Tackling the Challenges of
Pulsed Signal Measurements

Application Note

This Application Note describes characterization of devices used in radar systems with pulsed signals. The emphasis is on measurements using vector network analyzers (VNAs), signal generators, vector signal generators and spectrum analyzers.

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Contents

1 Overview

Radar systems, most of which employ pulsed signals, require a unique set of measurements, and their signals are not often easy to generate or analyze. However, there are specific techniques, from signal generation to network and spectral analysis that when properly applied make characterization of devices with pulsed signals easier and more repeatable and accurate. This Application Note describes these measurement scenarios, with emphasis on measurements using vector network analyzers (VNAs), signal generators, vector signal generators, and spectrum analyzers. Our goal is to provide basic information on both the measurements and the equipment used to make them in terms that designers will find useful.

This Application Note was formerly published as a White Paper at the R&S North America website under http://test-rsa.com/milaero/index.shtml and partly in Microwave Journal Sept. 2007.

2 Measuring Pulsed Signal Devices with Vector Network Analyzers and Signal Generators

In many cases, devices must be characterized by using pulsed signals instead of CW signals, either by being stimulated with a pulsed RF signal or a pulsed control voltage. For example, during on-wafer measurements of power amplifiers, heat sinks are difficult or even impossible to implement, and by using pulsed stimulus signals, S-parameters can be measured at the power levels to which the devices will be subject in their intended use without exceeding a power level that could destroy them. By using an appropriate duty cycle, the average power can be reduced significantly while maintaining a high peak power. In addition, components designed for use in radar systems exhibit their desired performance only under pulsed stimulus conditions.

Characterizing Time-Dependent Behavior

There are several kinds of pulses in use, the most common being a single pulsed RF signal as shown in **Figure 1.** Using periodic single pulses reduces the average power while maintaining peak power by selecting an appropriate duty cycle. As a result, the average power of the DUT can be reduced to a tolerable value to avoid thermal destruction.
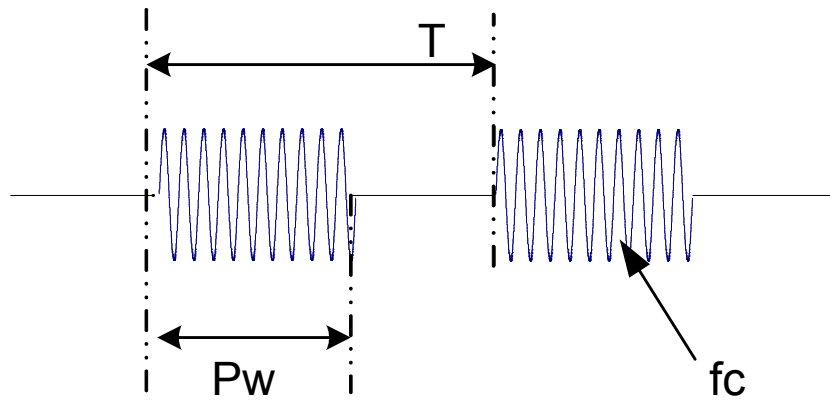
Figure 1. Single Pulses

Double pulses are used in various types of radar systems, including weather radar, target tracking radar, and astronomical Doppler-radar. A double pulse produces a double echo, which goes through signal processing efficiently and eliminates most noise and other interferers, ensuring high measurement accuracy. Radar systems employ pulse trains (**Figure 2**) in contrast to single or double pulses, and are formed with a combination of different kinds of pulses such as periodic or non-periodic, and modulation can be applied to each pulse.
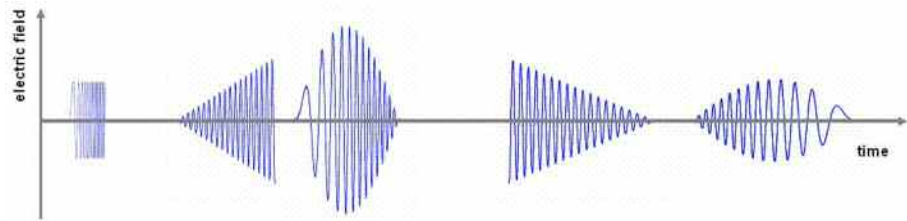
Figure 2. A typical pulse train

Modulated Pulses.

There are three basic types of modulated pulsed signals. Chirp pulses are essentially frequency-modulated signals that vary their frequency over time, and in an analogy to bird sounds, are called chirped pulses (**Figure 3**). They can be linearly or non-linearly chirped, and can have a specific shape such as Gaussian.
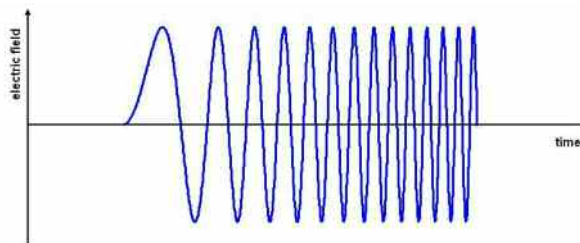

Figure 3. A pulse with variations in frequency over time (chirped pulse)

A Barker pulse (**Figure 4**) is a binary phase shift keying (BPSK) modulation, and a bit value of 1 sets the phase to π, whereas 0 bits leaves the phase at 0. An additional phase offset may be specified to rotate the constellation points. This signal processing technique is used for pulse compression (pulses with inherent modulation applied). In contrast to the analog chirp signal, it is digitally modulated. For high distance resolution, short pulses are normally used, which decreases the signal-to-noise ratio. To overcome this problem, pulse compression is employed to achieve wider pulses and good signal-to-noise ratio.
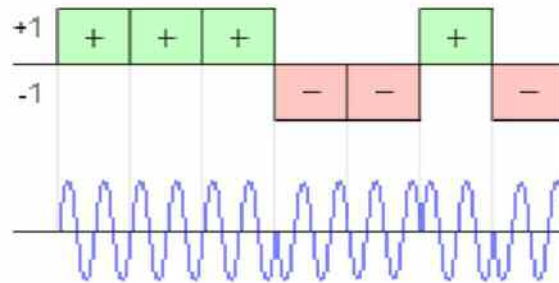
Figure 4. A 7-bit Barker code

Point in Pulse Measurement

The point-in-pulse measurement enables accurate S-parameter and power measurements to be made, allows the moment of data acquisition within the pulse to be easily shifted, and eliminates the dependency of dynamic range on duty cycle. However, it requires a VNA with a wide measurement bandwidth. Using the point-in-pulse measurement technique, the pulse is monitored only during the "on" phase of the RF bursts so the sampling time (T_{spl}) to acquire the raw data of a wave quantity or an S-parameter must be shorter than the pulse width, t_{on} (**Figure 5**).
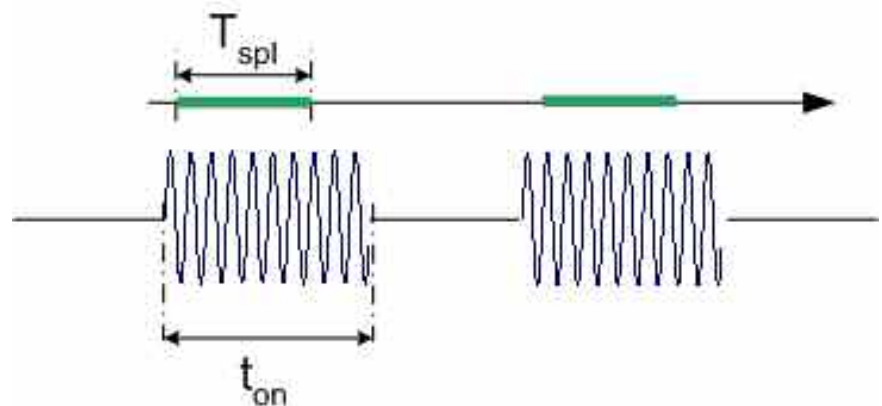
Figure 5. Sampling time for point-in-pulse measurements

The sampling time is determined mainly by the receiver's measurement bandwidth, and minimum sampling time and measurement bandwidth is defined as $T_{spl} \approx 1/IFBw$. This means that with increasing measurement bandwidth, sampling time decreases and shorter pulses can be analyzed. VNAs implement IF filters digitally and typically offer measurement bandwidths up to 600 kHz, so the sampling time is 1 µs or more. Some network analyzers, such as the R&S ZVx Series, have IF bandwidths of 5 MHz or more, which allows sampling times as fast as 400 ns with a 5 MHz bandwidth. The sampling process should only occur during the on-phase of the pulse, so a trigger signal synchronous to the RF pulse is necessary to synchronize the data acquisition of the VNA with the on-period of the pulse. The VNA is used in "point-trigger mode", which means that data sampling for every measurement point starts after the detection of a trigger event.

Active devices such as amplifiers often show settling or ringing effects at the beginning of the pulse, but designers are typically interested in device behavior after it has settled. By selecting a suitable trigger delay, the start of the sampling process can be shifted to the quiet pulse roof of the ampli-fier. Dynamic range and sensitivity using the point-in-pulse method depends on sensitivity and the measurement bandwidth of the receivers, which are independent of the duty cycle of the RF pulse. Consequently, dynamic range depends on pulse width, which determines sampling time and thus the required measurement bandwidth. Averaging can be applied to increase dynamic range by maintaining the measurement bandwidth. Ten times averaging in the IQ domain (for example) increases the dynamic range by a factor of 10.

Averaged Pulse Measurement

Since the point-in-pulse measurement requires a VNA with a wide measurement bandwidth, many VNAs are not suited for it when pulse widths are short. Instead, the averaged pulse measurement technique (also called the narrowband or high-PRF technique) is recommended. It places lower demands on the VNA's performance but requires more knowledge to configure the setups properly and is dependent on the pulse and VNA parameters. A pulsed signal is generated by multiplying a periodic low frequency rectangular signal (LF signal) that varies between 0 and 1 with a high frequency continuous wave (CW) signal. Multiplication in the time domain is a convolution of the spectra of both signals in the frequency domain (**Figure 6**).
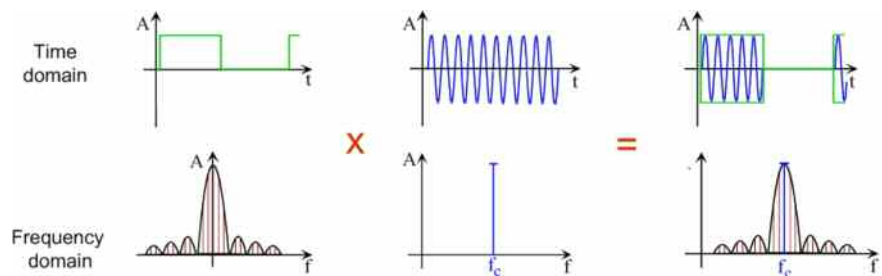

Figure 6. Signals in the frequency and time domains

The spectrum of the pulse envelope (LF signal) is shifted by the convolution to the frequency fc, and because S21 equals b2/a1 (where a1 is the incident wave into a device and b2 is the transmitted wave through it), the ratio between one specific spectral line of a1 and the equivalent spectral line of b2 can be measured. That is, all S-parameters can be measured. To achieve maximum dynamic range, the strongest spectrum line at fc (i.e. the main carrier) is selected:

S21 = b2 (fc) / a1 (fc)

S11 = b1 (fc) / a1 (fc).....etc.

For averaged pulse measurements, the bandwidth must be narrow enough so it captures only the main carrier. The frequency spacing between the carriers is equal to the pulse repetition frequency (PRF = 1/T).

To ensure low trace noise, it is important that the adjacent carriers are suppressed by 40 dB or more, so a measurement bandwidth roughly 10 times narrower than the carrier spacing with respect to the pulse repetition frequency is typically selected. Decreasing the measurement bandwidth translates into increased measurement time. The VNA samples and measures the averaged value of the pulse during several pulses, so it is called an averaged pulse measurement. Only the main carrier is detected, which is the convoluted carrier of the LF signal at frequency 0, which represents the "DC value" of the LF pulse — actually just the average value of the LF signal.

A typical problem for this kind of measurement is the shape of the VNA's digital IF filters. VNAs typically stimulate a device with a CW signal, and the IF filters are designed for fast settling but not for high sidelobe suppression, which is often 20 dB or less. This can cause problems as soon as one of the adjacent tones falls into the maximum of a sidelobe. To overcome this problem, two different procedures can be used. Some instruments use "spectral nulling" (**Figure 7**), and depending on the period of the pulse, IF filters can be selected so that the nulls of the filter are exactly where the tones to be suppressed are expected. Other "high-end" VNAs use highly-selective filters without sidelobes, so no spectral nulling is required (**Figure 8**).

Blue trace:
Spectrum of $T_p = 218.58 \ \mu s$
→ Tone spacing **4.545 kHz**

Red trace:
Shape of **3 kHz** IF-filter with nulls at **4.545 kHz** offset
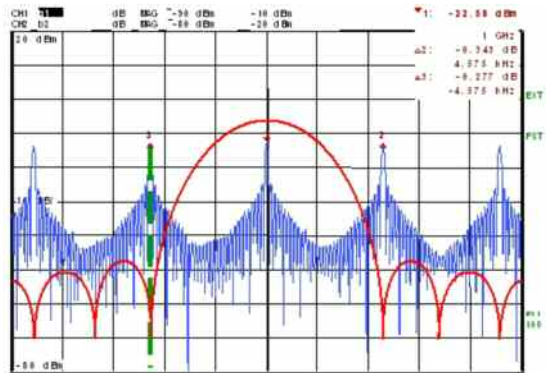
Figure 7. Example of spectral nulling
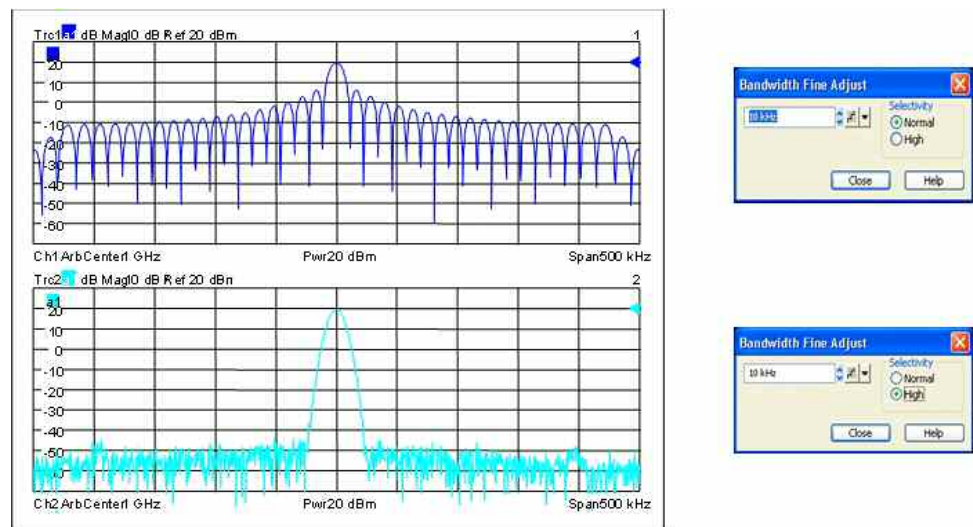
Figure 8. Digital IF filters of a VNA and the highly-selective IF filters of a "high-end VNA"

Averaged pulse measurements can be performed in swept mode as well. The setup is the same as for point-in-pulse measurements, but no trigger is required. The averaged pulse measurement technique determines the average values of the wave quantities, so an absolute power measurement is influenced by the duty cycle. For a duty cycle of 1%, the measured power of the main carrier is 40 dB lower than the peak power. This phenomenon is

called pulse desensitization. For very low duty cycles, the signal-to-noise ratio becomes very low and limits the dynamic range of the measurement.

So in summary, the averaged pulse measurement technique can be applied to very short pulses, and does not require a special bandwidth or special trigger capabilities. However, in contrast to the point-in-pulse measurement, the averaged pulse method requires a periodic pulsed signal, and the results represent only average values, including ringing or overshoots that may occur at the beginning of a pulse.

The VNA must also be able to suppress other signals except for the main carrier, which requires IF filters without sidelobes or a suitable selection of IF filter shapes, depending on the repetition frequency of the pulse. The dynamic range drops by 20 dB as soon as the duty cycle is reduced by a factor of 10, which can result in poor performance at low duty cycles. In these cases a point-in-pulse measurement is recommended.

Pulse Profile Measurements

To analyze the time-dependent behavior of a device during a burst, the VNA must perform a so-called "pulse profile" measurement. Typical parameters required to characterize the time dependent behavior include rise time, overshoot, and droop. A representative pulse waveform is shown in **Figure 9**. For this measurement, the VNA must have time resolution significantly higher than the pulse duration. A typical VNA's time resolution ranges from 3 to 20 µs for measurements in the frequency or time domain, which is not great enough to analyze behavior versus time with sufficient resolution. Most VNAs have a measurement bandwidth of 600 kHz or less, which is the limiting factor for high time resolution of pulse widths of 1 µs or below.
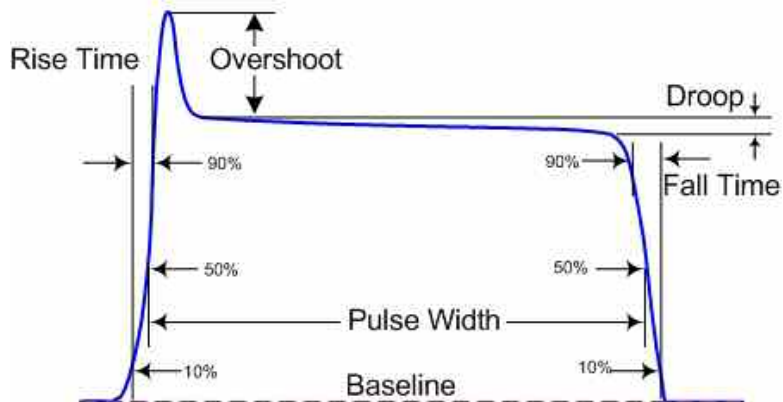

Figure 9. A pulse waveform with various characteristics identified

To achieve resolution of better than 1 µs, additional external hardware and software can be used to "chop up" the pulsed signal into slices with different timing positions within the pulse (**Figure 10**). The magnitude of these pulse slices with regard to a specific delay is measured and calculated in accordance with the averaged pulse method. The delay is then increased and the next "slices" are measured until a desired portion of the pulse is analyzed. This chopping can occur in either the receiver paths at the RF frequency or directly inside the instrument in the IF path. If the IF is chopped, losses incurred by the required external switches can be minimized.
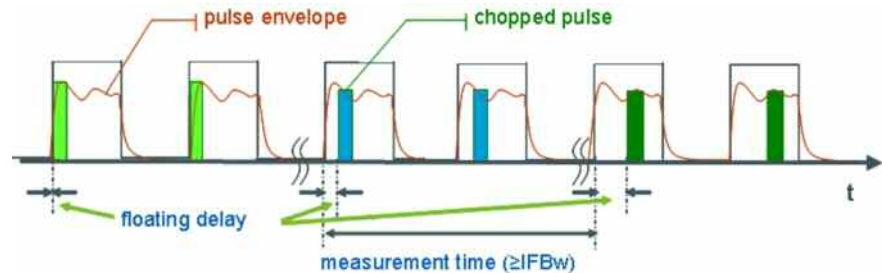

Figure 10.   An example of pulse chopping

The pulse profile method can be performed with most VNAs in conjunction with an external setup for pulse profile measurements. Its disadvantages are that analysis of non-periodic pulses, double pulses, pulse trains, or complex modulated pulsed signals cannot be performed, and that offers low dynamic range for low duty cycles and high resolution, low measurement speed, and requires recalibration with a change of duty cycle.

An Enhanced Pulse Profile Solution

A new technique developed at Rohde & Schwarz employs wideband detection and fast data recording that greatly improves pulse profile measurements. Pulse profile analysis of pulsed signals or S-parameters with pulsed stimulus is limited by the sampling rate of the A/D converter, the processing time between two data points, and the available bandwidth. Sampling rate and data processing time between two data points limit the time resolution, while the measurement bandwidth determines the minimum rise and fall time of the pulse that can be analyzed.

The bandwidth-limiting factors are the analog bandwidth of the receivers and the capabilities of the digital signal processors (DSPs) for digital filtering. A high-end VNA has an analog bandwidth of 15 MHz (with some performance degradation to 30 MHz), but the DSP's IF filters offer adequate performance only for normal CW or time sweeps with a 5 MHz bandwidth. The VNA samples downconverted IF signals at a sampling rate of 80 MHz, which results in time resolution of 12.5 ns. In addition to the sampling time, there is data processing time between two measurement points, which is a bottleneck for achieving high-resolution measurements in the time domain. The limitations are the IF filtering by the DSPs, and the data processing time limiting the time resolution to 1.5 µs plus sampling time.

However, pulse profile measurement resolution can be dramatically improved by sampling the raw data and storing it directly without filtering. Instead of the DSP, the instrument's software performs digital downconversion and digital filtering after recording. The A/D converter continuously digitizes the data with a sampling rate of 80 MHz and writes it into high-speed RAM, which ensures that no delay occurs between the samples of individual measurement points as shown in **Figure 11**. Because of the high sampling rate, a measurement point is output every 12.5 ns, so the time resolution is 12.5 ns. The trigger signal, usually derived from the rising edge of the pulse, determines the zero point in time. Consequently, the exact time relation between the trigger detection and the incoming RF pulse can be measured as well. This relation is especially important for determining the correct trigger delay in point-in-pulse measurements versus frequency or level.
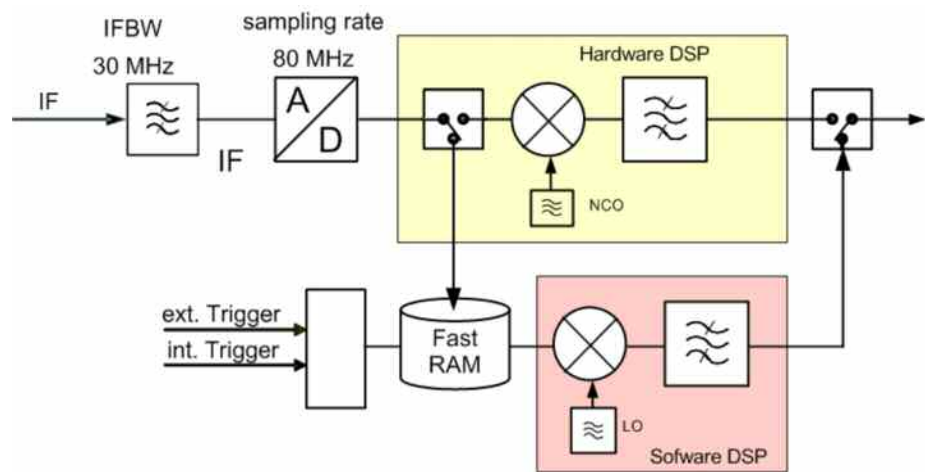
Figure 11.   Fast data recording employed in the improved high-performance pulse profile technique

The VNA can then perform extremely-fast pulsed measurements, and with more than 10 sweeps/s at 1001 test points, devices can easily be adjusted during the pulse profile measurement. In addition to periodic single pulsed signals, this new technique handles double pulses as well as user-defined pulse trains. Devices stimulated with pulses that have frequency and magnitude modulation, such as chirps, can also be analyzed.

The new techniques also benefits measurement of the S-parameters of devices with group delays on the order of the pulse width, which has been difficult or even impossible before. The stimulated RF signal may no longer be present at the device's input by the time the VNA receives the transmitted RF signal from the output. A correct S21 parameter can only be measured with temporal signal overlapping. Using the new technique, the VNA solves this problem by applying a time offset to the wave quantities. Before calculating the S-parameters, it mathematically shifts the wave quantities by the device's group delay. A specific time delay can be assigned to each wave quantity depending on the measurement direction, so the VNA correctly displays the gain (S21) versus the entire pulse duration.

Pulse Measurements and Signal Generation

Most VNAs cannot modulate their internal generator with sufficient performance, so it is more convenient to use external modulation sources, especially for very complex pulse scenarios. In most cases, pulses range from less than a microsecond to several hundred microseconds and carry data in various modulation schemes. A limited spectral bandwidth may also require dedicated pulse shaping and often high on-off ratios.

The generation of these pulse signals is not trivial, and simple CW pulses from analog microwave sources are sometimes not sufficient to fulfill testing needs. Today's powerful vector signal generators are generally the best choice for generating arbitrary pulses containing digitally modulated data content. The arbitrary waveform mode of these instruments provides enough memory and great enough resolution for complex and long pulse trains. With flexible software for vector signal and baseband generators, the generation of complex pulse patterns used in communication or military applications can be dramatically simplified. In addition, the precalculated results (e.g. FFT) can be displayed and directly compared with real measurements made with a VNA.

Comparing Analog and Vector Signal Generators

An analog generator contains a pulse modulator and a pulse generator. The pulse modulator is driven by the pulse generator with a rectangle wave signal. The pulse modulator is essentially a simple switch that activates and deactivates the RF signal. Its main advantage is in generating very short (nanosecond-range) pulses with an excellent on/off ratio. However, applying specific shaping to pulses or modulating them is not possible. In contrast, for focusing on a specific modulation in a pulse or a user-defined pulse train, a vector signal generator is the only choice. It takes a precalcu-lated pulse waveform stored in its internal arbitrary waveform generator and cyclically generates it. The waveform is then upconverted to the desired RF frequency by an internal IQ modulator.

In contrast to a normal pulse modulator/generator solution, this concept offers wide flexibility in setting up pulse scenarios or pulse trains. Software makes it much easier to set up the pulse scenario, and pulse parameters can be set and controlled on FFT, vector plane, or time plan displays. A comparison of the strengths and weaknesses of each type of signal generator for making pulsed measurements is shown in **Table 1** (page 13).

Table 1 – Signal Generators Compared

Generator type	Advantages	Disadvantages
Analog with pulse generator and pulse modulator	• High pulse on-off ratios (> 80 dB) • Very short rise and fall times (<5 ns typical) • Very short pulse widths (>20 ns) • Frequencies well into microwave region	• Limited pulse shaping • Generation of modulated pulses (e.g., Chirp and Barker) not possible
Vector signal generator	• Customized pulse shaping, modulation • Arbitrary pulse trains	• On-off ratio limited by the arbitrary waveform generator • Full dynamic range of arbitrary waveform generator provides 16 bits for I and Q signal. Theoretical dynamic range is 96 dBc, but is in practice limited to about -65 dBc. However, an internal marker signal can directly drive the instrument's pulse modulator, increasing dynamic range to more than 80 dBc. • Rise and fall times and pulse widths limited by the IQ bandwidth.

Test Configurations

For applications in which the device under test requires a pulse-modulated input signal, a generator with pulse modulation or a vector signal generator with complex waveforms can be used. The modulated RF signal of the generator is directly injected into the generator path of the VNA instead of using the non-modulated internal VNA generator (**Figure 12**). Because the modulated signal is also measured by the reference receiver when it passes the internal coupler, system error correction can be applied on S11 and S21 measurements. A system error or level calibration recorded under CW conditions thus also applies under pulsed conditions and need not be repeated when the duty cycle is changed. As the VNA controls power and frequency of the external generator via LAN or IEEE-488 bus, this setup is suitable for pulsed measurements versus frequency and level.
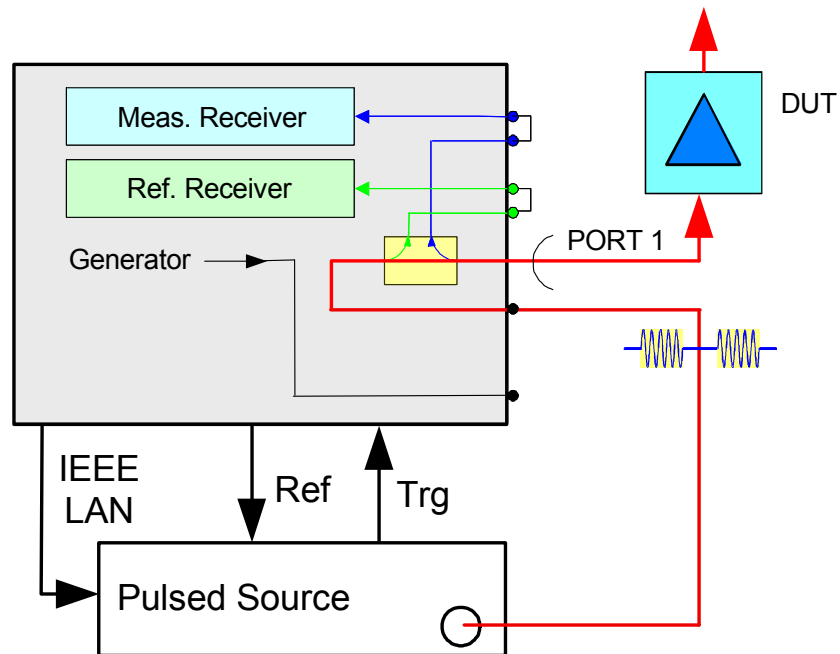
Figure 12. A test signal generator set-up as a modulated signal source

For measurements with simple RF pulses, a pulse modulator can be inserted into the generator path enabling bidirectional measurements and also two-port calibration. With a modulator applied in the generator path of port 1, the forward parameters S11 and S21 are measured under pulsed stimulus conditions and the reverse parameters S12 and S22 under non-pulsed stimulus conditions. Only an additional arbitrary waveform generator is required to control the pulse modulators (**Figure 13**).

Figure 13. A typical test configuration with an external pulse modulator

Either test setup — with external pulsed signal generator or with an external modulator — does not require recalibration if the duty cycle is changed. A calibration performed in CW mode is also valid under pulsed conditions. This setup allows an accurate, calibrated measurement of S-parameters as well as accurate calibrated measurements of absolute power levels.

3   Spectrum Analyzers and Analysis of Pulsed Signals

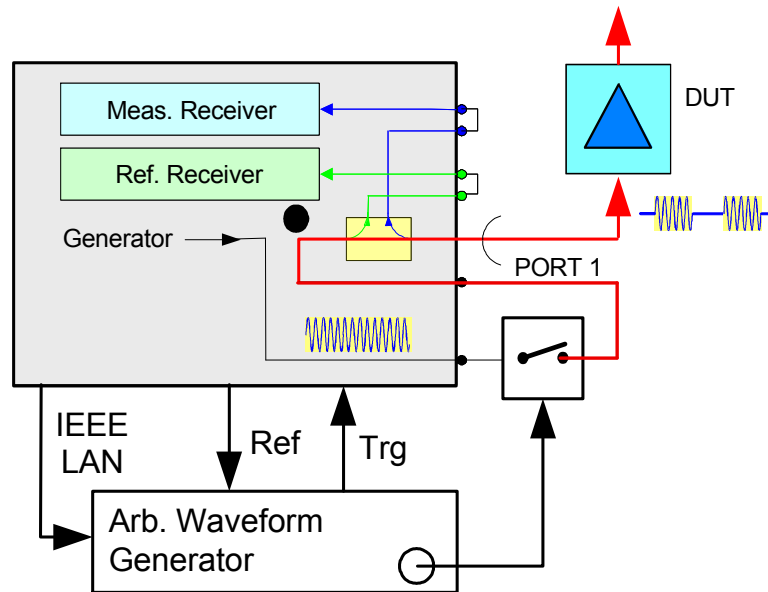In addition to VNAs and signal generators, spectrum analyzers are invaluable tools for characterizing the pulsed signals employed in radar systems. From a measurement perspective, pulsed signals are difficult to evaluate because their width and repetition frequencies are not constant and depend on the radar mode. This effectively eliminates RF power meters as tools for calculating pulsed signal peak power from mean power. In addition, many parameters must be measured in order to effectively characterize a pulsed signal, including peak and average power, pulse shape, and a pulse profile that includes rise time, fall time, pulse width, and pulse period. Other measurements include carrier frequency, occupied spectrum, carrier on/off ratio, pulse repetition frequency, and phase noise. Spectrum analyzers are by far the best solution for analyzing their characteristics. Depending on the parameters of the pulse and resolution bandwidth (RBW), the results can be displayed on a spectrum analyzer in three ways:

• If the RBW is smaller than the spacing of the spectral lines, changing it does not change the measured level.

• With a narrower bandwidth than the spacing of the first null in the envelope (1/pulse width), an envelope spectrum can be displayed.

• If the bandwidth is wider than the null spacing, the entire spectrum falls within the bandwidth, so the spectrum of the signal cannot be displayed.

With further increases in bandwidth, the response approaches the time domain function of the pulse. Depending on the pulse parameters, the pulse desensitization factor can also be calculated, which is the reduction of the level measured within the pulse bandwidth of the spectrum analyzer. In this case, the marker reading plus the desensitization factor equal the peak power. The RBW value is very important for pulsed signal measurements because a change in RBW produces changes in the measured level. The pulse desensitization factor depends on the pulse parameters and the RBW if the bandwidth is greater than the spacing of the spectral lines, and the measured amplitude depends on the number of lines within the bandwidth and the total signal bandwidth. The RBW correction factor is driven by the shape of the filter in the instrument because the shape of the bandwidth reflects the power within the filter bandwidth. If the RBW is too wide, the line or envelope spectrum changes to a time domain spectrum, and the impulse response of the RBW filter becomes apparent. Using a spectrum analyzer in time domain, it is possible to obtain a direct measurement of pulse width. The peak marker allows measurement of peak power, while the delta markers allow meas-urement of parameters such as rise time, fall time, pulse repetition interval, and overshoot. With a wide RBW and video bandwidth (VBW), the spectrum analyzer can track the envelope of the RF pulse so the impulse response of the pulse can be seen. The maximum RBW/VBW limits the spectrum analyzer's capability to measure narrow pulses, and a general rule has long been that for the shortest pulse that can be measured, the pulse width is greater than or equal to 2/RBW.

Modulation in the Pulse

Radar systems generally use modulation within the RF pulse. Understanding the power characteristics of this modulation is important because radar range is limited by the power available within the pulse. Conversely, a longer pulse length will lead to limited resolution. Modulation formats can range from simple FM (chirp) to complex digital modulation formats, which modern spectrum analyzers can describe. Spectrum analyzers can measure traditional analog modulation in pulse (AM, FM, and phase modulation), as well as perform additional analysis functions involving demodulation of many digital modulation formats such as Barker code BPSK modulation within the RF pulse, and pulse-to-pulse phase measurement.

Pulsed Power Measurement and Detectors

Testing output power is one of the important measurements on radar transmitters, and several different types of measurements can be made. Average power is usually made as a mean power measurement with a power meter. Another very important value is peak power, and if the Pulse Repetition Frequency (PRF) and the pulse width are known, the power of the measured mean power can be calculated. The waveform of a signal in the time domain is displayed on a spectrum analyzer using a raster scan CRT or an LCD. The number of pixels in these displays in the level axis as well as in the frequency or time axis is limited. This leads to limited resolution for both level and frequency or time. To display the full amount of measurement data taken in a sweep, detectors are used to compress the data samples into the allowable number of displayed pixels.

For the measurement of peak power, spectrum analyzers have a peak detector that can display the highest power peak within a given

measurement interval. However, for the mean power measurement of amplitude-modulated signals like pulse modulation, the peak detector in spectrum analyzers is not appropriate because the peak voltage is not related to the power of the signal. However, these instruments also provide either a sample detector or RMS detector.

A sample detector checks the envelope voltage once per measurement point and displays the result, but this can cause total loss of signal information because it is limited to the number of pixels available in the x-axis of the screen. An RMS detector samples the envelope signal at the full sample rate of the A/D converter and all samples within the range of one pixel are used for the RMS power calculation. As a result, the RMS detector displays a greater number of measurement samples than a sam-ple detector.

The RMS detector measures the power of the spectrum represented by a pixel by applying the power formula to all samples. For higher repeatability, the number of samples per pixel can be controlled by the sweep time. With longer sweep times the time for power integration of each pixel increases. In the case of pulsed signals, repeatability is dependent on the number of pulses within the pixel. For a smooth, stable RMS trace result, the sweep time must be set to a value long enough to capture several pulses within one pixel. The RMS detector calculates the RMS value of all samples linearly represented by a single pixel on the screen.

For accurate measurement of peak and mean power on pulse modulated signals, the instrument's IF bandwidth and A/D converter sampling rate must be high enough so it does not influence the pulse shape. With the 10 MHz resolution bandwidth and 32 MHz sampling rate available in the R&S®FSP spectrum analyzer for example, it is possible to measure pulse modulated signals with pulse widths as narrow as 500 ns with high accuracy.

A Typical Test Setup

For the measurement examples described here, the R&S®SMU signal generator is used to create a simulated radar signal and the output signal is an AM-modulated RF carrier. The broadband AM modulation is generated by an arbitrary waveform generator to create a sequence of pulses with 500 ns pulse width and a 1 kHz pulse repetition frequency. The pulse level is changed over time to simulate the effect of antenna rotation for the long-term average power measurement.

For measuring peak power, the spectrum analyzer must be set to a resolution and video bandwidth wide enough to settle within the pulse width. In this measurement, the RBW and VBW are set to 10 MHz. The spectrum analyzer is set to zero span and displays the power over time. The sweep time is set to a value that allows a single pulse to be investigated. The spectrum analyzer uses a video trigger to show a stable display of the pulse shape. The pulse width is varied, and three measurements are plotted with pulse widths of 100 ns, 200 ns, and 500 ns to investigate the effect of the resolution filter settling time. The three results of a typical peak power measurement are shown in **Figure 14**.
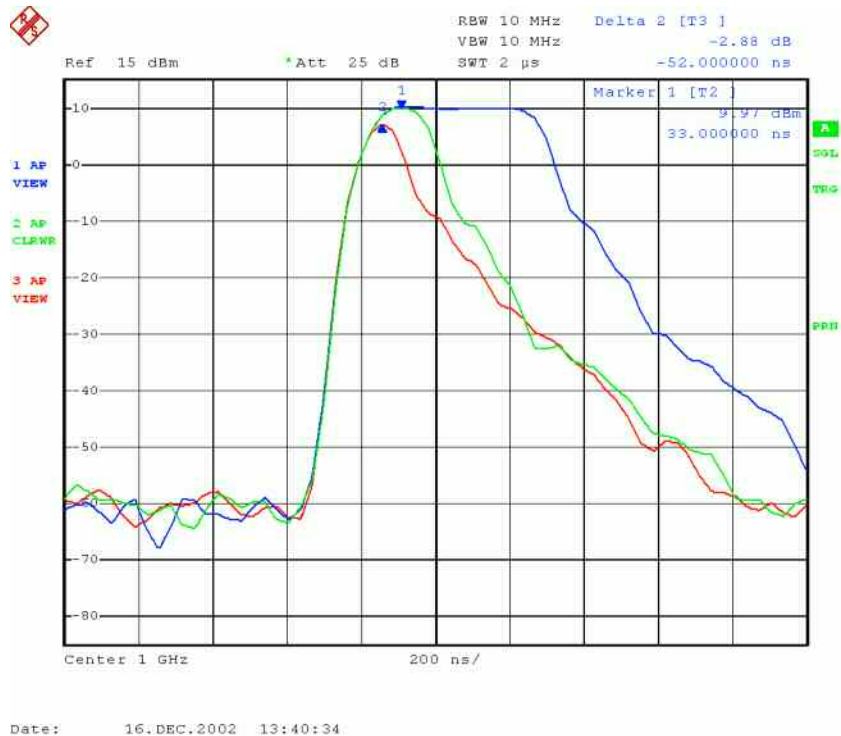

Figure 14. A typical peak power measurement. The blue, dotted trace is measured with 500 ns pulse width and the green, dashed trace is measured with 200 ns pulse width and is equal to the calculated settling time. The red, solid trace is measured with a 100 ns pulse width that is shorter than the settling time of the resolution filter.

The blue, dotted trace is measured with 500 ns pulse width and shows a flat response on the top of the pulse. The green, dashed trace is measured with 200 ns pulse width. This value is equal to the calculated settling time. The peak level in this measurement just reaches the value measured with the 500 ns pulse. Marker 1 (T2) is set to the peak value and shows 9.97

dBm. This pulse width is the minimum value that can be accurately measured with the 10 MHz resolution bandwidth. The red, solid trace is measured with a 100 ns pulse width that is shorter than the settling time of the resolution filter. In this plot the delta marker reading "Delta 2 (T3)" is set to the peak value and shows a loss of about 3 dB versus the nominal pulse level.

The next step is a measurement of pulse width, which is usually defined as the point at which the signal level is at 50% of its average voltage across the pulse length (**Figure 15**). This point is 6 dB below the peak level in a logarithmic level grid typically used on a spectrum analyzer. For the measurement of pulse width, a marker is set to 6 dB below the average pulse power on the rising edge, and a delta marker is placed on the point 6 dB below the average power on the falling edge of the pulse.

Figure 15. Pulse width is usually defined as the point at which the signal level is at 50% of its average voltage across the pulse length.

The level reading of the delta marker in this case should be 0 dB. Because of the limited resolution of the measured points, a small level difference must be accepted. The reading of the delta marker "Delta 2 (T1)" in this measurement shows a pulse width of 508 ns. The accuracy of this measurement is influenced by the A/D converter sampling rate that defines the positions within the trace at which real measurement values are available. In between these points, the trace data is interpolated to generate the displayed points of the trace. The sampling rate of the A/D converter is 32 MHz, leading to measurement samples spaced by 31.25 ns.

The pulse modulation the output signal of a radar transmitter is spread across a wide bandwidth, which can be seen on a spectrum analyzer as the well-known sin x/x spectrum shape. The individual spectral lines do not allow direct calculation of the peak or mean power. Without knowing modulation parameters like pulse width or PRF, the calculation of power is

not possible. For channel power measurement, most modern spectrum analyzers provide software routines for calculating power within given channels. These routines calculate the power by integrating the power represented by the displayed trace pixels within the frequency range of the channel bandwidth.

Measuring mean power requires an RMS detector. When evaluating a radar signal, integration over several side lobes allows calculation of mean power, since most of the energy is contained in the main and adjacent side lobes of the sin x/x spectrum. By using a channel bandwidth broad enough to capture the main and several side lobes of the signal, the mean power can be measured.

Figure 16 shows the result of a channel power measurement. The channel bandwidth is set to a value of 10 MHz to capture the main lobe and both adjacent sidelobes.
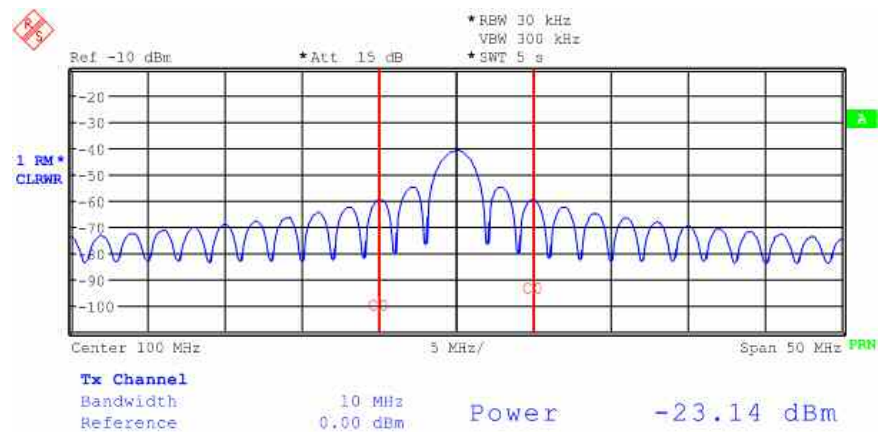

Figure 16.   A channel power measurement with a 10 MHz channel bandwidth.

The same measurement with 50 MHz channel bandwidth captures a bit more than 10 side lobes on each side (**Figure 17**). The measurement result of -23.01 dBm channel power agrees with the calculated mean power of the pulse signal. Even the measurement with 10 MHz shows good agreement with the target value, since most of the power is concentrated in the main and the first adjacent side lobes. For this method of measuring mean power, no knowledge of the pulse modulation parameters is necessary, and it is usable for pulse signals with continuously-changing pulse parameters.
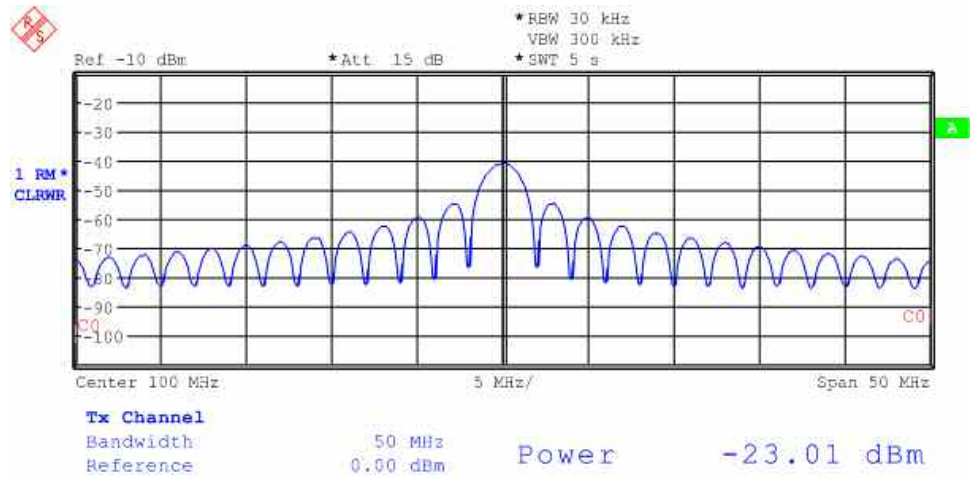
Figure 17. A channel bandwidth measurement with 50 MHz channel bandwidth captures more than 10 side lobes on each side.

4 Literature

1) Application Note 1EF48: Power Measurement on Pulsed Signals with Spectrum Analyzers
http://www.rohde-schwarz.com/appnote/1EF48.html

2) Application Note 1EZ52: Antenna Measurements, RCS Measurements and Measurements on Pulsed Signals with Vector Network Analyzers R&S ZVM, R&S ZVK
http://www.rohde-schwarz.com/appnote/1EZ52.html

3) Application Note 1MA32: Noise Figure Measurements on Amplifiers in Pulsed Mode
http://www.rohde-schwarz.com/appnote/1MA32.html

5 Additional Information

This application note is frequently updated. Please visit the website **1MA124** in order to download new versions. Please send any comments or suggestions about this application note to **TM-Applications@rsd.rohde-schwarz.com**.

6 Appendix: Rohde & Schwarz Aerospace and Defence Solutions

Signal generators: Versatile performance to 43.5 GHz

R&S®SMB100A: Redefining the "mid-range" signal generator
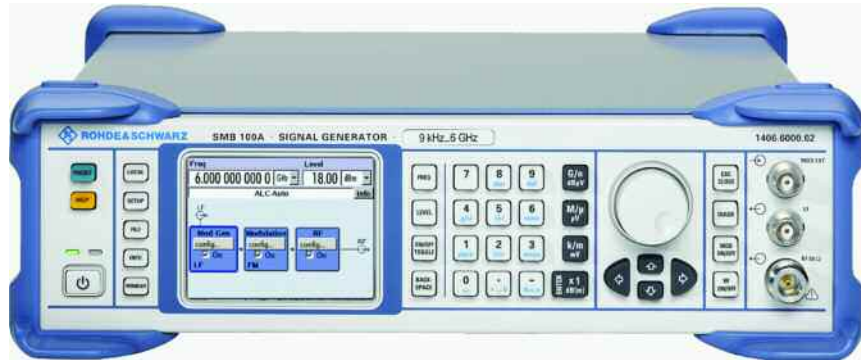
• 9 kHz to 1.1, 2.2, 3.2 or 6.0 GHz

• Best signal accuracy and highest output power of any instrument in its class

• Maximum output of +18 dBm

(+25 dBm in overrange)

• Frequency setting time <3 ms (frequency), <2.5 ms (level), and less than 1 ms in list mode

• Streamlined four-module architecture enables on-site self maintenace

• Optional pulse generator with minimum pulse width of 20 ns

• Optional pulse modulator with 90 dB on/off ratio and rise/fall times of 10 ns

• Environmentally robust with 0° C to 55° C operating temperature and a maximum altitude of 4600 m

• Compact unit weighs only 11.6 lb.

http://www2.rohde-schwarz.com/en/products/test_and_measurement/product_categories/signal_generation/rf_analog/SMB100A.html

R&S®SMF100A: Features tailored for defense applications

• 1 GHz to 22 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.

• Instrument's operating system, firmware, and data can be completely removed to ensure security as well as transport of data and test routines from one SMF100A to another

• Pulsed measurements begin with signal generation, and Rohde & Schwarz signal generators deliver the highest levels of performance. Each one is tailored to serve specific user needs -- and all are well suited for aerospace and defense applications.

http://www2.rohde-schwarz.com/en/products/test_and_measurement/product_categories/signal_generation/microwave/SMF100A.html

## R&S®SMA100A: Perfect fit for ATE and avionics receiver testing

• 9 kHz to 3 or 6 GHz

• Best SSB phase noise performance 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

• Extremely high measurement speed, excellent signal purity and compact footprint make it a perfect choice for ATE systems

• Can be equipped with ICAO-compliant VOR/ILS avionics signal generation option, which combined with its low modulation error and high level accuracy make the SMA100A an excellent choice for testing avionics receivers

http://www2.rohde-schwarz.com/en/products/test_and_measurement/product_categories/signal_generation/rf_analog/SMA100A.html

Signal and spectrum analyzers: Tailored for tough signal environments

### R&S®FSU67: 20 Hz to 67 GHz – without external mixers
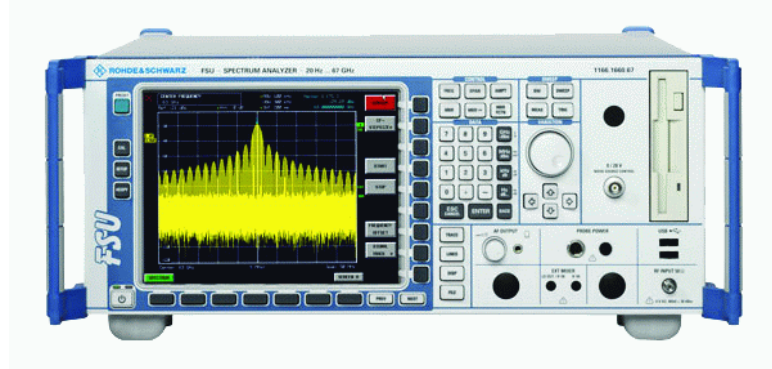
• Only spectrum analyzer to cover this broad frequency range without external harmonic mixers -- and their inherent drawbacks

• 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 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 perform as RF power meter just the addition of a sensor

• Broad array of analysis options

• Wide range of detectors: Sweep from 10 Hz to 50 MHz, FFT filters from 1 Hz to 30 kHz, and channel filters from 100 Hz to 5 MHz, 6-dB-bandwidth filters include 10 Hz, 100 Hz, 1 kHz, 10 kHz, 100 kHz, and 1 MHz filters needed for MIL-STD testing

Whether you're evaluating the performance of components and subsystems or analyzing the characteristics of suspect emitters, Rohde & Schwarz spectrum analyzers are the high-performance solution. For example, we offer the industry's only spectrum analyzer to cover up to 67 GHz without external harmonic mixers, as well as instruments that combine both spectrum analysis and vector signal analysis in a single enclosure.

http://www2.rohde-schwarz.com/en/products/test_and_measurement/product_categories/spectrum_analysis/FSU67.html

R&S®FSQ40: Vector signal analysis and spectral analysis in a single instrument
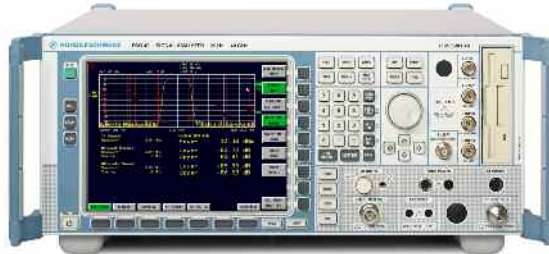
• 20 Hz to 3.6, 8, 26.5 and 40 GHz

• All the features of a high-performance spectrum analyzer combined with versatile signal analysis

•Resolution bandwidth settings up to 50 MHz provide more insight into pulsed signal analysis in zero-span mode.

•Maximum dynamic range of 170 dB

• 28 MHz demodulation bandwidth - and optionally 120 MHz

•Analog and digital baseband signal analysis flexibility

•Optional external harmonic mixers extend measurement range to 110 GHz

• Demodulates numerous modulation formats

•Support for all current commercial communication standards including WiMAX, WLAN, WCDMA, LTE, CDMA2000, GSM/Edge, and others.

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

Vector network analyzers: The industry's highest performance

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

• 300 kHz to 8 GHz

• Up to eight ports

• 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

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

- 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 while you sweep

- High-speed control of external components

The industry standard in pulse profile measurements

Option R&S®ZVA-K7 "Pulsed Measurements" for the R&S®ZVA and ZVT Series VNAs employs wideband detection and fast data recording to reduce or eliminate the bottlenecks that limit a VNA's ability to make pulse profile measurements with high resolution at high speed. The raw data is sampled and stored directly without filtering, and instrument firmware immediately performs digital downconversion and filtering. An A/D converter continuously digitizes and samples the data at 80MHz and writes it into high-speed RAM. The technique produces the fastest, most detailed and accurate pulsed profiling of any technique commercially available -- more than 10 sweeps/s over 1001 test points.

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

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download area of the Rohde & Schwarz website.*