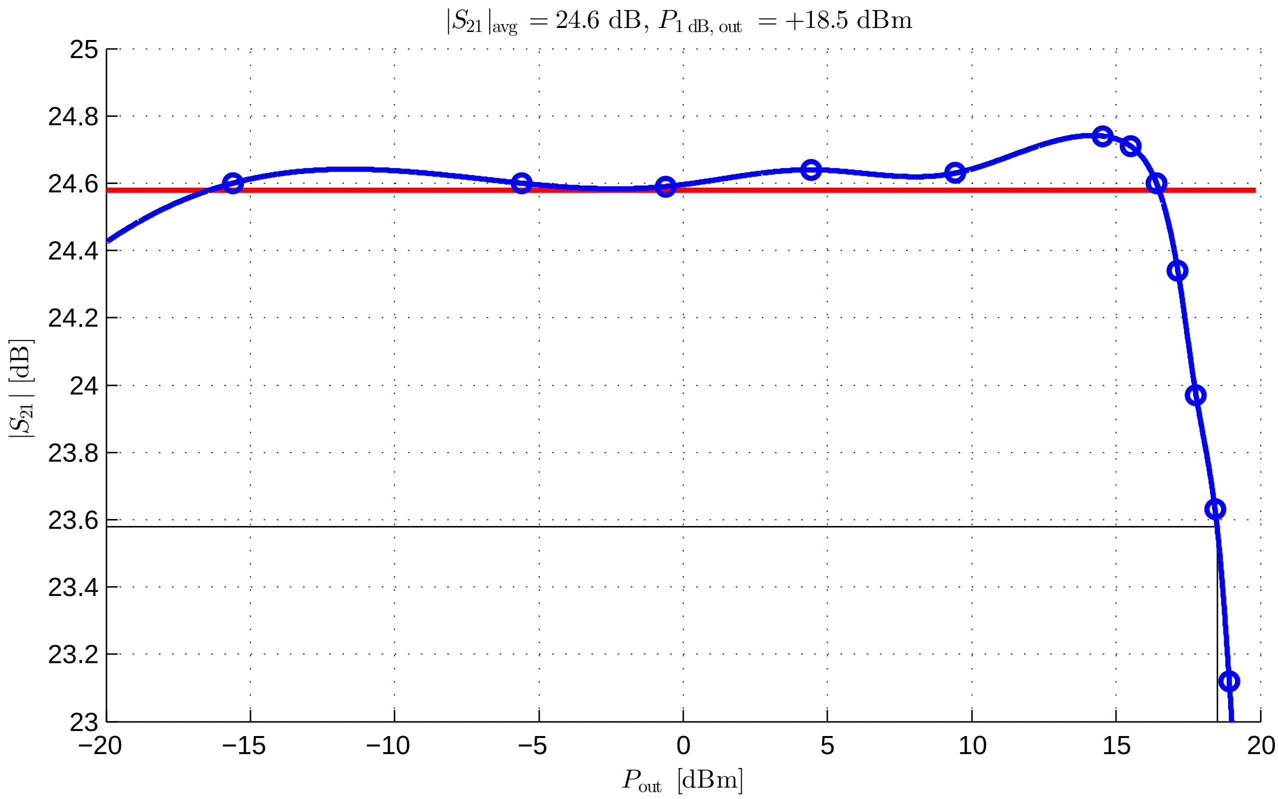

Figure 12: Results from the diplexer characterization.

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,

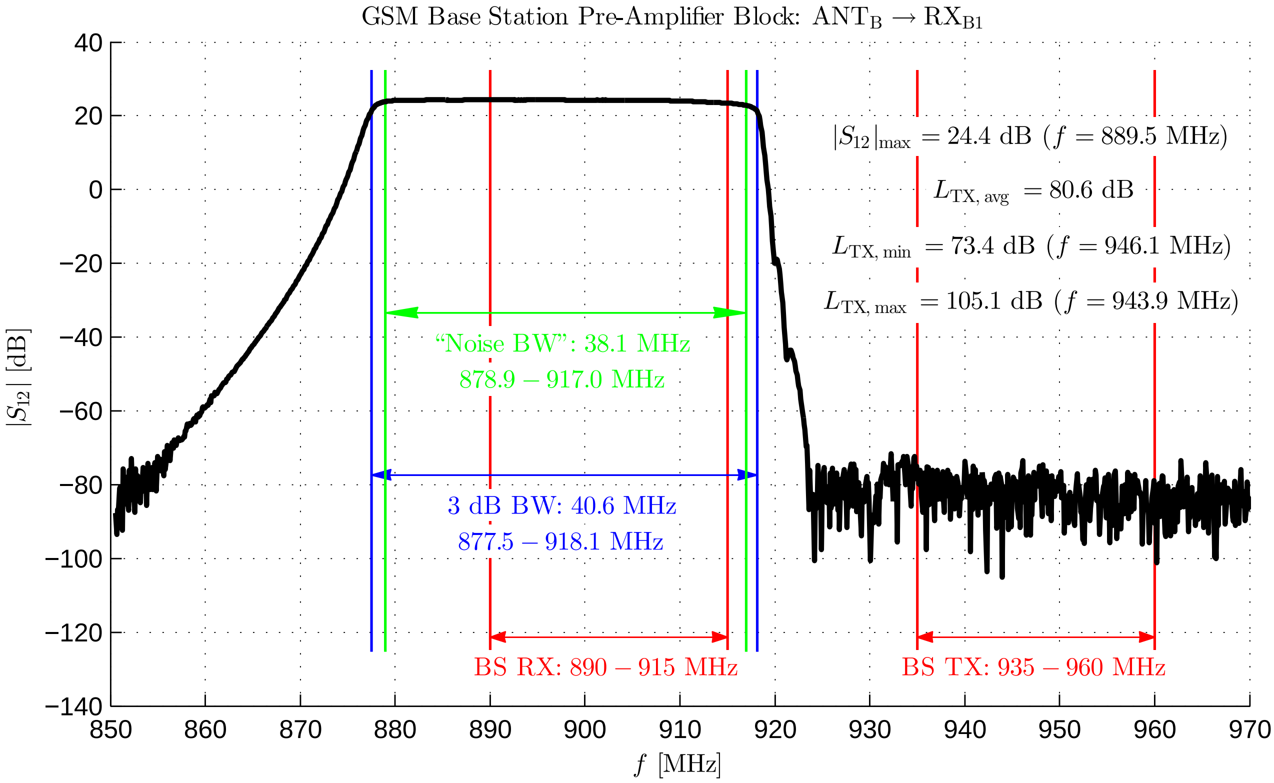

Figure 13: Results from the diplexer characterization.

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.

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. 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.

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5 Conclusions

TODO: Huy and Sampo

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6 Feedback

TODO: Huy and Sampo

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

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