Agilent
Pulsed Measurements Using The Microwave PNA Series Network Analyzer

White Paper

Agilent Technologies

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Introduction

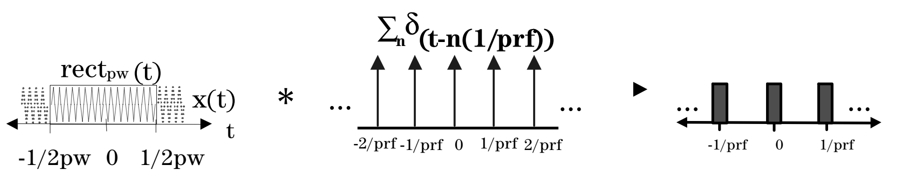
Vector network analyzers are traditionally used to measure the continuous wave (CW) S-parameter performance of components. Often under these operating conditions the analyzer is functioning as a narrowband measurement instrument. It transmits a known CW frequency to the component and measures the CW frequency response. If we were to look at the response of a single CW frequency we would see a single spectral tone in the frequency domain. The analyzer has a built in source and receivers that are designed to operate together in a synchronous manner, utilizing narrowband detection, to measure the frequency response of the component. Most analyzers can be configured to generate a frequency sweep over many frequency tones.

In some cases, the signal applied to the component must be pulsed (turned on and off) at a specific rate and duration. If we were to look at the frequency-domain response of a single pulsed tone, it would contain an infinite number of spectral tones making it difficult to utilize a standard narrowband VNA. This document describes how to configure and make accurate pulsed S-parameter measurements using the Agilent Microwave PNA Series network analyzer.

Pulsed Signals

To visually generate what the spectrum of a pulsed signal looks like we first mathematically analyze the time-domain response. Equation 1 illustrates the time-domain relationship of a pulsed signal. This is generated by first realizing a rectangular windowed version (rect(t)) of the signal with pulse width PW. A shah function is then realized consisting of a periodic train of impulses spaced 1/PRF apart where PRF is the pulse repetition frequency. This can also be viewed as impulses at spacing equal to the pulse period. The windowed version of the signal is then convolved with the shah function to generate a periodic pulse train in time corresponding to the pulsed signal.

$$y(t) = (rect_{pw}(t) \cdot x(t)) * shah_{\frac{1}{prf}}(t)$$



Equation 1. Time-domain relationship of a pulsed signal.

To look at this signal in the frequency domain we need to perform a Fourier transform on the pulsed signal y(t).

$$Y(s) = (pw \cdot sinc(pw \cdot s) * X(s)) \cdot (prf \cdot shah(prf \cdot s))$$
$$Y(s) = (pw \cdot sinc(pw \cdot s) \cdot (prf \cdot shah(prf \cdot s))$$
$$Y(s) = DutyCycle \cdot sinc(pw \cdot s) \cdot shah(prf \cdot s)$$

Equation 2. Frequency-domain spectrum of the pulsed signal.

Equation 2 shows that the frequency-domain spectrum of the pulsed signal is a sampled sinc function with sample points (signal present) equal to the pulse repetition frequency.

Figure 1 illustrates what a typical pulsed spectrum would look like for a signal that has a pulse repetition frequency of 1.69 kHz and a pulse width of 7 us. Figure 2 is the same pulsed spectrum zoomed in on the fundamental frequency that is pulsed (center of plot). Notice that the spectrum has components that are n*PRF away from the fundamental. It is also worthy to note that the magnitudes of the spectral components close to the fundamental tone are relatively large.

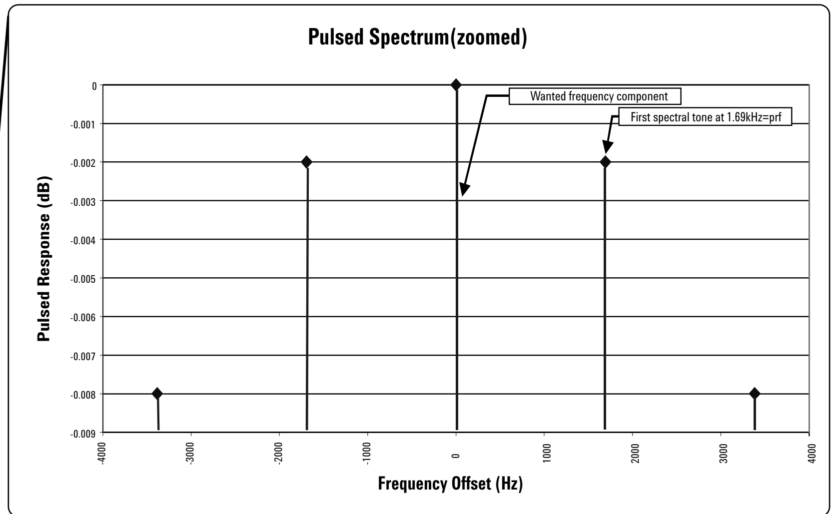


Figure 1.

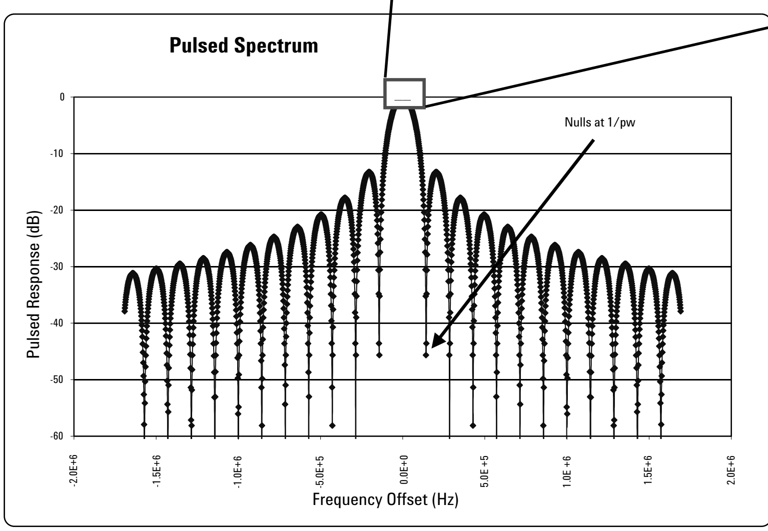


Figure 2.

Pulsed Measurement Technique

The microwave PNA is a high performance network analyzer that uses narrowband detection. The PNA downconverts the received signal to an intermediate frequency (IF) that is then digitized and digitally filtered for display and analysis. During the downconversion process, filtering is applied to reject unwanted noise and signal components. Once the signal is digitized using an analog to digital converter, the analyzer applies a digital filter with an IF bandwidth specified by the user. Typically this filter is used to reduce measurement noise and increase dynamic range.

The digital filtering algorithm works fine for non-pulsed signals, but what occurs when the receiver receives a pulsed signal? Using a narrowband detector, we ideally want a digital rectangular filter to filter out everything but the fundamental pulsed frequency component. This would require a filter that would have a minimum stop-band frequency less than the PRF of the pulsed signal with high rejection. The filter transition slope should be well away from the first PRF tone (as illustrated in Figure 3), so that there is maximum rejection of the unwanted tones. This filter may be difficult to design because the PRF tones may be in close proximity to the fundamental tone. Strict rectangular filters in the frequency domain have some trade-offs such as excessive ringing in the time domain. As such, filter designers adopt differing techniques to achieve the best performance in both frequency and time domain while still offering significant filtering performance.

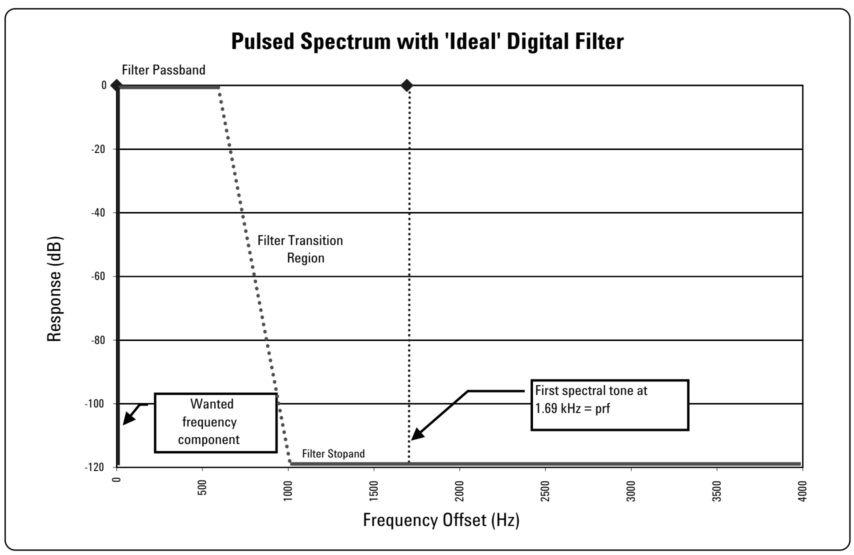


Figure 3.

Figure 4 shows one possible digital IF filter used in the microwave PNA. Notice that it is not rectangular in shape and therefore, if used unaltered, would possibly pass unwanted components in the frequency domain, causing measurement error. Also notice that the digital filter has nulls, which are periodically spaced in the frequency domain. The period of these nulls is proportional to the sample rate of the receiver and the architecture of the digital filter. Using the microwave PNA we are able to filter out the unwanted signal components by aligning the nulls of the digital filter with the unwanted pulsed spectrum components leaving the fundamental tone as illustrated in Figure 5. One advantage of this filtering technique is that the nulls of the filter are very deep and provide substantial rejection of the pulsed spectral components, if aligned. Another advantage is that the nulls can be placed in close proximity to the fundamental tone because the transition regions at the nulls are very abrupt. Using this technique the microwave PNA can make accurate pulse measurements using narrowband pulse detection.

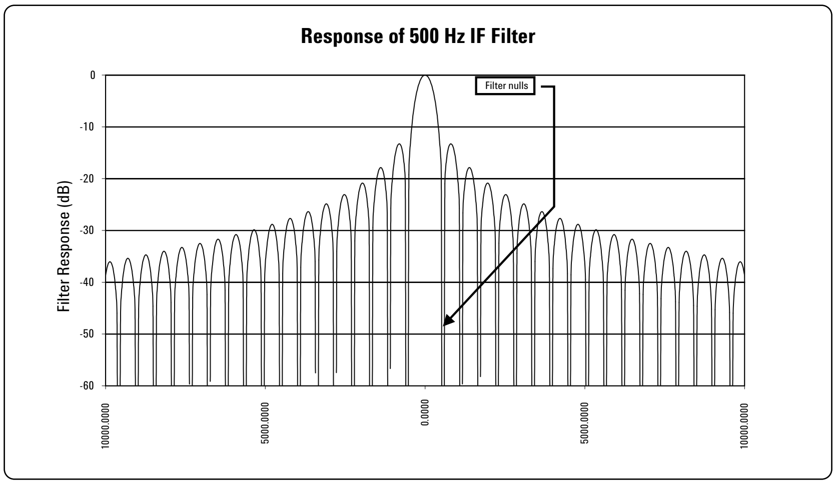


Figure 4.

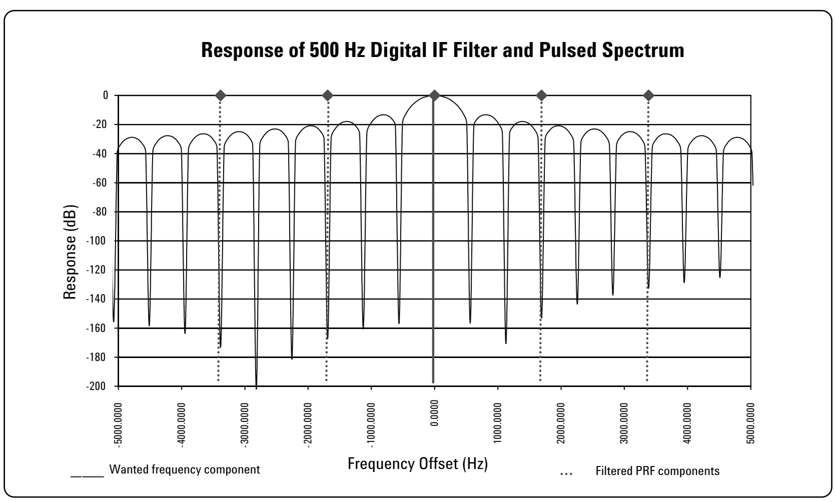


Figure 5.

Narrowband Filter Table

The following table provides information on the null placement of the digital filter for different IF bandwidth settings on the microwave PNA. The 'Offset of first null' represents how far the first digital filter null is from the frequency of interest. Because the microwave PNA digital filter nulls are repetitive in nature, the 2^{nd}, 3^{rd}, n^{th} nulls and their corresponding offsets can be determined by multiplying the first null offset value in the table by an integer 'n'. This table[1] can be used to align the digital filter nulls with the pulsed spectrum.

Table 1. PNA IF filter table.

MW PNA IF BW (Hz)	10000	7000	5000	3000	2000	1500	1000	700	500	300	200	150
Offset of first null (Hz)	24813.90	16977.93	11520.74	6863.42	4543.39	3395.59	2255.81	1573.56	1127.90	680.55	451.79	338.13

Table 1 continued...

MW PNA IF BW (Hz)	100	70	50	30	20	15	10	7	5	3	2	1
Offset of first null (Hz)	224.95	158.59	112.24	67.29	44.84	34.05	22.60	16.50	11.25	6.76	4.50	2.25

1. Maximum usable IF bandwidth settings for pulsed is 10 kHz.

Measurement Dynamic Range

When using narrowband pulsed detection, there is a loss in dynamic range corresponding to the duty cycle, equal to 20*log(Duty Cycle). This is due to the fact that the narrowband filter is filtering out everything but the fundamental tone of the pulsed signal. As the duty cycle decreases, more energy moves into the sidebands and less energy remains in the fundamental tone. This can be illustrated by analyzing equation 2 and noticing that magnitude of the tones in the frequency domain decrease proportionally to the pulse width and the pulse repetition frequency (i.e. DutyCycle=(PW•PRF)). For some analyzers this may limit measurement usability. As the duty cycle decreases, the dynamic range reaches a point where the measurement results are inaccurate. The microwave PNA excels using narrowband detection because of its outstanding performance in trace noise and dynamic range over other network analyzers (see Figure 6[1]).

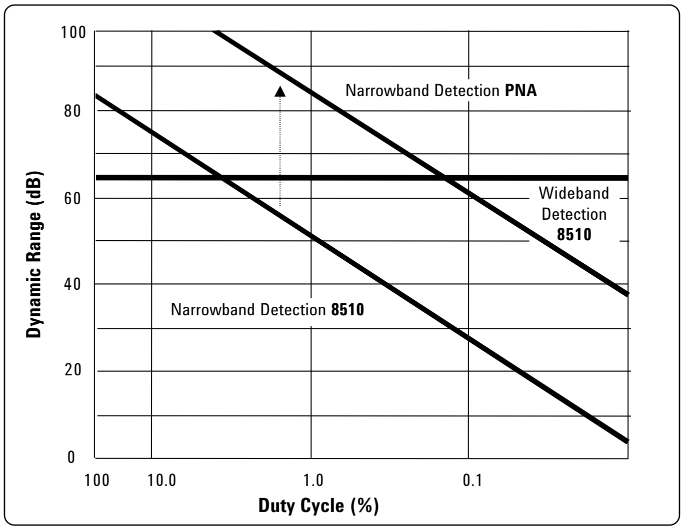


Figure 6. Pulsed dynamic range.

Hardware Architecture

To measure a component under stimulus pulsed conditions the analyzer must supply a pulsed signal to the component and measure its response to the pulse, which in most cases, is a modified version of the pulsed signal applied. The fundamental idea is that gate switches (modulators) are placed in front of the source providing the means for pulsing the analyzers internal source. One key benefit to using the microwave PNA in this configuration is that very narrow pulse widths (i.e. less than 1us) can be used as long as the duty cycle is large enough to provide acceptable measurement dynamic range. The external modulators and pulse generator largely define pulse width limitations.

1. This figure is for illustration purposes and is not an exact representation of dynamic range.

Hardware Setup

To measure pulsed S-parameters using the microwave PNA, the analyzer's internal source must be modulated by adding a pulse modulator between the source and device. This can be accomplished by using a microwave PNA with Option 014 (configurable test set) and Option 080 (frequency-offset mode). Option 014 provides front panel jumpers to add the required external pulse components. Option 080 allows the user to pulse the reference receivers[1] by placing the analyzer in frequency-offset mode so that all four receivers (A,B,R1,R2) can operate independently from the analyzer's internal source. Pulsing both the measurement and reference receivers will help reduce any possible measurement drift from external components such as modulator(s) and amplifiers when measuring ratioed parameters. An example setup is illustrated in Figure 7.

Equipment details:

1. **Agilent 81110A Pulse/Pattern Generator:** The pulse generator provides the pulse timing for the external source modulators. The 81110A pulse/pattern generator mainframe should be ordered with an 81111A output module to provide one channel to pulse the source modulator. The pulse generator must have a PLL reference (10 MHz) input to lock the analyzer and pulse generator to the same time base. This is essential to make sure the frequency domain components of the filter and pulsed spectrum are locked together during alignment of nulls with PRF components.

2. **Agilent Microwave PNA Series:** The E8362/3/4B and E8361A Microwave PNA Series of network analyzers can be used and should be configured with Options 014 and 080.

3. **Pulse Modulators:** Modulators are placed after the source and must have a frequency response equal to the DUT requirements (i.e. It must be able to pass the signal from the source with minimum attenuation). An amplifier should be placed after the modulator to provide a constant source match during measurement and calibration, and may also be used to increase the pulsed signal power. An isolator may be required (before the modulator) to isolate the analyzer source from the modulator. This is so that when the modulator is in the off state (no energy passing through modulator) that any high reflections, due to the off state match of the modulator, are minimized before reaching the analyzer. A high-pass filter may also be required (after the modulator) to filter out any video-feedthrough[2], generated by the modulator, which may interfere with the operation of the PNA.

4. **Coupler:** An external coupler is used to couple back the pulsed source signal to the reference receiver. This is beneficial when measuring ratioed parameters because any deviations in the external components after calibration will have minimal affect on the measurement results. Both the measurement and reference receiver will see the same deviations.

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1. Pulsing the reference receivers without Option 080 will cause phase lock errors to occur.
2. Low frequency content that is generated by pulsing the modulator.

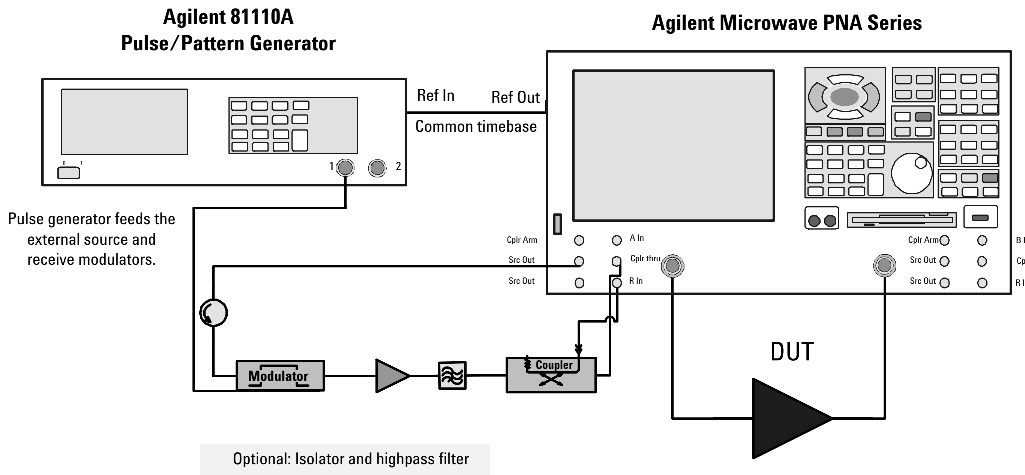

Figure 7. PNA Series pulsed setup.

Measurement Configuration

> **NOTE**
> Care should be taken that all RF/uW and DC power levels to the analyzer and external components remain within their respective limits to prevent damage to equipment.

The following illustrates a general measurement configuration using the Microwave PNA:

1. Connect the hardware as illustrated in Figure 7.
2. Create the required S-parameter measurements (i.e. S21, S11)
3. Place the analyzer in frequency-offset mode with zero offset so that the source and receiver are at the same frequency during measurement sweep. This will allow the reference receivers to receive a pulsed signal without loosing phase lock.
4. Set the analyzers internal IF gain to the optimum level for pulsed measurements by sending the following SCPI commands. This can be accomplished either with a program or using the 'GPIB Command Processor Counsel' under the 'System->Configure->SCPI/GPIB' menu on the PNA:
   - 4.1. 'DIAG:ACQGAIN:AUTO OFF'
   - 4.2. 'DIAG:ACQGAIN 85'
   - 4.3. To turn IF auto gain back on (for normal CW S-parameter measurements) send: 'DIAG:ACQGAIN:AUTO ON'
5. Calculate and set the analyzer IF bandwidth setting based on the pulse repetition frequency required for the measurement (utilize table 1).
6. Set the required pulse width and pulse repetition frequency on the pulse generator.
7. Make sure the pulse generator and the analyzer's time-base are locked together by connecting the 10 MHz reference lines.
8. Calibrate system under pulsed conditions and perform measurements.

Measurement Example

Figure 8 shows an S-parameter measurement comparison between the filter with no pulsing (memory trace) and that with pulsing (data trace). With 5% duty cycle, we have effectively reduced our specified dynamic range at 1.5 kHz by 26 dB (20*log(Duty Cycle)). If required one can gain back 10 dB (10*log(# of averages)) by applying 10 averages to the measurement. The measurement settings were as follows:

- Pulse parameters
  - Pulse period = 58.9 us
  - Pulse width = 3.0 us
  - Duty cycle = 5%

- PNA settings
  - 1.5 kHz IF BW (using 5th null)
  - Stepped-sweep mode

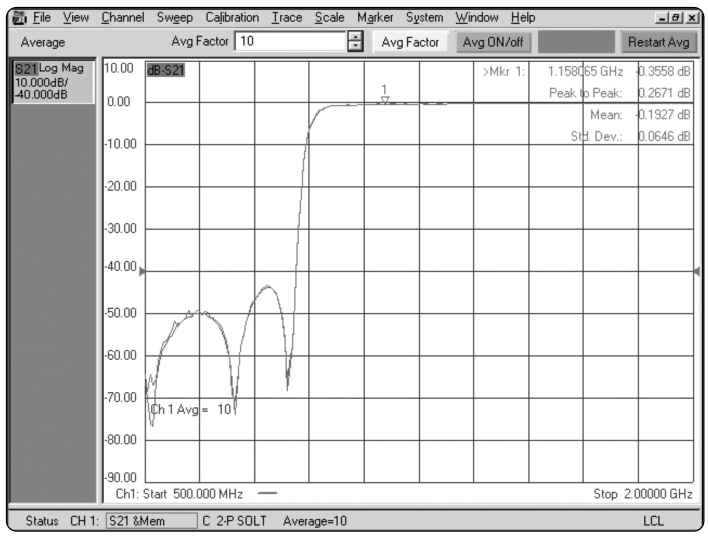

Figure 8. PNA Series pulsed measurement comparison.

Conclusion

The results show that pulsed measurements can be made with existing microwave PNA hardware by using external pulse components. Narrow pulse widths can be used as long as the duty cycle is large enough for acceptable measurement dynamic range. The exceptional hardware performance of the microwave PNA largely offsets the limitations of using a narrowband detection technique for pulsed measurements.

Contact Agilent Technologies for information on other possible pulsed configurations.

Web Resources

For additional literature and product information visit the Microwave PNA Series Web site: **www.agilent.com/find/pna**

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