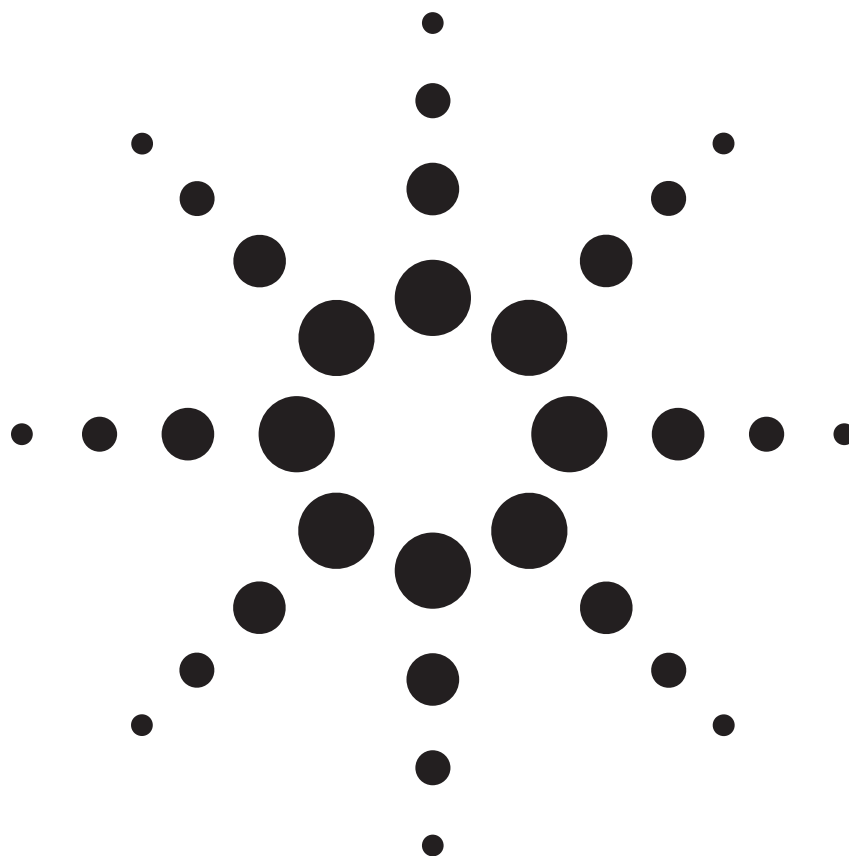


Agilent Pulsed Antenna Measurements Using PNA Network Analyzers

White Paper



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Abstract

This paper presents advances in the instrumentation techniques that can be used for the measurement and characterization of antennas that are to be tested in a pulsed mode of operation. A digital filtering process is described which allows accurate measurements under a wide range of pulse conditions using a single receiver. A novel approach to achieving point-on-pulse measurements using receiver time-gating at the IF frequency is described. Measurements made using an Agilent E8360 PNA series Microwave Network Analyzer are presented as a demonstration of a practical implementation of these techniques.

Keywords: antenna measurements, gating, pulsed measurements, measurement systems, receiver sensitivity, S-parameters.

1. Introduction

In some applications, it is preferable to make antenna measurements using pulsed-RF signals. Examples are active array antennas, which may only operate using pulsed RF signals, and antennas designed for use in pulsed applications. Among the most common techniques used to make accurate vector antenna pattern or S-parameter measurements under pulsed conditions are the wide-bandwidth, or full pulse characterization approach, and the narrow-bandwidth, or high PRF approach[1]. The selection of which approach to use for a given measurement depends upon several factors, including the characteristics of the measurement receiver, the pulse width and pulse repetition frequency (PRF) of the signal being measured, and the desired time resolution of the measurement.

To use the full pulse characterization approach successfully, the rise time of the receiver must be sufficiently fast to capture the pulse being measured without distortion. This technique provides good dynamic range, and the ability to measure single or non-periodic pulses. However, since the rise time of any receiver is limited, all receivers have a lower limit to the measurable pulse width that they are able to characterize in the wide-bandwidth mode.

When the pulse width of the signal being measured is less than several times the rise time of the receiver, the receiver will not reach a steady-state value for an individual pulse. This complicates the measurement and calibration significantly, and it is, therefore, preferable to use an alternative technique to measure narrow pulses.

If a pulsed RF signal is repetitive with a constant PRF (as is frequently the case), the frequency domain spectrum of the pulsed signal will consist of a series of evenly spaced discrete tones, centered at the RF signal frequency and spaced by the PRF[2]. If we define the stop bandwidth of the receiver as the bandwidth around the receiver center frequency beyond which the receiver has no significant sensitivity, then for pulsed signals with a PRF higher than $1/2$ the receiver stop bandwidth, the receiver will be sensitive only to the central tone of the pulsed RF signal spectrum, and will therefore measure the pulsed signal as though it were a CW signal.

Figure 1 illustrates this situation. In this figure, a segment of the constant PRF pulse spectrum is shown in the bottom half of the diagram, while the frequency response of an example receiver is shown in the top half. This ability to convert a pulsed RF waveform into a representative CW signal makes the measurement of pulsed signals possible with almost any receiver, so long as the PRF is greater than $\frac{1}{2}$ the stop bandwidth of the receiver. This has been referred to as the high PRF technique for making pulse measurements.

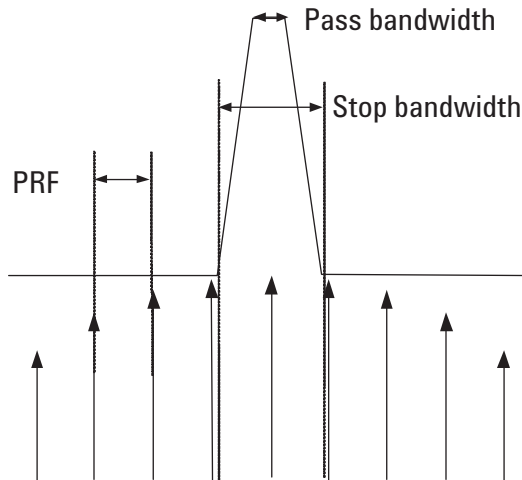


Figure 1. Relationship between receiver filter and Pulsed RF spectrum in standard high PRF technique

Unfortunately, the simple high PRF technique described above has four significant characteristics that may limit its usefulness in any given antenna measurement. These are:

1. The lack of time discrimination (no point-on-pulse).
2. The requirement that the PRF must be greater than $\frac{1}{2}$ the stop bandwidth, which may force the PRF and/or the duty cycle of the pulse to be too high.
3. The potential presence of other signals in the pulse spectrum that fall within the receiver stop-bandwidth, degrading the measurement.
4. The reduction of dynamic range due to the loss of the energy in the harmonics rejected by the receiver.

The Agilent PNA series of microwave network analyzers incorporate many features that make them attractive for use as receivers in antenna measurement applications. These include integrated microwave LO and RF synthesizers, fast synthesized sweeping, flexible microwave architecture, and the connectivity of the Windows® operating system. However, the maximum receiver bandwidth of 40 kHz, along with other architectural considerations, limit the PNA to minimum pulse widths of approximately 30 μ s when using the full pulse characterization technique. For narrower pulses, the narrow bandwidth high PRF approach may be used, but the characteristic limitations of this technique listed above may unacceptably limit the performance in some pulse applications. In this paper, we describe techniques that have been implemented in the Agilent PNA with Pulsed-RF Measurement Capability (Option H08) that reduce or eliminate these limitations and enhance the pulsed measurement capability in narrow bandwidth receivers.

2. Time Discrimination in High PRF Measurements: Time Gating

In many applications, it is desirable to determine the response of the device being tested at some particular time during the pulse. If the response of interest occurs over a fraction of the pulse period, but significant signal strength is present for a longer period of time, then simple high PRF measurements will not provide the desired results, since the signal measured will represent the average response over the duration of the pulse. Fortunately, this limitation may be eliminated through the use of time gating. A time gate is a fast switch that is inserted in the signal path between the device under test and the bandwidth-limiting receiver. By properly synchronizing the opening and closing of the switch with the pulsed RF signal, only the signal of interest is allowed to charge the band-limiting filter, and therefore only the desired portion of the pulse is measured.

Time gating may either be performed at the signal frequency or at the intermediate frequency (IF). In IF gating, the gate switch is inserted between the broadband mixer and the bandwidth-limiting filter. Since the receiving mixer is a broadband linear device, the pulse is preserved through the mixing process (although for short-duration pulses, care must be taken that the pulse harmonics, which may “wrap” around DC, do not degrade the measurement). Since IF gate switches operate at a single frequency, it is usually possible to obtain better switching speed, on to off ratio, and full frequency coverage for less cost using IF gating. Also, the mixer provides significant isolation between the gate switch and the device being measured, minimizing any errors that may otherwise occur due to the differing impedance of the switch in its on and off state. A low-noise IF amplifier with adequate bandwidth to preserve the pulse shape within the desired time resolution may be inserted between the mixer and the gate switch. This further isolates the gate and can improve the sensitivity of the system.

Using the Agilent PNA with Option H08 and H11, gating may either be performed using either internal (provided) IF gate switches or external (customer supplied) RF or IF gate switches. The internal gate switches have a minimum time resolution of less than 50 ns, with an on-to-off isolation of greater than 90 dB. For narrower time resolutions in distributed antenna measurement systems with external mixers, such as the system shown in Figure 7, it may be preferable to use an external gate switch, located close to the device under test, in order to reduce the degradation in time resolution that may be caused by multiple reflections in the long IF signal path.

Examples of time-gated pulse measurements made with the PNA are shown in Figure 2 and Figure 3 below. Both figures show transmission measurements made on a microwave switch, which is switched on 0.7 μs after the start of an 5 μs RF pulse, and switched off 3 μs later. The receive channel gate resolution was set to 100 ns. The PRF was 32 kHz. In Figure 2, the switch is measured at a single frequency (10 GHz), while the delay of the receive gate is swept from 0 to 5 μs . This type of measurement is called a pulse profile measurement, and provides useful information about the dynamic performance of the device being measured in both magnitude and phase. Note the variation in the transmission of the switch in both magnitude and phase as it turns on, reaching a stable value by 3 μs . Note also the dynamic range of the measurement, with the measured noise level prior to the switch turning on at approximately -85 dB (relative to a through).

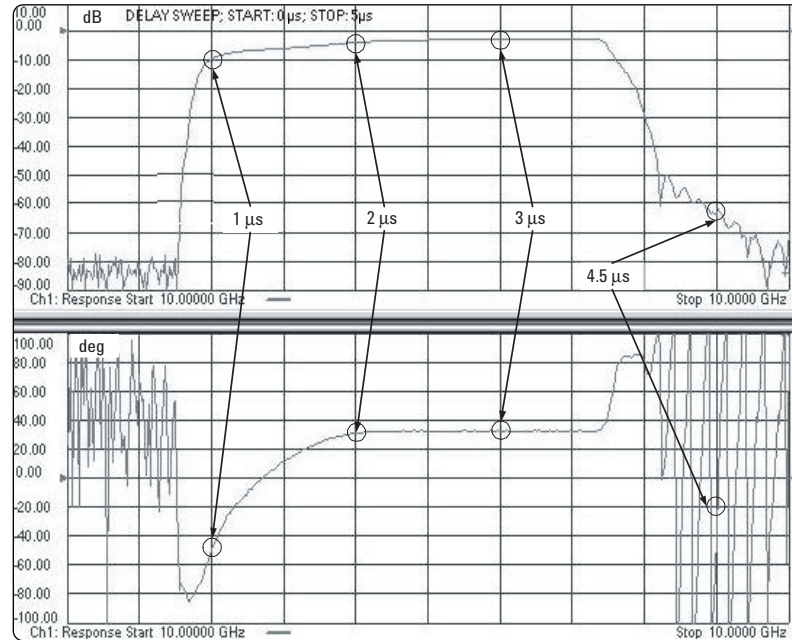


Figure 2. Pulse profile measurement example

In Figure 3, the frequency response of the switch from 2 to 19.9 GHz is measured for delays of 1 μs , 2 μs , 3 μs , and 4.5 μs , again with a time resolution of 100 ns. This is called a point-on-pulse measurement.

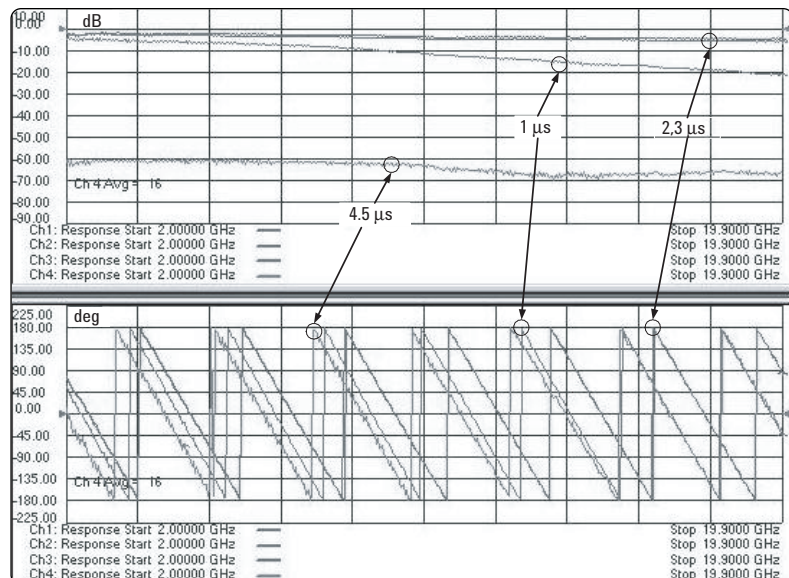


Figure 3. Point-in-pulse measurement example

3. Using Digital Filtering to Allow Lower PRFs in Narrowband Pulsed measurements.

For accurate high PRF pulsed measurements, it is important that only the center tone of the pulse response pass through the filter. If the PRF of the measurement is sufficiently high, the rejection of the receiver analog filter will be sufficient to accomplish this. In some cases, however, it is desirable to make measurements at lower PRFs.

In Figure 1 all of the harmonics of the pulse spectrum are eliminated by the stopband rejection of the bandpass filter. While this approach is effective, all that is actually required is that the receiver filter reject all of the discrete tones (other than the center frequency) present in the pulsed RF signal. The frequency response of an FIR filter with a rectangular window[3] is shown in Figure 4, juxtaposed with the pulsed spectrum. Note that this response has evenly occurring nulls, spaced by $1/(N \cdot T)$ Hz, where N is the number of filter taps and T is the sample time. By aligning the nulls in the filter response with the tones in the pulse spectrum, the desired result is achieved. This is accomplished by collecting the number of samples N , spaced by the sample time T , such that the equation $PRF = K/(NT)$ ¹ is satisfied for some integer K (in Figure 4, $K=2$). Using this approach, it is in principle possible to measure down to an arbitrarily low periodic PRF by selecting an appropriate number of taps N , although in practice the dynamic range losses due to pulse desensitization limit the lowest practical PRF to approximately 100 Hz.

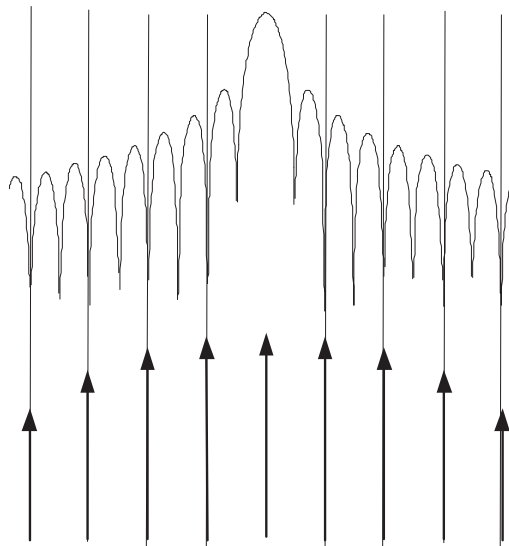


Figure 4. FIR filter response and pulse spectrum

1. In the actual implementation used in the PNA, a slightly non-rectangular window is used, and the null equation is modified to $PRF = K/((N-6) \cdot T)$.

4. Identifying and Filtering Other Interfering Signals

Up to this point, the only tones assumed to be present in the pulse spectrum measured by the receiver are those centered at the stimulus frequency and spaced by the PRF, and the only receiver sensitivity has been assumed to be given by the digital filter response centered at the stimulus frequency. In practice, however, there are several other potential signals and receiver responses that could interfere with measurement accuracy. These include source harmonics, gate switch video feed-through, and receiver effects such as sensitivity to the first LO image frequency. For CW signals, these sources are insignificant due to the inherent frequency selectivity of the PNA. For pulsed signals, however, each source of interference causes a corresponding series of interfering frequencies in the frequency domain, centered at the source interference frequency and spaced by the PRF. If the sources of interfering signals and receiver sensitivities are known, their effects can be reduced to acceptable levels through careful selection of the digital filter characteristics and pulse repetition frequencies. For example, in the Agilent PNA with pulsed-RF measurement capability (Option H08), a filter constructing algorithm is used to reduce the potential interference from eight different combinations of pulse spectral energy and receiver sensitivities to negligible levels.

5. Dynamic Range Considerations

Since only the central tone in the pulse spectrum is allowed to pass through the filter, The high-PRF pulse technique results in a signal loss of $20 \log_{10}(\text{duty cycle})$ relative to a non-pulsed signal measured by the same receiver. In this equation, the duty cycle is given by the ratio of either the gate width or the pulse width (whichever is smaller) to the pulse period when gating is being used, or by the pulse width to the pulse period when no gating is used.

Because of this inherent loss, pulsed measurements and pulse measurement systems using the narrow-band technique should be designed to obtain the best possible sensitivity and dynamic range. Some of the factors to consider are the gate resolution setting and PRF of the measurement, the gain of the IF amplifiers, and the analog filter bandwidth of the system.

As noted previously, the sensitivity of the measurement will decrease as the gate width becomes smaller. Therefore, in order to optimize the measurement performance, the widest gate width that will provide the required time resolution for the measurement should be used. One approach to determining the optimal gate width setting is to perform a pulse profile measurement (described in section 2), in order to identify the time dependency of the device being measured. This will inform the selection of both the maximum permissible gate width and the optimal delay for the parameter in question. Similarly, to optimize measurement sensitivity, the PRF should be set as high as possible.

In CW measurements, IF amplification is often selected to optimize the trade-of between increased sensitivity (more gain) and higher compression levels (less gain). In pulsed measurements, if the compression occurs after the bandwidth-limiting filter, it may be beneficial to use higher IF gain, since the filter will reduce the peak signal level for narrow pulse widths.

Other factors that may effect the dynamic range for an antenna measurement include the power from the source; losses prior to the receive mixer; mixer conversion loss and noise figure; IF amplifier gain, compression, and noise figure; and noise in the LO distribution system. Although a thorough discussion on the proper design of an antenna measurement system is beyond the scope of this paper, some of these factors will be considered briefly in the following sections, especially as they pertain to pulse measurements.

6. Pulsed Antenna Measurement System

Figure 5 shows a block diagram for the pulsed measurement system used to perform the measurements shown in this paper. This is one of several possible system architectures that can be constructed using the PNA as a receiver. The system shown employs fundamental mixing, using the Agilent 85320 mixers. The Agilent 85309 LO-IF Distribution Test Set provides isolated LO signals at the proper power levels to the two mixers, as well as IF amplification. The RF and LO signals are provided by the PNA (with Option H11). An additional gain block of 12 dB or more in the LO path is used to set the LO power at the 85309 input to at least 0 dBm. This ensures that the LO signal is compressed, which reduces AM noise on the LO. RF pulse modulation is performed with an external pulse modulator. IF gating is performed by the internal IF gates provided as part of the PNA Option H11. One or more Agilent 8110 (or equivalent) pulse generators provide the pulse control signals to the internal IF gates, the RF pulse modulator, and the test device. One of these is designated the master pulse generator, and it generates the PRF, which is phase locked to the 10 MHz time base provided by the PNA. This ensures the synchronization required by the digital filter. All other pulse generators are synchronized to the master using their external trigger inputs. The IF frequency is approximately 8.33 MHz, although the precise value is set as required by the digital filter constructor of the PNA Option H08. The IF amplification of approximately 23 dB provided by the 85309 is perhaps 10 dB more than optimal for non-pulsed systems, but the extra gain was found to increase the sensitivity for gate widths of 1 μ s or less. This effect is discussed in the next section. Some benefits of this system architecture are that

1. No additional microwave sources are required.
2. Since The PNA controls the frequencies in a standard way (frequency offset mode), and since the signal being measured by the PNA is a CW signal, all normal features and performance of the PNA are available for use, once the pulse set-up is established by the H08 software.
3. Fundamental mixing provides excellent sensitivity and dynamic range for the measurements.

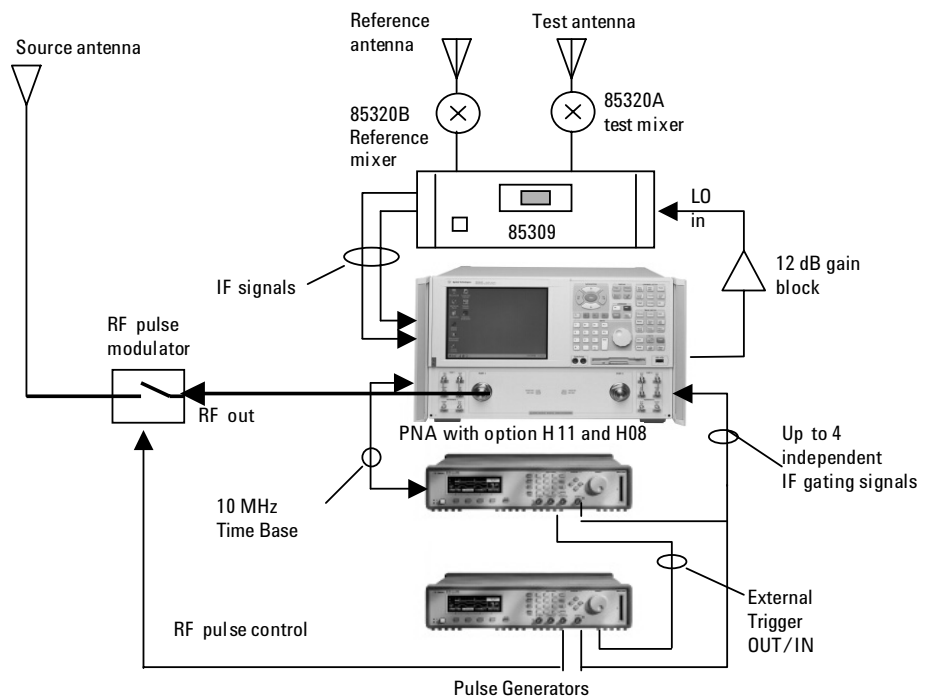


Figure 5. PNA based pulsed antenna system block diagram used for measurements

7. Measurements

The results shown below were obtained on the system described in the previous section.

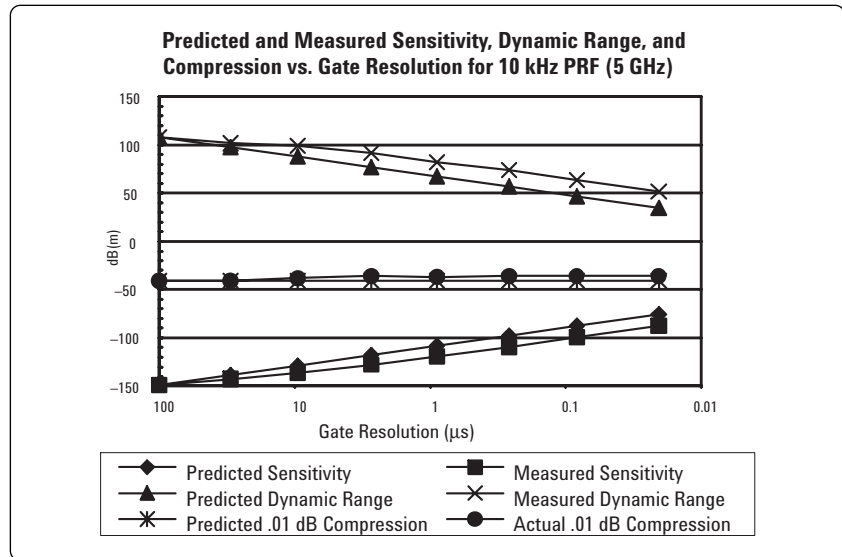


Figure 6.

Figure 6 shows the measured sensitivity, compression, and dynamic range at 5 GHz as a function of gate resolution for a PRF of 10 kHz. Sensitivity is measured as equivalent noise power in a 10 Hz bandwidth at the test mixer input. The gain compression is the power at the mixer input that results in 0.01 dB degradation in linearity. Notice that the sensitivity degrades less than the $20 \cdot \log_{10}(\text{duty cycle})$ pulse desensitization. This is because the excess average noise contributed by the IF amplifiers is also attenuated by the pulse desensitization, although to a lesser degree than the signal.

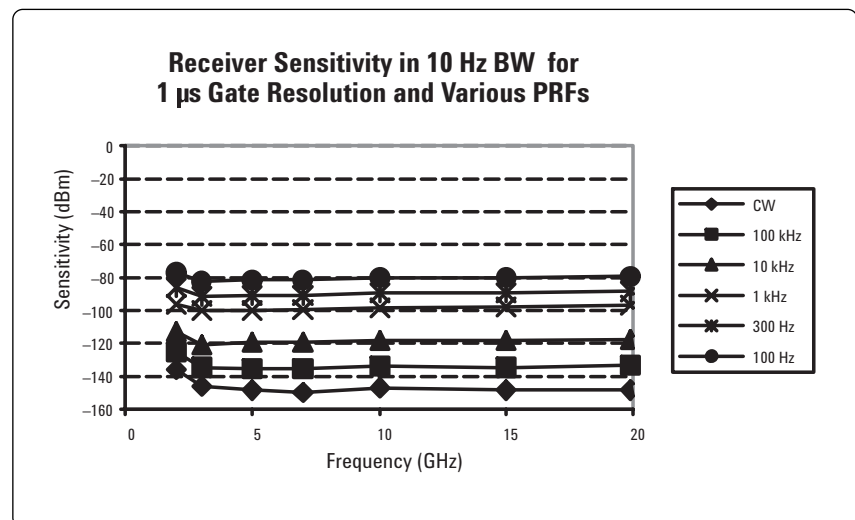


Figure 7.

The net result is approximately 15 dB less loss in dynamic range than predicted by duty cycle desensitization alone. Figure 7 shows sensitivity as a function of frequency for a 1 μs gate resolution and PRFs of 100 kHz, 10 kHz, 1 KHz, 300 Hz and 100 Hz. Here again we see less degradation than predicted by the signal desensitization of $20 \cdot \log_{10}(\text{duty cycle})$.

8. Summary

In this paper, we have described the narrow bandwidth high-PRF technique for making measurements using pulsed RF signals. We have discussed several techniques that may be used to overcome the traditional shortcomings of this approach, including the use of time gating to provide time resolution and the use of digital filtering, both to allow low PRF measurements, and to eliminate potential interfering signals. We have described the factors that contribute to dynamic range loss. We presented a system block diagram based on the Agilent PNA series network analyzer, which we have used to make several measurements demonstrating these concepts.

9. Conclusions

The high PRF technique for making pulsed measurements, which has always been valuable due to its ability to measure arbitrarily narrow pulses, has never the less been hampered by the lack of point on pulse capability and the inability to measure low PRF pulses. The Agilent PNA Series Vector Network Analyzer (with options H11 and H08) has successfully addressed these limitations for a wide range of applications through the use of time gating and the careful application of digital filtering. Although dynamic range and sensitivity degradation are still realities for low duty cycle measurements, this paper has presented methods of reducing this effect as well, by using careful planning in the measurement design, and by taking advantage of IF amplification prior to the gate switch. Together, these techniques provide a viable approach to pulsed antenna measurements for a broad range of applications.

10. References

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