S-26.3120 Radio Engineering, laboratory course

Lab 2: GSM Base Station Receiver

Pre-study report

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1 Measurement and setup descriptions

Present all the required measurement setups (draw a figure) and procedures. Take into account the attenuation of the cables. In which range is the attenuation of coaxial cables at 900 MHz? Pick the most suitable measurement equipment if there are several options to choose from.

The figure on page 8 in [1] suggests that for a standard PE coax cables the attenuation ranges between $0.32 \ldots 1.36$ dB/m at a frequency of 900 MHz. Even lower losses may be achieved with more expensive cables (down to roughly 0.2 dB/m, as suggested on page 29 in [1]). Similarly, some maltreated cables may have an attenuation in excess of 2 dB/m. In addition, one should not overlook the attenuation from connectors and connecting.

When it comes to this lab course and our measurements, an attenuation of roughly 0.5 dB/m would most likely be a realistic estimate.

1.1 1 dB compression point of the RX pre-amplifier block

The compression point is a measure of maximum power at which the input amplifier works in linear mode and sets limit to the received signal power level. The frequency of 900 MHz is conveniently around the center of the RX band.

The measurement setup suitable for this measurement is shown in Fig. 1. 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 1: 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.

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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 avearing 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.

1.2   Gain of the RX pre-amplifier block

The bandwidth of the RX block should account for the GSM specification for the RX band limits. Measure the 3 dB bandwidth of the block and determine approximately the equivalent noise bandwidth (graphically using the additional material) and the TX-band (stop band) attenuation.

Wasn't this already covered in the first laboratory assignment as a part of the diplexer characterization? Fig. 2 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).
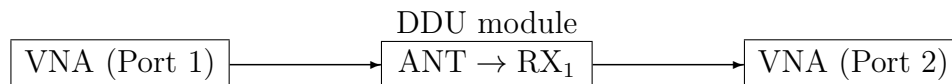

Figure 2: Measurement setup used when determining the gain of the pre-amplifier block.

The following figure (Fig. 3) 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 $850\ldots1000$ MHz with $|S_{12}|_{\mathrm{max}} = 24.4$ dB was used instead.

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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.
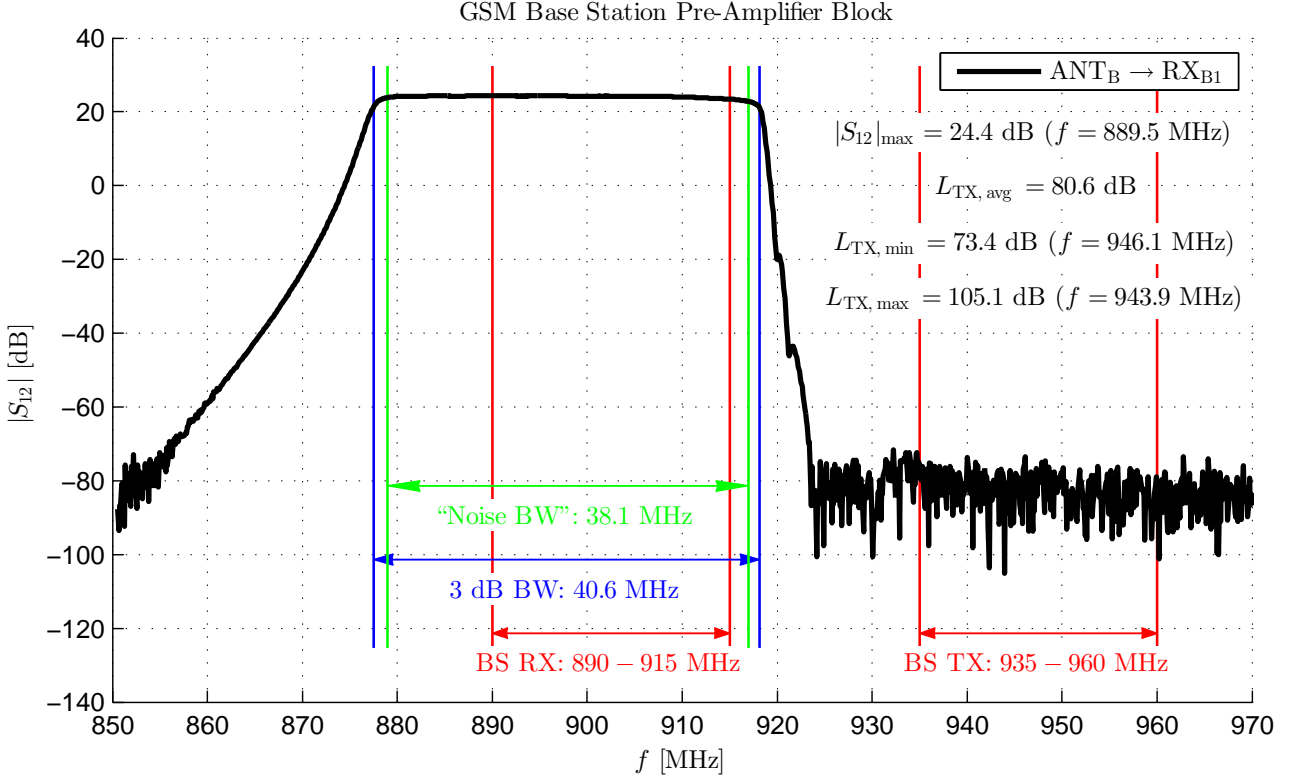

Figure 3: Results from the diplexer characterization.

In the graphical approximation method we need to investigate the effect of frequency roll-off speed. From Fig. 3 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 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. 1. The output power is kept constant while frequency is swept over the range, taking notes on the relative power levels observed in the detector.

1.3   Noise temperature of the RX pre-amplifier block

Determine the noise temperature of the RX block (consisting of bias tee, diplexer and pre-amplifier) with the Y-coefficient method. Use the noise diode as active noise source (and as

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passive noise source at room temperature when supply voltage is switched off).

In the third measurement task, we'll use a setup shown in Fig. 4. 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 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.
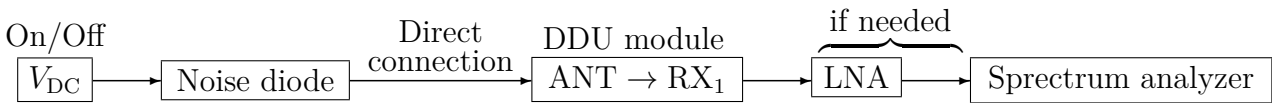

Figure 4: Noise temperature measurement setup

In room temperature, a matched load (an approximation in this case) outputs a noise power of -159 dBm for a 30 Hz band. With a maximum gain of 24.4 dB and a total noise figure of 3.9 dB, the expected noise level is around -131 dBm. This value is considerably lower than the given sensitivity of the SA: $P_{\text{SA, min}} < -125$ dBm when $B_{\text{res.}} = 30$ Hz. LNA could be used to boost the signal to a more appropriate level as it's effect on the noise temperature could be compensated using the Friis' noise formula.

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

1.4 Sensitivity of the RX pre-amplifier block

Measure the sensitivity of the RX block using suitable equipment.

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

Figure 5: Measurement setup used in the sensitivity measurement.

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The measurement starts be measing 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.

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 (-112.5 dBm $+ 24.4$ dB $= -88.1$ dBm), it's best to disable the input attenuator.

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2   Pre-study calculations and related tasks

The following subsections will present answers to pre-study tasks $2.2 - 2.4$.

2.1   Mismatch attenuation

A signal generator is connected to the input of the RX pre-amp block. The VSWR (voltage standing wave ratio) of the pre-amp is 2.0 and the VSWR of the output of the signal generator is 1.6.

   a) *What is the range of additional attenuation due to this mismatch in the measurement of the pre-amp block?*

   b) *In what range is the attenuation due to mismatch, when an ideal 10 dB attenuator is connected between the signal generator and the pre-amp block? What is the benefit/drawback of inserting this attenuator?*

Text here.

2.2   Noise temperature

The noise temperature of the pre-amp block is determined using the Y-coefficient method. The noise level of the spectrum analyzer HP8596E is $P_{\mathrm{SA}} < -125$ dBm when the input is matched and the resolution bandwidth is 30 Hz.

   a) *How much gain is required from the LNA in order to measure the noise temperature with the HP8596E? The noise figure of the amplifier is 2.8 dB and the attenuation of the bias Tee and the diplexer is 0.7 dB and 0.4 dB, respectively.*

   b) *Does the order (i.e. which is first in the chain) of the amplifier, bias tee and the diplexer in the pre-amp block have any influence on the result of Y-coefficient measurement? If yes, say why.*

Text here.

2.3   Requirements with evolving standards

Discuss briefly the major changes in the requirements for the RF performance of the blocks in the RX chain when we move from 2G to 3G to 4G systems.

Write (at least) these out in a table and conclusions -like manner, for example.

    More frequency bands, higher bandwidth, modulation methods, sensitivity, linearity requirements, carrier aggregation, multiaccess method, FDD/TDD

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References

[1] Huber + Suhner, *RF Cables*, Edition 2013/09. Available online at `http://ipaper.ipapercms.dk/HUBERSUHNER/Technologies/Radiofrequency/RFCablesEN/` [Retrieved: January 10th, 2014].