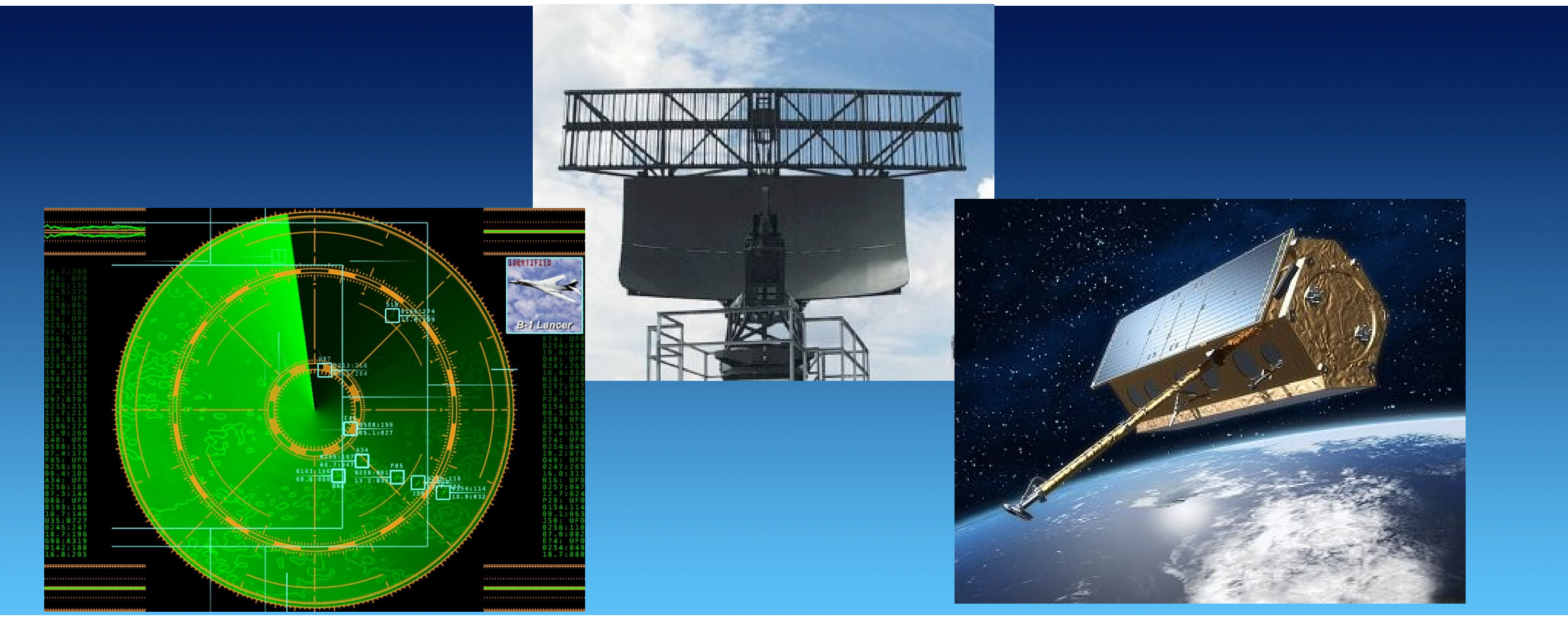


Overview of Tests on Radar Systems and Components

Application Note

This Application Note provides a general overview of different radar systems. It also covers typical measurements on such systems and their components with a special focus on the use of R&S test & measurement equipment.

ROHDE&SCHWARZ

Contents

1 Abstract

This Application Note provides a general overview of both conventional and modern radar systems and their applications. It also covers typical measurements on these systems and their components with a special focus on the use of R&S test & measurement equipment.

2 Overview of Typical Radar Applications and Common Radar Types

Typical radar applications

Typical radar applications are listed here to give an idea of the huge importance of radar in our world.

Surveillance

Military and civil air traffic control, ground-based, airborne, surface coastal, satellite-based

Searching and tracking

Military target searching and tracking

Fire control

Provides information (mainly target azimuth, elevation, range and velocity) to a fire-control system

Navigation

Satellite, air, maritime, terrestrial navigation

Automotive

Collision warning, adaptive cruise control (ACC), collision avoidance

Level measurements

For monitoring liquids, distances, etc.

Proximity fuses

Military use: Guided weapon systems require a proximity fuse to trigger the explosive warhead

Altimeter

Aircraft or spacecraft altimeters for civil and military use

Terrain avoidance

Airborne military use

Secondary radar

Transponder in target responds with coded reply signal

Weather

Storm avoidance, wind shear warning, weather mapping

Space

Military earth surveillance, ground mapping, exploration of space environment

Security

Hidden weapon detection, military earth surveillance

Radar frequency bands and their usage

Band	Frequency	Wavelength	Application
HF	3–30 MHz	10–100 m	Coastal radar systems, over-the-horizon (OTH) radars; 'high frequency'
P	< 300 MHz	1 m+	'P' for 'previous', applied retrospectively to early radar systems
UHF	300–1000 MHz	0.3-1 m	Very long range (e.g. ballistic missile early warning), ground penetrating, foliage penetrating; 'ultra high frequency'
L	1–2 GHz	15–30 cm	Long range air traffic control and surveillance; 'L' for 'long'
S	2–4 GHz	7.5–15 cm	Terminal air traffic control, long-range weather, marine radar; 'S' for 'short'
C	4–8 GHz	3.75-7.5 cm	Satellite transponders; a compromise (hence 'C') between X and S bands; weather radar
X	8–12 GHz	2.5-3.75 cm	Missile guidance, marine radar, weather, medium-resolution mapping and ground surveillance; in the USA the narrow range 10.525 GHz ±25 MHz is used for airport radar. Named X band because the frequency was kept secret during WWII.
Ku	12–18 GHz	1.67-2.5 cm	High-resolution mapping, satellite altimetry; frequency just under K band (hence 'u')
K	18–27 GHz	1.11-1.67 cm	K band is used by meteorologists for detecting clouds and by police for detecting speeding motorists. K band radar guns operate at 24.150 ± 0.100 GHz.
Ka	27–40 GHz	0.75-1.11 cm	Mapping, short range, airport surveillance; frequency just above K band (hence 'a'); photo radar, used to trigger cameras which take pictures of license plates of cars running red lights, operates at 34.300 ± 0.100 GHz.
mm	40–300 GHz	7.5 mm - 1 mm	Millimeter band, subdivided as below. The letter designators appear to be random, and the frequency ranges dependent on waveguide size. Multiple letters are assigned to these bands by different groups
Q	40–60 GHz	7.5 mm - 5 mm	Used for military communication
V	50–75 GHz	6.0–4 mm	Very strongly absorbed by the atmosphere
W	75–110 GHz	2.7 - 4.0 mm	76 GHz Long Range (LRR) and 79 GHz Short Range (SRR) automotive radar, high-resolution meteorological observation and imaging

Common radar types

This section lists the most common types of radar systems with brief explanations of how they work.

CW (Doppler) and FMCW (Doppler (speed)/range) radar

A continuous wave (CW) radar system with a constant frequency can be used to measure speed. However, it does not provide any range (distance) information. A signal at a certain frequency is transmitted via an antenna. It is then reflected by the target (e.g. a car) with a certain Doppler frequency shift. This means that the signal's reflection is received on a slightly different frequency. By comparing the transmitted frequency with the received frequency, we can determine the speed (but not the range). Here, a typical application is radar for monitoring traffic.

Radar motion sensors are based on the same principle, but they must also be capable of detecting slow changes in the received field strength due to variable interference conditions that may exist.

Radar speedtraps operated by the police use this same technology. Camera systems take a picture if a certain speed is exceeded at a specified distance from the target.

Figure 1: Modern traffic monitoring radar TRAFFIPAX SpeedoPhot from ROBOT Visual Systems

There are also military applications:

CW radars are also used for target illumination. This is a straightforward application: The radar beam is kept on target by linking it to a target tracking radar. The reflection from the target is then used by an antiaircraft missile to home in on the target.

CW radars are somewhat hard to detect. Accordingly, they are classified as low probability of intercept radars.

CW radars lend themselves well to detecting low-flying aircraft that attempt to overcome an enemy's air defense by "hugging the ground". A pulsed radar has difficulties in discriminating between ground clutter and low-flying aircraft. A CW radar can close this gap because it is blind to slow-moving ground clutter and can pinpoint the direction where something is going on. This information is relayed to a co-located pulse radar for further analysis and action. [4]

FMCW radar

The disadvantage of CW radar systems is that they cannot measure range due to the lack of a timing reference. However, it is possible to generate a timing reference for measuring the range of stationary objects using what is known as "frequency-modulated continuous wave" (FMCW) radar. This method involves transmitting a signal whose frequency changes periodically. When an echo signal is received, it will have a delay offset like in pulse radar. The range can be determined by comparing the frequency. It is possible to transmit complicated frequency patterns (like in noise radar) with the periodic repetition occurring at most at a time in which no - ambiguous echoes are expected. However, in the simplest case basic ramp or triangular modulation is used, which of course will only have a relatively small unambiguous measurement range.

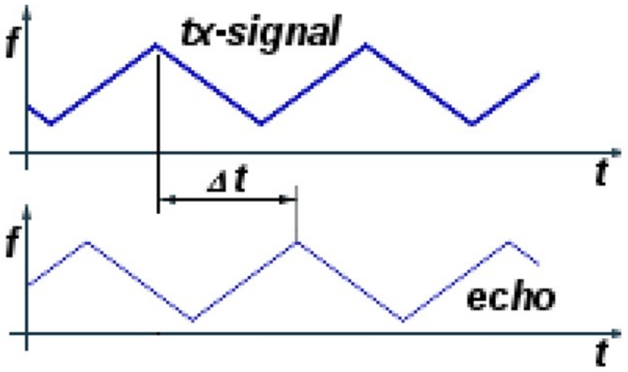


FIG 2: Basic principle of FMCW radar. The target’s velocity is calculated based on the measured delay between the transmit signal and the echo ramp.

This type of range measurement is used, for example, in aircraft to measure altitude (radio altimeter) or in ground tracking radar to ensure a constant altitude above ground. One benefit compared to pulse radar is that measurement results are provided continuously (as opposed to the timing grid of the pulse repetition frequency).

FMCW radar is also commonly used commercially for measuring distances in other ways, e.g. level indicators.

Simple pulse (range) and pulse Doppler (speed/range) radar

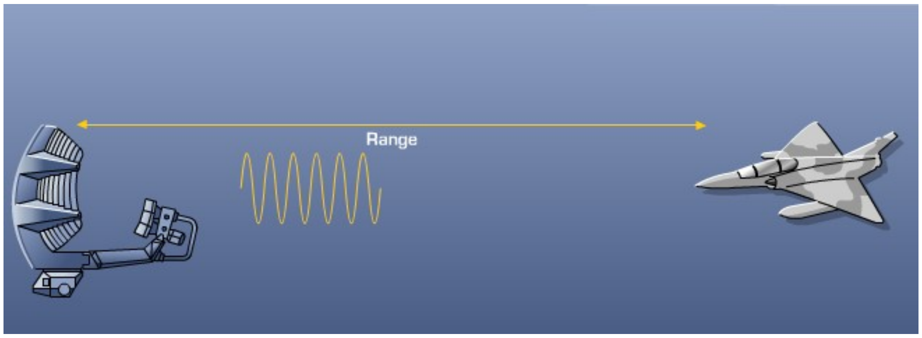


FIG 3: Basic principle of a simple pulse radar system

A simple pulse radar system only provides range (plus direction) information for a target based on the timing difference between the transmitted and received pulse. It is not possible to determine the speed. The pulse width determines the range resolution.

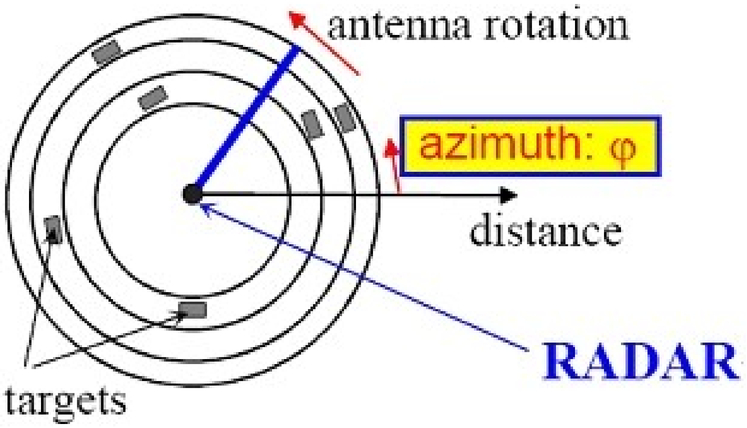


Figure 4: Direction information with azimuth angle determination in a radar system with a rotary antenna

The direction information (azimuth angle φ) is determined from the time instant of the receive pulse with reference to the instantaneous radiation direction of the rotating antenna.

The important measurements on (non-coherent) radar equipment of this sort are the range accuracy and resolution, AGC settling time for the receiver, peak power, frequency stability, phase noise of the LO and all of the pulse parameters.

Pulse Doppler radar

A pulse Doppler radar also provides radial speed information about the target in addition to range information (and direction information). In case of coherent operation of the radar transmitter and receiver, speed information can be derived from the pulse-to-pulse phase variations. I/Q demodulators are normally used. The latest pulse Doppler radar systems normally use different pulse repetition frequencies (PRF) ranging from several hundred Hz up to 500 kHz in order to clarify any possible range and Doppler ambiguities.

More advanced pulse Doppler radar systems also use a "staggered" PRF, i.e. the PRF changes on an ongoing basis. Important criteria for achieving good performance in pulse Doppler radar systems include very low phase noise in the LO, low receiver noise and low I/Q gain phase mismatch (to avoid "false target indication") in addition to the measurement parameters listed above.

Pulse compression radar (FM chirp and phase coded) (high resolution)

Classic pulse and pulse Doppler radar transmits extremely short pulses. Increasing the pulse power allows the radar system to achiever greater range results. Decreasing the duration of the transmit pulses also decreases the pulse volume and provides better range resolution for the radar system, i.e. closely-spaced targets can be distinguished with smaller distances between them.

Pulse compression combines the power-related benefits of very long transmit pulses (good range) with the benefits of very short transmit pulses (high distance resolution). Lower peak power can then be used.

By modulating the transmit pulses, a timing reference is produced within the transmit pulse, similar to frequency-modulated continuous wave (FMCW) radar systems. Several different modulation techniques can be used. The most common are:

- Linear frequency modulation (FM chirp)
- Non-linear frequency modulation
- Encoded pulse phase modulation (e.g. Barker code)
- Polyphase modulation and time-frequency coded modulation

Although pulse compression technique has various benefits such as low pulse power with good range and distance resolution, there is a significant disadvantage: The minimum measurement range is degraded depending on the pulse length since the radar receiver is blocked during the transmit pulse. Since this is a major disadvantage for radar systems used for air traffic control, they typically use both techniques. Between the frequency-modulated pulses for the larger range, small (very short) pulses are transmitted which only have to cover the nearby area and do not require very high pulse power.

- Linear FM is most common in older radar systems - Non-linear FM is not used very often so far despite its various benefits

- Encoded pulse phase modulation is very common, particularly Barker Codes with lengths of 11 and 13

- In advanced military radar systems, polyphase pulse compression is also used increasingly with special codes

Frequency agile radar (FAR) (suppression of jamming and improved clutter rejection)

Frequency hopping is an effective technique for a radar system to circumvent jamming and electronic counter countermeasures (ECCM). It is typically used in military radar applications. Clutter rejection is also possible using FAR. Submicrosecond switching times and bandwidths ranging from several hundred MHz in the X band to over 2 GHz at 95 GHz are typical.

Other measurement parameters that are relevant with FAR include the frequency switching/settling time, hop sequence, switching spurious and broadband amplitude and phase stability.

Stepped frequency radar (imaging application)

Stepped-frequency radar systems are used in imaging applications. With typical bandwidths ranging from several hundred MHz to 2 GHz, resolutions of < 10 cm can be achieved.

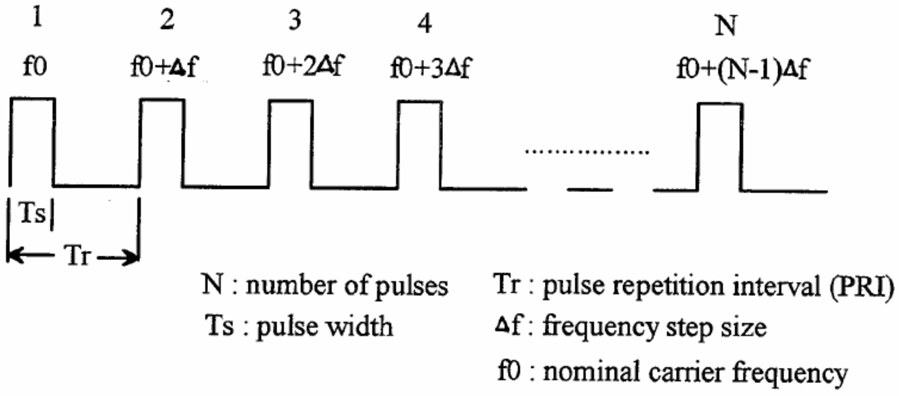


FIG 5: Timing diagram for stepped frequency radar

The frequency is increased by a fixed value from pulse to pulse. Typical bursts contain 128 pulses. The benefit of a stepped frequency radar system is that we can obtain wide bandwidth and thus good resolution without needing a large realtime bandwidth.

Due to the wide RF bandwidth of the transmitter and receiver, these subsystems must exhibit excellent stability in order to obtain the desired high resolution. Important measurements include the pulse-to-pulse stability of the magnitude and phase. As was the case with frequency agile radar, the settling time of the local oscillator is also an important measurement parameter.

Moving target identification radar (MTI)

The idea behind MTI radar is to suppress reflected signals from stationary and slowly moving objects such as buildings, mountains, waves, clouds, etc. (clutter) and thus obtain an indication of moving targets such as aircraft and other flying objects. Here, the Doppler effect is exploited since signals reflected by targets moving radially with respect to the radar system exhibit an offset vs. the transmitted frequency which is proportional to their speed (e.g. in linear FM radar). In pulse radar systems, the pulses reflected by moving objects have a variable phase from pulse to pulse referred to the phase of the transmitted pulses.

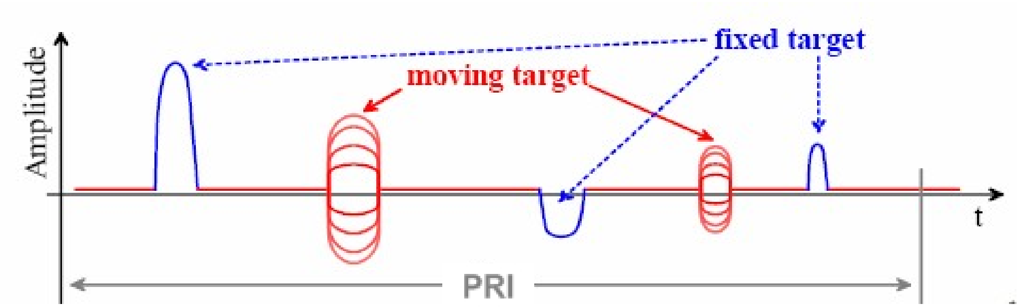


FIG 6: Moving target indication

Optimizing MTI requires the use of very sophisticated techniques such as staggered PRF (a variable pulse interval from pulse to pulse) in order to offset "blind velocities" or make them visible. Important measurement parameters when optimizing MTI or the clutter suppression include:

- Good pulse-to-pulse phase and amplitude stability for the transmit signal
- Highest possible phase stability or lowest possible phase noise for the LO in the radar system, particularly for MTI involving targets with low radial speeds

Monopulse radar (phase or amplitude comparison) / (range and angle measurement)

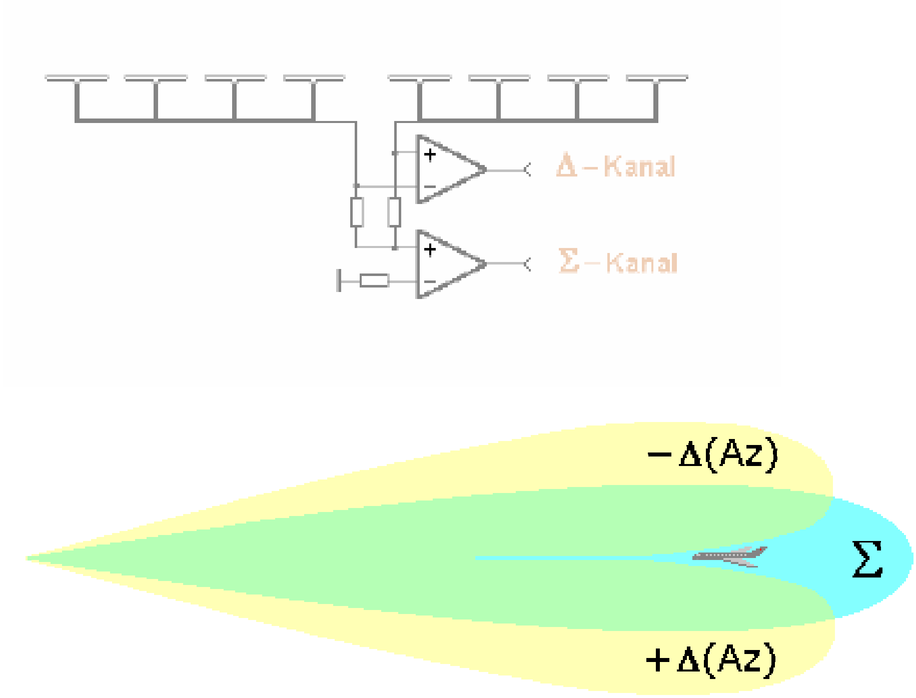


FIG 7: A monopulse radar antenna

In monopulse radar systems, at least two antenna groups are used which are arranged at spatially distinct locations.

By comparing the summation and difference channels, it is possible to localize the reflecting object within the radar beam.

Using counterphase coupling of the left and right antenna groups, a difference channel (ΔAz) is formed ("delta azimuth"). The azimuth is determined by exploiting the fact that at this angle for a maximum of the summation channel, the difference channel must be at a minimum. Since the summation channel (Σ) and the difference channel can be formed from just a single echo, one pulse is enough to accurately compute the coordinates. (This is why this way of grouping antennas is also referred to as "monopulse antenna".)

The ratio of the summation channel to the difference channel provides a measure of the offset of the real direction from the center axis of the antenna ("boresight"). The angular difference between the antenna boresight and the actual offset angle of the target is known as the "off-boresight angle"..

In 3D radar systems, the elevation angle is also measured as the third coordinate. The same technique can be applied in this case too. The antenna is divided into upper and lower halves. The second difference channel (ΔEl) is now known as the "delta elevation".

The channel matching of the different channels is critical in monopulse radar systems and must be measured. Phase-coherent synthesizers with adjustable phase offsets are typically used for this purpose.

Phased array radar

Phased array radar antennas have hundreds or even thousands of individual radiator elements (as opposed to a reflector antenna with a single radiator). The magnitude and phase of the power fed to the radiator elements can be individually controlled, making it possible for the overall antenna to produce wave fronts with nearly any desired shape. In real-world operation, the pattern can be turned by about ±60°. The efficiency of the antenna drops at larger angles. Unlike a conventional antenna that is moved mechanically, a phased array can rotate its pattern in space with practically no delay.

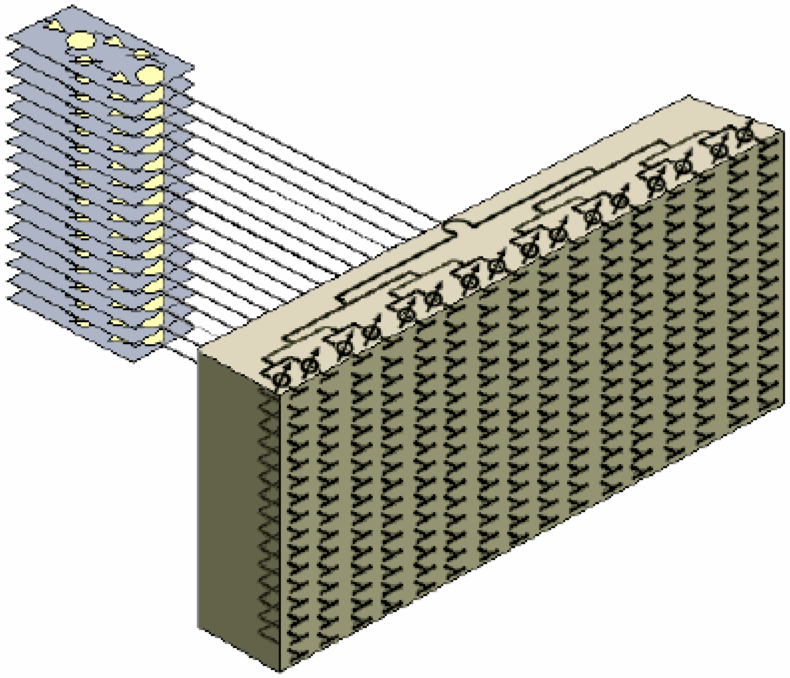


FIG 8: An active electronically scanned array antenna (AESA)

Since phased arrays are very costly, they are used primarily in military and SAR satellite applications. The standard is now an active phased array radar (or active electronically scanned array, AESA) based on many individual, small transmit/receive modules, whereas the passive variant (PESA) uses a common RF source whose signal is modified using digitally controlled phase shifter modules.

What is important with AESA is the uniformity of the different modules in terms of the amplitude and phase, which involves considerable test and calibration expense.

Synthetic aperture radar (SAR)

Synthetic aperture radar (SAR), like the related real aperture radar (RAR; see also side-looking airborne radar), belongs to the class of imaging radar systems. Such radar systems are deployed in aircraft or satellites to provide a two-dimensional view of a section of terrain by scanning the earth's surface using electromagnetic waves.

The basic principle behind SAR involves an antenna that can be moved perpendicularly to the radiation direction. The position must be precisely known at all times. The direction of motion is normally referred to as the "along track" or azimuth and the related cross coordinate as the "cross track" or range. The "footprint" is the area which the real antenna is currently covering. The "swath" is the strip of terrain which the footprint crosses through ongoing motion of the real antenna.

SAR involves replacing the instantaneous snapshot produced by a large antenna with many snapshots produced using a small, mobile antenna. During the course of the related movement, each object in the target area is illuminated at a different angle of view and recorded accordingly. As long as the path of the real antenna is known with sufficient accuracy, the aperture of a large antenna can be synthesized based on the magnitude and phase of the received radar echoes in order to attain a high spatial resolution in the direction of motion of the antenna.

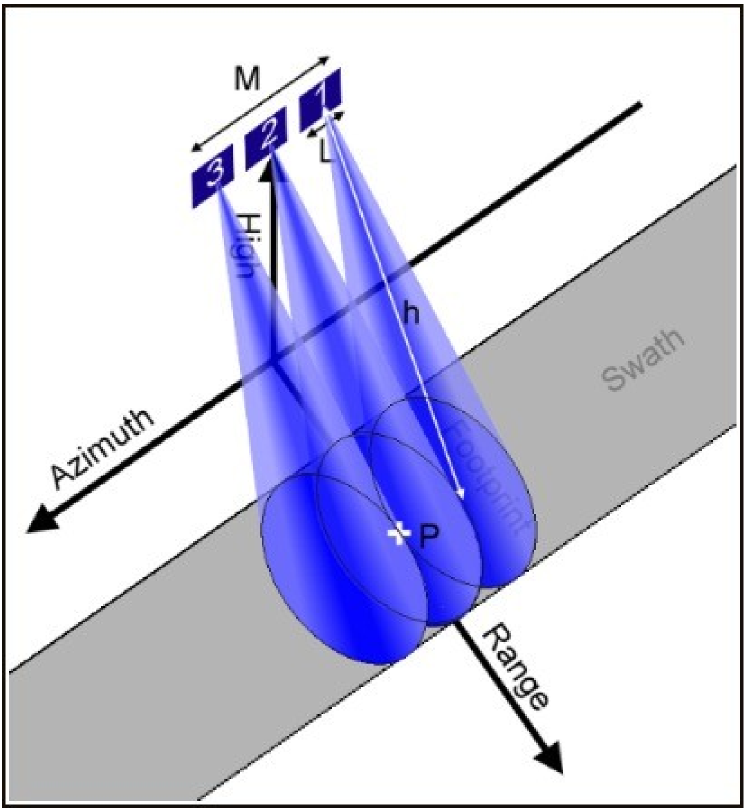


FIG 9: Synthetic aperture radar (SAR). The SAR antenna beam is moved back and forth while traveling along the azimuth.

The best possible resolution that can be attained in the azimuth or flight direction using SAR is equal to half the length of the real antenna, i.e. for a decrease in the azimuth antenna length L_{Az} (designated as L in the figure above) of the real antenna, its resolution capacity δ_{Az} improves as follows:

$$\delta_{Az} = \frac{L_{Az}}{2}$$

[2], [3]

The resolution in the radial direction (slant range) is determined in principle by the signal bandwidth of the transmit signal that is used:

$$\delta_{S\,l} = \frac{c_0}{2B_R}$$ Where: [2], [3]

$$c_0 = \frac{300m}{\mu s} = speed\ of\ light$$

For a resolution of 1 m, we thus need a signal bandwidth of 150 MHz. Today's SAR systems use a signal bandwidth > 1 GHz (2 GHz is desirable) in order to attain a resolution < 10 cm.
The signal bandwidth is normally attained using pulse compression techniques such as linear frequency modulation. More advanced SAR systems also used stepped frequency, polarization switching and other complex techniques (e.g. intrapulse beamsteering, multiaperture recording in azimuth, spatiotemporal waveform encoding, etc. in the TerraSAR X).

Bistatic, multistatic radar

In most cases, the transmitter and receiver use the same antenna through time-domain multiplexing. This type of radar system is known as "monostatic radar". A bistatic radar system has one transmitter location and one or more receiver locations with a larger distance or offset angle between them. It is easy to turn a monostatic radar system into a bistatic radar system by setting up additional receiving sites. A bistatic radar system can also be created using two monostatic radar systems that operate on the same frequency.

In a bistatic radar system, the transmitter and receiver are separated by a larger distance and usually also have a larger azimuth offset. This means that a signal will be received even if no power (or only very little power) is reflected directly towards the monostatic radar system due to the geometry of the reflecting object (stealth technology!). This type of system has practical applications in weather radar and the military, e.g. to intercept stealth flying objects.

When using multiple spatially separated receivers, we use the term multistatic radar.

Passive radar

Passive radar is a location technology which, unlike conventional radar, does not actively transmit electromagnetic energy in order to detect and track the reflections that are produced. Instead, reflections and the Doppler effect are evaluated for transmissions from known broadcast transmitters, mobile radio transmitters and other systems that produce constant signals. Passive radar systems are difficult to locate since they do not transmit any signals. This is a decisive advantage in military applications. Another advantage is the ability to intercept stealth aircraft, which is very limited with existing active radar technology.

Of course, there are no transmitter tests for passive radar. Receiver tests would most likely be very complex. Multiple coherent signal generators are among the necessary equipment.

Low probability of intercept radar

Low probability of intercept (LPI) radars are military radar systems which are designed for the modern electronic combat environment. More or less successfully, they try to avoid being detected by ELINT (**El**ectronic **In**teligence, electronic acquisition of radar parameters) sensors by using some combination of the features outlined below:

- Multistatic radar
- Ultra-low sidelobe antennas
- Ultra-wideband signals
- Long pulse
- Low power
- Passive radar

Instrumentation radar

Instrumentation radar systems also evaluate the polarization (horizontal, vertical, circular) of radar signals (intra-pulse polarization agile radar) in order to obtain more information about the target.

Calibration of this type of radar system requires polarization measurements in addition to the conventional measurements used on coherent radar systems.

Multimode radar

Many of the radar systems used nowadays in military applications (e.g. in aircraft) are multimode radar systems which must handle a wide range of tasks:

- Target searching and tracking
- Weapon guidance
- High-resolution ground mapping
- Bad weather and terrain avoidance
- Electronic counter countermeasures (ECCM)

Different PRF modes are used in these applications, including FM chirp, Barker phase modulation or complex modulation, AESA antennas, SAR, frequency hopping, intrapulse polarization, etc.

Testing a multimode radar system of this sort is complex and costly.

Example:

Technical specifications for a military airborne data acquisition system [5]
Operates from airborne platforms)

Multimode
Multiband
Fully coherent
Fully polarimetric
Frequency bands
Polarizations
Linear vertical and horizontal
Circular left- and right-hand
Antennas
Various (depending on application)
A, B & C 100 to 600 MHz
F 2.9 to 3.4 GHz
I 9.0 to 11.25 GHz
J 15.5 to 16.0 GHz
Frequency-agile
Polarization-agile
Pulse-by-pulse data recording to Ampex DCRSi or compatible media
User-definable transmit waveforms up to 32 k samples
1 to 40 kHz PRF
User-selectable range ambits (768 to 12288 cells)
Simultaneous two-channel, co- and/or cross-polar receiver

Up to 500 MHz instantaneous bandwidth
(2.25 GHz using eight 500 MHz 50 % overlapped pulses)
Data sampling at 100, 250 or 500 MHz
DATA GATHERING MODES
High range resolution
0.36 m using DPDPS linear chirp modulation over 500 MHz bandwidth
768 to 12288 contiguous 0.3 m range cells
Ultra high range resolution
0.1 m using DPDPS linear chirp modulation over 2.25 GHz bandwidth
(eight 500 MHz 50 % overlapped pulses)
3072 to 49152 contiguous 0.075 m range cells

Outlook for future radar developments

In the future, we can expect to encounter multisensor systems that combine radar and infrared (or other) systems. This will make it possible to combine the benefits of the different types of systems while suppressing certain weaknesses.

Military onboard radar systems will be increasingly confronted with the stealth characteristics of advanced aircraft. The contradiction between the different requirements imposed on aircraft must be solved (i.e. planes should exhibit stealth properties while not revealing their position through the use of onboard radar). One possibility involves the use of a bistatic radar system with a separate illuminator and only a receiver onboard the aircraft.

In the future, radar antennas will no longer exist as discrete elements with suitable radomes in many cases. Instead, they will be integrated into the geometrical structure of the aircraft, ship or other platform that contains them. The next generation of AESA radars used onboard aircraft will have more than one fixed array in order to be able to handle greater spatial angles.

Finally, the speed of the digital equipment used to process the radar data will increase through parallel processing in order to handle the high data rates needed for high-resolution radar operating modes.

3 Typical Tests on Radar Systems and Components

This chapter will discuss some of the typical tests on radar systems and their components.

Transmitter tests

Output power measurement with a power meter

The output power of a radar transmitter represents one of the most important parameters which we must measure on a radar system. It is a critical factor in the performance (e.g. range) of a radar system.

The most popular and economical method of determining the radar transmitter power involves the use of a suitable power meter.

Due to the high power used in radar systems (pulse power levels can range from a few kilowatts to a few megawatts), we must always use a directional coupler as well as attenuator pads in certain cases to ensure that our test equipment will measure in a safe range.

There are a number of terms that are used when discussing the power of radar transmitters. See FIG 1 and FIG 2 for an illustration of these terms. The average power is the power integrated over the entire time period (pulse repetition interval = on-time + off-time). In case of a variable pulse width or a variable pulse repetition frequency (PRF), the integration time must an integer multiple of the overall period.

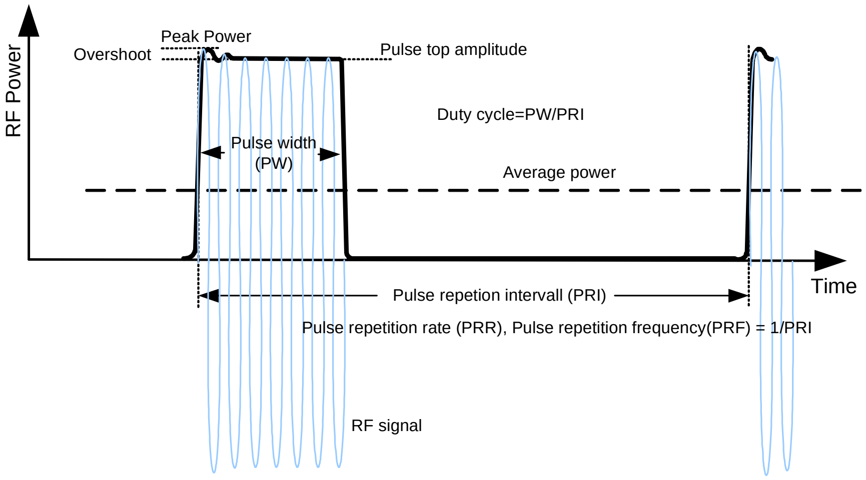


FIG 10: Power-related pulse parameters

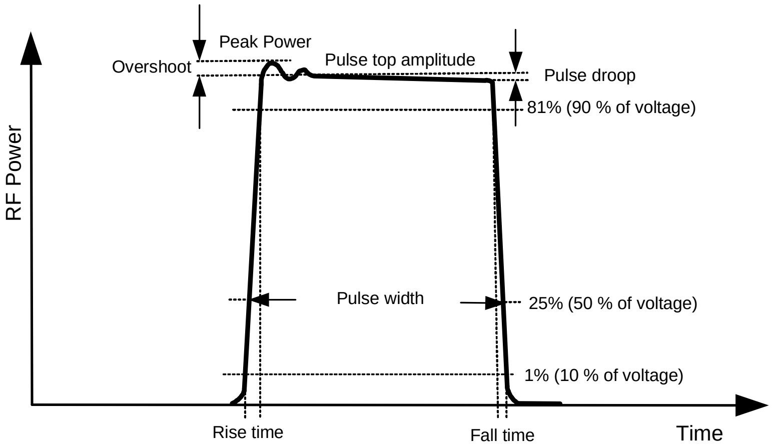


FIG 11: More power-related pulse parameters

Traditional RF power meters usually measure the average power. For example, the precision R&S NRP-Z51/Z55 power sensors make use of the thermoelectric principle to cover the frequency range from DC to 40 GHz.

The peak power is the maximum power level which occurs. The pulse power is defined as the average power of a complete pulse (i.e. the power integrated over the complete pulse).

If we know the duty cycle or pulse width and pulse repetition interval (PRI), we can compute the pulse power from the average power. Or (in case of non-ideal pulses), we can estimate the pulse power with the following formula:

$$P_{Pulse} = \frac{PRI}{Pulse\_width} * P_{Av}$$

Where:

P_{Av} = average power

P_{Pulse}= pulse power

PRI = pulse repetition interval

If we have an ideal rectangular pulse (the formula above applies only to this ideal case), then the pulse power is also identical to the peak power which occurs. Special care should be taken not to overload the power sensor by the peak amplitude of the pulse especially with low duty cycles. The max. pulse energy of the NRP-Z51/Z55 is limited to 10 W/µs.

Example:

P_{Av} = 20 mW (assumed indication of power sensor NRP-Z51/Z55)

PW = 1 µs

PRI = 1 ms

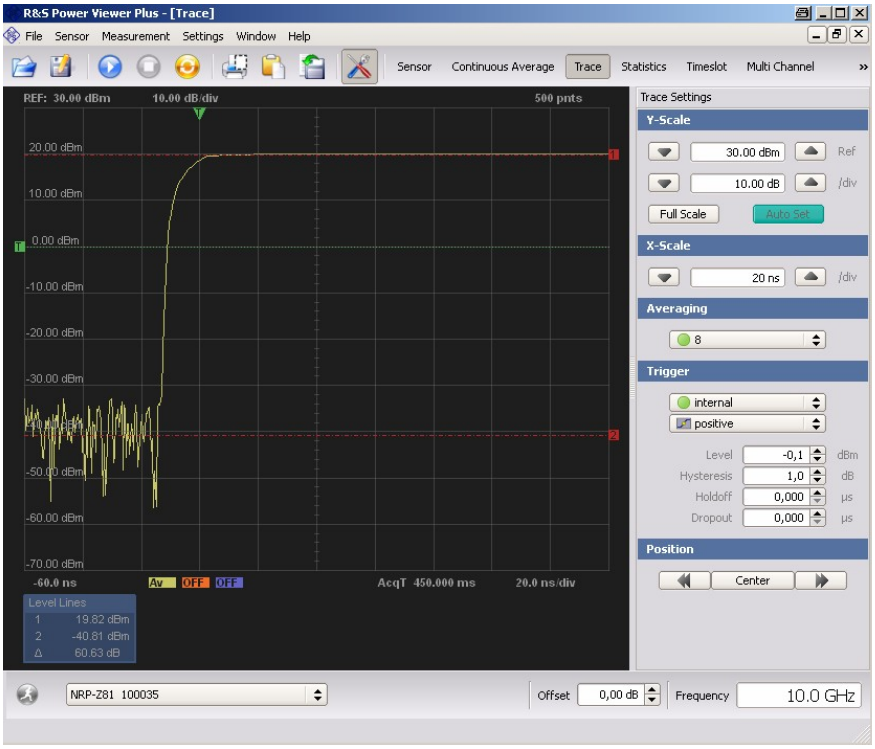
Calculated pulse power P_{Pulse}= 20 W (which is already twice the max. rated pulse energy of 10 W/µs!)

For any radar system, it is the pulse power which is most important. Accordingly, we have an interest in investigating the individual pulses. This is particularly important with advanced radar systems with variable pulse width and PRF. Here, it is important to analyze the pulse shaping (slope steepness, pulse droop, overshoot, etc.). Suitable test instruments include wideband power sensors such as the R&S NRP-Z81 power sensor with versatile measurement functions. However, a spectrum analyzer with a wide IF bandwidth in zero span mode will provide even greater flexibility for assessing the measurement parameters.

FIG 12: The R&S NRP power meter with different power sensors. Up to four sensors can be connected to this instrument.

The R&S NRP-Z81 is based on the latest power measurement technology. It offers all of the features of a conventional peak power meter in a very compact package. It can be operated with the NRP power meter or (like all of the R&S NRP sensors) with a Windows PC, e.g. as a cost-effective solution for performing radar transmitter tests in the field. No compromises were accepted in the areas of measurement accuracy and functionality. This makes the R&S NRP-Z81 very well suited to detailed analysis of radar signals with bandwidths of up to 30 MHz for individual pulses. In addition, the R&S NRP-Z81 also allows precision measurements of the average power of signals in the power level range from –60 dBm to +20 dBm. The actual frequency range is from 50 MHz to 18 GHz.

R&S Power Viewer Plus is easy-to-use test software that provides a number of universal measurement functions such as continuous average power, trace, statistics and data logging. Up to four sensors which are directly connected to the Windows PC via USB can be simultaneously evaluated in continuous average power mode. Various mathematical functions (e.g. sum, difference, ratio, SWR, etc.) are available for analyzing the measurement results produced by the sensors. Versatile trigger function (internal,external trigger, defineable holdoff and dropout time) ensure correct measurements even under difficult trigger conditions.



REF: 30.00 dBm 10.00 dB/div 500 pnts

-60.0 ns AcqT 450.000 ms 20.0 ns/div

Level Lines

1	19.82 dBm
2	-40.81 dBm
Δ	60.63 dB

Y-Scale: 30.00 dBm Ref; 10.00 dB /div

X-Scale: 20 ns /div

Averaging: 8

Trigger: internal; positive

Level -0,1 dBm

Hysteresis 1,0 dB

Holdoff 0,000 µs

Dropout 0,000 µs

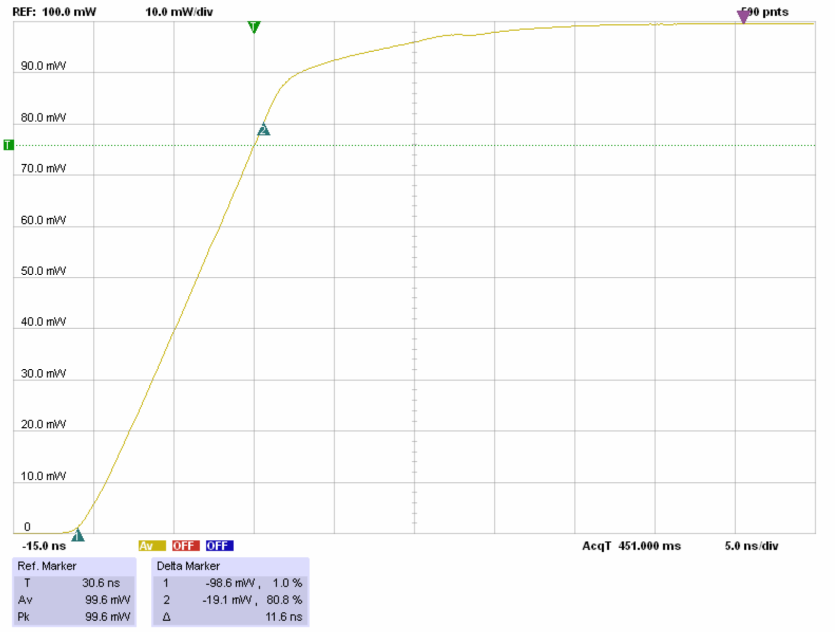
NRP-Z81 100035

Offset 0,00 dB

Frequency 10.0 GHz

FIG 13: User interface of the Power Viewer Plus software. In Trace mode, the power is displayed vs. time. With NRP-Z81 a dynamic range of approximately 60 dB is achieved.

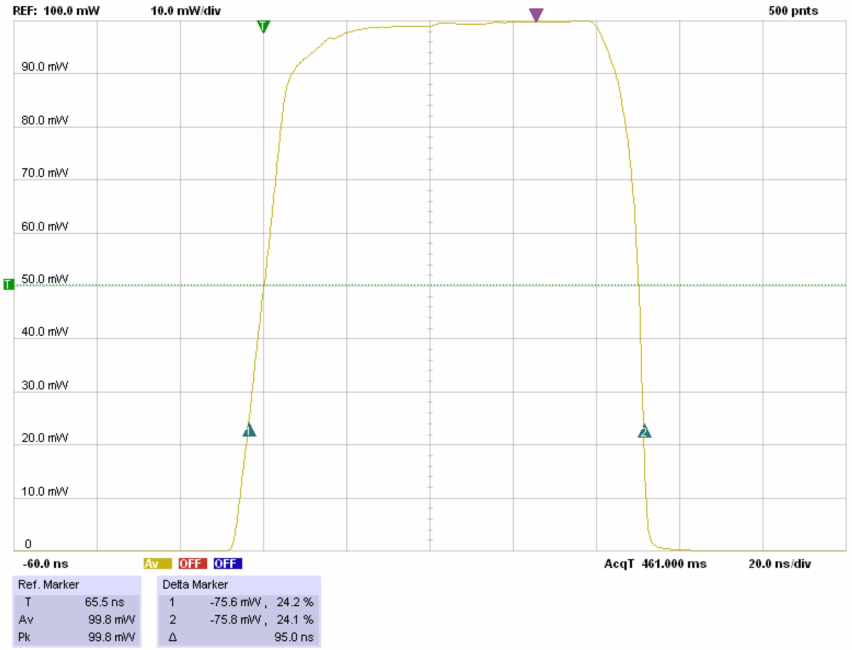
For repetitive signals, the **Power Viewer Plus** software provides high time resolution in conjunction with the R&S NRP-Z81 power sensor to enable display of the time-domain behavior even for very steep-edged pulses. See FIG 14 and FIG 15. This allows determination of all of the relevant pulse parameters with high accuracy.



Ref. Marker	
T	30.6 ns
Av	99.6 mW
Pk	99.6 mW

Delta Marker		
1	-98.6 mW ,	1.0 %
2	-19.1 mW ,	80.8 %
Δ		11.6 ns

FIG 14: Rise time measurement with Power Viewer Plus and the R&S NRP-Z81 using the delta markers (1 % to 81 % of peak power)



Ref. Marker	
T	65.5 ns
Av	99.8 mW
Pk	99.8 mW

Delta Marker		
1	-75.6 mW ,	24.2 %
2	-75.8 mW ,	24.1 %
Δ		95.0 ns

FIG 15: Pulse width measurement with Power Viewer Plus and the NRP-Z81 on a short pulse using the delta markers (pulse width = 95 ns measured between 25% of power markers)

Measurement of the pulse power and spectrum using a spectrum analyzer

The main advantage of a spectrum analyzer is that it can also be used to test frequency-dependent power components (with a wide dynamic range). Let's consider an example that involves checking that a radar transmitter has a symmetrical pulse spectrum. An asymmetrical spectrum wastes power and generates undesirable spurious emissions, thereby degrading the performance of the radar system.

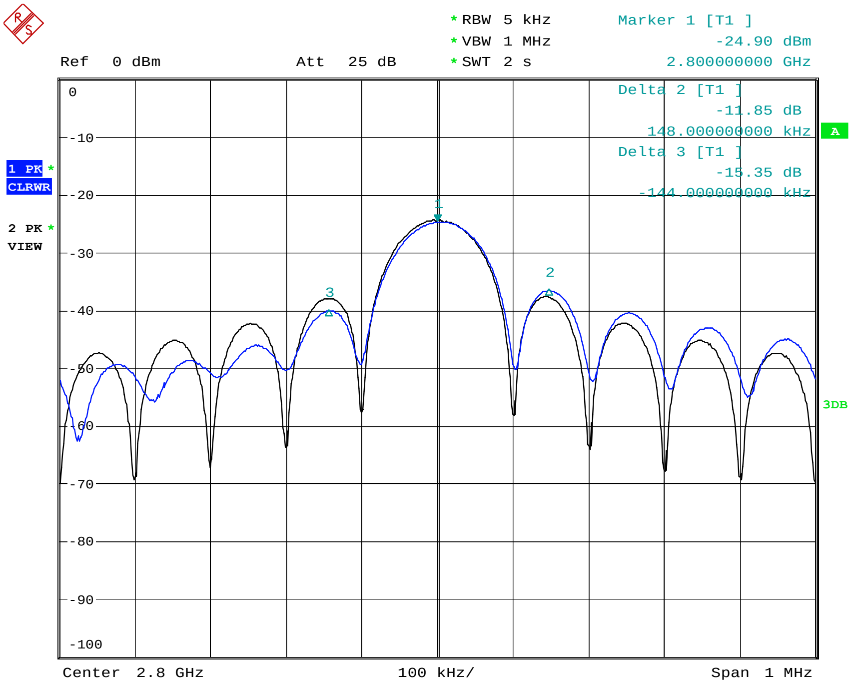


FIG 16: Spectrum of a radar transmitter before (blue trace) and after a timing adjustment.

When making measurements using a spectrum analyzer on pulsed signals and particularly on signals with a low duty cycle (common in radar systems), we need to be aware of various peculiarities related to the settings for the resolution bandwidth (RBW), sweep time, etc. in order to produce informative results.

Let's first take a quick look at the spectral characteristics of a simple pulsed RF signal with pulse width τ and pulse repetition interval T. We obtain discrete spectral lines with a spacing of 1/T. The amplitude of the spectral lines is determined by the envelope curve about the center frequency f_0. This is a $\frac{\sin x}{x}$ function and the zeroes are repeated at an interval of the center frequency $f_0 \pm n * \frac{1}{\tau}$, where n = 1, 2, 3…

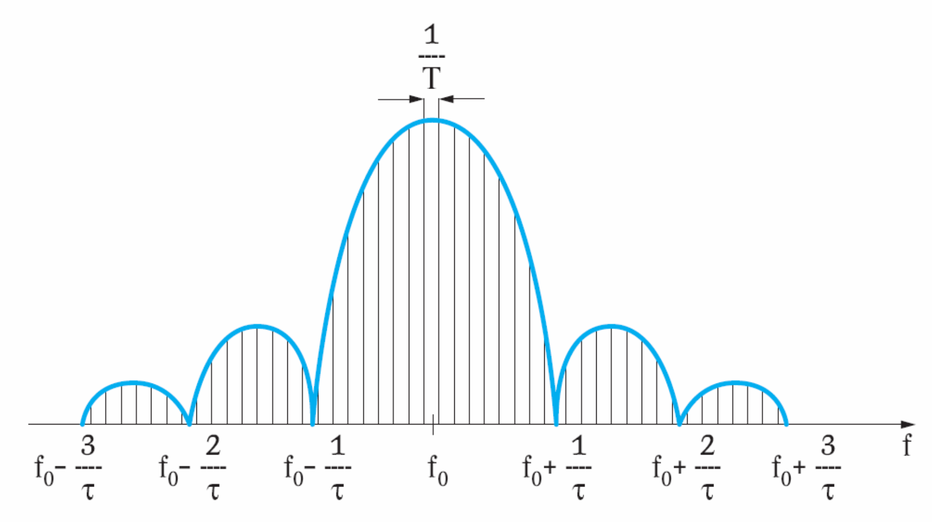


FIG 17: Spectrum of a pulse train with pulse width τ and pulse interval T

When measuring a spectrum using a spectrum analyzer, it is possible to display the individual spectral lines or the envelope curve of the pulse spectrum depending on the current settings (especially the setting for the resolution bandwidth, RBW).

If we set the RBW to a value that is significantly less than the pulse repetition frequency (= 1/T), the line spectrum will be displayed. The line spacing is equal to the pulse period (pulse repetition interval) and is independent of the setting for the sweep time on the spectrum analyzer. The height of the individual spectral lines is independent of the RBW.

The largest spectral line is below the pulse amplitude by the "pulse desensitization factor" (PDF). The PDF depends on the pulse width to the pulse period ratio):

PDF = $20 * \log(\tau / T)$

Using the line spectrum, the peak power of the pulse signal is calculated as follows once we place the marker on the tallest spectral line:

Peak power = marker reading - PDF = marker reading - $20 * \log(\tau / T)$

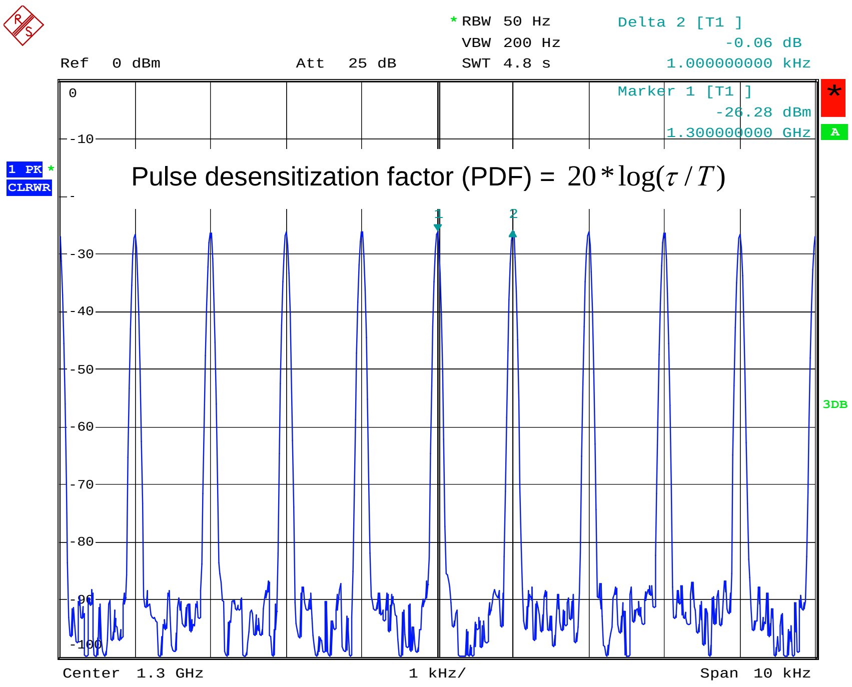


FIG 18: Line spectrum of a pulsed signal measured with the FSU spectrum analyzer (RBW << 1/T where 1/T = 1000 Hz, here: RBW = 50 Hz)

If we increase the resolution bandwidth of the analyzer until it is greater than the reciprocal of the pulse period (but still smaller than the reciprocal of the pulse width), the spectrum analyzer will display the envelope spectrum. The amplitude of the envelope increases linearly with the resolution bandwidth. Doubling the resolution bandwidth produces a 6 dB increase in the amplitude.

Note:
*The sweep time set on the analyzer should be much greater than the reciprocal of the pulse period (> 1000 * pulse period) so that on average one pulse occurs for each display point. Use the max. peak detector in order to obtain a clearer display of the envelope curve.*

The pulse desensitization factor for the envelope spectrum ($PDF_{Envelope}$) obeys the following formula:

$$PDF_{envelope} = 20 * \log(\tau KB)$$

Using the envelope spectrum, we can compute the peak power of the pulse signal by placing the marker on the maximum and the delta marker on the first minimum as follows:

Peak power = marker reading - PDF = marker reading - $20 * \log(\tau KB)$

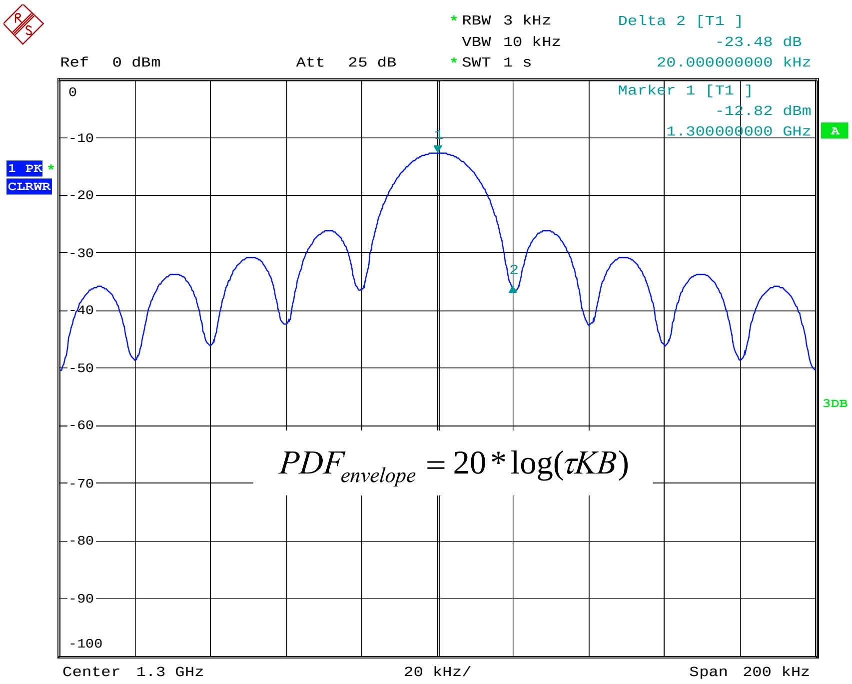
Where B = resolution bandwidth (RBW) of the spectrum analyzer (3 dB)

τ = Pulse width

K = correction factor depending on the type of RBW (four-pole filter: k=1.8, five-pole filter: k=1.73 or Gaussian filter k=1.5)

FIG 19 shows an envelope spectrum measured using the R&S FSU. The delta marker indicates the reciprocal of the pulse width. The pulse width determined in this manner is equal to 1/20 kHz = 50 µs. The peak power can be computed in this example as follows:

Peak power = -12.82 dBm - 20*log(50µs*1.5*3kHz) dB = -0.13 dBm



*RBW 3 kHz
VBW 10 kHz
*SWT 1 s
Ref 0 dBm
Att 25 dB

Delta 2 [T1]
-23.48 dB
20.000000000 kHz

Marker 1 [T1]
-12.82 dBm
1.300000000 GHz

Center 1.3 GHz
20 kHz/
Span 200 kHz

$$PDF_{envelope} = 20 * \log(\tau KB)$$

FIG 19: Envelope spectrum measured using the FSU spectrum analyzer for 1/T < RBW < 1/τ, where 1/T = 1 kHz and 1/τ = 20 kHz (here: RBW = 3 kHz)

If we further increase the resolution bandwidth until it is > 1/τ , the spectrum analyzer will approximately display the peak power of the pulse signal since the main spectral components now are within the bandwidth of the resolution filter. Of course, the spectrum analyzer is now no longer capable of displaying the envelope spectrum.

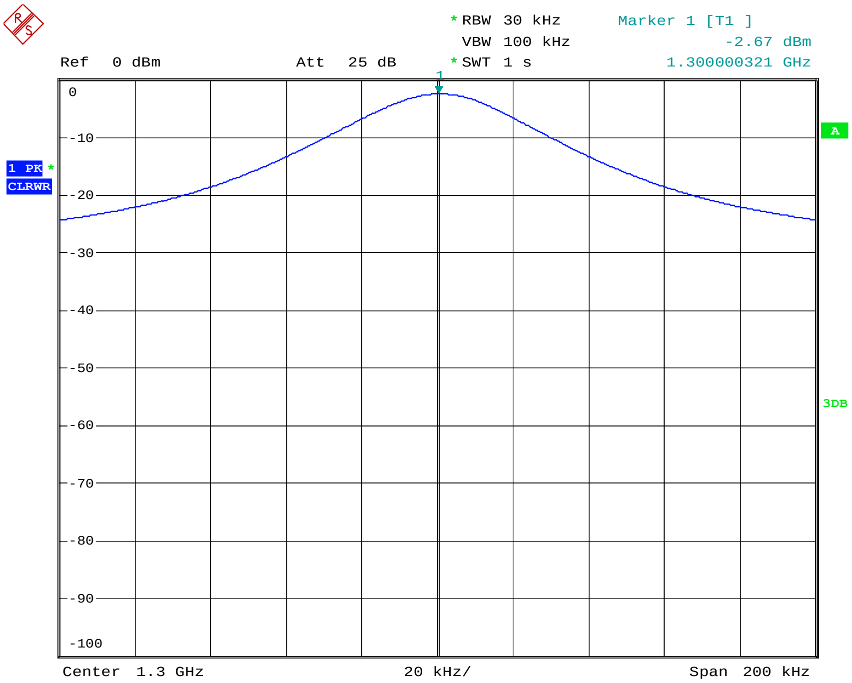
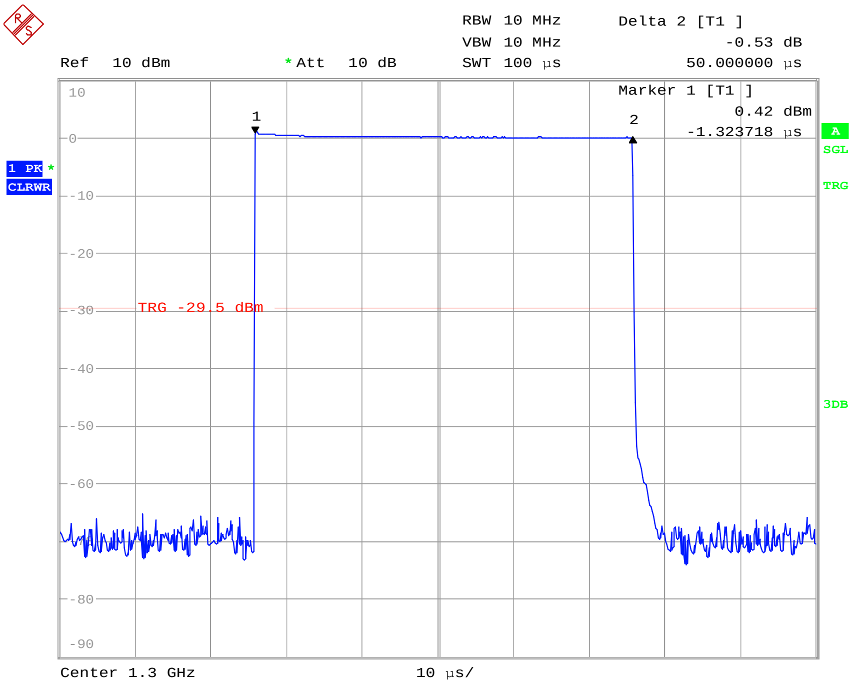


FIG 20: Spectrum measured using the FSU spectrum analyzer for RBW > 1/τ, where 1/T = 1 kHz and 1/τ = 20 kHz (here: RBW = 30 kHz. The envelope spectrum is no longer visible.

Zero-span measurements using a spectrum analyzer

Besides measurements in the frequency domain (spectra), spectrum analyzers are also capable of making measurements in the time domain using zero-span mode. In zero-span mode, a spectrum analyzer operates as a receiver with fixed frequency tuning and the set resolution bandwidth. The spectrum analyzer display is similar to an oscilloscope except that it displays the envelope of the time-domain signal



RBW 10 MHz
VBW 10 MHz
SWT 100 µs
Ref 10 dBm
*Att 10 dB
Delta 2 [T1]
-0.53 dB
50.000000 µs
Marker 1 [T1]
0.42 dBm
-1.323718 µs
TRG -29.5 dBm
Center 1.3 GHz
10 µs/

FIG 21: Zero-span measurement on a pulsed signal using the FSU spectrum analyzer. The pulse width is measured using the marker and delta marker

The dynamic range of a spectrum analyzer is far superior to that of an oscilloscope. Spectrum analyzers like the R&S FSU provide different trigger modes (video signal, IF power, external) as well as the ability to set a trigger offset in both directions in order to display the pulses in a stable manner at the desired position. Many important pulse parameters such as the rise time, fall time, pulse droop and pulse width variation which cannot be assessed in the frequency domain are very easy to measure using zero-span mode. Of course, it is critical for most of the signal power to be within the resolution bandwidth. If we want to be able to determine the pulse power in zero-span mode, the resolution filter must be capable of reaching a steady state during the pulses. The following rule of thumb applies:

Pulse width > 2/RBW

To be able to determine the rise and fall time of a pulse signal, the settling time of the analyzer must be less than that of the signal of interest. The following rule of thumb applies here:

Rise time of the pulse >> 0.7/RBW

The R&S FSU and R&S FSQ spectrum analyzers provide a bandwidth of 50 MHz which is adequate for many radar applications. The peak power can be measured very accurately for pulse widths down to about 100 ns. See FIG 22 and FIG 23.

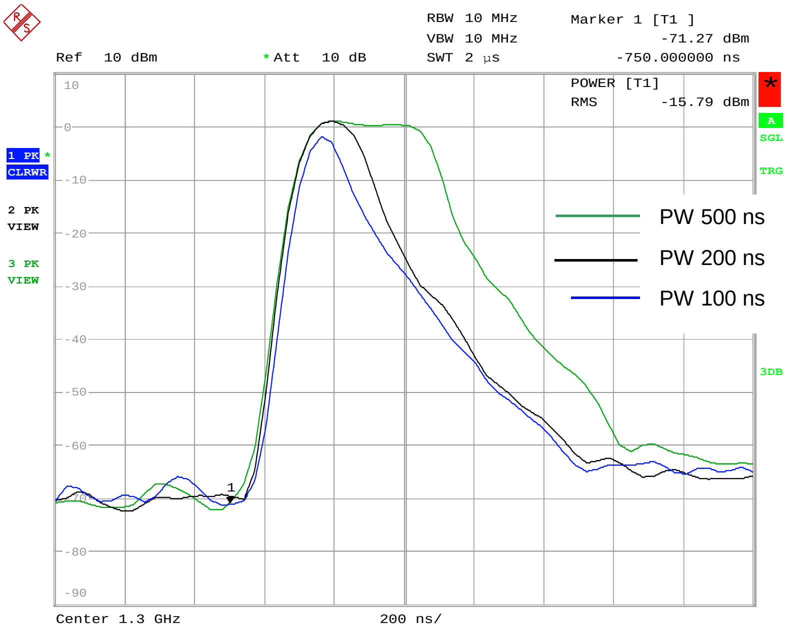


FIG 22: Zero-span measurement with RBW = 10 MHz on pulsed signals with pulse widths of 100, 200 and 500 ns. The peak power can be measured correctly for pulse widths as low as 200 ns.

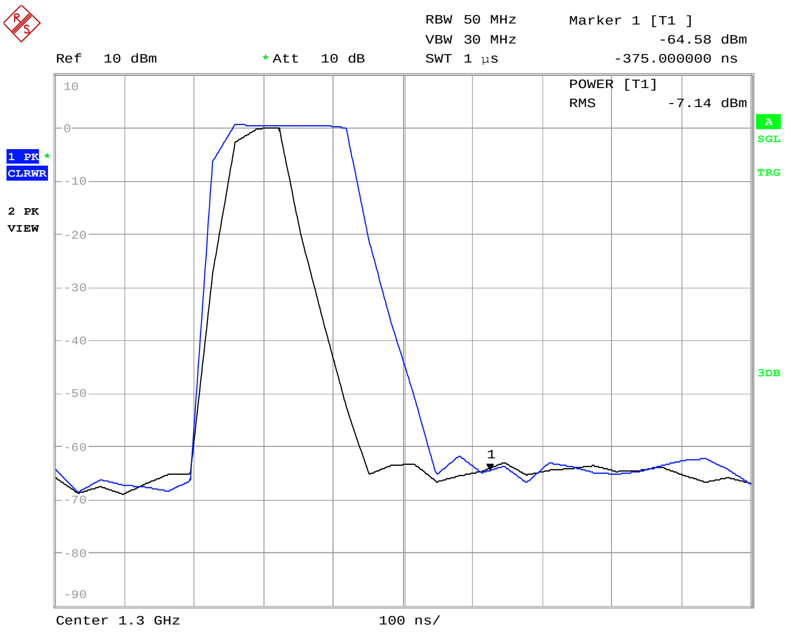


FIG 23: Zero-span measurement on a pulsed signal with RBW = 50 MHz and pulse widths of 100 and 200 ns. The peak power can be measured with little error for pulse widths as low as 100 ns.

When equipped with the R&S FSQ-K7 option and the R&S FSQ-B72 I/Q bandwidth extension, the R&S FSQ can even deliver a bandwidth of 120 MHz. This makes it possible to measure peak power even for pulse widths < 30 ns; see FIG 24.

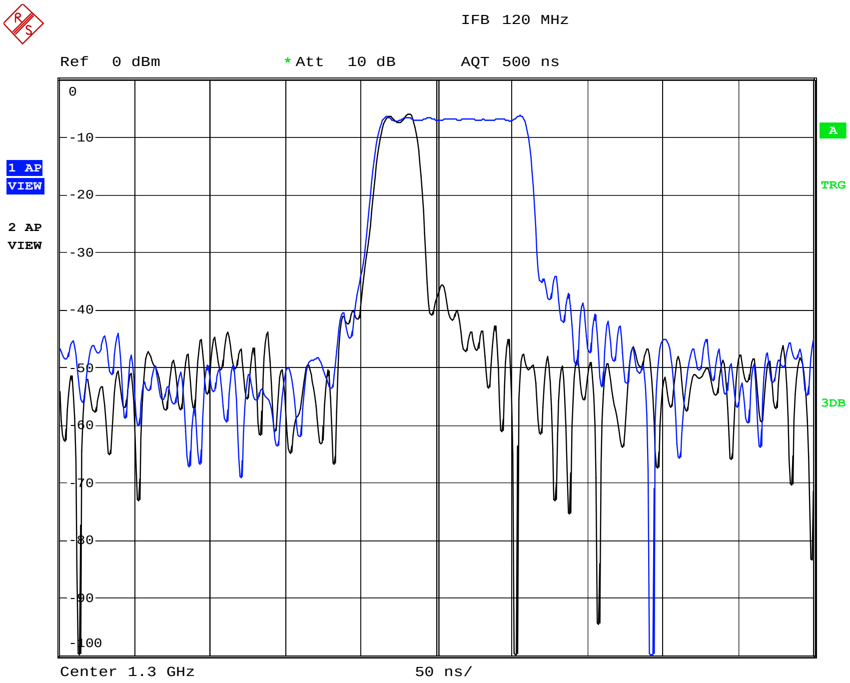


FIG 24: Zero-span measurement using the R&S FSQ and R&S FSQ-B72 and analog demodulation (result display: RF power) and demod bandwidth of 120 MHz (pulsed signal with 30 ns and 100 ns pulse width).

Time domain power

The time domain power function measures the integrated power over the selected time interval in zero-span mode. This is useful for determining the pulse power. Of course, the bandwidth occupied by the pulse spectrum must be smaller than the spectrum analyzer's resolution bandwidth (max. 50 MHz for R&S FSU/FSQ). The triggering is either video, RF power or external. The time interval to be measured is determined using the limits (*START LIMIT*, *STOP LIMIT*). These limits are activated with *LIMITS ON*. The RMS detector should be selected to ensure proper measurement of the power.

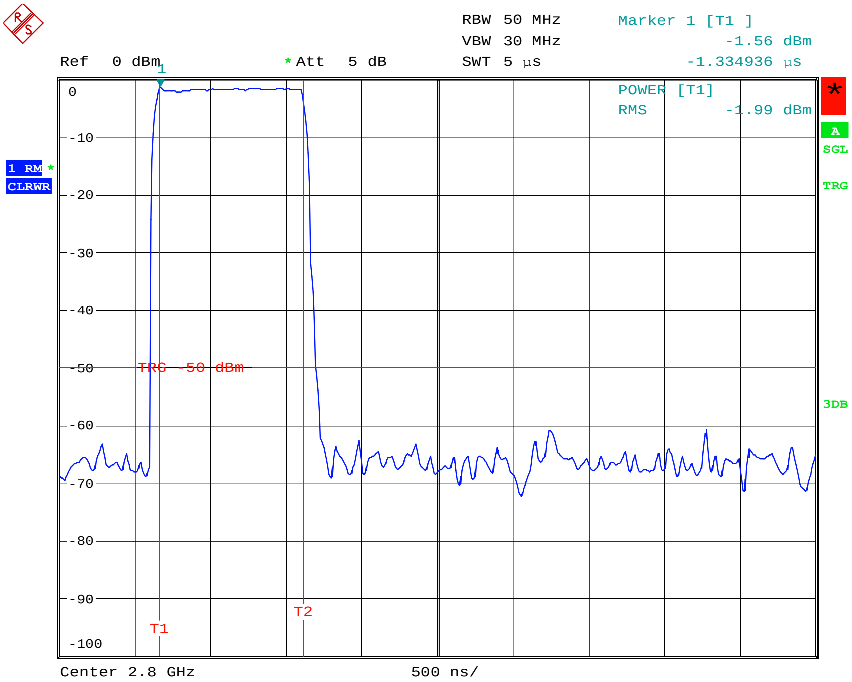


FIG 25: Time domain power measurement on a radar signal with a pulse width of 1 us. The red vertical lines T1 and T2 indicate the range within which the power is integrated vs. time. The result is displayed under Power [T1] RMS (in this case, -1.99 dBm)

Channel power

The channel power measurement function is used to measure the average power within a defined frequency band. This measurement is typically based on the integration bandwidth method, i.e. the spectrum analyzer integrates the power while sweeping the integration bandwidth. However, R&S spectrum analyzers use the RMS detector, enabling measurement of the average ("thermal") power regardless of the signal shape. The resolution bandwidth (RBW) of the analyzer should be small in comparison to the integration bandwidth (channel bandwidth) while the video bandwidth should be a multiple of the RBW (>= 3 * RBW) for proper power averaging. R&S spectrum analyzers ensure optimum settings for these parameters (RBW, VBW, detector) using the "ADJUST SETTINGS" function.

As a rule of thumb, the integration bandwidth (channel bandwidth) should be set wide enough so that spectral components lying > –23 dB below the maximum can still be detected. The error which will then result from the band limitation will typically equal < 0.1 dB. See FIG 26 (large integration bandwidth) and FIG 27 (limitation of the integration bandwidth to spectral components > –23 dB). The integration bandwidth (channel bandwidth) is indicated by the vertical red lines.

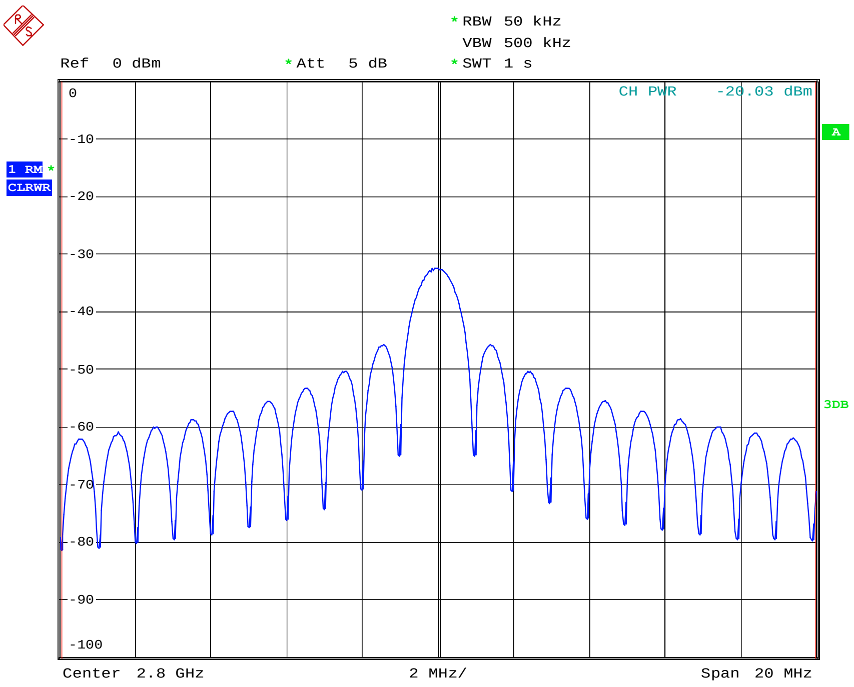


FIG 26: Channel power measurement on a pulsed signal (pulse width 100 μs, PRI 100 us, channel bandwidth 19.9 MHz)

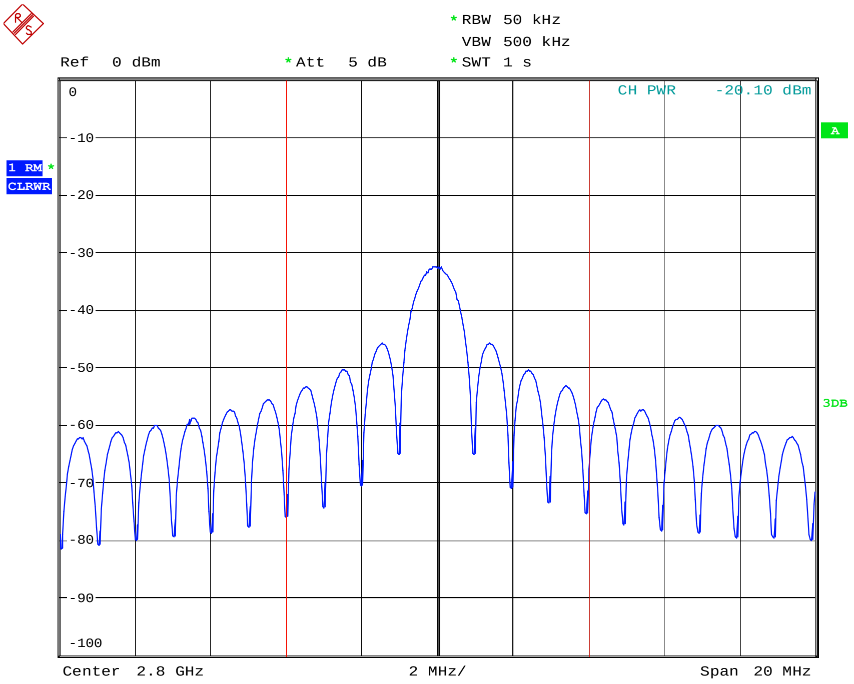


FIG 27: Same as before but with channel bandwidth of only 8 MHz (covering spectral components > –23 dB below main lobe), producing an error less than 0.1 dB compared to FIG 26

The channel power function measures the average power regardless of whether the conditions for the line spectrum or the envelope spectrum are met.

The channel power function measures the correct average power even for pulsed signals with complex modulation or a variable pulse width or pulse repetition rate. See FIG 28 for details on a measurement on an ASR radar. The ASR signal has different pulse widths and the pulses undergo nonlinear FM modulation so that the sin x/x function is no longer recognizable.

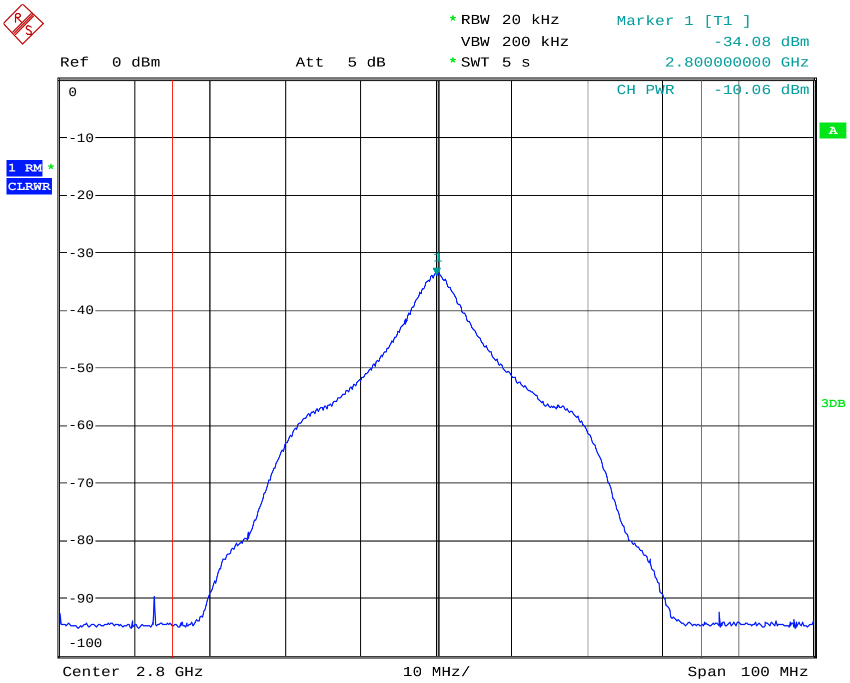


FIG 28: Channel power measurement on a complex ASR radar signal

Occupied bandwidth (OBW)

The occupied bandwidth measurement function provided by R&S spectrum analyzers automatically measures the bandwidth in which a certain percentage of the overall power is contained. In the default setting, the bandwidth is measured in which 99 % of the overall power is contained. See the measurement example shown in FIG 29.

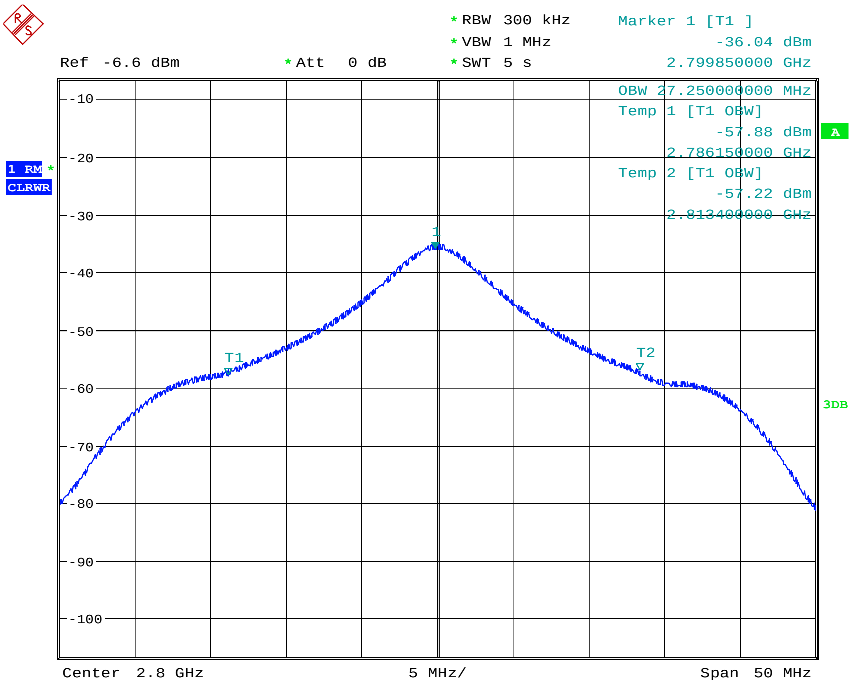


FIG 29: Occupied bandwidth measurement using the R&S FSU on an ASR radar signal: The bandwidth containing 99% of the overall power is measured and displayed as the OBW (27.25 MHz in this example).

Testing pulse compression radar systems with a spectrum analyzer and the AM/FM/PM demodulator option

The R&S FSU/FSQ can be used in conjunction with the R&S FS-K7 AM/FM/PM measurement demodulator to perform a functional check on pulse compression radar systems. Thus radar transmitters which use linear or non-linear FM techniques (see FIG 30, FIG 31) can be checked. It is also possible to analyze the phase behavior for Barker code phase modulation in PM demodulation mode (FIG 32). The demodulation bandwidth of the R&S FSU is max. 10 MHz. On the R&S FSQ, it is l to max. 28 MHz. In conjunction with the R&S FSQ-B72 I/Q bandwidth extension option, the R&S FSQ can even achieve a demodulation bandwidth of 120 MHz and thus handle frequency deviations of 60 MHz (120 MHz pk-pk).

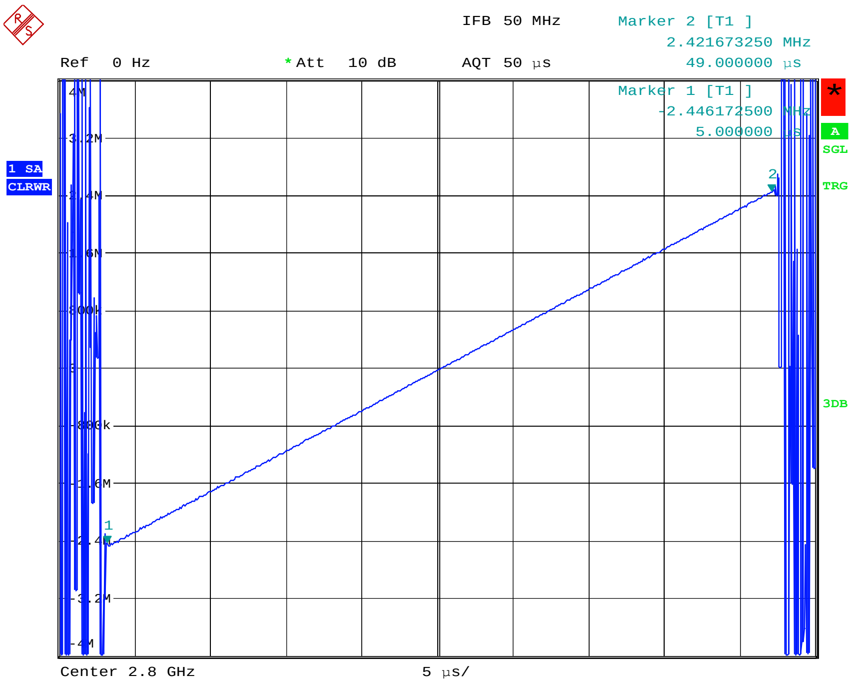


FIG 30: Test of FM linearity on a linear FM chirp radar transmitter using the R&S FSQ and the R&S FS-K7 AM/FM/PM demodulator option

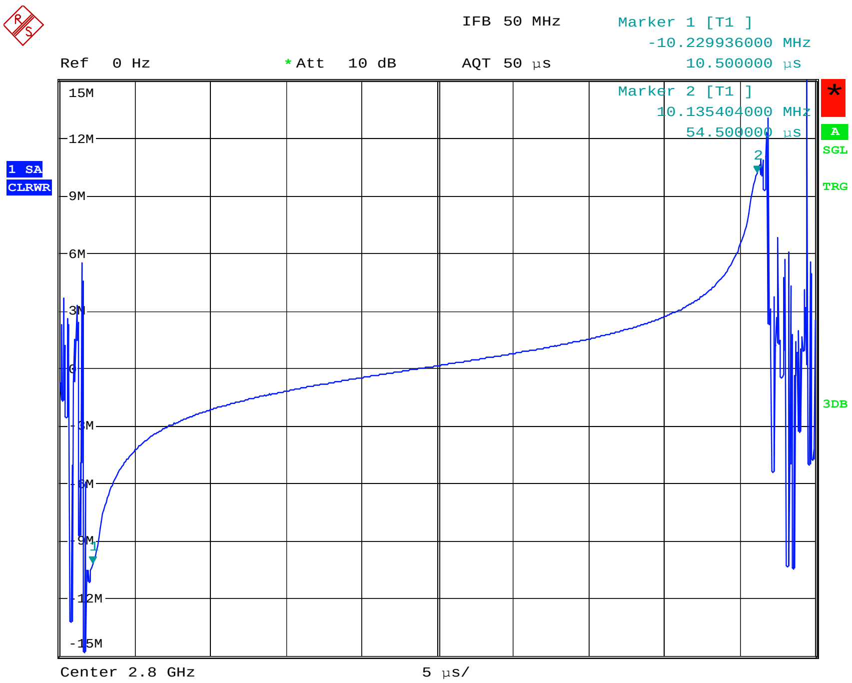


FIG 31: Characterizing a non-linear FM chirp radar transmitter using the R&S FSQ and the R&S FS-K7 AM/FM/PM demodulator option

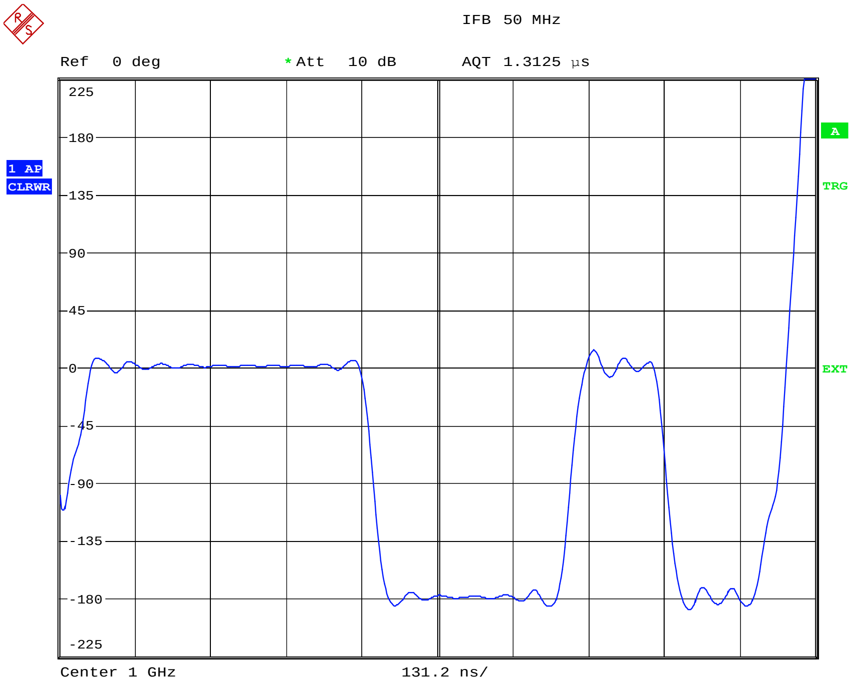


FIG 32: Demodulating a radar transmitter with 11-bit Barker code PM modulation using the analog PM demodulator of the R&S FSQ and the R&S FS-K7

Simple receiver tests

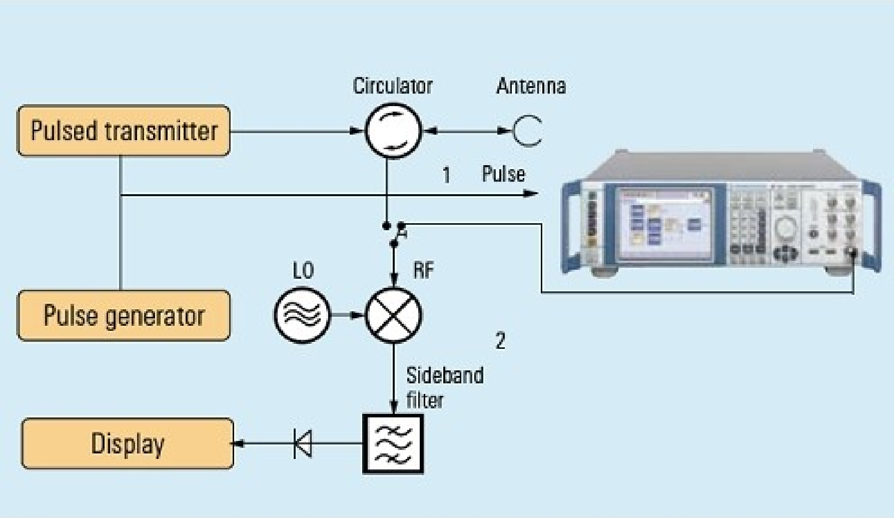


FIG 33: Calibrating a pulse radar system with a rotating antenna using the R&S SMF100A

Pulse radar with a rotating antenna

The R&S SMF100A can be used to simulate pulse radar applications with a rotating antenna. In this example (see FIG 33), the external pulse from the pulse generator is applied to the external pulse input of the R&S SMF100A and is used as a trigger for the internal pulse generator and modulator. You can delay this trigger in order to perform range and direction simulations and check them on the radar equipment's display.

Component and subassembly tests

Achieving optimum performance in an overall radar system requires analysis and optimization of the individual functional groups and components. This includes noise figure measurements on amplifiers in the radar receiver, phase noise measurements on local oscillators, substitution of components and modules to discover trouble spots in the radar system, attenuation measurements on passive components, S-parameter measurements on active components (even during pulsed operation), etc. Optimization of radar antennas requires special attention. Complicated measurements must be performed in the near field and/or far field. The reflection characteristics of targets are investigated as part of radar cross section tests.

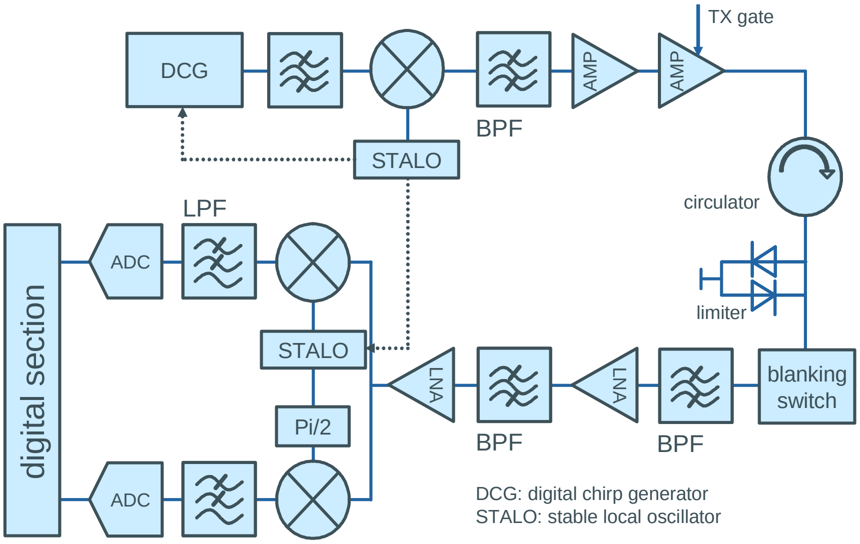


FIG 34: Typical (simplified) schematic diagram for a radar system

Noise figure

The input noise of the radar receiver has a major influence on the performance of the radar system. The input noise is determined primarily by the noise in the input amplifier (low noise amplifier, LNA). The input noise is quantified by determining the noise figure which is defined as follows:

$$NF_{dB} = 10 * \log \frac{Signal\,/\,Noise_{Input}}{Signal\,/\,Noise_{output}} \qquad \text{Formula1}$$

Besides low input noise, a radar receiver or an LNA must meet further requirements which can be contradictory to some extent, e.g.:

- Phase stability
- Amplitude stability
- Wide dynamic range
- Fast recovery from overdrive conditions and jamming
- Overloading protection

Nevertheless, a low noise figure still represents an important optimization factor within the context of the limitations listed above.

Rohde&Schwarz spectrum analyzers in the R&S FSP, R&S FSU and R&S FSQ series are ideal for making automatic measurements of the noise figure and gain due to their high sensitivity and power level accuracy in conjunction with the switchable calibrated noise sources. The R&S FS-K30 application firmware provides features for these high-performance analyzers which are otherwise available only in conjunction with special noise measuring setups. The following parameters can be measured with excellent precision at a defined frequency or across a selectable frequency range:

- Noise figure in dB
- Noise temperature in K
- Gain in dB

Besides LNAs, frequency converters can also be tested. The measurement results can be displayed in either graphical or tabular format.

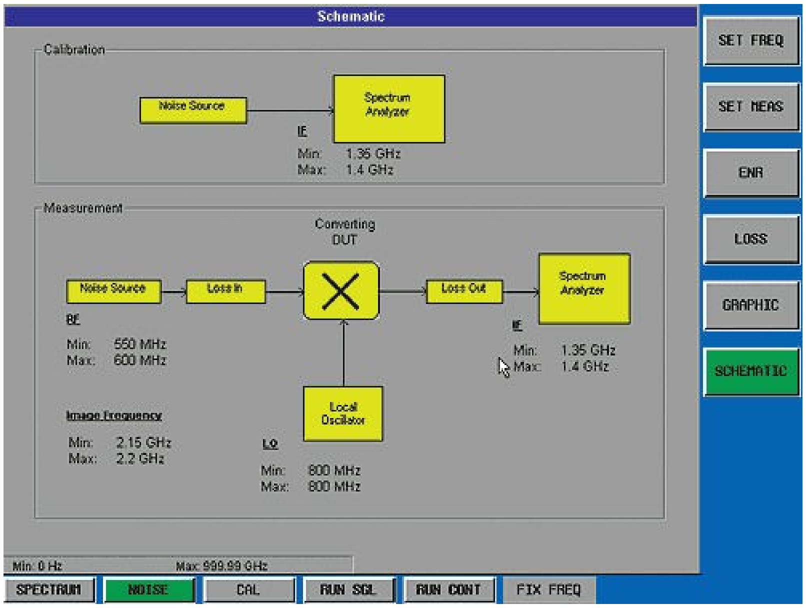


FIG 35: Schematic representation of a frequency-converting DUT with the R&S FS-K30 application firmware

Direct — NOISE & GAIN — CALIBRATED

RBW:	1 MHz	RF Atten.	0 dB	2nd Stage Corr.	On
Average:	1	Auto Ref Level	On	Image Rejection	...

Current Value

RF:	135 MHz	ENR	15.34 dB	NF.	1.29 dB
LO:	...	Loss In	0 dB	Noise Temp.	100.62 K
IF:	...	Loss Out	0 dB	Gain	10.4 dB

Frequency List Results

RF	NF	Noise Temp	Gain
135.00 MHz	1.29 dB	100.62 K	10.40 dB
135.50 MHz	1.30 dB	101.21 K	11.05 dB
136.00 MHz	1.25 dB	96.99 K	11.71 dB
136.50 MHz	1.13 dB	86.00 K	12.42 dB
137.00 MHz	1.07 dB	80.95 K	13.09 dB
137.50 MHz	0.99 dB	74.55 K	13.78 dB
138.00 MHz	0.90 dB	67.10 K	14.49 dB
138.50 MHz	0.87 dB	63.95 K	15.13 dB
139.00 MHz	0.80 dB	58.67 K	15.81 dB
139.50 MHz	0.70 dB	51.01 K	16.45 dB
140.00 MHz	0.70 dB	50.61 K	17.04 dB
140.50 MHz	0.64 dB	46.10 K	17.59 dB
141.00 MHz	0.60 dB	42.77 K	18.07 dB
141.50 MHz	0.54 dB	38.61 K	18.48 dB
142.00 MHz	0.50 dB	35.49 K	18.79 dB

Measurement Complete

FIG 36: Tabular representation of measurements results with the R&S FS-K30 application firmware

Substitution of radar components with a signal generator

During development of radar systems, signal generators can be very useful for detecting trouble spots in the system. A few applications are described in the following section. For example, we can replace the stable local oscillator (STALO) with a signal generator with extremely low phase noise such as the R&S SMB100A (or even better, the R&S SMA100A) in order to check to what extent the STALO has a negative influence on the system performance due to its (possibly higher) phase noise (FIG 37).

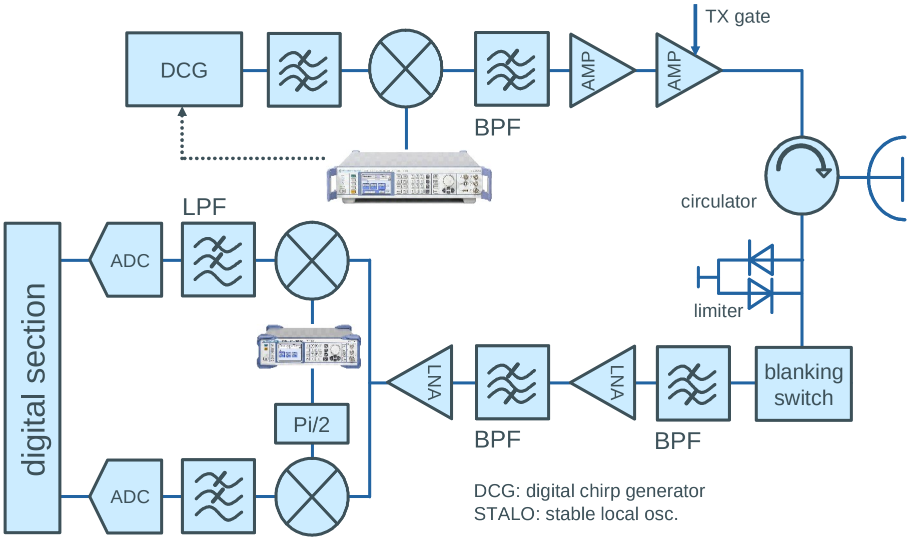


FIG 37: STALO substitution with the R&S SMA100A or R&S SMB100A

The entire transmitter unit in a radar system (except for the power amplifier) can be replaced with the R&S SMU200A vector signal generator which allows complex modulation in order to determine whether there are any problems in the signal processing (FIG 38).

With pulse radar systems (without pulse compression) or when using linear FM chirp modulation with frequency deviations up to a maximum of 40 MHz, the R&S SMF microwave generator is suitable for use up to the highest RF frequencies (–43.5 GHz).

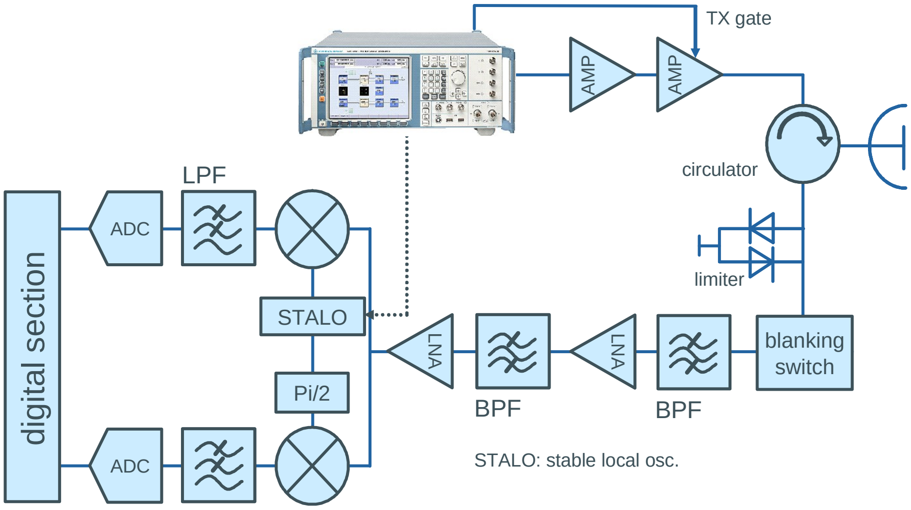


FIG 38: Exciter substitution with the R&S SMU200A with its complex modulation capability up to 6 GHz

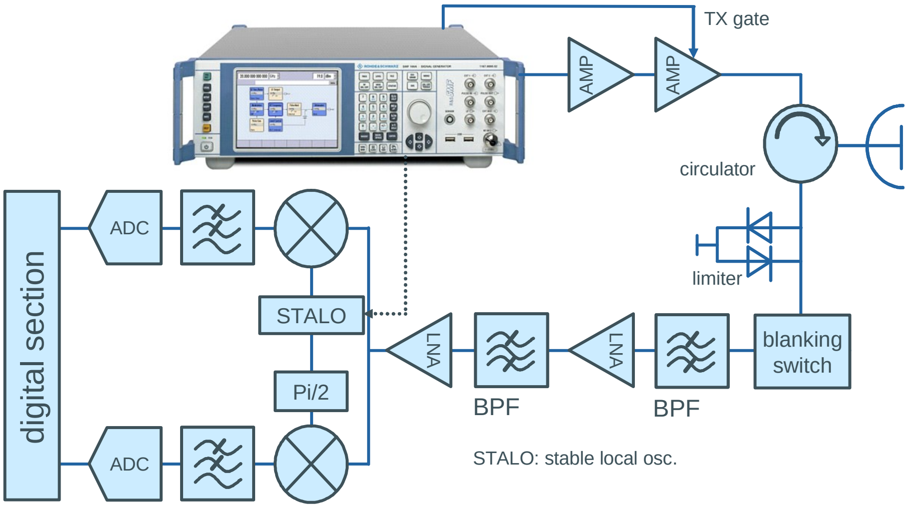
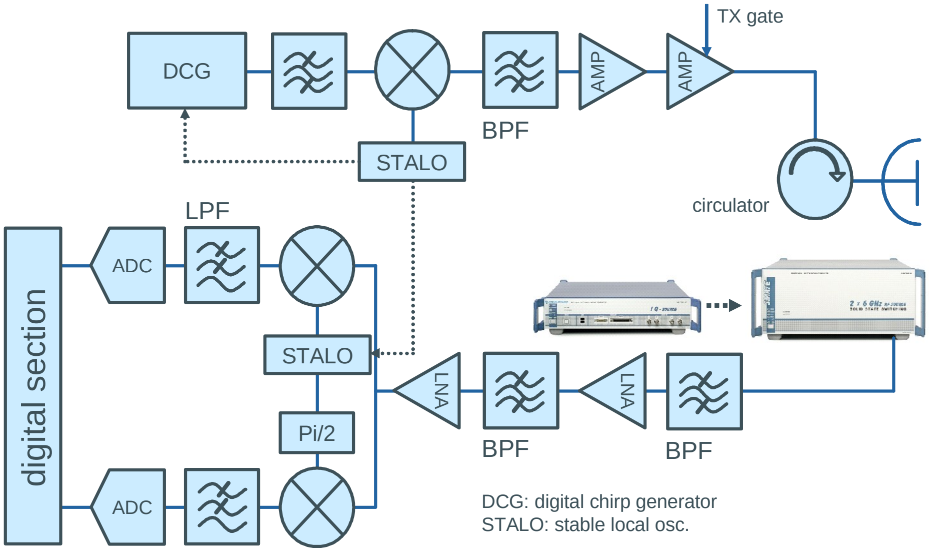


FIG 39: Exciter substitution with the R&S SMF100A up to 43.5 GHz

The receiver unit in a radar system can be tested separately based on complex receiving scenarios. Useful instruments here include the R&S

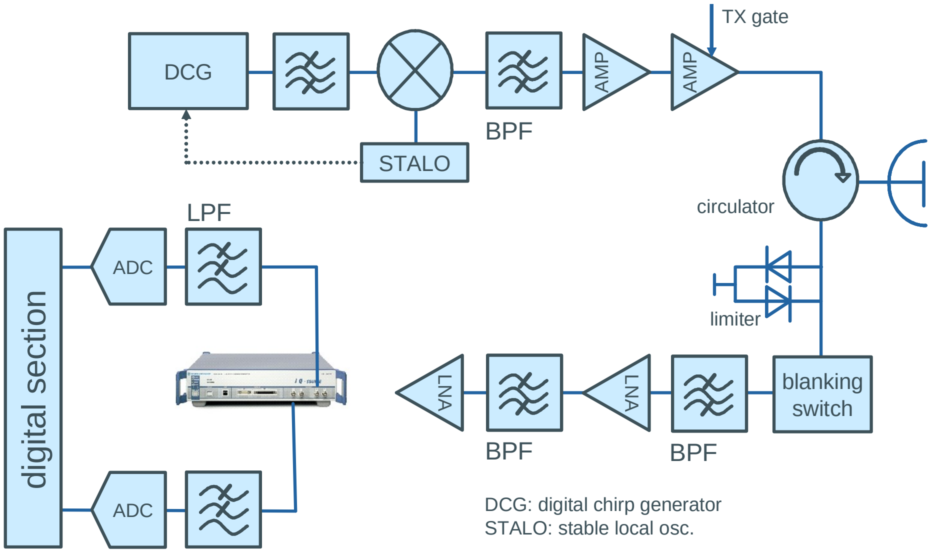
AFQ100A I/Q modulation generator in conjunction with the R&S SMU200A or R&S SMJ100A vector signal generator, allowing generation of very broadband signals (up to 200 MHz RF bandwidth) as well as very long signal sequences (up to 1 Gsample of memory) (FIG 40).



DCG: digital chirp generator
STALO: stable local osc.

FIG 40: Receiver testing using complex waveforms

Using the R&S AFQ100A, the baseband receiver unit can be tested separately from the rest of the radar system using broadband and very long sequences (real-world signals).



DCG: digital chirp generator
STALO: stable local osc.

FIG 41: Testing with long real-world signals using the R&S AFQ100A

Generation and loading of complex radar signals

There are different ways of loading data into the ARB memory of an R&S vector signal generator or R&S I/Q modulation generator as shown in FIG 42:

1. The R&S K6 pulse sequencer software simplifies generation of pulsed signals with complex modulation and also handles the transfer of the signals to the R&S generators (see FIG 43).
2. The ARB toolbox (AN 1GP62) converts existing I/Q signals into the R&S waveform format and transfers them to the R&S generators.
3. The R&S Matlab transfer toolbox (AN 1GP60) loads IQ signals generated using MATLAB® directly into an R&S signal generator via GPIB or a TCP/IP connection.

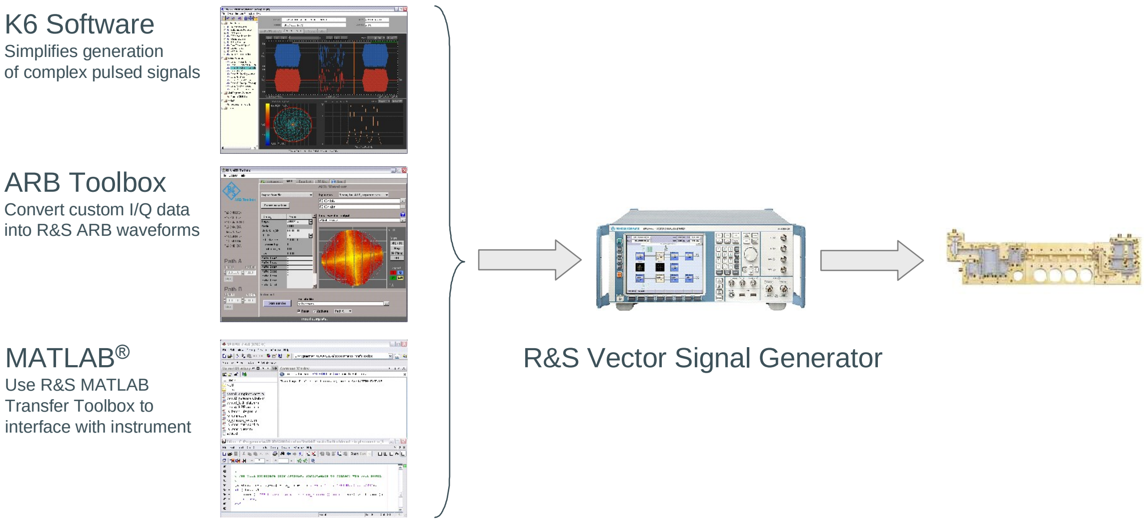
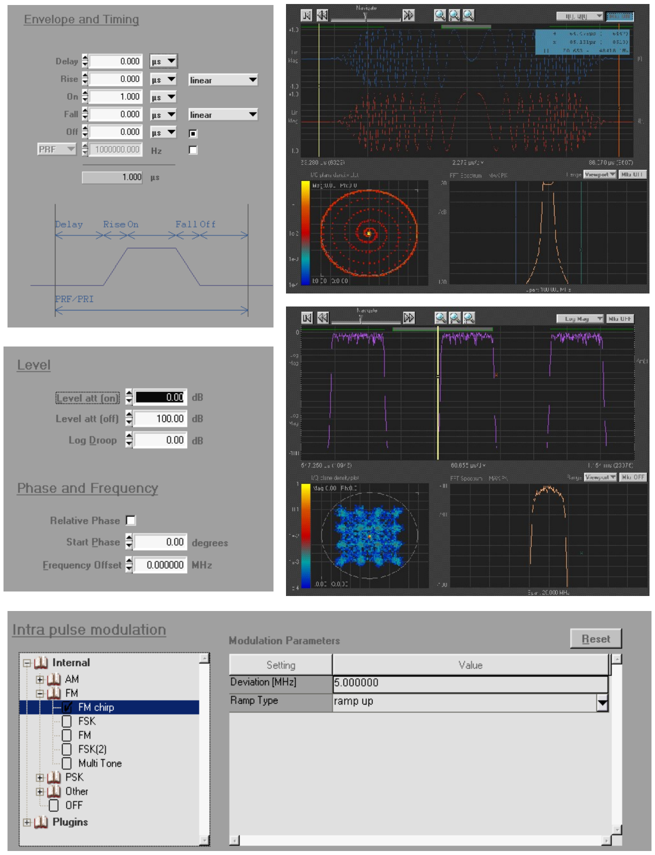


FIG 42:Various ways of loading data into the arbitrary waveform generator



Envelope and Timing

Delay	0.000	µs	
Rise	0.000	µs	linear
On	1.000	µs	
Fall	0.000	µs	linear
Off	0.000	µs	☒
PRF	1000000.000	Hz	☐
	1.000	µs	

Level

Level att (on) 0.00 dB

Level att (off) 100.00 dB

Log Droop 0.00 dB

Phase and Frequency

Relative Phase ☐

Start Phase 0.00 degrees

Frequency Offset 0.000000 MHz

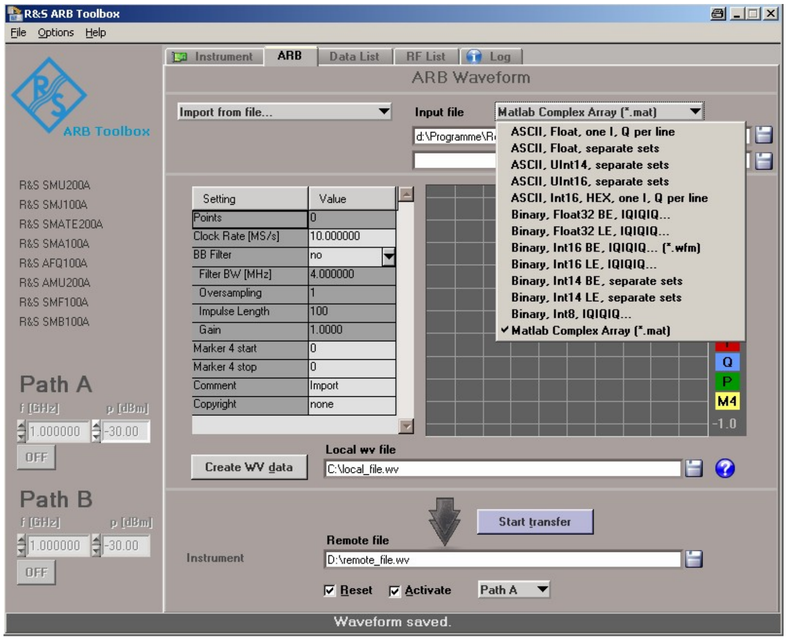
Intra pulse modulation

- Internal
  - AM
  - FM
    - ☑ FM chirp
    - ☐ FSK
    - ☐ FM
    - ☐ FSK(2)
    - ☐ Multi Tone
  - PSK
  - Other
  - ☐ OFF
- Plugins

Modulation Parameters

Setting	Value
Deviation [MHz]	5.000000
Ramp Type	ramp up

FIG 43: The R&S Pulse Sequencer’s user interface and some possible settings



ARB Waveform

Import from file...

Input file: Matlab Complex Array (*.mat)

d:\Programme\R

- ASCII, Float, one I, Q per line
- ASCII, Float, separate sets
- ASCII, UInt14, separate sets
- ASCII, UInt16, separate sets
- ASCII, Int16, HEX, one I, Q per line
- Binary, Float32 BE, IQIQIQ...
- Binary, Float32 LE, IQIQIQ...
- Binary, Int16 BE, IQIQIQ... (*.wfm)
- Binary, Int16 LE, IQIQIQ...
- Binary, Int14 BE, separate sets
- Binary, Int14 LE, separate sets
- Binary, Int8, IQIQIQ...
- ✓ Matlab Complex Array (*.mat)

Setting	Value
Points	0
Clock Rate [MS/s]	10.000000
BB Filter	no
Filter BW [MHz]	4.000000
Oversampling	1
Impulse Length	100
Gain	1.0000
Marker 4 start	0
Marker 4 stop	0
Comment	Import
Copyright	none

Path A

f [GHz] 1.000000 p [dBm] -30.00

OFF

Path B

f [GHz] 1.000000 p [dBm] -30.00

OFF

Local wv file: C:\local_file.wv

Instrument

Remote file: D:\remote_file.wv

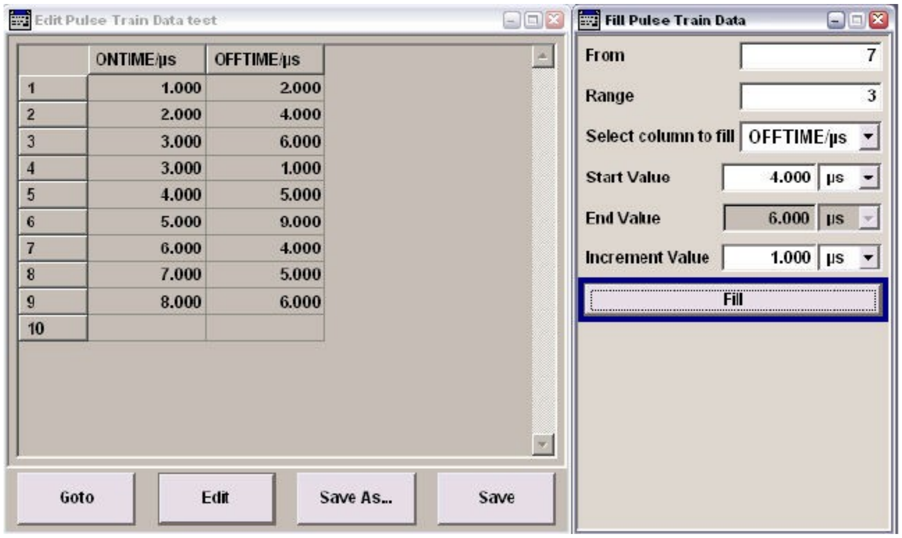
☑ Reset ☑ Activate Path A

Waveform saved.

FIG 44: User interface of the R&S ARB Toolbox Software for transferring I/Q data to R&S signal generators

The R&S SMF-K27 pulse train option for the R&S SMF100A microwave signal generator (or the R&S SMA-K27 for the R&S SMA100A signal generator)

The R&S SMF100A microwave signal generator can be equipped with the R&S SMF-K27 pulse train option to generate pulse sequences containing jitter or even staggered pulses (pulses with variable pulse pause lengths). This makes the R&S SMF100A ideal for making measurements on radar receivers or for simulating pulse radar signals (without pulse compression). Pulse trains are created with an easy-to-use editor. Lengths of up to 1023 individual pulses are possible.



	ONTIME/µs	OFFTIME/µs
1	1.000	2.000
2	2.000	4.000
3	3.000	6.000
4	3.000	1.000
5	4.000	5.000
6	5.000	9.000
7	6.000	4.000
8	7.000	5.000
9	8.000	6.000
10		

From 7

Range 3

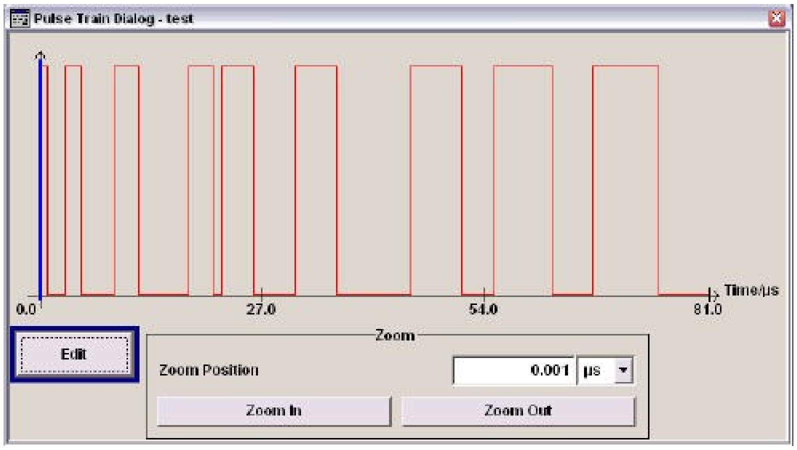
Select column to fill OFFTIME/µs

Start Value 4.000 µs

End Value 6.000 µs

Increment Value 1.000 µs

FIG 45: User interface for the R&S SMF100A with the R&S SMF-K27 pulse train option for editing pulse trains



Zoom Position 0.001 µs

FIG 46: Graphical presentation of the edited pulse train on the R&S SMF100A with the R&S SMF-K27 pulse train option

Measurement of phase noise in local oscillators (STALOs and COHOs)

Making precision Doppler speed measurements requires investigation of the phase noise of the involved coherent oscillators (COHO) and stable local oscillators (STALO). In Doppler radar systems, excessive phase noise in the RF source and all of the other oscillators that are used in the radar system can mask targets at low speeds. In FMCW radar systems, targets in close proximity to the radar system can be masked.

The test instrument that is used for this measurement must meet very demanding requirements for the phase noise. The spectrum analyzers in the R&S FSU/R&S FSQ family from Rohde&Schwarz are well suited to such tests.

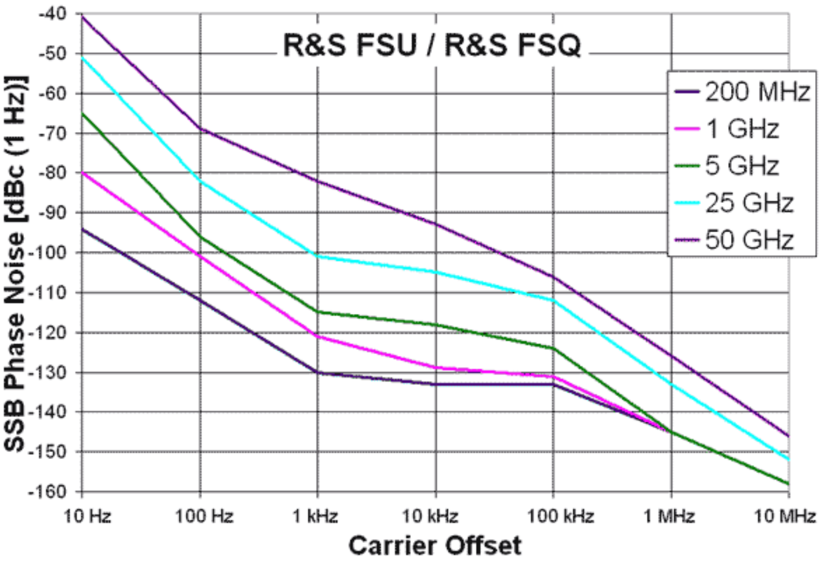
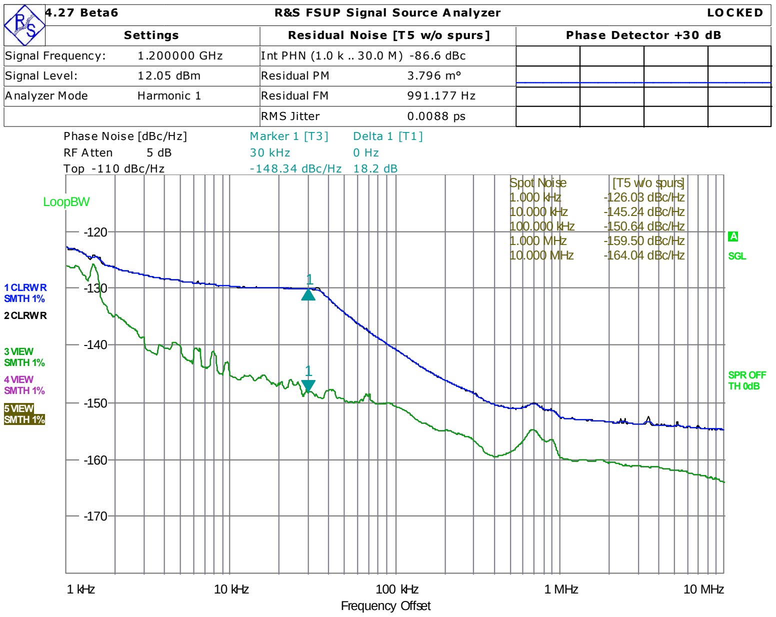


FIG 47: Typical intrinsic phase noise produced by the spectrum analyzers in the R&S FSU/R&S FSQ families

The R&S FSUP signal source analyzer provides an extremely wide measurement dynamic range along with very flexible test capabilities. When equipped with the optional R&S FSUP-B60, the R&S FSUP signal source analyzer has two parallel receiving paths. Due to the symmetrical structure that exists, crosscorrelation between the two paths is possible, allowing elimination of the uncorrelated intrinsic noise of the two reference sources. This method can be used from 10 MHz to 8 GHz. The sensitivity is thus increased significantly and is no longer limited by the phase noise of the internal references. An improvement of up to 20 dB is possible depending on the number of averaging steps.



4.27 Beta6 **R&S FSUP Signal Source Analyzer** **LOCKED**

Settings		Residual Noise [T5 w/o spurs]		Phase Detector +30 dB
Signal Frequency:	1.200000 GHz	Int PHN (1.0 k .. 30.0 M)	-86.6 dBc	
Signal Level:	12.05 dBm	Residual PM	3.796 m°	
Analyzer Mode	Harmonic 1	Residual FM	991.177 Hz	
		RMS Jitter	0.0088 ps	

Phase Noise [dBc/Hz]	Marker 1 [T3]	Delta 1 [T1]
RF Atten 5 dB	30 kHz	0 Hz
Top -110 dBc/Hz	-148.34 dBc/Hz	18.2 dB

Spot Noise	[T5 w/o spurs]
1.000 kHz	-126.03 dBc/Hz
10.000 kHz	-145.24 dBc/Hz
100.000 kHz	-150.64 dBc/Hz
1.000 MHz	-159.50 dBc/Hz
10.000 MHz	-164.04 dBc/Hz

Figure 48: Intrinsic phase noise of the FSUP in the L band with correlation using the optional R&S FSUP-B60 (green curve) and uncorrelated (blue curve)

The R&S FSUP signal source analyzer offers the following comprehensive test capabilities for use in investigating COHO/STALO:

- Phase noise measurement using the phase detector method with internal and external reference
- Direct phase noise measurement with the spectrum analyzer
- Measurement of characteristic COHO/STALO oscillator parameters
- Tuning characteristic with constant and variable supply voltage
    - Tuning sensitivity
    - Output power vs. frequency and supply voltage
    - Spurious frequencies and harmonics
    - Transient response when changing frequencies

Power loss tests with power meters

One simple way of measuring insertion loss involves using two power test probes to determine the difference in power between the input and output of a two-port network under test, e.g. an antenna feed line for a radar antenna. This measurement is less accurate than the result that can be obtained using a vector network analyzer. However, the benefit is that the measurement can be performed with the real operating power since it is possible while the radar system is operational.

Amplifier testing: S-parameters under pulse conditions

Components such as amplifiers are typically characterized in terms of their gain, frequency response, matching and phase responseby S-parameter measurements. S-parameter measurements are generally performed with a vector network analyzer using CW signals. However, this technique can be inadequate (or totally impractical) with pulse radar components such as radar transmitter amplifiers. The amplifier might behave differently in CW mode compared to pulse mode or might even be subject to thermal overloading.

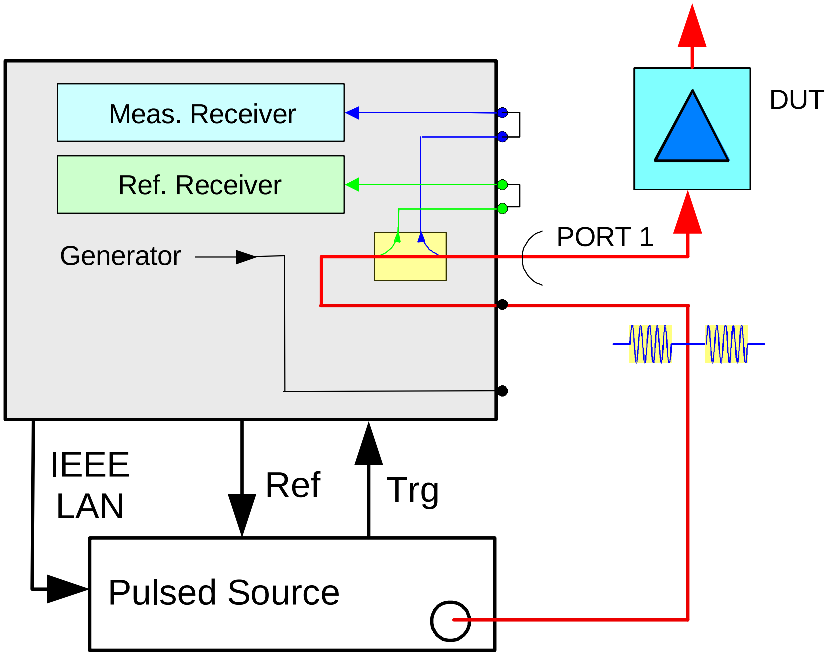


FIG 49: Schematic diagram using a signal generator (e.g. the R&S SMF100A) as a pulse source with a vector network analyzer (e.g. the R&S ZVA)

FIG 49 shows a schematic diagram with a pulsed signal source such as the R&S SMF100A connected to a R&S ZVA vector network analyzer. FIG 50 shows a detailed block diagram as an example of a test setup for pulsed S-parameter measurement on an L band radar power amplifier. External couplers are used due to the need for high drive power (approx. 1 W) and much higher output power (100 W). The decoupled signals are fed to the corresponding R&S ZVA receiver inputs for measurement of S11 and S21.

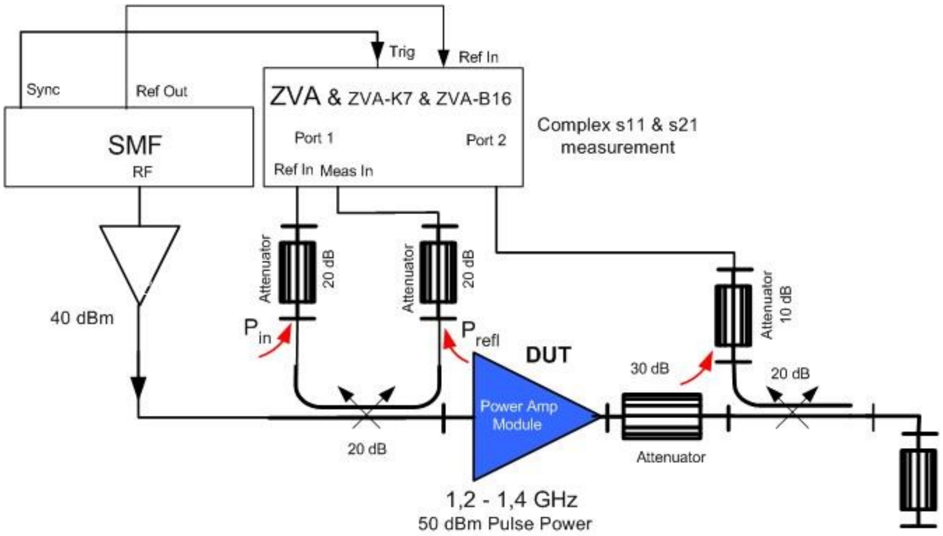


FIG 50: Test setup for characterizing an L band radar pulsed power transistor with the R&S ZVA

Point-in-pulse measurement

In point-in-pulse mode, the ZVA makes measurements either at one frequency point per pulse vs. frequency or at one power level per pulse vs. power level. The ZVA trigger is set to Point and a suitable trigger delay is selected.

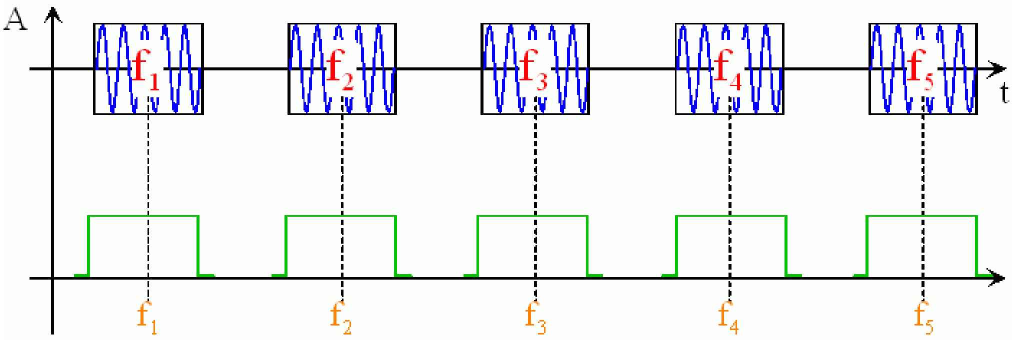


FIG 51: Point-in-pulse mode on the R&S ZVA. In point trigger mode, the R&S ZVA measures at one measurement point per pulse repetition frequency.

FIG 52 shows a pulsed S21 measurement made in this manner vs. frequency on an L band radar power amplifier.

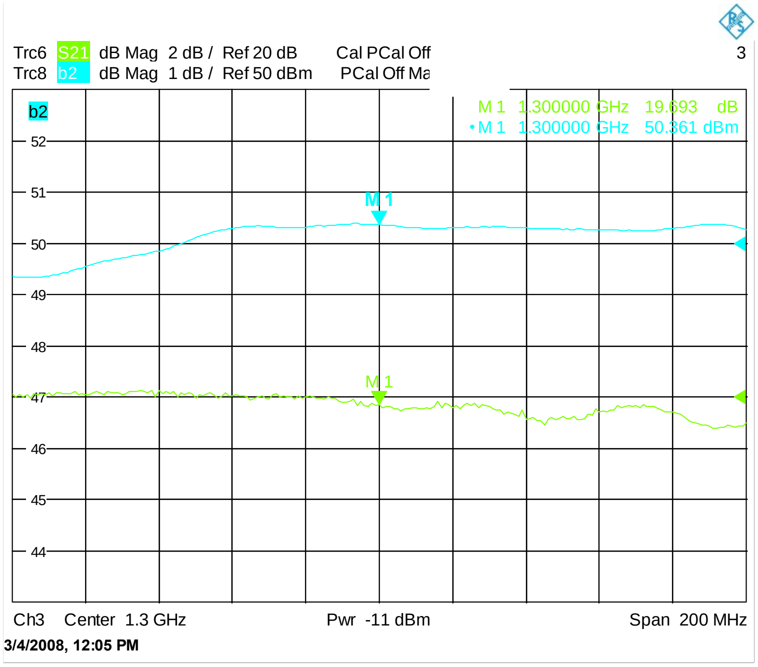


FIG 52: Pulsed s21 and output power measurement vs. frequency on an L band radar power transistor using the point-in-pulse mode provided by the R&S ZVA vector network analyzer

Pulse-profile measurements

In pulse-profile mode, the R&S ZVA measures S-parameters vs. time. With its 30 MHz maximum measurement bandwidth and 80 MHz sampling rate, it is possible to determine the exact timing behavior of the S-parameters even when dealing with the very short pulses that are commonly encountered in radar technology. In pulse-profile mode, the R&S ZVA writes the raw data into its own RAM. Further signal processing such as filtering is then handled by the instrument software.

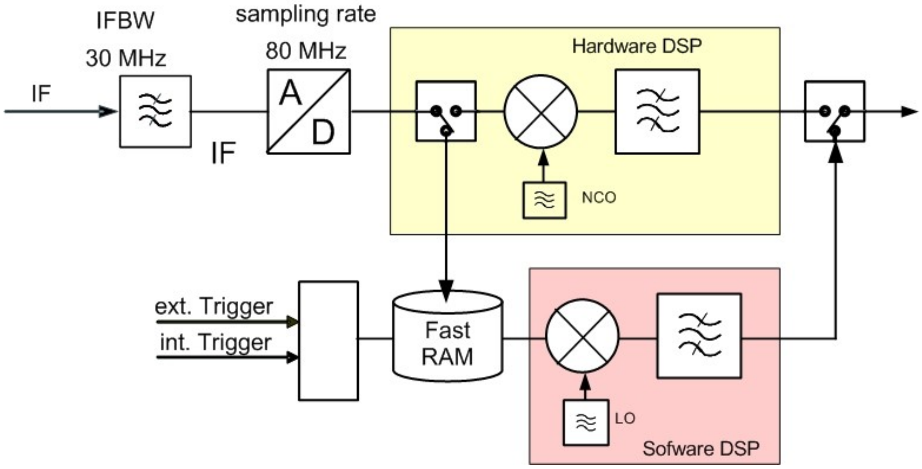


FIG 53: Fast data recording using the R&S ZVA's high-performance pulse profile technology

FIG 54 illustrates an S-parameter measurement made in this manner vs. pulse duration on an L-band radar power transistor.

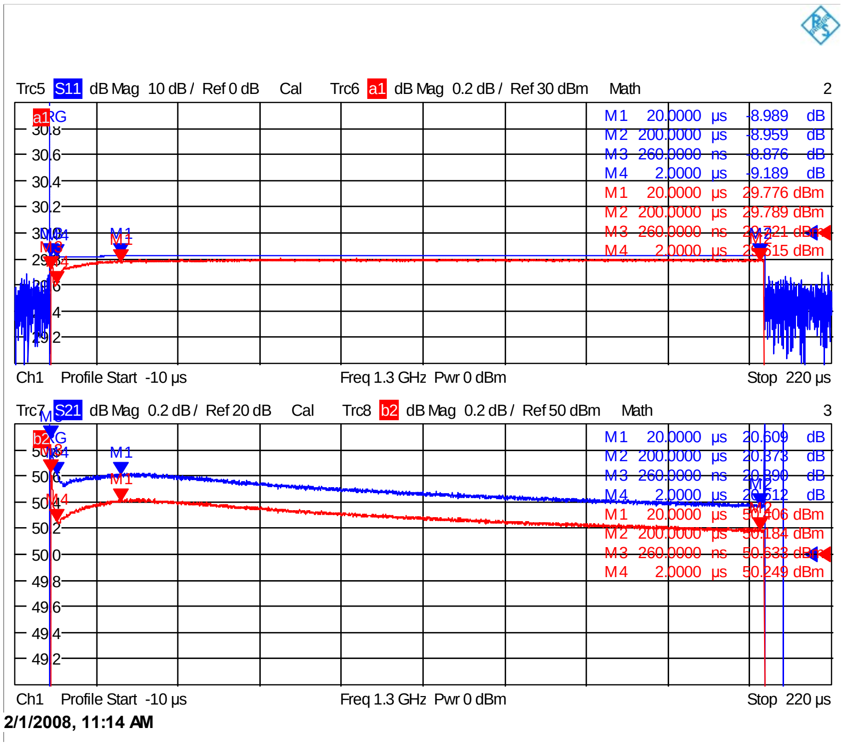


FIG 54: Pulsed s11, a1(input power), b2(output power) and s21 measurement vs. time on a L-band radar power transistor using the pulse-profile mode provided by the R&S ZVA vector network analyzer

Antenna testing (near field, far field)

Antenna performance is critical in any radar system. The antenna gain directly influences the range of the radar system. Other important parameters include the antenna polarization as well as the matching of the transmit and receive antennas, the beamwidth, the boresight angle (offset of the measured radiation direction from the ideal radiation direction), the sidelobe suppression, the front-to back-ratio, the antenna matching and the frequency response.

Antenna measurements can be made in the near field as well as the far field with various advantages and disadvantages.

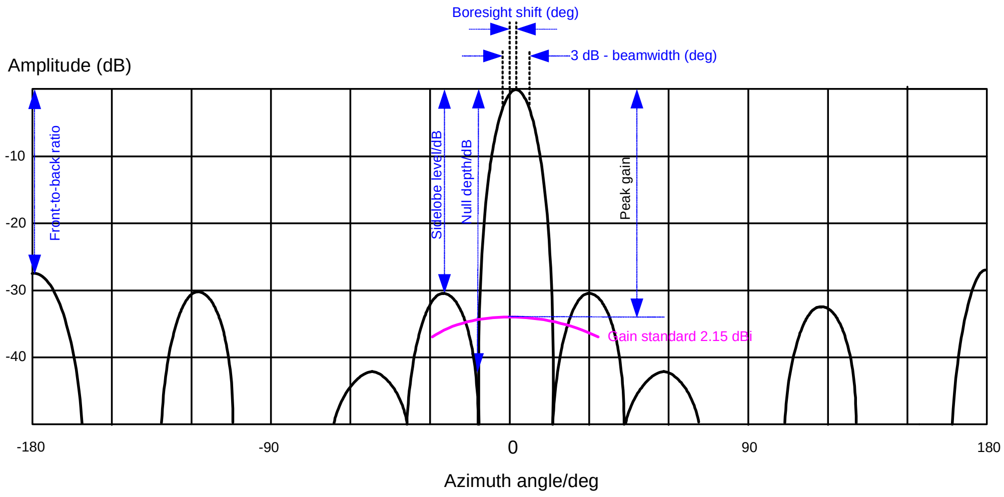


FIG 55: Example of a Cartesian antenna scan diagram for a high-gain antenna vs. azimuth angle (used to determine important antenna characteristics)

Far-field measurements are simpler and faster, but they require a large area. Near-field measurements involve lengthy computations and are more time-consuming due to the many measurement points that are required. However, the space requirements are significantly lower.

FIG 56 shows a typical basic test setup for a near-field measurement using the R&S ZVA. This setup handles test frequencies up to about 2 GHz.

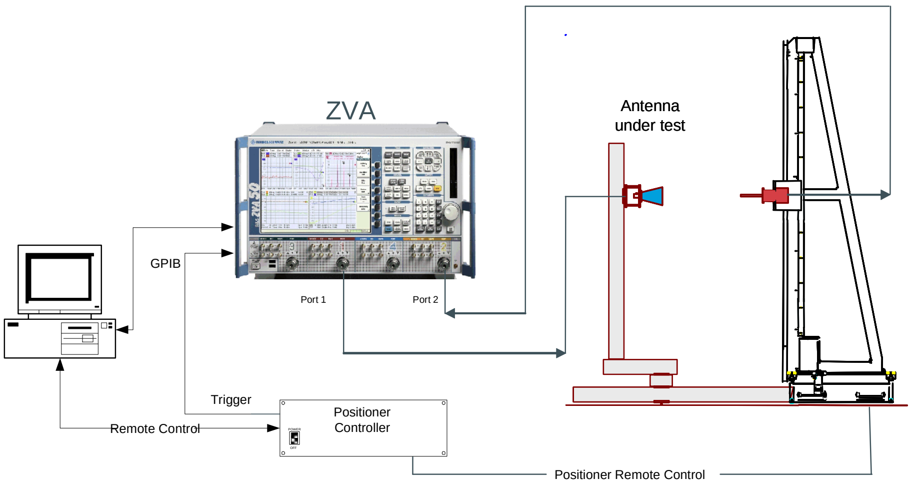


FIG 56: Basic test setup (near field) for an antenna measurement using a vector network analyzer

For a near-field test setup at microwave frequencies, the attenuation due to the cable length may be unacceptable. Accordingly, a test setup with mixers at both the antenna under test (AUT) and the probe for downconversion to an intermediate frequency (IF) is necessary. One of the R&S ZVA channels provides the LO signal. An amplifier might be necessary to provide sufficient LO level at the probe antenna. FIG 57 shows a simplified schematic diagram for a near-field test setup usable in the microwave frequency range.

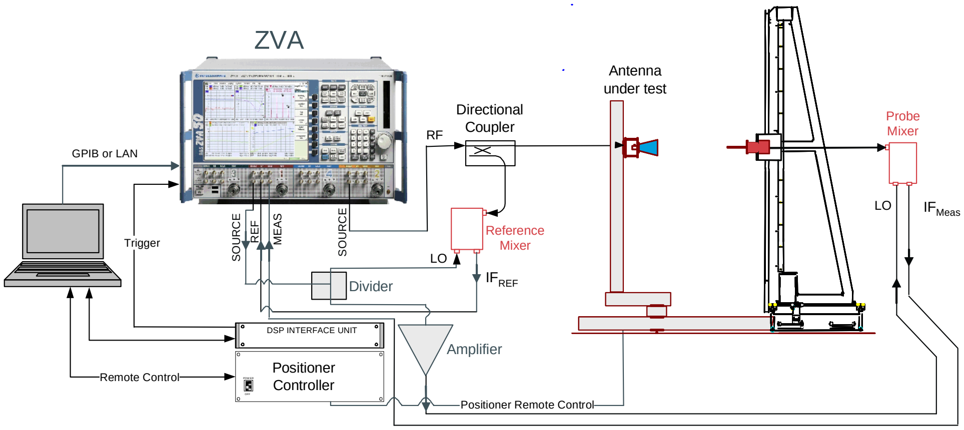


FIG 57: Simplified test setup for near-field antenna measurements in the microwave range

A far-field test setup involves greater distances with even longer cable lengths, necessitating an even more complicated test setup in some cases. As before, external mixers and conversion to a lower IF are used. Two microwave signal generators situated close to the antennas ensure low signal loss for the AUT and for the LO distribution to the probe mixer. A power amplifier with high gain ensures sufficient LO level at the reference mixer (see FIG 58).

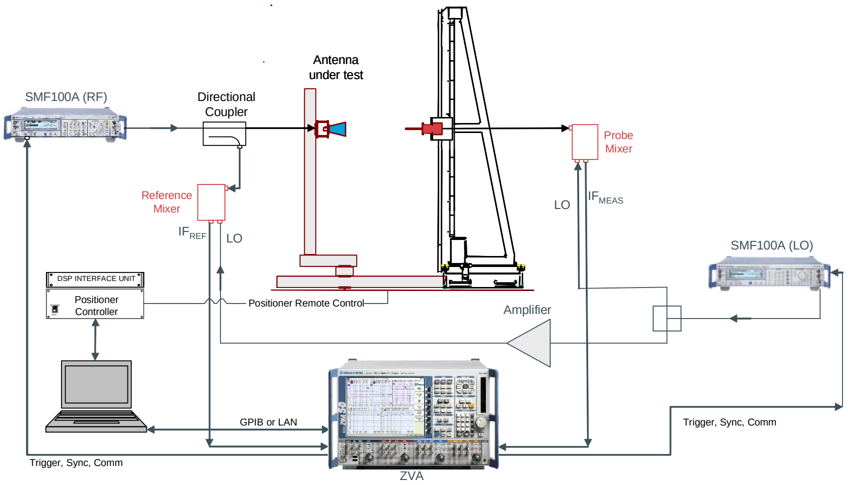


FIG 58: Schematic diagram of a far-field test setup

Radar cross section tests

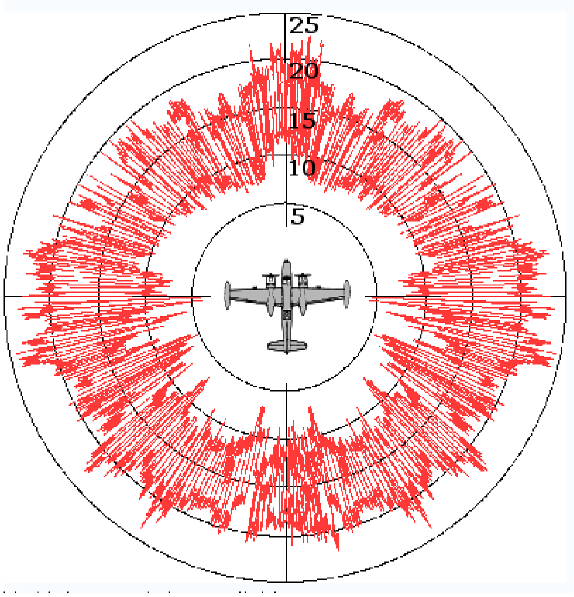


FIG 59: Radar cross section diagram for a military aircraft (bomber)

The radar cross section (RCS) of an object (target) provides a measure of its radar reflection behavior vs. direction. Low reflection of radar signals is particularly important for military aircraft in order to ensure detection by enemy radar as late as possible (or ideally not at all). On the other hand, it is also possible to analyze the timing-dependent (and thus generally also the direction-dependent) radar reflection behavior of a target in order to get an idea of what type of aircraft is involved. Accordingly, radar cross section measurements are very important during development of all sorts of flying objects used in the military.

FIG 60 shows a basic setup for radar cross section measurements and for transmission and reception of co-polarized and cross-polarized signals based on a model of a fighter aircraft. The R&S ZVA vector network analyzer measures both polarizations in parallel via two independent receiving channels. At the same time, it supplies the signal for the transmit antenna. A PIN switch is used to switch the transmit signal between the horizontally and vertically polarized transmit antennas.

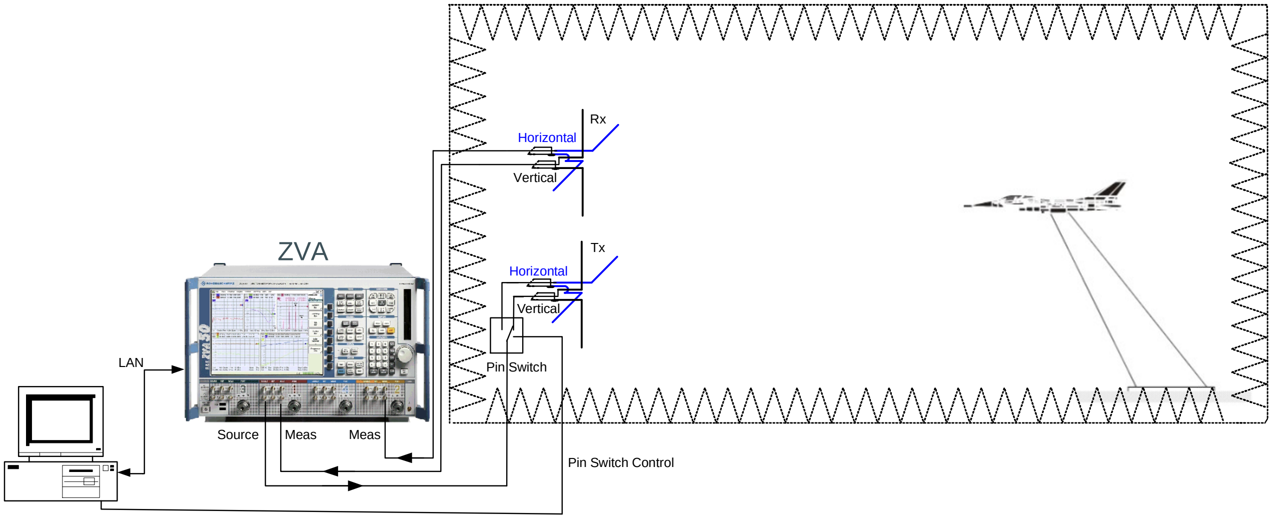


FIG 60: Basic setup for making radar cross section tests on a fighter aircraft using the R&S ZVA

The R&S ZVA vector network analyzer (RF to 50 GHz) and the ZVT multiport vector network analyzer (RF to 20 GHz) are ideal instruments for performing antenna and radar cross section tests. Relevant features include high sensitivity (down to –130 dBm), wide dynamic range (up to 145 dB), high measurement speed (up to 285,000 test points/s), fast data transfer and flexible configuration capabilities (direct generator/receiver access option).

FIG 61: The R&S ZVA24 vector network analyzer with four test ports

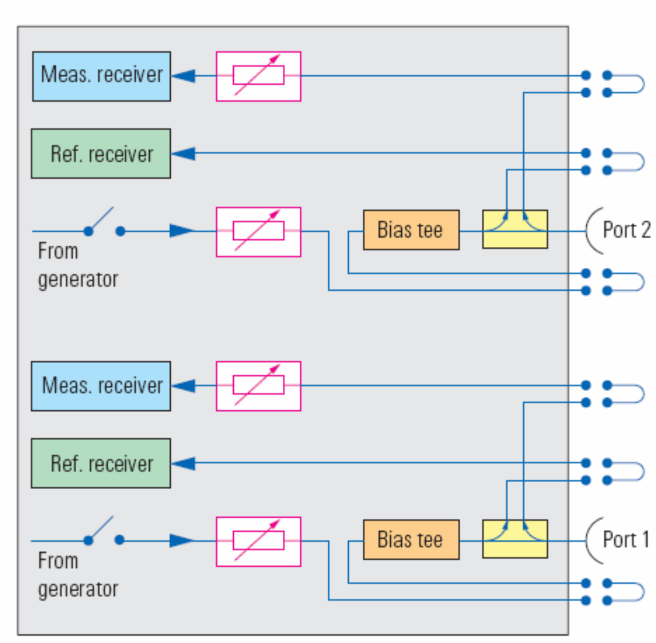


FIG 62: The direct generator/receiver access option (blue); generator and receiver step attenuators (red) on a 2-channel R&S ZVA

4 R&S Instruments for radar testing

The R&S SMF100A microwave generator: Special features for radar applications

- 1 GHz to 22 GHz or 43.5 GHz
- Extremely low phase noise and high rejection of harmonic and spurious signals
- Fast frequency and level setting times
- RF output up to +16 dBm (optionally up to +25 dBm)
- Flexible generation of single or double pulses and pulse trains
- Optional pulse modulator has on/off ratio greater than 80 dB, rise/fall times of <10 ns, and a minimum pulse width of 20 ns

http://www.smf.rohde-schwarz.com

The R&S SMA100A signal generator: The perfect substitute for local oscillators

- 9 kHz to 3 GHz or 6 GHz
- Lowest SSB phase noise up to 6 GHz (typ. –140 dBc/Hz at 1 GHz with 20 kHz offset)
- Optional high-performance pulse generator and standard pulse modulator offer better than 80 dB on/off ratio, 20 ns rise/fall time and 20 ns pulse widths

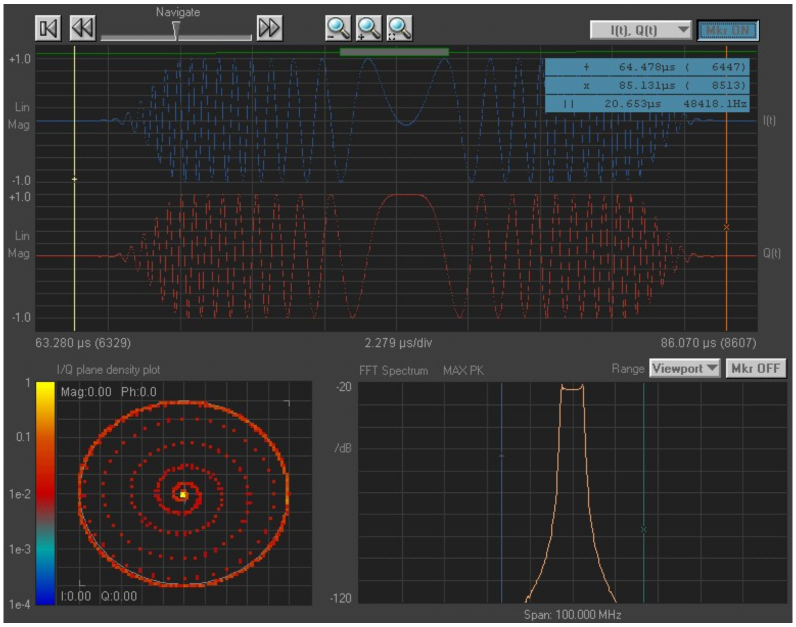
http://www.sma.rohde-schwarz.com

The R&S SMU200A vector signal generator: Versatile wideband digital modulation

- RF up to 6 GHz
- Optional second RF path up to 3 GHz
- Up to 2 internal baseband generators
- Versatile internal digital modulation
- I/Q modulator with 200 MHz RF bandwidth
- Pulse modulator
- Very low SSB phase noise
- Very high level repeatability of 0.05 dB
- High output power up to +19 dBm (PEP), overrange +26 dBm

http://www.smu.rohde-schwarz.com

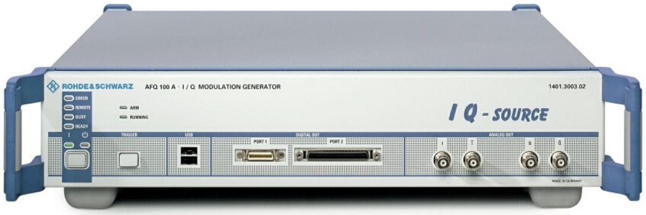
R&S K6 pulse sequencer software



- Standalone PC-based application
- Intuitive user interface with integrated waveform display and analysis
- Build pulse and sequence libraries
- Set any pulse parameter and add modulation such as AM, FM, PM, digital modulation, chirps, etc.
- Independently vary pulse parameters by applying jitter
- Plug-ins allow the user to add proprietary / classified pulse content
- Batch build multiple sequences and assemble multisegment waveforms
- Transfer waveforms to instrument
- Interacts with all R&S ARB generators (R&S SMU, R&S SMJ, R&S AMU, R&S AFQ)

http://www2.rohde-schwarz.com/file/Software_SMx-K6_v1.0.0.zip

The AFQ 100A arbitrary waveform generators: Meeting new challenges in radar baseband signal generation



- Variable clock rate up to 300 MHz
- Maximum I/Q bandwidth of up to 100 MHz for an RF bandwidth of 200 MHz
- Ideal for generation of complex wideband radar signals with the R&S SMU
- Long signal duration – 256 Msample or 1 Gsample
- Analog I/Q outputs (balanced and unbalanced)
- Optional digital outputs

http://www2.rohde-schwarz.com/en/products/test_and_measurement/product_categories/signal_generation/Baseband/AFQ100A.html

The R&S NRP power meter: Handles up to 4 power sensors

The R&S NRP-Z51/55 power sensor: Thermoelectric accuracy at its best

- DC to 40 GHz
- Measures average power with best possible accuracy
- Measurement range 1 µW to 100 mW
- Γ correction to reduce matching errors
- Operation of sensor directly from PC via USB interface

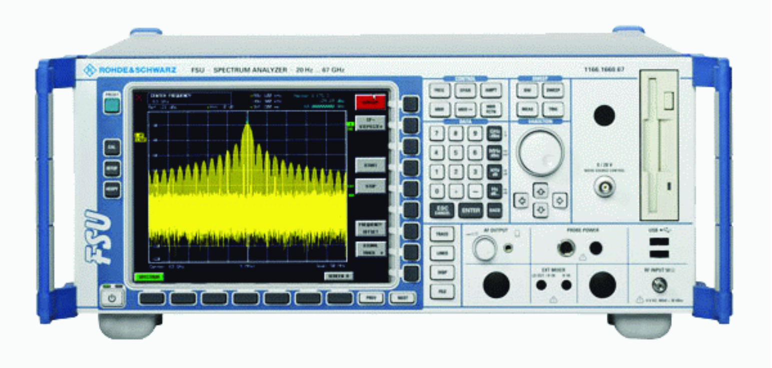
http://www.nrp.rohde-schwarz.com

The R&S NRP-Z81 power sensor: The sensor of choice for analysis of radar signals

- Frequency range from 50 MHz to 18 GHz
- Analysis of radar and communications signals up to 30 MHz RF bandwidth (sensor rise time <13 ns)
- Accurate continuous average power measurements on modulated and unmodulated signals from –60 dBm to +20 dBm
- Ultrafast statistical analysis (1 million point CCDF in 25 ms)
- Operation of sensor directly from PC via USB interface

http://www2.rohde-schwarz.com/en/products/test_and_measurement/product_categories/power_volt_meter/power_meters/NRP-Z.html

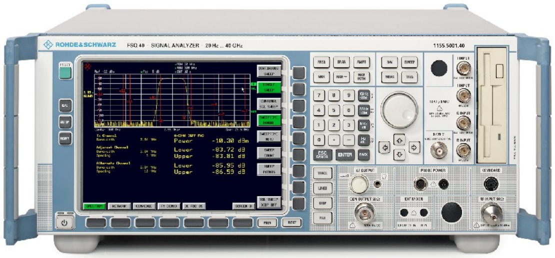
The R&S FSU spectrum analyzer family, models up to 67 GHz without external mixers



- Models with upper frequency range of 3, 8, 26.5, 43, 46, 50, 67 GHz according to your needs
- FSU67 is the only spectrum analyzer to cover the frequency range up to 67 GHz without external harmonic mixers and their inherent drawbacks
- Instrument-controlled internal RF attenuator (0 to 75 dB in 5 dB steps) eliminates the external manually-operated attenuator needed when harmonic mixers are used
- Reference level range (-130 dBm to +30 dBm) is much higher than typically achievable with harmonic mixers
- Unique choice for evaluating radar, electronic warfare, electronic countermeasures and battle-field communications systems
- Can make 80 measurements/s in manual mode and 70 measurements/s including data transfer over IEC/IEEE 488 bus
- Noise floor of –158 dBm at 1 GHz and –130 dBm at 65 GHz
- Resolution bandwidth of 1 Hz to 50 MHz
- Total measurement uncertainty <0.3 dB
- Frequency resolution of 0.01 Hz
- Low phase noise over entire measurement range
- Can function as an RF power meter just by adding a sensor
- Broad array of analysis options

http://www.fsu.rohde-schwarz.com/

The R&S FSQ40 signal analyzer: Vector signal analysis and spectral analysis in a single instrument



- 20 Hz to 3.6, 8, 26.5 and 40 GHz
- All of the features of a high-performance spectrum analyzer combined with versatile signal analysis
- Resolution bandwidth settings up to 50 MHz provide more insight with pulsed signal analysis in zero-span mode.
- Maximum dynamic range of 170 dB
- 28 MHz demodulation bandwidth - and optionally 120 MHz
- I/Q data recording (16 Msample each for I and Q data, optionally up to 705 Msamples)
- Analog and digital baseband signal analysis flexibility
- Optional external harmonic mixers extend measurement range to 110 GHz
- Demodulates numerous modulation formats

http://www.fsq.rohde-schwarz.com/

The R&S FSUP signal source analyzer: Phase noise tester and high-end spectrum analyzer in a single instrument

- Frequency range up to 8/26.5/50 GHz
- Up to 110 GHz with external mixers
- Maximum flexibility in phase noise measurements:

  Phase detector method

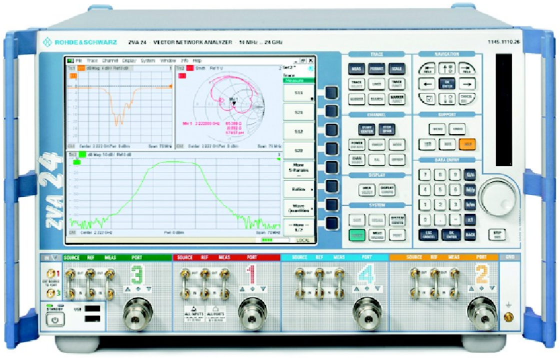
  Phase detector method with cross-correlation

  Spectrum analyzer method
- Complete characterization of oscillators:
  - Phase noise
  - Transient response
  - Harmonics
- Maximum sensitivity in phase noise measurements (e.g. at 1 GHz input frequency: –134 dBc (1 Hz) at 10 kHz offset)

http://www2.rohde-schwarz.com/en/products/test_and_measurement/product_categories/spectrum_analysis/FSUP.html

Vector Network Analyzers

The R&S ZVA series: Unparalleled measurement speed and accuracy



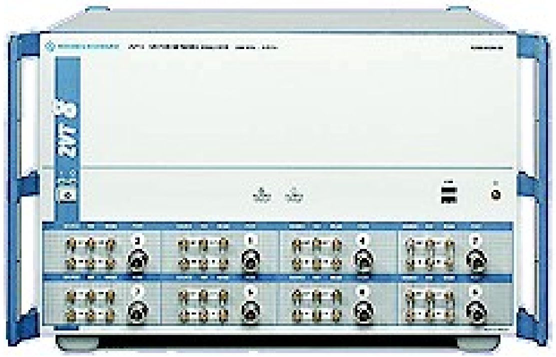
- 8, 24, 40 or 50 GHz maximum measurement frequency
- Up to four test ports
- Industry-leading signal RF performance
- Wide dynamic range for fast and accurate measurements
  - >135 dB at test port
  - >145 dB with direct receiver access
- Segmented sweep increases speed, accuracy and dynamic range
- Pulse profile measurement with 12.5 ns time resolution and up to 30 MHz measurement bandwidth
- Point in pulse measurements for pulse widths down to 450 ns
- Parallel measurements up to four times faster
- Two internal phase coherent sources for true differential measurements
- Data transfer during sweeping
- High-speed control of external components
- Wide dynamic range and high sensitivity
  - >135 dB at test port, >145 dB with direct receiver access
  - <–115 dBm at test port, <–130 dBm with direct receiver access

The industry standard in pulse profile measurements

The **R&S ZVA-K7 Pulsed Measurements** option for the R&S ZVA and R&S ZVT series VNAs employs wideband detection and fast data recording for pulse profile measurements with high resolution at high speed.

http://www2.rohde-schwarz.com/en/products/test_and_measurement/product_categories/network_analysis/ZVA/Pulsed Measurementsl

The R&S ZVT8 and ZVT20: The first (and only) VNA with up to eight ports



- 300 kHz to 8 GHZ or 10 MHz to 20 GHz
- Up to 6 ports for the ZVT20, up to 8 ports for the ZVT8
- Up to 3 internal sources for the ZVT20, up to 4 for the ZVT8
- Dynamic range >120 dB
- Output power >13 dBm on all ports
- Power sweep range of –40 dBm to 13 dBm
- Measurement speed of 8 ms for all ports
- Simple configuration of multiport measurements
- Unlimited number of channels and traces
- Can simultaneously perform measurements on all ports of a device

http://www2.rohde-schwarz.com/en/products/test_and_measurement/product_categories/network_analysis/top_class/ZVT8.html

5 Abbreviations

Abbreviation	**Meaning**
AESA	**A**ctive **E**lectronically **S**canned **A**rray
ASR	**A**irport **S**urveillance **R**adar
ASR-S	**A**irport **S**urveillance **R**adar Mode**-S** (Mode S is an extension to secondary radar. Mode S makes it possible to query additional information, e.g. the speed of the aircraft.)
COHO	**Coh**erent Local **O**scillator
ECM	**E**lectronic **C**ounter **M**easures are a subsection of electronic warfare which includes any sort of electrical or electronic device designed to trick or deceive radar or other sensor systems
ECCM	**E**lectronic **C**ounter **C**ounter **M**easures describes a variety of practices which attempt to reduce or eliminate the effect of Electronic countermeasures (ECM)
ELINT	**El**ectronic **Int**elligence (intelligence derived from electromagnetic radiations from foreign sources)
ESM	**E**lectronic Warfare **S**upport **M**easures Passive usage of the electromagnetic spectrum to obtain information about enemy forces in the battlefield so as to enable immediate tactical action. Such information can serve as a basis for initiating artillery fire, air attacks or electronic countermeasures, for example. Example: Radar warning receiver in fighter aircraft
LPI	**L**ow **P**robability of **I**ntercept
MTI	**M**oving **T**arget **I**ndication
PRI	**P**ulse **R**epetition **I**nterval (PRI = 1/PRF)
PESA	**P**assive **E**lectronically **S**canned **A**rray
PDF	**P**ulse **D**esensitization **F**actor
PRF	**P**ulse **R**epetition **F**requency (PRF = 1/PRI)
RADAR	**Ra**dio **D**etection **a**nd **R**anging

Abbreviation	**Meaning**
SIGINT	**Sig**nals **Int**elligence (SIGINT) involves gathering information from intercepted radio signals (COMINT, Communication Intelligence) and detecting and analyzing radar signals (ELINT, Electronic Intelligence).
STALO	**Sta**ble **L**ocal **O**scillator
RCS	**R**adar **C**ross **S**ection “The radar cross section of a target is the (imaginary) area intercepting that amount of power which, when scattered equally in all directions, produces an echo at the radar equal to that from the target.” [1]

6 References

[1] Radar Handbook, Second Edition, Merrill Skolnik

[2] http://de.wikipedia.org/wiki/Synthetic_Aperture_Radar

[3] http://keydel.pixelplaat.de/uploads/File/vorlesung07-08/SAR.pdf

[4] http://www.bbc.co.uk/dna/h2g2/C1215

[5] http://www.armedforces.co.uk/releases/raq43f463831e0b7

[6] http://www.pa.op.dlr.de/poldirad/BISTATIC/index.html

[7] R&S Power Viewer Plus (part of R&S NRP Toolkit)

[8] R&S Application Note 1EF48 “Power Measurement on Pulsed Signals with Spectrum Analyzers” www.rohde-schwarz.com/appnote/1EF48.html

[9] R&S Pulse Sequencer Software to generate complex pulse patterns for R&S SMU200A, R&S SMJ100A, R&S SMATE200A, R&S AFQ100A and R&S AMU200A

[10] ARB Toolbox (comes along with R&S Application Note 1GP62 “Importing Data in ARB, Custom Digital Modulation and RF List Mode”)

[11] 1GP60: R&S Transfer Toolbox for Matlab (Rohde & Schwarz Application Note)

[12] 1EF48: Power Measurement on Pulsed Signals with Spectrum Analyzersy (Rohde & Schwarz Application Note)

[13] Antenna and RCS measurements with Vector Network Analyzers R&S ZVA8/24 and R&S ZVT8 - Data sheet

7 Additional Information

We welcome your comments and questions relating to this Application Note. You can send them by e-mail to customersupport@rohde-schwarz.com
Please visit the Rohde & Schwarz website at www.rohde-schwarz.com. There, you will find additional Application Notes and related information.

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