APPLICATION NOTE

Time-Gated Spectral Analysis with X-Series Signal Analyzers

Techniques for Measuring Pulsed Signals

KEYSIGHT TECHNOLOGIES

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What is Time Gating?

Time gating allows you to measure the spectrum of a periodic signal during a specific portion of time, typically the on-time of the bursted signal. A trigger is used to synchronize when the burst occurs. In many cases the spectral components that otherwise would contribute to the pulse’s rising and falling edge will mask spectral components that contribute to the spectrum of the pulse during its on time. Gating is also useful for applied spectral measurements such as channel power, adjacent channel power, and spectral emission mask measurements of a modulated signal that is bursted in the time domain.

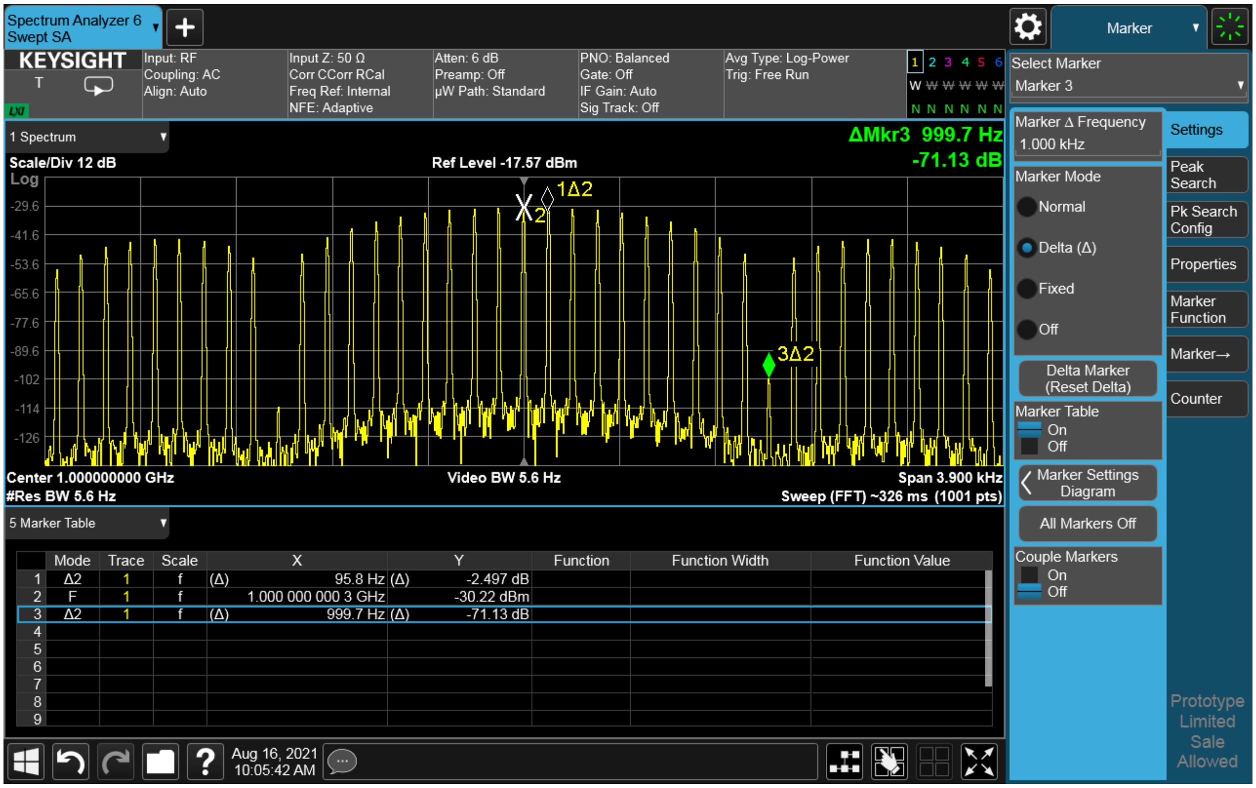
When making measurements with time gating, you need four basic items:

1. An externally or internally supplied gate trigger signal
2. A gate control or trigger mode (edge or level)
3. A gate delay setting (determines how long after the trigger signal the gate becomes active)
4. A gate length setting (determines how long the gate is on)

We will discuss this further with examples to illustrate effective time-gated spectral analysis.

Frequency Spectrum of a Pulsed Signal

The frequency spectrum of a pulsed continuous wave (CW) signal can be determined by the pulse width, identified by τ, and the pulse period of the signal in time domain, represented by T. Due to the realistic nature of a pulse, the spectrum of a CW pulsed signal is a carrier with infinite sidebands, spaced at 1/T, with an envelope of sinc($\Delta\tau$/T). An example of the spectrum of a pulsed CW signal is shown below and it shows why time gating is so useful for signal analysis.



Practically, it would be difficult to determine the spectral purity of the pulse during its on-time due to the presence of the infinite sidebands, which could be masking an unwanted modulation product or spurious signal. You could remove the excess spectral components by performing time gating on the signal and only be measuring the spectrum when the pulse is on. Ultimately, time gating allows you to perform measurements that are otherwise difficult to make using traditional frequency-domain spectral analysis. Examples of some signals that would require time gating include pulsed radio frequency (RF), time multiplexed, and TDMA signals.

Time Gating on a Pulsed CW Signal

Many analyzers today include features that help easily set up time-gated measurements, such as the gate-view setup screen available on Keysight's X-Series Analyzers shown below.

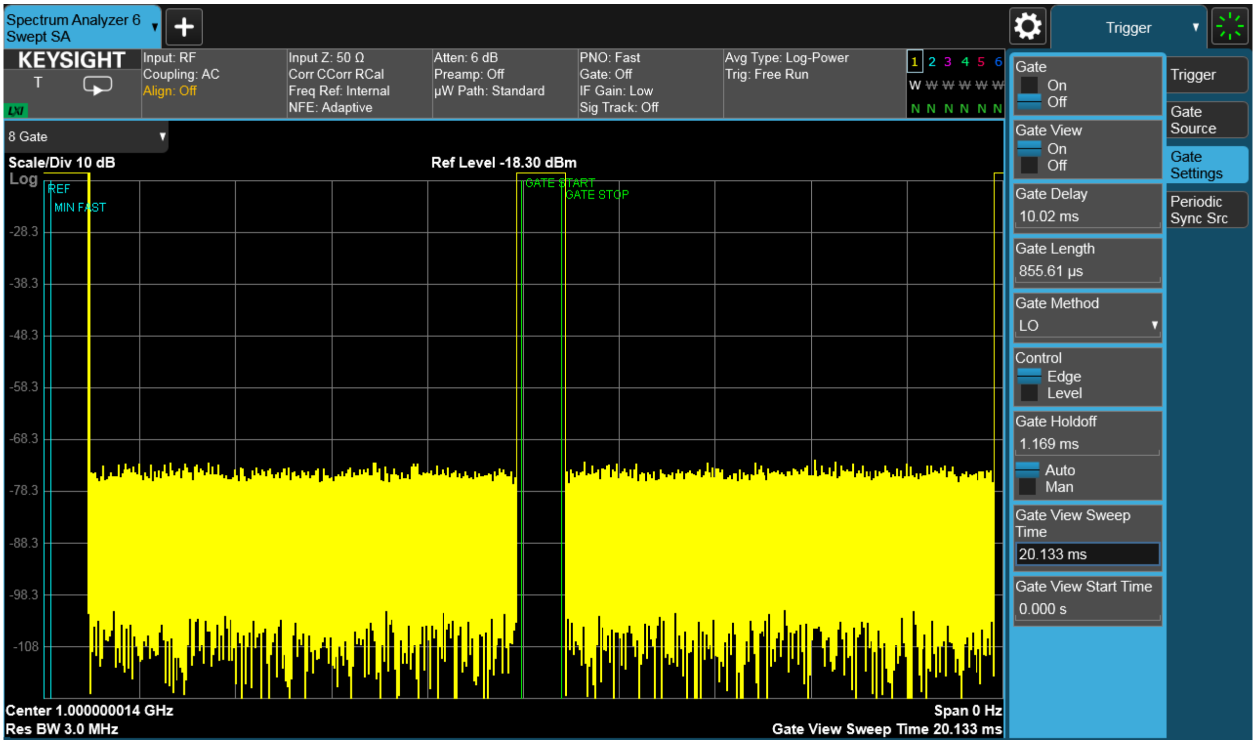
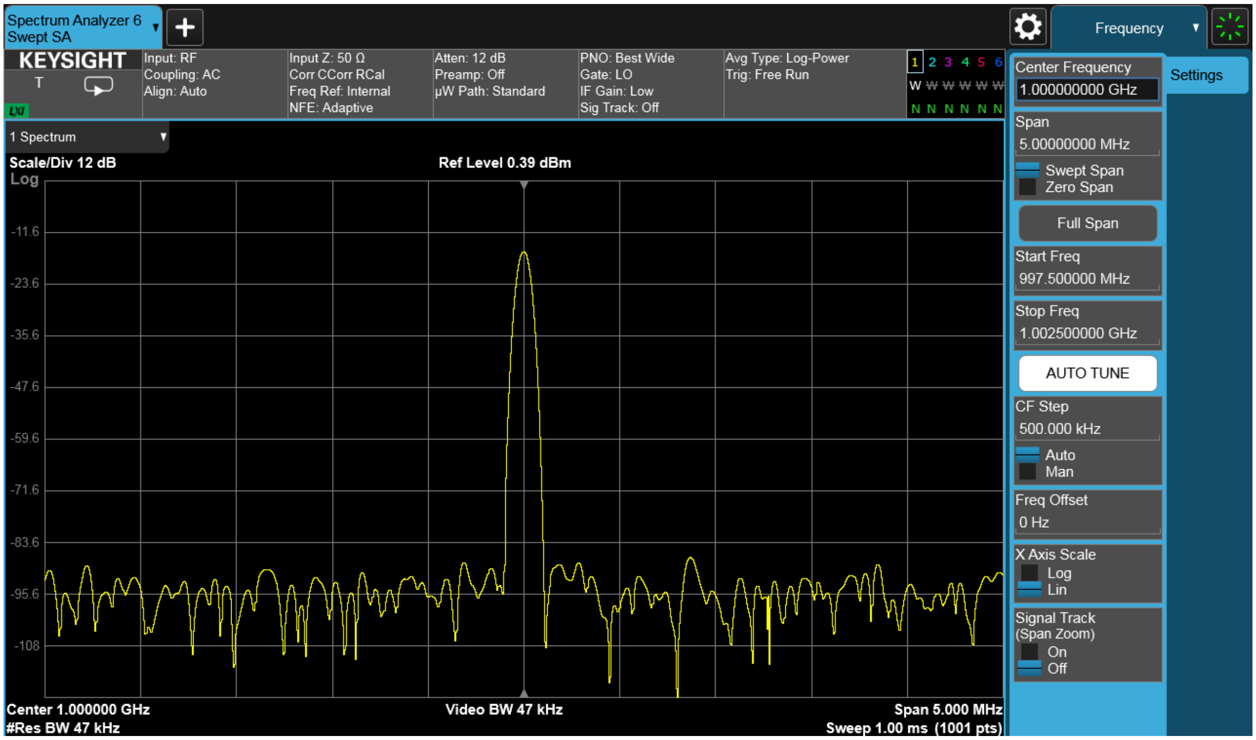


Figure 2. Gate-view setup screen on a UXA N9040B

The feature displayed above allows you to set the appropriate gate delay and length, known together as the “gate”, on the portion of the pulse that is of interest to you. In the example pictured, the portion of interest is when the pulse is on, which means you would need to take care to ensure the rising and falling edges are not captured in the gate. The RBW has a rise time of 0.7/RBW. As a rule of thumb, it is best to have an RBW rise time of at least 10 times greater than the Pulse Width. The externally supplied gate trigger signal is used to synchronize the gate with the portion of the CW pulse being measured. Figure 3 illustrates the result of time gating performed on this pulsed CW signal. Note the difference in RBW and Span setting values throughout the three figures. If possible, it would be ideal to keep the RBW and Span as close as possible between Figures 1 and 3, but this may not be often realizable to obtain accurate spectrums of both the pulsed measurement and its time-gated version. The RBW will have to change in Figure 2, known as the Gate View, to properly time-gate the original CW pulse.



As seen above, applying time gating has effectively resulted in the removal of the pulse modulation that was originally applied to the signal. Now you can determine if there are spurious signals present on the spectrum, whereas before, they would have been masked by the closely spaced sidebands. It was also mentioned earlier that care needed to be taken to ensure the rising and falling edges of the pulse were not included in the gate capture; while this was true in the example above, it may be beneficial to include those edges when observing a spectrum caused by switching transients as the pulse transitions from off to on or on to off. This can be done easily by adjusting the gate delay and length in the Trigger menu.

Time Gating Methods

The previous example was completed using a particular method of time gating known as LO Gating. This method gives you control of the voltage ramp produced by a scan generator to sweep the local oscillator (LO). By only allowing the oscillator to ramp up in frequency while the gate is active, the analyzer will only sweep during this time as well. This approach has many advantages over the other time gating methods, such as allowing you to freely change many of the signal analyzer settings. This is the method that we will focus on in this application note.

Older analyzers such as the ESA Series Spectrum Analyzer used a gating method called Gated Video. The analyzer would switch off the video voltage during times in which the gate is blocked. Since there is no synchronization between the gate trigger and the sweep, extra precautions must be taken to ensure data is collected from every trace point bucket for the spectrum to be displayed completely. This results in longer sweep times than other methods and requires the use of a peak detector.

Time gating can also be accomplished via FFT gating, which takes an FFT over only the gate time. This method is not as flexible as LO Gating. A trigger source and specified gate delay is used to adjust the FFT window. This method is ideal for signals with narrow pulse widths and relatively long pulse periods because it optimizes sweep times, so long as the signal span is narrower than the FFT width. To obtain the best possible frequency resolution, choose the narrowest available RBW with a capture time that fits the period of interest. Lastly, remember there are practical limits to how narrow the gate width, and thus the pulse width, of a signal can be and still have time gating via FFT gating applied to it.

Gate Triggering

There are typically two types of gating conditions: edge and level. Edge gating conditions are satisfied when we see either a rising or falling edge on the gating signal. With this method, the gate length should be set to match the length of the RF burst with a buffer zone at the beginning and trailing ends of the burst to allow the burst to be settled. Level gating looks at the signal so long as the gate signal is at the specified level (high or low), which does not require a specified gate length. The choice of edge or level gating is presented to the user as the Gate Control function. Refer to Figure 4 for an illustration of level gating.

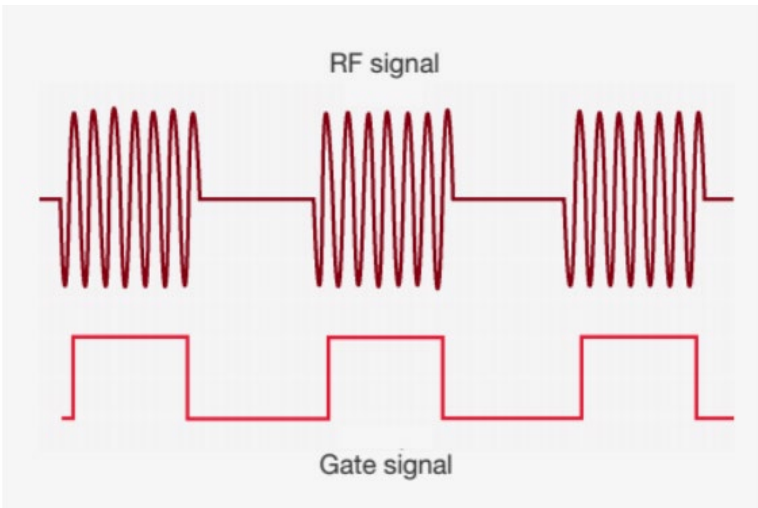


Figure 4. Time gating using level triggering, or only measuring the spectrum when the signal is above a certain level.

In the past, an external trigger signal typically needed to be provided to achieve time gating, whether it was the DUT or an external burst carrier trigger that supplied it. Most modern signal analyzers now contain additional gate trigger methods, with the most common one being the RF burst gate trigger. This trigger is generated by the rising and falling edges of a pulsed signal that are captured in the spectrum analyzer's intermediate frequency (IF). It works best for frequency spans that are less than the bandwidth of the instrument's IF. The RF burst is handy to use, since most devices don't have an external trigger signal that can be directly connected to the trigger input of the analyzer.

An alternative gate trigger is the periodic timer, which is used for time gating on a signal whose bandwidth exceeds the spectrum analyzer's IF when no external gate trigger is available. Upon selection, this trigger is automatically generated in the spectrum analyzer at some specific time interval. The instrument then synchronizes the periodic time at its center frequency between each of the sweeps to ensure the periodic timer does not drift out of sync with the signal to be measured.

Time gating can be used with many built-in power measurements such as channel power, adjacent channel power (ACP) and spectral emissions mask (SEM). Refer to the section Time Gating in PowerSuite measurements to see an example of how this can be done.

Gate Delay Compensation

The response of the RBW filter to the signal being received by the spectrum analyzer causes a known delay in its reception. Normally, this delay can be ignored, but with time gating it becomes an issue. When using Power Suite measurements such as ACP where the RBW is varying based on offset frequency, this becomes more of a challenge to ensure that gating is accomplished correctly at each offset measurement. The Gate Delay Compensation feature can be used to account for the delay imposed by the change in RBW and consists of two options, group delay and settling. This feature is available in the Power Suite measurements in the Spectrum Analyzer mode and helps with time gating when the RBW setting varies. This feature is not available in the Swept SA measurement, since the RBW would not be varying.

Group delay, or the setting named “Compensate for RBW Group Delay”, increases the hardware’s trigger delay by the difference in group delay between RBWs selected. The delay through the RBW filter is 1.81/RBW. For example, the group delay through a 1kHz RBW filter is 1.81 / 1,000Hz = 1.81ms. As the RBW is reduced, more gates are used in the Field Programable Gate Array (FPGA) on the digital IF assembly to create that RBW filter, and so there is a larger delay. This option compensates for the group delay difference between RBW setting, keeping the gate position relatively the same even as Res BW changes. With this setting, if an RF burst occurs simultaneously with the trigger, the 6 dB point on the burst response will correspond to a delay setting of zero. Refer to the image below to see the effect of “Compensate for RBW Group Delay”.

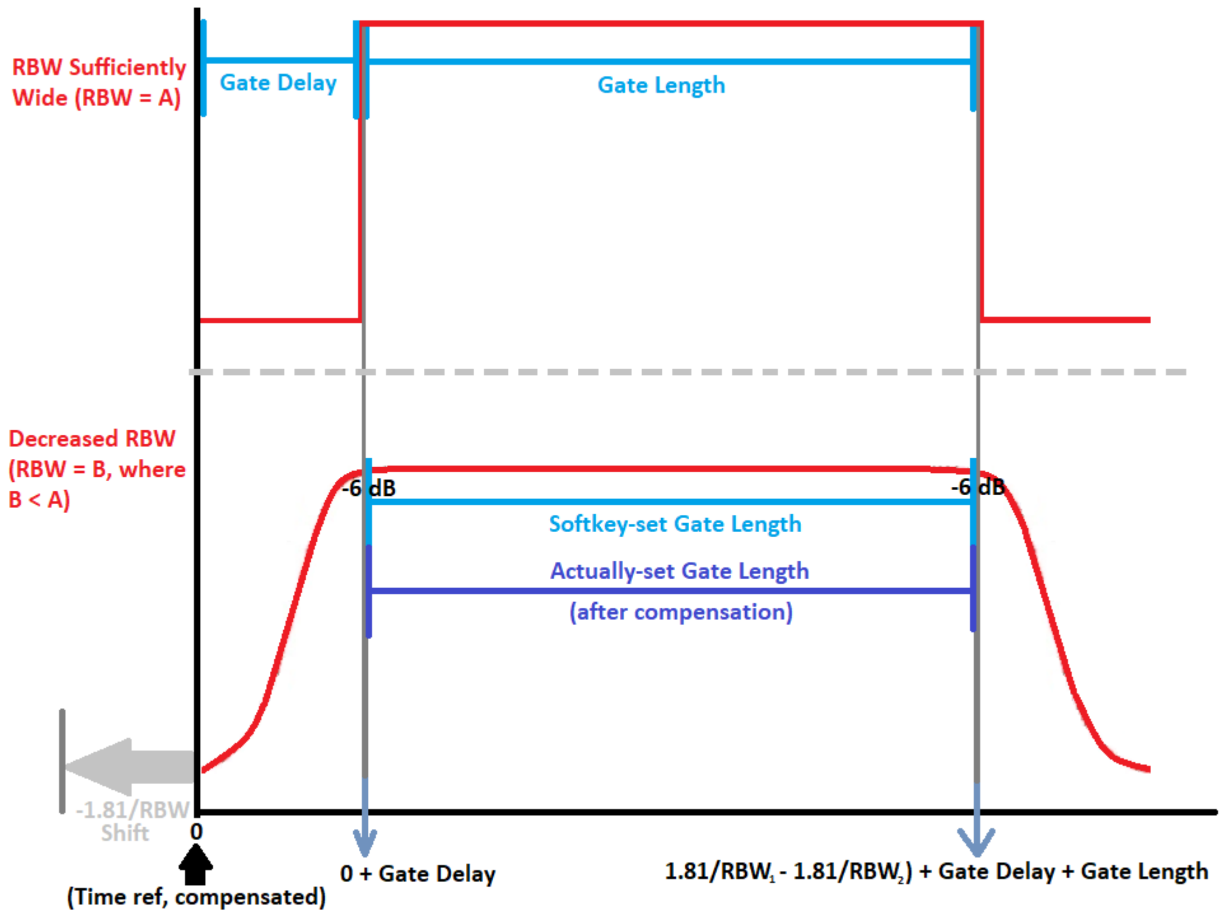


Figure 5. Gate Delay Compensation setting of "Compensate for RBW Group Delay"

The other option, named "Delay Until RBW Settled", increases the hardware's trigger delay by 3.06 seconds for every Hz increase in Res BW. This decreases the gate size as Res BW is decreased because it will only apply the gate to the "on" portion of the signal where it is considered stable (or settled). Although the former option has the advantage of being able to adjust the RBW setting without having to reset the gate each time, the latter is the recommended selection of the two because fully settled measurements are the most accurate. The image below describes the effect of the "Delay Until RBW Settled" compensation method.

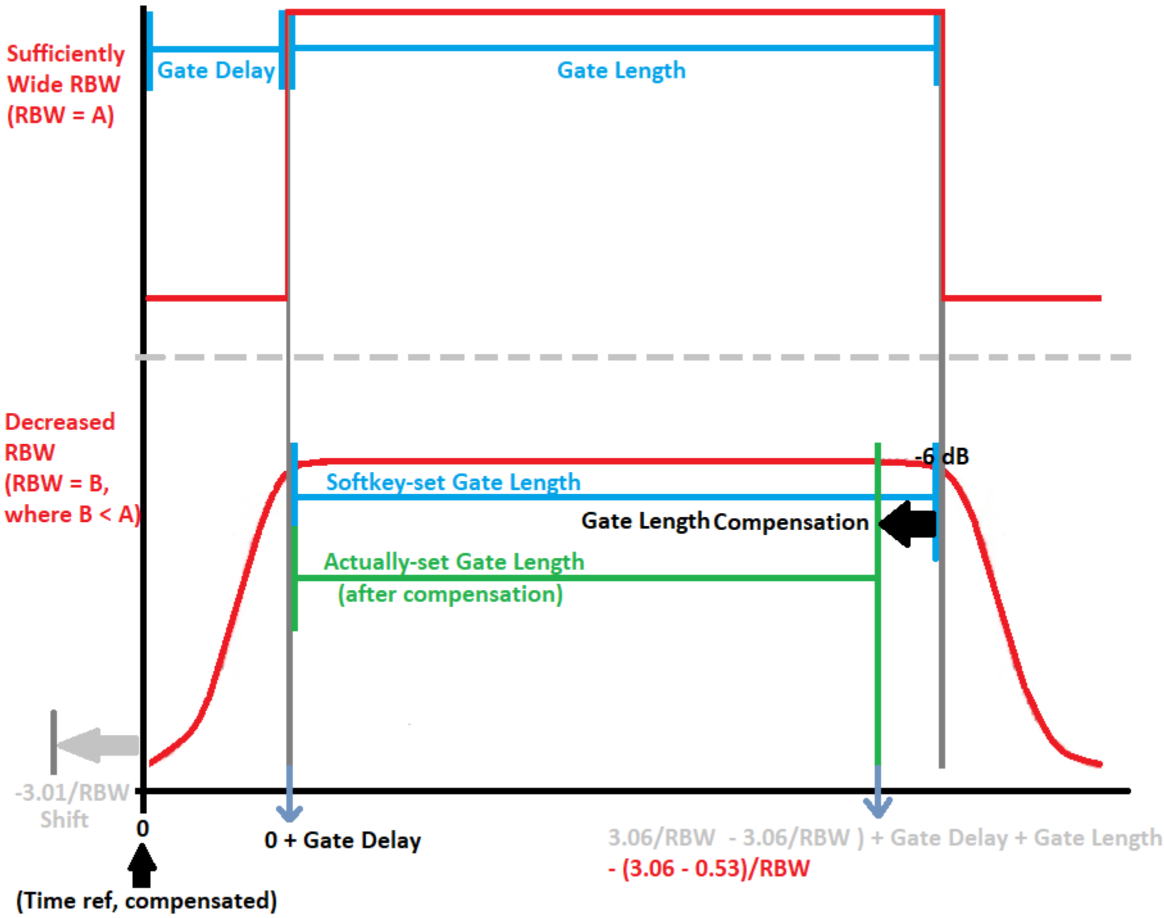


Figure 6. Gate Delay Compensation setting of “Delay Until RBW Settled”

It is useful to understand that between these two compensation methods, the group delay shifts the gate start (which would play no role if you were experimentally fine tuning the start time), while the settling delay reduces the gate window.

Burst Sync Gated Sweep

As mentioned before, the RF Burst trigger has a limited bandwidth and will need an external trigger at a large enough span. The Burst Sync Gated Sweep provides a method to measure a wideband burst signal without an external trigger by generating the accurate burst timing by itself using the RF Burst Trigger circuit and the Periodic Timer Circuit.

As an example, a signal is generated with a frequency centered at 1.5GHz with an amplitude of -5dBm. It is pulse modulated with a Pulse Period of 1ms and a Pulse Width of 80µs. Without any sort of gate or trigger set on the analyzer, the signal is displayed in the image below.

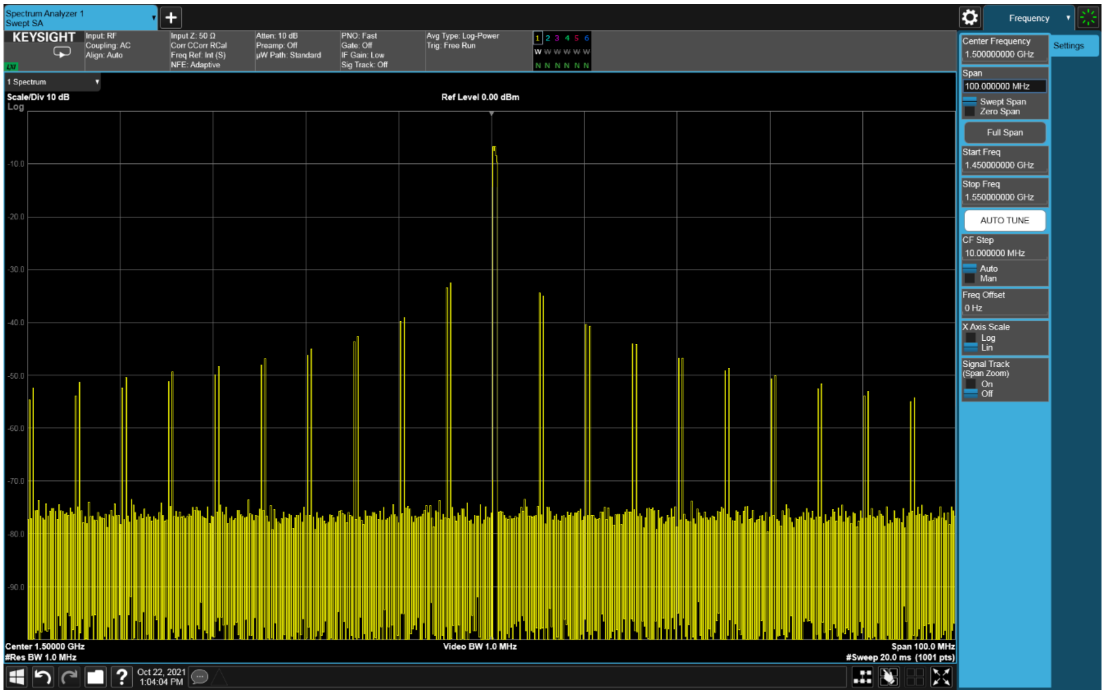


Figure 7. Pulsed signal with no time gating

To begin setting up the Gate, the Gate Source should be set to RF Burst. From there, in the Gate Settings Tab, the Gate Delay, Length, and View Sweep Time can all be adjusted to match the Gate in the image pictured below. It is necessary to set the gate to the first burst after the Min Fast line to ensure that the LO is fully settled.

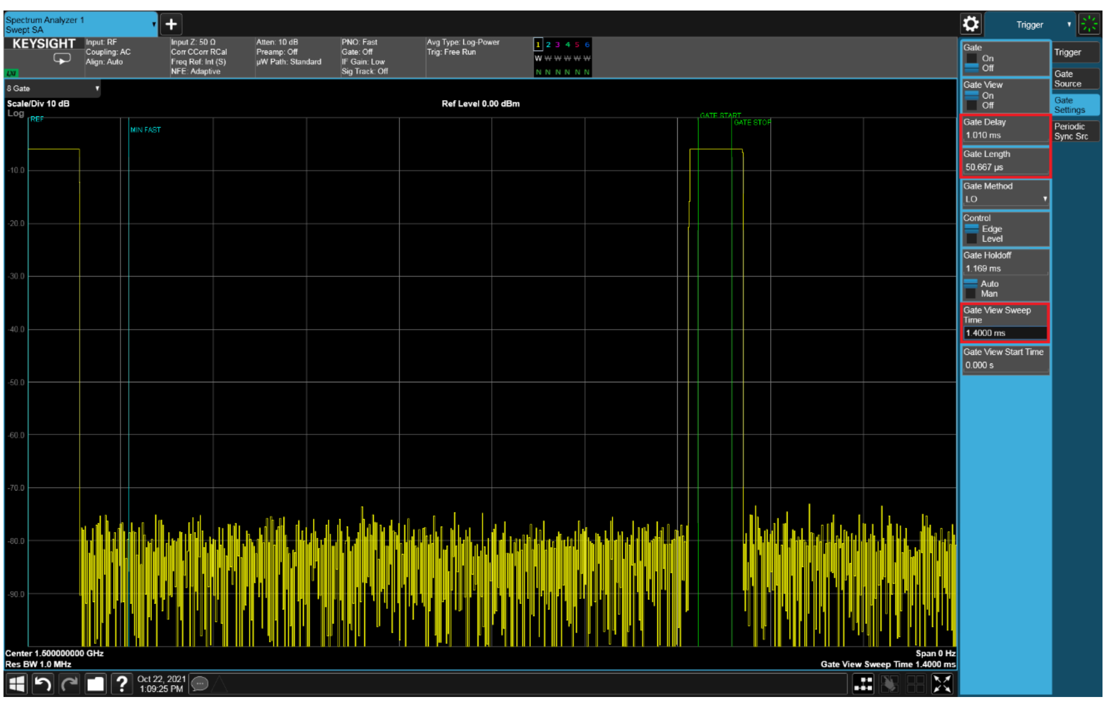


Figure 8. Gate View of RF Burst trigger

The Gate View Sweep Time can be changed to isolate one or two pulses into the display. If you can't see pulses in Gate View, changing the RBW can be helpful. From there, increasing the Gate Delay will move both the Gate Start and Gate Stop lines highlighted in green to the right. Increasing the Gate Length will do a similar thing to only the Gate Stop line. The goal here is to capture almost all of one pulse, which must be done with the pulse at least one period to the right of the Min Fast line highlighted in blue. The analyzer is not able to reliably gate over any bursts that occur prior to the Min Fast line. Once the Gate View looks similar to the picture above, turning the Gate On produces the display below.

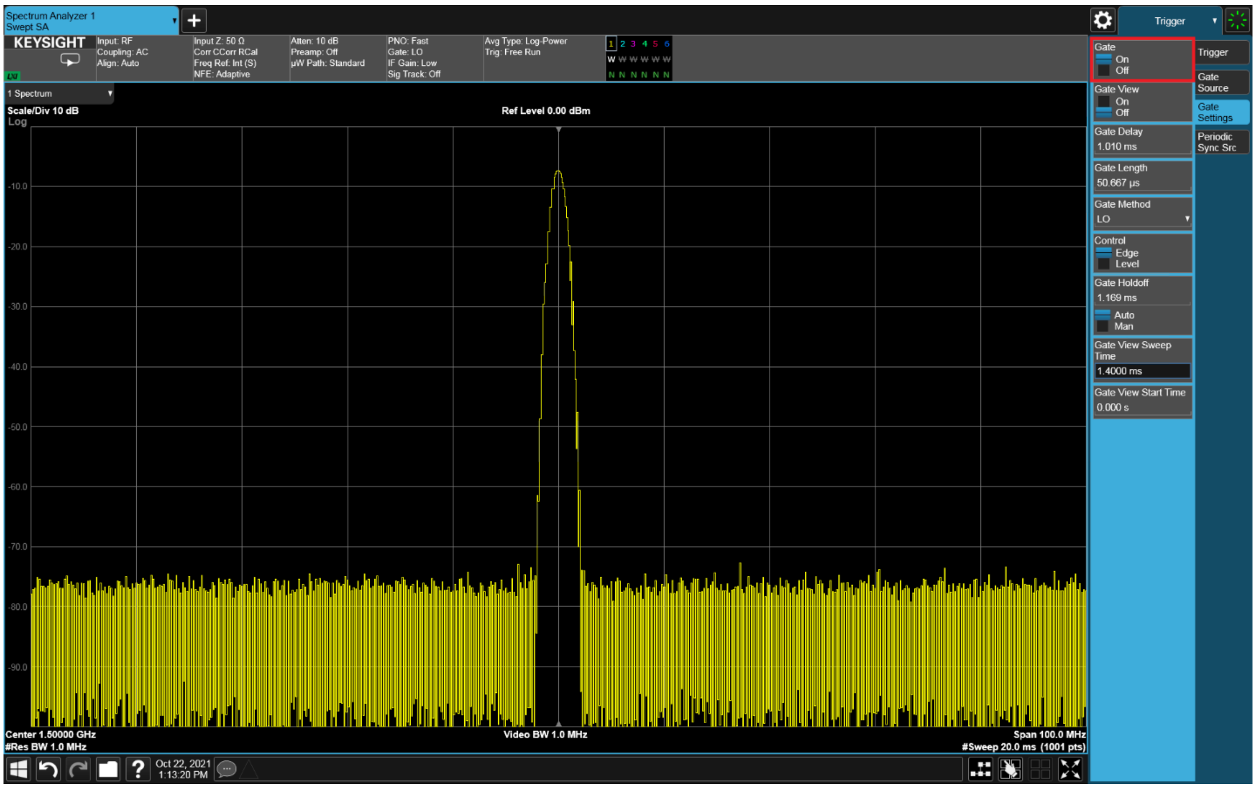


Figure 9. Gated signal using RF Burst trigger

When the Span is increased from 100MHz to 1GHz, the analyzer is no longer able to see an RF burst trigger at the start of the sweep when using the RF burst trigger as a source. The analyzer shows the previous trace data over the center 100MHz but is not able to begin sweeping from the start frequency due to the lack of a trigger. The RF burst trigger circuitry is limited in bandwidth based on its location in the IF path of the analyzer. So, in this case, the start of the sweep is outside of where the RF burst trigger can detect a signal.

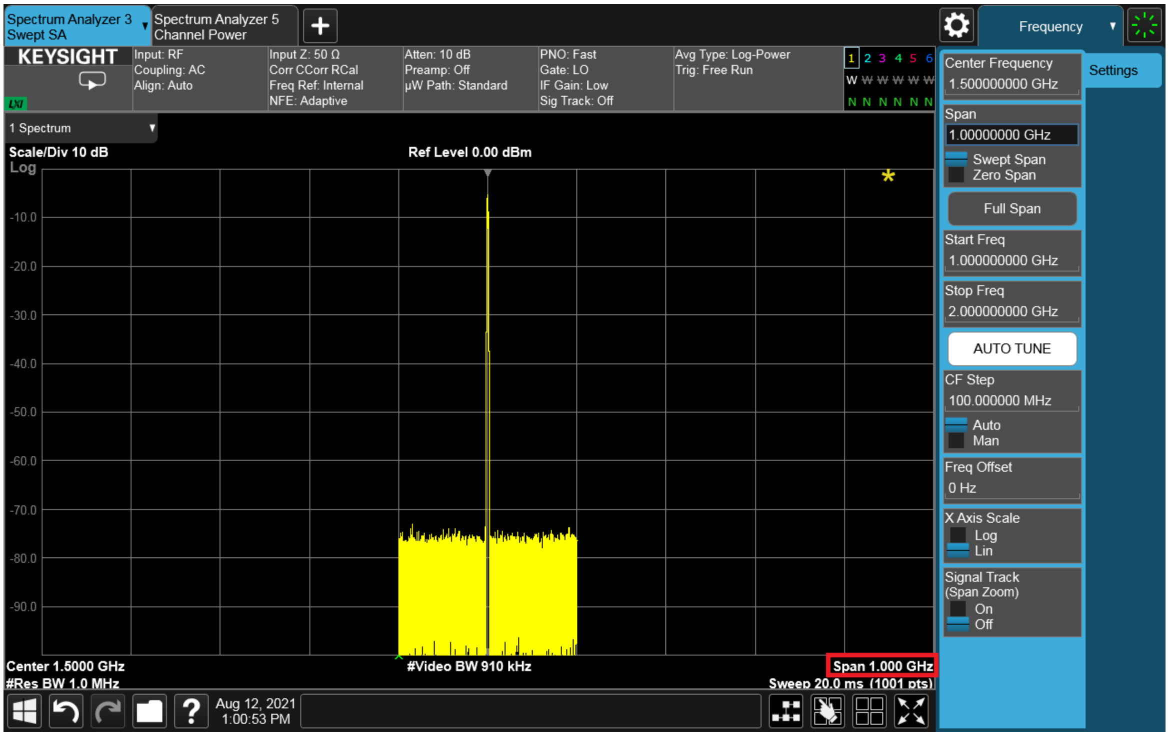


Figure 10. Large span with RF Burst trigger

One solution is to use Periodic Trigger, and to train the Periodic Trigger at a narrower span using the RF Burst Trigger. At the narrower span such that RF burst triggering is reliable, set the Gate Source to Periodic and the Period Sync Source to RF Burst. Furthermore, the Period of the Gate Source needs to be the same as the Pulse Period of the original signal and the Center Frequency should equal the frequency of the carrier. The image below shows what can also be referred to as Burst Sync Gated Sweep to gate over the larger Span.

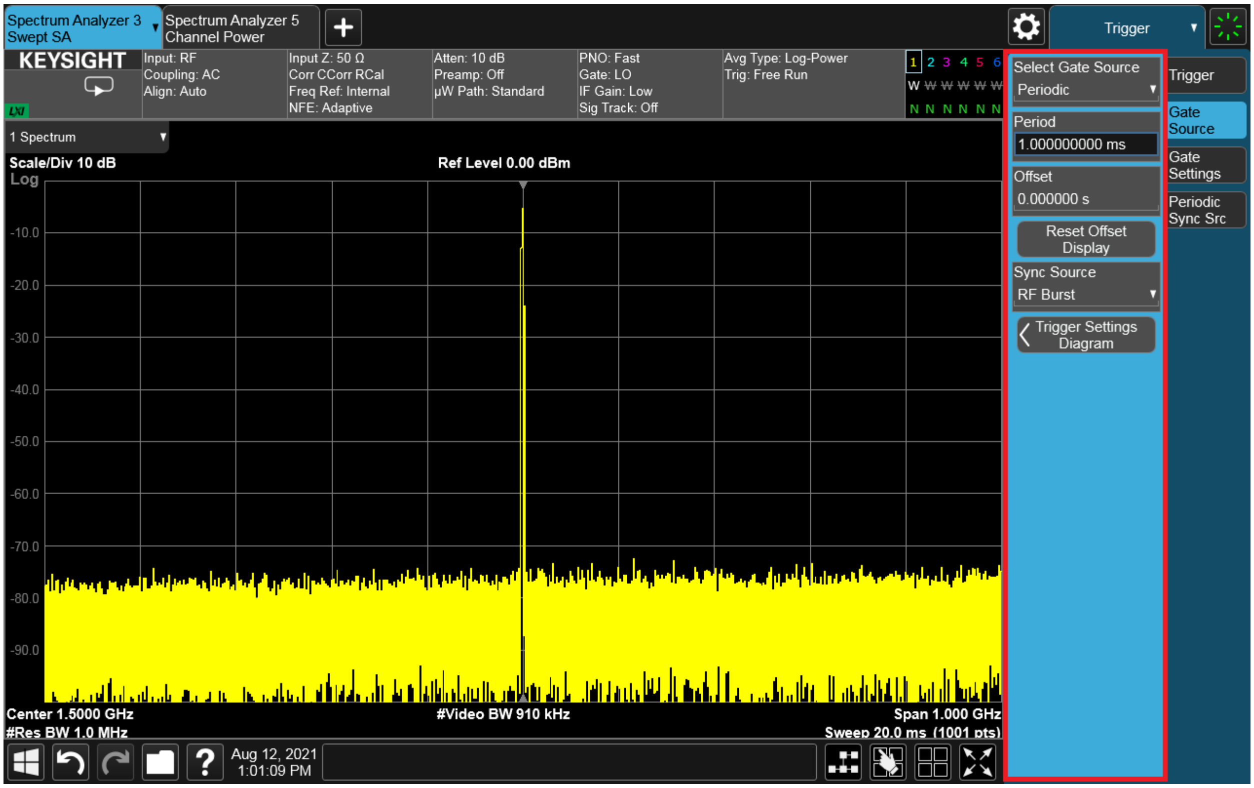


Figure 11. Large span with Burst Sync Gated Trigger

Utilizing the Periodic Trigger over a wide span can be tricky. To improve or troubleshoot the trigger, first try training the Periodic Timer in a smaller span before increasing it, which can help make more accurate measurements. Also, it may be helpful to slow down the sweep by changing the Sweep Time Rules to Accuracy (This setting is under the Sweep -> Sweep Config -> Sweep Time Rules).

The RBW value is critical when making pulsed measurements, so an ample value must be determined and used for the best results. As a reminder, the RBW has a rise time of 0.7/RBW, and it is best to have an RBW rise time of at least 10 times greater than the Pulse Width. In the example above, the signal had a Pulse Width of 80µs. According to the equation above, you would need a RBW of at least 87.5kHz to have a rise time of 8µs. The example above was done with an RBW of 1MHz which is well above the necessary bandwidth to measure the signal.

Time Gating in PowerSuite Measurements

There are multiple PowerSuite measurements that can utilize Time Gating: Channel Power, Occupied Bandwidth, Adjacent Channel Power, Spurious Emissions, and SEM. The example below takes the Channel Power measurement of a pulse modulated carrier signal with a frequency of 1.5GHz and an amplitude of -5dBm. It has a Pulse Width of 2ms and a Pulse Period of 5ms and is displayed below with no time gating.

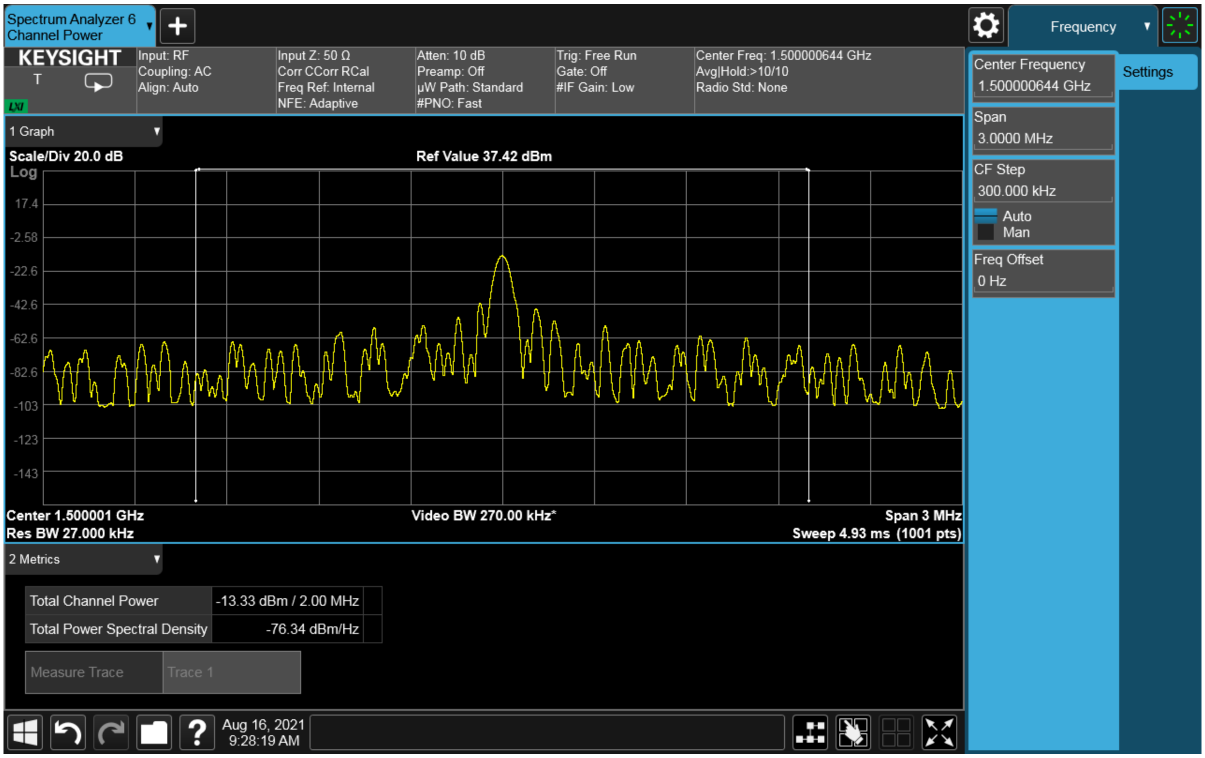


Figure 12. Pulsed Channel Power with no time gating

For this measurement, the RF Burst as the Gate Source will be useful in isolating the signal. One advantage with PowerSuite measurements is that you can display the Gate View and the Graph on the same screen, as seen below, allowing you to adjust the Gate and see the live reaction on the Graph.

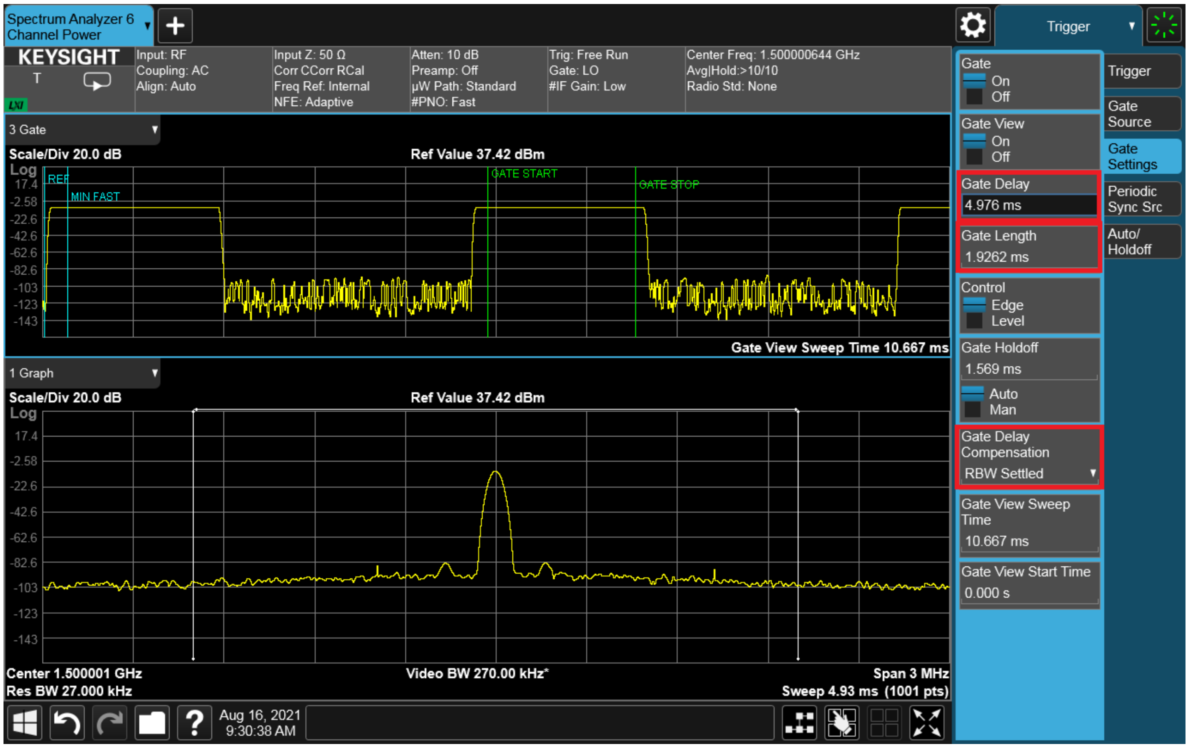


Figure 13. Gate and Graph View in PowerSuite measurements

Like the previous section, a large enough RBW is necessary to see the pulses themselves in the Gate View. From there, adjust the Gate Delay and Gate Length to cover most of one pulse. A good way to start is to set the Gate Delay to the Pulse Period and the Gate Length to the Pulse Width and then adjust from there. Following that, turning the gate on will apply it to the graph, and the Gate Delay and Gate Length can be adjusted until all the spurs have disappeared, like the bottom half of the picture above. As mentioned in the Gate Delay Compensation section, Power Suite measurements have access to this corresponding setting and RBW Settled is being used because of an unchanging RBW and to get the most accurate results.

Gated Phase Noise Measurements

Pulse modulation of a CW carrier unintentionally aliases as phase noise, and phase noise information on at offsets above the PRF/2 (the PRF is the Pulse Repetition Frequency or 1/Period of the pulse) are ultimately under sampled. From a Phase Noise measurement perspective, after detection, there is no new Phase Noise info at offsets above the PRF/2. Pictured below is the Phase Noise Log Plot of a signal that is pulse modulated with a carrier frequency of 1.5GHz and amplitude of -5dBm. The PRF in this case is 100kHz, which translates to a Pulse Period of 10µs.

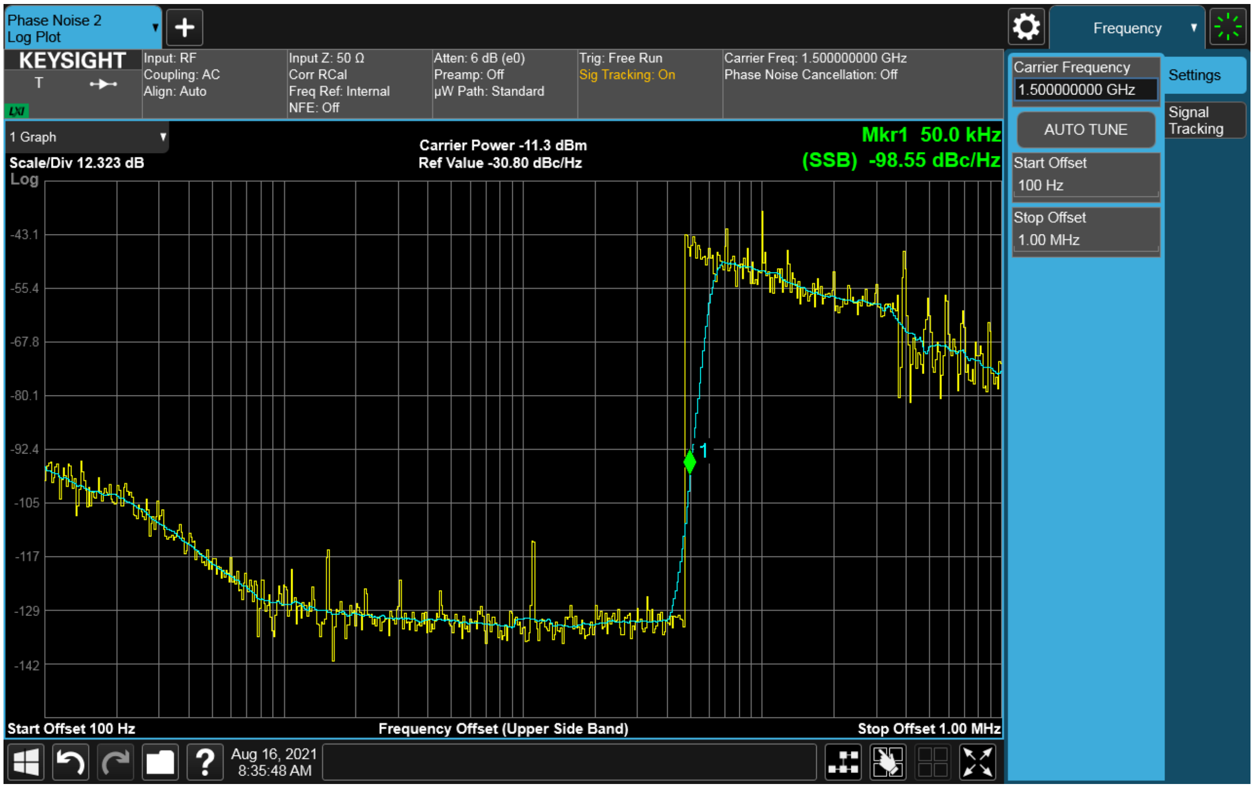


Figure 14. Pulsed phase noise with no time gating

The X-Series Phase Noise Application can measure pulsed CW Phase Noise for close-in offsets. Therefore, the Phase Noise Log Plot will have valid measurements up to just below PRF/2, at which point the measurements become invalid. This can be seen by the Marker that is set at 50kHz, which is equal to PRF/2. Opening the Trigger Menu and turning on a Gate with a Periodic Gate Source and Period equal to the Pulse Period allows measurement up to exactly the PRF/2.

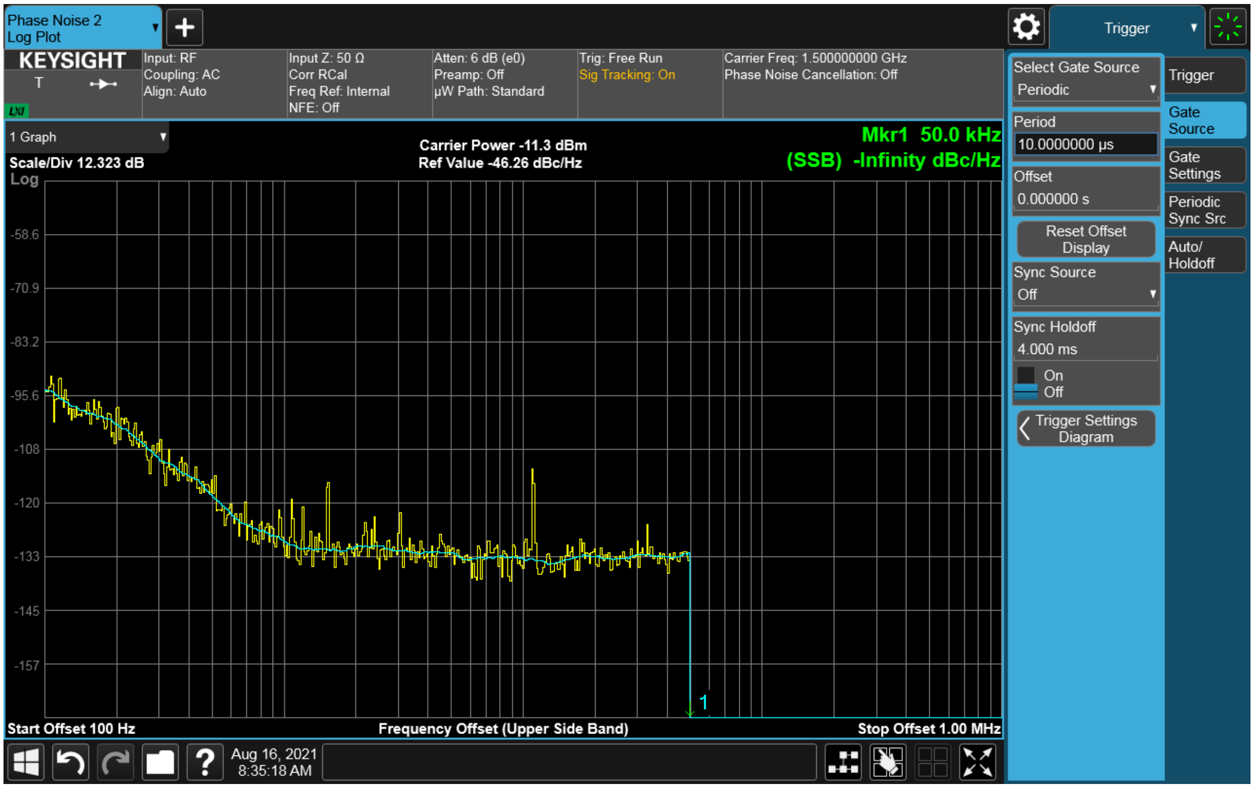


Figure 15. Gated phase noise measurement

Another thing to keep in mind when conducting Pulsed Phase Noise measurements is the idea of carrier suppression. Pulse modulated carrier power is actually decreased by 20log(Pulse Width*PRF) which will also decrease the carrier to noise ratio. This should be considered since the carrier power being reduced affects the theoretical noise floor and general sensitivity for systems, which are both important for Phase Noise measurements.

Additional Resources

1. Application Note: Radar Measurements (Publication: 5989-7575)
   https://www.keysight.com/us/en/assets/7018-01694/application-notes/5989-7575.pdf

2. Application Note: Spectrum and Signal Analysis, Pulsed RF (Publication: 5952-1039)
   https://www.keysight.com/us/en/assets/7018-06767/application-notes/5952-1039.pdf

3. RF and Microwaves, Bringing New Power and Precision to Gated Spectrum Measurements, Author: Tom Wright, Joe Gorin, Ben Zarlingo
   https://www.highfrequencyelectronics.com/Aug07/HFE0807_Zarlingo.pdf

4. Application Note: Spectrum Analysis Basics (Publication: 5952-0292)
   https://www.keysight.com/us/en/assets/7018-06714/application-notes/5952-0292.pdf

5. Spectrum Analysis Basics: Part 5 -Time Gating, Author: Jessica Patterson
   https://blogs.keysight.com/blogs/tech/rfmw.entry.html/2020/12/16/spectrum_analysisba-ObEM.html