

Chapter 1

Scattering parameters (S- parameters)

Vector Network Analysis opens up completely new perspectives of measurement, which to the user of a scalar network analyzer remain closed. That user sees only the measurement of the amount of a signal (magnitude) on a measurement object content (device under test [DUT]). In contrast the vector network analysis gives additionally a wide insight into the frequency-dependent resistance and phase behavior. It is based on the application of the so-called S-parameters (scattering parameters). The following relationships are shown partially simplified.

The vector network analyser (VNA) sends a known magnitude wave to the input of the measurement object (DUT). In the case of any mismatch (based on 50 Ohms), the VNA will measure the reflected part of the magnitude and also the phase shift between the emitted and the reflected wave (**Figure 1.1**). Overall, it is a reflection measurement (S-parameter: S_{11}). If the DUT has only a single connection (example: antenna), it is called a 1-port. On a 1-port only a reflection measurement is possible! This represents the classic matching measurement.

If the object to be measured (DUT) has an input, and also an output (examples: amplifiers, filters, phasing lines), then it is called a 2-port. Often of first interest in a 2-port is, how large the magnitude of the output signal versus the input signal is – gain or a desired attenuation, respectively.

In other cases, one would like to know the phase shift of the output signal relative to the input signal – such as when measuring a phase-shifting line or the making of two long lines electrically exactly equal. This is all done with a so-called thru (transmission) measurement (S-parameter: S_{21}). **Figure 1.2** presents the measurement of the S-parameter S_{21} idealized.

But the reverse is also possible: The VNA can feed a wave into the DUT output, and measure what fraction of magnitude comes out of the input. This measurement shows the feedback of the output by the DUT circuit on the input (S-parameter: S_{12}), **Figure 1.4**.

On a 2-port, reflection measurements are also possible. They show the existing adjustment (based on 50 ohms) each at the input (S-parameter: S_{11}) and output (S-parameter: S_{22}) of the DUT (see Figure 1.4). Here it is important, that the unused port has a correct impedance connected. That is, terminated with the reference impedance, usually 50 ohms.

Furthermore, measurement objects can have one input and two outputs or two inputs and one output (examples: power divider, power combiner, antenna switch). This is a 3-port - **Figure 1.5** and **Figure 1.6** (for reasons of clarity a two part presentation is selected). As already noted for the 2-port, for the 3-port all unused ports must have always a correct impedance connected!

Below is the summary of the S-parameters for 1- port, 2- port and 3- port measurements:

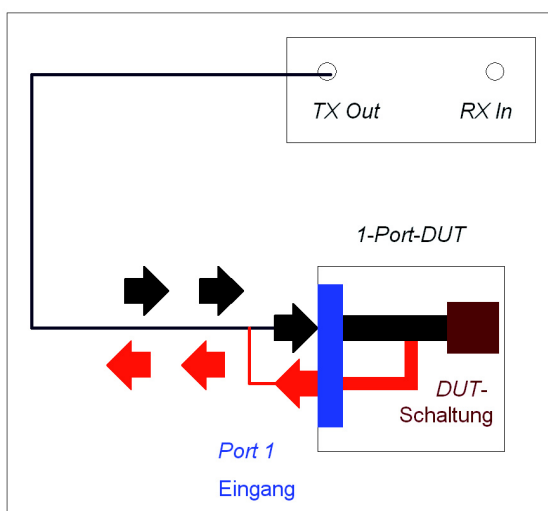


Figure 1.1: Reflection measurement on a 1-port; the classic matching measurement.
(Eingang = Input, Schaltung = Circuit)

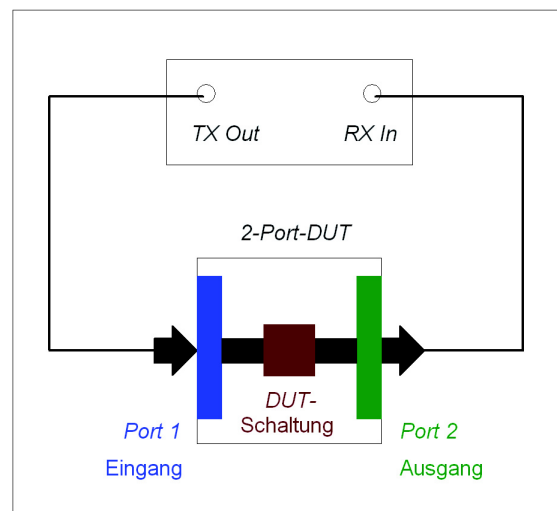


Figure 1.2: With a thru (transmission) measurement you can make gain/attenuation- and phase-measurements.
(Eingang = Input, Ausgang = Output, Schaltung = Circuit)

Chapter 5

Contexts and Concepts TX Out, RX In, Port 1, Port 2; S-Parameter Test Set

Definitions *TX Out, RX In, Port 1, Port 2*

This chapter first has some definitions and explanations which concern the correlations of different S-parameter measurements and the different ways of connecting the necessary VNWA2/VNWA3 to the DUT with proper understanding. They also provide the necessary basis for chapter 6.

The interest of VNWA3 beginners usually grows after a short time, in addition to the initial S_{11} - and S_{21} -measurements, to take advantage of the S_{22} - and S_{12} -measurement capabilities. This is only possible on a simple VNWA2/VNWA3, with the manual exchanging of the *TX-Out* and the *RX-In* terminals of the measured object, and additionally the measured *Forward* and *Reverse* direction has to be switched.

This effort is annoying and inconvenient, and it also does not allow the rapid assessment of the two directions of measurement - how to improve the matching, for example, of a bandpass filter with the (almost) simultaneous observation of the input and output impedances (S-parameters S_{11} , S_{22}). An S-parameter test set which satisfies such requirements, will be presented in the second part of this chapter.

Firstly, the paths of the measurement signal and other characteristics of S_{11} -, S_{22} -, S_{21} - and S_{12} -measurements are taken into account:

- The S_{11} -measurement is a reflection measurement. Only the *TX-Out* test lead goes from VNWA2/VNWA3 to the input of the DUT, which is called *Port 1* (**Figure 5.1 A**). S_{11} -measurement measures into the input of the measuring object; measuring the

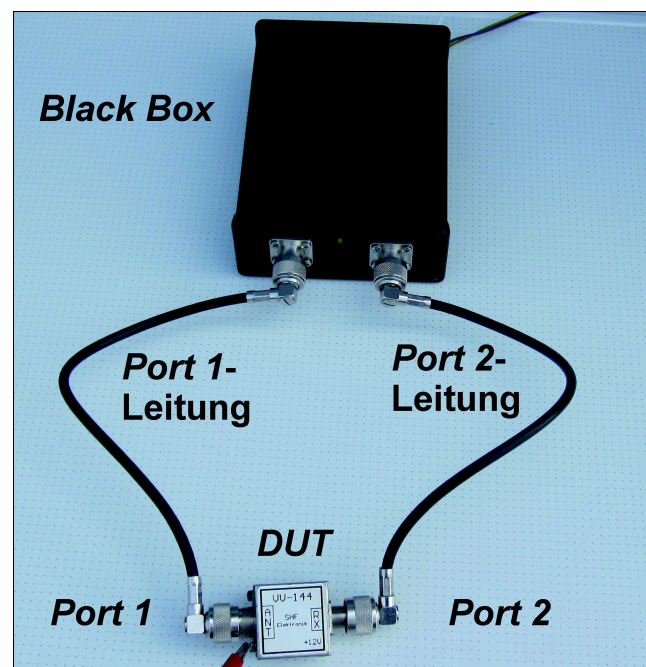
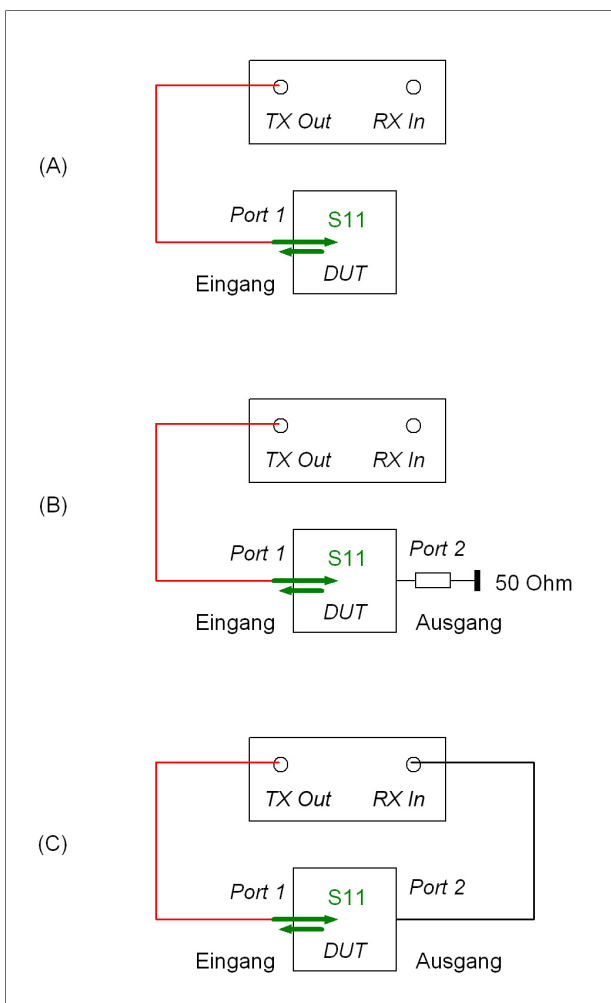


Figure 5.1 (left) Paths of the measurement signal and the necessary connections in an S_{11} -measurement of (A) a 1-port DUT, (B) and (C) a 2-port DUT.

(Eingang = Input)
(Ausgang = Output)

Figure 5.4 (top): The Black Box includes the VNWA3 and the S-parameter test set. The left port belongs to port 1 of the measurement object, the right connection to the port 2 of the measurement object!

All else is controlled by the VNWA software.
(Leitung = Line)

Chapter 14

Measuring Phase Angle

As noted in Chapter 4, the major advantage of a Vector network analyser over a Scalar network analyzer, lies in the possibility of phase angle measurement. It is for example necessary for a line within which a well-defined phase rotation is to take place - as is the case in the 180° phasing line for a dipole feed. Also, creating a right- or left- handed circular polarization with linearly polarized antennas requires a defined phase shift between the participating antennae. This is also possible with a line length calculation and has been practiced for decades, but “the better is always the enemy of the good”! Once one or more coaxial transfer relays are inserted in such a system (such as in a switchbox for different polarization planes), they also add to the cable lengths and must be considered in the crucial 90° phasing lines.

The higher the operating frequency, the larger is the phase angle for a given length (see Chapter 4, Phase), whereby the thing is trickier! If you can grasp all this measuring technology, compared to a calculated solution, there are advantages.

14.1 Measuring the phase angle of an Ecoflex10 coaxial cable with 3.6 meter length

The measurement example in **Figure 14.1.1** works with a 3.6 meter long coaxial type Ecoflex10 for phase angle measurement with the VNWA2/VNWA3. We need to discover, for what frequency is this piece of cable a quarter wavelength ($\lambda/4$)? Since $\lambda/4$, the phase angle 90°, exists there, you can go to this value after the measurement of the results graphically and obtaining the frequency display.

Operation Mode

Options => Operation Mode => VNWA

(A) Measurement setup

- Test lead **Port1 (TX Out)**
- Adapters before (!) the calibration standards

Type of Calibration Standards

- Manufacturer **Kusch UG 57 TA**
- Type / Series **N**
- male/female **female**

(B) Display window: Key „d“ => Display Settings: Trace enable

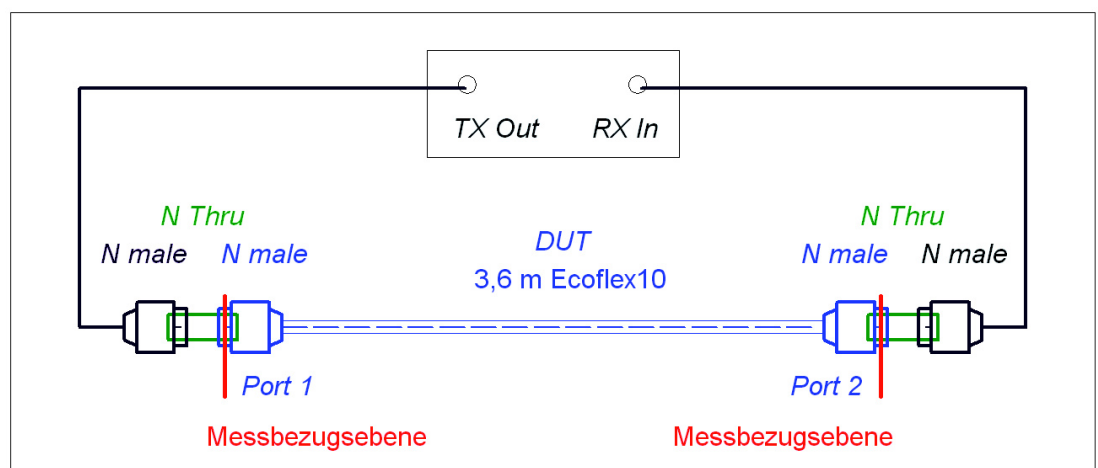
Traces 1, 4

Apart from the actual measurement curve for the phase angle display, the transmission loss is also shown for control purposes. The choice of the trace numbers is arbitrary.

Figure 14.1.1:

In the measurement set-up, each measuring line terminates in an N-connector (N male). To connect the 3.6 m long Ecoflex10-line (DUT), therefore one needs two female Thru-connectors. The Calibration is performed with a male connector through ; N double plug, Kusch UG57TA.

(Messbezugsebene = Measurement calibration plane)



Chapter 15

Measuring of the wave resistance (S_{11})

It is important for good impedance matching, to have knowledge of the wave resistance, or Characteristic Impedance, of a cable as well as that of its associated components. Otherwise extra signal level is lost, than just that from the attenuation of the transmission line alone.

The classical example, for Amateur Radio stations, is of course the coaxial cable between the antenna and the transceiver with nowadays commonly 50 ohms wave resistance. There are also "exotica" with 25 ohms, 35 ohms, 75 ohms and 93 ohms wave resistance; also symmetrical cables with 240 ohms, 300 ohms and 450 ohms wave resistance. So when you come across a cable with no number, it can only help to measure it's wave resistance.

Just as for measuring cable lengths, in the case of a wave resistance measurement the VNWA2 / VNWA3 first performs a wideband-frequency measurement and then evaluates the so-called Step Response, using a (mathematical) inverse Fourier-transformation. The Step Height is scaled to the respective cable impedance.

15.1 Measuring the wave resistance of a coaxial cable

For this example measurement, the wave resistance published by the manufacturer of RG-62 of 93 ohms, is checked. A piece of the coaxial cable with a length about 2.83 m is available. The far end is left open-circuit.

VNWA mode of operation:

Options => operation mode => VNWA

(A) Measuring setup

Figure 15.1.1 shows the measurement setup as a circuit diagram: The piece of coaxial line is plugged into an SMA connector (SMA thru) connected to the SMA male, which is bolted to the end of the *Port-1- (TX-out)* test lead. The practical implementation is illustrated in **Figure 15.1.2** , but an alligator clip was used to clamp the shielding braid onto the through connector, removed for the photo.

The following calibration standards are to be used:

Type of Cal standards

- Manufacturer
- Standard
- Female / male

Rosenberger
SMA
female

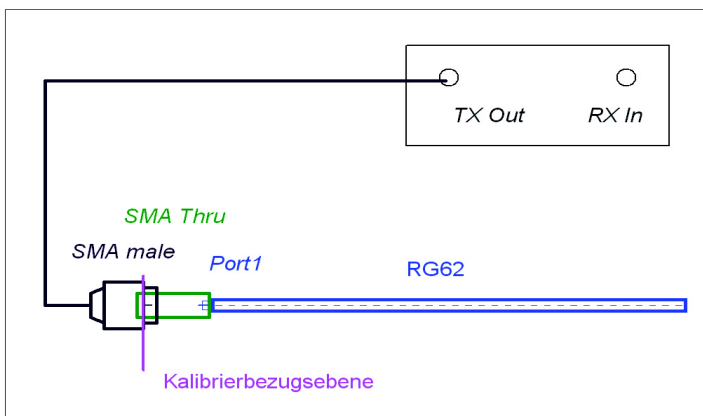


Figure 15.1.1: Circuit diagram for measuring the wave resistance of 93-ohm coaxial cable RG62.

(Kalibrierbezugsebene = Calibration reference plane)

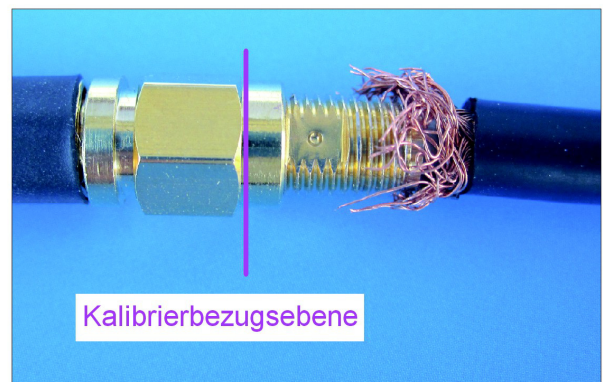


Figure 15.1.2: The pictured RG 62 inner conductor continues with its insulation to right inside of the SMA-Thru. a crocodile clip (not in picture) provides for the contact of the shielding braid.

(Kalibrierbezugsebene = Calibration reference plane)

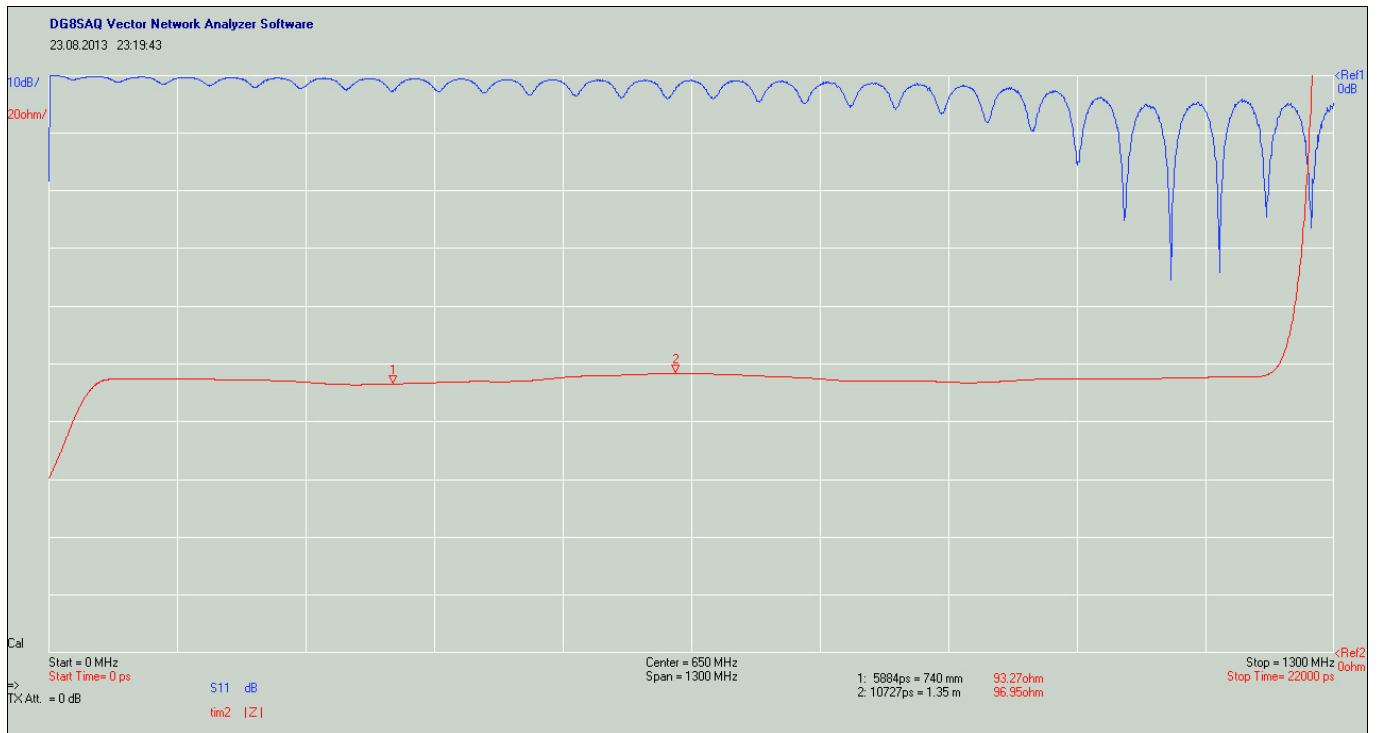


Figure 15.1.4: The display of the number of results is done by setting time markers.

(I) Keyboard "**p**" => **Port Extensions**: Depending on the desired measurement reference plane now move the calibration plane:

- Measurement reference plane = Calibration plane (Male Reference Plane)

In order to exclusively measure the characteristic impedance of RG-62 coaxial cable and display an image like Figure 14.1.1 the measurement reference plane lies to the right of the standard reference plane used for connecting the female SMA connector (SMA Thru, green). Will be seen as equal in the measuring graphics, but you can, for general characteristic impedance determination, waive the coaxial cable to it, since the measurement results of this small initial area (at the beginning of the trace) is not taken into account by the calculation.

Measurement access and viewing the results

Figure 15.1.4: The mouse to *single sweep* - or Keyboard "Spacebar" - gets the measurement started. After the sweep of S_{11}/dB the red $tim2 / |Z|$ -measurement-curve suddenly appears.

To have a somewhat more accurate representation, the resolution is set to 20 ohms. To do this, click with the left mouse button either on the main screen top left *ohm/* or to its right *< Ref2 0 Ohm*. The window opens *Input: Trace 2* (**Fig. 15.1.5**), in which at top left, the value "20" must be entered, and the associated unit *ohm / Div* in the pull-down menu right next to it is selected.

The view of the red trace reveals that the wave resistance is not perfectly constant. To obtain some numerical values, we use two *time markers* (because we get the measured result of the time-function): First move the mouse cursor to the main screen of the measurement graph, and click the right mouse button. This opens the in **Figure 15.1.6** left, larger windows. Appears by setting the cursor on *Add Time Marker* to the right of addition a smaller window. There *Add Normal Time Marker* is clicked with the left mouse button. Now you can move the generated Marker1 along the red curve (to position the cursor over Marker1 and when moving, the left Mouse button held down) and read off the wave impedance in the add text to marker 1.

Here is the display text: *Marker1 : 5884 ps = 740 mm 93.27 ohm*, and for the (generated in the same way, second): *Marker: 2 10727 ps = 1.35 m 96.95 ohm*.

To get the graphic representation to a very fine resolution of eg 1 ohm/div (*1 ohms/div*), apply the settings shown in **Image 15.1.7 Input: Trace 2**: Instead of the previous 20 ohms per division (*20 ohm/div*) enter 1 ohm per scale division (*1 ohm/div*). This means that the vertical scale (with the commonly used 10 scale units) already ends at the top of the visible screen with 10 Ohms - yet the trace is virtually invisible after plotting. The expected 93 ohms is "on the monitor off screen". If we now virtually project beyond the monitor 90 ohm scale mark in the visible area of the screen at the position of the 0-ohm scale mark "Pull down", we get the visible range of 90 ohms to 100 ohms.

few picoseconds difference in the use of high-quality calibration standards by mere screwing and unscrewing! Not without reason, the industry uses torque wrenches to screw the connector elements, which guarantee a constant pressure force!

For calibration standards, the UHF and BNC connection standards are not documented here. The former are only suitable for the short-wave range, so you have to use the setting *ideal calibration standards* (accessible by keyboard "k", then *General Settings* tab) and do not worry about *offset* input values. BNC connectors are indeed well specified, but here it always comes down to the spring force generated by a good contact with the outer shield.

A regular cleaning of grease, finger sweat and thread wear is advised even for the presently preferred SMA and N connectors. Tarnished silver coatings and dirty threads on Calibration elements are measurable! If you already calibrated under such conditions, then any subsequent measurements are wasted and inaccurate!

Offset values for selfmade Calibration Standards „N“						
		Short	Open	Short	Open	Thru
		male	male	female	female	male-male
						female-female
1	Rosenberger					
	Flansch plan			-86,88 ps	-91,72 ps	
2	UG 58 TG			-118,81 ps	-119,43 ps	
	hohl				+16,69 ps	
3	UG 58 KF			-110,78 ps	-86,28 ps	
4	Radiall					
	R161444037	-158,34 ps	-159,22 ps			
5	UG 59 STG	-152,86 ps	-168,53 ps			
6	UG 129 TA					-79,40 ps
7	UG 29 TA					-80,84 ps
8	UG 57 TA					-140,34 ps

Table 7.1: All measurements with a semi-professional calibration kit as a basis.

To 1) Make Rosenberger, type unknown. As described in the section "N-self-assembly calibration *Short* and *Open* with female connector" see Figure 7.4. Sources: flea market, internet.

To 2) *Open*: The protruding flange back on the solder connection is first cut and then filed to the level of the circular injection (similar to Figure 7.4, middle).
Open "hollow": The PTFE insulation and the inner conductors are heated with two powerful soldering irons or a heat gun and patience and the metal casing is removed. Caution: Very hot! Risk of injury!
Short: A bored small copper plate is pushed over the pin causing the short circuit and it is soldered all round in compression and the solder connection is similar to Figure 7.4, left; Reference [7.5].

To 3) *Open*: The protruding flange back on the solder connection is cut and filed to the level of the circular Ground plane.
Short: Flush to the PTFE insulation, Solder a brass washer and (pushed together) solder to the circular ground plane. Reference [7.5].

To 4) See "N-type self-made *Short* and *Open* Calibrations with male Connector" and Figure 7.6. Source Internet.

To 5) Preparation (similar to 4).
Open: The solder connection on back of flange is cut and filed to the level of the circular ground plane.
Short: A bored and pushed-on Solder-tinned small copper plate causes the short circuit in which the solder connections are at the surrounding ground surface. Reference [7.5].

To 6) Figure 7.9: reference [7.5].

To 7) Figure 7.8: reference [7.5].

To 8) Figure 7.10: reference [7.5].