Application Note

LEVEL RANGE EXTENSION OF THE R&S®SMW200A USING AN EXTERNAL AMPLIFIER

Products:

- ► R&S®SMW200A
- ► R&S®NRP
- ► R&S®FSW

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Contents

1 Overview

Testing RF devices, like power amplifiers, requires a certain input power at the device under test (DUT). Sometimes, more power than a signal generator can deliver is needed. This may be the case when devices require higher input power, or when they need to be connected using long cables, which introduce large insertion losses at high frequencies.

In these cases, an external amplifier can be used to deliver the required power to a DUT.

This application note gives a guideline how to increase the power delivered to a DUT by an R&S®SMW200A vector signal generator using an external amplifier.

It covers shifting the power reference plane from the generator output to the DUT input using an R&S®NRP power sensor and mitigating linear and nonlinear distortions using an R&S®FSW signal and spectrum analyzer.

2 Introduction

The chain of components between the RF output of the R&S®SMW200A vector signal generator and the input of the device under test (DUT) will be referred to as "channel" throughout the application note. Figure 1 shows a block diagram of a general fixture when using an external amplifier to increase the power delivered to the DUT. The DUT may in turn be an amplifier. However, it may also be any other component.

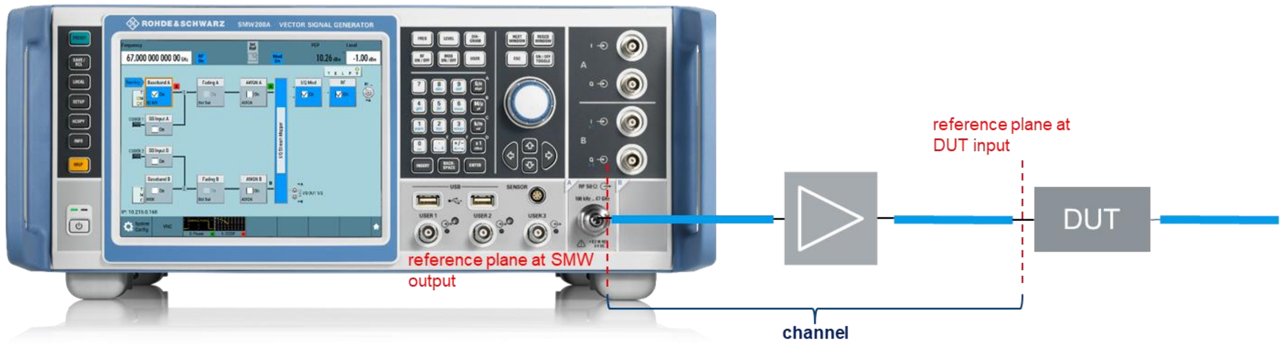

Figure 1: Block diagram showing R&S®SMW200A, external amplifier, cables and DUT

Depending on the application, it is desirable

- to shift the power reference plane from the RF output port of the R&S®SMW200A to the input of the DUT, and
- to mitigate linear and nonlinear distortions originating from the external amplifier.

The application note is structured as follows:

- Section 3 provides information on how to prevent damage to the DUT or other devices.
- Section 4 covers shifting the reference plane without mitigating signal distortions of the channel. You can skip that section if you intend to mitigate linear and nonlinear distortions of the channel using an R&S®FSW signal and spectrum analyzer.
- Section 5.1 deals with mitigation of linear and nonlinear distortions of the channel.
- Section 5.2 provides information for the case that your DUT is an amplifier and you need to find the best performance of the DUT using Direct DPD in FSW-K18.

Please note that this application note does not recommend a specific amplifier, as the choice of a suitable amplifier depends on the application.

The application note does not provide a recommendation for the exact location of the amplifier in the channel. The order of amplifier and cables, along with their attenuation, affects the signal-to-noise ratio and intermodulation products. However, it is the application and possibly constraints such as available space and required cable lengths that determine the optimal position of the amplifier in the channel for a given application and setup.

R&S®SMW200A, R&S®FSW and R&S®NRP will be referred to as SMW, FSW and NRP, respectively.

3 How to prevent damage to the DUT or other devices

In order to prevent damage to the DUT or other devices caused by too much power, it is useful to limit the maximum output power of the SMW to a value that is safe for your current application. To limit the maximum peak envelope power (PEP) at the RF output port of an SMW, you can **set the "Limit"** (under "RF" > "RF Level" > "Limit") to the desired value. This value determines the maximum PEP into a 50 Ohm load (not taking specified level uncertainty into account) directly connected to the SMW's RF output. Please note that the value of the parameter "Digital Attenuation" is not taken into account. If "Digital Attenuation" is negative, the output power may be higher than the limit by the absolute value of "Digital Attenuation". Example: If "Digital Attenuation" is "-1 dB", the power may be 1 dB higher than the limit.

The field in Figure 1 is intentionally left empty. Please enter a value that is safe for your application. In general, it is good practice to keep some safety margin.

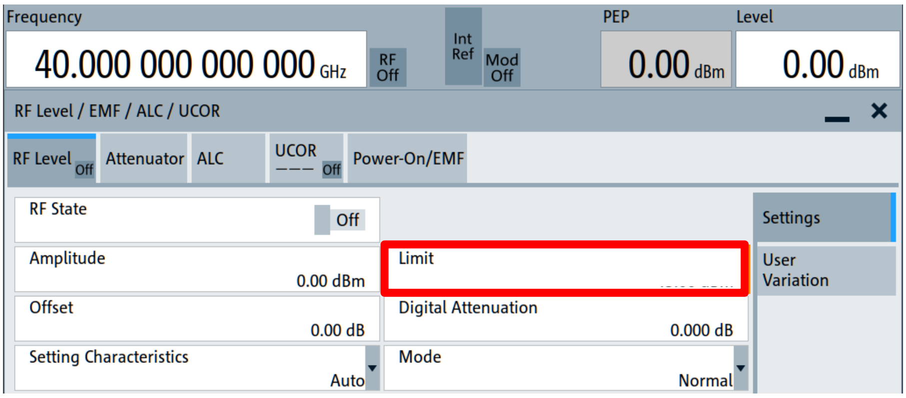

Figure 2: Set a limit that is safe for your application

It is **useful** to use an **external attenuator** at the RF input of a power sensor or signal and spectrum analyzer in case there is a risk that signal power might exceed the maximum allowed input power. It is **necessary** to use an **external attenuator** if you need to measure signals with powers higher than the maximum allowed input power. Please consult the datasheet of your NRP or FSW to find the maximum input level for the desired operating conditions.

Depending on the external amplifier used, it may be necessary to follow a **specific sequence** for switching on or off the input power, the amplifier itself, or terminating the amplifier output. Since the sequence depends on the amplifier used, it is not explicitly stated in the instructions below. Make sure you follow the required sequence.

4 How to shift the power reference plane to the input of the DUT

Two ways of shifting the power reference plane to the input of the DUT are:

1. Measure the power at the amplifier output **once** using an NRP power sensor and compensate the gain of the channel by a **level offset** in the SMW. This is useful if the channel has a stable gain.
2. Let the SMW **continuously** control the output power of the amplifier using **NRP Power Control**. This is useful if the gain of the channel varies over time. Please find detailed information on that feature in the section "Power Control" of [1].

You can skip section 4 and proceed with section 5 if you intend to mitigate linear and nonlinear distortions of the channel using an FSW.

4.1 Using a level offset

This section describes how to shift the power reference plane to the input of the DUT using a level offset. In case you intend to mitigate linear and nonlinear distortions using an FSW as described in sections 5.1 and 5.2, you can directly proceed with these sections.

4.1.1 Requirements

- SMW200A
- External amplifier
- NRP power sensor

No particular options in addition to the options that are needed for your application are required to execute the steps described in this section.

4.1.2 Prepare the setup

Please follow the guidelines in section 3 to prevent damage to the DUT or other devices.

It is assumed that the setup that shall be used for testing the DUT looks like in Figure 3.

Figure 3: Setup for the testing the DUT, which may also be an amplifier

The output of the DUT, if existent, may be connected to another measurement instrument. In order to shift the power reference plane to the input of the DUT, disconnect the DUT and connect an NRP instead. Now, the setup looks like in Figure 4

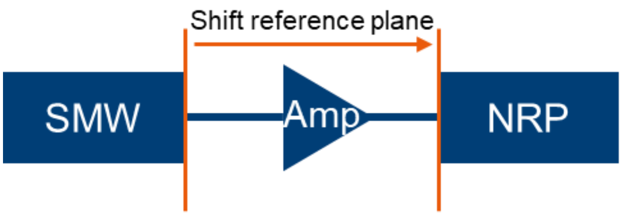

Figure 4: Setup to shift the reference plane

4.1.3 Shift the reference plane

1. **Please follow the guidelines in section 3 to prevent damage to the DUT or other devices.**
2. Make sure the external amplifier is in a state where it is allowed to receive input power from the SMW.
3. Preset the SMW.
4. Connect the NRP's host interface cable to the SMW's SENSOR or USB connector.
5. Set the frequency at which the setup shall be operated.
6. Configure the desired baseband signal and start the baseband.

7. Set “Level” to a value that is safe for the amplifier and all the other components and representative for the intended operating point. If in doubt, start with a lower value and repeat these steps with increasing power.
8. Turn RF on.
9. Go to “RF” > “NRP Power Viewer” > “Power Viewer”.
10. Make sure that “State” is “On”.
11. Locate your power sensor in the list and press the “Config” button. This brings you to the “Sensor Configuration” tab.
12. In case you are using an attenuator attached to the input of your NRP power sensor, set “Level Offset State” to “On” and enter the attenuation of your attenuator as “Level Offset”. Example: If the attenuation of the attenuator is 10 dB, enter the value 10 dB. This “Level Offset” parameter is not to be confused with the parameter “Offset” in the “RF Level” tab that we will care about in one of the next steps.
13. Read off the “Average” value. If this value fluctuates, this might be related to the characteristics of the modulated signal. Refer to the section “Dealing with Modulated signals” in [1] in this case.
14. Calculate “Average” minus “Level” and enter the result at “RF” > “Level” > “RF Level” > “Offset”. Example: You set the level to 15 dBm, the measured average level is 21 dBm. In this example, “Offset” needs to be set to “Average” - “Level” = 21 dBm - 15 dBm = 6 dB.
Alternatively, you can adjust the value of the parameter “Offset” until the “Level” value matches the “Average” value.

After following the preceding steps, the measured level should be very similar to the set level. If the measured level deviates significantly from the set level, please review the preceding steps to ensure all configuration steps were accurately followed.

Figure 5 shows an example how the levels along the signal path relate to the displayed values, and how the “Offset” and the “Level Offset” values relate to the gain of the amplifier (reduced by cable losses) and an attenuator attached to the NRP, respectively. In this example, the used baseband signal has a crest factor of 0 dB. Therefore, the “PEP” and the “Level” are equal. In case of signals with crest factors higher than 0 dB, the “PEP” and thus the peak envelope powers along the signal path are higher than the shown levels by the value of the crest factor. As an example, a crest factor of 8 dB and a “Level” of 21 dBm would result in a “PEP” of 29 dBm.

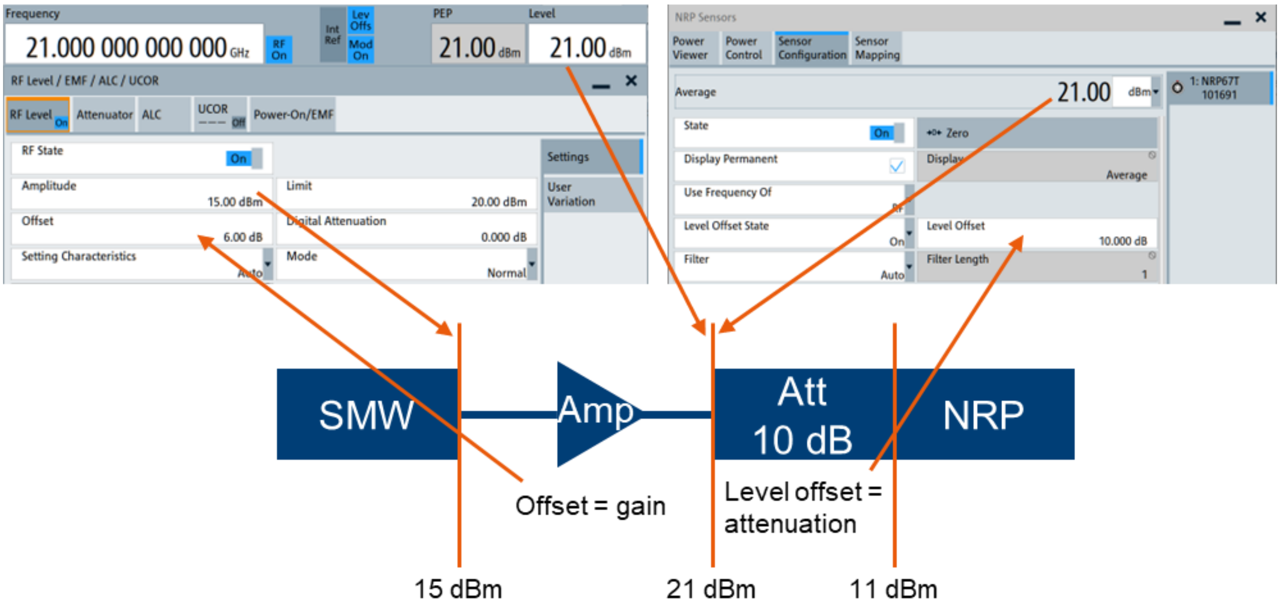

Figure 5: Relation between parameters in the SMW's GUI and levels along the signal path as well as properties of the components. For signals with crest factors higher than 0 dB, the “PEP” is higher than the “Level” by the value of the crest factor. As an example, a crest factor of 8 dB and a “Level” of 21 dBm would result in a “PEP” of 29 dBm.

4.1.4 What's next?

After following the preceding steps, the "Level" displayed on the SMW is representative for the level measured by the NRP and thus representative for the level at the DUT (which is 21 dBm in the example in Figure 5) when the NRP and the attenuator are replaced by the DUT.

The setting range of the parameter "Level" is automatically shifted by the value of the parameter "RF" > "Level" > "RF Level" > "Offset" to account for the output level of an amplifier being higher than that of the SMW. An example: If the maximum value that could be entered for "Level" was 30 dBm after presetting the SMW, it is 36 dBm in case the "Offset" is set to 6 dB.

You can now turn off the RF signal, disconnect the NRP (including an existing attenuator) and attach the DUT instead of the NRP.

The setup is ready for testing your DUT.

5 How to mitigate linear and nonlinear distortions originating from the external amplifier

In general, amplifiers cause linear and nonlinear distortions.

For applications, in which these distortions need to be compensated in order to provide the DUT with an undistorted signal, the channel can be characterized and modeled using an FSW. There are multiple ways of modeling the channel, e.g. memory polynomial, generalized memory polynomial and Hammerstein model. We use the Hammerstein model. This can be automatically transferred from the FSW to the SMW. In the SMW, it is applied in real-time to pre-distort the wanted signal such that the linear and nonlinear distortions are compensated for at the input of the DUT. The Hammerstein model can be used for a range of levels and for different signals that have similar crest factor and bandwidth.

A procedure for that is described in section 5.1.

In case the purpose of testing is finding the best performance that a DUT can deliver when it is pre-distorted, it is possible to pre-distort the channel including the DUT, which renders separate pre-distortion of the channel unnecessary.

This use case is described in section 5.2.

5.1 Using a Hammerstein model to pre-distort the SMW and the external amplifier

This section describes how an FSW is used to generate a pre-distorted waveform and eventually derive a Hammerstein model of the channel, and how that is used in the SMW to pre-distort the wanted signal such that the linear and nonlinear distortions are compensated for at the input of the DUT. Information on the Hammerstein model can be found in [2] and [3].

5.1.1 Requirements

- SMW with options
  - SMW-K544 (User Defined Frequency Response Correction)
  - SMW-K541 (AM/AM, AM/PM predistortion)
- External amplifier

- FSW with options
  - FSW-K18 (Amplifier Measurements)
  - FSW-K18D (Direct DPD measurements)
  - FSW-K18M (Memory polynomial DPD)

5.1.2 Prepare the setup

Please follow the guidelines in section 3 to prevent damage to the DUT or other devices.

It is assumed that the setup that shall be used for testing the DUT looks like in Figure 6.

Figure 6: Setup for the testing the DUT, which may also be an amplifier

The output of the DUT is connected to an FSW. In order to generate a Hammerstein model of the channel, disconnect the DUT and connect the FSW instead. Now, the setup looks like in Figure 7.

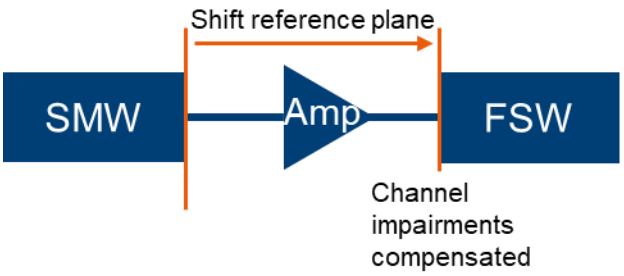

Figure 7: Setup for running Direct DPD and generating a Hammerstein model

SMW and FSW need to be connected to the same LAN.

5.1.3 Shift the reference plane, run Direct DPD and generate and apply a Hammerstein model

1. **Please follow the guidelines in section 3 to prevent damage to the DUT or other devices.**
2. Make sure the external amplifier is in a state where it is allowed to receive input power from the SMW.
3. Preset the SMW and the FSW.

The purpose of the following 2 steps is an initial configuration of the SMW. These 2 steps are carried out on the SMW.

4. On the SMW, set a limit to ensure safety of your components.
   "RF" > "RF Level" > "Level" > "Limit"
   See section 3 for details.
5. Set "Level" to a value that is safe for the amplifier and all the other components and representative for the intended operating point. If in doubt, start with a lower value and increase the power later.

The next steps are carried out on the FSW.

6. On the FSW, go to "Mode" > "Amplifier"
7. Select "Input/Output" > "Generator Setup" > "Generator IP Address" > "Configure"
8. Enter the IP address of the SMW and press "Connect".
9. Close the current window. This will take you back to "Meas Config" > "Input/Output" > "Generator Setup".

10. Press “Query all Settings from Generator”. Do **not** change any other settings in that window, and do **not** press any other button for the moment. Particularly, do **not** change the “Max DUT Input Level” setting since that has an immediate effect on the limit that is set in the SMW.

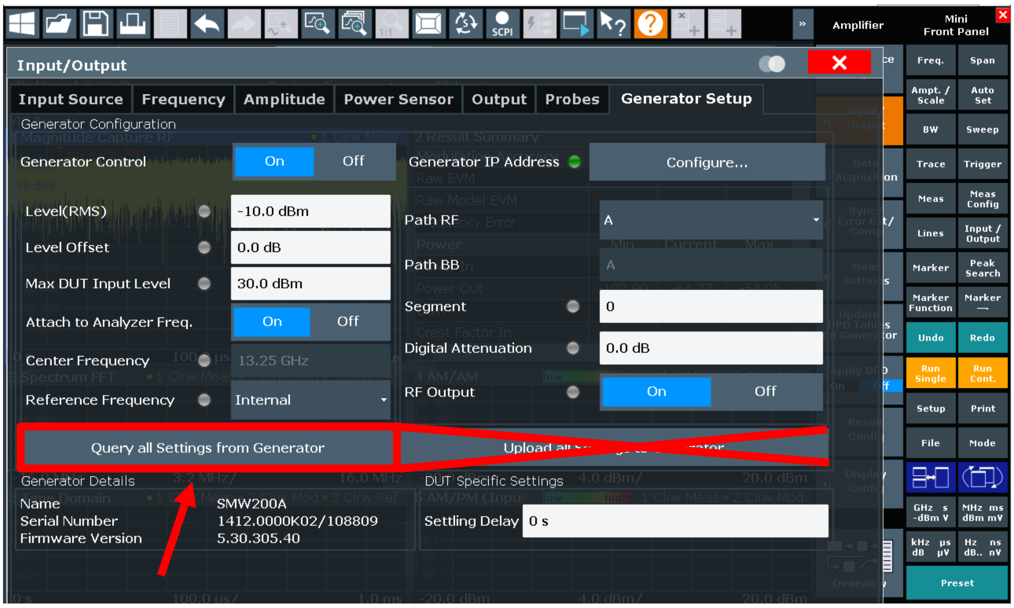

Figure 8: Location of the button "Query all Settings from Generator"

11. After pressing “Query all Settings from Generator” you see the respective settings of the SMW displayed on the FSW.

12. Press “Freq.” and enter the frequency at which the setup shall be operated. The SMW’s frequency will automatically be updated.

13. In order to characterize the channel, you need to play an IQ modulated signal on the SMW. You can either use the signal that you will be using for testing your DUT, or you can use an IQ modulated signal with the same bandwidth and the same crest factor.

    a. In order to use your own waveform file, you can

        1. either load it in the ARB of the SMW, go to “Meas Config” > “Reference Signal” > “Current Generator Waveform” and press “Read from Generator, Load”

        2. or, if the waveform file is stored on the FSW, go to “Meas Config” > “Reference Signal” > “Current Waveform File” and press “Load, Play on Generator”.

    b. In order to generate a signal that can be used instead of your custom waveform file, go to “Meas Config” > “Reference Signal” > “Generate Own Signal”. Enter the signal bandwidth and the target crest factor according to the bandwidth and crest factor of the signals that you will be using for testing your DUT. Make sure that the occupied bandwidth of the resulting signal (displayed at “Meas Config” > “Reference Signal” > “Currently Active Reference Signal” > “Bandwidth (OBW)”) is at least as high as the bandwidth of your test signal.

       As an example, we will be using the feature “Generate Own Signal” with a Signal Bandwidth (“Signal BW”) of 100 MHz and a “Target Crest Factor” of 8 dB. We start signal playback on the SMW by pressing “Generate, Play on Generator” in the FSW GUI.

14. Press “Open Generator Control” and set “RF Output” to “On”.

15. In case you attached an attenuator to the input of the FSW, set “Ampt. / Scale” > “Ref Level Offset” to the attenuation of that attenuator. As a result, the FSW will account for the external attenuator.

16. Make the SMW’s level display and level setting representative for the power measured by the FSW (and later at the input of the DUT) when the external amplifier is in the channel by following this procedure: Observe the “Gain” reading in the FSW’s “Result Summary” display (see Figure 9) and enter that value under “Ampt. / Scale” > “Generator Level Offset”.

Alternatively, you can adjust the value of the parameter “Generator Level Offset” (**not**: “Reference Level Offset”) until the displayed “Gain” is 0 dB.

Figure 9: Enter the value of "Gain" under “Ampt. / Scale” > “Generator Level Offset”

17. In case you followed the previous steps using a level that was lower than the level that will be used for testing the DUT, increase the parameter “Ampt. / Scale” > “Generator Level” until “Power Out” shows the value that is desired as an input level to the DUT when the FSW is replaced by the DUT.
18. Set the FSW’s reference level (“Ampt. / Scale” > “Reference Level”) to the sum of “Power Out” and the crest factor of the signal. Example: If “Power Out” is 20 dBm and the crest factor is 8 dB, set the reference level to 28 dBm.
19. Nonlinearities might have changed the displayed “Gain”. If that is the case, add the current “Gain” reading to the parameter “Ampt. / Scale” > “Generator Level Offset” (**not**: “Reference Level Offset”). As a result, the displayed “Gain” should now be 0 dB.

At this point, the setup is in the desired operating point. The level displayed on the SMW is representative for the level measured by the FSW and thus representative for the level at the input of the DUT when the FSW is replaced by the DUT. Figure 10 shows the relation between parameters of the SMW and parameters of the FSW.

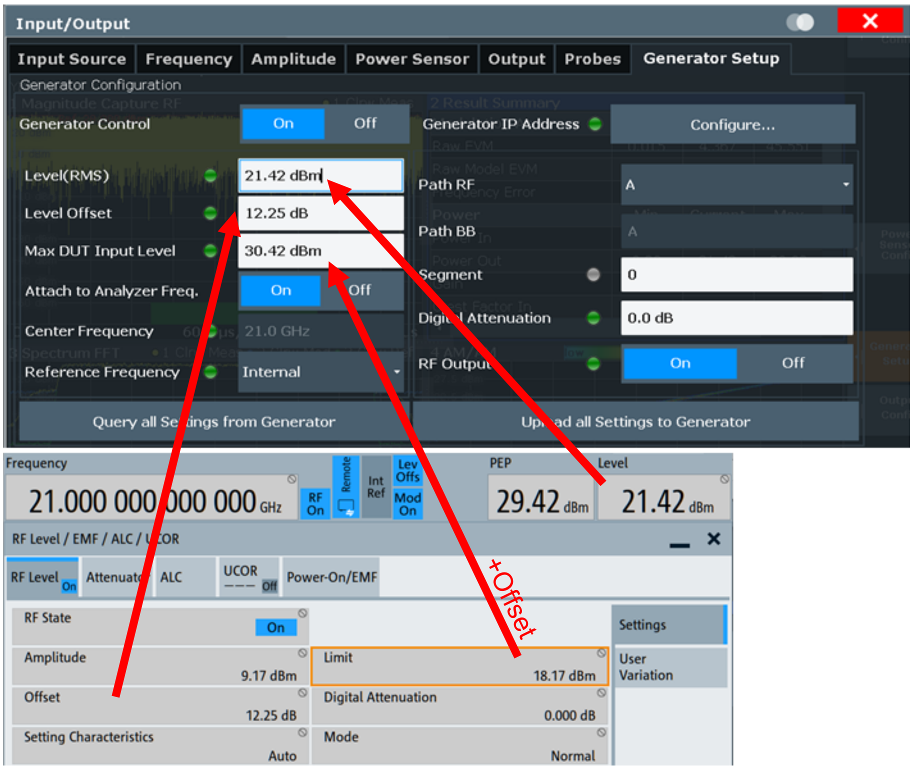

Figure 10: Relation between parameters of the SMW and parameters of the FSW

It is the purpose of the next steps to configure and run a Direct DPD. The used parameter values are reasonable starting points. Refer to [2], [3] **and** [4] **for more information on these parameters in order to optimize them for your application if necessary.**

20. It is recommended to activate I/Q averaging to reduce the effect of noise on the measured reference signal and therefore on the generated model. To do this, navigate to
“Meas Config” > “Data Acquisition” > “Sweep” > “MultiFrame Statistics Settings”
and set

    a. “State”: On

    b. “Count”: 10

21. It is recommended to increase the measurement bandwidth to not only consider in-band distortions but also out-of-band intermodulation products (“shoulders”). If the used FSW doesn’t provide the desired bandwidth, use the maximum bandwidth the instrument supports. As an example, we choose a measurement bandwidth of 200 MHz for our previously generated test signal that has an occupied bandwidth of approximately 92 MHz.To set sample rate or measurement bandwidth, navigate to
“Meas Config” > “Data Acquisition” > “Data Acquisition”
and set

    c. “Sample Rate”: Manual

    d. “Meas Bandwidth”: 200 MHz

22. Activate and configure Direct DPD. To do this, navigate to “Meas Config” > “Meas Settings” > “DPD” > “Direct DPD” and set

    a. Status: On

    b. “DPD Power / Linearity Tradeoff”: 50 %

    c. “Iterations”: 10

    d. Gain Expansion: 0 dB

    e. Start Direct DPD: “Meas Config” > “Start Dir. DPD”

Now that the Direct DPD sequence has finished, the DUT could be attached instead of the FSW and be tested with the pre-distorted waveform. However, in order to take advantage of model-based pre-distortion, we generate a Hammerstein model and transfer it to the SMW as described in the next steps.

23. Generate the Hammerstein model and transfer it to the SMW. To do so, navigate to “Meas Config” > “Meas Settings” > “DPD” > “Hammerstein Model” and set

    a. Status: On

    b. “Polynomial Order”: 1-5

    a. “Memory Depth”: 0-5

    b. Press “Model and Update Generator”

5.1.4 What’s next?

In the preceding steps, the FSW has generated a Hammerstein model. The Hammerstein model has been transferred to the SMW. This model is applied to the baseband signal while the signal is being played back. The model is applied using features of the options SMW-K541 (AM/AM, AM/PM predistortion) and SMW-K544 (User Defined Frequency Response Correction). After transferring the Hammerstein model from the FSW to the SMW, the features AM/AM, AM/PM predistortion and User Defined Frequency Response Correction are automatically turned on in the SMW. Details on how the model files are used in the SMW can be found in the section “Handling Hammerstein Model Files” in [3].

As stated before, the parameters used for configuring the Direct DPD and the Hammerstein models are reasonable starting points. Refer to [2], [3] and [4] for more information on these parameters in order to optimize them for your application if necessary.

The result of the preceding steps is that linear and nonlinear distortions of the channel are compensated and the parameter “Level” on the SMW is representative for the level at the FSW and thus at the DUT when FSW is replaced by the DUT.

The setting range of the SMW’s parameter “Level” has automatically been shifted by the value of the parameter “Offset” to account for the output level of an amplifier being higher than that of the SMW. An example: If the maximum value that could be entered for “Level” was 30 dBm after presetting the SMW, it is 36 dBm in case the “Offset” is set to 6 dB.

It is advantageous to have the SMW’s RF path in the same configuration while testing the DUT as it was while generating the Hammerstein model.

1. To do so, go to the SMW,
   a. Navigate to “RF” > “Attenuator”,
   b. read off the value of the parameter “Attenuation active” and
   c. note that value down.
2. Navigate (in the FSW’s GUI) to “Input / Output” > “Generator Setup” and
   a. turn off the RF output of the SMW (in the FSW: “RF Output”: Off)
   b. turn off “Generator Control” and disconnect the SMW logically (in the FSW: “Generator Control”: Off, then press “Configure…” and after that “Disconnect”).
3. Disconnect the FSW (including an existing attenuator) from the amplifier and attach the DUT instead.
4. In the SMW,
   a. set “RF” > “Attenuator” >
      a) “Mode”: “Manual”
      b) “Attenuation Manual” to the value that you read off before and noted down.

The setup is now ready for testing the DUT at the current frequency, at a range of levels and for different signals that have similar crest factor and bandwidth as the reference signal

5.2 Using Direct DPD to pre-distort SMW, external amplifier and DUT

In case the purpose of testing your DUT is finding the best performance that the DUT can deliver when it is pre-distorted, it is possible to pre-distort the whole channel including the external amplifier and the DUT, which renders separate pre-distortion of the external amplifier unnecessary. This section describes how this can be done.

5.2.1 Requirements

- SMW
- External amplifier
- FSW with options
  - FSW-K18 (Amplifier Measurements)
  - FSW-K18D (Direct DPD measurements)

5.2.2 Prepare the setup

Please follow the guidelines in section 3 to prevent damage to the DUT or other devices.

It is assumed that the setup that shall be used for testing the DUT looks like in Figure 11.

Figure 11: Setup for the testing the DUT, which may be an amplifier

The output of the DUT is connected to an FSW. In order shift the SMW's level reference plane to the input of the DUT, disconnect the DUT and connect the FSW instead. Now, the setup looks like in Figure 12.

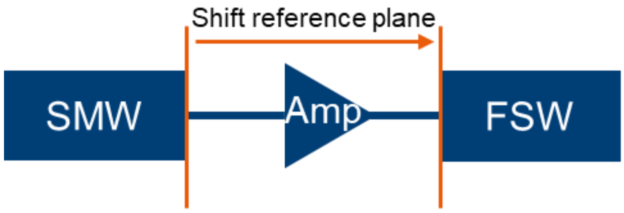

Figure 12: Setup for shifting the power reference plane

SMW and FSW need to be connected to the same LAN.

5.2.3 Shift the power reference plane

Follow the steps 1 to 19 in section 5.1.3.

5.2.4 What's next?

After following the preceding steps, the level displayed on the SMW is representative for the level measured by the FSW and thus representative for the level at the input of the DUT when the FSW is replaced by the DUT.

1. Turn off the RF output of the SMW using the FSW GUI: “Input / Output” > “Generator Setup” > “RF Output”: Off.
2. Disconnect the FSW (including an existing attenuator) from the amplifier and attach the DUT and the FSW (including an existing attenuator) instead such that the setup looks like in Figure 11.
3. Make sure the set level is appropriate for all components in the signal chain.
4. Increase the FSW's reference level by the expected gain of the DUT.
5. Turn on the RF output of the SMW using the FSW GUI: “Input / Output” > “Generator Setup” > “RF Output”: On.
6. You can now run a Direct DPD by following the steps 20 to 22 in section 5.1.3.

This approach pre-distorts the DUT as well as the external amplifier.

Since the performance of Direct DPD is not limited by a maximum polynomial degree or maximum filter order – as models like the Hammerstein model generally are – using Direct DPD allows you finding the best performance of your DUT when it is pre-distorted. Alternatively, a Hammerstein model can be used, but it will not yield the best possible pre-distortion performance.

The setup is now ready for testing the DUT at the current frequency with the chosen reference signal.

6 Summary

This application note gives a guideline how to increase the power delivered to a DUT by an R&S®SMW200A vector signal generator using an external amplifier.

It covers shifting the power reference plane from the generator output to the DUT input using an R&S®NRP power sensor and mitigating linear and nonlinear distortions using an R&S®FSW signal and spectrum analyzer for applying Direct DPD and generating a Hammerstein model and applying it on the SMW.

7 Literature

[1] Rohde & Schwarz, "Application Note: Using R&S NRP Power Sensors with R&S Signal Generators," [Online]. Available: https://www.rohde-schwarz.com/appnote/1GP141.

[2] Rohde & Schwarz, "User Manual: R&S®FSW-K18 Amplifier Measurements," [Online]. Available: https://www.rohde-schwarz.com/manual/r-s-fsw-k18-amplifier-measurements-user-manual-manuals_78701-70273.html.

[3] Rohde & Schwarz, "Application Note: Digital Pre-distortion for Improved EVM Performance," [Online]. Available: https://www.rohde-schwarz.com/appnote/1GP139.

[4] Rohde & Schwarz, "R&S Amplifier Masterclass Video 6 – Memory Polynomial Digital Pre-Distortion," [Online]. Available: https://youtu.be/vglAYsUvN5E.

8 Abbreviations

Abbreviation	Meaning
DPD	Digital pre-distortion
DUT	Device under test
FSW	R&S®FSW signal & spectrum analyzer
GUI	Graphical User Interface
NRP	R&S®NRP power sensor
PEP	Peak envelope power
SMW	R&S®SMW200A vector signal generator

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1GP | Version 0e | 03.2025
Application Note | Level Range Extension of the R&S®SMW200A using an External Amplifier
Data without tolerance limits is not binding | Subject to change