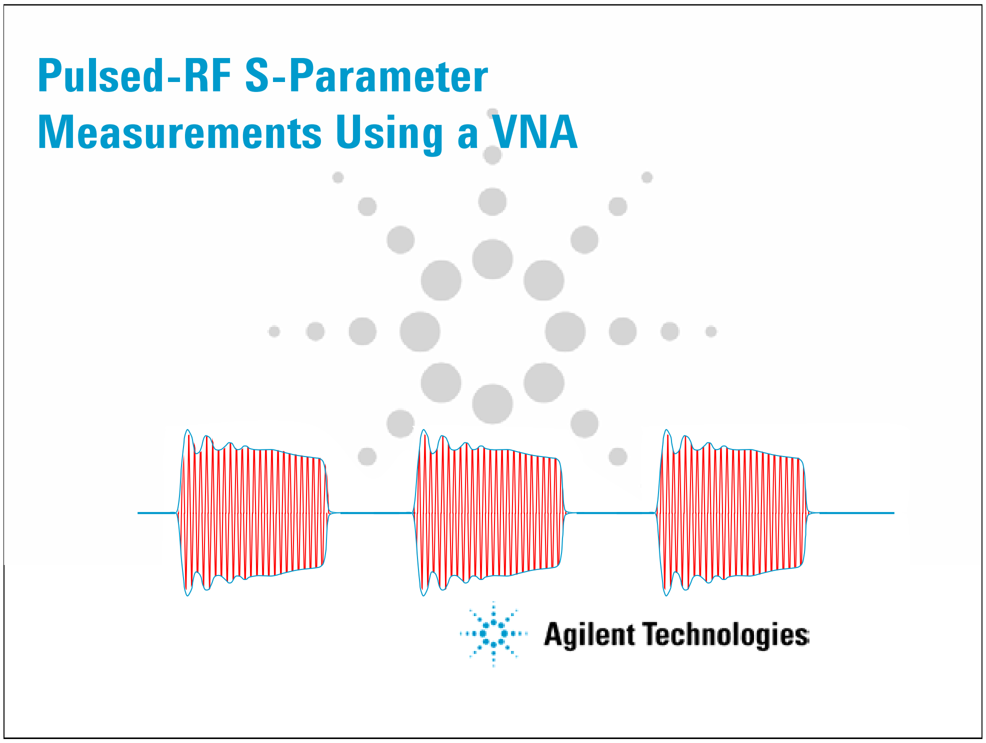
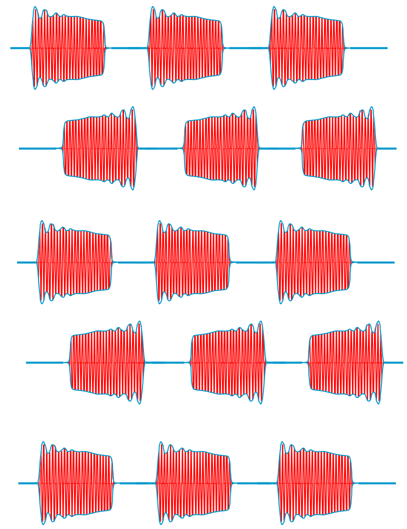


Welcome to the “Pulsed-RF S-parameter Measurements Using a VNA”. In this paper, we will focus on new measurement techniques and capability provided by Agilent’s PNA Series of microwave vector network analyzers.

Agenda

- Pulsed-RF Overview
- Pulsed-RF measurement techniques
  - Wideband/synchronous
  - Narrowband/asynchronous
  - Comparison PNA/8510
- PNA configurations



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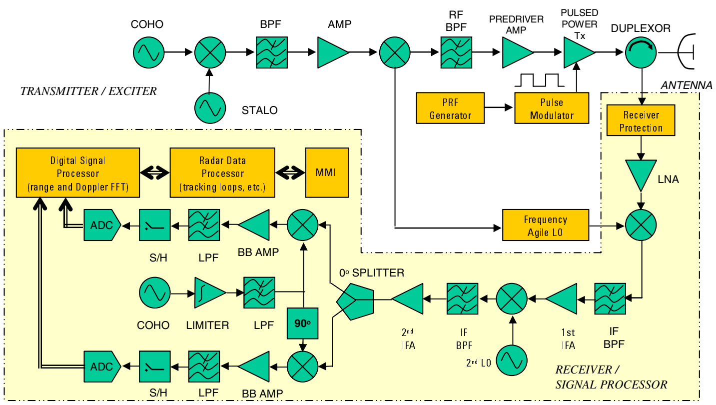
As part of our discussion of the two different measurement types (wideband and narrowband detection), we will compare and contrast the PNA with the industry standard for pulsed S-parameter measurements, the 85108A (the pulsed version of the 8510).

Component-Level Characterization

- Accurate characterization of components such as amplifiers, mixers, filters, and antennas is critical for effective system simulation
- Pulsed-RF stimulus crucial for many components in A/D applications



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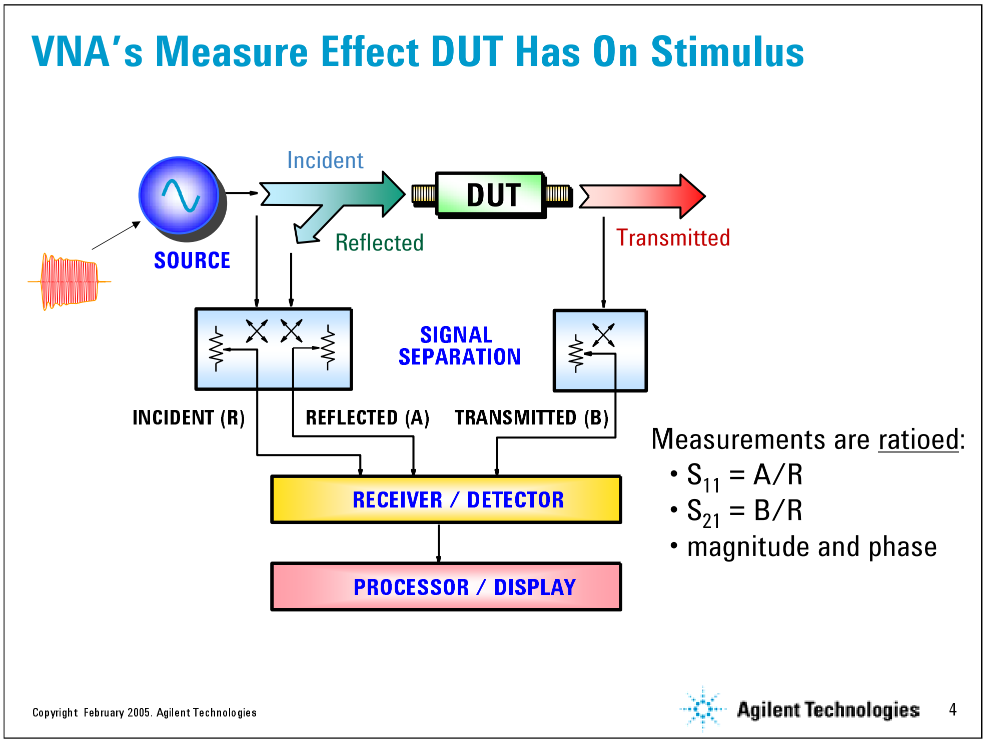
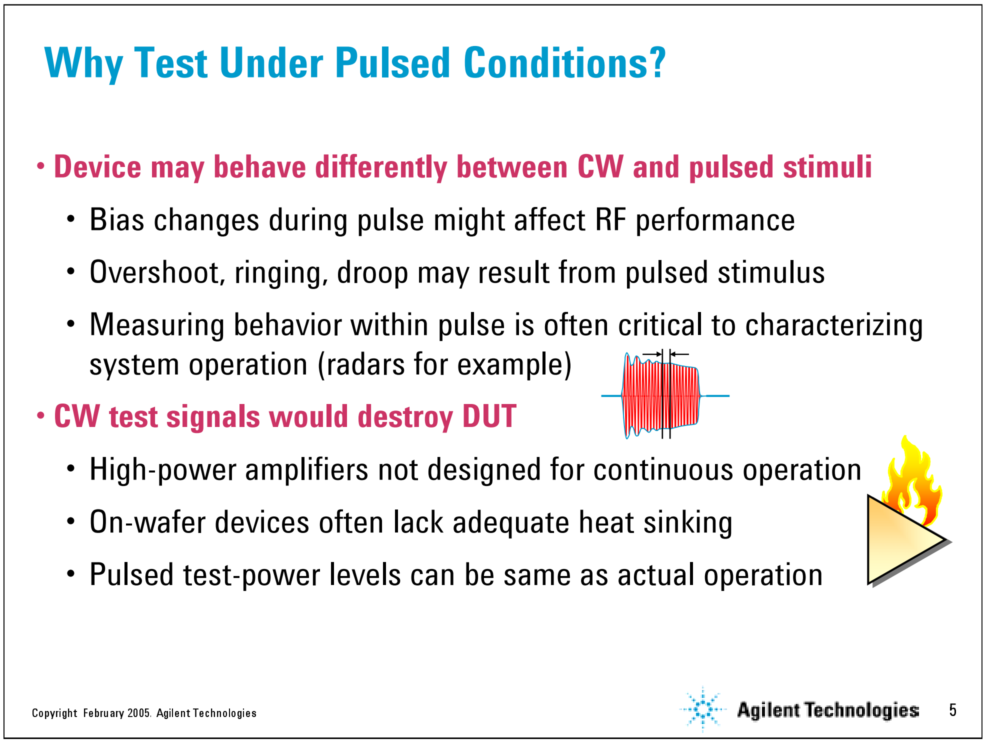
This slides shows an example of a modern microwave system – in this case, a radar. As can be seen from the slide, these systems are composed of many individual RF and microwave components, such as amplifiers, mixers, filters and antennas. Accurate characterization of these components is critical for effective system simulation and verification. Some of these components can be tested with conventional swept, continuous-wave (CW) signals, yielding traditional S-parameters. However, some of the components must be tested under pulsed-RF conditions to simulate their intended operating environment. We will cover both the required pulsed-RF measurements as well as the techniques by which they are achieved.



The topic of pulsed-RF testing is often focused on measuring the pulses themselves. This is critical, for example, in evaluating radar system performance and effectiveness. When measuring components however, the pulses are merely the stimulus, and the vector network analyzer (VNA) measures the effect that the device under test (DUT) has on the pulsed stimulus. Any non-ideal behavior of the pulses themselves is removed from the measurement since the VNA performs ratioed measurements. This means that each S-parameter measurement compares a measured reflection or transmission response with the incident signal, providing ratioed magnitude and phase results. In the slide above, which shows forward S-parameter measurements, the R receiver measures the incident signal, the A receiver measures the reflection response, and the B receiver measures the transmission response. S11 is the ratio of the A receiver and R receiver, and S21 is the ratio of the B receiver and R receiver.



Testing under pulsed-RF conditions is very valuable for devices that will be used in a pulsed-RF environment, since the behavior of many components differs between CW and pulsed-stimulus test. For example, the bias of an amplifier might change during a pulse. Or, the amplifier might exhibit overshoot, ringing, or droop as a result of being stimulated with a pulse. Also, particularly for radar systems, measuring the transient behavior within the pulse is critical for understanding system operation. Unintended modulation on the pulse (UMOP) can cause several system problems in radar systems:

•decreased clutter rejection

•decreased target velocity resolution

•undesired spread of phased-array-antenna beam patterns

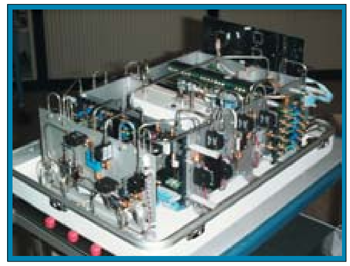
•unintentional identification of a radar system

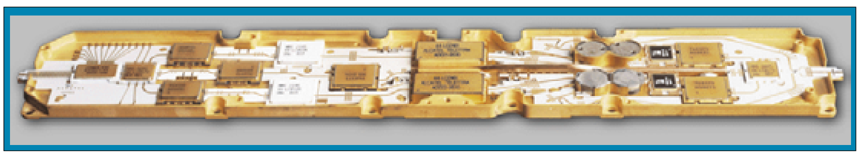
Characterizing the amplitude and phase versus time in the pulse is crucial to characterizing and containing UMOP.

Many devices simply cannot be tested with CW stimulus at the desired power levels. For example, many high-power amplifiers are not designed to handle the power dissipation of continuous operation, and when testing on-wafer, many devices lack sufficient heat sinking for CW test. Testing with pulses allows the test-power levels of these devices to be consistent with actual operation (which gives more realistic characterization), without thermal-induced damage. Characterizing these devices on-wafer prevents devices that don’t meet their specifications from being packaged, saving the manufacturer considerable time and money.

Radar and Electronic-Warfare

- Biggest market for pulsed-RF testing
- Traditional applications ≤ 20 GHz
- Devices include
  - amplifiers
  - T/R modules
  - up/down converters





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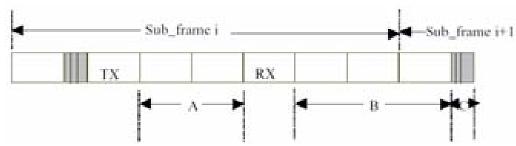
When we look at the various markets that use pulsed-RF stimulus, aerospace/defense applications covering radar and electronic warfare represent the biggest segment. Traditionally, radar applications have largely been in the 2 to 18 GHz range, but modern radars are pushing carrier frequencies up to 30 or 40 GHz. Typical devices that are tested include amplifiers, transmit/receive (T/R) modules, as well as frequency-translating devices such as up or down converters.

Wireless Communications Systems

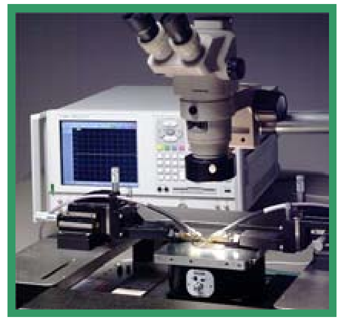
- TDMA-based systems often use burst mode transmission
  - Saves battery power
  - Minimizes probability of intercept
- Power amplifiers often tested with pulsed bias
- Most of wireless communications applications ≤ 6 GHz



Another important segment for pulsed-RF testing involves components that are used in burst-mode transmission systems, such as time-division multiple access (TDMA) cellular-telephone protocols. One example is GSM, which is employed worldwide. Most of this market is below 6 GHz, largely due to the proliferation of commercial cellular communications. However, military radios also employ this technique, which not only saves battery power, but also minimizes the probability of intercept. The most important components tested for these systems are the output power amplifiers. Often, the bias to these amplifiers must be pulsed in place of or in addition to pulsing the RF input signal.

On-Wafer Amplifier Test and Modeling

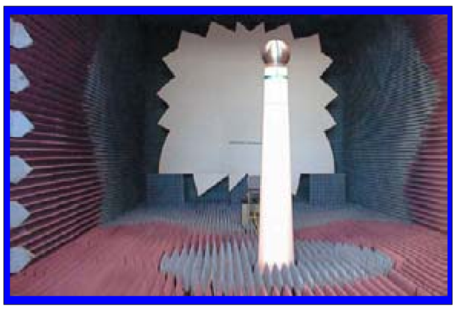
- Most applications are at microwave frequencies
- Devices lack adequate heatsinking for CW testing, so pulsed-RF used as a test technique to extract S-parameters
- Arbitrary, stable temperature (isothermal state) set by adjusting duty cycle
- Duty cycles are typically < 1%
- Often requires synchronization of pulsed bias and pulsed RF stimulus

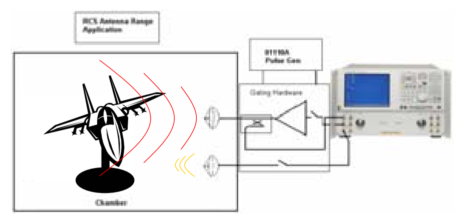


This market segment, which is predominantly at microwave frequencies, requires pulsed testing to prevent thermal damage to on-wafer devices that lack adequate heat-sinking for CW testing. With pulsed stimulus, S-parameters can be measured at power levels similar to those used in actual operation, and the duty cycle of the pulses can be adjusted to obtain arbitrary, stable temperatures. This process can yield S-parameter measurements versus device temperature, helping generate data necessary for accurate device models. Generally, the duty cycles are below 1% and are often below 0.1%. Also, the bias to the DUT is typically pulsed as well, requiring synchronization with the pulsed RF stimulus.

Pulsed Antenna Test

- About 30% of antenna test involves pulsed-RF stimulus
- Test individual antennas, complete systems, or RCS
- RCS (Radar Cross Section) measurements often require gating to avoid overloading receiver





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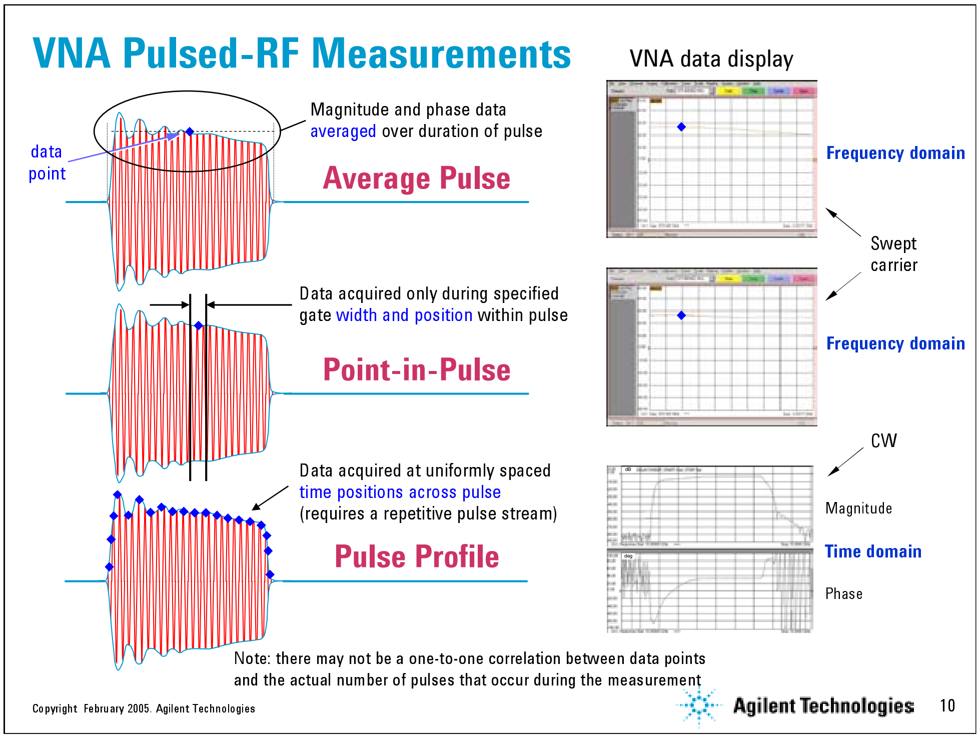
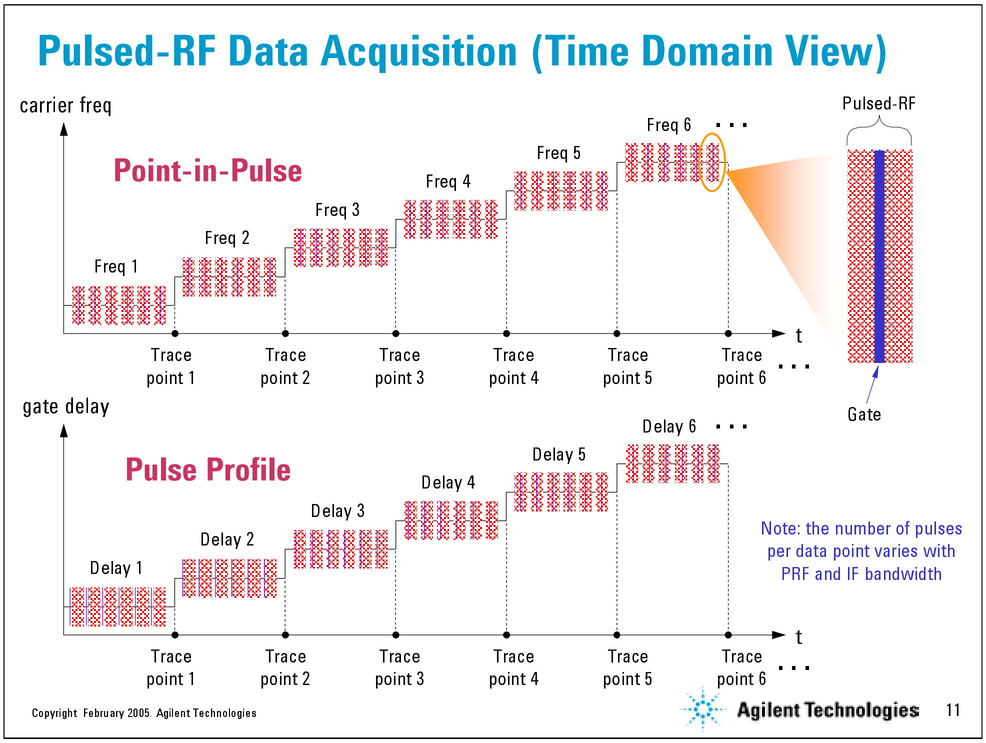
Approximately one third of antenna-test applications involves pulsed-RF stimulus. These can be measurements where the DUT is an antenna, or a larger system with an antenna at the front end. Also included in this segment are applications where the DUT is not an antenna, but an antenna is critical to the measurement of the DUT. Examples include radar cross-section (RCS) measurements, and free-space materials measurements. High-power pulses are often used in RCS measurements to overcome the high losses due to low device reflection and two-way transmission path loss. For this reason, receiver gating is often required in RCS measurements to avoid overloading the receiver during the transmission of the pulsed-RF signal.

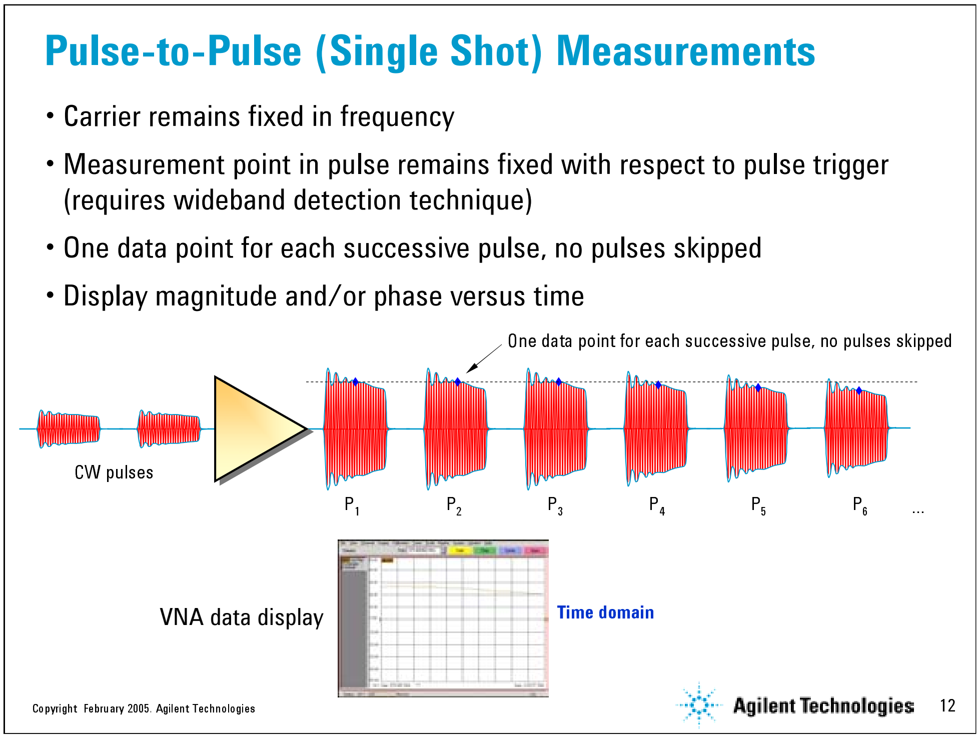


This slide shows three major types of pulsed-RF measurements. The first two are pulsed S-parameter measurements, where a single data point is acquired for each carrier frequency. The data is displayed in the frequency domain as magnitude and/or phase of transmission and reflection. Average pulse measurements make no attempt to position the data point at a specific point within the pulse. For each carrier frequency, the displayed S-parameter represents the average value of the pulse. This occurs for example when doing narrowband detection without any receiver gating. Point-in-pulse measurements result from acquiring data only during a specified gate width and position (delay) within the pulse. There are different ways to do this in hardware, depending on the type of detection used, which will be covered later. Pulse profile measurements display the magnitude and phase of the pulse versus TIME, instead of frequency. The data is acquired at uniformly spaced time positions across the pulse. This is achieved by varying the delay of measurement with respect to the pulse while the carrier frequency is fixed at some desired frequency.

For all of these measurements, there may not be a one-to-one correlation between data points and the actual number of pulses that occur during the measurement. For example, with narrowband detection, many pulses can occur before enough data is collected for each data point. With wideband detection, the analyzer may not be able to completely process a data point during the time between pulses, resulting in skipped pulses between displayed data points.

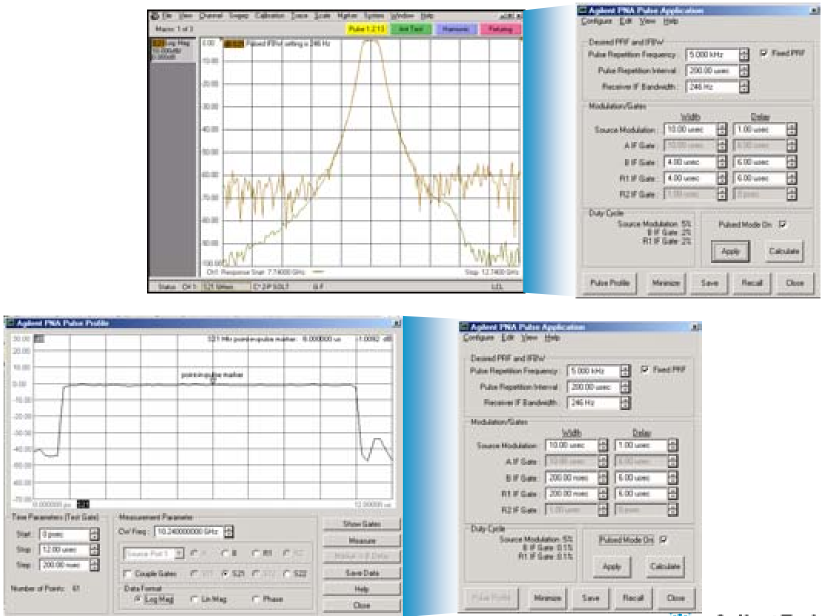


This slide shows in more detail how the data acquisition occurs for point-in-pulse and pulse-profile measurements. Although in this example we show that 6 pulses are required for every data point, the number of pulses needed varies with PRF and IF bandwidth, and ranges from one (using wideband detection) to many (using narrowband detection). We will explain the differences between detection techniques later in this presentation. For point-in-pulse measurements, the gate position is constant (relative to the pulse trigger) for all the pulses, regardless of carrier frequency. Each successive data point represents a higher carrier frequency. For pulse-profile measurements, the gate position is constant only during the time it takes to measure one data point. For each successive data point, the gate delay is increased, so that after all the trace points are acquired, the delay will have spanned the range set up in the pulse-profile measurement.



Pulse-to-pulse measurements are used to characterize how a pulse stream changes versus time due to variations in the performance of the DUT. For example, thermal effects in an amplifier can cause gain reduction and phase shifts. These measurements are done with a fixed RF carrier, so the data is displayed in the time domain. The measurement point remains fixed in time with respect to a pulse trigger. This technique requires wideband detection and the data processing in the analyzer must be fast enough to keep up with the pulses. There must be one data point per pulse and no pulses can be skipped.

PNA Option H08 Demo: Point-in-Pulse, Pulse Profile



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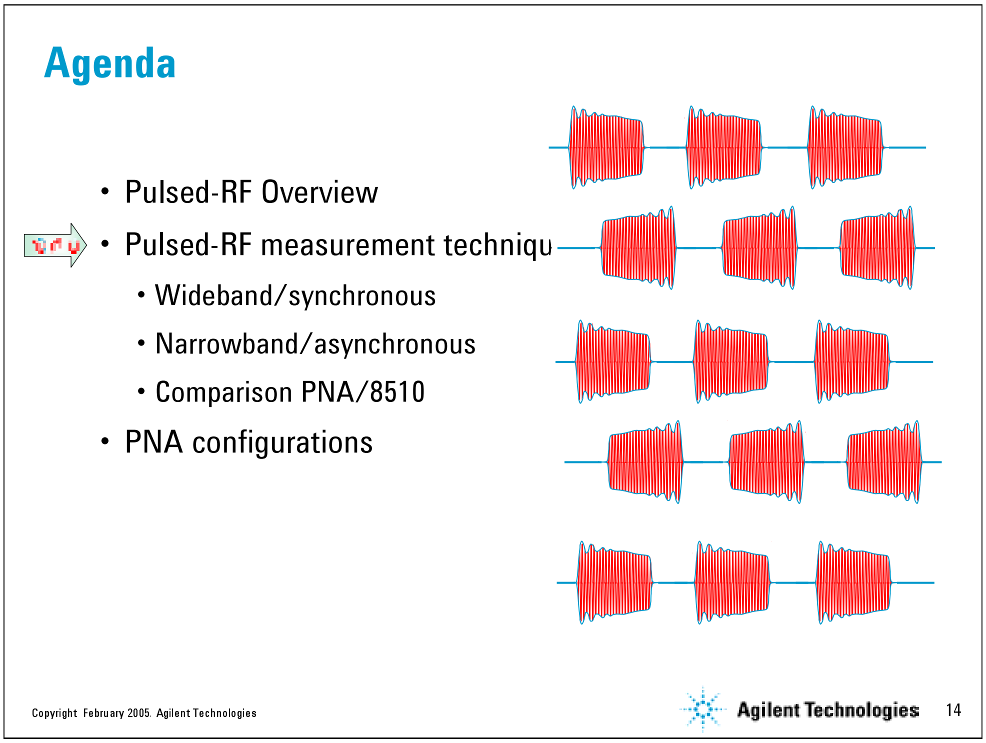
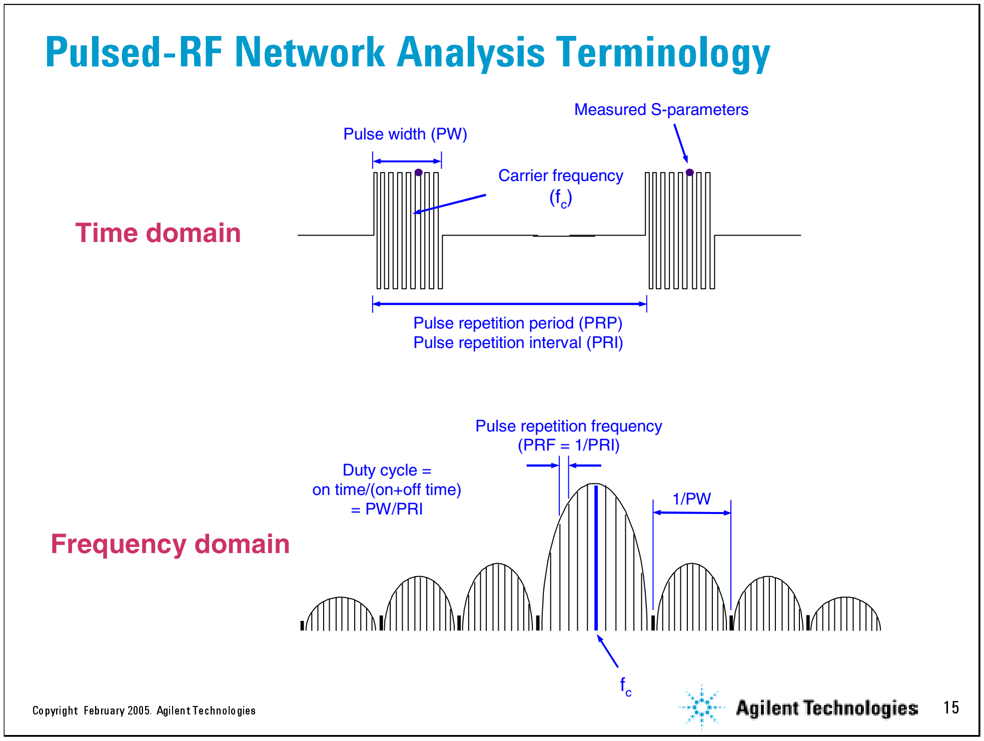
With this demonstration, we show the PNA making point-in-pulse and pulse-profile measurements.



As part of our discussion of the two different measurement types (wideband and narrowband detection), we will compare and contrast the PNA with the industry standard for pulsed S-parameter measurements, the 85108A (the pulsed version of the 8510).



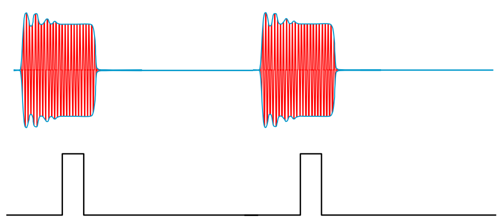
This presentation assumes the reader already is familiar with pulsed-RF measurements. The basic concepts of pulsed RF are reviewed on this slide. When a signal is switched on and off in the time domain ("pulsed"), the signal's spectrum in the frequency domain has a sin(x)/x response. The width of the lobes are inversely related to the pulse width (PW). This means that as the pulses get shorter in duration, the spectral energy is spread across a wider bandwidth. The spacing between the various spectral components is equal to the pulse repetition frequency (PRF). If the PRF is 10 kHz, then the spacing of the spectral components is 10 kHz. In the time domain, the repetition of pulses is expressed as pulse repetition interval (PRI) or pulse repetition period (PRP), which are two terms for the same thing.

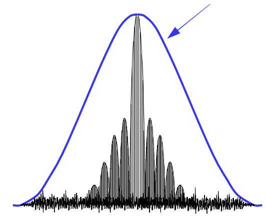
Another important measure of a pulsed RF signal is its duty cycle. This is the amount of time the pulse is on, compared to the period of the pulses. A duty cycle of 1 (100%) would be a CW signal. A duty cycle of 0.1 (10%) means that the pulse is on for one-tenth of the overall pulse period. For a fixed pulse width, increasing the PRF will increase the duty cycle. For a fixed PRF, increasing the pulse width increases the duty cycle. Duty cycle will become an important pulse parameter when we look at narrowband detection.

Pulsed S-parameter Measurement Modes

Wideband/synchronous acquisition

- Majority of pulse energy is contained within receiver bandwidth
- Incoming pulses and analyzer sampling are synchronous (requires a pulse trigger, either internal (8510) or external (PNA)
- Pulse is "on" for duration of data acquisition
- No loss in dynamic range for small duty cycles (long PRI's), but there is a lower limit to pulse width





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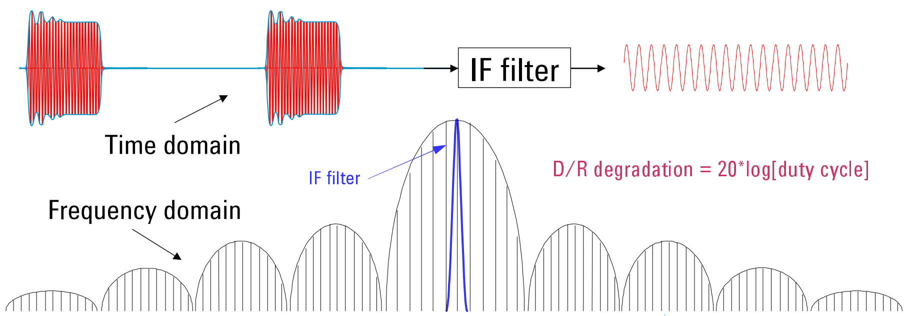
Wideband detection can be used when the majority of the pulsed-RF spectrum is within the bandwidth of the receiver. In this case, the pulsed-RF signal will be demodulated in the instrument, producing baseband pulses. This detection can be accomplished with analog circuitry or with digital-signal processing (DSP) techniques. With wideband detection, the analyzer is synchronized with the pulse stream, and data acquisition only occurs when the pulse is in the "on" state. This means that a pulse trigger that is sync'd to the PRF must be present, and for this reason, this technique is also called synchronous acquisition mode. 8510-based systems had a built-in pulse generator to synchronize the data acquisition, while the PNA relies on external pulse generators.

The advantage of the wideband mode is that there is no loss in dynamic range when the pulses have a low duty cycle (long time between pulses). The measurement might take longer, but since the analyzer is always sampling when the pulse is on, the signal-to-noise ratio is essentially constant versus duty cycle. The disadvantage of this technique is that there is a lower limit to measurable pulse widths. As the pulse width gets smaller, the spectral energy spreads out -- once enough of the energy is outside the bandwidth of the receiver, the instrument cannot detect the pulses properly. Another way to think about it in the time domain is that when the pulses are significantly shorter than the rise time of the receiver, they cannot be detected.

Pulsed S-parameter Measurement Modes

Narrowband/asynchronous acquisition

- Extract central spectral component only; measurement appears CW
- Data acquisition is not synchronized with incoming pulses (pulse trigger not required)
- Sometimes called “high PRF” since normally, PRF >> IF bandwidth
- “Spectral nulling" technique achieves wider bandwidths and faster measurements
- No lower limit to pulse width, but dynamic range is function of duty cycle

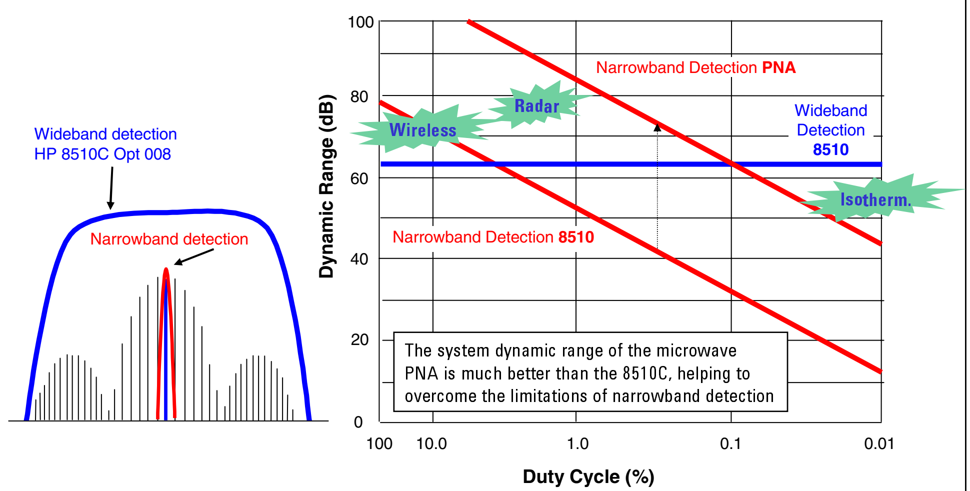


Narrowband detection is used when most of the pulsed-RF spectrum is outside the bandwidth of the receiver. With this technique, all of the pulse spectrum is removed by filtering except the central frequency component, which represents the frequency of the RF carrier. After filtering, the pulsed RF signal appears as a sinusoid or CW signal. With narrowband detection, the analyzer samples are not synchronized with the incoming pulses (therefore no pulse trigger is required), so the technique is also called asynchronous acquisition mode. Usually, the PRF is high compared to the IF bandwidth of the receiver, so the technique is also sometimes called the “high PRF” mode.

Agilent has developed a novel way of achieving narrowband detection using wider IF bandwidths than normal, by using a unique “spectral-nulling” technique that we will explain in the following slides. This technique lets the user trade dynamic range for speed, with the result almost always yielding faster measurements than those obtained by conventional filtering.

The advantage to narrowband detection is that there is no lower pulse-width limit, since no matter how broad the pulse spectrum is, most of it is filtered away anyway, leaving only the central spectral component. The disadvantage to narrowband detection is that measurement dynamic range is a function of duty cycle. As the duty cycle of the pulses gets smaller (longer time between pulses), the average power of the pulses gets smaller, resulting in less signal-to-noise ratio. In this way, measurement dynamic range decreases as duty cycle decreases. This phenomenon is often called “pulse desensitization”. The degradation in dynamic range (in dB) can be expressed as 20*log (duty cycle).

Duty Cycle Effect on Pulsed Dynamic Range



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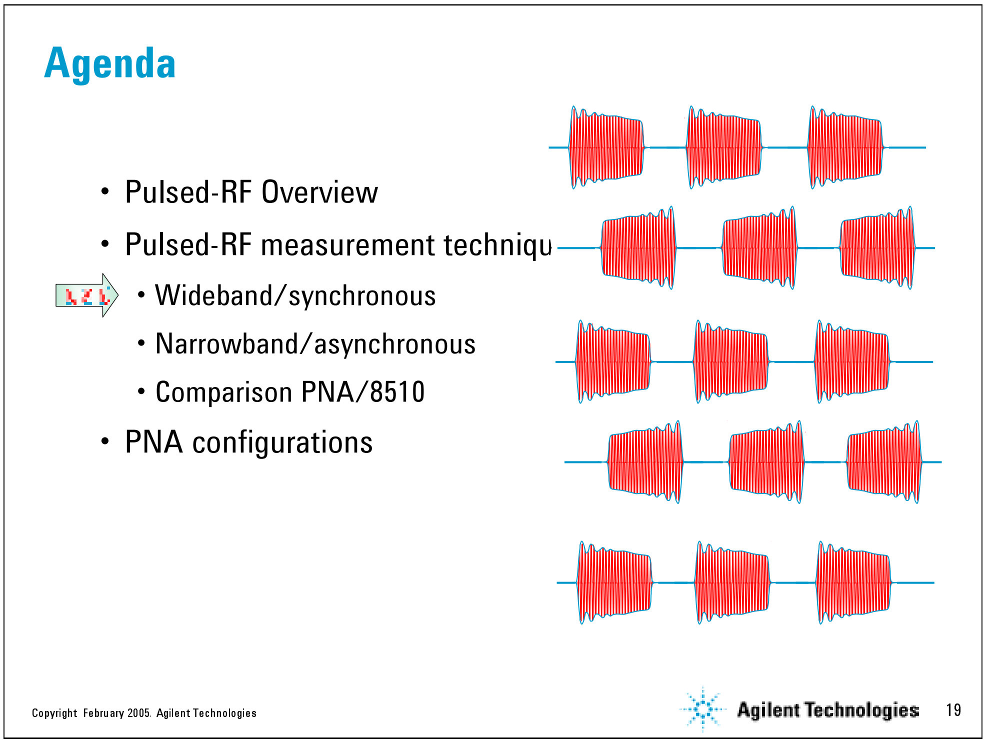
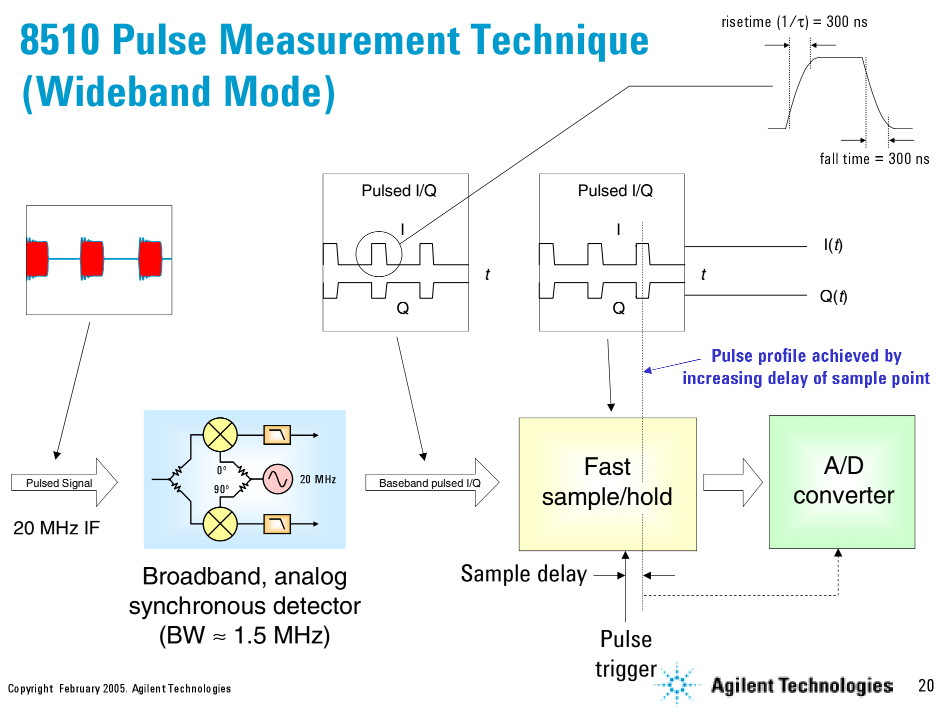
This slide shows the effect of duty cycle on pulsed dynamic range. We see the 8510, using broadband detection, has around 62 dB of dynamic range, independent of duty cycle. The PNA's dynamic range decreases with decreasing duty cycle. For every factor of 10 decrease in duty cycle, the dynamic range is reduced by 20 dB. The cross-over point is approximately 0.1% -- this means that for duty cycles of 0.1% or more, the PNA will have as much or more dynamic range than an 85108A system. This duty cycle range covers most radar/EW and wireless communications measurement applications. The PNA's inherent high dynamic range (compared to the 8510) helps it overcome the limitations of narrowband detection. Also, the PNA has the advantage of being able to measure pulses narrower than 1 us, which is the 8510's limit.

Note that the x-axis of this chart is the system duty cycle, which takes into account any gating that the PNA uses for point-in-pulse or pulse-profiling measurements. If the gate is such that only one-fifth of each incoming pulse is measured, then the overall duty cycle is effectively reduced by a factor of 5.



Let's look more in-depth now at wideband detection. We will compare how 8510 and PNA hardware and firmware implement this mode of operation.

8510 Pulse Measurement Technique (Wideband Mode)



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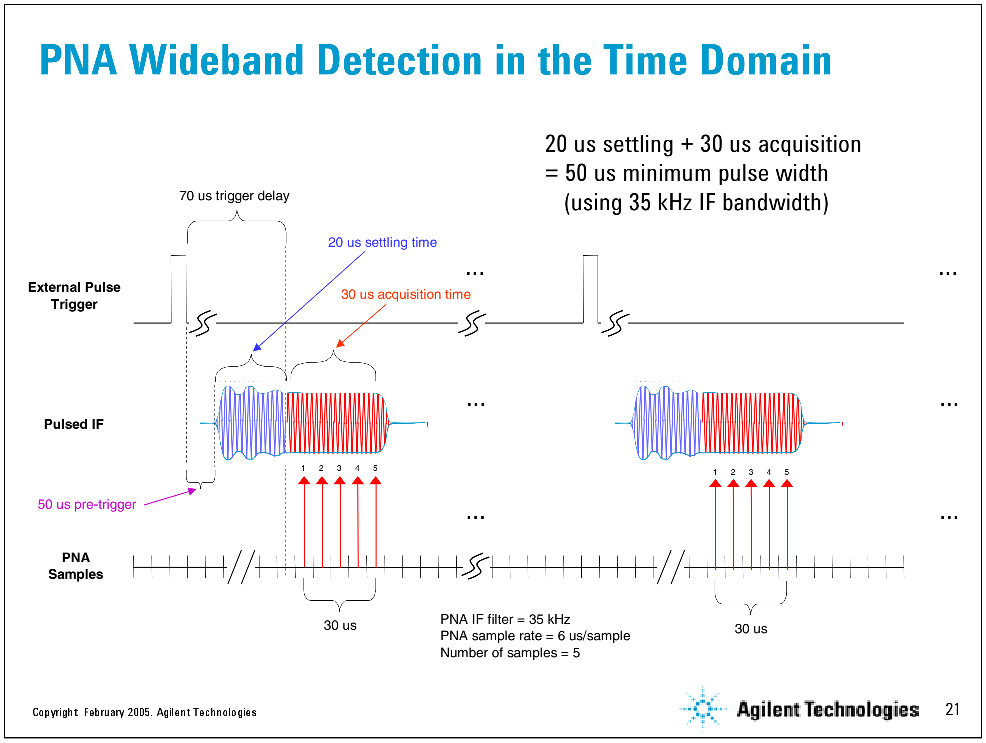
Here is a block diagram of the 85108 (the 8510-based pulsed-RF system). The incoming 20 MHz pulsed IF signal is synchronously detected (using homodyne mixing) to produce baseband I/Q pulses. The detection bandwidth is about 1.5 MHz for the I and Q outputs (equivalent to a 3 MHz pre-detection bandwidth), yielding pulses that have about a 300 ns rise time (1/τ). The pulse width must be greater than several τ in order for the detector to fully respond to the pulses. The specification for minimum pulse width on the 85108 is 1 us, but the pulse width can be pushed down to perhaps 500 ns or so.

After the pulses are detected, a fast sample-and-hold is used prior to the relatively slow analog-to-digital converter (ADC). Once the pulses are digitized, magnitude and phase is calculated. The actual sample point can be programmed with any arbitrary delay with respect to the pulse trigger, which is how the 8510 performs point-in-pulse measurements. Pulse profiling is achieved by stepping the sample delay from zero to some arbitrary value that covers the duration of the pulse.

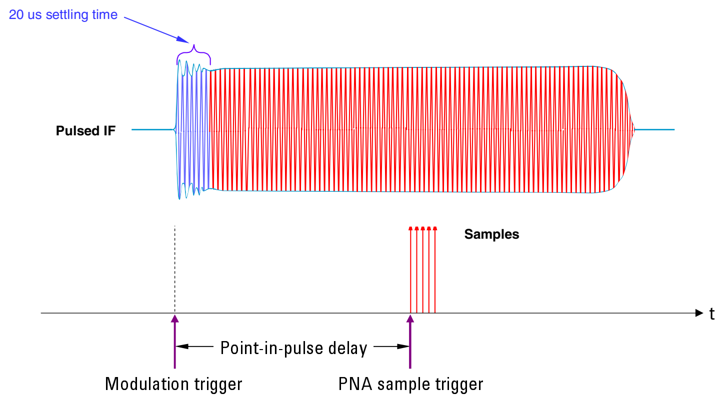


Here is a conceptual block diagram of how the PNA achieves wideband detection. Since all of the PNA's processing (filtering and detection) is done with DSP, the incoming pulsed-IF is sampled directly. The 35 kHz of the PNA requires 5 samples (more on this later), which requires 30 us of acquisition time (6 us per sample). However, due to settling-time issues, the pulse must be present about 20 us prior to sampling. This yields a minimum pulse width of about 50 us. To achieve this value, the "auto-IF-gain" mode of the PNA's receivers must be turned off. Note that the trigger delay of the PNA (the time between the external pulse trigger and when the PNA actually takes data) is about 70 us. This means the PNA must be triggered about 50 us before the trigger is applied to the pulse modulator. This 50 us plus the 20 us of pulse settling time gives 70 us.

The PNA-L, a lower-cost version of the PNA, can also perform wideband pulse detection. The PNA-L has wider maximum IF bandwidths than the PNA, allowing wideband detection to work with pulses as narrow as 10 us or 2 us, depending on the particular model (the "auto-IF-gain" mode must also be turned off for some models). Note that the PNA-L cannot utilize narrowband detection with spectral nulling, as can be done with the PNA. We will discuss narrowband detection in the next section.

PNA Wideband Detection – Point-in-Pulse

- Set delay of PNA sampling (relative to RF modulation) to establish desired position within pulse (controlled by pulse generator outputs)
- Width of acquisition window is determined by IF bandwidth



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Shown on this slide is a longer pulse than that shown on the previous slide, illustrating how the PNA can perform point-in-pulse and pulse-profile measurements using wideband detection. We can specify where in the pulse we acquire data by setting the delay of the PNA sample trigger relative to the modulation trigger. The width of the acquisition window (which determines the resolution of the point-in-pulse or pulse-profile measurement) is determined by the PNA's IF bandwidth. Due to the 35 kHz maximum IF bandwidth on the PNA, the smallest resolution that can be achieved using wideband detection is 30 us. We will see later on that narrowband detection and IF gates can provide much higher resolution (20 ns).

Minimum Pulse Widths for Point-in-Pulse Measurements Using Wideband Detection

	Maximum IF bandwidth	Minimum pulse width	IF auto-gain mode*
PNA models (20, 40, 50, 67 GHz)	40 kHz	50 us	Yes
PNA-L models (2-port, 20, 40, 50 GHz)	250 kHz	10 us	Yes
PNA-L models (2-port, 6, 13.5 GHz; 4-port, 20 GHz)	600 kHz	2 us	No

* Note: for point-in-pulse measurements, the IF auto-gain mode should be turned off (i.e., set IF gains manually)

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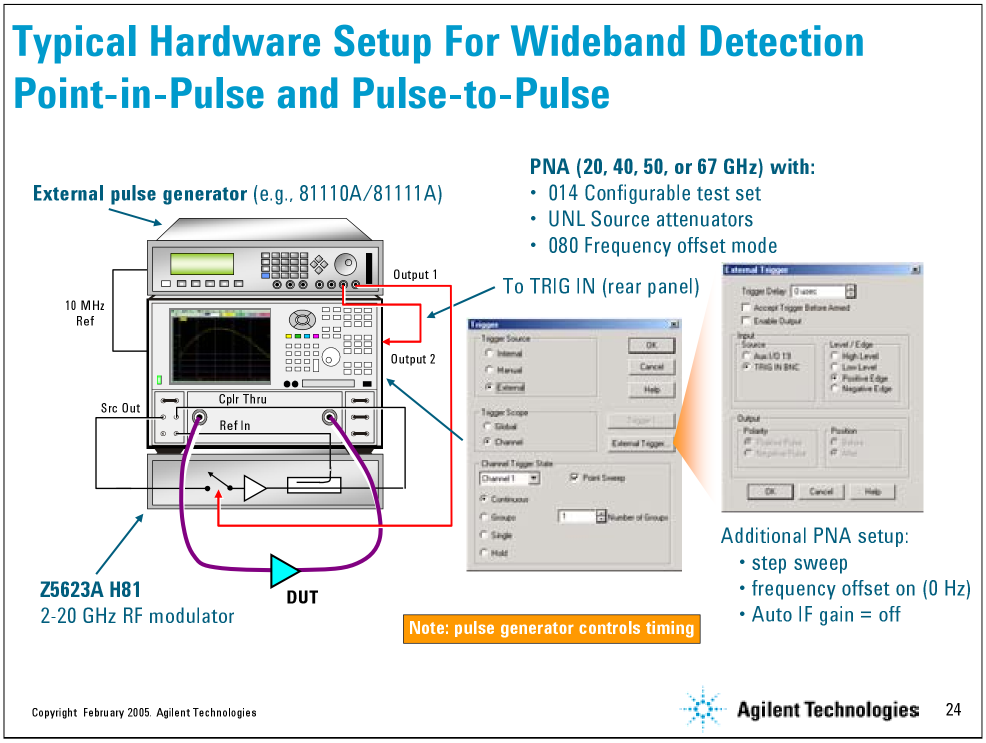
Here is a summary of the different PNA models for point-in-pulse measurements using wideband detection.



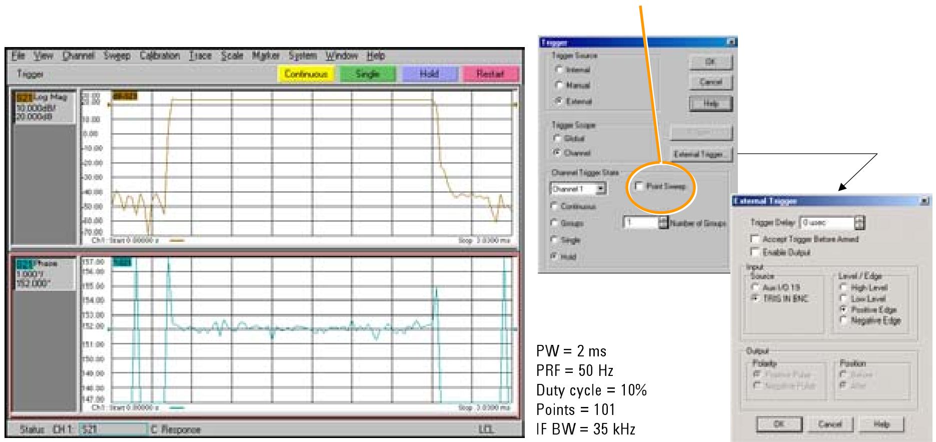
Here is a typical PNA setup for making wideband pulsed-RF measurements. This configuration can be used for pulse-to-pulse measurements or point-in-pulse measurements, when the pulse width is sufficiently wide. In this example, the overall pulse timing is set by the pulse generator. Note that Option H11 is not needed, since point-in-pulse measurements are done by adjusting the pulse delay of the trigger signal to achieve acquisition at the desired point in time. Wideband measurements also do not require Option H08, which is the pulse application used for narrowband detection. For point-in-pulse measurements, which essentially are S-parameter measurements, the start and stop frequencies must be set up to the proper values. For pulse-to-pulse measurements, the PNA is set up in CW-Time mode. In this case, each trace point is a subsequent pulse, and all pulses have the same carrier frequency. The minimum PRI that the PNA can keep up with without missing pulses depends on which PNA or PNA-L is used.

Wideband Pulse Profiling

8510: vary delay of sampling point

PNA: trigger once at start of sweep

Point sweep is turned off for wide-band pulse profiling



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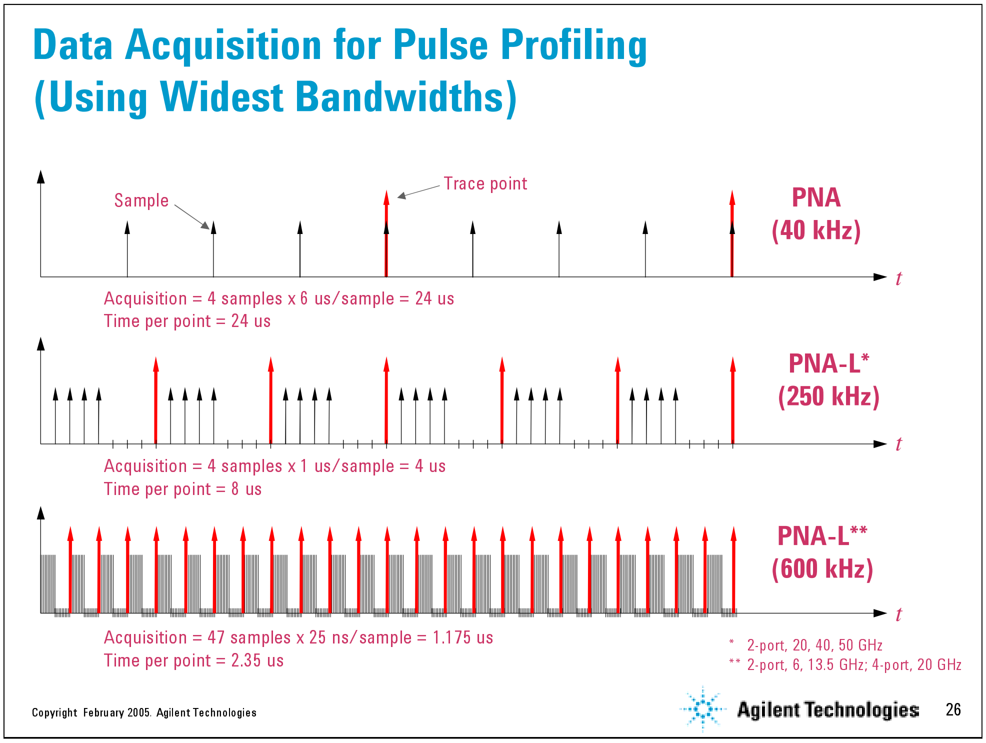
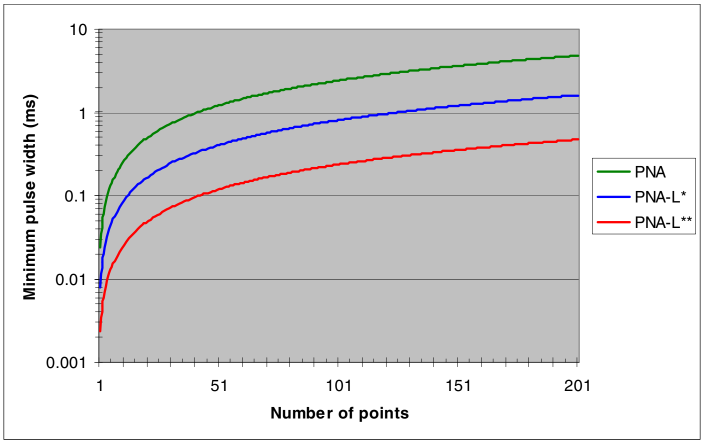
To do pulse profiling using wideband detection with the PNA, the point-sweep mode is not used. An external trigger is used to start the measurement, and then the PNA takes data as fast as it can (see the timing diagram on the next slide). There is no need to increment the delay of the trigger as was done with the 8510. Note that for n-points, the pulse must be longer than n x the PNA's data-point acquisition time. This results in a minimum measurable pulse width than is much longer than the minimum pulse width that can be used for point-in-pulse measurements, where the pulse must only be longer than 1 x the PNA's data-acquisition time (plus a bit extra for IF settling time).



This slide shows how data is taken during pulse profiling using wideband detection. Using the widest bandwidth in the PNA results in a trace point every 24 us, with no gaps in the data-acquisition process. The 20, 40, and 50 GHz PNA-L models have 8 us/trace-point resolution, although the measurement for each trace point only takes 4 us. The discrepancy between these values is because the data-acquisition chain cannot keep up with the fundamental sampling rate of the analyzer, resulting in 4 unused samples for each trace point. The lower frequency PNA-L models have an even faster sampling rate, resulting in a resolution of 2.35 us/trace-point, but with a 50% effective sampling rate as well.

Minimum Pulse Widths for Pulse Profile Measurements Using Wideband Detection



* PNA-L 2-port, 20, 40, 50 GHz

** PNA-L 2-port, 6, 13.5 GHz; 4-port 20 GHz

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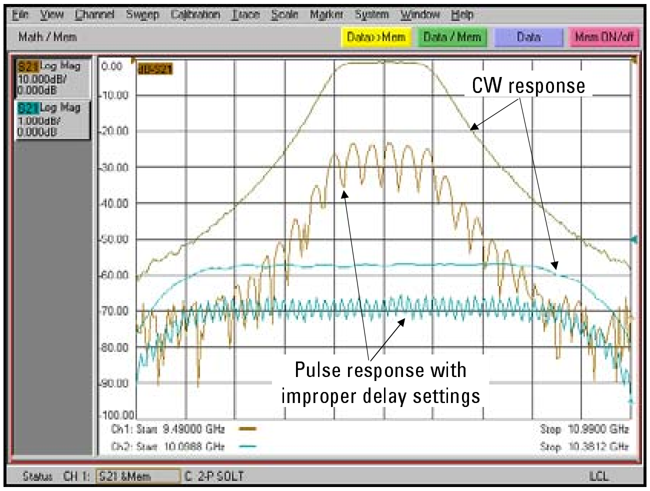
The data for this slides assumes that the widest available IF bandwidth is used.

Demo of Wideband Detection



PRF = 4 kHz
Width = 50 us
PNA IF BW = 35 kHz

Note:
Trace 2 has a narrower span and a more sensitive scale than Trace 1

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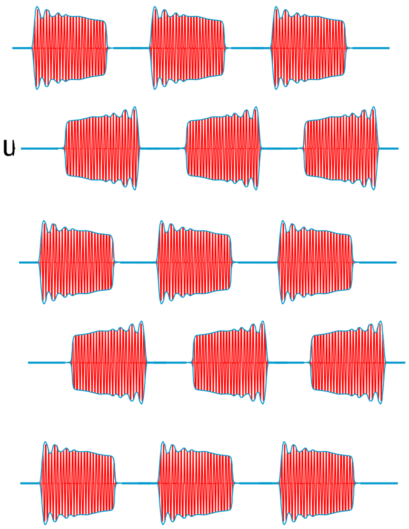
In this demo, we see the importance of setting the proper trigger delay for the PNA, to give accurate point-in-pulse measurements. When the PNA’s data acquisition is not properly positioned within the pulse, we see either pure noise, or a noisy response that is smaller than the true response. The correct trigger delay setting is generally derived empirically. The trigger delay can be set using the PNA’s trigger-delay feature, or via the pulse generator’s timing. Note that most pulse generators have more timing resolution for the delay setting than can be achieved using the PNA’s trigger-delay feature.

Agenda

- Pulsed-RF Overview
- Pulsed-RF measurement techniqu
  - Wideband/synchronous
  - Narrowband/asynchronous
  - Comparison PNA/8510
- PNA configurations



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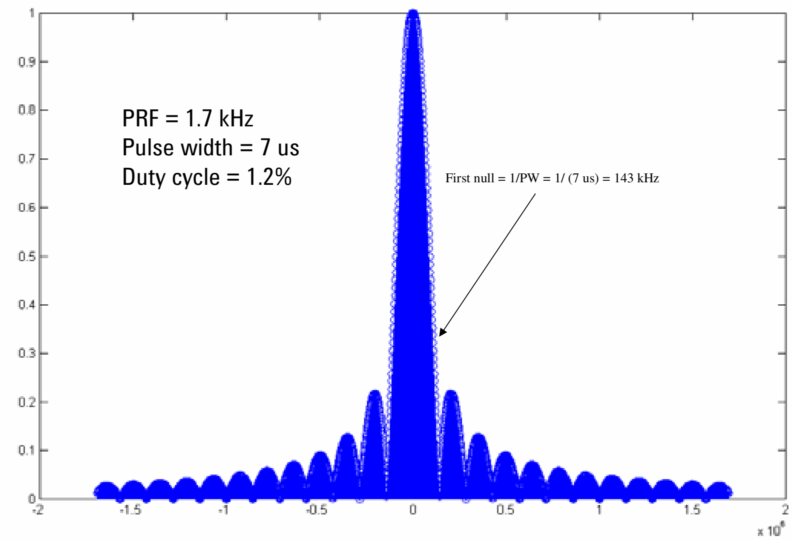
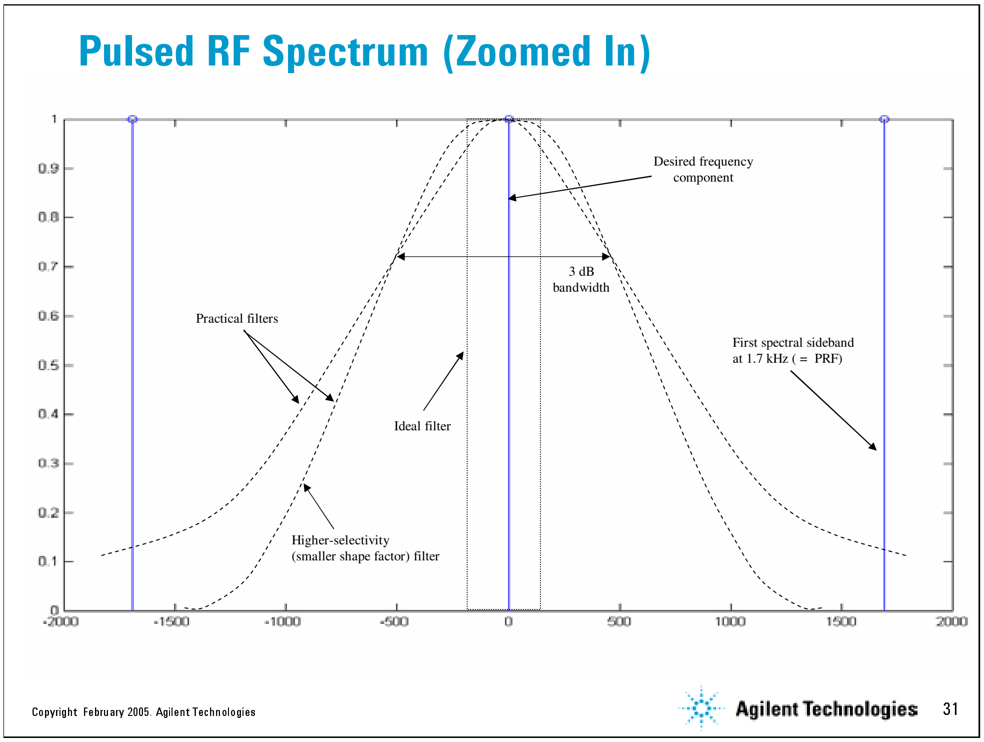
This section will focus exclusively on the PNA and its unique “spectral nulling” technique for narrowband detection. Spectral nulling allows the use of wider bandwidths, improving measurement speed.

Pulsed RF Spectrum of Measurement Example



To understand how the spectral nulling works with narrowband detection, we will use the pulsed-RF signal shown on the slide as an example. Let's now zoom in around the central spectral component, which is shown in the "zero" or center position on the slide, since the pulsed-RF signal has been normalized to the carrier frequency in this example. The PRF in this example is 1.7 kHz, so we would expect to see spectral components on either side of the carrier at 1.7 kHz spacings.

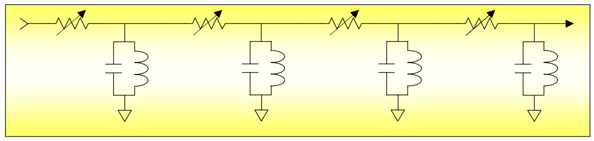


Here we see the central spectral component at zero (representing the RF carrier) and the first spectral components on either side of the carrier, each 1.7 kHz away (equal to the PRF). Remember that there are thousands of other spectral components that are beyond the scale of the slide. If we could build an ideal filter, it would look like a rectangle centered at 0 Hz. A practical filter however requires a transition region between the passband and stopband. Typically, the stopband must be attenuated by 70 dB or more for all of the undesired spectral components, to give sufficient measurement dynamic range. This means that the 3 dB bandwidth of the filter must be some fraction of the PRF. The value of the fraction depends on the selectivity of the filter. The selectivity is often expressed as shape factor, which is the ratio of the 60 dB bandwidth divided by the 3 dB bandwidth. The smaller the shape factor, the faster the filter rolls off, and the wider the IF bandwidth that can be used for narrowband detection. The slide shows that for a given 3 dB bandwidth, filters with different shape factors will roll off at different rates.

Analog versus Digital Filtering

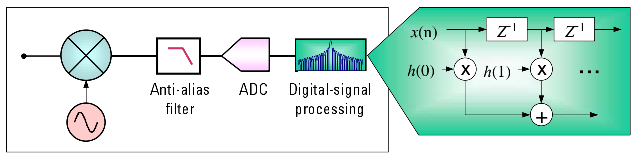
Classic analog variable-bandwidth bandpass filter:

- Multiple-resonator synchronously tuned filter
- Vary bandwidth by varying series resistances, vary shape factor by number of resonators



Digital filtering: digital-signal processing after analog-to-digital conversion

- Two filter types: finite impulse response (FIR) and infinite impulse response (IIR)
- Vary bandwidth and shape factor by topology, number of delay elements, and weighting factors



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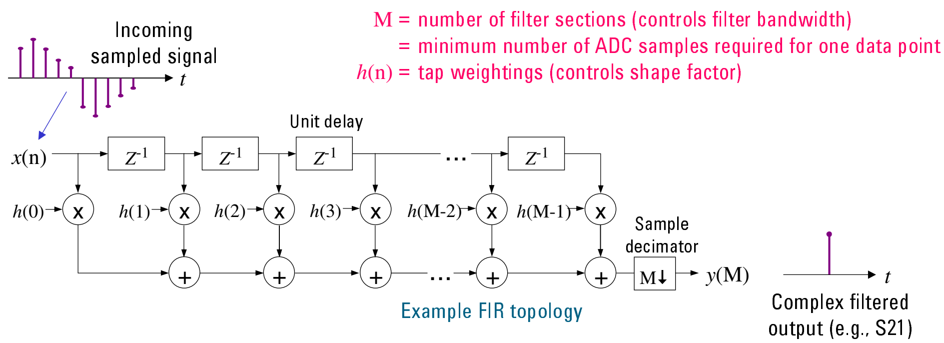
Narrowband detection can be accomplished either with analog or digital filtering. To accommodate a wide range of PRF's, variable bandwidth filters are very desirable to optimize measurement speed. The classic way to implement analog, variable-bandwidth IF filters is by using the synchronously tuned topology. The heart of the filter is a parallel LC (inductor/capacitor) resonator driven by a variable series resistance, usually achieved with a PIN diode. As the series resistance is increased, the bandwidth of the filter section gets smaller. Concatenating multiple resonator stages increases the selectivity of the filter.

Variable-bandwidth digital filters are done using DSP algorithms performed after an analog-to-digital conversion occurs. There are two basic types of digital filters: finite-impulse response (FIR) and infinite-impulse response (IIR). The topology of these two filters differs, and each has their advantages and disadvantages. The PNA uses FIR filters. The bandwidth and selectivity (shape factor) of digital filters are controlled by the filter topology, number of delay elements, and weighting factors.

So, how wide a filter can we use on the PNA? To answer that question, we need to understand a little more how the PNA's digital IF filters work.

Finite Impulse Response (FIR) Filter Basics



Example FIR topology

BW	M	BW	M	BW	M
40k	4	1.5k	101	30	4800
35k	5	1k	149	20	7200
30k	6	700	211	15	9480
20k	8	500	292	10	14,280
15k	16	300	480	7	19,560
10k	19	200	720	5	28,680
7k	25	150	960	3	47,760
5k	34	100	1440	2	71,640
3k	53	70	2040	1.5	95,520
2k	77	50	2880	1	143,280

PNA standard IF filters

As IF bandwidth gets narrower:
- Number of sections (M) gets larger
- More ADC samples needed per data point
- Acquisition and processing time gets slower

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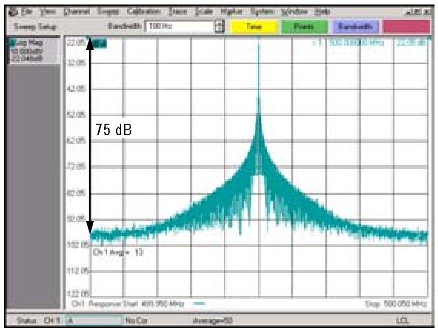
The PNA's IF filters are implemented as finite-impulse-response (FIR) digital filters. The slide shows an example FIR topology. The number of filter sections or "taps" (M) is variable, depending on the IF bandwidth. The narrower the bandwidth, the larger the required number of filter sections. M is also the minimum number of ADC (analog-to-digital converter) samples required to produce one data point. As the filter bandwidth narrows, more samples are required, resulting in longer measurement times. The table on the slide shows M (the number of sections and the number of samples required) for each of the PNA's standard IF filter bandwidths. Once enough samples are taken to produce a data point, the analyzer steps to the next point, which would be a new carrier frequency for point-in-pulse measurements, or a new delay value for pulse profiling. The tap weightings (filter coefficients) h(n) control the shape factor or selectivity of the filter.

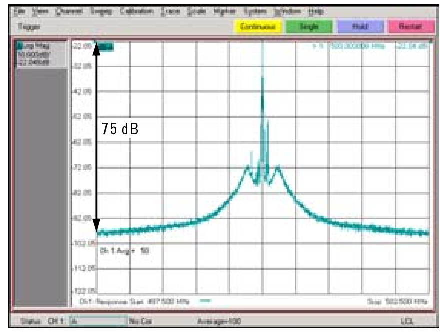
In order to implement the "spectral nulling" technique, it will be necessary to create non-standard or custom IF filters, with M values that fall between those listed in the table.

PNA IF Filters

- Selectivity of the PNA's digital IF filters is not very high (they're optimized for speed)
- With standard IF filters:
  - IF bandwidth must typically be between 1% and 0.1% of PRF to achieve necessary suppression of unwanted spectral components
  - Measurement is slow!



100 Hz filter / 100 kHz span (PRF/IF = 500)
Shape factor (60 dB/3 dB) = 400



10 kHz filter / 5 MHz span (PRF/IF = 250)
Shape factor (60 dB/3 dB) = 67

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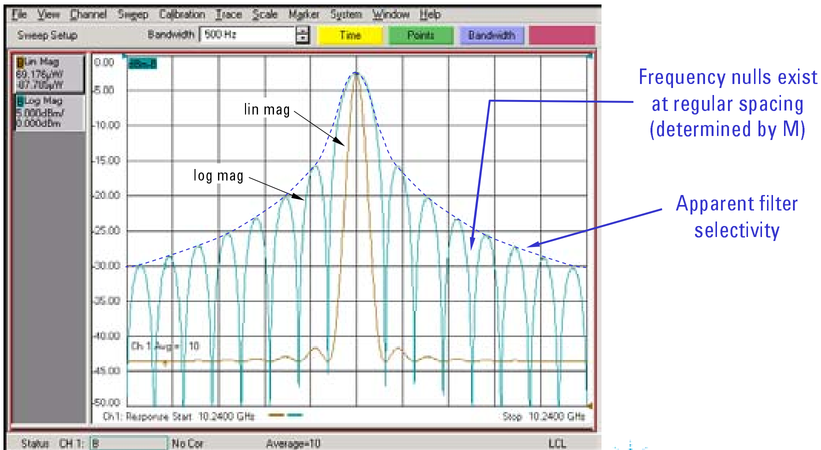
Now that we know more about the digital filters in the PNA, we can look at their selectivity. Here we see two of the PNA's standard filters in the frequency domain. It is clear that these are not rectangular filters. The 100 Hz filter on the left requires +/- 50 kHz to achieve stopband attenuation of 75 dB. Using the filter without any "tricks" (like spectral nulling) means the PRF must be 50 kHz or greater to ensure that the unwanted spectral components are sufficiently filtered. In this case, the IF bandwidth would be 0.2% of the PRF. The shape factor (the ratio of 60 dB bandwidth to 3 dB bandwidth) of the 100 Hz filter is 400, compared to a typical spectrum-analyzer digital-filter shape factor of about 4. For the 10 kHz filter, the PRF would have to be greater than 2.5 MHz to ensure that the unwanted spectral components are sufficiently filtered. In this case, the IF bandwidth would be 0.4% of the PRF. The shape factor of the 10 kHz filter is 67, which is better than the 100 Hz filter, but is still far less selective than the filters on a spectrum analyzer. So, we can see that the standard IF filters, if used in a conventional manner, are not particularly well suited for narrowband pulse detection, as the IF bandwidths must be very narrow compared to the PRF, resulting in slow measurements. VNA digital filters are not optimized for selectivity (as are spectrum analyzer filters), because for S-parameter measurements, the filter is always exactly tuned to the incoming signal (or, the signal always falls in the center of the filter). With tracking filters, good selectivity is not needed. Instead, VNA filters are optimized for sweep speed and low noise bandwidth.

But wait! There’s more...

- We can take advantage of characteristics of PNA’s digital IF filters to increase IF bandwidth for narrowband detection
- Result is significantly faster measurement speeds



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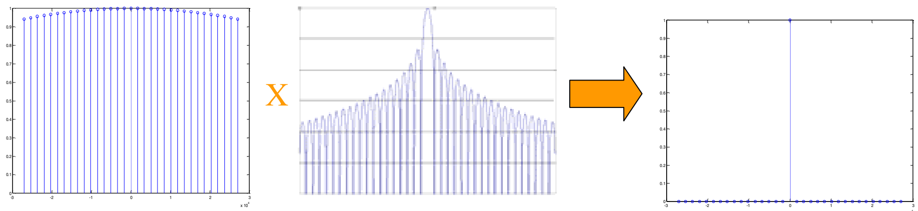
But wait! The story doesn’t end here. There are attributes of the digital IF filters in the PNA that we can take advantage of to improve our measurement speed significantly. The plot shows a typical narrowband filter on the PNA (500 Hz in this case). If we look near the center of the filter response on the linear-magnitude trace, we notice something very interesting. There appear to be nulls in the frequency response at periodic intervals. When we display the filter response with a log-magnitude format, the frequency nulls are quite clearly seen. The frequency interval between nulls is directly proportional to the IF bandwidth, which in turn is inversely proportional to the number of sections of the digital filter (M). We will see on the next slide how we can take advantage of these nulls. Incidentally, the peaks of the filter response show the poor selectivity that we saw on the previous slide.

Filtered Output Using Spectral Nulling



Pulsed spectrum　　Digital filter (with nulls aligned with PRF)

- With “custom” filters, number of filter sections (M) can be chosen to align filter nulls with pulsed spectral components
- With spectral nulling, reject unwanted spectral components with much higher IF bandwidths compared to using standard IF filters
- Result: faster measurement speeds!

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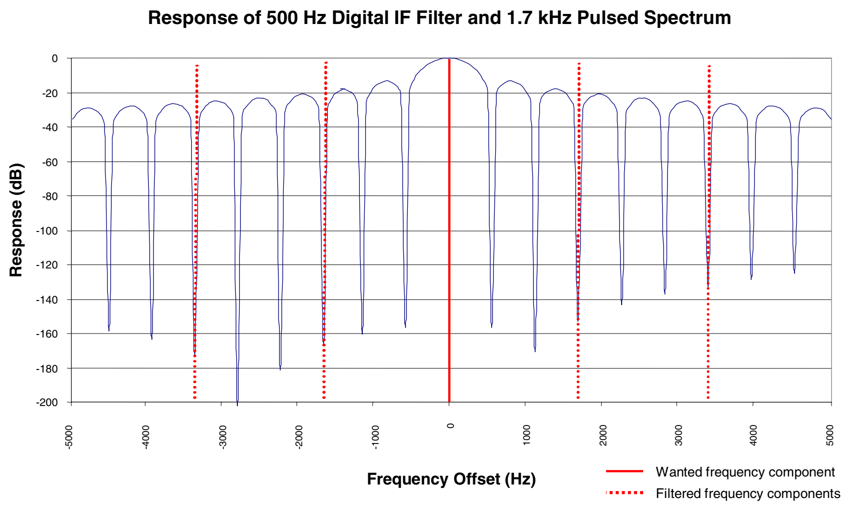
If the number of filter sections can be chosen such that the filter’s frequency nulls exactly align with the PRF, then the undesired pulsed spectral components will be filtered away, leaving the desired center spectral component. PNA Option H08 allows these custom IF filters to be created. Instead of the standard 1, 1.5, 2, 3, 5, 7, 10 filter sequence, we can construct IF filters with arbitrary bandwidths like 421 Hz or 87 Hz. The bandwidth of these filters must be chosen based on the PRF, to ensure proper spectral nulling. With this technique, the IF bandwidth can be much higher compared to conventional filtering, shown previously, resulting in faster measurement speed. In practice, if a really wide bandwidth is desired, the PRF of the pulses may need to be adjusted slightly to ensure proper nulling. If the PRF cannot be adjusted, then the IF chosen will be as narrow as necessary to achieve proper spectral nulling.

Zoomed in View of Spectral Nulling



- Nulling occurs at every 3rd null in this case (BW = 29% of PRF)
- A narrower IF bandwidth would skip more nulls
- Trade off dynamic range and speed by varying IF BW

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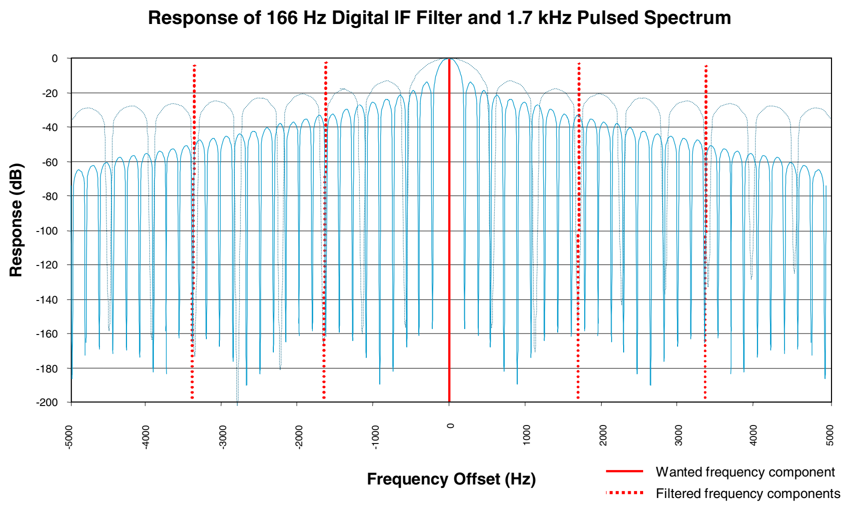
Here we see the previously shown 500 Hz filter superimposed on our 1.7 kHz PRF pulse stream. We see in this case that we are actually using every third null of the filter. This represents an IF bandwidth that is 29% of the PRF, instead of the 1% to 0.1 % required with conventional filtering.

If we chose a narrower bandwidth to improve our measurement dynamic range (at the expense of measurement speed), the spectral components would skip more nulls. In this way, we can trade off dynamic range and measurement speed by varying the IF bandwidth.

Zoomed in View of Spectral Nulling



- Nulling occurs at every 9th null in this case (BW = 9.9% of PRF)

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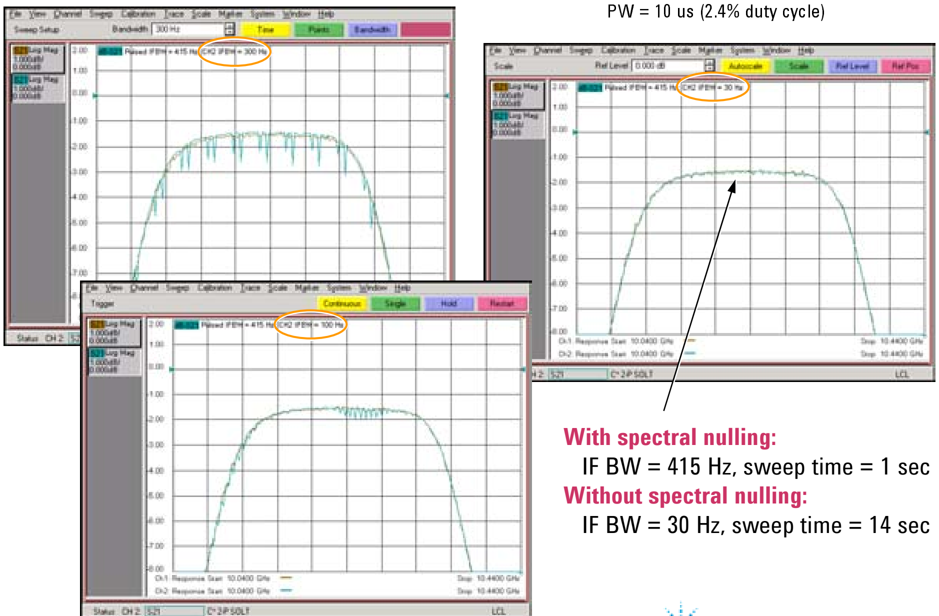
Now we see what the nulling looks like when we narrow the IF filter bandwidth by a factor of 3, to 166 Hz. In this example, we are now using every ninth null of the filter. This represents an IF bandwidth that is about 9.9% of PRF, instead of the 0.1% to 1% required with conventional filtering. Narrowing the filter in this manner increases the dynamic range by about 5 dB (10*log[3]).

IF Bandwidth Comparison

PRF = 2.349 kHz
PW = 10 us (2.4% duty cycle)



With spectral nulling:
IF BW = 415 Hz, sweep time = 1 sec
Without spectral nulling:
IF BW = 30 Hz, sweep time = 14 sec

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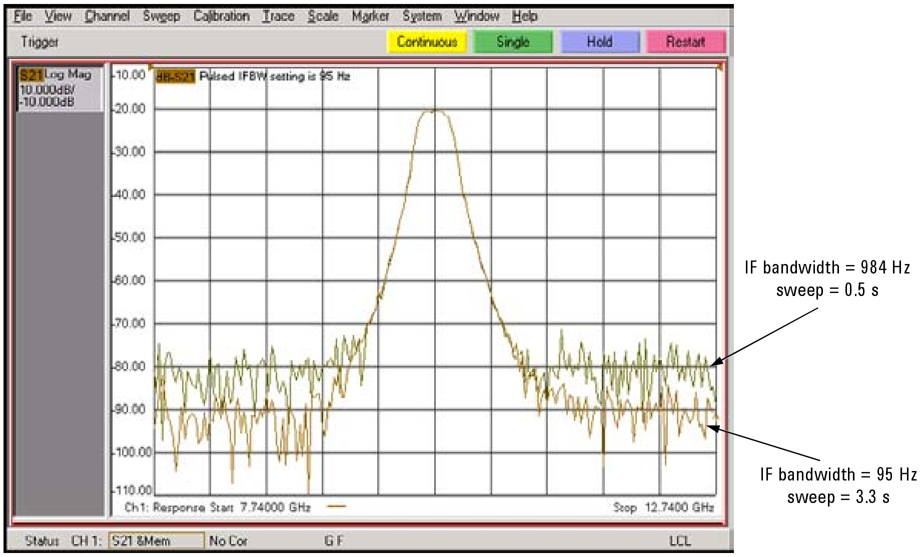
This demonstration compares the speed differences between two traces that both use narrowband detection. One trace uses the PNA's IF filters in a conventional manner, and the other trace utilizes the spectral nulling technique.

Delta Bandwidth Comparison



Δ_{noise} = 10*log[984/95] = 10.2 dB

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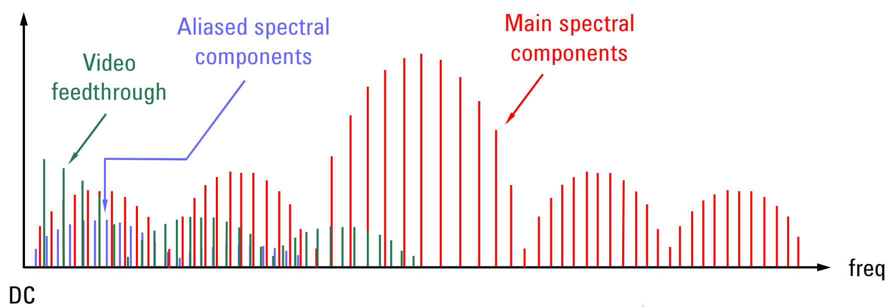
This demonstration shows that decreasing the IF bandwidth of point-in-pulse measurements results in more measurement dynamic range (and slower sweep times), just like what occurs during normal S-parameter measurements.

Elimination of Additional Interfering Signals

- Spectral nulling eliminates main pulse spectrum plus other undesired signals
- Sources of spectral contamination:
  - Spectral components can wrap around DC and fold back into pulse spectrum
  - Harmonics of "video feed-through" (leakage of baseband modulation signal) due to RF modulator and IF gates
  - Receiver sensitive to 1st and 2nd LO images



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The algorithm that Option H08 uses to null unwanted spectral components is more sophisticated than we have shown thus far. In addition to the main pulsed-RF spectrum, other sources of interfering signals are also nulled, such as:

•Aliased spectral components – for narrow pulses with broad frequency content, the unfiltered pulsed signal can wrap around DC in the analyzer's receiver, and fold back on top of itself. Although the spacing of these folded signals is the same as the unaliased spectral components, the aliased components are unlikely to fall exactly on top of the unaliased components. They will appear as a new set of pulsed components that are offset in frequency from the unaliased spectrum.

•Baseband leakage – often in pulsed-RF systems, the baseband modulating signal leaks onto the pulsed-RF signal, causing another set of spectral lines that, in general, do not align with the main pulsed-RF spectrum. This leakage signal is often called "video feed-through", an old term dating back to the early days of radar.

•Images – because of the two conversions used in the PNA to down-convert the incoming RF to an IF signal, image frequencies exist where the receivers have an undesirable response.

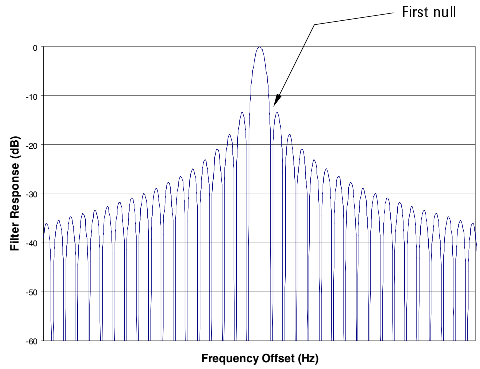
These signals are nulled by selecting a narrower IF filter bandwidth than what would be needed to null just the main pulsed-RF spectrum. The narrower filter has more nulls that are more closely spaced in frequency, and these nulls can be used to cancel multiple sets of offset spectral components.

Standard Filters and Corresponding Nulls

- Nulling can be done with standard filters, but allowable PRFs are limited
- PRF must be a harmonic of the frequency of first filter null
- Difficult to null all undesirable spectral components
- H08 allows "custom" IF BW's, allowing full PRF flexibility and better rejection

PNA standard IF filters

BW (Hz)	M	First null offset (Hz)	BW (Hz)	M	First null offset (Hz)
10k	19	24,813.90	100	1440	224.95
7k	25	16,977.93	70	2040	158.59
5k	34	11,520.74	50	2880	112.24
3k	53	6863.42	30	4800	67.29
2k	77	4543.39	20	7200	44.84
1.5k	101	3395.59	15	9480	34.05
1k	149	2255.81	10	14,280	22.60
700	211	1573.56	7	19,560	16.50
500	292	1127.90	5	28,680	11.25
300	480	680.55	3	47,760	6.76
200	720	451.79	2	71,640	4.50
150	960	338.13	1	143,280	2.25



$$\text{null spacing} = \frac{2}{(\#\text{ taps} - 6) \times \text{sample-time}}$$

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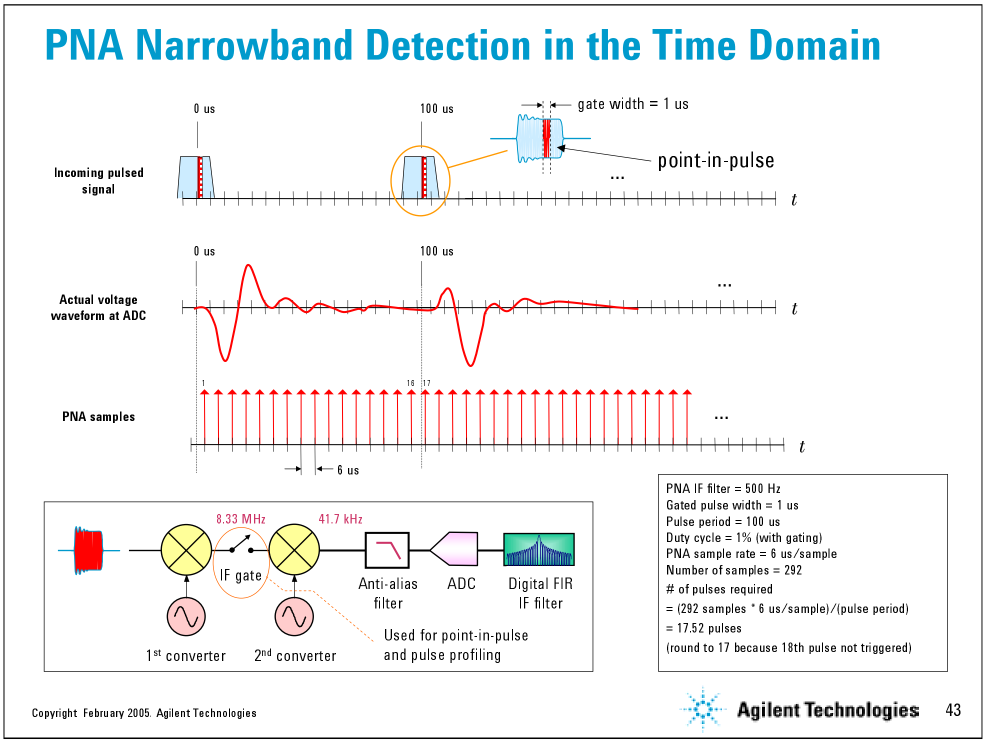
Spectral nulling can also be done without Option H08, by using the PNA's standard IF filters. However, the PRF must be set to a multiple of the null spacings of one of the IF bandwidth filters. This limits the flexibility of having arbitrary PRFs and in many cases will prevent measuring at a PRF specified by a system designer. In addition, it would be very difficult to null out all of the undesired spectral components shown on the previous slide. Using Option H08 allows "custom" IF bandwidth filters, which yields full PRF flexibility, and less trace noise and higher dynamic range due to better rejection of undesired signals.

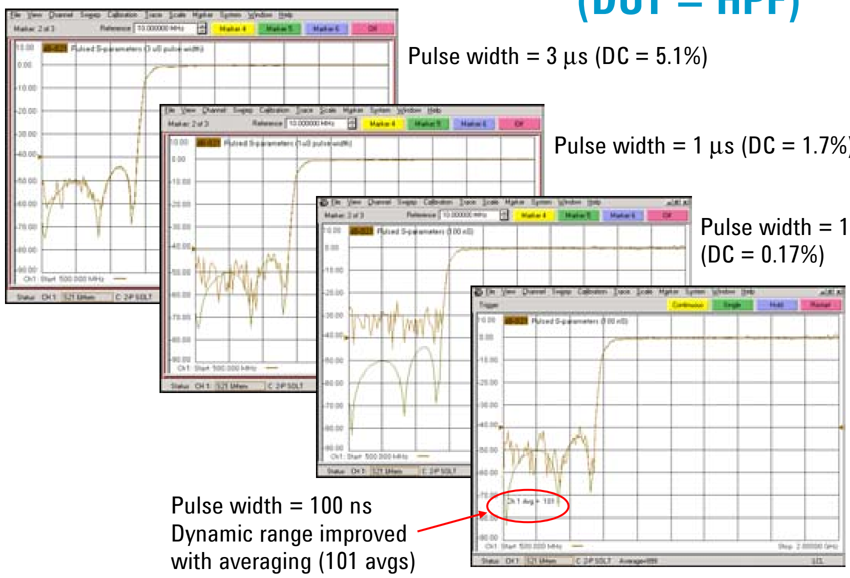


Here is a picture of narrowband detection on the PNA, in the time domain. The bottom image shows the actual down-conversion chain in the PNA. The IF gate switches, which are used for point-in-pulse and pulse-profiling measurements to restrict the data acquisition to a specific region within the pulse, are placed in the 8.33 MHz first-IF path. A second down-conversion stage follows, producing the final IF of 41.7 kHz. An anti-alias filter is placed just in front of the analog-to-digital converter (ADC). The top waveform shows the incoming pulses, with a 1 us PW after gating, and a PRP of 100 us (1% duty cycle).

The middle waveform is the actual voltage waveform at the input to the ADC, and it shows the pulses spread out by the anti-alias filter. In this example where the pulses are relatively narrow, this waveform represents the impulse response of the PNA's receiver. The lower waveform shows the sampling process, which occurs continuously, and is asynchronous to the incoming pulses. We can easily see that as the duty cycle gets smaller, the impulse response falls into the noise before the next pulse appears. The ADC samples a lot of noise in-between pulses, which lowers the signal-to-noise ratio, decreasing dynamic range. The longer the time between pulses, the more noise that is sampled, and the lower the dynamic range.

Continuing with our example of a 500 Hz filter, 292 samples are required to produce one S-parameter data point. At 6 us per sample, this takes 1.75 ms. With our PRP of 100 us, we see that 17 pulses occur for each data point that we acquire. If the pulse is changing during the measurements, then the resulting data point will represent the average over the 17 pulses. The number of pulses that are required for one data point varies according to the PRF and the IF bandwidth. Because multiple pulses occur for each data point, point-in-pulse measurements require a hardware gate before the ADC conversion.

Duty Cycle Effects with Narrowband Detection (DUT = HPF)



Pulse width = 3 µs (DC = 5.1%)

Pulse width = 1 µs (DC = 1.7%)

Pulse width = 100 ns (DC = 0.17%)

Pulse width = 100 ns
Dynamic range improved
with averaging (101 avgs)

Note: this is frequency domain data, not a pulse profile

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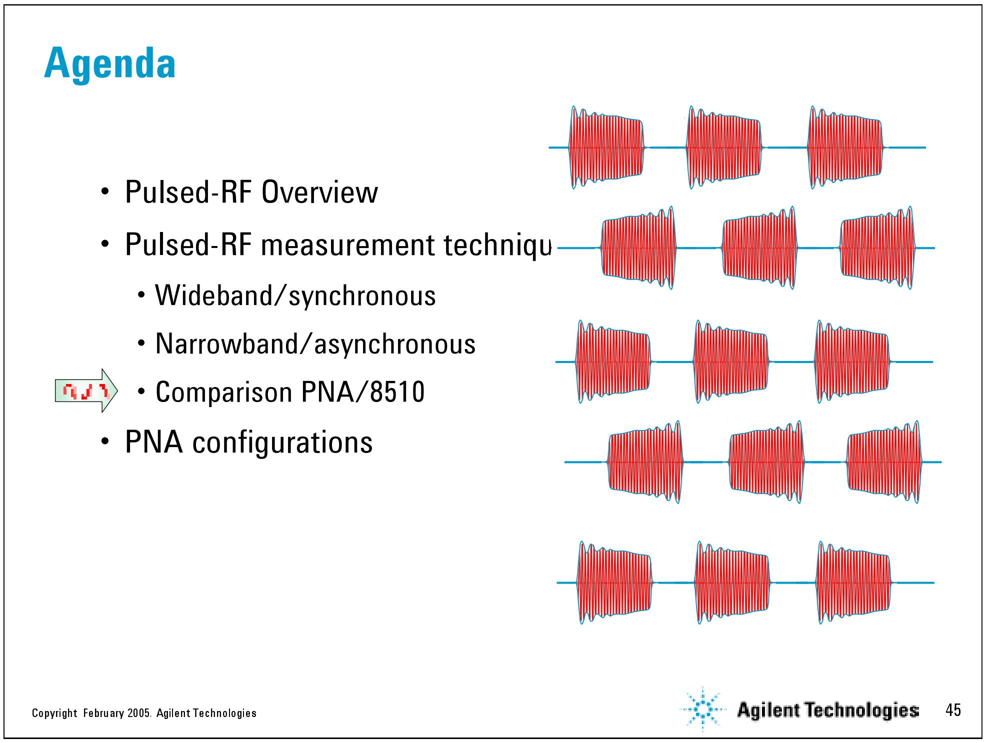
This slide shows that decreased dynamic range with decreased duty cycle can easily be observed on the network analyzer by measuring a device with high dynamic range, a high pass filter in this example. Although filters are not normally measured under pulsed conditions, they do serve as a useful DUT to demonstrate pulse de-sensitization effects.

In each plot, we compare a pulsed S-parameter (noisy trace) with a normal, swept-sinusoid S-parameter (clean trace). The top plot shows that with a 5% duty cycle, we can still measure the filter stopband with reasonable accuracy. The next plot down (second from top), shows the effect of decreasing the duty cycle by a factor of three, resulting in a decrease in dynamic range of about 10 dB, and a rather noisy measurement of the filter's stopband. The next plot down (second from the bottom) shows that with another decrease in duty cycle (a factor of 10 this time), the analyzer's noise floor has increased by 20 dB, and is now above the filter stopband all together. Note that the PW is 100 ns in this example. The lowest plot shows that we can improve dynamic range by averaging. 100 averages results in a 20 dB improvement in dynamic range, so the measurement shows about the same dynamic range as the plot second from the top.

For all of these examples, a unique calibration was performed for each set of pulse conditions.



In this next section, we will explore the performance differences between the PNA and 8510 in more detail.

Comparing the 8510 and PNA

8510 (85108A)

- Dominant mode is wideband detection
- Detection is done BEFORE analog-to-digital conversion
- Analog synchronous detector produces baseband I/Q output (detector bandwidth = 1.5 MHz)
- Pulse profiling achieved by varying sample point of baseband pulses
- Trade off speed and dynamic range with averaging

PNA

- Dominant mode is narrowband detection
- All processing (filtering and detection) is done digitally
- Widest bandwidth = 35 kHz
- Pulse profiling achieved with analog switches that gate IF (or RF) signals
- Trade off speed and dynamic range with variable IF bandwidths and averaging

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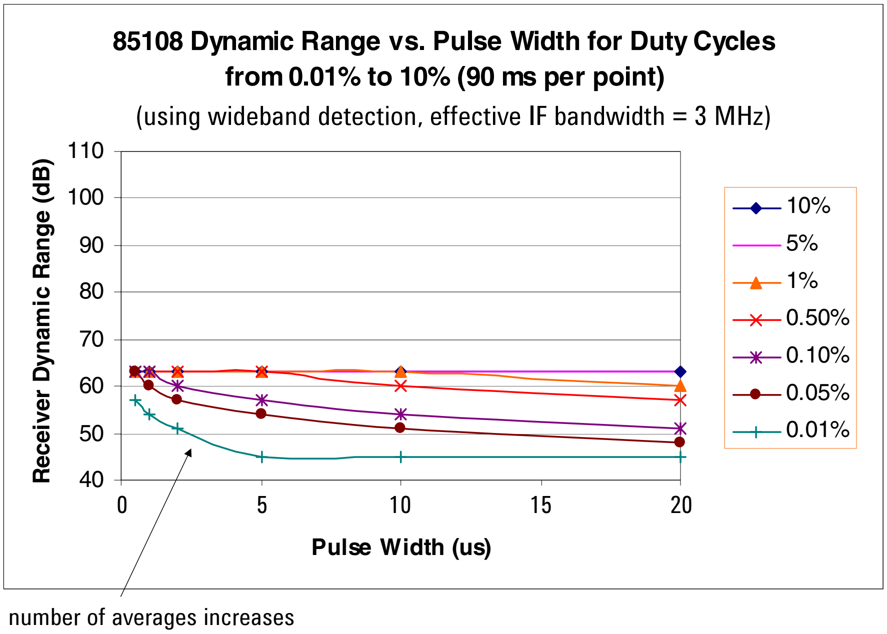
Here we see a comparison between the PNA and the 8510, reviewing what we have covered already. The 8510's dominant detection mode is wideband, due to its relatively large bandwidth (about 3 MHz before detection, 1.5 MHz for I and Q pulses after detection). The detection is done before the analog-to-digital conversion, and is achieved with analog circuitry. The detector consists of a synchronous down-converter which produces baseband I/Q outputs. Pulse profiling is achieved by varying the sample point along the baseband pulses. The only way to trade off speed and dynamic range with the 8510 is with averaging.

The PNA's dominant detection mode is narrowband, due to its relatively low bandwidth of 35 kHz. All filtering and detection is done after the analog-to-digital conversion, using digital-signal processing. Pulse profiling is achieved with analog switches that gate the IF (or RF) signals prior to filtering and detection. The PNA's narrowband mode trades off speed and dynamic range using variable IF bandwidths as well as averaging. The PNA can also do broadband detection with pulses as narrow as 50 us with the PNA, and 10 us with the PNA-L.

Although the PNA and 8510 make measurements with different hardware and different types of detection, the resulting pulsed S-parameter and pulse-profile measurements are identical for a given device tested on either system.



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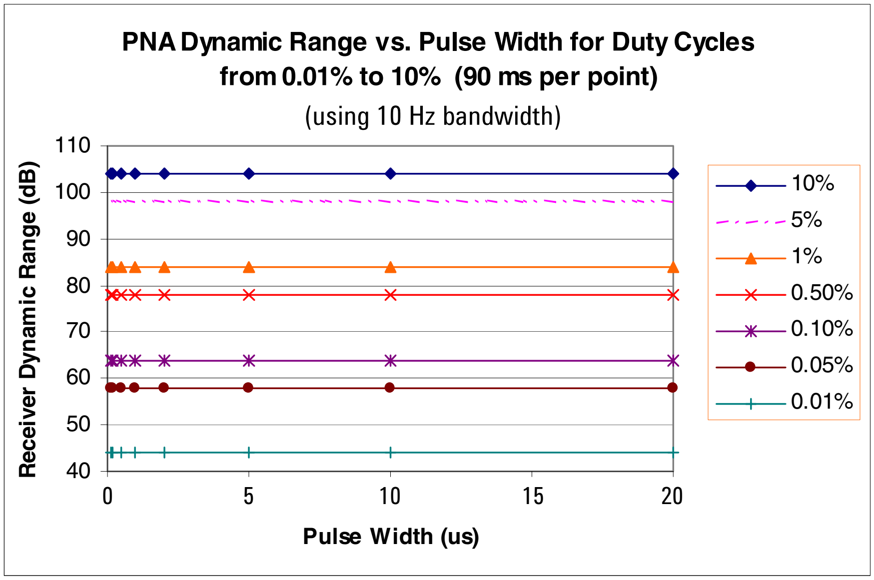
This slide was done using a constant time per point of 90 ms. For some 8510 cases, more averaging could be done in this time frame, resulting in increased dynamic range.



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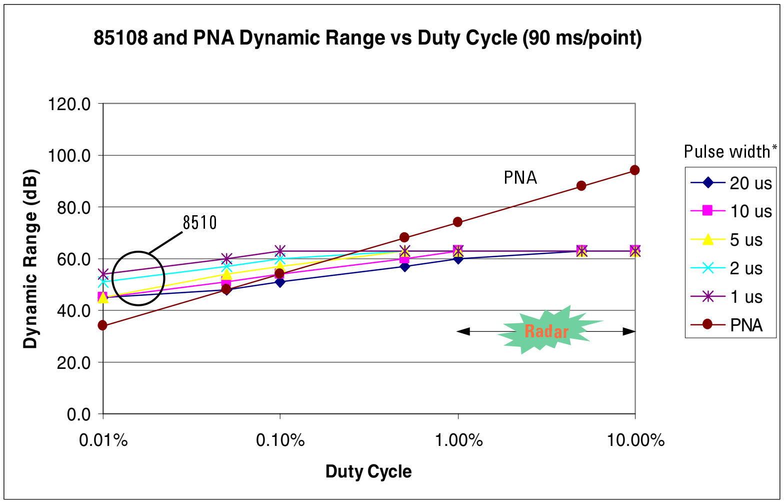
The PNA's bandwidth was 10 Hz, to keep the time per point to 90 ms.

Comparing Dynamic Range



* Pulse widths are for the 8510. The PNA's dynamic range is a function of duty cycle, irrespective of pulse width

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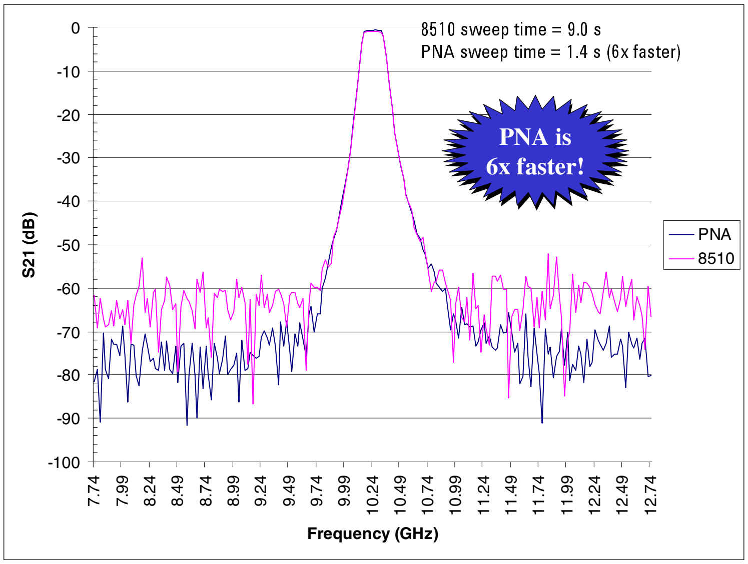
This slide shows actual dynamic range versus duty cycle, between the 8510 and PNA. The bandwidth of the PNA was chosen to give the same time-per-point as the 8510. The PNA's dynamic range varies with duty cycle, but the crossover point is at about 0.1% duty cycle. For most radar applications (duty cycles in the 1 to 10% range), the PNA has superior dynamic range compared to the 8510.

Example PNA/8510 Comparison



PW = 5 us
PRF = 10 kHz
Duty cycle = 5%
Points = 201
8510: no avg
PNA: no avg, BW=567 Hz
Calibration: 2-port

Agilent Technologies 50

This slide shows a point-in-pulse measurement of a bandpass filter. Although filters are not normally measured under pulse conditions, they are very useful to show the overall dynamic range of the test system. The pulse conditions used for this example were chosen to be representative of a typical radar application. We see that in the passband and transition region of the filter, there is excellent correlation between the PNA and 8510. We also can see that, for this example, the PNA has about 10 dB better dynamic range, and sweeps 6 times faster than the 8510.

Pulse Summary

	Wideband/Synchronous	Narrowband/Asynchronous
Advantages	Constant dynamic range	Narrow pulse widths
Disadvantages	Lower pulse width limit Elevated noise floor	Dynamic range loss with small duty cycles No pulse-to-pulse
8510	PW > 1 us	Limited*
PNA	PW > 50 us/10 us/2 us**	PW > 20 ns (limited by IF gate)
PNA Options	None required	H11/H08***
Measurements	Average Point-in-pulse Pulse profile Pulse-to-pulse	Average Point-in-pulse Pulse profile

* Hi PRF, no nulling, no point-in-pulse
** PNA/PNA-L 2-port 20, 40, 50 GHz/PNA-L 2-port 6, 13.5, 4-port 20 GHz
*** Option H08 is usually used in conjunction with Option H11. Without H11, the user can perform average pulse, or point-in-pulse measurements using external RF gates.

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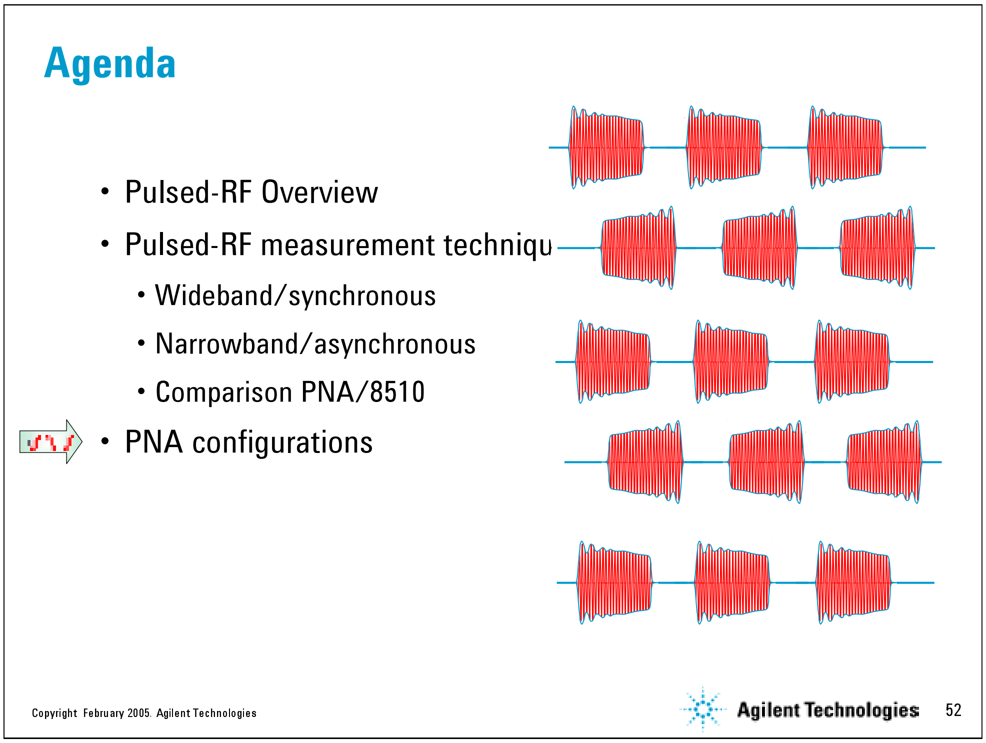
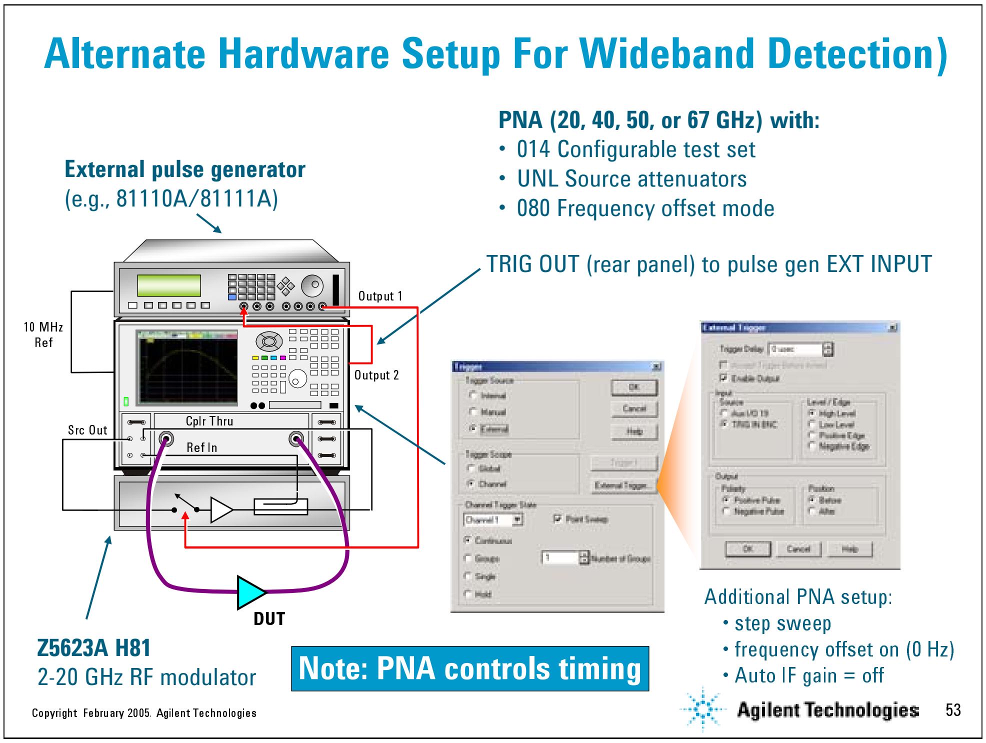
This slide is mostly a review of what we have already covered. One thing to note is that the 8510's narrowband mode is limited to high PRF's (minimum PRF around 50 kHz to 100 kHz), and no spectral nulling is available.



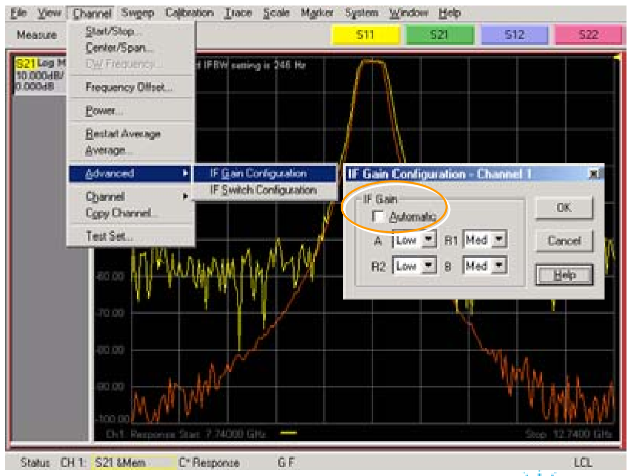
As part of our discussion of the two different measurement types (wideband and narrowband detection), we will compare and contrast the PNA with the industry standard for pulsed S-parameter measurements, the 85108A (the pulsed version of the 8510).



Here is an alternate setup for making wideband point-in-pulse or pulse-to-pulse measurements. In this example, the PNA controls the timing by providing an external trigger to the pulse generator. This approach is useful if there is some danger of missing a pulse because the PNA is not ready. Note that with this setup, the PRF may be somewhat variable, as the PNA crosses a frequency band or retraces at the end of a sweep.

Some Things to Remember: IF Gain

- Uncheck “Automatic” setting of IF Gain to decrease pulse settling time
- Set gains of appropriate receivers manually (typically “Low” or “Med”)



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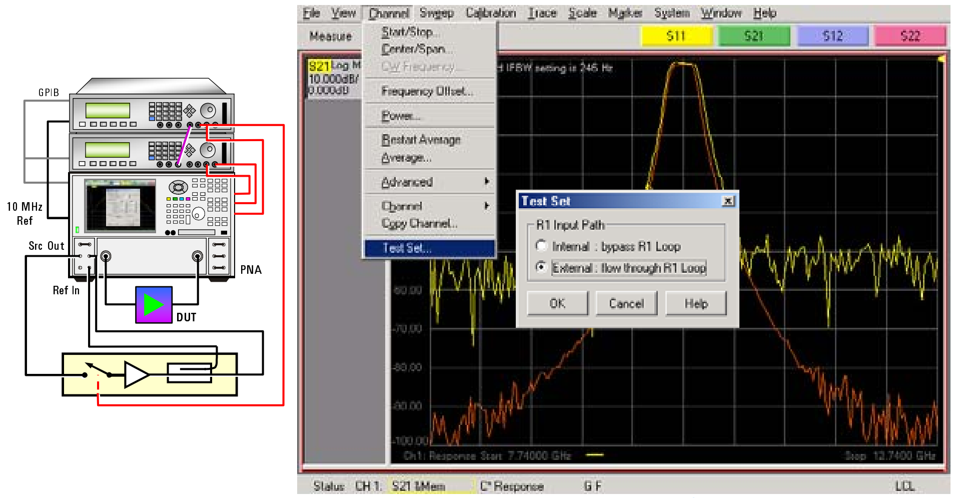
For normal S-parameter measurements, the PNA has an IF-automatic-gain-control feature that maximizes measurement dynamic range. For pulsed-RF measurements, it is best to turn off the “auto” mode and set the gain of each receiver manually. This decreases the pulse-settling time of the PNA significantly. With the auto gain on, the settling time is around 100 us. When it is off, the settling time drops to about 20 us.

Some Things to Remember: Reference Loop

- If your PNA has Option 081 and you're using an external reference signal (CW or pulsed), be sure to set R1 Input Path to "External"



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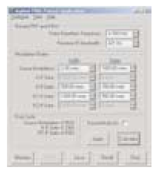
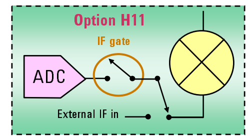
If your PNA has Option 081 (reference receiver switch used for frequency-converter measurements) and you are using a pulse setup that routes some of the stimulus back to the PNA's reference receiver, be sure that the R1 input path is set to external. If not, the PNA will use the internal CW source as the reference, and any external signal-conditioning components (like an amplifier for example) will not get ratioed out of the measurement.

Configuring the PNA for Narrowband Detection

- Majority of applications will require combination of Option H11 (hardware) and Option H08 (application software)





Simplified Receiver

- A PNA without H11 or H08 can provide basic narrowband pulsed-RF measurements with limited flexibility
- H08 can be used without H11 for:
  - average pulse measurements
  - point-in-pulse and pulse-profiling using external RF switches ("gates") instead of internal IF switches

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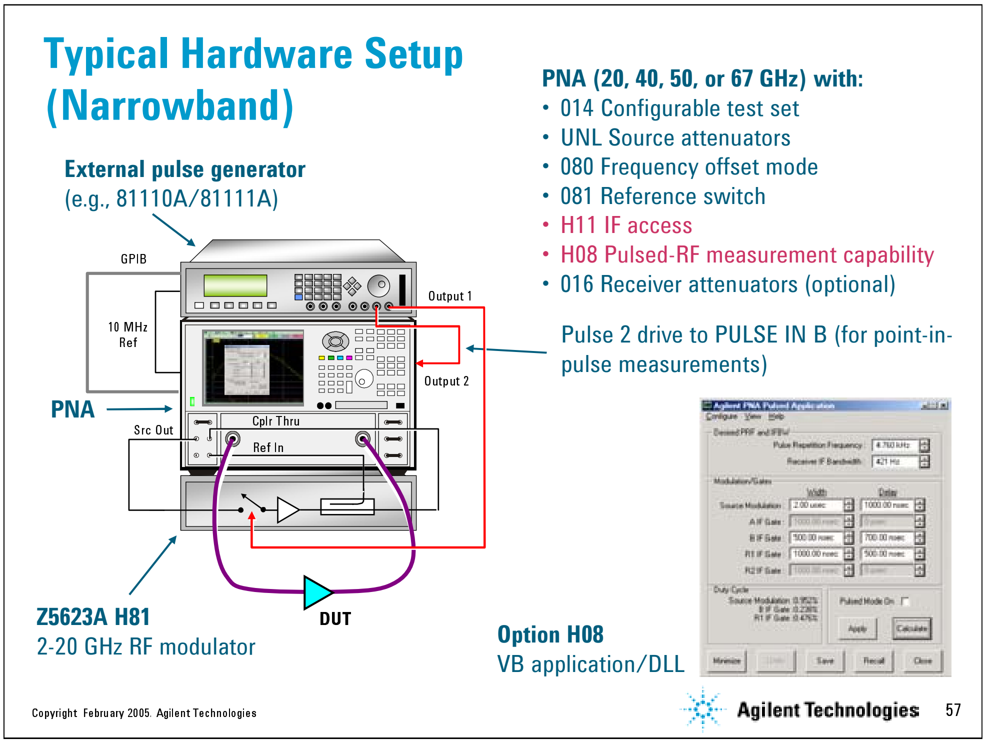
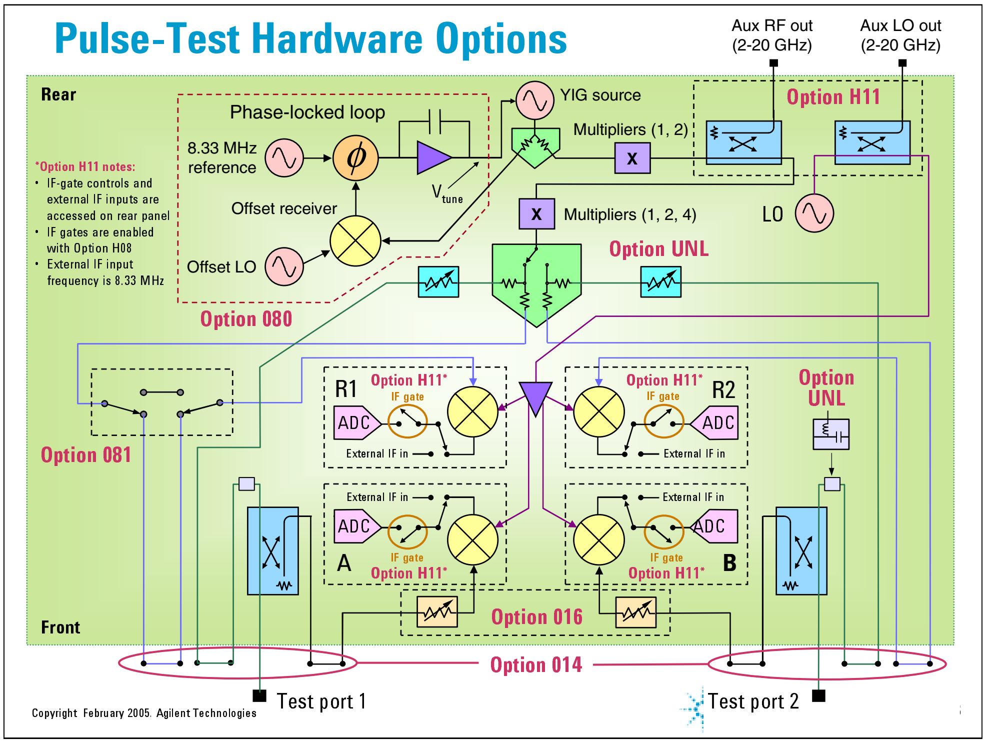
Most narrowband pulse applications for the PNA will required a combination of Option H11 (which supplies the IF gates for point-in-pulse and pulse-profiling measurements) and Option H08 (which provides the spectral nulling and control of the pulse generators). For cost-sensitive applications, a PNA without either option can be used, with limited flexibility and perhaps increased trace noise and degraded dynamic range due to sub-optimal spectral nulling. Option H08 can be used without H11 if average pulse measurements are sufficient (i.e., no point-in-pulse), or if external RF switches are used in place of the internal IF switches for point-in-pulse and pulse-profile measurements.



Here is a typical PNA setup for making narrowband pulsed-RF measurements. When using internal IF gates, the PNA requires several options which are listed on the slide. The external RF modulator shown provides a switch, amplifier, and directional coupler (for the reference receiver) and it is connected to the PNA via the front-panel RF loops (Option 014). The pulse generator provides the pulse timing to control the modulator and the PNA's internal receiver gates, which are used for point-in-pulse and pulse-profile measurements. The pulse generator is controlled via GPIB, and at least one pulse generator in a system must be locked to the PNA's 10 MHz timebase. The system is controlled by the PNA Pulsed Application software (Option H08).

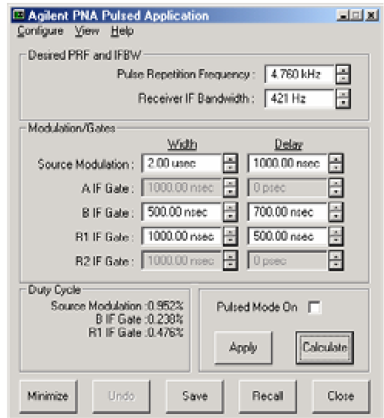


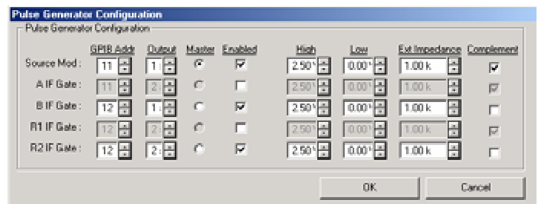
This slide shows all of the options associated with Agilent's pulsed-RF solution. Option H11 adds the IF gating switches necessary for point-in-pulse measurements. These switches are enabled with the H08 software. For a PNA configured with Option H11, Option 016 is the only "optional" option. The other options are required. Note that although the PNA uses dual-conversion receivers, only one conversion is shown for simplicity.

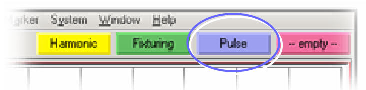
Option H11 also adds external IF inputs and auxiliary RF and LO outputs. This additional hardware is necessary for antenna and mm-wave applications.

H08 – What is it?

- Enables IF gates provided with H11
- Calculates spectral-nulling parameters
- Controls pulse generator(s)
- Includes:
  - Dynamic-link library "sub-routine" for automated environments
  - Visual Basic application for bench-top use (runs on PNA)
- May be purchased without H11 if:
  - gating is not required
  - external RF gates are used







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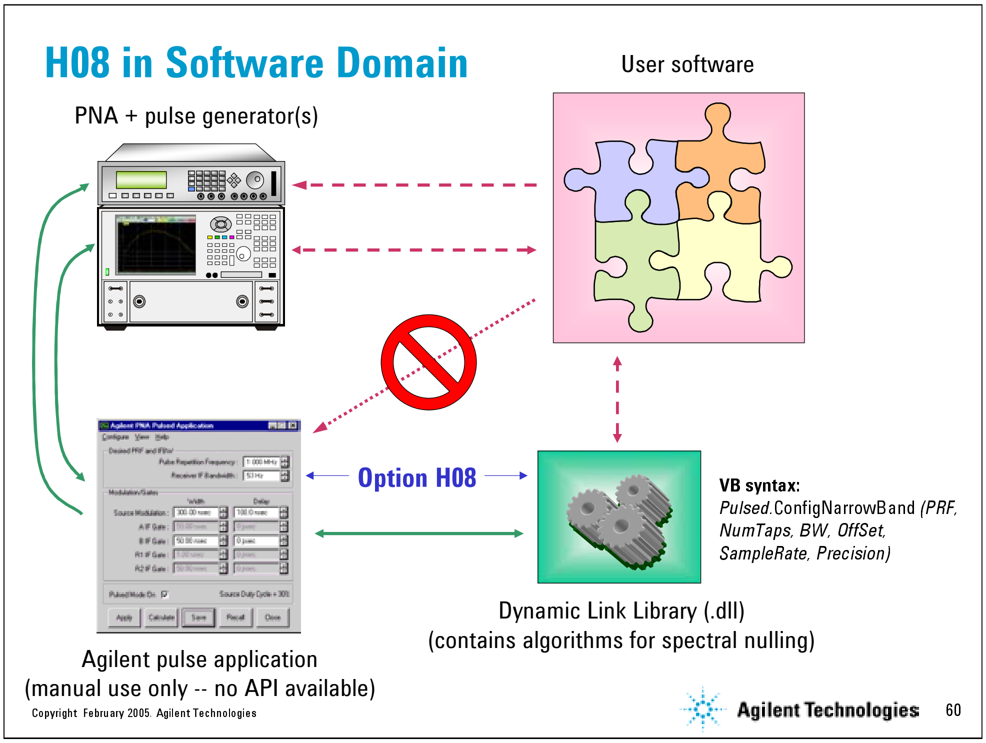
The IF gates supplied with Option H11 can only be used with Option H08. H08 includes all of the proprietary algorithms that we have previously discussed to implement the spectral nulling technique used with narrowband detection. H08 also controls the pulse generator(s) used in the system, and performs pulse-profile measurements.

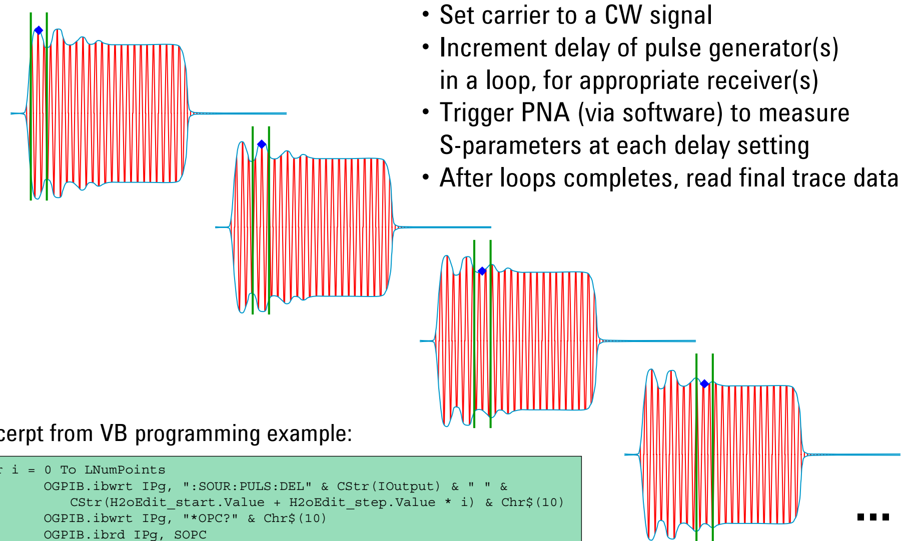
Option H08 comes with two software components. One is a dynamic-link library (DLL) which acts as a "sub-routine", and is needed for automated environments. The second portion is a Visual Basic (VB) application that runs on the PNA. This VB application is used for stand-alone, bench-top use. It interacts with the DLL and sends appropriate commands to the PNA and the pulse generator(s). The VB application is assigned to one of the PNA's macro keys for easy access.



Here is the way H08 operates in the “software domain”. In stand-alone operation (indicated by the solid arrows), the Visual Basic (VB) application interacts with the DLL, to get the necessary spectral-nulling parameters. The application then sends these values to the PNA. The application also controls the pulse generator(s). The VB application does not have an application-programming interface (API), so in a remote environment where the user has their own software to control the pulse measurements, the software cannot interact directly with the VB application. Instead, the user’s software must call the DLL, and the returned values must then be sent to the PNA. The software must also directly program the pulse generator(s). Remote operation is indicated by the dashed arrows.

Pulse Profiling with Software

- Set carrier to a CW signal
- Increment delay of pulse generator(s) in a loop, for appropriate receiver(s)
- Trigger PNA (via software) to measure S-parameters at each delay setting
- After loops completes, read final trace data



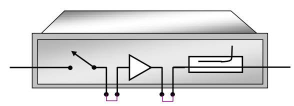
Excerpt from VB programming example:

```
For i = 0 To LNumPoints
        OGPIB.ibwrt IPg, ":SOUR:PULS:DEL" & CStr(IOutput) & " " &
           CStr(H2oEdit_start.Value + H2oEdit_step.Value * i) & Chr$(10)
        OGPIB.ibwrt IPg, "*OPC?" & Chr$(10)
        OGPIB.ibrd IPg, SOPC
        OApp.ManualTrigger True
        pgb_meas.Value = i
    Next
```


While the H08 application supports manual pulse profiling (with the ability to save data), it does not support remote (software controlled) pulse profiling. This can easily be accomplished however with a small amount of programming. Basically, the delay of the pulse generator output that controls the IF gate(s) for the signal or parameter we wish to profile is stepped in delay across a predetermined start and stop delay. At each delay, the PNA is triggered via software to make a receiver or S-parameter measurement. This is done in a loop. Agilent will include a Visual Basic programming example in the H08 documentation to demonstrate pulse profiling.

Z5623A Hxx RF Modulators

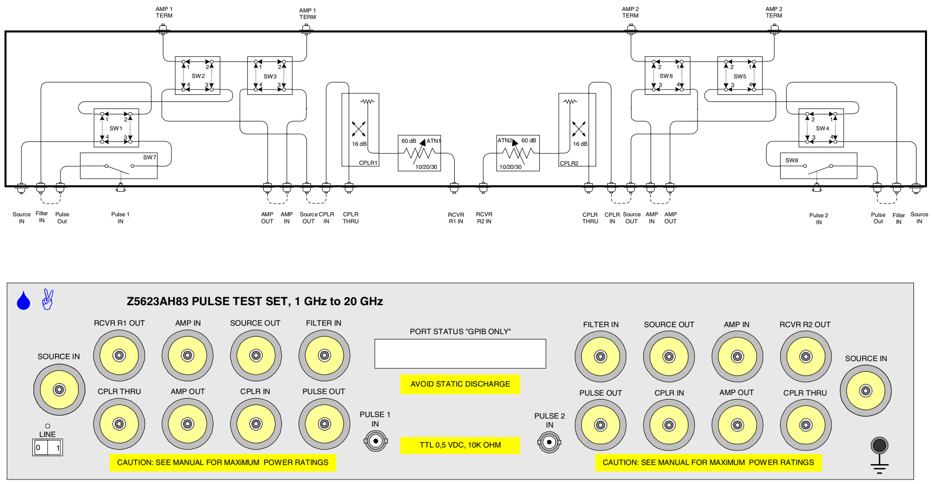
- **Z5623A H81 (2-20 GHz)**
  - Expected to be most common configuration ($43K)
  - Contains pin switch, amplifier, directional coupler
  - Use jumpers to bypass internal amp or use high-power external amp
- **Other quoted test sets:**
  - Z5623A H83 1-20 GHz Bidirectional (two pin switches) $80K
  - Z5623A H84 20-40 GHz Bidirectional (two pin switches) $105K
  - Z5623A H85 20-40 GHz Unidirectional, no amplifier $35K
  - Z5623A H86 2-40 GHz Unidirectional, dual band (incl. band switch) $65K
- **Customization via Agilent's "Special Handling" group:**
  - Different frequency ranges
  - No amplifier or higher power amplifiers
  - High power components



Z5623A H81

The Z5623A H81 2-20 GHz RF modulator gives the PNA pulsed-RF system similar capability to the 85108 in terms of frequency range and output power levels. With only one modulator, pulsed S-parameters can be done in the forward direction only, which is typical for amplifier measurements. Note that there are front-panel jumpers on the modulator to bypass the internal amplifier or to substitute higher-power amplifiers. Agilent can supply other RF modulators as needed to fulfill customer applications, through its Component Test "Special Handing" group. For example, other applications might require higher frequency ranges, different internal amplifiers, or two modulators for forward and reverse pulsed S-parameters. These test sets will be quoted on an individual basis. Several examples are shown on the slide.

Z5623A H83 RF Modulator   1-20 GHz



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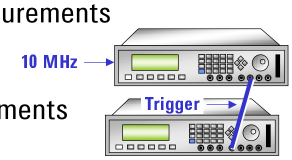
Here is an example of a more sophisticated RF modulator. It includes two pin switches for bi-directional (forward and reverse) pulsed-RF stimulus and two directional couplers for the reference channels. It does not include internal amplifiers, but has provisions for switching in external amplifiers to boost port power.

Pulse Generators

- At least one pulse generator must have a 10 MHz reference to lock to the PNA (master)
- Remainder of pulse generators are triggered by master
- Number of output modules depends on desired measurements
  - Minimum number is 1 to control RF modulator
  - Other modules needed for point-in-pulse measurements
  - IF gates can share a common output module



Required number of output modules	Output module usage for independent gate control	Point-in-pulse measurements available
2	RF modulator; B gate	S21 with *ungated* reference
3	RF modulator; A and B gates	S11, S21 with *ungated* reference
3	RF modulator; R1 and B gates	S21 with *gated* reference
4	RF modulator; R1, A and B gates	S11, S21 with *gated* reference
5	RF modulators; R1, R2, A and B gates	S11, S21, S12, S22 with *gated* references

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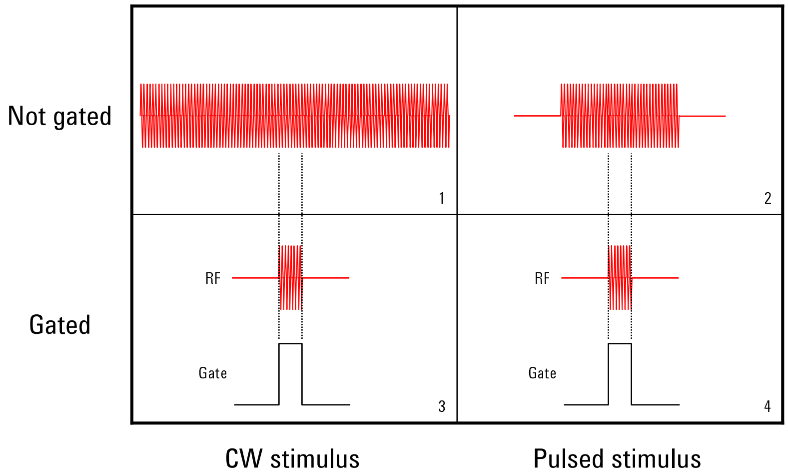
Here we see the requirements for external pulse generators. At least one pulse generator must have a 10 MHz reference to lock to the PNA. This pulse generator is the master. The remainder of the pulse generators (if any) are triggered by the master. The number of output modules depends on the desired measurements. Generally, each pulse generator can have two output modules. The minimum number of output modules required is one, to control the RF modulator. Other modules are needed for point-in-pulse and pulse-profile measurements, to control the internal IF or external RF gates. Note that gates can share a common output module if the same pulse width and delay can be applied to two or more receivers. The table summarizes the number of output modules required for independent gate control for various point-in-pulse S-parameter measurements. If independent control of forward and reverse modulators is desired in addition to all four pulsed S-parameters, then six output modules are required (3 pulse generators).

Reference Signal Choices



Any of these four signals can be used as a reference signal

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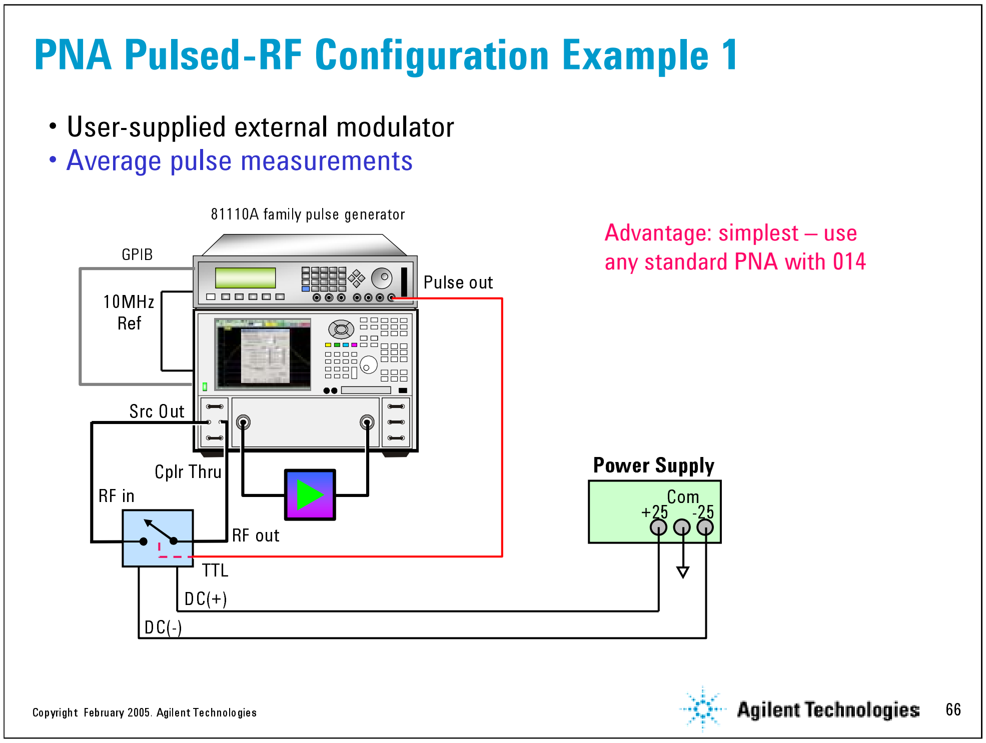
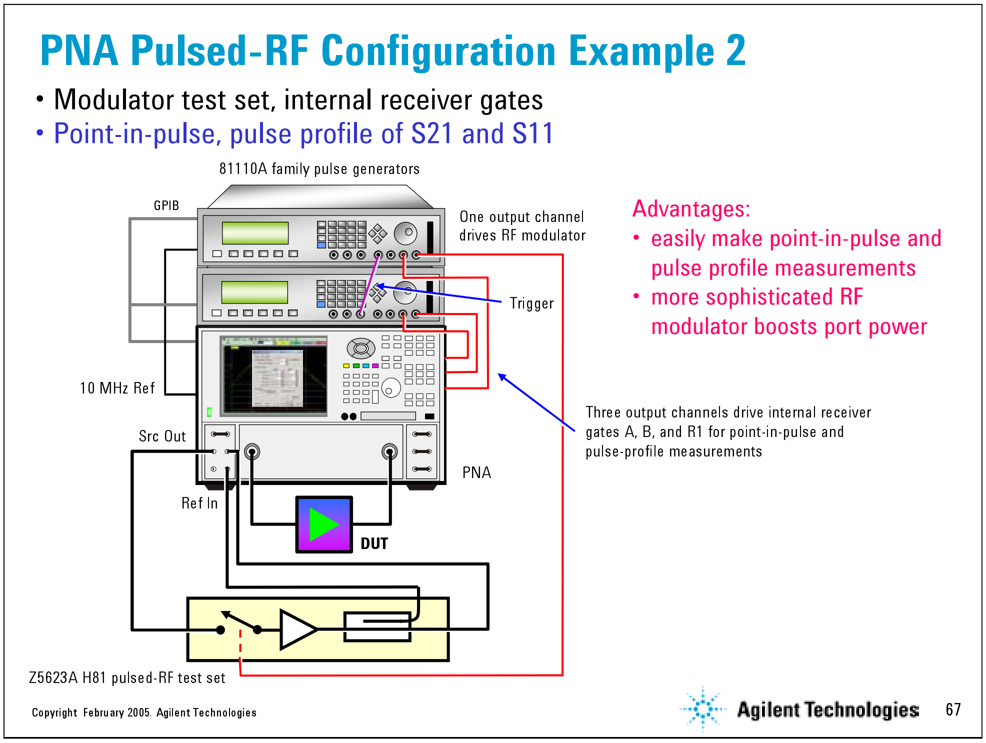
There are four ways in which the reference receiver can be used for pulsed S-parameter measurements. A non-gated, CW stimulus (1) gives the best dynamic range (no pulse desensitization occurs), but the effect of the pulsed stimulus cannot be ratioed out. When a pulsed stimulus is used, it is best to use have a pulsed signal for the reference receiver (2, 4). Gating of the reference receiver is generally required for pulse-profile measurements (4). For the case of a pulsed-bias system with CW input, choice 3 is often used.



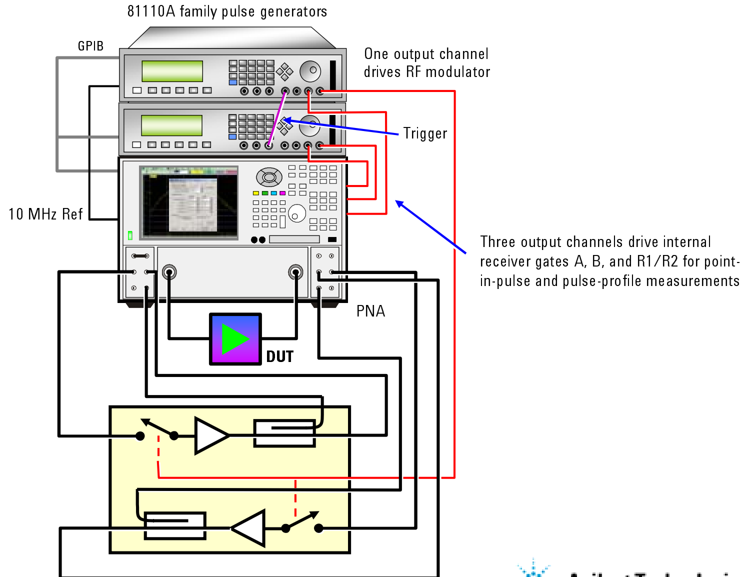
This setup is the simplest pulsed-RF configuration. Here, the customer supplies an external switch to modulate the PNA's source, and no IF or RF gating is used. With this setup, narrowband detection can be used to measure the average pulse response (no point-in-pulse or pulse-profile measurement capability) using any arbitrary width pulse, or wideband detection can be used for pulses greater than 50 us (PNA) or 10 us (PNA-L).



This example shows a typical radar-application setup. We have added a more complicated RF modulator assembly. Not only is there a switch to pulse the PNA's source, but an amplifier has been added to boost the available power at test port one. Higher test-port power is often needed for radar components like T/R modules. The directional coupler is used to provide a reference signal after the booster amplifier, so any drift of the booster amp is removed from the measurement by ratioing.

In this example, we are also using the PNA's internal IF gates for point-in-pulse and pulse-profile measurements. A total of four pulse output channels is shown; one for the RF modulator, and one each for the A, B and R1 (reference) receivers.

PNA Pulsed-RF Configuration Example 3: Full Forward/Reverse S-Parameter Configuration



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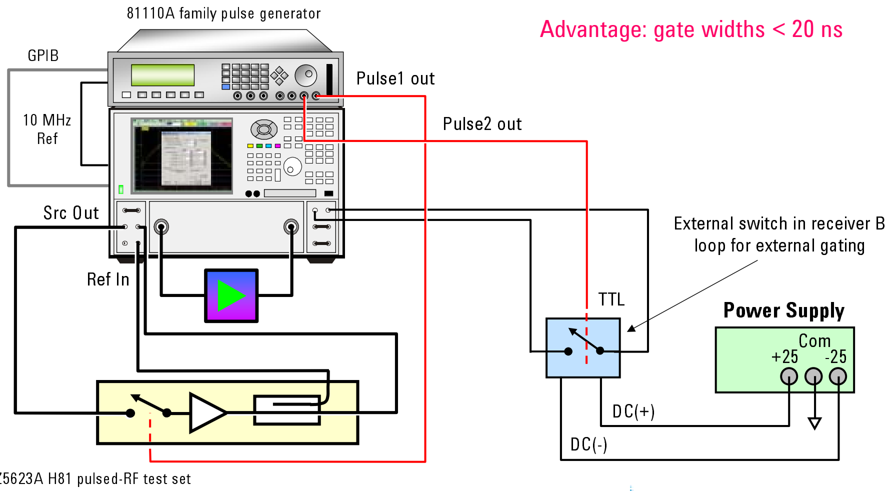
This example is similar to the last except we have added a bi-directional RF modulator. Note that in this example, the R1 and R2 reference receivers share a common pulse drive. If independent control of the R1 and R2 receivers is desired, then a fifth pulse output (and a third pulse generator) is required.

PNA Pulsed-RF Configuration Example 4

- Modulator test set, external receiver gate
- Point-in-pulse, pulse profile



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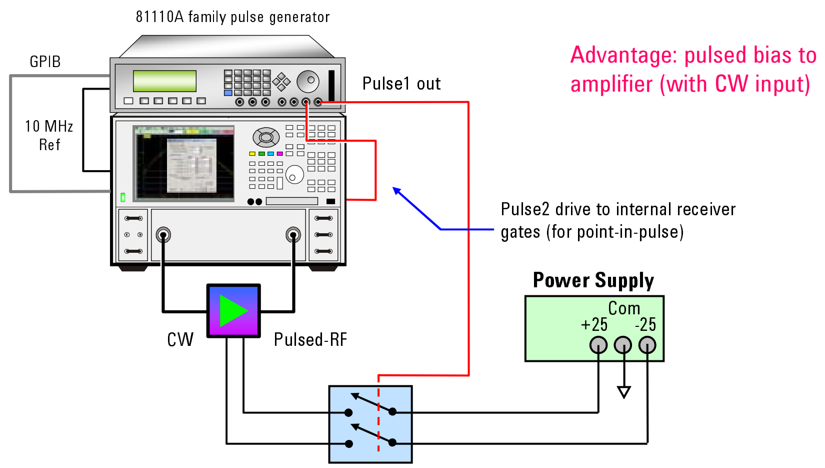
This example shows the use of an external switch for RF gating, instead of using the PNA's internal IF gate switches. One might do this to get a shorter gate width (<20 ns) or to use a stock PNA (without H11). For ratioed pulse-profile measurements, a second RF switch would be needed for the R1 reference channel.

PNA Pulsed-RF Configuration Example 5

- User-supplied pulsed bias to amplifier, internal IF gate
- Point-in-pulse, pulse profile



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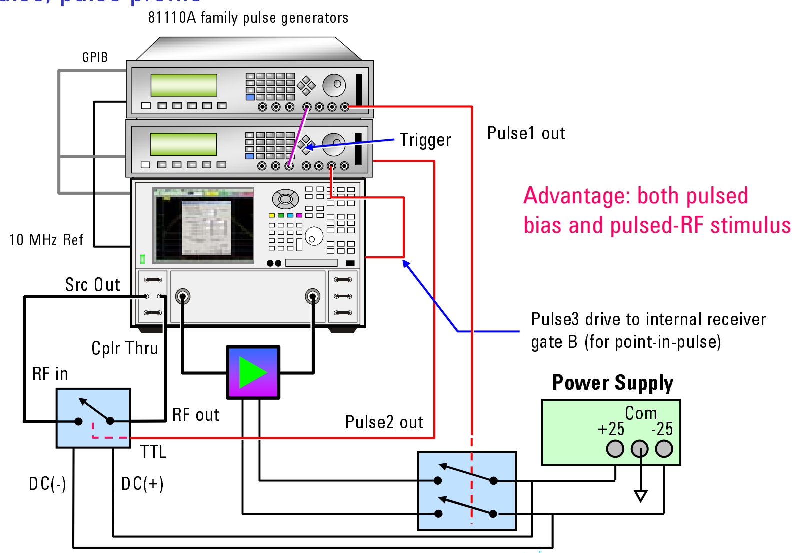
This example shows that the PNA can be used when the pulsed RF signal is created by pulsing the DC bias of the DUT. In this example, the input to the DUT is a swept CW signal, but the output is a pulsed signal. The user has to supply the switches in the DC path, or use a power supply that can be pulsed on and off.

PNA Pulsed-RF Configuration Example 6

- Customer-supplied pulsed bias and pulsed RF, internal IF gate
- Point-in-pulse, pulse profile



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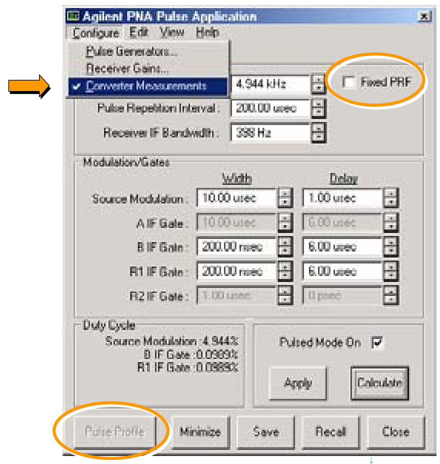
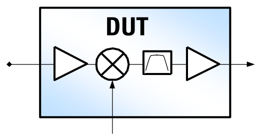
In this last example, we combine pulsed-RF stimulus with pulsed bias. This will be a common configuration for on-wafer testing. We also show one pulse output channel driving the B receiver gate. For ratioed pulse-profile measurements, the fourth pulse channel would be needed for the R1 reference channel. In that case, both pulse generators would be fully used.

Measuring Converters

- Check "Converter Measurements"
- Don't use "Fixed PRF"
- Measure average or point-in-pulse, but not pulse profile





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Option H08 has a special mode that allows it to work when a frequency offset is present in the measurement channel. This allows pulsed-RF testing of mixers and converters. In this mode, the "Fixed PRF" choice should not be used, and pulse-profile is not available.

Calibrating Your Pulsed-RF System

- Calibration is performed under pulsed conditions
- Calibration methodology is identical to normal (swept sinusoid) mode
- ECal or mechanical standards can be used
- In general, each unique set of pulse and gating conditions requires a separate calibration

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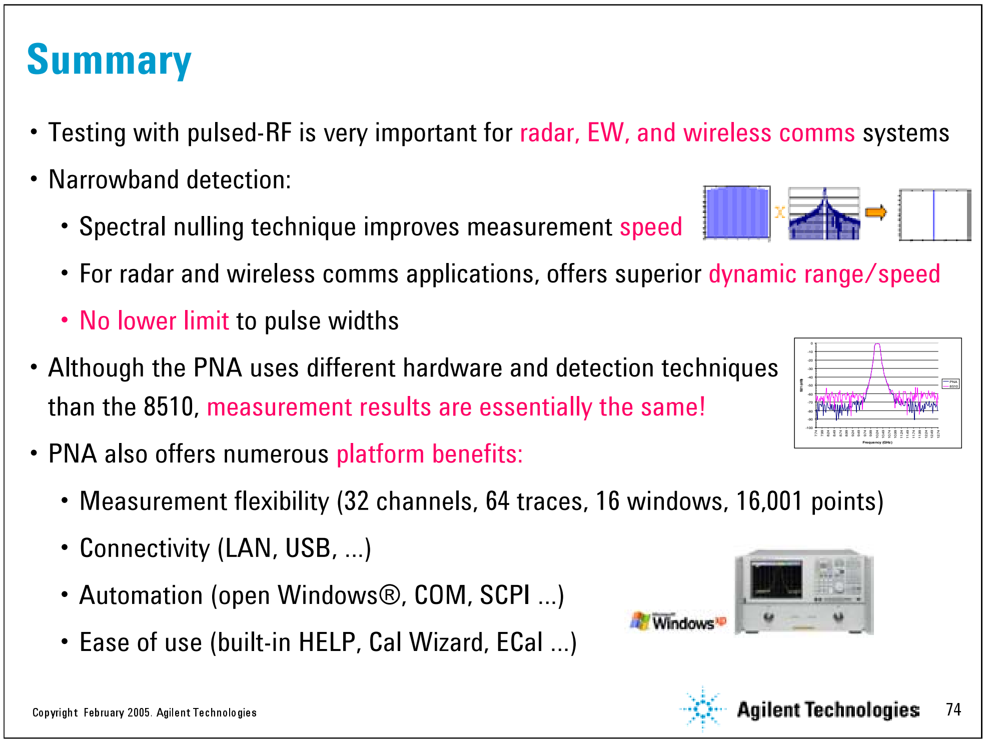
Calibrating a pulsed-PNA system is no different than cal'ing a normal S-parameter measurement. Either mechanical or ECal modules may be used. The cal should be done under pulsed conditions, and each unique set of pulse and gating parameters usually requires a separate calibration. ECal modules are especially useful for pulsed-RF measurements, because numerous measurement setups with unique pulse conditions can be calibrated with a single connection to the ECal module, making calibration fast and easy.



At the start of the paper, we described the markets and measurements relating to pulsed S-parameter measurements. Testing with pulsed RF stimulus is very important for radar, electronic warfare and wireless communications systems.

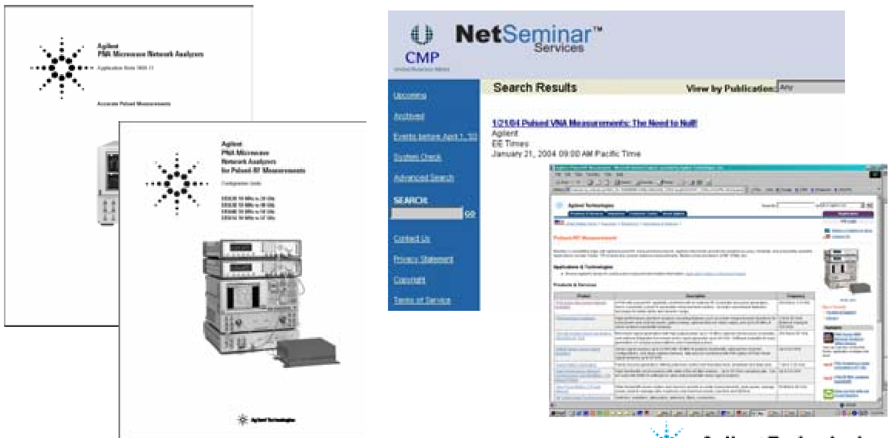
We also showed that narrowband detection is a powerful way to analyze pulsed-RF signals, providing point-in-pulse and pulse-profile measurements. Agilent's unique spectral nulling technique improves measurement speed considerably by using wider IF bandwidths. For radar and wireless communication applications, narrowband detection offers superior dynamic range and speed compared to the 8510. And with narrowband detection, there is no lower limit to pulse widths.

It is important to remember that although the PNA uses different hardware and detection techniques than the 8510, the measurements that can be made and the measurement results are essentially the same – they both provide accurate pulsed-RF S-parameter measurements.

Finally, the PNA offers many platform benefits compared to the 8510. The PNA has more measurement flexibility with 32 measurement channels, 64 traces, 16 windows, and up to 16,001 data points. The PNA also offers all of the connectivity you'd expect from a PC-based instrument, such as connecting to printers via LAN, and using USB peripherals. The open Windows® environment allows maximum flexibility for automating measurements, like running software right on the instrument, and using COM and DCOM for fast program execution and data transfer. The PNA also has many features to ease the task of vector network measurements, like a built-in HELP system, a Calibration Wizard, and electronic calibration (using ECal modules) that works up to 67 GHz.

Resources

- PNA Pulsed RF Configuration Guide (5988-9833EN)
- New! App Note 1408-11: Accurate Pulsed Measurements (5989-0219EN)
- www.netseminar.com: “Pulsed VNA Measurements: the Need to Null!”
- www.agilent.com/find/pulsedrf



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Other resources to help you with pulsed S-parameter measurements are shown here.