Exercise 5: Power amplifier measurement

The objective of this laboratory exercise is the calibrated measurement of important parameters of a power amplifier. This includes performance parameters like gain, output power, input matching, efficiency, intermodulation, etc.

Laboratory preparation

This exercise is based on the contents of Exercise 3 (spectral analysis). Furthermore, you should be familiar with Chapters 3 and 8 of the lecture notes of "RF Techniques".

Laboratory procedure

For power amplifier measurements a setup according to Figure 1 shall be used. The RF signal source can be modulated for further amplifier characterization in addition to utilizing sinusoidal signal (single tone, CW continuous wave). Such measurements are for example two-tone experiments as well as the measurement of digitally modulated signals.

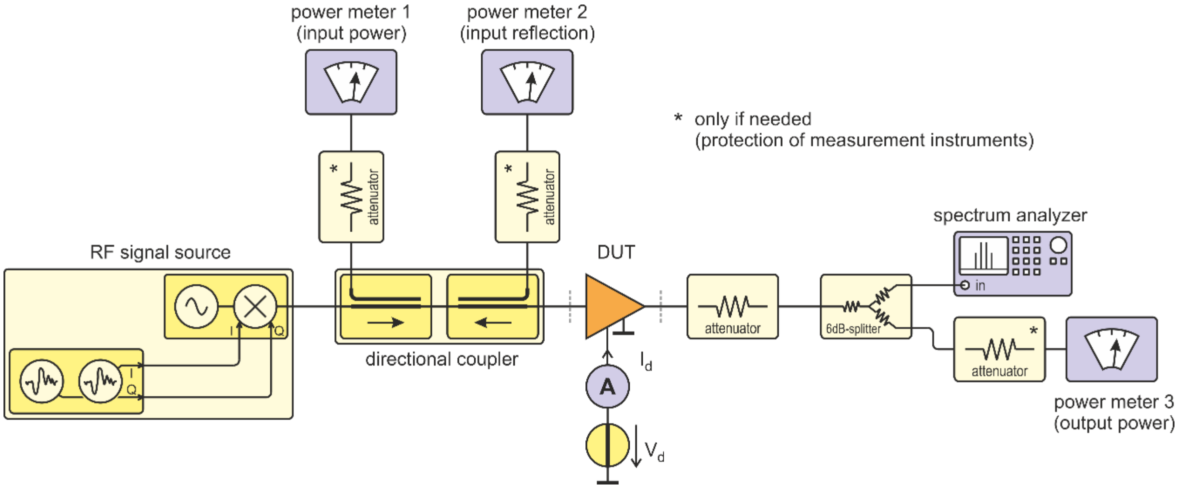

Figure 1: Measurement setup for power amplifier characterization

The power meters 1 and 2 are used to measure the input power and reflected power of the DUT (device under test). By the use of the directional couplers, the forward and reflected wave can be investigated separately. The power attenuator reduces the output power of the DUT for not overloading the measuring equipment (spectrum analyzer and power meter 3).

Please note that power sensors must not be overloaded. Too much input power leads to an immediate damage of the sensor. Therefore, consider the worst case input power into the sensor (e.g. oscillating power amplifier). Make use of proper attenuators so that damage of the sensor can be excluded with certainty. CAUTION: The amplifier used in this exercise can be damaged at input powers greater than P_{in} > 0dBm. **Do not turn on the setup before you were told so by your supervisor!**

The entire setup has to be calibrated before accurate measurements can be accomplished. This applies to all elements in the setup introducing attenuation (e.g. cables, adapters, coupling loss of directional couples, etc.). Since there is no network analyzer available in this exercise, the calibration shall be done in a scalar way by the use of power sensors.

As the DUT (device under test), a power amplifier (Mini-Circuits ZHL-30W-252+) is used. This amplifier operates in the frequency range from 0.7 to 2.5 GHz and provides a gain of about 50 dB with a typical maximum output power of $P_{out,3dB}$ = +46 dBm (!!!). A switching power supply (28 V) is mounted on top of the amplifier.

All measurements in this exercise shall be carried out at a frequency of $f = 2.45$ GHz.
Never turn on the amplifier without having it terminated on input and output!

Calibration of the power sensors

Before starting the calibration of the whole test setup, including power meter, all of the connected power sensors need to be calibrated. The power sensors have to be connected to the power meter for starting the calibration procedure. The calibration is always composed of zeroing and level calibration, resp. The former is used to compensate a potential offset of the power sensor so that high measurement accuracy for small power levels can be achieved (of course no signal is applied to the sensor at this step). For the level calibration a defined power level is provided to the power sensor by the power meter. This will set the absolute accuracy of the power meter measurement.

It is important for the power meter to know the measurement frequency. This allows the power meter to automatically correct the frequency response of the sensor using a factory preset table. Please note that the power meter is not measuring frequency-selective. For example: Although $f = 2.45\,\text{GHz}$ is set, all frequencies with $f \neq 2.45$ GHz add up to the power measurement.
Therefore, especially in the measurement of power amplifiers (where the harmonic content is not known in general), there is always the need for an additional spectrum analyzer that can be used to check for other spectral content. With this information a statement can be made whether the display of the power meter shows correct values or not.
Please consider which frequencies will be using during the measurements already in the calibration phase. In the case of a frequency sweep, all components for each (!) frequency point have to be calibrated.

Calibration of the measurement setup – DUT's input side

The directional coupler takes care of splitting the signal on the cable between source and DUT into the forward and reflected power (see figure 1). Due to the coupler's coupling losses and other losses in the setup, both power meters 1 and 2 only show a fraction of the power levels at the DUT input. Thus, it is the goal of this calibration to find correction values (so called offsets) in order that power meter 1 displays exactly the forward going power (into the DUT's input) and power meter 2 exactly displays the reflected/reverse going power (from the DUT's input).

This can be done by the following steps:

Step 1: By replacing the DUT's input by power meter 3, this power meter will show the correct forward going power which is made available to the DUT (Figure 2). Please note that this power differs from the source's output power due to cable losses and the coupler's main line insertion loss.

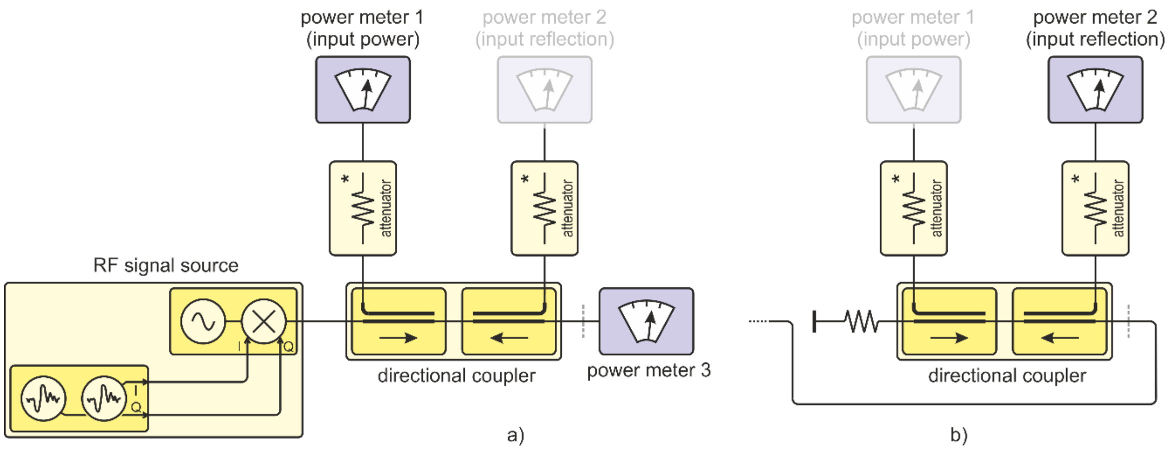

Figure 2: Characterization of the directional couplers

Now, the power levels of power meter 3 and power meter 1 are compared and an offset is calculated for power meter 1. Assume the following example:

source power:	0.0 dBm
DUT's input power (measured by power meter 3):	–1.7 dBm
power meter 1 readout:	–15.8 dBm

To have power meter 1 showing the DUT's input power, it should also show the value of –1.7 dBm, thus an offset of (–1.7 dBm) – (–15.8 dBm) = +14.1 dB must be configured for power meter 1. Then, the power meter 1 readout directly shows the DUT's input power:

power meter 1 readout (incl. +14.1 dB offset): –1.7 dBm

It is important to note that for all measurements of the DUT, the DUT's input power has to be read from power meter 1 and not from the source!

Step 2: To calculate the offset needed for power meter 2, a signal has to be injected from the DUT's input reference plane (to emulate a reflected/reverse travelling wave). This is shown in Figure 2b). It is very important that the injected signal power has to be precisely known and needs to be measured in advance. Trusting the RF source's output power display is much too inaccurate for the calibration!

To measure the precise power level, a power meter must be used (Figure 3). It is essential for the calibration to measure the power exactly at the DUT's input reference plane. You are not allowed e.g. to measure the source's output power directly at the source but connecting the source with a long cable (with unknown losses) to the calibration setup (Figure 2b) – this would void the calibration!

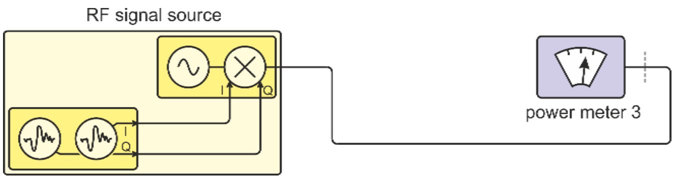

Figure 3: Measurement of signal generator output power

The calculation of required offset for power meter 2 is done similar to power meter 1: Power meter 3 has shown the correct value of the reflected power at the DUT's input reference plane. Therefore, the offset of power meter 2 has to be set to a value so that the readout from power meter 2 will become identical to the measurement of power meter 3.

Question	• Can you think of a faster way to find the offset for power meter 2? • The calibration for power meter 1 and 2 is called a scalar calibration. Is this calibration perfect? What are the drawbacks?

Calibration of the measurement setup – DUT's output side

Having calibrated the input power meters, it is a very simple task to calibrate the output power meter and the spectrum analyzer. Instead of the DUT a thru-connection is used, thus the DUT's input and output reference plane are merged (Figure 3).

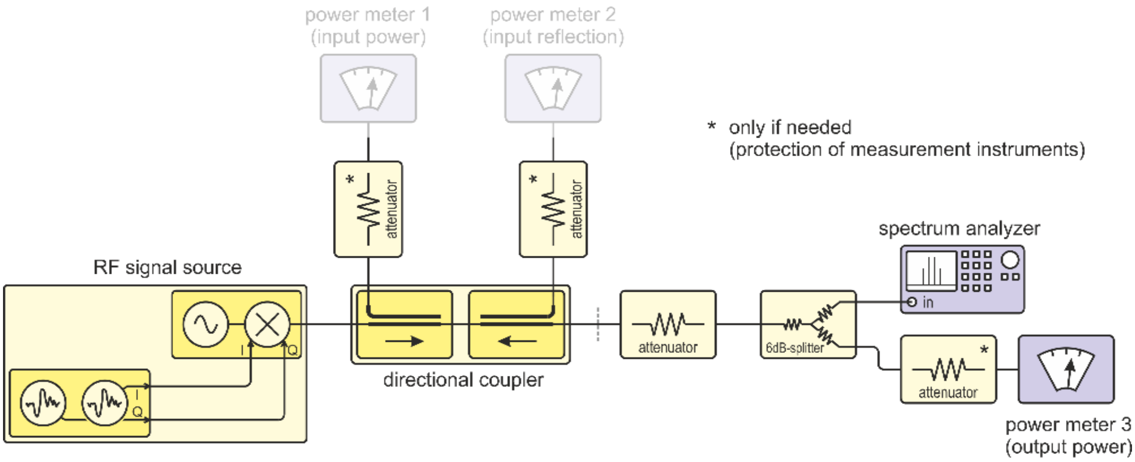

Figure 4: Characterization of the power attenuator and the 6dB splitter

If the RF signal source is switched on, power meter 1 measures the input power at the DUT's reference plane – which is identical to the output power in case of a thru-connection. Thus, the offset of power meter 3 (which shall measure the DUT's output power) is simply calculated by comparing the readings from power meter 3 and power meter 1: Both should show exactly the same value after the correct offset for power meter 3 has been applied.

The same procedure can be used for the spectrum analyzer, if needed. The instrument also allows consideration of offsets.

Measurements

As part of the exercise the below listed measurements shall be carried out. Results shall be prepared in chart form (a PC with a spreadsheet is available). Choose the measured input powers depending on the non-linearity (e.g. 5 dB steps in the linear region and 1 dB steps in compression region).

1. **Power sweep with a CW signal:** $f = 2.45$ GHz

   Measurements: input matching, gain, PAE, output power.

Questions/ Tasks	• Determine the output power 1dB and 3dB compression point! • Determine the linear gain!

2. **Power sweep with a two tone signal:** $f_C = 2.45$ GHz, tone spacing $\Delta f = 1$ MHz

   Measurements: power of the tones, power of IM-products of 3rd and 5th order.

Questions/ Tasks	• Determine output IP3 and IP5!

3. **Power sweep with a 3GPP WCDMA signal:** $f = 2.45$ GHz

   Measurements: ACPR1, ACPR2

Questions/ Tasks	• Is it possible to determine output IP3 and IP5 from the measurements?

Used Equipment

RF signal source:	• Rohde&Schwarz SMBV100A
Power meters:	• Agilent N1914A (2 channels + 2 x USB channels)
Power sensors:	• Agilent E9301A (0.01…6 GHz, -60…+20 dBm, Average) • Agilent U2001A (0.01…6 GHz, -60…+20 dBm, Average, USB)
Spectrum analyzer:	• Rohde&Schwarz ZVL6 (6GHz) • Agilent N4010A Signal Analyzer (alternative to ZVL6)
Direct. couplers:	• Krytar 1850 (0,5…18,5GHz, dual directional)
Attenuators:	• Weinschel 49-30-43 (105W, 30dB)
Device Under Test (DUT)	• Mini-Circuits ZHL-30W-252-S+ (0.7…4.2 GHz, $P_{out(3dB)}$ = +46 dBm typ !!!, Gain ~ 50 dB)