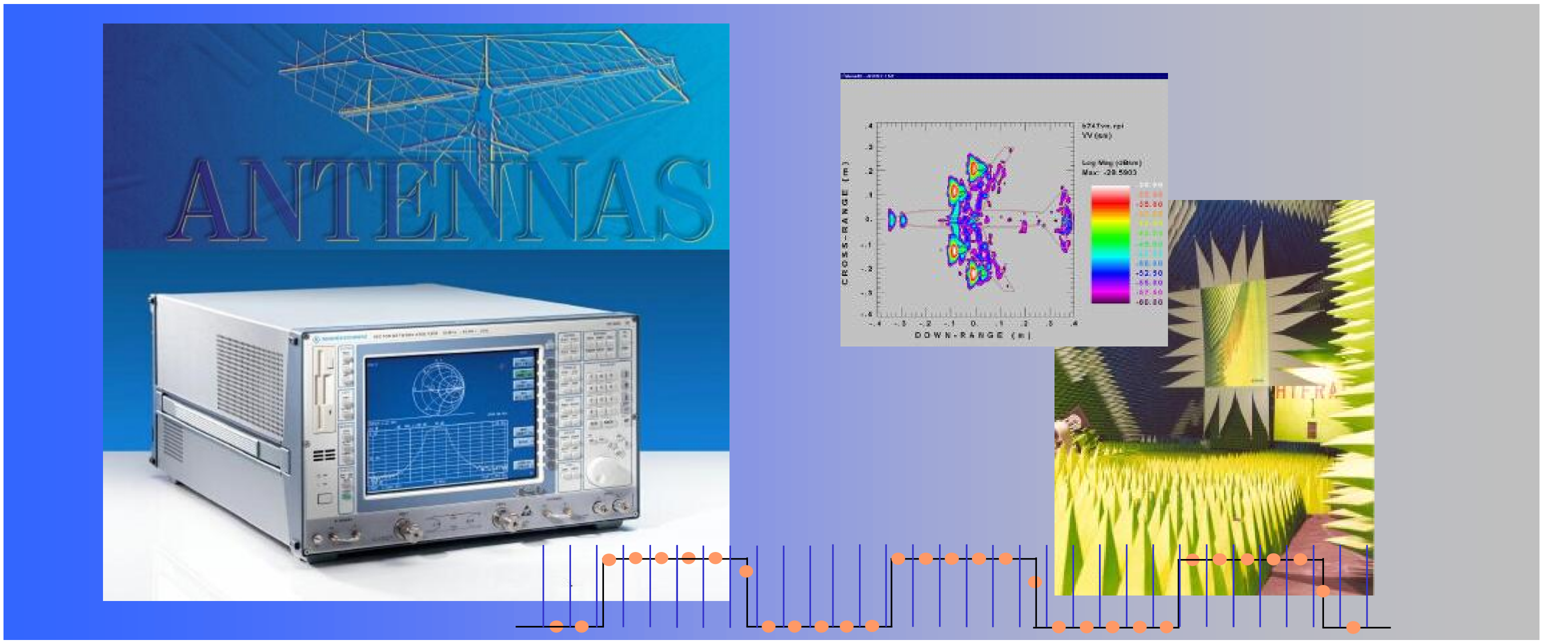

Products: Vector Network Analyzers R&S® ZVM, R&S® ZVK; Microwave Signal Generators R&S® SMR

Antenna Measurements, RCS Measurements and Measurements on Pulsed Signals with Vector Network Analyzers R&S ZVM, R&S ZVK

Application Note

This application note describes the suitability of the R&S® ZVM and R&S® ZVK as multichannel microwave receivers for antenna measurements and RCS measurements including measurements on pulsed signals. Application examples describe the measurement possibilities on pulsed signals using the R&S® ZVM/ZVK as stand-alone units. In addition, various R&S® ZVM/ZVK-based antenna measurement systems of the March Microwave company are presented in detail.

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Contents

1 Introduction

Measurement systems for antennas cover a wide range of various systems and measurement methods, from simple matching and transmission measurements to high-resolution measurements of radiation patterns, RCS- (**R**adar **C**ross **S**ection), or measurements of pulsed signals over long distances. The classic use of network analyzers is actually to characterize RF or MW components like filters or amplifiers by S-parameters. However, because of their basic quality as multichannel microwave receivers, R&S® network analyzers are highly suited for antenna measurement systems.

R&S® ZVM and R&S® ZVK can be used as a stand-alone unit for a number of antenna measurements. Many applications in this field, however, require extensive systems equipped with shielded chambers, reflectors, positioning mechanics, control and evaluation software, etc. The March Microwave company (Netherlands) is a supplier of all-in-one measurement systems of this kind, including corresponding control and analysis software packages. The R&S® ZVM and R&S® ZVK were integrated into different customized measurement systems in cooperation with Rohde & Schwarz.

This application note is therefore divided essentially into three parts:

Chapter 2: Description of the specifications and functions of which the R&S® ZVM and R&S® ZVK are suitable as multichannel microwave receivers and core components for antenna measurement systems. Focus is on flexibility of the test set, the four integrated receiver channels and their sensitivity, the synchronous control of the internal and external signal sources, measurement speed and other useful detail functions. The sensitivity of up to 140 dBm is outstanding, as are the excellent system sweep speed values.

Chapter 3: Measurements on pulsed signals using the R&S® ZVM/ZVK as stand-alone units. The measurement speed is discussed, and appropriate methods for measurements on "long" pulses in a synchronized and settled state and on "short" pulses in the unsynchronized high PRF[1] mode are presented. Measurements of the average amplitude of a pulse stream and of the corresponding spectrum, the complex S-parameters or phase and group-delay measurements of a pulse stream are possible. Depending on the repetition rate, the average values of pulses well under a width of 0.1 µs can be measured.

Chapter 4: Detailed description of R&S® ZVM-based systems of the March Microwave company including theoretical background. Systems for direct transmission measurements, with external mixing for signal transmission over long distances, for near/far-field measurements, for RCS measurements and for pulse profile measurements - in contrast to R&S® ZVM/ZVK as stand-alone-units - on single pulses are presented. For example, a sensitivity of 80-90 dBsm in a shielded chamber, excellent system sweep times and a hitherto unattained resolution for pulse profiling of 5 ns can be achieved.

Note 1: In this application note, the abbreviation “R&S ZVx” is used, standing for both network analyzers, R&S ZVM and R&S ZVK.

[1] **P**ulse **R**epetition **F**requency

2 Application-Specific Functions of the R&S ZVM/R&S ZVK

The R&S ZVM (10 MHz to 20 GHz) and the R&S ZVK (10 MHz to 40 GHz) are vector network analyzers with an integrated generator and two measurement and two reference channels. The following sections describe important characteristics of the R&S ZVM and the R&S ZVK that are useful for antenna measurements.

2.1 Test Set of R&S ZVM/ZVK: Design, Sensitivity, Attenuators

One requirement of many antenna measurement systems is to detect signals from a number of receivers as loss-free and interference-free as possible – typically from antennas to capture the horizontally, vertically or circularly polarized radiation portion or from antennas at different locations. The basic model of the R&S ZVM and the R&S ZVK, featuring two measurement and two reference channels, can be used for such applications as a four-channel microwave receiver. The quasi-simultaneous measurement of up to four signals avoids reconnecting or interference from external switches.
The reference paths run via the front panel using cable clips: after removing the cable clips, the test signals can be fed to PORT 1 and PORT 2 as well as to R1 CH IN and R2 CH IN. The measured power from all 4 channels a1, a2, b1 and b2 as well as all ratios of these wave quantities and of course all possible S-parameters can be simultaneously displayed.

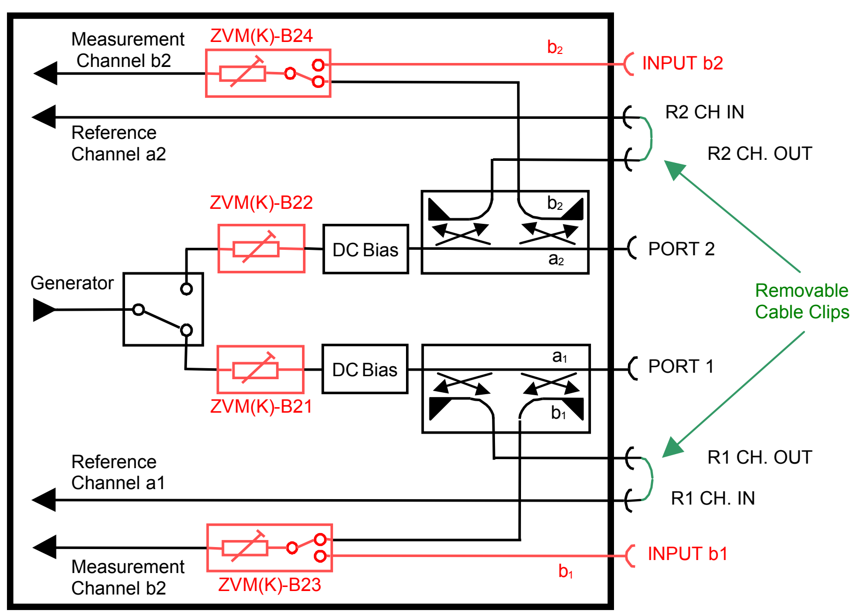


Figure 1:

Test set of the Network Analyzers R&S ZVM and R&S ZVK. The optional Generator Step Attenuators R&S ZVM/ZVK-B21/22 and Receiver Step Attenuators R&S ZVM/ZVK-B23/24, as well as the additional inputs for direct receiver access INPUT b1 and INPUT b2 are marked in red.

Optionally all generator and receiver paths can be equipped with mechanical step attenuators (Figure 1) . The installation of a receiver step attenuator automatically includes the additional Input b1 or Input b2 for direct receiver access. The attenuators allow the generation of very small signals down to -90 dBm or the direct measurement of powers up to +27 dBm at the standard test ports PORT 1 and PORT 2 and up to +20 dBm via the additional inputs.

In addition, this increases the number of test ports, as six signals can be detected via PORT 1 and PORT 2, the two reference channel ports and input b1/b2 without a switching matrix or reconnecting. The mechanical switches in the Receiver Step Attenuators R&S ZVM/K-B23 and R&S ZVM/K-B24 and the switch after the generator can be set independently of each other as follows by using an IEC/IEEE bus command or manually via softkeys:

MODE: INPUTS : PORT 1 - INPUT b1 or PORT 2 - INPUT b2

MEAS: WAVE QUANTITY : DRIVE PORT 1 - PORT 2

Another advantage of the direct receiver inputs b1 and b2 is that they prevent coupler loss and thus increase sensitivity. The following diagrams show the typical sensitivity of the R&S ZVM and R&S ZVK using the standard test ports PORT 1 and PORT 2 and the direct receiver inputs b1 and b2 at different IF bandwidths. The data was collected by terminating the unused test ports with MATCHes. No averaging was applied.

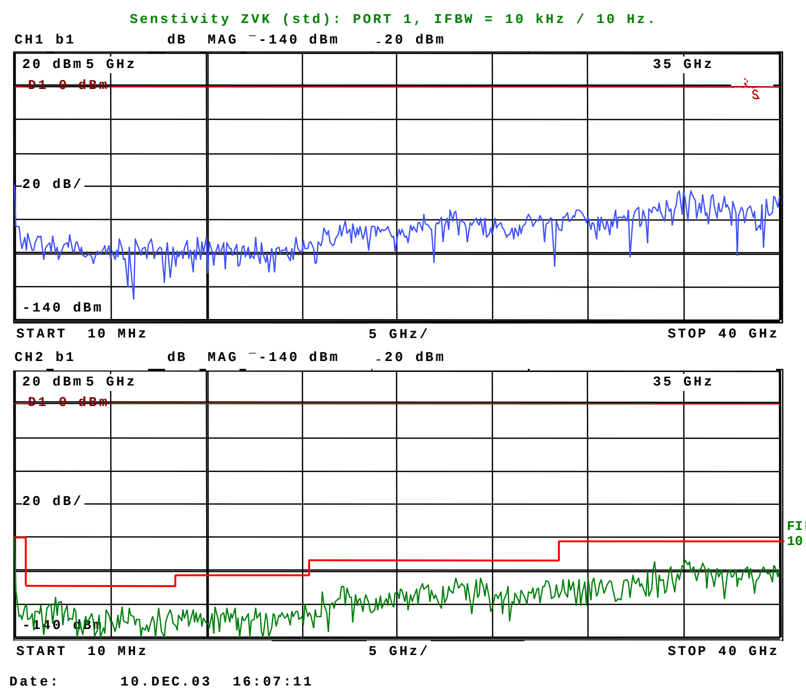


Figure 2:
Typical sensitivity of the **R&S ZVK** (up to 40 GHz) using test **PORT 1** with IF bandwidths of 10 kHz and 10 Hz. The specified data sheet values (@ 10 Hz) are indicated by red lines in the bottom diagram.

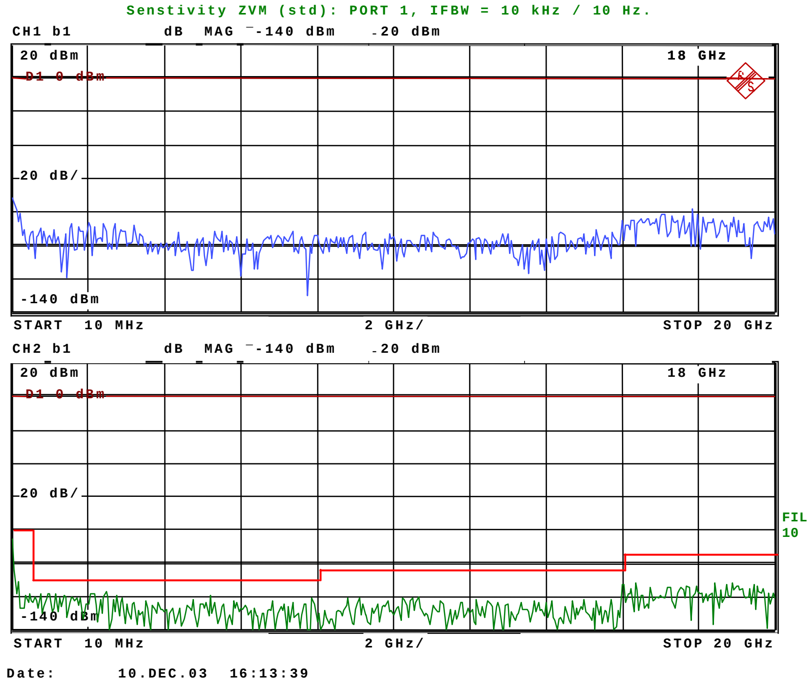


Figure 3:

Typical sensitivity of the **R&S ZVM** (up to 20 GHz) using test **PORT 1** with IF bandwidths of 10 kHz and 10 Hz. The specified data sheet values (@ 10 Hz) are indicated by red lines in the bottom diagram.

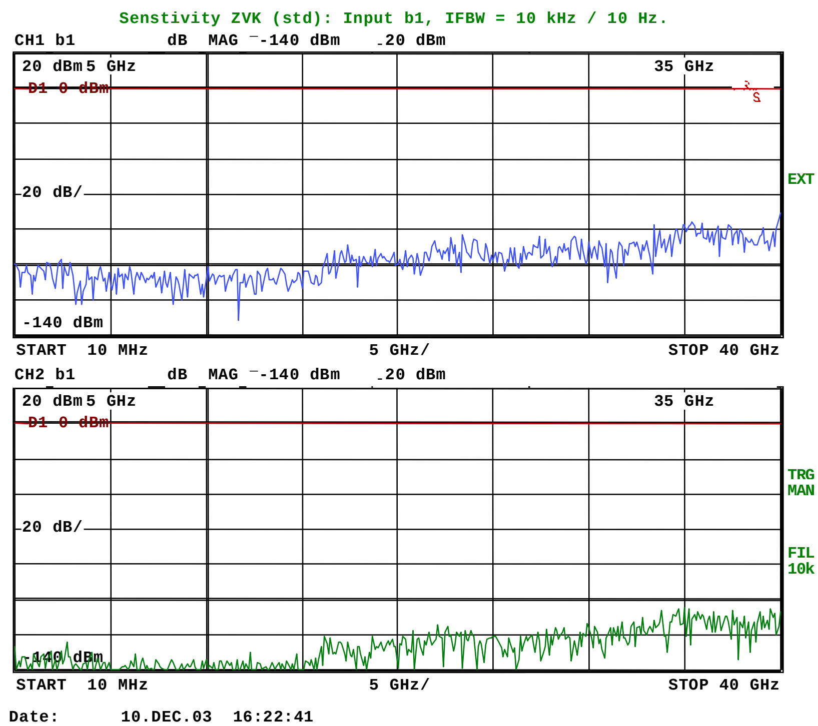


Figure 4:

Typical sensitivity of the **R&S ZVK** (up to 40 GHz) using **Input b1** with IF bandwidths of 10 kHz and 10 Hz.

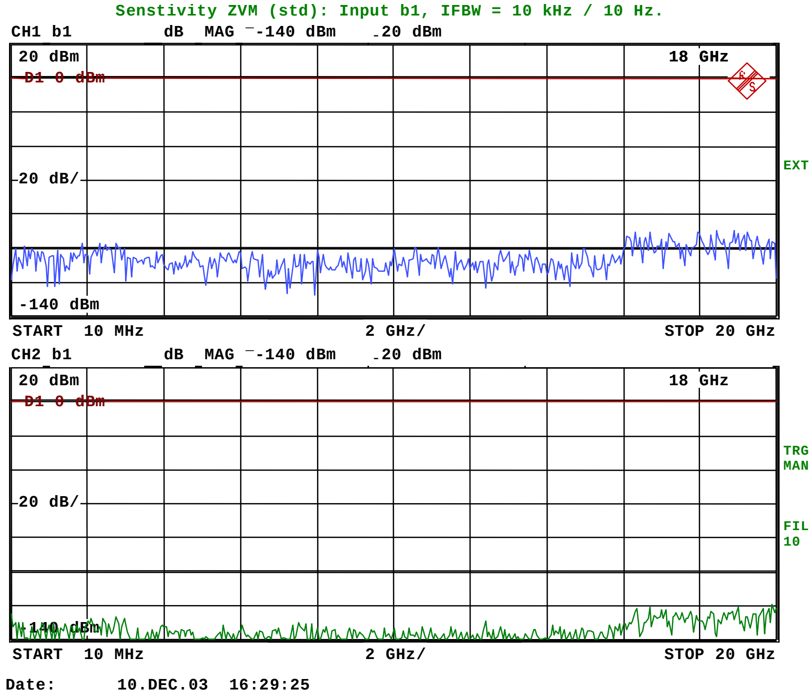


Figure 5:

Typical sensitivity of the **R&S ZVM** (up to 20 GHz) using **Input b1** with IF bandwidths of 10 kHz and 10 Hz.

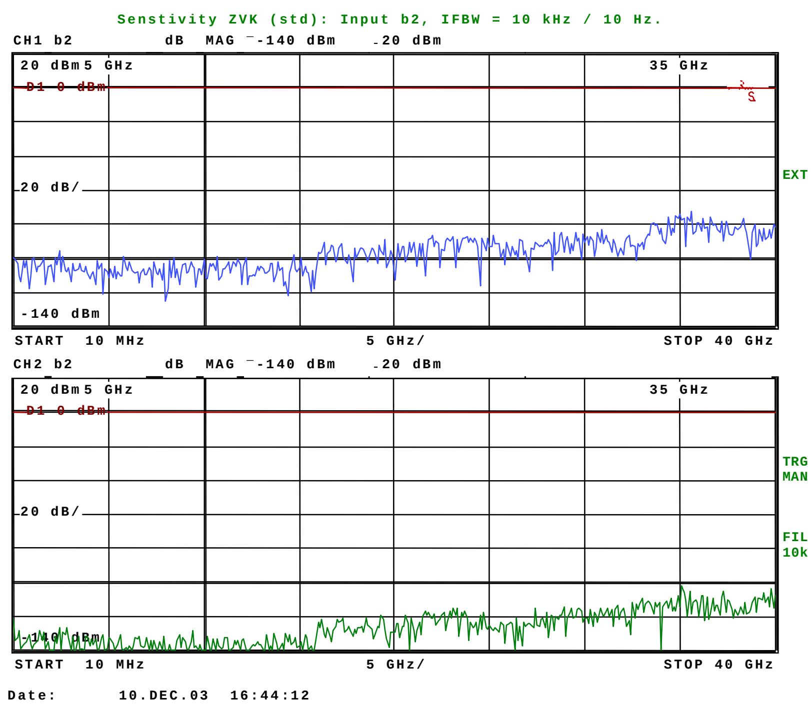


Figure 6:

Typical sensitivity of the **R&S ZVK** (up to 40 GHz) using **Input b2** with IF bandwidths of 10 kHz and 10 Hz.

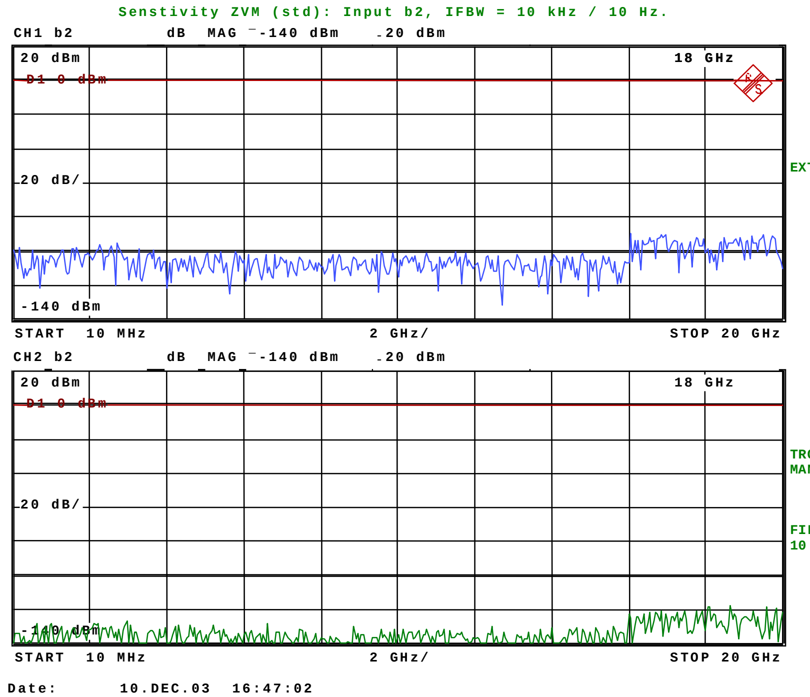


Figure 7:

Typical sensitivity of the **R&S ZVM** (up to 20 GHz) using **Input b2** with IF bandwidths of 10 kHz and 10 Hz.

2.2 Test Set of R&S ZVM/ZVK: Modified Version (Bypass Option)

It can be advantageous to completely decouple the generator path from the receiver paths – for example, if an active antenna connected to PORT 1 or PORT 2 can only receive and the test signal cannot be output via the standard ports.
Another reason for decoupling is to decrease internal crosstalk in certain cases. If, for example, part of the output power is reflected at PORT 1 due to non-ideal matching of the connected antenna, crosstalk in the R&S ZVM(ZVK)-B23 switch causes some of the power to get into measurement channel b1, which results in a decrease of the sensitivity for the signal fed to Input b1 and asymmetry of the measured signals.

To avoid such effects, it is possible to output the generator signal via rear panel jacks of type PC3.5 (R&S ZVM) or 2.92 mm (R&S ZVK) independently of PORT 1 and PORT 2. This modification is available on request as option R&S ZVM-B10 or R&S ZVK-B10.

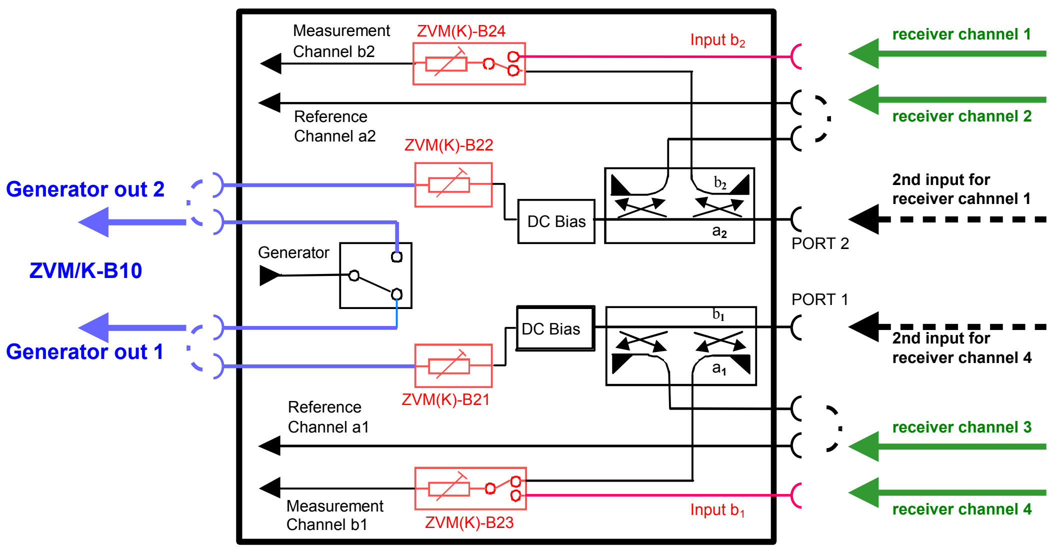


Figure 8:

Modified test set of the R&S ZVM/ZVK for decoupling the generator signal from all output and receiver paths. The generator signal is output via rear panel jacks on the R&S ZVM/ZVK (modification is marked in blue).

The sensitivity improvement provided by this R&S ZVM(ZVK)-B10 option is presented in the following. Settings:

- Output of –10 dBm at test PORT 1
- Generation of "worst case condition" by total reflection at PORT 1 (caused by connecting a SHORT)
- Measurement via the direct receiver input b1

The following typical traces compare the sensitivity decreased by crosstalk with the sensitivity when using the R&S ZVM(ZVK)-B10:

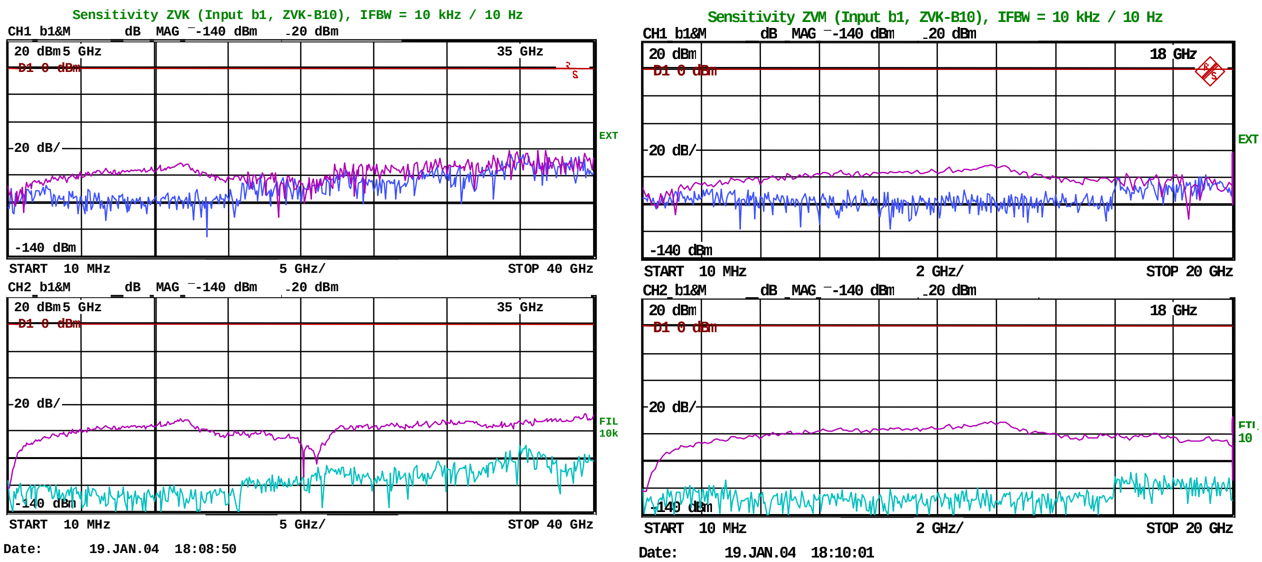


Figure 9:
Typical sensitivity of the R&S ZVK (up to 40 GHz, left) and the R&S ZVM (up to 20 GHz, right) at 10 kHz (top) and at 10 Hz (bottom) IF bandwidth using input b1:
Violet traces:
Total reflection of the output signal at PORT 1. Reduced sensitivity due to crosstalk in the R&S ZVM(ZVK)-B23 switch.
Dark blue/light blue traces:
Increased sensitivity by guiding the signal out via the "Generator Out 1" jack on the rear panel.

2.3 Measurement Speed

Due to the data volumes involved in measurements – primarily at a high angular resolution – a high measurement speed is usually required. An indication of the total time of a frequency sweep is the measurement time per point, which is specified for the R&S ZVM and R&S ZVK as follows:

Measurement time per frequency point - 10 kHz IF bandwidth - Averaging over at least 400 points	**R&S ZVM** **10 MHz to 20 GHz**	**R&S ZVK** **10 MHz to 40 GHz**
With system error correction	<0.9 ms	<1.1 ms
With normalization or measurement of wave quantities	<0.5 ms	<0.7 ms

Table 1:
Specified measurement time per point. The data represent the measurement time per point, calculated as an average value of 400 data points distributed over the entire frequency range. Therefore they prescribe an upper limit ("worst case").

Besides the number of points, the IF bandwidth and the type of system error correction, there are other network analyzer parameters that determine the total time of a sweep. These parameters include the switching of internal paths and the changing of the LO position at certain frequency points or frequency-dependent settling times. The sweep time therefore depends on the frequency and the frequency span. Furthermore, the execution time depends on the sweep mode of the entire system. In the case of frequency-converting measurements, the R&S ZVx controls up to two external generators. If the generators are operated in swept mode, the IEC/IEEE bus transfer time increases the sweep speed.
Consequently, the total sweep time can only be reliably determined with the specific measurement settings. The following table gives examples of different settings. In this case, the typical measurement time per frequency point (until data are displayed) is about 0.3 ms for a standard sweep, which is considerably shorter than the conservative specification for the upper limit. If the sweep range is decreased, another decrease of the measurement time can be expected, depending on the position of the sweep range.

Sweep times **in different operating modes** 10 kHz IF bandwidth, 401 frequency points (Both, times for the bi-directional and the uni-directional sweep mode are presented)	**R&S ZVM** **10 MHz to 20 GHz**	**R&S ZVK** **10 MHz to 40 GHz**
Linear sweep	140 ms / 210 ms	130 ms / 260 ms
Control of an external mixer[2] (fixed LO signal, no impact on measurement time)	140 ms / 210 ms	130 ms / 260 ms
Control of an external mixer[2] (conversion to fixed IF with swept external generator)	760 ms	760 ms

Table 2:

Examples of sweep times: the times apply to a sweep over the entire frequency range of the instrument including display of the values.

[2] Requires the optional Mixer Measurements R&S ZVR-B4

2.4 Frequency-Converting Mode

In antenna measurement systems, mixers can be used to expand the frequency range or to convert signals from the high microwave range to the MHz range in order to prevent losses and disturbing effects when transporting high-frequency signals over long distances.

Systems of this kind can be quickly and flexibly configured with the mixer measurement option (R&S ZVR-B4). Basically, this option is designed to operate the R&S ZVM/ZVK internal receivers, the internal generator and up to two external generators in swept or fixed mode in arbitrary frequency ranges, to enable almost unlimited measurements with any kind of frequency converting devices. Examples are the conversion loss, the amplitude of intermodulation products or harmonics of mixers, amplifiers or frontends. For antenna measurements, the option makes it possible to configure up to three sources and capture data from all four receivers of the R&S ZVx, merely by means of entries in the ARBITRARY SYSTEM FREQUENCIES definition table. The external sources are automatically controlled by the R&S ZVx. A sample test set and the configuration of the definition table are shown in **Figure 11**.

This function is based on the hardware concept of all R&S ZVx instruments being equipped with separate internal generators for generating the output signal and supplying the internal mixer stages in the receiver section. This is why the frequency ranges of output signals and receivers can be set completely independently of each other. The generators are synchronized via a common frequency reference, provided from the network analyzer, or one of the external sources. Using the R&S ZVR-B4 software option, the internal generator of the R&S ZVx and up to two external generators can be operated in independent frequency ranges and at different levels in swept mode or at a fixed frequency. The frequency range for the receivers can be defined independently of the generators. This frequency range can also be swept or set at a fixed frequency, but it is identical for all four receivers.

For a detailed description of the frequency-converting mode, refer to the R&S ZVx manual, application notes ([2], [3]), and the "Getting Started II" instructions and presentations ([6]).

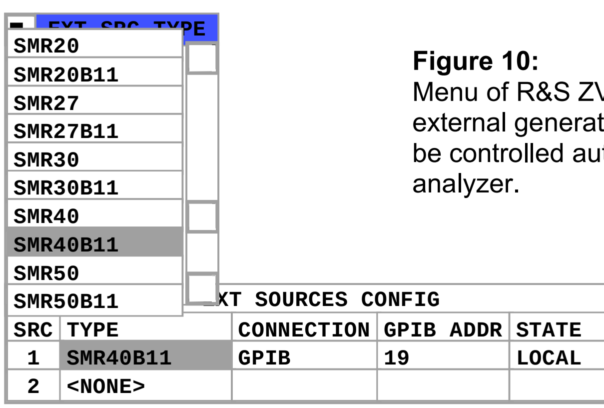
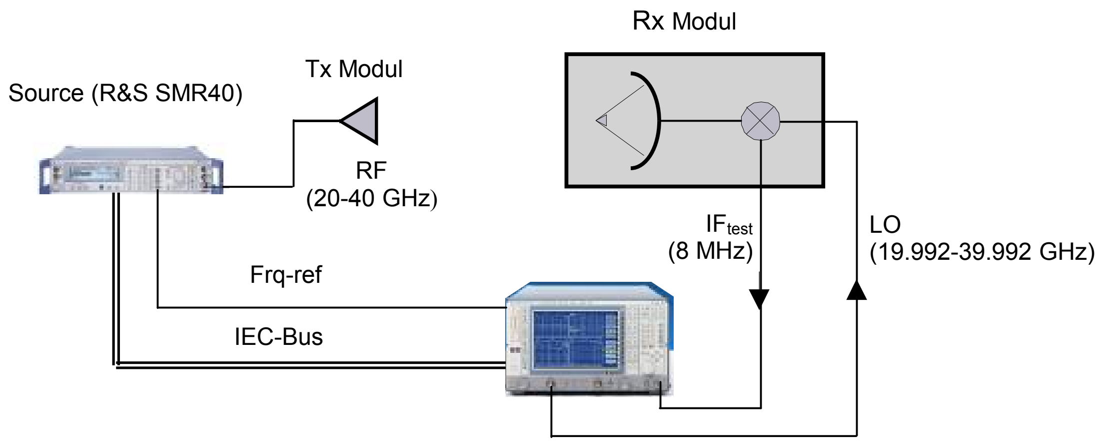


Figure 10:
Menu of R&S ZVR-B4 option for selecting external generators (SRC1 and SRC2) to be controlled automatically by the network analyzer.



ARBITRARY SYSTEM FREQUENCIES							
BASE FREQUENCY: 20GHz ...40GHz							
	ON	POWER	(NUM / DEN)	xB	+ OFFSET	RESULT
INT SRC	/	0 dBm	(1 / 1)	xB	-8MHz	19.992GHz..39.992GHz
EXT SRC1	/	10 dBm	(1 / 1)	xB		20GHz..40GHz
EXT SRC2						
RECEIVER	/				8MHz	8MHz
STIMULUS AXIS:			BASE FREQUENCY			20GHz..40GHz

Figure 11:
Exemplary test set for a transmission measurement with downward mixing and the associated configuration table of the frequency-converting mode: the external source R&S SMR40 (EXT SRC1) is controlled by the R&S ZVK to output a swept RF signal of 20 GHz to 40 GHz . The internal source of the R&S ZVK (INT SRC, output to PORT 1) supplies the mixer with a LO signal offset by 8 MHz. The IF fed via Input b2 to the R&S ZVx receiver (RECEIVER), which was set to a fixed frequency of 8 MHz.

Owing to the frequency selectivity of the R&S ZVM and R&S ZVK, additional components like external filters for sideband suppression are usually not required for such measurements. Furthermore, the receivers of the R&S ZVx operate regardless of the amplitude of the input signal: the receiver settles stably onto the required frequency during the sweep even if there is strong signal suppression or pure noise. This allows a proper sweep over the full range, even if there is strong signal suppression in some sub-ranges, typically with frontends as DUT.

All Rohde & Schwarz generators as well as some other generators are supported for automatic control by way of the IEC/IEEE bus. The driver files with the control commands are accessible in ASCII format in the C:\USER\DATA directory on the hard disk; they can therefore be easily modified and new files for other generators can be created. After the R&S ZVx is restarted, the new driver files are included in the selection menu of the R&S ZVR-B4 option (see **Figure 10**).
If the generators are controlled via the IEC/IEEE bus, each frequency value during a sweep is individually transferred. With R&S SMR family of generators, the sweep time can be considerably reduced by using the GPIB+TTL mode, in which case the required frequency list is loaded into the generator at the start of the sweep. The frequency points are incremented with TTL signals during the sweep. The optional control cable (R&S SMR-Z3) required for this can be ordered.

2.5 Power Dynamic Range, Power Calibration

It is typical of antenna measurement systems that signals often have to be transported over long distances. For example, although the signal generator in the system described in **Figure 11** supplies the test signal directly to the transmission antenna, the LO signal may have to travel several meters. The cable attenuation and frequency response of preamplifiers must be taken into account to compensate for losses and to reach a sufficiently flat LO level, which is usually high.
In the case of broadband measurements with mixing to a constant low IF, the LO signal covers a sufficiently wide frequency range and a considerable frequency response occurs. For an estimate, the following assumptions are made: a cable length of 10 m with an attenuation of approximately 0 dB in the MHz range and of 1 dB per meter at 20 GHz, and a frequency response of ± 2 dB per preamplifier, if two amplifiers are used. These assumptions yield a maximum frequency response of 24 dB between the lowest and the highest frequency. To nevertheless ensure a flat curve of the LO signal to the mixer, a level correction value for each frequency value can be introduced by means of one of the power calibration methods described in the following:

Power calibration and response correction

The power calibration option (R&S ZVR-B7) controls an external power meter via IEC/IEEE bus. The power meter sensor is connected to the required reference plane in the test set. The power of the output signal a_1 or a_2 is measured at each frequency point by the power meter during a correction sweep and compared with the desired power. The difference between the current and the desired power in the reference plane is eliminated by varying the power from the internal generator of the R&S ZVx. To prevent nonlinearities of the generator, this procedure can be repeated as often as necessary at each frequency point. As a result, a level correction list is created, which eliminates the power uncertainty of the internal generator and, above all, the frequency response of the test set. This list is stored in the R&S ZVx.

The attainable accuracy is mainly determined by the accuracy of the sensor and stability of the test setup and may achieve therefore the range of several tenths of a dB. In addition, this option also allows the levels of the external signal generators in the required reference plane to be corrected.

If the level correction is made after a pre-amplifier in the test set, the level may be too high for the sensor. In this case, an attenuator whose values are precisely known and taken into account in the calibration can be inserted during the calibration. The attenuator is removed on completion of the calibration procedure, whereby the required level in the reference plane is exactly applied.

Besides calibrating the generator signals, this option can also be used to calibrate the reference and measurement channels. Details are described in the R&S ZVx manual or the application note [4].

Power Dynamic Range

A correction of the frequency response requires a sufficient dynamic range of the internal or external generator power. The specified values for the dynamic range of the R&S ZVM and R&S ZVK vary from 15 dB to 25 dB depending on the instrument (see data sheet [1]). However, the R&S ZVM and R&S ZVK allow the value of the output level to be set several dB above the specified value up to the unspecified frequency-specific maximum value of the generator.

In addition, the hard limitation of the lower level limit of –20 dBm is eliminated after the power calibration.

These two extensions ensure that in practice a typical dynamic range of 30 dB to ~40 dB (depending on the frequency) is available for correcting the frequency response or for a level sweep.

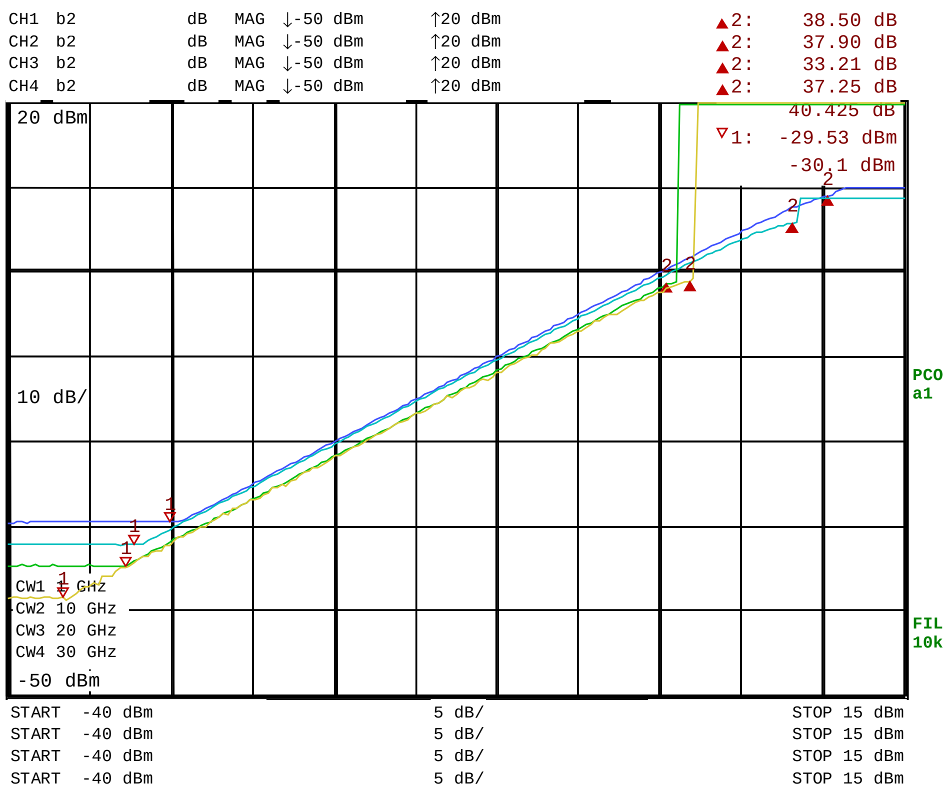


Figure 12:

Unspecified maximum power dynamic range after user power calibration with option R&S ZVR-B7 of the R&S ZVM (up to 20 GHz) and the R&S ZVK at:
1 GHz (dark blue)
10 GHz (light blue)
20 GHz (green)
40 GHz (yellow)
Depending on the frequency, the dynamic range varies from approx. 30 dB to almost 40 dB.

2.6 Trigger Functions and Sweep Modes

Antenna measurements with spatial resolution usually require the sweep to be synchronized with the positioning system. The R&S ZVx provides various trigger settings for this purpose, such as external triggering on the rising or falling edge, choice of selecting triggering of a single test point or an entire sweep per trigger, or a trigger delay that can be varied from 1 µs to 255 s with a resolution of 0.5 µs.
A practical function is switching the sweep direction, enabling the R&S ZVx to sweep continuously also from the highest to the lowest frequency. This permits measurement sequences in which a sweep is triggered and performed with increasing frequency and then, after switching the sweep direction, the next sweep is performed with decreasing frequency.

This operating mode enables the frequency points to be recorded always with the desired sequence during moving the positioning system in forward and reverse direction. This avoids driving the positioning system back to zero position for the next angle sweep and thus greatly cuts down measurement time.

2.7 R&S ZVx Interfaces and Control of System Components

Vector Network Analyzers R&S ZVx are equipped with several rear panel interfaces: the serial, parallel, IEC/IEEE bus and LAN interfaces can be used by programs that run on the internal PC of the R&S ZVx to control other system components or exchange data. Users have full access for this and all user rights for the Windows NT operating system of the R&S ZVx. Besides these standard interfaces, the USER PORTS digital TTL interface is used to query status messages or output control signals. This interface is set or queried either manually or by using an IEC/IEEE bus command. Especially with antenna measurements, this is a simple way to operate external switches or to switch between different signal paths in antennas – for example, to change between the horizontally and vertically polarized radiation characteristics of an antenna.

3 Measurements on Pulsed Signals with R&S ZVM / R&S ZVK as Stand-Alone Units

Since vector network analyzers output only CW signals, a pulsed signal is generated by switching the DUT on and off at clocked intervals, or by externally chopping up the CW signal from the network analyzer or directly by a suitable signal generator. In the tests described here, a Microwave Signal Generator R&S SMR40 with pulse option was used.

Without being integrated in a system, the R&S ZVM/ZVK enables the following measurements on pulsed signals:

- Synchronized measurements of complex S-parameters if the pulses are "long" and in a settled state compared with the measurement time per point of the NWA (**full pulse**, pulse-to-pulse).
- Measurements of the average amplitude of a pulse stream, average of complex S-parameters as well as phase and group-delay measurements in the **high PRF range** of "short" pulses (Measurement time per point of NWA “long” in comparison to the pulse length).

Measurements of the pulse profile or derived quantities as contour measurements are possible when the instruments are integrated in a system (see chapter 4).

3.1 Synchronous Pulse Measurements (“Long Pulses”)

This measurement method can be used if the pulse in comparison with the settling and measurement times per point of the NWA is long enough to record at least one test point during the pulse width. The beginning of the measurement is synchronized with the pulse signal by a trigger.

At least two sweep modes are possible:

- Operation with a sweep trigger, i.e. a full sweep is performed after a trigger. The setting is made with:
  SWEEP : DEF TRIGGER : TRIGGER **SWEEP** POINT.
  If the pulse width is long enough relative to the measurement time per point or a multiple thereof, a pulse profile over time can be recorded. For this purpose, the carrier frequency is selected as the CENTER frequency and a very narrow span is set with SPAN (the R&S ZVx accepts a minimum of 100 mHz). The frequency thus remains virtually constant during the sweep, and the x axis can be considered the time axis.

- Operation with a point trigger, i.e. switching to the next frequency point with each pulse or trigger (pulse-to-pulse measurement). The setting is made with:
  SWEEP : DEF TRIGGER : TRIGGER SWEEP **POINT**.
  In this case, each frequency point is recorded at a different pulse. With a finite frequency span, it is possible to measure, for example, the transmission characteristic of an amplifier in pulsed operation. The time at which the measurement is to be made during the pulse on state can be set by means of a trigger delay. For details on such measurements on GSM amplifiers, refer to [5].

Assuming the R&S ZVx is settled in a steady state with each pulse, in this mode the instrument measures using the full dynamic range corresponding to the IF bandwidth. The shortest practical pulse width for this mode is estimated in the following:

The measurement time per point depends mainly on the IF bandwidth. This can be selected in the range from 1 Hz to 10 kHz and at 26.5 kHz (FULL). Thus the shortest measurement time is to attained with the setting **AVG** : IF BANDWIDTH : FULL.

The measurement time is also influenced by the settling of the preamplifiers inside the NWA: At each frequency point, the gain is adapted to the currently applied level, to use the full resolution of the A/D converter, thus attaining maximum sensitivity at each test point. This mode, however, reduces the measurement speed, may yield an incorrect gain with pulse signals, and produces a delay between the trigger and start of recording the current test point. The delay cannot be exactly predicted.
It can therefore be helpful to activate the FAST mode (**MODE** : FAST MODE). This mode deactivates the preamplifiers and sets the full bandwidth of 26 kHz (subsequently the IF bandwidth can be changed again if necessary via **AVG** : IF BANDWIDTH, the preamplifiers remain deactivated). This mode is indicated by the label FST at the right-hand edge of the screen. However, the instrument operates at the limits of the required settling times, which is why increased trace noise can be expected in fast mode. Trace noise can be considerably reduced by averaging.

To accurately determine the measurement time, the operating principle of the instrument must be considered: during the measurement time of a frequency point, the R&S ZVx records a certain number of samples on the input signal (converted to IF) at the rate of the A/D converter of $\frac{1}{5.12\mu s}$ i.e. at approx. 200 kHz. The samples are transferred to a digital signal processor to calculate the IF filtering and – using the samples from a second channel used as a reference – to calculate a complex pointer. The exact sampling time is determined by multiplying the number of samples required for the IF filter by 5.12 µs. **Table 3** lists the number of samples and the sampling time required for a few large bandwidths.

IF bandwidth	Number of samples per test point	Sampling time (fast mode)	Sampling time (minimum, std. mode)
26.5 kHz (full)	8	35.84 µs	~ 80 µs
10 kHz	26	128.00 µs	~ 160 µs
3 kHz	84	424.96 µs	~ 460 µs

Table 3:

Number of samples and sampling time for large IF bandwidths. In the “Fast Mode”, accurate values can be stated. Due to the varying settling time of the pre-amplifiers in the standard mode, values are stated as “approximately”.

Due to the 35 kHz band limitation of the analog path of the R&S ZVx (essentially the aliasing filter), a suitable settling time of approx. 30 µs must be taken into account. The **shortest pulse** whose amplitude can be measured with at least one point **in the settled state** of the network analyzer is therefore approx. 65 µs long (approx. 110 µs length in standard mode).

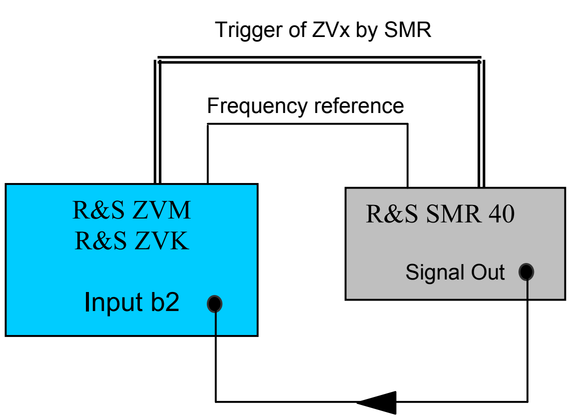
The settings for two measurements in the synchronous mode are described in detail in the following:

1) Setting an amplitude measurement of a 65 ms pulse with one test point per pulse

PRESET
MODE : INPUTS : PORT 2 / **input b2** (arbitrary selection)
MEAS : WAVE QUANTITY : b2 (switches also automatically to amplitude display; otherwise: **FORMAT** : MAGNITUDE)
CENTER : (carrier frequency, 10 GHz here)
SPAN (100 mHz)
MODE : FAST
SWEEP : SINGLE POINT
SWEEP : DEF TRIGGER : TRIGGER DELAY (30 µs)
(ev **AVG** : AVERAGE, AVG TYPE **SWEEP** POINT)

§ A common reference-frequency transmission line must be connected between the R&S ZVx and the generator, using the corresponding BNC plugs at the rear panel of the instruments. One of them must be master (ref frq out), the other one slave (ref frq in). At the R&S ZVx, the setting is via:
SETUP : REFERENCE EXT/INT.
Correspondingly, generator must be set to be master or slave.

§ Furthermore, triggering of the R&S ZVx is required to synchronize the measurement with the pulses. This is done by connecting the trigger output of the signal generator (e.g. SYNC OUT jack of the R&S SMR40) to the trigger input jack (TRIGGER IN) on the rear panel of the R&S ZVx.
External triggering and the point trigger must be activated by:
SWEEP : DEF TRIGGER : EXTERNAL and
TRIGGER SWEEP/**POINT**.



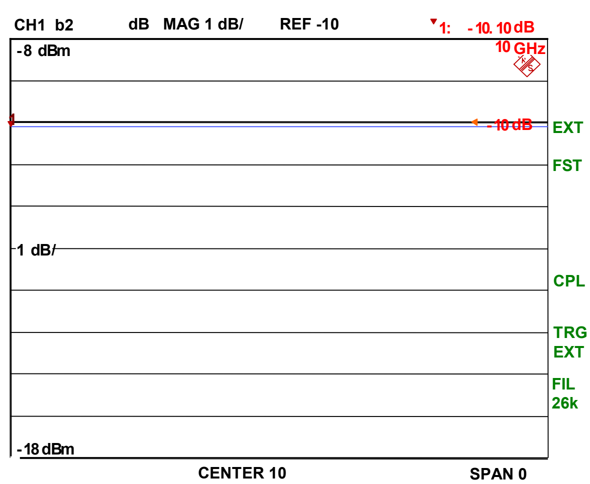


Figure 13:

Measurement of the average amplitude of a pulse stream with SINGLE POINT sweep, center frequency 10 GHz, FAST mode (26.5 kHz IF bandwidth). Settings on the Microwave Signal Generator R&S SMR40: evel -10 dBm, pulse width 65 µs, repetition rate 100 µs, 10 GHz carrier frequency.

However, even shorter pulses can be measured, down to about 50 µs in length, if the trigger delay is reduced.

2) Setting a pulse pattern measurement for "long" pulses

If the pulse width is a multiple of the measurement time, an increased number of test points allows the pulse pattern to be displayed. As an example, a pulse signal with 10 ms pulse period and 5 ms pulse width was recorded with the following settings:

PRESET (hint: after PRESET, 10 kHz IF BW and standard operating mode are default)
MODE : INPUTS : PORT 1 / **input b1** (arbitrary selection)
MEAS : WAVE QUANTITY : b1
CENTER : (carrier frequency, 1 GHz here)
SPAN (100 mHz)
SWEEP : LIN SWEEP
SWEEP : NUMBER OF POINTS : 101
To display the rising pulse edge clearly, a trigger delay is introduced:
SWEEP : DEF TRIGGER : TRIGGER DELAY (8 ms)

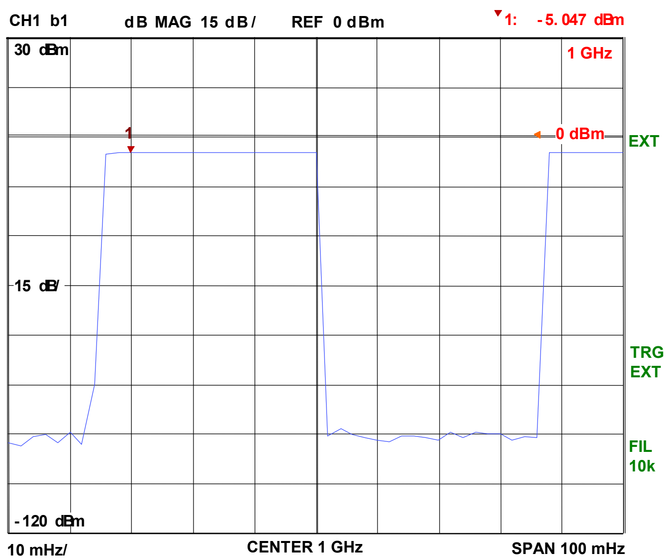


Figure 14:

Pulse profile over time (quasi zero span applied). Linear sweep with 101 test points. Center frequency 10 GHz, span 100 mHz, IF bandwidth at 10 kHz. Settings on the Signal Generator R&S SMR40: level -5.9 dBm, pulse width 5 ms, pulse period 10 ms, 1 GHz carrier frequency.

Estimation:
With these settings, the scaling of the above figure corresponds to 160 µs/point * 101 points / 10 grid lines = 1.6 ms/grid line. Due to the screen dump above, the pulse period lasts about 7 grid lines, corresponding to ~ 11 ms, in quite good accordance with the pulse period.

After pressing the SWEEP key, information on the measurement time and thus the x-axis time range is indicated. However, this value refers to the entire data flow up to the display, which is why the pure measurement time is somewhat shorter.

3.2 Measurements on "Short" Pulses

3.2.1 High Pulse Repetition Frequency (PRF) Range

This method (high PRF) is used when the pulse time is shorter than the minimum measurement time per point. In this case, the measurement time per point can be set considerably longer than the pulse width or the pulse repetition rate, allowing a series of pulses per frequency point to be sampled. Unlike CW signals, ideal pulses exhibit a theoretically unlimited frequency spectrum whose spectral line offset Δf equals to the reciprocal of the pulse repetition time (Δf = 1/prt), and whose first null offset ΔF from the carrier is equal to the reciprocal of the pulse width (ΔF = 1/pw). If a pulse signal is applied with a constant carrier frequency and if the center frequency and frequency span are appropriately set on the network analyzer, the amplitudes of the carrier and the spectral lines can be measured.

The amplitude of the carrier is of primary interest here. Since the pulse power is spread across the entire spectrum, the carrier's amplitude is proportional to pulse amplitude (pulse desensitization). If the pulses are ideally square, the measured carrier amplitude yields the pulse amplitude after a correction by:

$20 * \log\left(\frac{pw}{prt}\right)$; (pw = pulse width, prt = pulse repetition time)

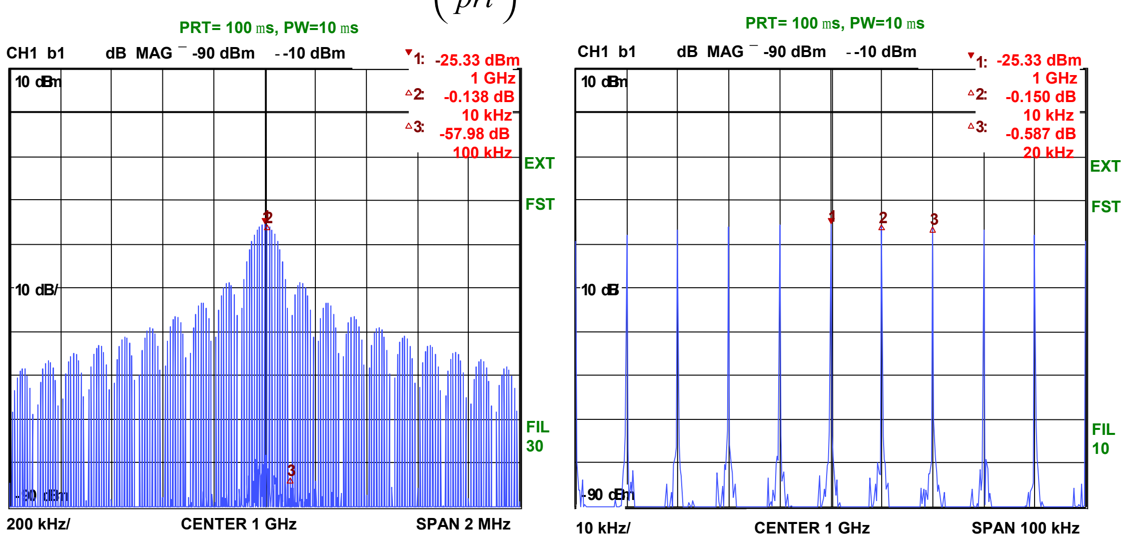


Figure 15:

Frequency spectrum of a pulse signal with a period of 100 µs and a pulse width of 10 µs, carrier frequency 1 GHz.
Left/right screen dump: identical measurement, but different frequency span. The corresponding harmonic offset of 10 kHz and the first null at 100 kHz are indicated by markers (measurements using the R&S SMR40 as the pulse source and the R&S ZVM with f[center] = 1 GHz and f[span] = 2 MHz and 100 kHz). The level is set to –5 dBm so that –25 dBm is measured on the carrier signal due to desensitization (some cable attenuation of ~0.3 dB contributes).
This means that, conversely, the average amplitude of an ideal pulse signal can be determined with high accuracy by means of the carrier amplitude, applying the desensitization formula and correction of test set response.

3.2.2 Spectral Nulling

Ideal narrowband recording of a single tone at each frequency point of a sweep or especially the carrier would require an IF filter with extremely steep edges, in order to sufficiently suppress adjacent sidebands when the pulse repetition rate is high. In addition disadvantages such as ringing in the time domain occur with narrowband or squarewave filters. To avoid such problems, another method can be used: with a suitable choice of pulse repetition rate and IF filter of the NWA, the positions of the spurious signals coincide with the nulls of the IF filter function. For example, the offset of the first null of the 26.5 kHz IF filter is at 24.45 kHz. If a pulse period of 1/24.45 kHz (= 40.9 µs) is selected, the first order spectral lines coincide exactly with the nulls of the filter function.

IF Bandwidth	Offset of the first null	Pulse period (1st null)
26.5 kHz	**24.45 kHz**	40.900 µs
10 kHz	**15.8 kHz**	65.876 µs
3 kHz	**4.575 kHz**	218.58 µs
1 kHz	**1.0875 kHz**	919.64 µs
300 Hz	**386 Hz**	2.5907 ms
100 Hz	**122.25 Hz**	8.1800 ms
30 Hz	**36.75 Hz**	11.527 ms
10 Hz	**11.85 Hz**	84.390 ms
3 Hz	**3.675 Hz**	272.11 ms
1 Hz	**1.2 Hz**	833.33 ms

Table 4:

IF bandwidths of the R&S ZVM/R&S ZVK and corresponding frequency offsets of the first null of the associated filter function. The pulse periods whose spurious signals coincide with the nulls of the filter function are listed for each IF bandwidth.

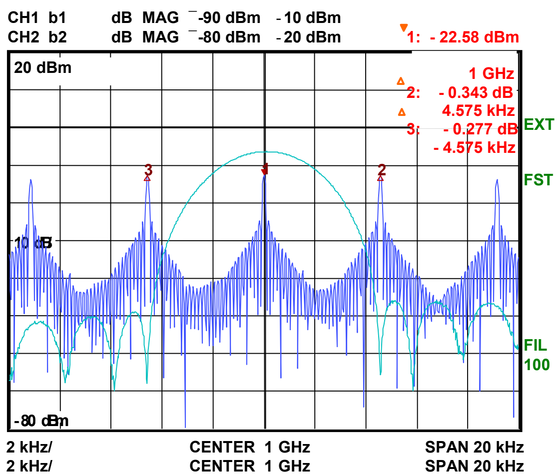


Figure 16:

Spectral lines of a signal with a 218.58 µs pulse period (dark blue), compared with the filter characteristic of the 3 kHz IF filter (light blue). With these settings, the first-order harmonics coincide with the first nulls of the filter.

If the pulse periods are shorter, the first spectral line coincides with a multiple of the first null. The positions of higher-order nulls of an IF filter can be easily measured by using Option Mixer Measurements R&S ZVR-B4 to set the generator of the R&S ZVx to a fixed frequency (or by manually setting an external generator), and sweeping only the R&S ZVx receiver around the carrier position. The resulting trace shows the shape of the current NWA IF filter, as shown in **Figure 16**.

3.3.3 Dynamic Range, Minimum Possible Pulse Width

Low pulse repetition rates compared with the IF bandwidth or measurement time require an estimation, if a sufficient high number of pulses per test point is recorded. The number of recorded pulses depends on the time per A/D sampling, the number of samples taken at each frequency point (depends on the IF bandwidth) and the pulse repetition rate. For example, with the constant sample time of 5.12 µs of the R&S ZVM/R&S ZVK, assuming a pulse repetition rate of 10 µs and an IF bandwidth of 3 kHz (requires 84 samples per frequency point), yield a measurement time per point of 84 * 5.12 µs = 0.43 ms, i.e. 43 pulses per point are recorded.

With very short pulses, the R&S ZVM/R&S ZVK allows for measuring a pulse stream with pulse widths down to well under 0.1 µs (if the duty cycle is sufficiently high). For example, the carrier amplitude of a spectrum exhibiting a 0.1 µs pulse width and 10 µs repetition rate can be determined with a low level error, stemming from the unsettled state of the NWAs analog path. Level deviations are eliminated by calibrating the entire system.

The aforementioned fact of the naturally occurring dynamic loss equal to 20*log(duty cycle) with narrowband reception of the carrier signal may result in limitations or an increase of the measurement error in the case of small signals. Owing to the dynamic range of the R&S ZVM and R&S ZVK, however, small signals with a large duty cycle can also be measured. The unspecified maximum dynamic range of the R&S ZVM (to 16 GHz) of approx. 140 dB is assumed as the absolute limit (use of the additional optional input b2, the maximum output level and 1 Hz IF bandwidth). If a signal-to-noise ratio of 20 dB is accepted, the remaining 120 dB dynamic range allows measurements on signals with duty cycles as low as 0.001%.

By employing this method – i.e. setting the center frequency to the carrier frequency and a quasi-zero span (minimally 100 mHz) or a finite span – the R&S ZVx can be used to measure the average amplitude of pulses down to well below 0.1 µs.

3.4 Pulsed S-Parameter and Group-Delay

The previous sections 3.1 and 3.2 of this chapter described two measurement principles:

§ In the case of pulses having a width of 55 µs to 65 µs or more, and with the pulse and measurement sweep synchronized, the R&S ZVM/R&S ZVK can be used to display the amplitude of the pulse in a settled state with at least one point.

§ In the high pulse-repetition-frequency (PRF) range, the network analyzer performs unsychronized sampling of a series of pulses during the measurement time of a frequency point – with the number of pulses determined by the PRF and the IF bandwidth setting. This covers amplitude and phase measurements on an extremely wide range of pulsed signals: from pulse widths in the ms range (provided the IF is small enough) down to pulses under 0.1 µs. The main information is supplied by measuring the carrier signal, whose amplitude – corrected by the pulse desensitization – represents the average amplitude of the pulse stream. Similar to a spectrum analyzer, the harmonics of the pulse signal are also measured if the frequency span is suitable. General pulse profile measurements, however, can only be performed by "gating" the pulses, which is made possible by March MicroWave systems (see chapter 4).

If the pulsed signal from the generator is split up and one path is routed to a receiver channel of the R&S ZVM/R&S ZVM (**Figure 17**), it can be used as a reference for complex S-parameter measurements and, consequently, for phase and group-delay measurements.

3.4.1 Calibration

Different test sets are used for antenna measurements, which is why no general calibration instructions can be given. In addition, full two-port calibration is usually not possible, since in many cases the signal comes from an external generator and the R&S ZVM/R&S ZVK is just used as a multichannel receiver. The following calibration methods are possible:

§ Calibration of the complete antenna measurement system. This is typically done by performing calibration measurements on a metal sphere or metal plate in the antenna chamber (see chapter 4).

§ Power calibration (option R&S ZVR-B7, see application note [4]) and normalization by means of trace mathematics, if measurements with an external pulse source are performed with the R&S ZVM/R&S ZVK as a stand-alone unit.

Normalization is used in the following descriptions for pulsed S-parameter measurements with the R&S ZVM/R&S ZVK.

3.4.2 S-Parameter Measurements on Carrier and Harmonics

An R&S SMR40 with pulse option is used as the source. Input b1 is used as the receiver channel for the reference signal and input b2 as the receiver channel for the test signal.

A pulsed signal with a constant carrier frequency is applied by the R&S SMR40 in this case. The frequency spectrum with which the S-parameters are determined is therefore defined by the harmonics (measurements using a swept carrier are described in the next section).

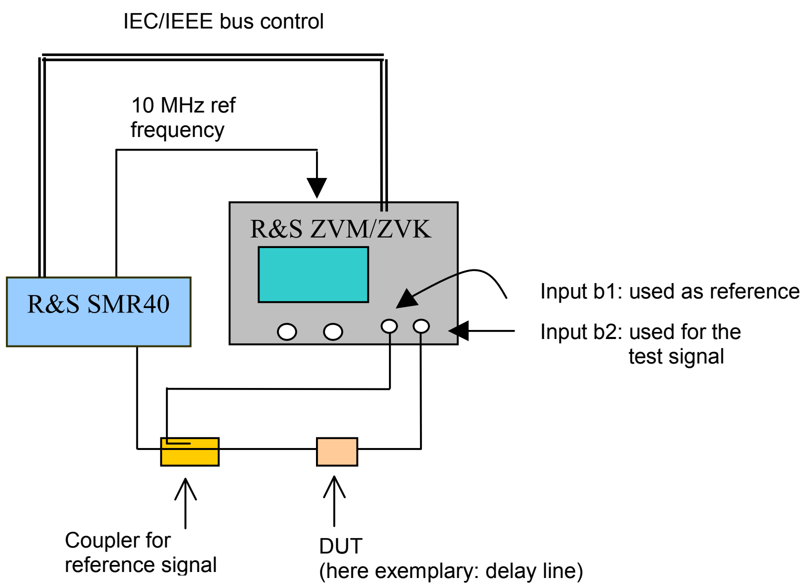


Figure 17:

Test set for S-parameter measurements on pulsed signals.

One of the two units must provide the 10 MHz reference frequency.
If it is provided by the R&S SMR, the following setting must be made on the R&S ZVM/R&S ZVK:

SETUP : REFERENCE EXT

The required rear-panel jacks on the units must be connected with each other.

Settings on the R&S SMR (incl. option R&S SMR-B14) for a pulse signal:

PRESET

FREQ	1 GHz
LEVEL	0 dBm

Modulation : Pulse : Pulse Mode Source : Pulse Gen

Pulse period:	5 µs
Pulse width:	0.5 µs
Pulse delay:	0 µs

Finally, the following exemplary measurements can be performed on the R&S ZVM/R&S ZVK:
(Figures show traces without a DUT, i.e. on the unimpaired pulse signal. Complex measurements in Display 3 and Display 4, traces normalized. Subsequently a transmission line with a 50 ns delay and 7.5 dB attenuation @ 1 GHz is connected as DUT, the result is depicted in **Figure 20** .)

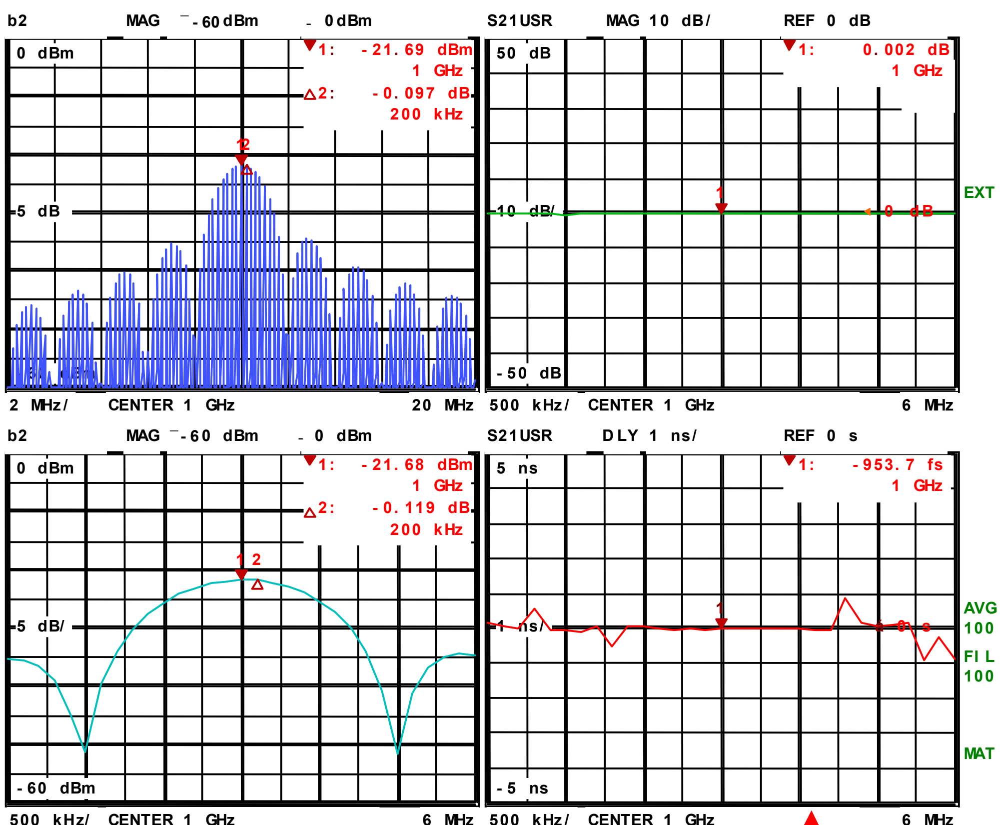
Display 1:

Discrete spectrum of pulsed signal ("arbitrary" number of test points)

Display 3:

S-parameter measurement (S_{21} is defined as b_2/b_1 using the direct channel access via Input b1 and Input b2)

:



Display 2:
Discrete spectrum of pulsed signal, but test points coincide with position of tones (required for group-delay measurement)

Display 4:
Group-delay measurement

Figure 18:
Measurement window: amplitude, S-parameter and group delay with pulsed signal (normalized, without DUT)

Settings on the R&S ZVM/R&S ZVK:
PRESET
Switching the test ports:
MODE : INPUTS : PORT 1 → INPUT b1
MODE : INPUTS : PORT 2 → INPUT b2
Four-channel display:
DISPLAY : QUAD CHANNEL QUAD SPLIT
Measurement settings:
SPAN (20 MHz)
CENTER (1GHz)
Decoupling the measurement channels for independent settings:
SWEEP : COUPLED CHANNELS (off)

Setup Display 1: Spectrum of pulsed signal (amplitude measurement) (with 5 µs pulse period, 0.5 µs pulse width, as previously set on the R&S SMR40, page 25 bottom)

(After PRESET, 401 frequency points per channel are set.
Otherwise: **SWEEP** : NUMBER OF POINTS : (401))
CH1
MEAS : WAVE QUANTITY : b2
Setting a marker on the carrier frequency (maximum at 1 GHz):
MARKER

Taking into account the amplitude reduction by -20 * log (duty cycle) = -20 * log (0.1) = 20 dB, the level of the carrier is accurately reproduced, taking about 1.7 dB cable loss into account.

Setup Display 2: Adjustment of the frequency grid (amplitude measurement)

A pulse signal is applied with a constant carrier frequency; the frequency sweep of the network analyzer measures the spectrum of the signal. As a result, the S-parameters and the group delay can be determined at frequency points of the harmonics in the subsequent measurements. For this reason, the frequency grid must be adapted such that the frequency points of the sweep coincide with those of the harmonics.
CH2
MEAS : WAVE QUANTITY : b2
SPAN (6 MHz)
Corresponding to 1/pulse repetition rate = 1/5 µs:
SWEEP : NUMBER OF POINTS : STEP SIZE (200 kHz)

Setup Display 3: S-parameters on pulsed signal (DUT attenuation)

CH3

Beginning with the same settings as in Display 2:

SPAN (6 MHz)

SWEEP : NUMBER OF POINTS : STEP SIZE (200 kHz)

Yields 31 frequency points (check using ARBITRARY)

Up to now, only amplitude measurements have been performed. For complex S-parameter measurements or phase and group delay, the Input b1 channel is used as a reference signal. $S_{21} = b_2/b_1$ is to be defined as an S-parameter:

USER DEFINED S-PARAMETERS

S-PARAM	NUMERATOR	DENOMINATOR
S11	/ b1	
	b2	
S21	b1	a1
	/ b2	/ b1
S12	/ b1	b2
	b2	
S22	b1	
	/ b2	

MEAS : DEFINE USER DEF´D S-PARAMS :
(setting in the table of S21 = b2/b1)

USER DEF ACTIVE (on)
⇑ (Menu Up) : S21 TRANS FWD

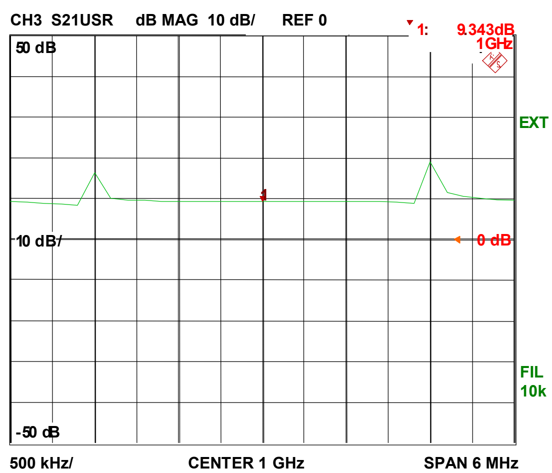


Figure 19:

Increased noise or spikes, as can be seen on the left, may occur at the frequency points at which the amplitude becomes very small (primarily at the nulls, the minima of the spectrum – see Display 2 of **Figure 18**).

Calibration is performed using trace mathematics (normalization):

TRACE : DATA TO MEM :
SHOW MATH

with: MATH = DATA/MEM (on), SHOW DATA (off)

A flat line should now be visible at 0 dB.

Setup Display 4: Group-delay measurement with pulsed signal

Identical settings as in Display 3:

CH4
SPAN (6 MHz)
SWEEP: NUMBER OF POINTS : STEP SIZE (200 kHz)
MEAS : DEFINE USER DEF´D S-PARAMS : (S21=b2/b1)
USER DEF ACTIVE (on)
⇑ : S21 TRANS FWD

Setting the group-delay measurement:

FORMAT : GROUP DELAY
STEP APERTURE (5)

Generation of a noise free trace for Normalization:
(The calibration should be performed with averaging)

AVG : IF BANDWIDTH (1 kHz) : ⇑
AVG FACTOR 100 : AVERAGE (on) (AVG TYPE SWEEP)

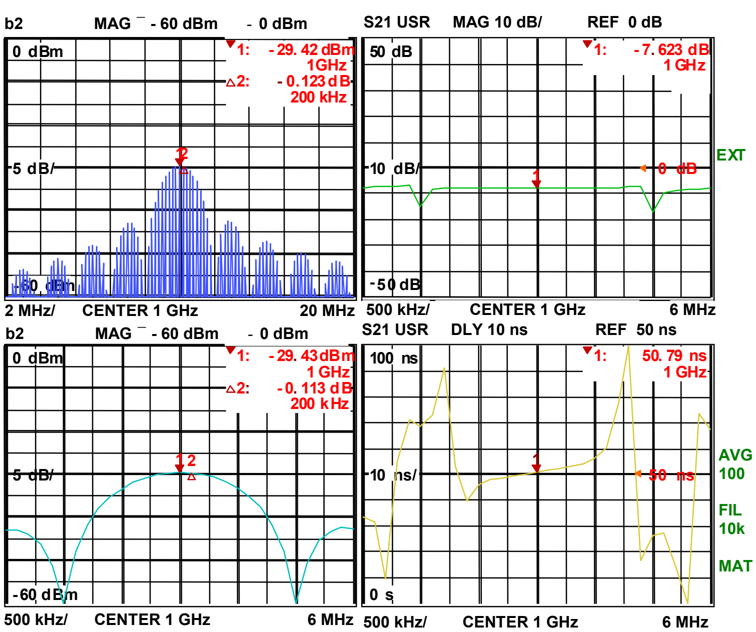
Wait until the execution time has elapsed.
Calibration/normalization:

TRACE : DATA TO MEM
MATH = DATA - MEM (on)
SHOW MATH
SHOW DATA (off)
MARKER

The marker indicates an extremely small value in the range of femto- to several picoseconds, ideally zero, as expected without DUT after calibration. The value in the middle of the curve is most accurate. Measurement uncertainty or noise increases further outward, since the measurements there are made using carriers of smaller amplitude.

In the measurement window below, a DUT was connected

(transmission line with 50 ns delay, 7.5 dB attenuation @ 1 GHz)



Display 1:
Spectrum. Amplitude of carrier corresponding to:
0.0 dBm output power
-20.0 dB desensitization
- 7.5 dB DUT attenuation
- 2.0 dB test cable, connectors

Display 2:
Like Display 3, but different span and grid. Frequency points coincide with harmonics.

Display 3:
S-parameter of DUT with pulsed signal (-7.6 dB specified for DUT)

Display 4:
Group delay of DUT with pulsed signal (50 ns specified for DUT)

Figure 20:
Measurement window: amplitude, S-parameter and group delay with pulsed signal (DUT: delay line)

3.4.3 S-Parameter Measurements with Swept Carrier

The test setup is identical to the one in the preceding section (**Figure 17**). For instance, the IEC/IEEE bus connection between the IEC SYSTEM BUS connector on the R&S ZVM/ZVK and the IEC/IEEE jack on the R&S SMR is required here.

In these measurements, the carrier frequency of the pulsed signal from the R&S SMR40 must be swept parallel to the measurement sweep of the R&S ZVM/ZVK. The result of this is, in contrast to the previous section, the S-parameter measurement is not performed at the frequencies of the harmonics but at arbitrary frequency points defined by the START/STOP frequencies and the number of test points.

The optional Mixer Measurements option (R&S ZVR-B4) is used to sweep the carrier frequency of the R&S SMR40 parallel to the frequencies of the R&S ZVM/ZVK receivers. Although this is not a frequency converting measurement, the option makes it possible to automatically sweep the external generator parallel to the R&S ZVx.

However, this requires a modification of the device driver for the signal generator used:

When the measurement is started, the option's driver files on the hard disk of the network analyzer reset the signal generator, thereby switching off the pulse generation settings. The driver must therefore first be edited, the PRESET command and the CW generation command deleted or deactivated and the file saved under a new name. After the R&S ZVM/ZVK is restarted, this modified driver automatically appears in the selection menu of the R&S ZVR-B4 option (keyboard and mouse must be connected before the R&S ZVx is switched on):

- The shortcut Alt-PrtScr switches to WIN NT mode
- Start WIN NT Explorer
- Start NOTEPAD
- Open the file C:\USER\DATA\(filename) of the generator used (SMR40B11 in this case)
- Delete the command "*RST;" from the command string
- Deactivate the line for the CW mode by keying in ";" at the beginning of the line
- Save the file under a new name, but with the ending *.GEN (e.g. SMR40MOD here)
- Close the editor
- End the measurement software by closing the symbol in the WIN NT status line and restart the measurement software in the START menu (or, alternatively, restart the firmware by switching the instrument off and then on again)

Settings on the R&S SMR (incl. option R&S SMR-B14) for a pulse signal:

PRESET

FREQ 1 GHz

LEVEL 0 dBm

Modulation : Pulse : Pulse Mode Source : Pulse Gen

Pulse period: 5 µs

Pulse width: 0.5 µs

Pulse delay: 0 µs

Settings on the R&S ZVM/R&S ZVK, control of the external generator:

PRESET

FORMAT : MAGNITUDE

Switching the test ports:

MODE : INPUTS : PORT 1 → INPUT b1

MODE : INPUTS : PORT 2 → INPUT b2

Settings for driving the R&S SMR40:

MODE : FREQUENCY CONVERS : DEF ARBITRARY

Selecting the generator:

Activate table EXT SRC CONFIG (table depicted below) by clicking the title bar or the corresponding softkey.

- Select the <u>modified</u> driver files in the TYPE row
- Enter the IEC/IEEE bus address under GPIB ADDR
- Switch to REMOTE by clicking the field under STATE

EXT SOURCES CONFIG				
SRC	TYPE	CONNECTION	GPIB ADDR	STATE
1	SMR40MOD	GPIB	26	REMOTE
2	<NONE>			

Activate table ARBITRARY SYSTEM FREQUENCIES

START (1 GHz)

STOP (2 GHz)

- Switch off the internal source of the R&S ZVx by clicking the ON field in the EXT SRC line
- Switch on the external source by clicking the ON field in the EXT SRC1 line
- ⇑ (switch to the above menu)
- ARBITRARY (on)

ARBITRARY SYSTEM FREQUENCIES						
BASE FREQUENCY: 1000MHz ...2GHz						
	ON	POWER	(NUM / DEN)	xB	+ OFFSET	RESULT
INT SRC						
EXT SRC1	/	0 dBm	(1 / 1)	xB		1000MHz..2GHz
EXT SRC2						
RECEIVER	/		(1 / 1)	xB		1000MHz..2GHz
STIMULUS AXIS:		BASE FREQUENCY				1000MHz..2GHz

Setting and changing the measurement parameter:

MEAS : DEFINE USER DEF´D S-PARAMS : (S21=b2/b1)
USER DEF ACTIVE (on)
⇑ : S21 TRANS FWD

Normalization (without DUT):
TRACE : DATA TO MEM : SHOW MATH
with: MATH = DATA/MEM (on), SHOW DATA (off)
A flat line should now be visible at 0 dB.

Setting the group-delay measurement:

DISPLAY : DUAL CHANNEL SPLIT
CH2

Setting the group-delay measurement:
FORMAT : GROUP DELAY

Normalization:
MATH = DATA - MEM (on)
TRACE : DATA TO MEM
SHOW MATH
SHOW DATA (off)
MARKER : ...

The result is depicted below:
(DUAL CHANNEL display left: calibrated, without DUT
DUAL CHANNEL display right: with DUT connected)

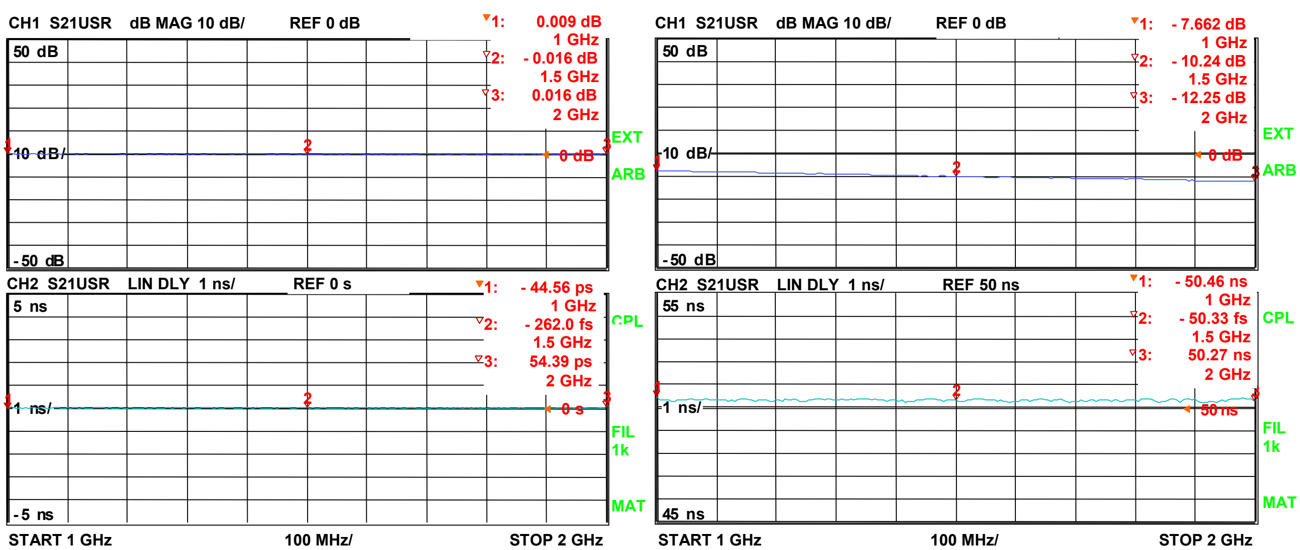


Figure 21:
S-parameter and group delay with pulsed signal, carrier swept
Left: Measurement normalized by means of trace mathematics, without DUT
Right: With DUT: Transmission line with approx. -7.5 dB attenuation @ 1GHz (Marker 1) and 50 ns delay (lower display)

Results at 1 GHz agree with the measurements in the preceding section.

4 Measurement Examples for Antenna and RCS Applications Using the R&S ZVM/R&S ZVK in March MicroWave Systems

Antenna and RCS measurements are usually carried out at frequencies between approximately 100 MHz and 100 GHz. For some special applications, frequencies as high as 500 GHz have been used recently. The corresponding far-field response can be obtained directly by measurements under so called far-field conditions at $R=2D^2/\lambda$, or by measuring the antenna under test in the near field and then compute the far-field pattern. Far-field ranges can be realized indoors or outdoors for small devices in terms of wavelength. For electrically large antennas, the distance can be as large as several kilometers, which means that testing on outdoor ranges can become difficult and costly. Furthermore, for sensitive devices such as space qualified hardware, these methods cannot be applied.

As an alternative, a Compact Antenna Test Range (CATR) creates similar electromagnetic environment as in the far field and it is thus eminently suitable for indoor applications. It has been shown during the last two decades that this technique is attractive for many applications, including satellite testing and RCS metrology.

For high-performance data acquisition and processing, high speed multi-channel microwave receivers are required for determining the amplitude and phase responses. In the following, several configurations including R&S ZVM/ZVK series analyzers for antenna and RCS measurements will be tested in operational conditions.

4.1 Antenna Measurements: System Examples, Specifications

The radiation pattern of an antenna is completely described by the magnitude and phase of the radiated field components in two orthogonal polarizations. For instance, an arbitrary elliptically polarized vector **E** can be subdivided into its E_x and E_y components:

$$\boldsymbol{E} = \boldsymbol{a}_x E_x e^{j(wt+f_x)} + \boldsymbol{a}_y E_y e^{j(wt+f_y)} \tag{1}$$

Circular polarization results when E_x and E_y are equal and $f_x - f_y = \pm\pi/2$. For linear polarization, one of the two orthogonal components is zero. Polarization losses will occur when, for instance, a receiving antenna has not the same polarization as the incoming wave. In many situations, both co-and cross polarization properties of an antenna under test need to be determined accurately. For instance, the cross polarization at -30 to -35 dB below the maximum of the main beam should be measured with an accuracy of ±0.75 dB. It should be noted that similar requirements apply for both linearly and circularly polarized antennas. The above indicates the importance of accurate amplitude and phase measurements in most antenna applications.

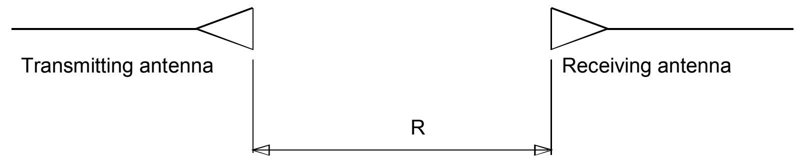


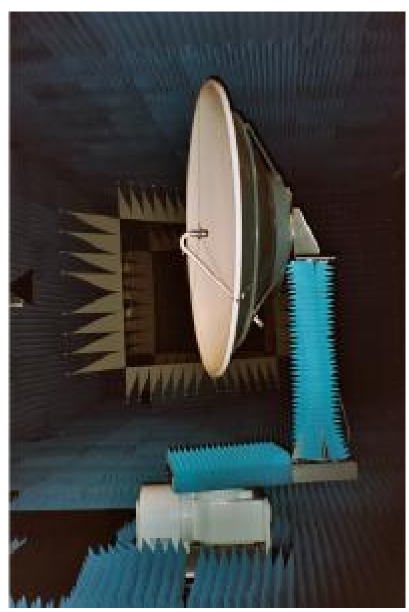
Figure 1:
Orientation of transmitting and receiving antennas aligned for maximum directional radiation and reception.

The Friis Transmission Equation relates the power received to power transmitted between two antennas operating under the far-field conditions and separated by a distance R [7]. The ratio of the received to the input power is represented by

$$\frac{P_r}{P_t} = \left(\frac{l}{4pR}\right)^2 G_{0t} G_{0r} \qquad (2)$$

In this equation it is assumed that the transmitting and receiving antennas are matched to their respective loads and the polarization of the receiving antenna is polarization matched to the incident wave. Furthermore, G_{0t} and G_{0r} represent the gain of the transmitting and receiving antennas aligned for maximum directional radiation and reception. The term $(l/4\pi R)^2$ is called the free-space loss factor and it takes into account the losses due to the spherical spreading of the energy by the antenna.

Experimental investigation has been carried out on a CATR model 4838A (see Photograph 1) for several RF and AUT configurations.



Photograph 1: CATR model 4838A and AUT of 1.8 metres in diameter.

Both swept and CW measurements have been applied at various frequency bands. Furthermore, the angular positioning has been carried out in both continuous and stepped modes. The measurement speed and receiver performance have been recorded for all configurations.

4.1.1 Antenna measurements - basic configuration

In this section, a simple antenna measurement is presented: One antenna is used as transmitting device, the second antenna is the AUT (**A**ntenna **U**nder **T**est). Typical measurement quantities are the attenuation of the transmission range, the characteristics of the AUT versus a reference antenna, or the angular response pattern of the AUT (requires a positioning system)

In this setup, the network analyzer ZVM (10 MHz - 20 GHz) has been used. The following options are included:

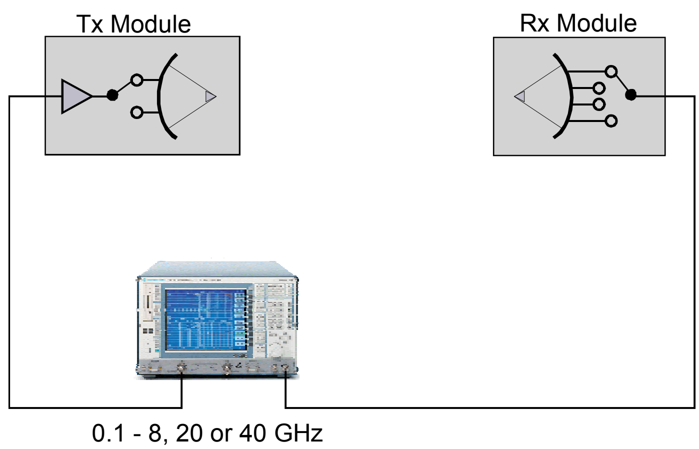
1:Time domain option,

2:Ethernet interface,

3:Receiver Step Attenuator Port 1 & Port 2,

4:Frequency converting measurements,

5:External output generator option`.



Internal ZV* user port can be used for switch control.

Figure 2: Antenna measurements - basic configuration.

This configuration is eminently suitable for indoor applications when cable losses are acceptable. Furthermore, the highest applicable frequency will also be determined by the (phase) stability of the cable and possible errors when rotary joints are applied. The measurements through X-band (8.2 - 12.4 GHz) will, in general, give excellent results. Depending on the accuracy requirements, measurements up to 20 GHz could still give satisfactory results for many applications.

The AUT is a focal plane (f/D = 0.25) parabolic reflector with an aperture diameter of 1.83 metres. The angular region was $\pm 20^0$ in azimuth and elevation. The antenna has been moved continuously in azimuth at 0.25^0/sec. The raw data (phase and amplitude) has been recorded at increments of 0.5^0 which results in 6561 data points. The most important parameters are shown in Table 1. The receiver settings and its performance are given in Table 2. Note that the power at the external output of the ZVM is 5 dBm.

Number of angular points	Measurement speed (degrees/sec)	Retrace speed (degrees/sec)	Average system load (%)	Measurement time (h:m:s)
81 x 81	0.25	6	7.9	3:50:25

Table 1: Measurement parameters.

Frequency (GHz)	Number of Frequency points	Number of Averages	IF Bandwidth (kHz)	Measurement speed (msec)
9.5 - 11.5	201	2	10	0.71[3]

Table 2: Receiver settings and performance.

Furthermore, the system control of the receiver and of the position controller has been executed by using the GPIB. The measured data files are stored directly on the server through LAN.

The acquired data at 10.5 GHz, normalized to 0 dB at the maximum of the main beam, is shown in Figure 3a for the co-polarization and in Figure 3b for the corresponding cross polarization.

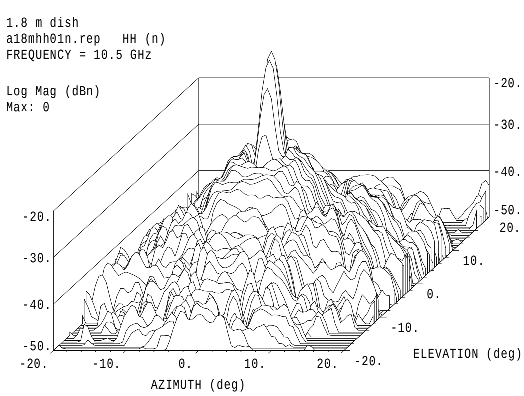


Figure 3a:
Co-polarization pattern at 10.5 GHz.

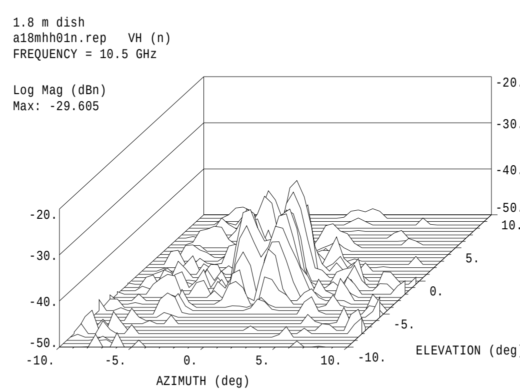


Figure 3b:
Cross-polarization pattern at 10.5 GHz.

3 Two channels, single frequency, includes data transfer and system overhead.

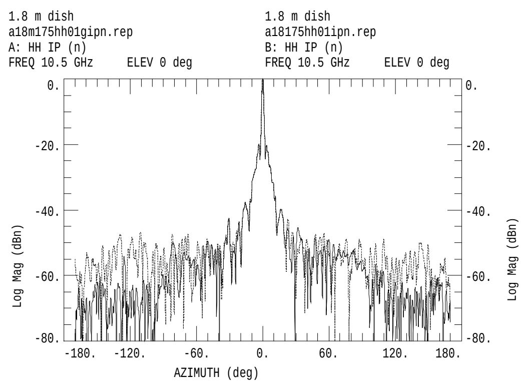


Figure 4a:
Co-polarization pattern at 10.5 GHz.
——— gated
- - - - - ungated

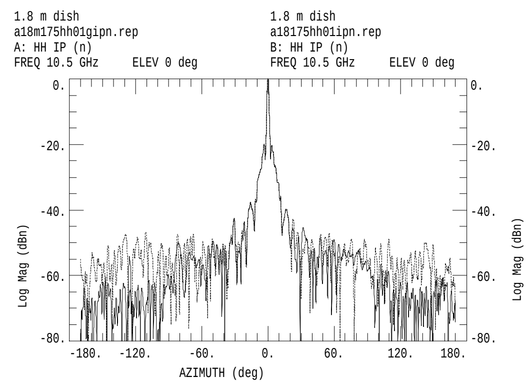


Figure 4b:
Cross-polarization pattern at 10.5 GHz.
——— gated
- - - - - ungated

In **Figure 4a** the azimuth scan over $\pm 170^0$ is shown. In this example the receiver settings as well as the other system parameters are identical to the previous experiment. The measurement includes 681 points and the corresponding measurement time is approximately 23 minutes. For purpose of comparison, both (software) gated and ungated data are presented. It is observed that beyond ±60 degrees, ungated data shows increased errors in sidelobes caused by (unwanted) reflections from both side walls of the anechoic chamber.

In **Figure 4b** both co- and cross polarization patterns are shown on expanded scale. As in the previous case, gated and ungated data are presented. It is observed that there are only minor differences between these patterns. The latter indicates that inside the angular region of approximately ±50 degrees the influence of the stray radiation is negligible.

Finally, in order to calculate the available power budget for the above described measurement session, the receiver characteristics, free space losses, gain of both receive and transmit antenna, as well as losses due to the cabling and rotary joints need to be taken into account. For this purpose we rewrite the Friis equation (3)

$$P_r = P_t \left(\frac{l}{4p} \right)^2 \frac{1}{R_1 (R_1 + R_2)} G_{0t} G_{0r} \qquad (3)$$

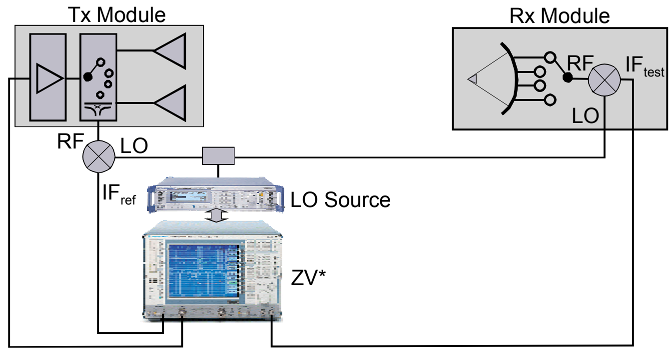
where R_1 is the distance between the feed and center of the subreflector and R_2 the distance between center of the subreflector and center of the main reflector. Note that the expression $R = R_1(R_1+R_2)$ applies only for dual-reflector CATR's with cylindrical reflectors.

Furthermore, P_t = 5 dBm, G_t = 12 dB, G_r = 41.2 dB and the free-space loss factor amounts to 71 dB. In addition, cable losses of 11.5 dB at 10.5 GHz have been included as well. In conclusion, the received power P_r is equal to -24.3 dBm. Applying the system specifications as defined in this section, we conclude that pattern measurements can be carried out to levels which are approximately 85 dB below the maximum of the main beam.

4.1.2 Antenna measurements - remote mixer configuration

The purpose of this measurement is in principle identical to that one presented in the chapter before. Just external mixers are introduced, to convert IF_{test} (the measurement signal) and IF_{ref} down to the MHz range, avoiding attenuation and signal disturbances occuring in the GHz range.

The principle of operation is given in Figure 5. As discussed previously, operation with remote mixers is preferred in certain situations, in particular at higher frequencies.



Notes: 1. Switch inside the Rx module can be controlled directly from ZV*.
2. Up to 4 channels are available when internal ZV* switches are applied. In this situation, additional test mixers are required.

Figure. 5: Antenna measurements - remote mixer configuration.

The maximum frequency between the mixer and the receiver will correspond to the LO frequency. In this situation, additional source will be required in order to provide sufficient power at LO input ports of the reference and test mixers. Both RF and LO sources are tuned such that a signal of 20 MHz (or other suitable IF frequency) is generated. This is called the fixed IF mode and the measurement speed will correspond to that of the externally triggered LO sources.

For the purpose of comparison, an azimuth scan over ±170^0 has been carried out. The measurement parameters are given in Table 3. In Table 4, receiver settings and performance are shown. When compared to the basic configuration of Section 4.1.1, the measurement speed is approximately 4 times slower.

Number of angular points	Measurement speed (degrees/sec)	Retrace speed (degrees/sec)	Average system load (%)	Measurement time (m:s)
681	0.25	N/A	57.3	22:30

Table 3: Measurement parameters, fixed IF.

Frequency (GHz)	Number of frequency points	Number of averages	IF Bandwidth (kHz)	Measurement speed (msec)
8 - 12	401	2	10	2.8 [(4)]

Table 4: Receiver settings and performance, fixed IF.

[4] Two channels, single frequency, includes data transfer and system overhead.

Furthermore, it should be noted that the system load increases to 57.3%, while the positioner speed is still kept at 0.25^0/sec. The radiation patterns are compared in Figure 6a.

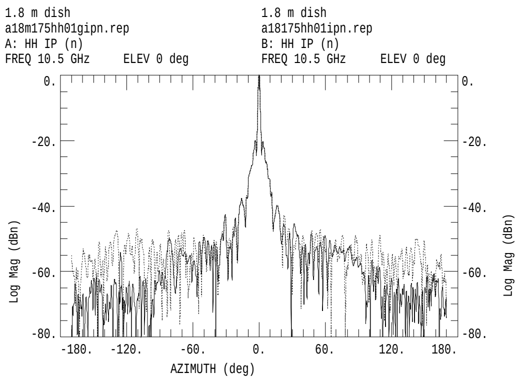


Figure 6a:
Co-polarization pattern at 10.5 GHz.
——— no mixers
- - - - - fixed IF mode

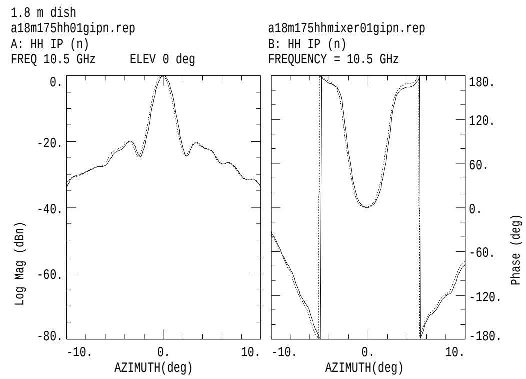


Figure 6b:
Cross-polarization and phase pattern at 10.5 GHz.
——— no mixers
- - - - - fixed IF mode

We observe that there are only minor differences in recorded patterns between both measurement configurations. In Fig. 6b the co-polar patterns and corresponding phase are shown on an expanded scale. Both patterns are identical but there is an angular displacement between both measurements of approximately 0.2^0. This is caused by lower acquisition speed when remote mixers are applied. However, since the positioner rotates at constant speed, it is possible to correct for this effect.

In order to improve the measurement speed, it is possible to use a so called fixed LO configuration. In this situation the internal source of the ZVx receiver executes the frequency sweep and the IF frequency spectrum is changed accordingly. This mode is also fully supported by the receiver firmware which means that the measurement speed increases approximately 4 times when compared to fixed IF and it thus becomes equal to that of the basic configuration. The applicable bandwidth is limited to that of the IF port of the mixers. For measurements in which the bandwidth does not exceed approximately 1 - 2 GHz, the fixed LO mode is an attractive option. Mixers with sufficient IF bandwidth are available for all frequencies of interest.

4.1.3 Antenna measurements - pulse operation option

Besides measurements with a sinusoidal signal, investigations with a pulsed signal are frequently desired. This requires enlargements like a pulse source, a trigger generator to provide synchronisation signals, and a control software. In addition, in this section RCS (Radar Cross Section) measurements with a signal reflected from a DUT (e.g. airplane model) and not only unidirectional antenna transmitting measurements are described.

In Figure 7 an antenna measurement configuration with external pulse generator is presented.

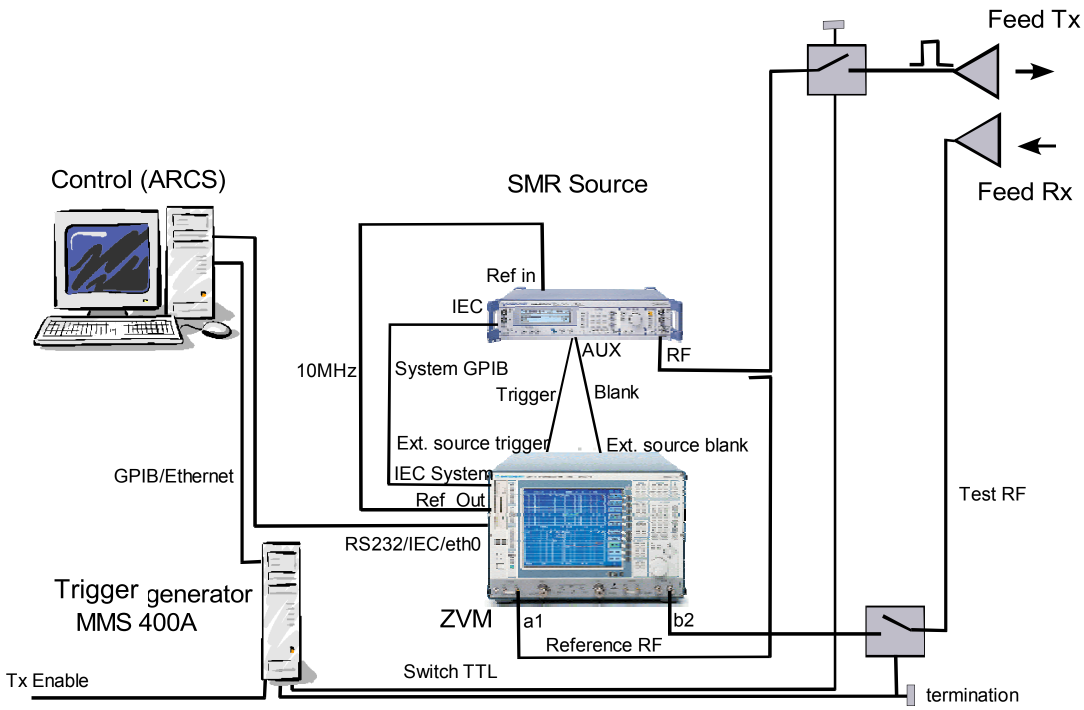


Figure 7: Antenna measurements with pulse generator.

Typically, these measurements are of importance in testing where limited number of frequencies are required, but the pulse operation is still needed. For instance, in indoor satellite testing, a considerable improvement in the accuracy of pattern measurements can be realized with such a system. This is because the effects of stray radiation can be directly eliminated. For most indoor applications the gate width of 20 ns or less will be needed in order to improve the range performance. Other possible applications include outdoor and RCS testing. The antenna under test is a standard gain horn designed for operation at 1.8 - 2.6 GHz. The aperture dimension is 360mm x 263mm (W x H) and the corresponding gain is 16 dB at 2.0 GHz. For this experiment, the range has been modified such that an unwanted signal is generated which is observed at approximately +34° with respect to the maximum of the radiation pattern. The corresponding intensity of this signal is -7.8 dB below the pattern peak at 2.0 GHz.

For purpose of comparison, the horn pattern has been recorded at 1.4 Ghz-3.4 GHz and for $-150^0<\theta<+150^0$. In Figure 8 the ungated normalized ungated pattern is given. The pattern disturbance around +34 degrees is clearly seen at all frequencies. In Figure 9, (software) gated pattern is shown. As expected, the unwanted radiation is fully eliminated and these patterns will be used as a reference for an experiment in which the pulse modulator is used. The measurement parameters and receiver settings are given in Tables 5 and 6 respectively.

Number of angular points	Measurement speed (degrees/sec)	Retrace speed (degrees/sec)	Average system load (%)	Measurement time (m:s)
301	4.5	N/A	48	1:06

Table 5: Measurement parameters, pulsed mode.

Frequency (GHz)	Number of frequency points	Number of averages	IF Bandwidth (kHz)	Measurement speed (msec)
2.0	1	512	10	102 [5]

Table 6: Receiver settings and performance.

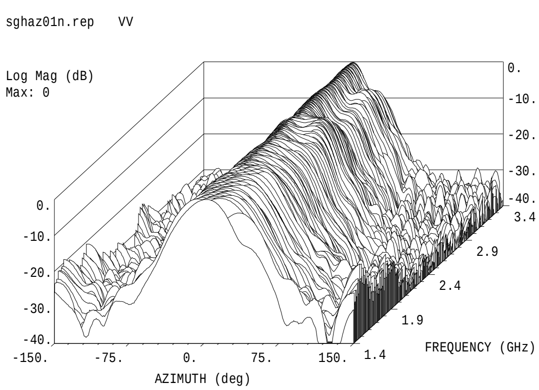


Figure 8:
Ungated pattern for 1.4 GHz to -3.4 GHz

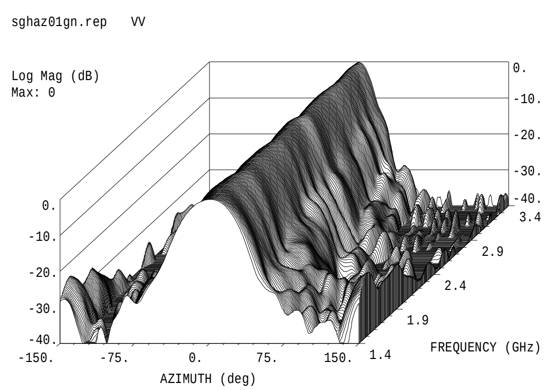


Figure 9:
Gated pattern for 1.4 - 3.4 GHz

5 Two channels, single frequency, includes data transfer and system overhead.

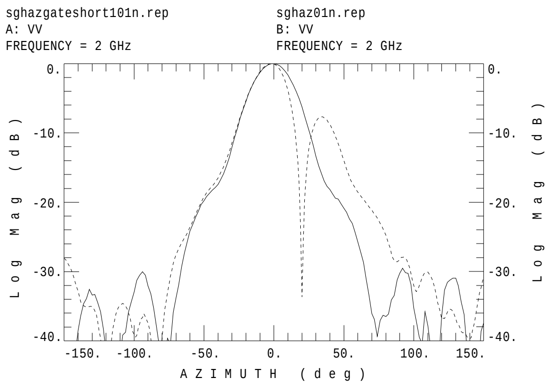


Figure 10:
Gated vs. ungated pattern at 2.0 GHz
——— gated
- - - - - ungated

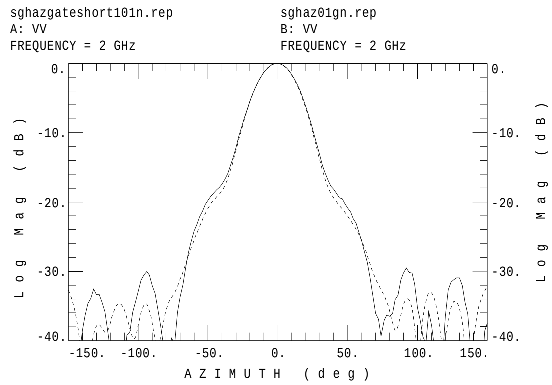


Figure 11:
Gated vs. ungated pattern at 2.0 GHz
——— hardware gating
- - - - - software gating

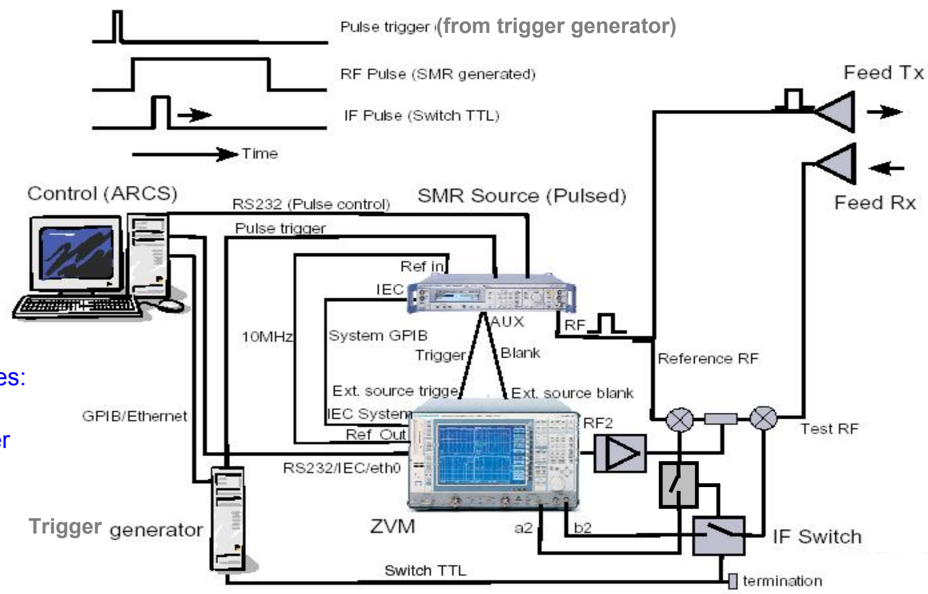
In Figure 10, gated vs. ungated pattern is shown at 2.0 GHz. We observe that the unwanted radiation is fully eliminated by applying the pulse generator. For purpose of comparison the resulting patterns for "hardware" vs. "software" gating are shown in Figure 11. We observe that both patterns are almost identical within the angular region of $-150^0<\theta<+150^0$.

Furthermore, the transmitting and receiving pulse widths have been set to 20 ns. The pulse period is 700 ms. The delay has been adjusted such that the effect of eliminating the unwanted stray radiation is clearly visible.

In conclusion, R&S ZVM/ZVK series analyzers give very good performance when short pulse operation is required. For some applications, this configuration can perform better and faster than software gating. The gate width, pulse period, number of averages and available power should be taken into account in such a comparison.

4.1.4 Antenna measurements - pulse profile measurements

A frequent requirement is to measure the response of the transmission range and the DUT to the pulse pattern, i.e. to determine the profile of undisturbed and disturbed pulses versus time. Such measurements can be realized by a system as depicted below in Figure 12 (the external mixers are not absolutely required):



Trigger generator synchronizes:

- SMR40 pulse generation
- ZVM point or sweep trigger
- IF switch

Figure 12:
Antenna and RCS measurement system for pulse profile measurements.

The R&S SMR40 provides the pulsed RF signal. One of the key instruments is the trigger generator: It provides trigger logic and trigger signals for the R&S SMR40, the R&S ZVx, and the IF switch. The principle of the measurement is that the pulses are chopped into subranges, and the magnitude and phase values just of the current subrange of the pulse is represented by a data point of the ZVx sweep. The R&S ZVx is controlled by point trigger and set to quasi constant frequency (f=f(carrier), span ~ 0 Hz), providing a quasi time axis. The NWA works in the high PRF mode, by which the magnitude and phase values are determined by sampling a bunch of pulses. The gating is realized by the external switch. The gate is shifted by a floating delay, thus representing the pulse envelope by the data points of the sweep (see sketch from Figure 13).

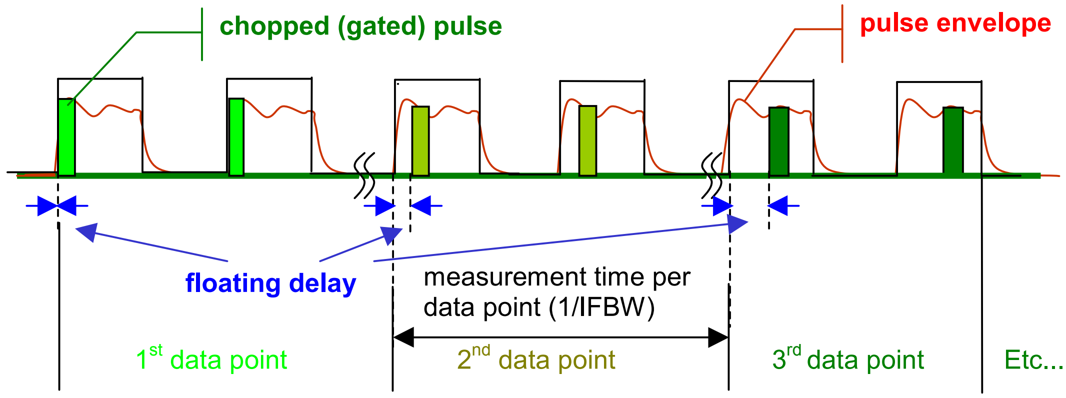


Figure 13: Principle of pulse profile measurement

Of course, for a high resolution, a sufficient narrow gate in comparison to the pulse length is required. To allow the system (e.g. switches) to settle at each data point, a finite delay (step between gates) is introduced. Figure 14 below presents a high resolution pulse profile measurement. The measurement was performed with a metal plate at the reference plane of the horn antennas, by which it depicts more or less the pulse pattern directly from the R&S SMR.

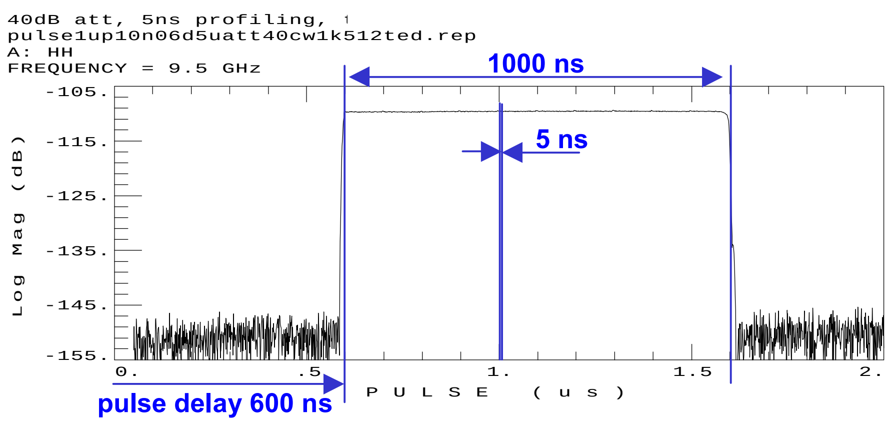


Figure 14: Pulse profile measurement results, derived by external software from the ZVM frequency sweep with quasi zero span.
System settings:

Pulse Width:	1 µs
Pulse Period:	10 µs
Gate length:	5 ns (resolution)
Step between gates:	1 ns
Frequency:	9.5 GHz

Figure 14 shows pulse profile measurements are possible with a resolution of up to 5 ns (gate length). Achieving a higher resolution is in in evaluation. Results will be published at a later time.

4.2 Radar Cross Section measurements

The development of Radar Cross Section (RCS) measurement techniques has grown rapidly during the last two decades. Most importantly, reduction of the detectability of the new generation of military aircraft initiated development of new indoor test ranges. Furthermore, advanced data processing techniques such as Inverse Synthetic Aperture Radar (ISAR) have been used for imaging of targets in two dimensions (down-range and cross-range) and identifying of individual scatterers inside the imaged area [9]. The latter can be seen as a most important tool for effective reduction of the RCS. Accurate prediction techniques are also available which makes modelling of complex targets possible. Accurate experimental verification becomes even more important. The principle of radar measurements is shown in Fig. 15.

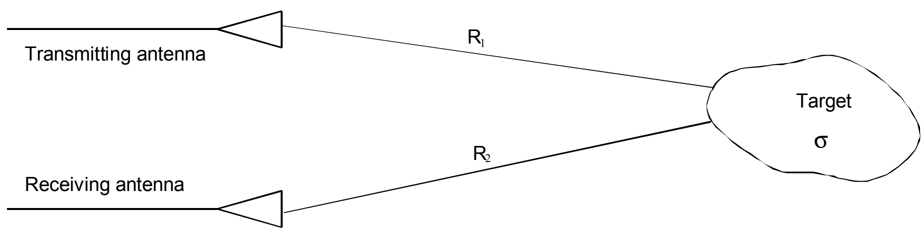


Figure 15:
Transmitter, target and receiver geometry for radar range equation.

The radar range equation is defined as

$$\frac{P_r}{P_t} = s\left(\frac{l}{4pR_1R_2}\right)^2 \frac{G_{0t}G_{0r}}{4p} \tag{4}$$

The above expression relates the power P_r (delivered to the receiver load) to the input power P_t transmitted by an antenna, after it has been scattered by a target with a radar cross section (echo area) of σ. Furthermore it is assumed that both antennas are polarization matched and aligned for maximum directional radiation and reception. It should be noted that the above equation applies for bi-static situation, i.e. the transmitting and receive antennas are at different locations. When one antenna is used for transmitting and receiving, $R_1 = R_2$ the equation (4) describes a mono-static radar geometry. If the complete scattering characteristics are required, the radar cross section is usually defined as a matrix.

$$s = \begin{bmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{bmatrix} \tag{5}$$

The first subscript refers to the polarization of the transmitting antenna and the second subscript to that of the receiving antenna. In most cases, two orthogonal polarizations are defined (for instance vertical and horizontal) and the polarization matrix consists of VV, HH, VH and HV components.

In general, the RCS of a target is a function of the polarization of the incident wave, the angle of incidence, the angle of observation, the geometry of the target, its electrical properties and the frequency of operation. The units of RCS of three-dimensional targets are meters squared (m^2) or for normalized values decibel per square meter (dBsm). For calibration purposes, a (metallic) sphere is a popular target. The sphere with radius r (for r≈λ) has the following radar cross section

$$s_s = p\, r^2 \qquad (6)$$

Consequently, a sphere with radius r = 0.564 meter has a radar cross section of 0 dBsm. For spheres with smaller radius in terms of wavelength, an exact solution for the RCS exists (see Fig. 16). This means that an accurate calibration is possible with spheres of several centimeters in diameter at most frequencies of interest.

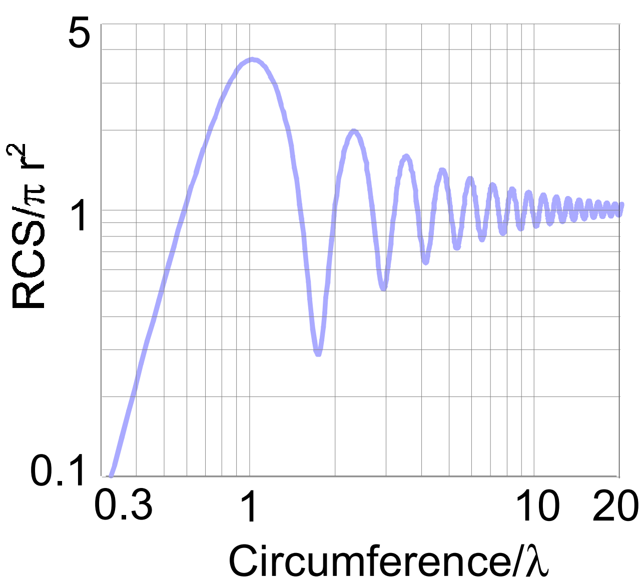


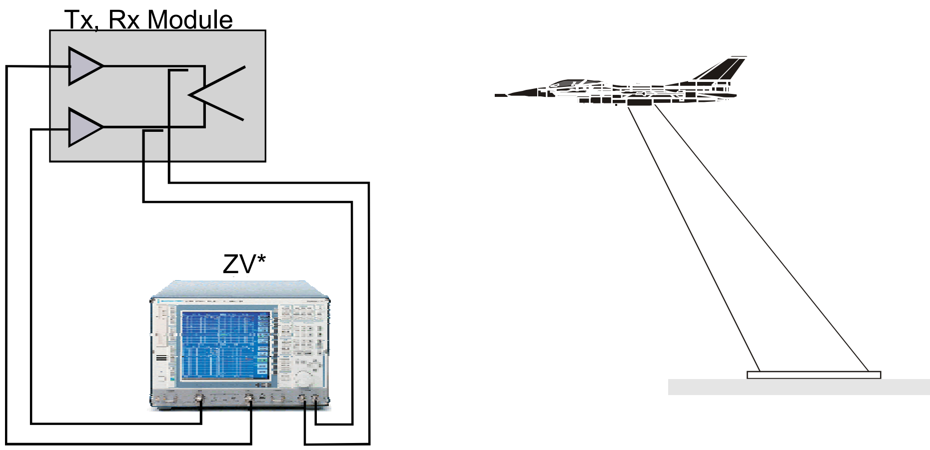
Figure 16: RCS of a metal sphere.

Another frequently used reference target is a flat plate. Its RCS corresponds to $4\pi A^2/l^2$, where A is the surface of the flat plate in m^2. The radar cross section of some typical targets is shown in Table 7.

Object	**Typical RCS** (m^2)	dBsm
Automobile	100	20
Commercial airliner	40	16
Fighter aircraft	2-6	3-7.78
Adult person	1	0
Bird	0.01	-20
Insect	0.00001	-50
Advanced stealth fighter	0.000001	-60

Table 7: RCS of some typical targets.

We observe that for accurate measurements on targets with low RCS, ranges with stable and low background level will be required. The most popular systems will usually include a Compact Antenna Test Range, mainly because of a good background performance (levels as low as -80 to -90 dBsm have been realized with dual-reflector CATR's). A typical hardware configuration is shown in Figure 17.



Available for frequencies up to 40GHz.
For higher frequencies active multipliers and external mixers can be used.

Figure 17: RCS measurement setup

The measurement parameters, receiver settings and performance are given in Tables, 8, 9 and 10.

Number of angular points	Measurement speed (degrees/sec)	Retrace speed (degrees/sec)	Average system load (%)	Measurement time (m:s)
1441	N/A	N/A	N/A	see **Note**

Table 8: Measurement parameters, stepped mode.
Note: Measurement times are approximately 79 and 97 minutes for 2 and 4 channel configurations, respectively.

Frequency (GHz)	Number of frequency points	Number of averages	IF Bandwidth (kHz)	Measurement speed (msec)
8.0 - 12.0	801	1	10	0.52 [6]

Table 9: Receiver settings and performance, two channels.

Frequency (GHz)	Number of frequency points	Number of averages	IF Bandwidth (kHz)	Measurement speed (msec)
8.0 - 12.0	801	1	10	1.24 [7]

Table 10: Receiver settings and performance, four channels.

[6] Two channels, single frequency, includes data transfer and system overhead

[7] Four channels, single frequency, includes data transfer, switching between two transmit channels and system overhead.

In the following, the compact range has been calibrated using a sphere with a diameter of 5 cm with the corresponding RCS of -27.1 dB. The calibration and measurements have been carried out for two and four channels. In Figure 18, two traces are shown in the time domain. First, the empty chamber (EC) response is recorded. Second, the calibration sphere is placed on a styrofoam column. After this measurement, the empty chamber response is subtracted and the resulting characteristics are generated. It should be noted that the sphere is clearly visible at the down-range position of approximately 19.5 meters.

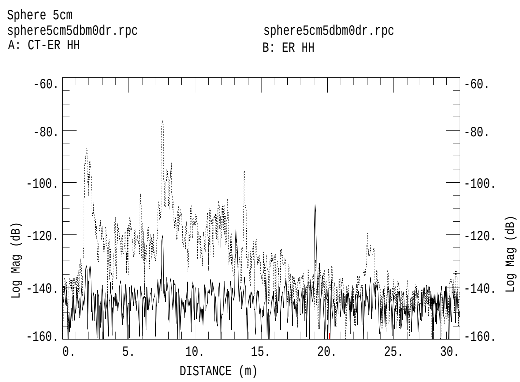


Figure 18:
Time domain calibration.
- - - - - empty chamber (EC)
——— Calibration sphere - EC

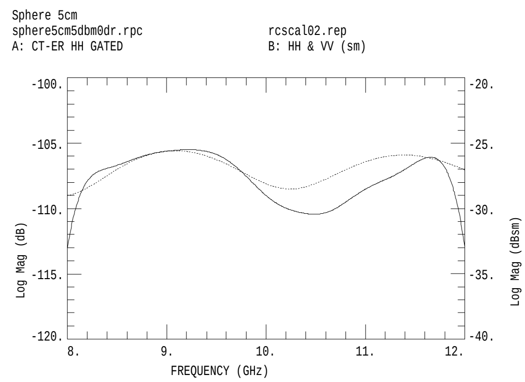


Figure 19:
Frequency domain data
- - - - - predicted
——— measured

In Fig. 19, both measurements and predicted characteristics of the calibration sphere are shown in the frequency domain between 8 - 12 GHz. Note that the latter response has been obtained by Fourier transform of the corresponding time domain data (gate width is ±1 meter around the maximum response of the calibration sphere). Furthermore, we observe that the background level is approximately 30 dB lower than the sphere response (-27.1 dBsm) which is acceptable for most RCS measurements.

After the calibration, RCS measurements have been carried out on a semi-scale model B747 (1:100 scale). The results for HH polarization are shown in Figure 20. An ISAR image clearly identifies the major scattering locations.

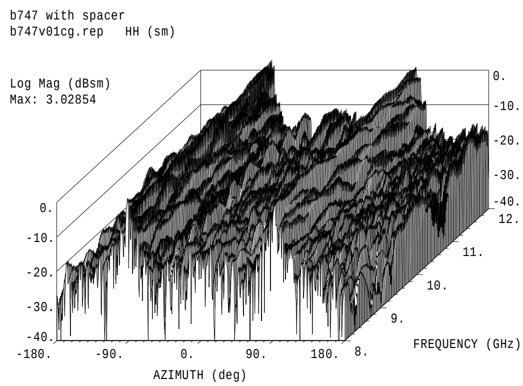


Figure 20: RCS response for ±180^0 and 8-12 GHz.

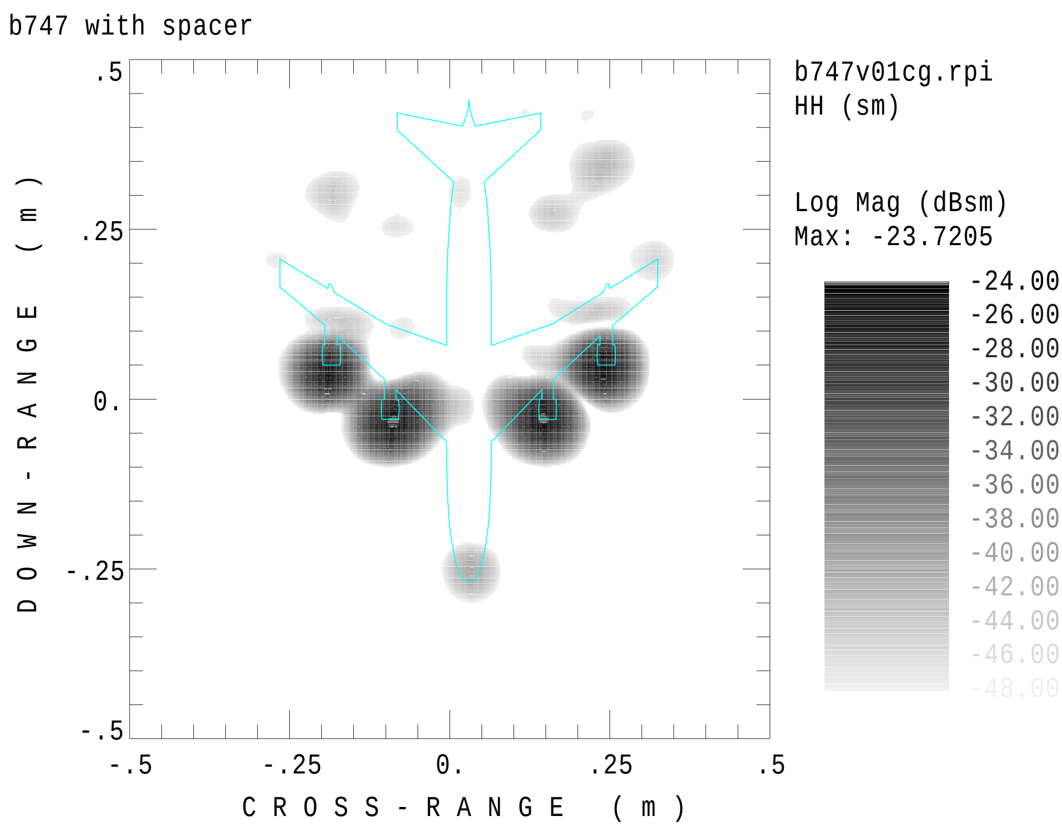


Figure 21: ISAR image of a B747 (1:100 scale).

5 Conclusions

In conclusion, R&S ZVM/ZVK series vector network analyzers are suitable for antenna measurements:

- By means of their hardware design and technical specifications, a lot of measurements are possible using them just as stand-alone-units. Mainly the four channel receiver capability and control of external sources allow external mixing, magnitude or complex S-parameters and phase/group delay measurements on a pulse stream. Depending from the repetition rate, measurements on a pulse stream can be performed with a pulse duration down to 0.1 µs and less. Pulse profiling measurements are just possible when the pulse duration is much longer than 65 µs.
- Systems of Company March Microwave based on R&S ZVM/ZVK, allow signal transmission over long distances, near/far-field measurements, pulse profile measurements and complex S-parameter measurements with down to 5 ns resolution (and even higher). Finally - capturing data from all 4 channels for the full polarization matrix (VV, HH, VH and HV) - comprising RCS measurements with very high system dynamic and system sweep are possible. Full system control and further data evaluation (like RCS results) is provided by March Microwave software packages.

6 References

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[3] Application Note 1EZ31_1E: "Measurements on Frequency-Converting DUTs using Vector Network Analyzer ZVR", (Peter Kraus, R&S)
[4] Application Note 1EZ42_2E: "Power Calibration of Vector Network Analyzer ZVR", (A. Gleissner, R&S)
[5] Application Note 1EZ42_1E: "Pulsed Measurements on GSM Amplifier SMD Ics with Vector Network Analyzer ZVR", (Olaf Ostwald, R&S)
[6] CD-ROM with documents on R&S ZVx Vector Network Analyzers
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[8] Balanis, Constantine A., *Antenna Theory: analysis and design, 2nd edition*, Wiley, New York, 1997, Ch2
[9] ARCS version 3.0, March Microwave Systems B.V., 2002

7 Additional Information

Please contact TM-Applications@rsd.rohde-schwarz.com for comments and further suggestions.

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