



NonLin-IM:

Vector analysis for non-linear intermodulation measurements

Operating Manual

For products:

**Vector-PIM NA-PIM1 and
NonLin-IM NA-IM1**

Status: 02.2012

1. NonLin-IM and Vector-PIM

Heuermann HF-Technik (HHF) is world-wide leading in vectorial IM measurements. Our novel product **NonLin-IM** allows you to perform calibrated complex intermodulation measurements with your VNA. An absolute novelty is the replacement of the comb generator by a new phase reference generator! These novel generators for the commercial frequency bands only reduce the technical effort and the price of the system.

HHF cooperate with Rosenberger Hochfrequenztechnik to support vector PIM-measurements. The resulting **Vector-PIM** testers use the adapted **NonLin-IM** software.

Vectorial IM measurements are useful for modelling and IM source finding. NonLin-IM bases on non-linear multi-port S-parameter using LMR or the novel and patented calibration procedure *Without Thru*. *Without Thru* uses only one-port calibration standards (short, open, match, a reference generator and a power sensor) at each port.

The necessary architecture of a modified 3-port network analyzer to measure vectorial IM-products is given in Fig. 1.

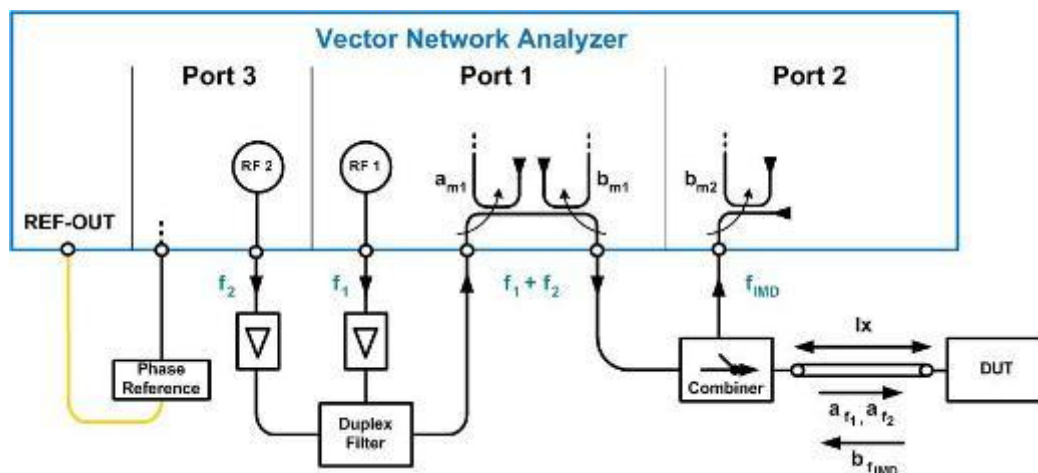


Figure 1: Block diagram of the full measurement set-up for reflection IM measurements with a 3-port VNA with open test-set

This block diagram is the basic structure of the full Rosenberger vector-IM-tester by using a VNA from Rohde & Schwarz (R&S).

However, we support also R&S 4-port VNAs for individual test-sets. The architecture of a 4-port network analyzer to measure vectorial IM-products is given in Fig. 2.

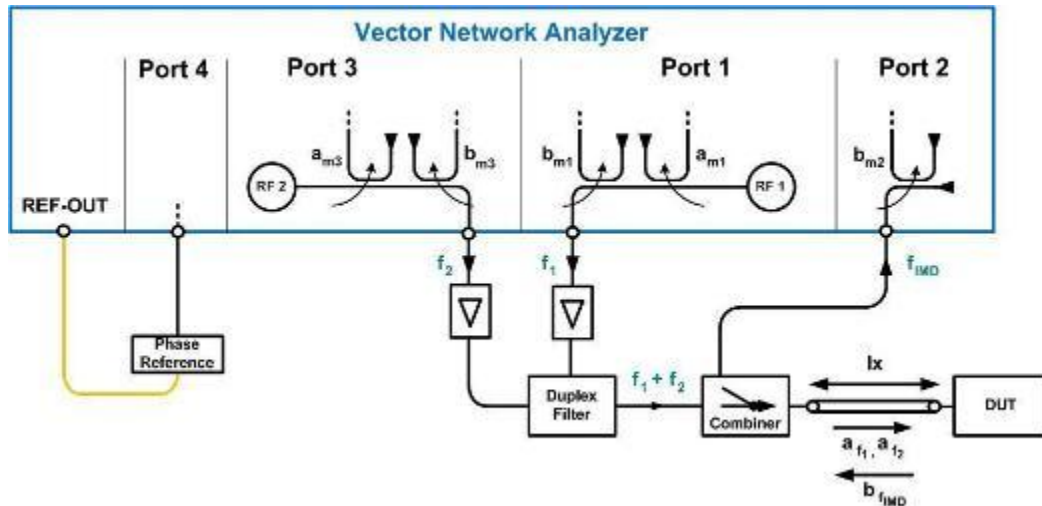


Figure 2: Block diagram of the measurement set-up for reflection IM measurements with a 4-port VNA

Additionally, the software supports two more IM test sets for transmission measurements. Measurement results exemplify the high quality of the novel vectorial IM measurement system under real-life conditions (Fig. 3a and 3b).

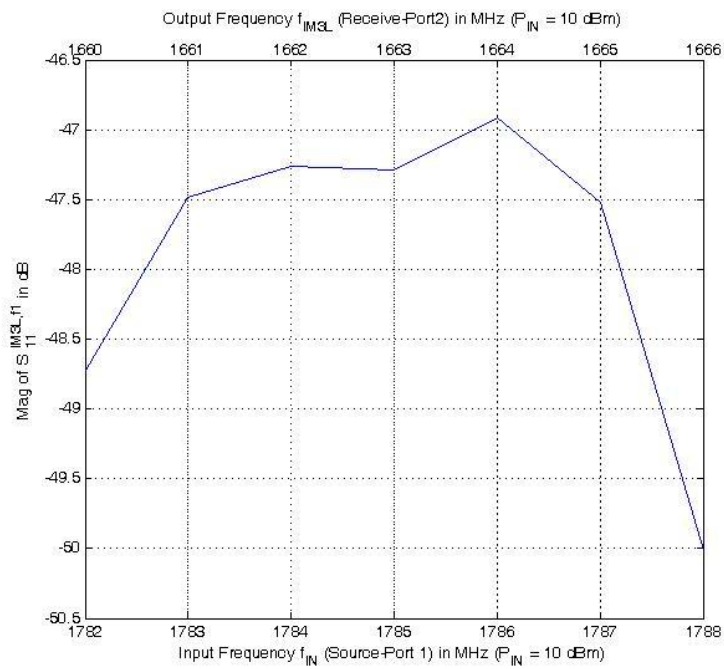


Figure 3a: Magnitude results of intermodulation measurement

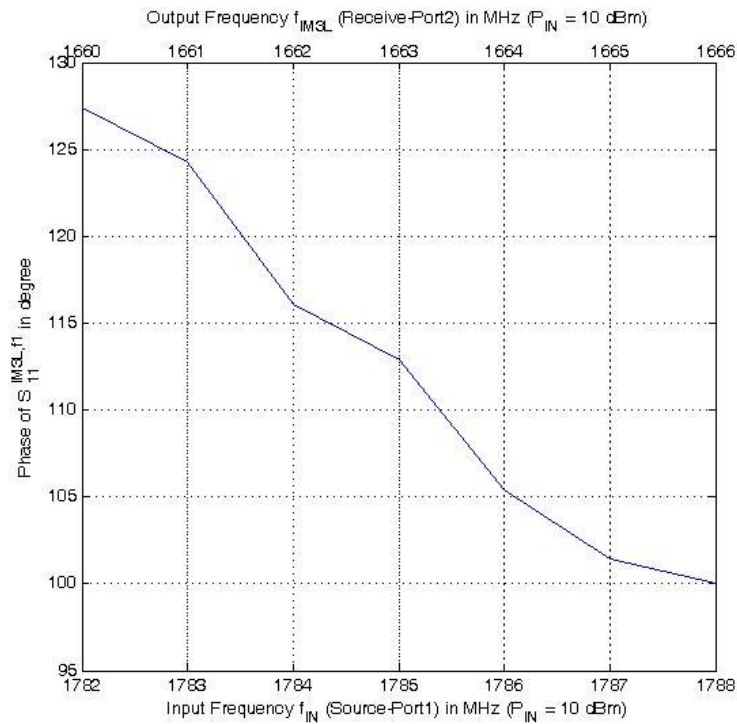


Figure 3b: Phase results of intermodulation measurement

A novel phase reference generator helps to perform best IM measurements with high accuracy and small frequency step size, Fig. 4.



Figure 4: Novel phase reference generator with very low phase noise and small step size (here SG 1624 for 1.6 to 2.4 GHz)

Fig. 5 shows a screen shot of the NonLin-IM software.

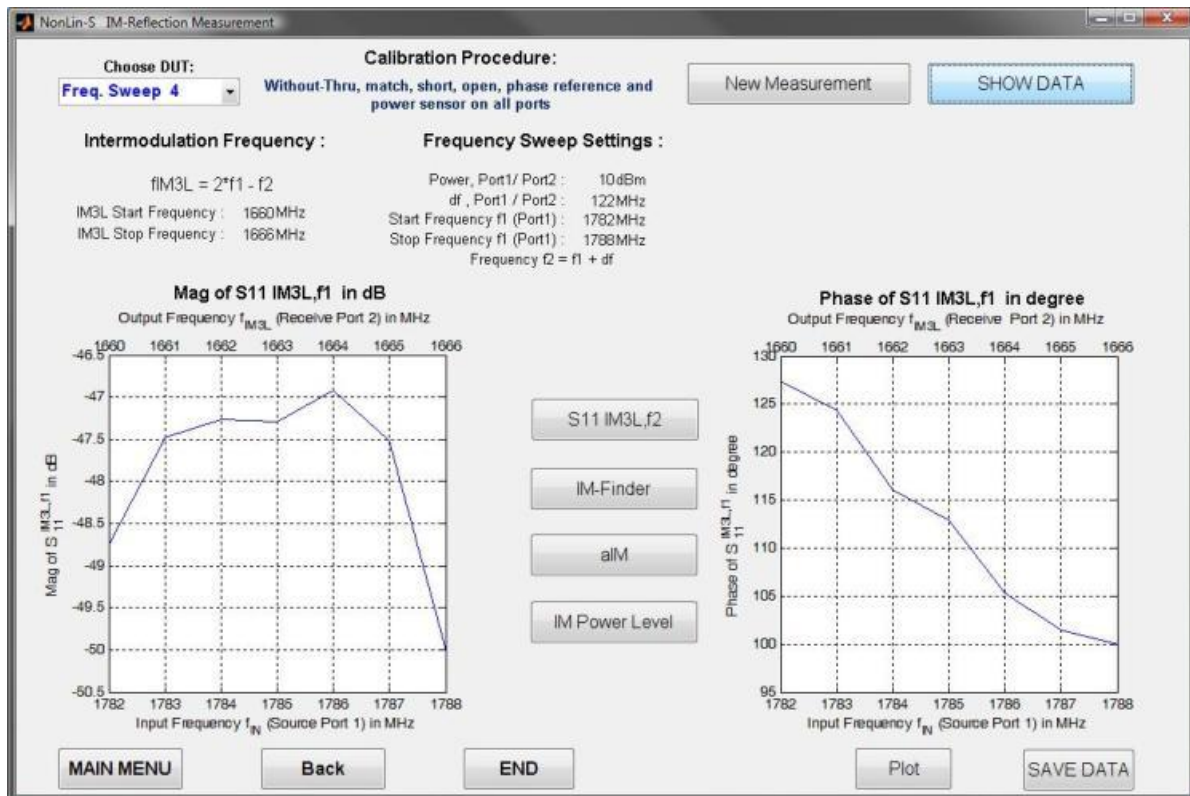


Figure 5: NonLin-IM software: screen to show the measurement results

This simple measurement system consists of a multi-port-VNA from Rohde & Schwarz (ZVA, ZVM), the software, a laptop to control and process one coaxial calibration kit, a power head, and the phase reference generator.

NA-IM1 features in detail:

- Optimized non-linear multi-port IM test system for vectorial measurements.
- Accuracy from non-linear calibration procedures LMR for all multi-port VNAs and Without Thru for R&S-VNAs.
- Special software for intermodulation measurements (supports four IM-test configurations).
- Supports frequency-, power- and time-sweep IM measurements.
- Allows the measurement of IM products in an accurate and complex manner.
 - Phase values help to find the location of IM-sources and to generated an accurate non-linear model of your device.
 - The included software module IM finder calculates out of the phase the distance to the IM-source.
- Fast and easy installation with pre-installed laptop or on your network analyzer.

The use of your own multi-port VNA from Rohde & Schwarz (ZVA, ZVM), calibration kit, and power head helps to reduce the price of entering into the non-linear world.

We offer a system composed of

- Software with dongle and operation manual (necessary),
- Laptop with National-GPIB-bus-card (software installed) or LAN-connection,
- Coaxial calibration kit (N or 3.5mm) from Rosenberger,
- Power sensor,
- Calibrated phase reference generator (necessary),
- Customer defined IM test sets.

Phase reference generators are for the following frequency ranges available:

- SG 0615: 600 MHz - 1500 MHz,
- SG 1024: 1000 MHz - 2400 MHz,
- SG 1327: 1300 MHz - 2700 MHz,
- SG 2633: 2550 MHz - 3250 MHz,
- SG 3135: 3090 MHz - 3500 MHz,
- SG 3542: 3500 MHz - 4200 MHz.

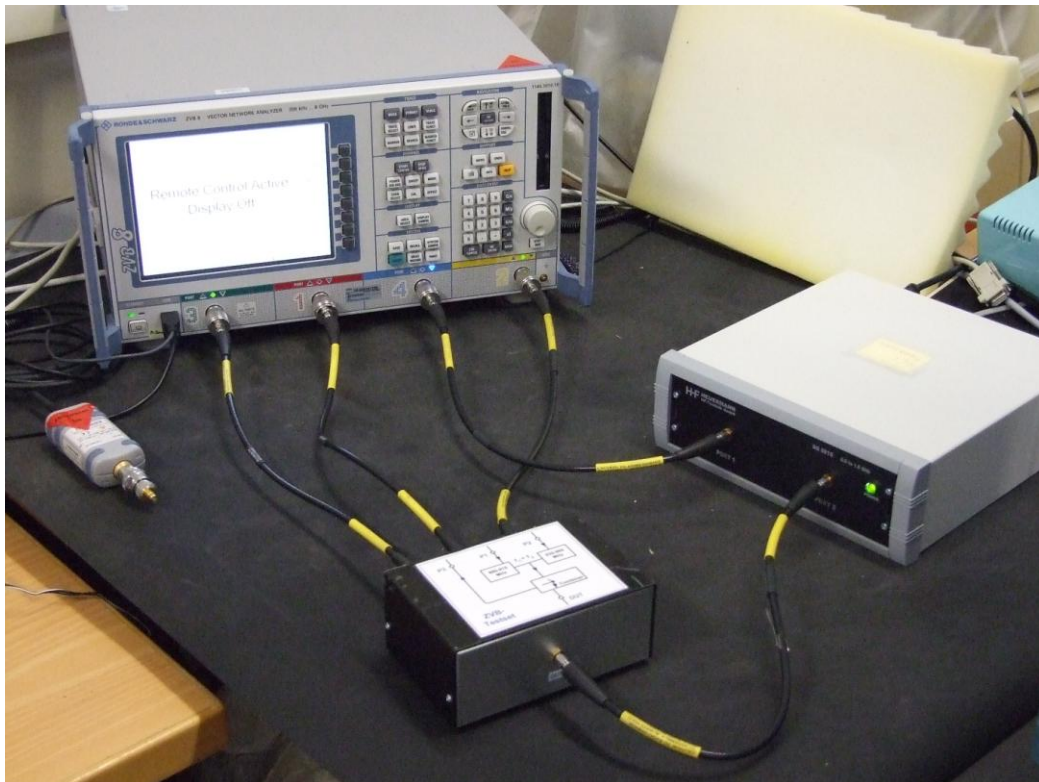


Figure 6a: NonLin-IM measurement set-up with R&S 4-port VNA and self-made test-set

NA-PIM1 features in detail:

- Includes all blocks of **NA-IM1**.
- The reference generator and the power head are implemented in a 19 inch rack with 7/16-connectors.
- The test-set is from Rosenberger (http://www.rosenberger.de/de/Products/18_Communication_PIM.php)

2. NonLin-IM application

Before starting the application make sure that the power sensor is connected to the Vector Network Analyzer (VNA) USB port and the phase reference generator to the 10 MHz reference out of the VNA.

Start Menu NonLin-IM

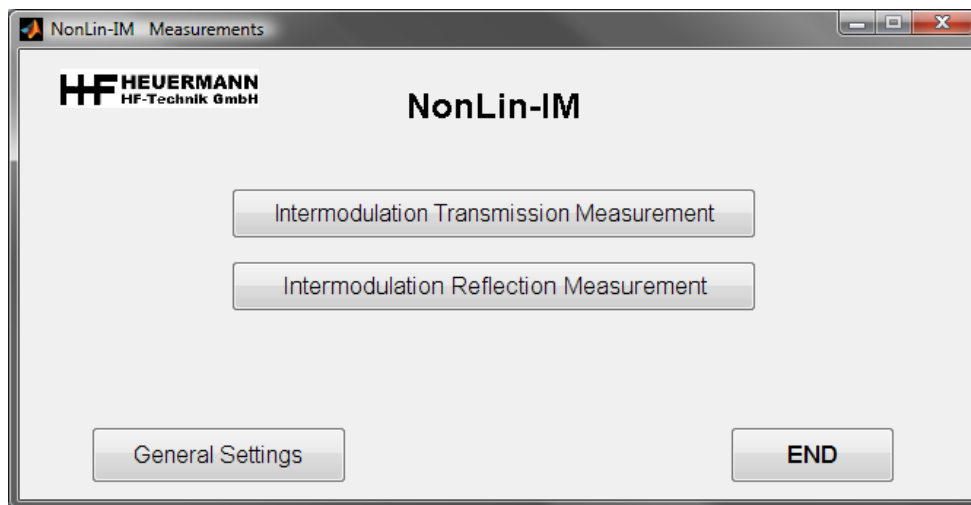


Figure 7: Start menu of NonLin-IM

NonLin-IM allows the user to perform two different non-linear intermodulation measurements:

1. **Intermodulation Transmission Measurement**
2. **Intermodulation Reflection Measurement**

The IM reflection measurements is for IM-finding applications the most used choice.

However, the user starts for the first time with the general settings.

General Settings

The menu “Settings” is shown in Fig. 7. It allows the user to set the necessary IP-address of the VNA to connect it to the notebook over LAN and to modify the calibration kit parameters as given in Fig. 8.

The serial COM-port connects the reference phase generator with the computer. You find this number in the system control menu from Windows.

The correct software modules for the phase reference generator are to choice with the number of the comb generator version. The code is:

- SG 0615: 600 MHz - 1500 MHz, no. 0
- SG 1024: 1000 MHz - 2400 MHz, no. 1
- SG 1327: 1300 MHz - 2700 MHz, no. 2
- SG 2633: 2550 MHz - 3250 MHz, no. 3
- SG 3135: 3090 MHz - 3500 MHz, no. 4
- SG 3542: 3500 MHz - 4200 MHz, no. 5

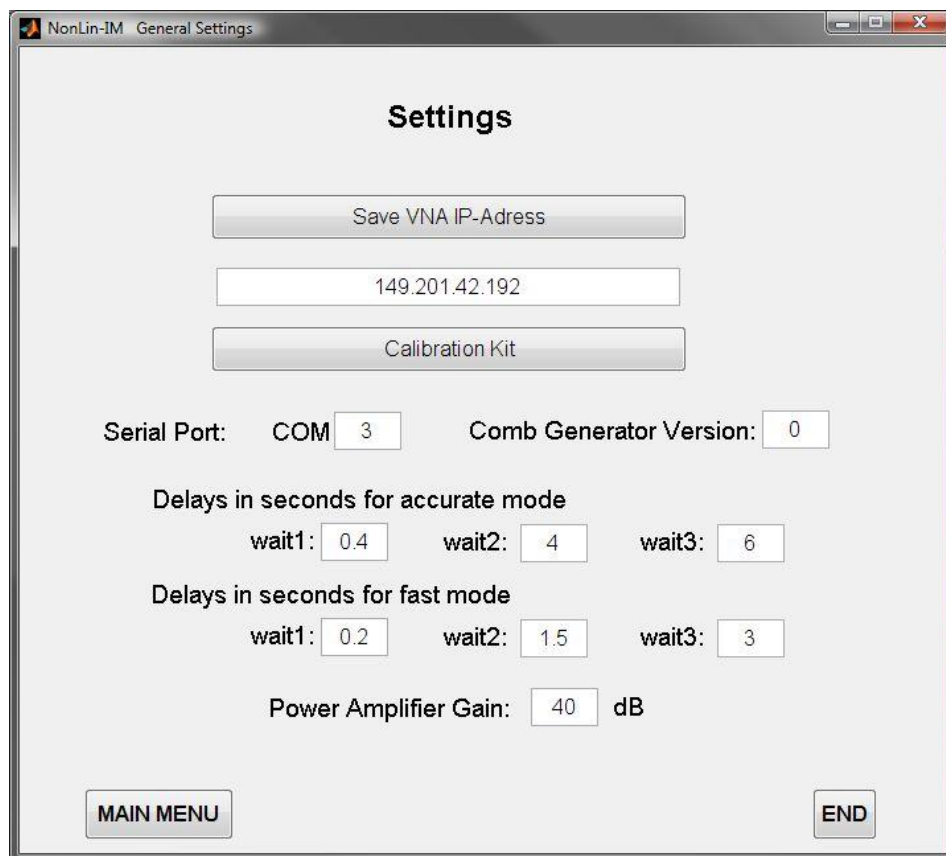


Figure 8: General Settings of NonLin-IM

Test-sets for IM-measurements include more or less small filters. [NonLin-IM](#) includes time-delays for the settling time of the filters. In Fig. 7 is given an example for very small filters for a Rosenberger-GSM PIM test-set.

[NonLin-IM](#) supports two modes: the “accurate mode” for best measurements and a longer measurement time and the fast mode for good measurements with shorter measurement time.

The power amplifier gain (including filter losses) of the test-set helps to control

OPEN FEMALE		OPEN MALE	
C0:	36.79 e ⁻¹⁵ F	C0:	46.96 e ⁻¹⁵ F
C1:	3.02 e ⁻²⁷ F/Hz	C1:	-0.64 e ⁻²⁷ F/Hz
C2:	50.65 e ⁻³⁶ F/Hz ²	C2:	-15.92 e ⁻³⁶ F/Hz ²
C3:	-1.09 e ⁻⁴⁵ F/Hz ³	C3:	0.83 e ⁻⁴⁵ F/Hz ³

FEMALE		MALE	
OPEN OFFSET LENGTH	7 mm	OPEN OFFSET LENGTH	7 mm
SHORT OFFSET LENGTH	7.8 mm	SHORT OFFSET LENGTH	7.8 mm
THROUGH OFFSET LENGTH		12.7 mm	

Port 1 :	Port 2 :	Port 3 :
female	female	female

BACK APPLY END

Figure 9: Calibration Kit Settings of NonLin-IM

2.1. Intermodulation Transmission Measurement

To calibrate the system for linear measurements choose between two different non-linear calibration procedures, **Without-Thru** and **TMR** calibration. Both procedures use the standards short, open, load, phase reference and power sensor.

With the “*Load old Calibration*” button the linear measurements GUI will open loading the old calibration. For this the desired calibration procedure must have been carried out before at least once in “*New Calibration*”, so that the necessary error correction data are given. The environment can be closed by pressing the “*END*” button.

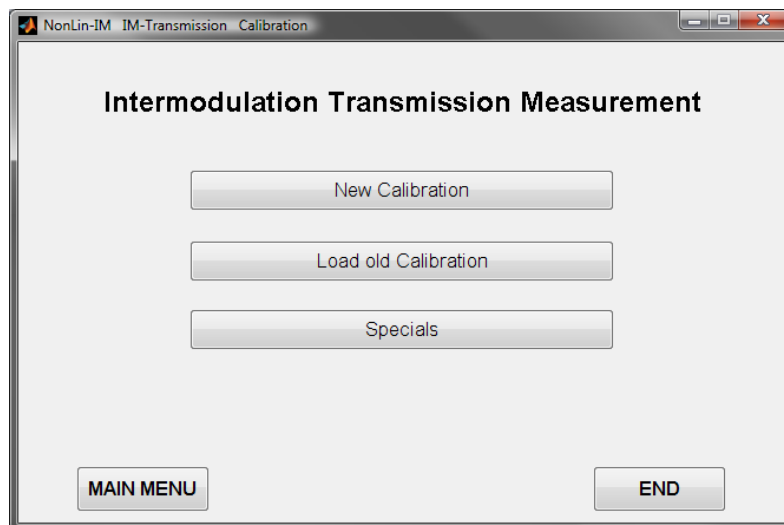


Figure 10: Intermodulation transmission calibration menu of NonLin-IM

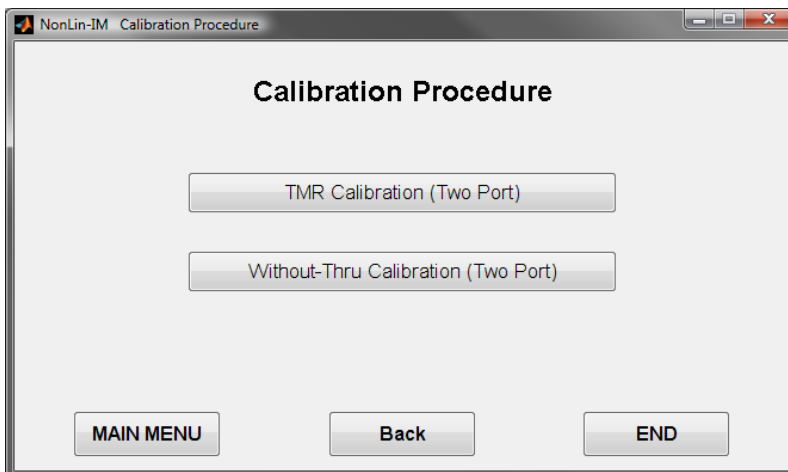


Figure 11: New Calibration menu for intermodulation transmission measurements of NonLin-IM

Without-Thru Three-Port Calibration

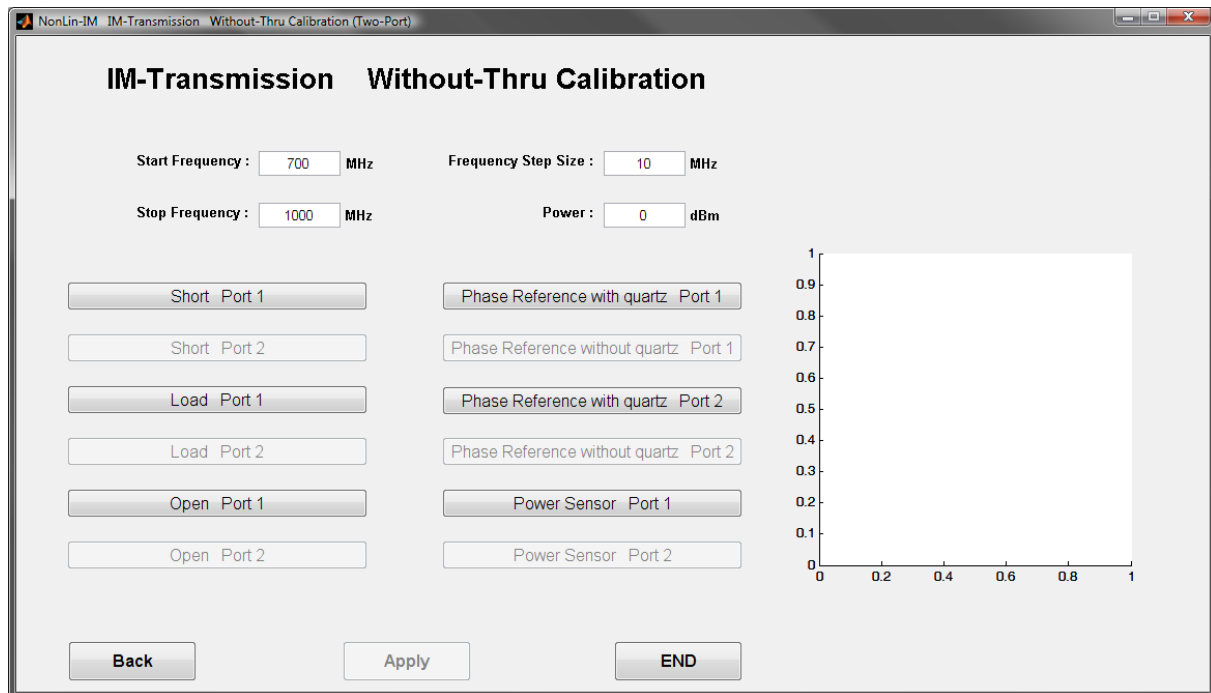


Figure 12: Without-Thru two-port calibration menu of NonLin-IM

The **Without-Thru** calibration procedure allows the user to calibrate the system completely without using a through connection, hence the name **Without-Thru**.

Before starting the calibration select a start and stop frequency, frequency step size (multiple of 1 MHz because of the step size of the phase reference generator) and the input power for the calibration measurement.

For the phase reference measurement, connect port 1 of the phase reference to port 3 of the VNA (for a three-port measurement to port 4) and port 2 of the phase reference has to be used for the other ports of the VNA. After the measurement with the active phase reference a measurement without the phase reference signal is needed to determine the miss match. For this measurement switch the phase reference off and start the measurement.

For the last measurement a power sensor will deliver the measurement results to the VNA.

TMR Calibration

For this procedure an additional standard the through connection is needed.

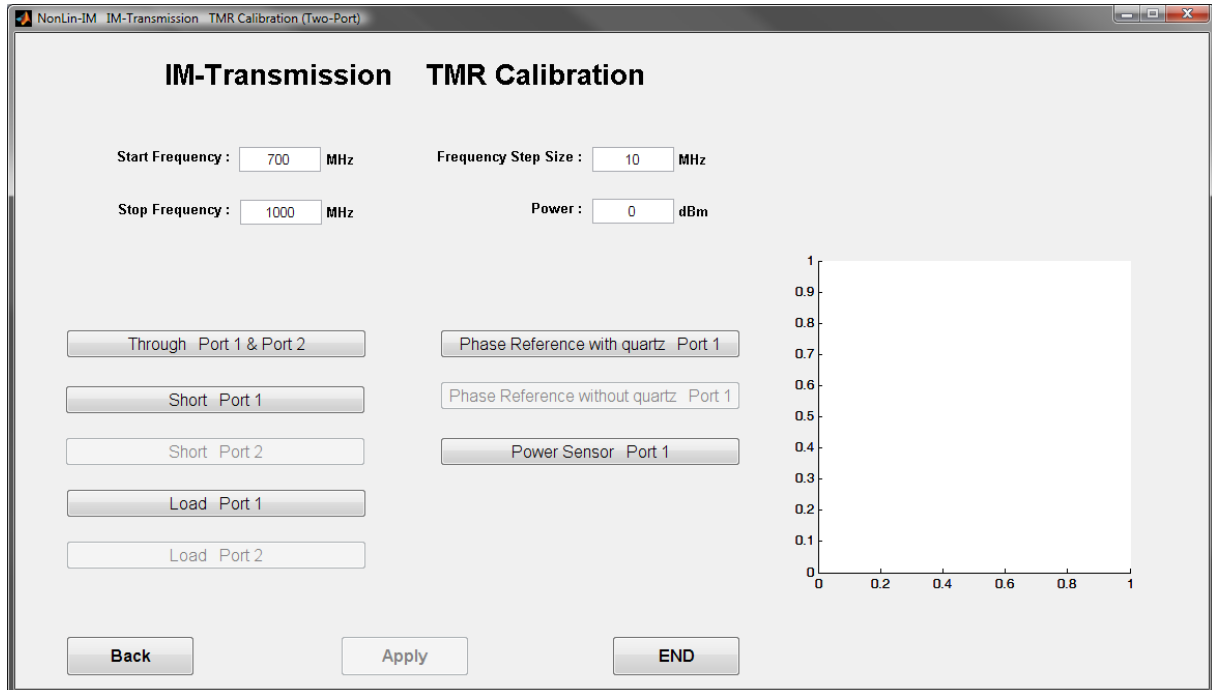


Figure 13: TMR two-port calibration menu of NonLin-IM

If the calibration was successful press the “Apply” button to go on with the linear measurements.

For all other measurement the calibration procedure is similar.

Specials

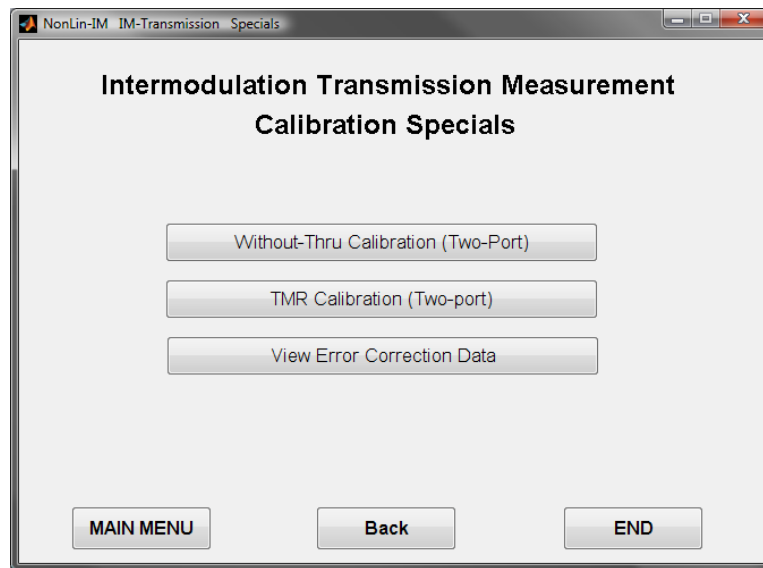


Figure 14: Calibration specials of NonLin-IM

In this feature the user has the opportunity to choose another calibration procedure with old calibration measurements or view the error correction data of the system as given in Fig. 15 and Fig. 16.

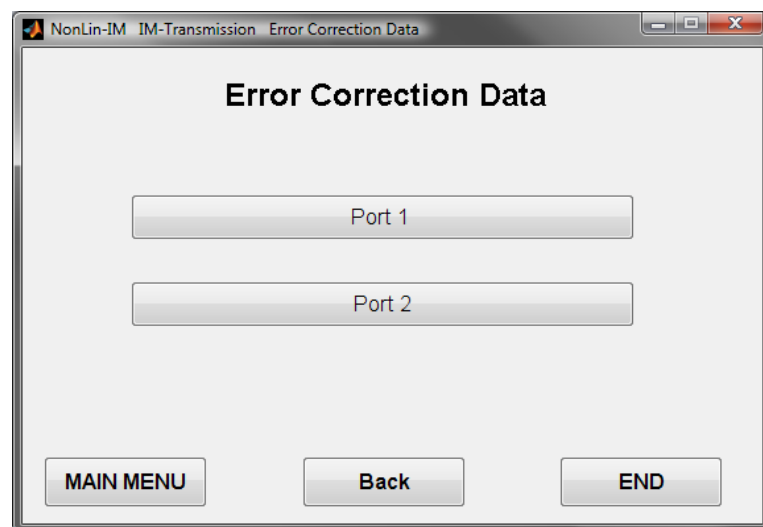


Figure 15: Menu for viewing the error correction data of the system

For example port 1:

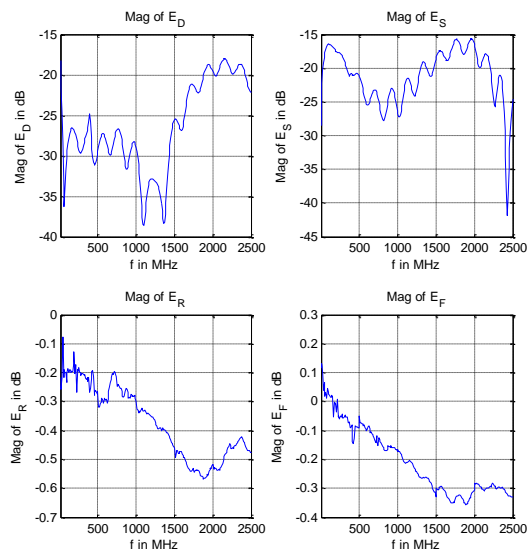


Figure 16: Magnitude of the error correction data of port 1

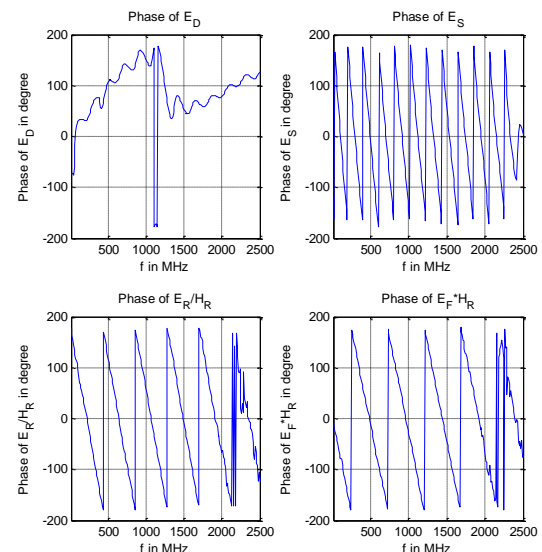


Figure 17: Phase of the error correction data of port 2

Intermodulation Transmission Measurement Set-Up

In intermodulation transmission measurement all functions of the harmonic measurement are given. The following shows the necessary measurement setup:

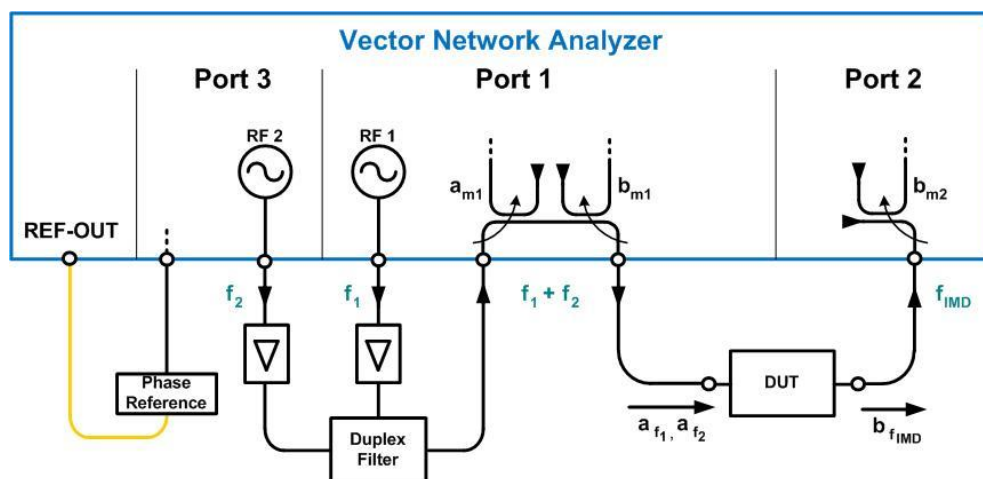


Figure 18: Block diagram of the full measurement set-up for transmission IM measurements with a 3-port VNA with open test-set

Intermodulation Transmission Measurement Results

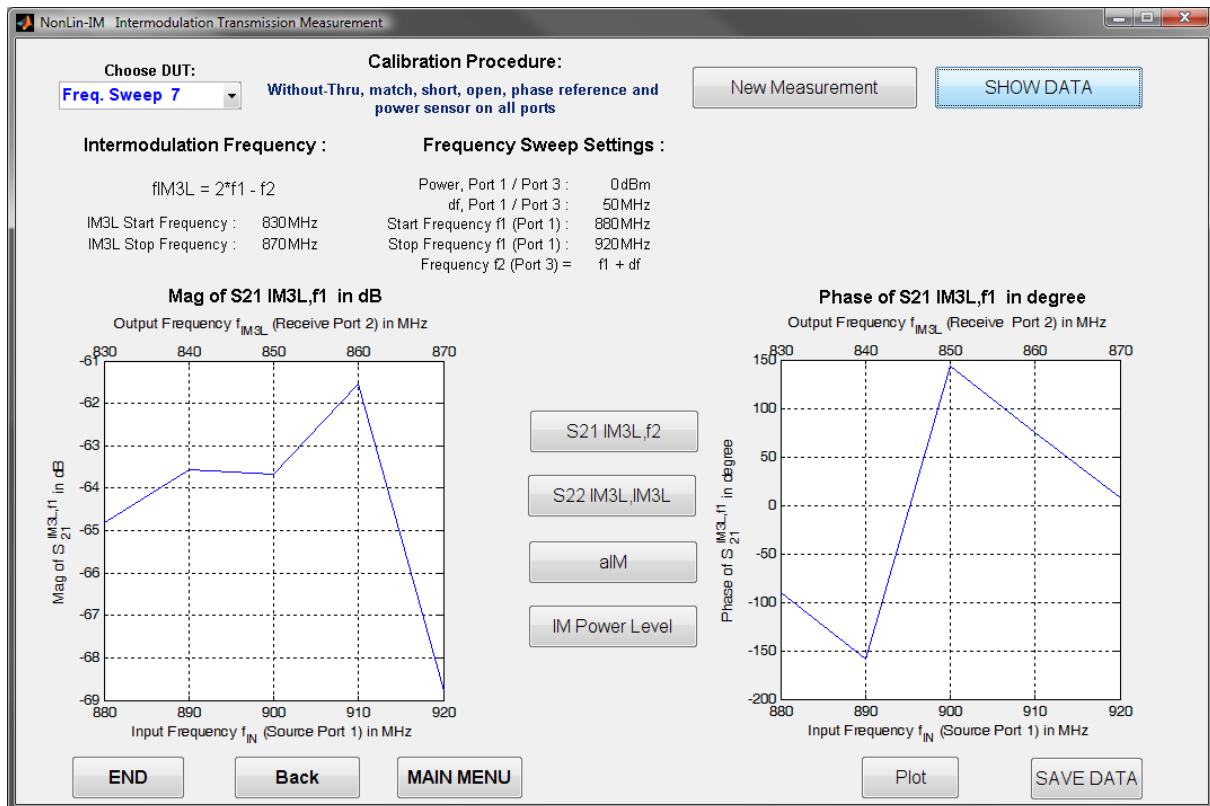


Figure 19: Intermodulation transmission measurement of NonLin-IM

The GUI shown in Fig. 18 visualizes the measurement results of the intermodulation transmission measurements. In this function, all parameter settings of the measurement will be loaded and displayed.

In addition to the magnitude and the phase of S_{21} of frequency f_1 to lower f_{IMD3L} the following features are given:

$S_{21}^{IM3L,f2}$ (Non-linear scattering parameter S_{21} of frequency f_2 to the measured output frequency f_{IMD3L})

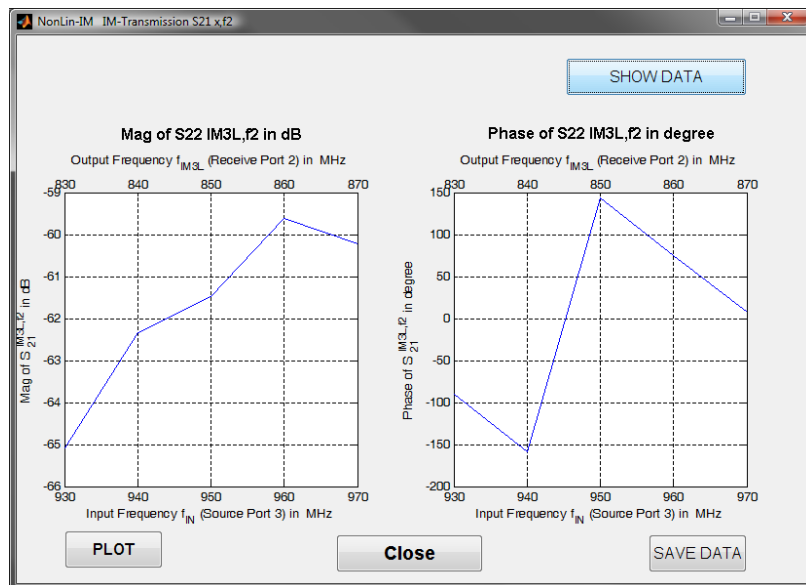


Figure 20: Measurement result of $S_{21}^{IM3L,f2}$

IMD Distance aIM

$$\text{IMD distance: } a_{IMD}^{dB} = S_{21}^{f1,f1/dB} - S_{21}^{IM3L,f1/dB}$$

IMD distance describes the distance between the non-linear S-parameter of frequency f_1 to f_{IMD3L} and the linear S-parameter for f_1 .

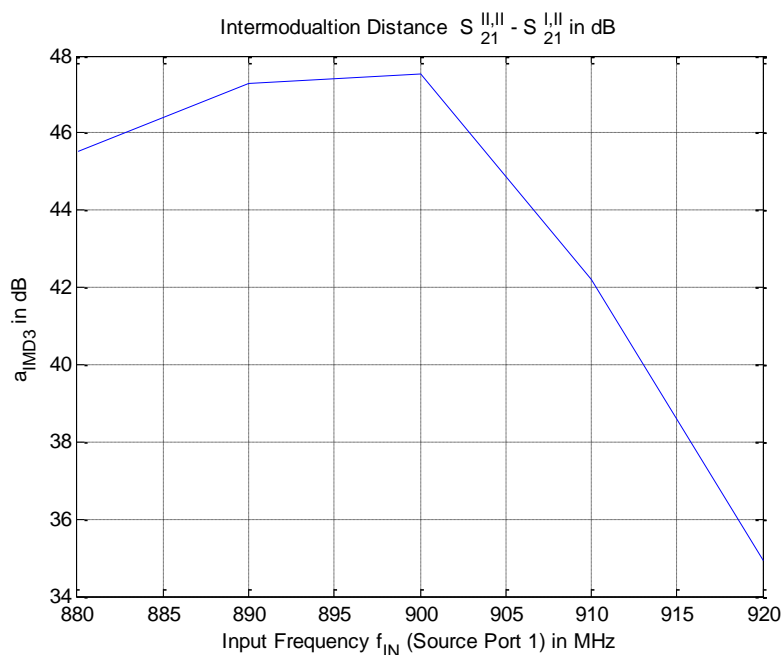


Figure 21: IMD distance of the intermodulation transmission measurement

IM Power Level

$$\text{IM power level: } P_{\text{out}}^{\text{IMD/dBm}} = P_{\text{in}}^{\text{dBm}} - S_{11}^{\text{IM3L,f1/dB}}$$

IMD power level is the level of the introduced power (here $P_{\text{in}} = 0 \text{ dBm}$), which transferred in the Intermodulation products.

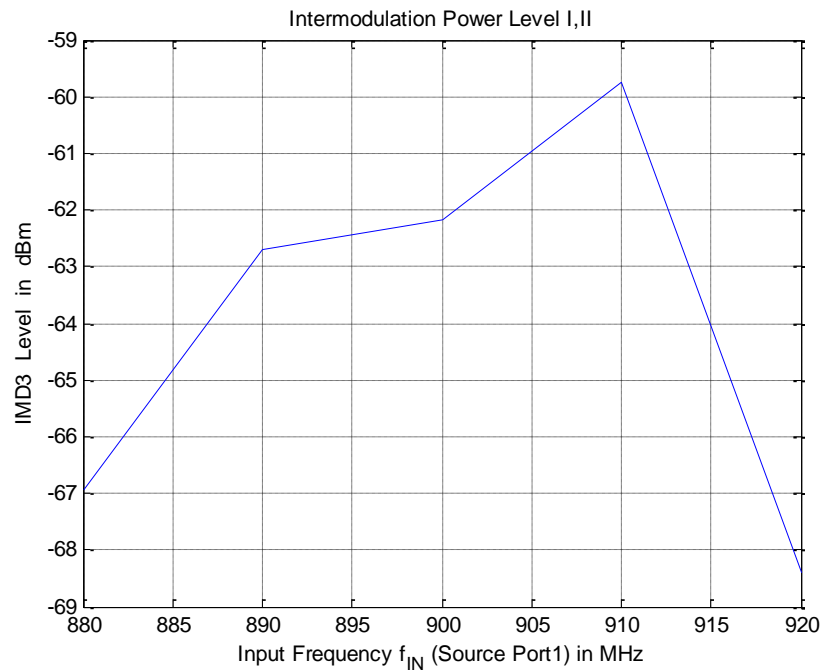


Figure 22: IMD power level of the intermodulation transmission measurement

IMD distance can only be used for the frequency sweep and not for the power or time sweep. The other features exist for all sweep types.

The remaining functions of the intermodulation transmission measurement are analogous to the linear measurement.

Intermodulation Measurement Settings

Frequency sweep:

Intermodulation Transmission Measurement Settings
Calibrated from 700MHz to 1000MHz

Frequency Sweep: f1 & f2 (Port 1 & Port 3) f_{imd} = 2 f₁ - f₂

Start Frequency (f1): MHz
Stop Frequency (f1): MHz
Power, Port 1 / Port 3: dBm
Freq. Skew between f1 & f2: MHz
Frequency Step Size: MHz
Save as Frequency Sweep: Frequency Sweep 8
f2 (Port 3) = f1 + Freq. Skew

Measurement Setup
Vector Network Analyzer

Diagram showing the measurement setup with ports REF-OUT, Port 3, Port 1, and Port 2. A Comb Generator is connected to Port 3, and a Duplex Filter is connected to Port 1. The DUT (Device Under Test) is connected between Port 1 and Port 2. Signals a_{f1}, a_{f2} and b_{fimd} are indicated.

Figure 23: IM measurement settings for a frequency sweep

Power sweep:

Intermodulation Transmission Measurement Settings
Calibrated from 700MHz to 1000MHz

Power Sweep: f_{imd} = 2 f₁ - f₂

Start Power: dBm
Stop Power: dBm
CW-Frequency f1 (Port1): MHz
Freq. Skew between f1 & f2: MHz
Number of Points:
Save as Power Sweep: Power Sweep 1
f2 (Port 3) = f1 + Freq. Skew

Measurement Setup
Vector Network Analyzer

Diagram showing the measurement setup with ports REF-OUT, Port 3, Port 1, and Port 2. A Comb Generator is connected to Port 3, and a Duplex Filter is connected to Port 1. The DUT (Device Under Test) is connected between Port 1 and Port 2. Signals a_{f1}, a_{f2} and b_{fimd} are indicated.

Figure 24: IM measurement settings for a power sweep

Time Sweep:

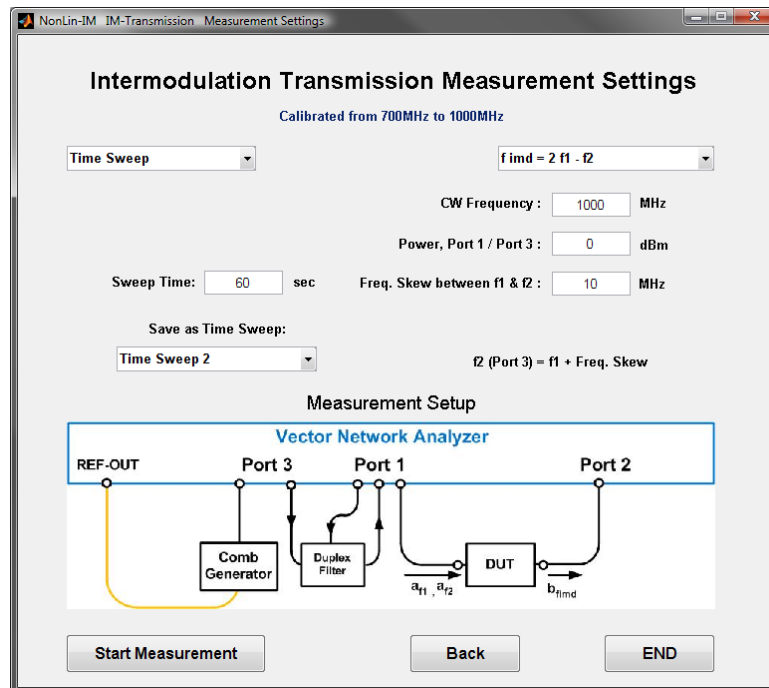


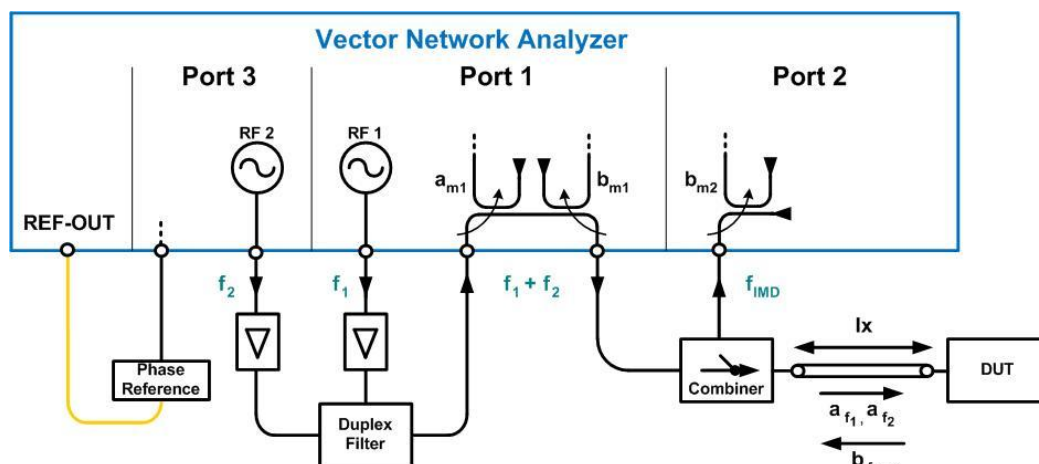
Figure 25: IM measurement settings for a time sweep

On the GUI shown in Fig. 22 to 24, all necessary parameter settings for the intermodulation transmission measurement can be carried out:

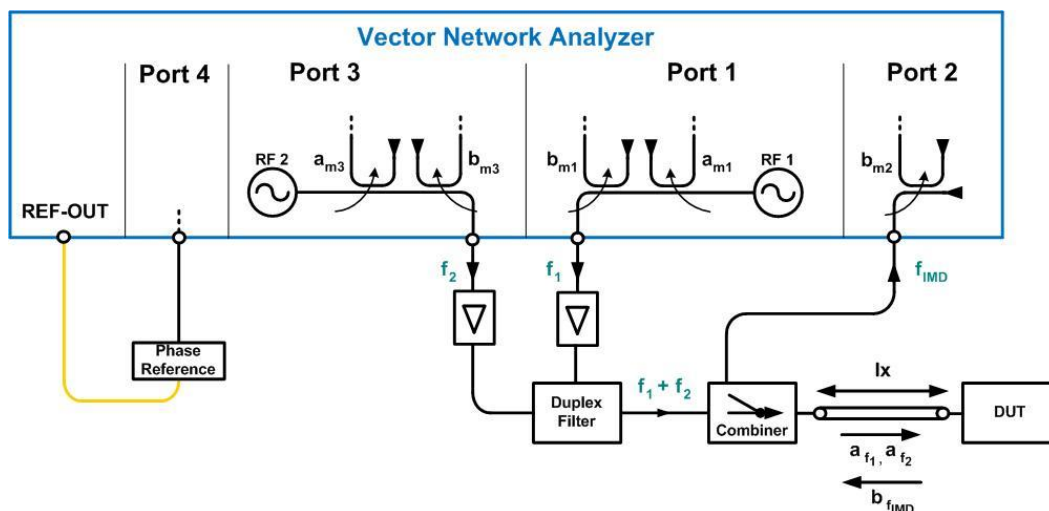
- Sweep Type:
 - Frequency Sweep
 - Power Sweep
 - Time Sweep
- Sweep frequency (Frequency Sweep shown in Fig. 22):
 - f_1
 - f_2
 - f_1 and f_2
- Intermodulation frequency:
 - $f_{IMD3} = 2 f_1 - f_2$
 - $f_{IMD3} = 2 f_2 - f_1$
 - $f_{IMD5} = 3 f_1 - 2 f_2$
 - $f_{IMD5} = 3 f_2 - 2 f_1$
- Start and stop frequency (Frequency Sweep)
- Start and stop power (Power Sweep shown in Fig. 23)
- Power (Frequency Sweep and Time Sweep)
- CW-frequency (Power, Time and Frequency Sweep, if you sweep only with one frequency)
- Frequency skew between f_1 and f_2
- Frequency step size (Frequency Sweep)
- Number of points (Power Sweep)
- Measuring time (Time Sweep shown in Fig. 24)
- Memory place for the later visualisation (differentiation whether Frequency, Power or Time Sweep)

2.2. Intermodulation Reflection Measurement

Three-port measurement setup:



Four-port measurement setup:



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The determined electrical length of the measurement will be displayed at “*Actual Length*” after pressing the “*Show Length*” button. For the calibration of these setups the calibration procedure **Without-Thru** was used. This patented procedure is the only known multi-port calibration method available for frequency converting measurements using only one-port standards, since all eight error correction data (for two-port measurements) are absolutely provided in magnitude and phase. This calibration procedure allows a precious detection of the intermodulation distortion.

Intermodulation Reflection Measurement Settings

The GUI in Fig. 26a shows the settings to perform a reflection measurement. This setting is very similar to the one of the transmission measurement.

New is the feature to choice to different measurements:

Accurate measurement: The speed is low, but the results better (typ. 5 dB more dynamic)

Fast measurement: The speed is higher and the results good.

The mean different is given by the “wait”-times to change in the “General Settings”.

Intermodulation Reflection Measurement Settings

Calibrated from 900MHz to 960MHz

Frequency Sweep: f1 & f2 (Port 1 & Port 3): f imd = 2 f1 - f2:

Start Frequency (f1) : MHz

Stop Frequency (f1) : MHz Power, Port 1 / Port 3 : dBm

Freq. Skew between f1 & f2 : MHz

f2 (Port 3) = f1 + Freq. Skew Frequency Step Size : MHz

Save as Frequency Sweep: Frequency Sweep 2: Three Port:

Measurement Setup

Vector Network Analyzer

REF-OUT Port 3 Port 1 Port 2

Comb Generator Duplex Filter Combiner DUT

I_x a_{f1} a_{f2} b_{fimd}

Start Accurate Meas. Start Fast Meas. Back END

Figure 26a: Intermodulation reflection measurement settings

IM-Finder

In addition to the functions of intermodulation transmission measurement the included software module **IM-finder** calculates out of the phase the distance to the IM-source.

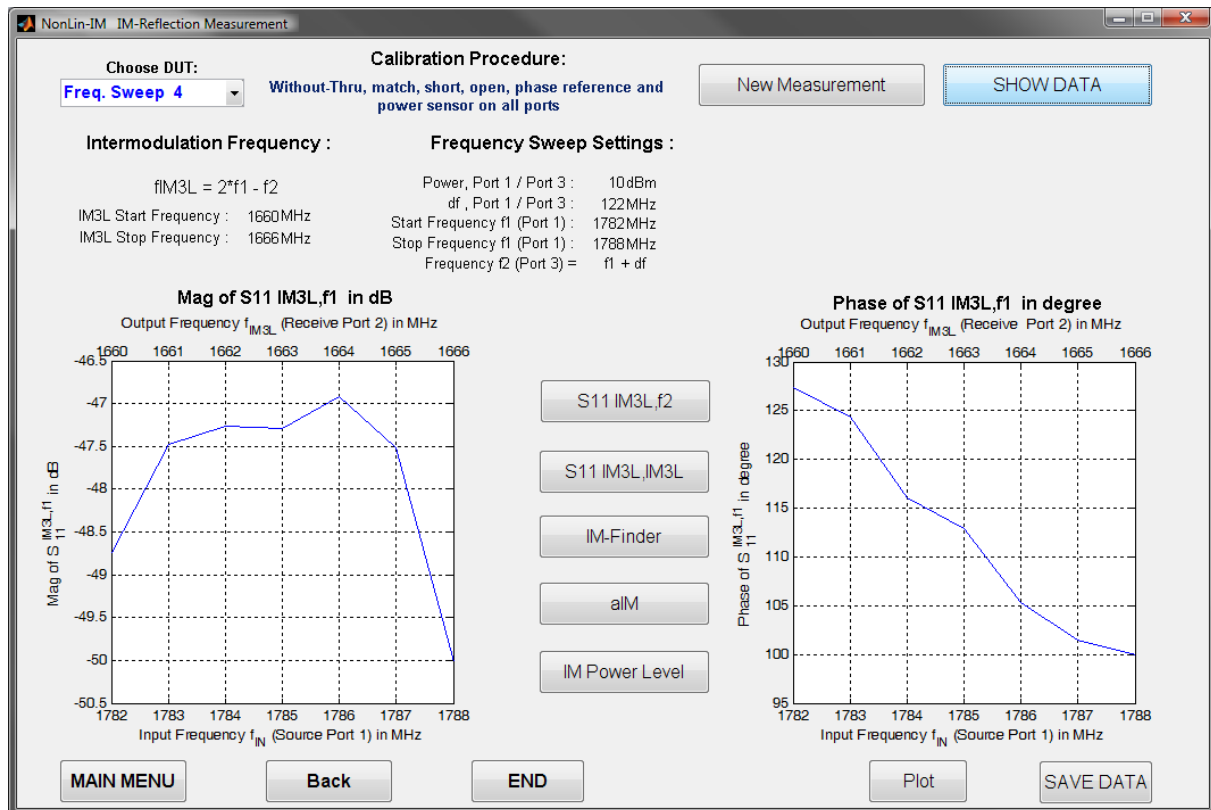


Figure 27: Intermodulation reflection measurement of NonLin-IM

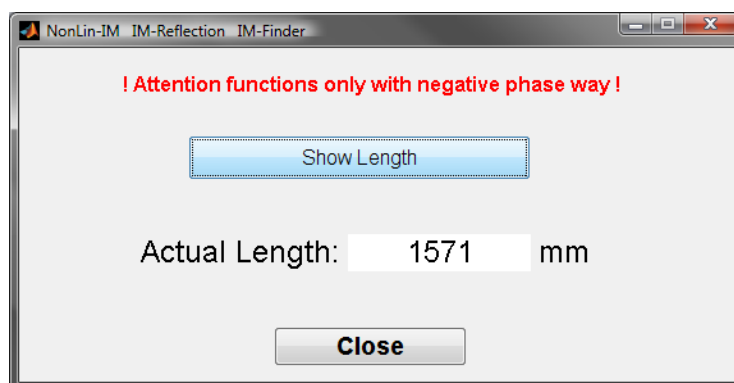


Figure 268: IM-finder for intermodulation reflection measurement with NonLin-IM

This feature allows the user to determine the location, where the intermodulation appears, but only if a negative phase way is given. To determine the location, the following measurement setups are required:

Intermodulation Reflection Measurement Results

The GUI in Fig. 18 shows the magnitude and the phase measurement results of an intermodulation source (measured in a very small band). This source DUT1 was very closed to the reference plane. However, the science has actually no models to identify this source.

The IM-phase of DUT1 is not fixed a one value over the frequency. It start by -160° and ends by 130° .

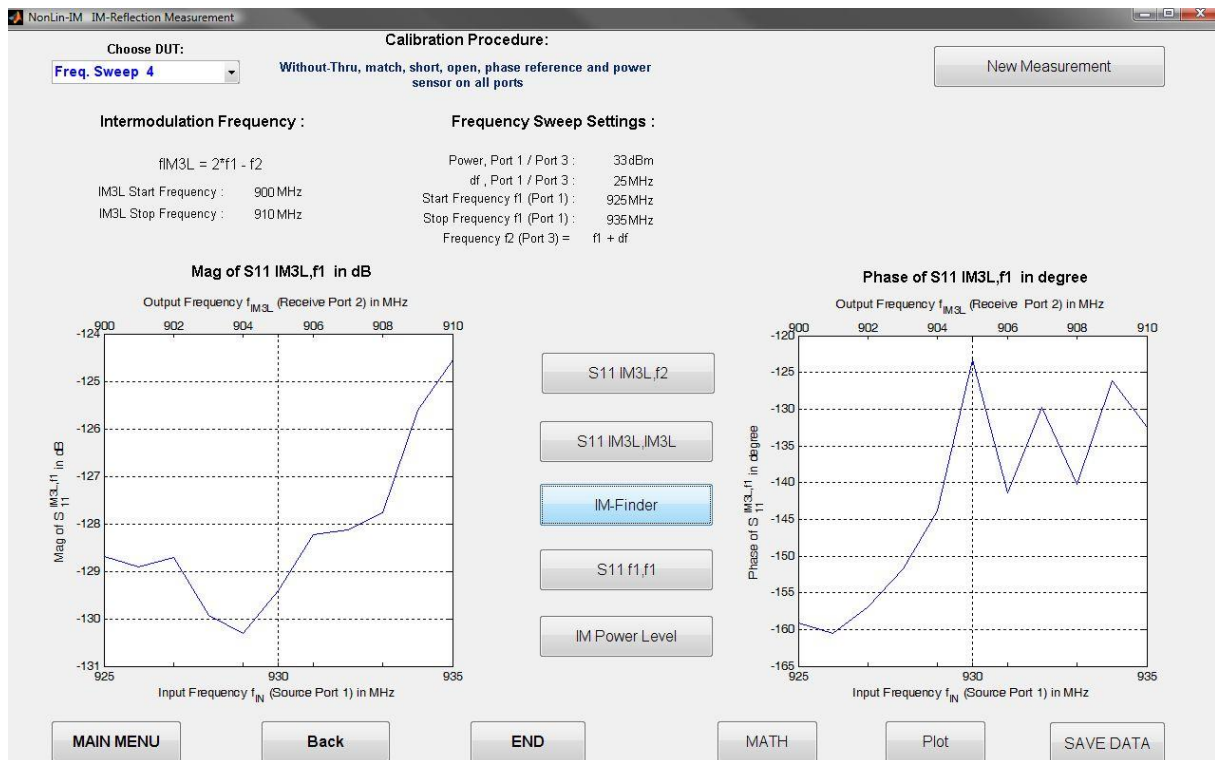


Figure 29: Intermodulation reflection measurement results of DUT1

Fig. 30 visualizes the fitted and interpolated results of the reflection intermodulation measurement of DUT1.

The IM-finder software calculates the lengths of a full reflected obstacle (open, short or other). This equivalent length is by -1429mm .

Another measurement of the same DUT1 with a transmission line in front of it is illustrated in Fig. 31. Here is the phase variation very small.

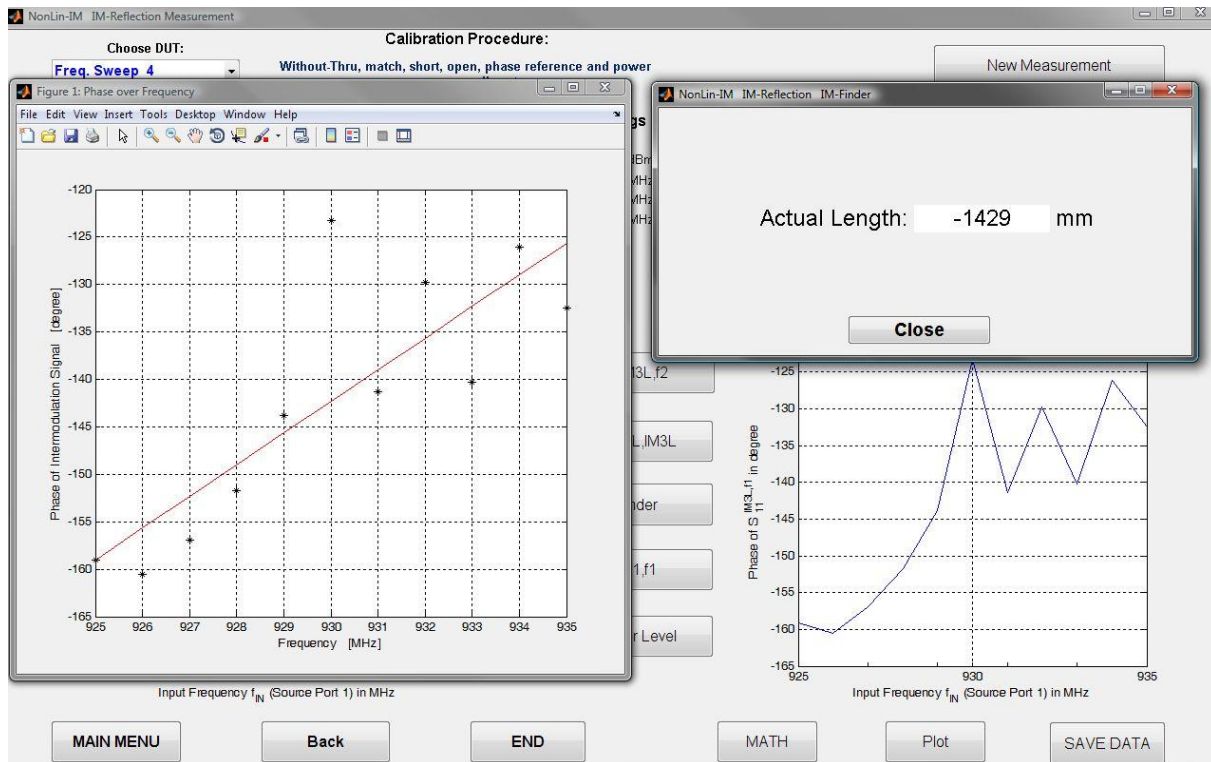


Figure 30: Calculated distance results of DUT1

Fig. 31 helps to locate the IM-source of DUT1.

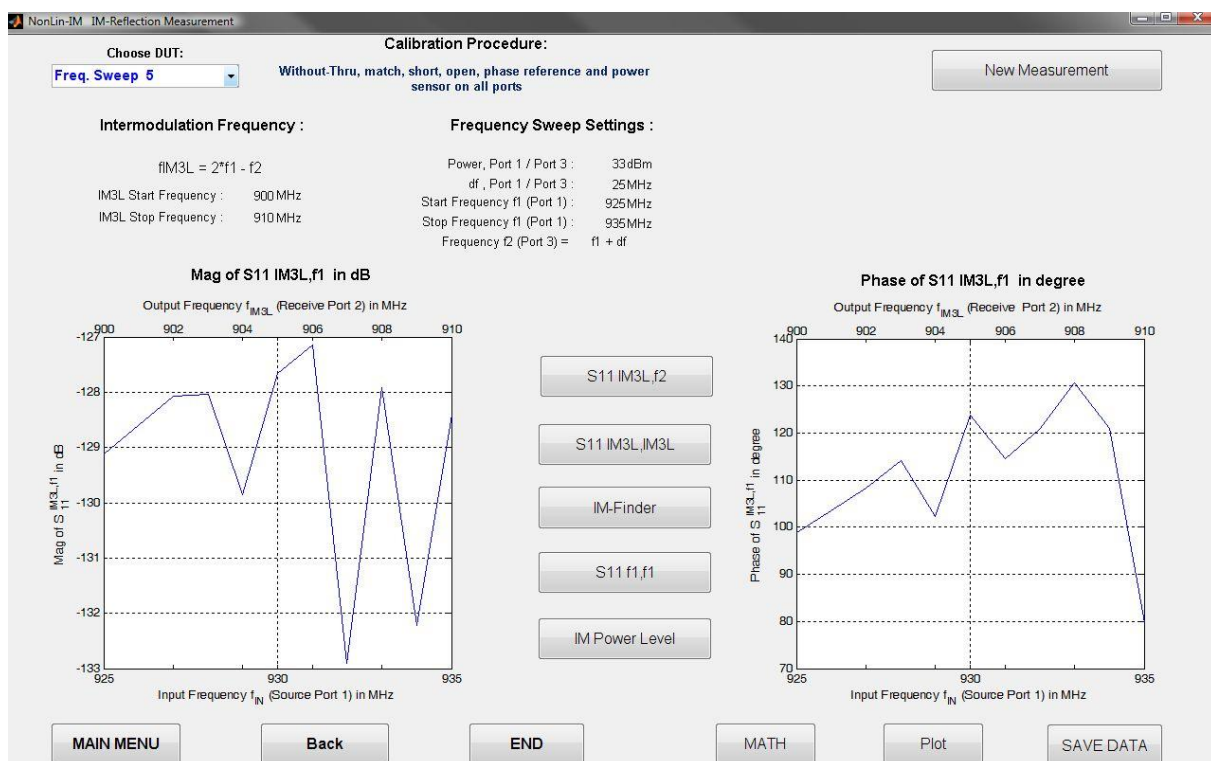


Figure 31: Intermodulation reflection measurement results of a transmission line and DUT1

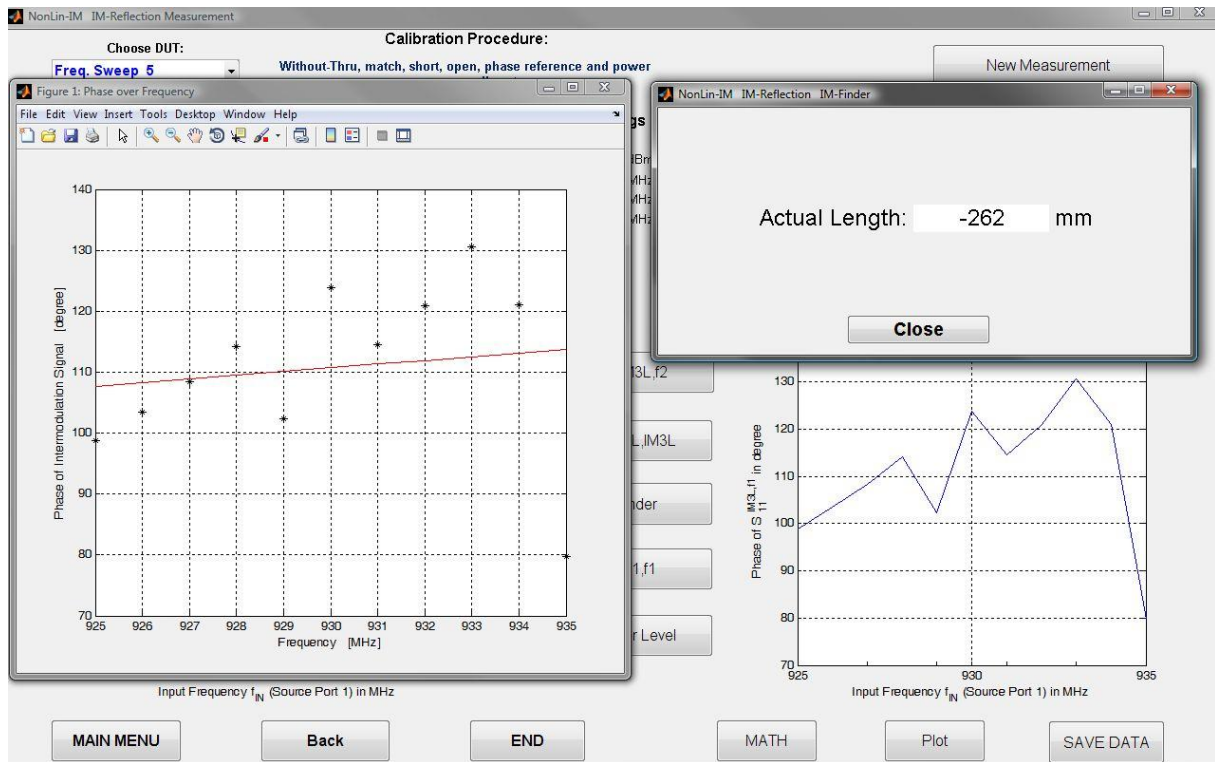


Figure 32: Calculated distance results of a transmission line and DUT1

Fig. 32 indicates the fitted and interpolated results of the reflection intermodulation measurement of transmission line and the DUT1.

The IM-finder software calculates the lengths of a full reflected obstacle (open, short or other). This equivalent length is by -262mm.

The transmission line reduced the electrical length by $1167^\circ/2$. That means the phase of S₂₁ (or electrical length) of the transmission line is close to 584° .

Ordering number

Model: NA-IM1 or NA-PIM1.

Contact information

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