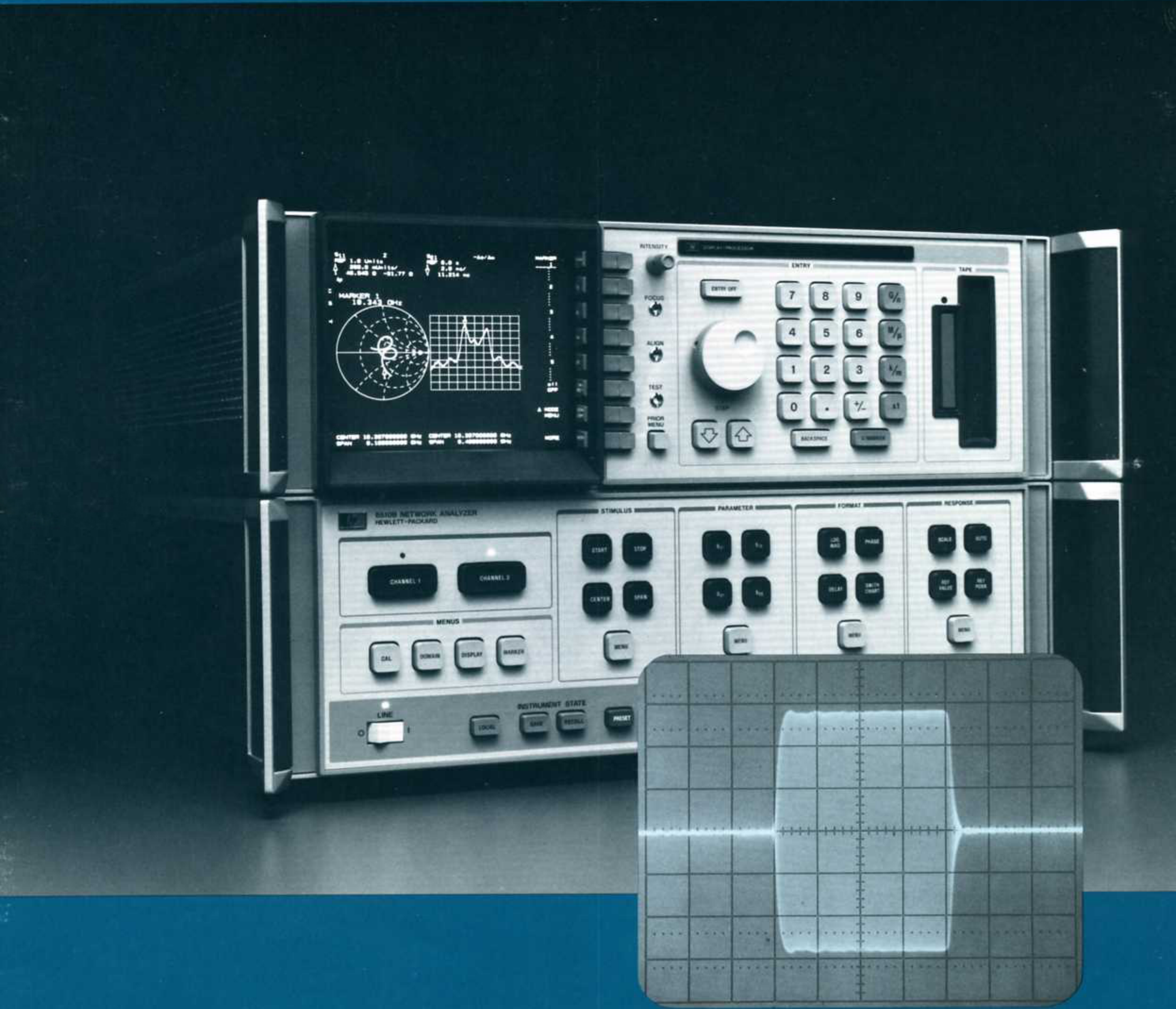
Product Note 8510-9

HEWLETT PACKARD

Microwave Component Measurements
Pulsed-RF network measurements
using the HP 8510B



Pulse Signals and the HP 8510

Vector network measurements have been an essential part of a microwave engineer's design process, both in the evaluation of prototype designs and in assuring that the end product meets specification. The HP 8510 has been a proven tool in providing high performance vector network measurements capability. However, an increasingly important class of components have an additional requirement not normally associated with standard vector network measurements. These components must be characterized under pulsed-RF conditions.

The requirement for pulsed-RF testing can arise for several reasons. The component may operate at such high peak powers that characterization using a CW measurement system would destroy it. There are also a number of components that will only operate under pulse conditions or have different characteristics under pulse conditions.

While the HP 8510 has been considered a non-pulsed measurement system, it can be configured to make pulsed vector network measurements. The pulsed-RF measurements available with the HP 8510 give similar results to a standard CW measurement of the device-under-test (they provide the absolute phase and magnitude shift through the device). These measurements include the S-parameters of a component, group delay, gain compression, and input and output impedance of the device-under-test. Understanding how the HP 8510 operates under pulsed-RF conditions also provides an understanding of the information provided by these measurements.

To understand how the HP 8510 can operate under pulsed-RF conditions, first consider the basic operation of the HP 8510. There are three parts to the standard HP 8510 measurement configuration (Figure 1). The source provides the RF and microwave stimulus, the test set separates and downconverts the desired reference and test signals, and the HP 8510 measures these signals to display the desired results.

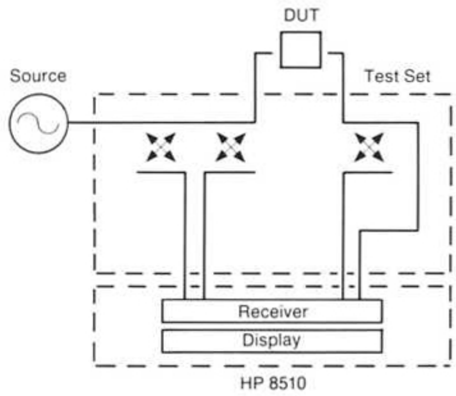


Figure 1. Block Diagram of Standard Network Analyzer Configuration

Although the HP 8510 is designed to operate with a continuous microwave driving signal, the HP 8510 receiver also can measure pulsed signals. The receiver (see Figure 2) is a double conversion superheterodyne with a 10 kHz wide bandpass filter in the second IF. How this filter responds to a pulsed-RF signal dictates the characteristics of the measurement system. The special tutorial at right explains the response of this filter to pulsed signals. This bandpass filter's characteristics divide the measurement into two categories:

1. For PRFs (Pulse Repetition Frequencies) greater than 30 kHz, the measurement data is the phase and magnitude shift through the device measured using only the center spectral line (carrier) of the pulsed-RF spectrum. The receiver measures only the center spectral signal of the pulsed-RF carrier as if it were a CW signal in a non-pulsed network analyzer configuration.

   Since this type of measurement actually filters off the modulation sidebands, the width or PRF of the pulse does not effect the measurement. Only changes to the duty cycle effect the measurement. Decreasing the duty cycle of the RF spreads the energy of this center spectral line to the pulsed-RF sidebands. The magnitude of this center spectral line, and thus the measurement, is dependent on the pulse duty cycle.

2. For PRFs less than 30 kHz, the IF will include not only the center spectral line but also the other spectral lines that enter the bandwidth of the filter. These additional spectral lines result in magnitude variations in the signal as a function of time (the pulses will appear in the IF). Since the receiver takes a ratio of the measurement and test channels, the magnitude and phase shift through the device is still provided. However, the receiver needs the added capability of providing a synchronization signal that can trigger the measurement at the peak of these IF pulses. This will then maximize the signal-to-noise ratio, thus maximizing the available dynamic range and accuracy.

Because of the different nature of the two categories, the measurement configuration for each are also different.

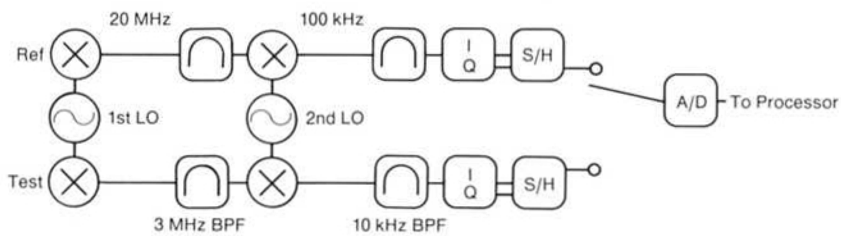


Figure 2. Receiver Block Diagram

Pulse Signals and the 10 kHz Bandpass Filter

The 10 kHz filter in the block diagram of the HP 8510 receiver is the component that dictates how the HP 8510 responds to the pulsed signal. The easiest approach to understanding its characteristics is to look into the frequency domain. The first illustration at right (A) is a time domain representation of the pulsed microwave energy. The second illustration (B) shows a frequency domain representation of the signal with the modulation sideband spacing being equal to the PRF of the signal. The signal must pass through the filter (frequency domain response shown in (C)) and since the energy of the signal is spread into the sidebands,some of this energy may be filtered off if it falls outside the bandwidth of the filter.

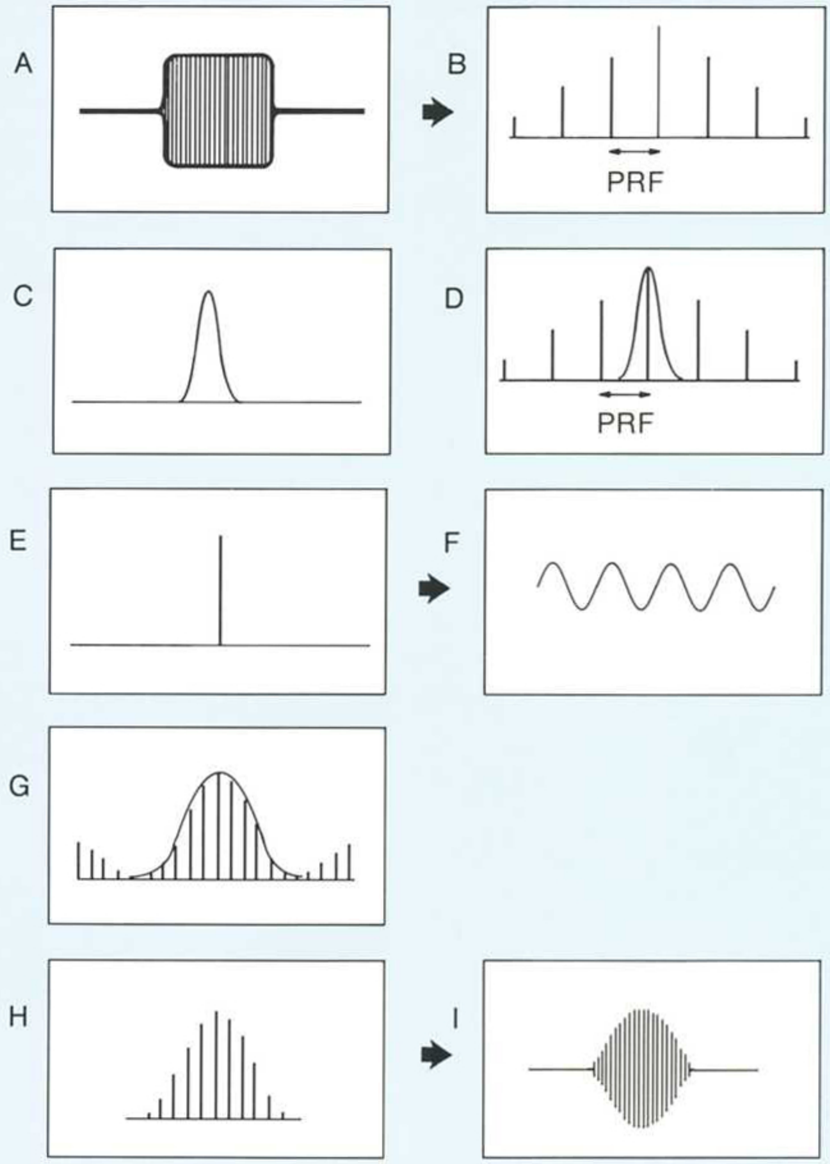
If the sidebands are spaced widely enough (D) that all the sidebands are filtered off by the filter (E), then the time domain representation shows that a CW signal exists at the output of the filter (F). This CW signal can be used directly to make magnitude and phase measurements. The phase of this signal will be directly related to the phase shift through the device-under-test at the center frequency. The level of this CW signal will be proportional to the magnitude response of the device-under-test but will also contain a magnitude decrease caused by the loss of the energy in the sidebands. The amount can be calculated using the formula:

$$\text{Pulse Desensitization} = 20 * \log(\text{Duty Cycle})$$

Although the offset caused by this pulse desensitization factor can be ratioed out using both a pulsed reference and test signal. This factor will decrease the dynamic range available.

If the sidebands on the filter are spaced closely enough (G), the pulse can pass through the filter (H). The rising and falling edges will be slowed by the filter (I). Since valid data is not present at all times, the HP 8510 requires an external signal to trigger when valid data is present.

If the pulse widths of the RF pulses are longer than 200 microseconds, the IF signal will rise to its steady state value. If the data is then triggered after this 200 microseconds, the HP 8510 will have the same measurement characteristics as a CW measurement. If the pulse is narrower than 200 microseconds, the pulse will not rise to its final value. Although the level does not reach the steady state level, it may reach a level that can be used to make a valid measurement. As a guideline, the measurement level falls off 6 dB for every octave decrease in pulse width below 200 microseconds.



Applications with PRFs>30 kHz

Configuring the Test System

The configuration (Figure 3) for making pulsed vector network measurements with a PRF of greater than 30 kHz is very similar to the standard configuration. The first difference between this configuration and the standard HP 8510 configuration is the coupler at the output of the source. This coupler supplies a CW signal to the a2 channel (port 2 reference channel). The HP 8510 requires this CW signal to phase lock the system as the phase lock loop cannot lock to a pulsed signal. Since a2 is now the phase lock signal, all parameters must be redefined to phase lock to a2. This is done using the following procedure:

1. Select the desired measurement using the **PARAMETER** section of the HP 8510 front panel.
2. Press the **MENU** key in the Parameter section.
3. Press the **REDEFINE PARAMETER** softkey.
4. Press the **PHASE LOCK** softkey.
5. Press the **a2** softkey. This parameter is now phase locked to the a2 signal.
6. Repeat for any other desired parameter.

Now that the phase lock signal is provided, the actual measurement can be configured. The signal passing through the main coupler arm is connected to the pulse modulator, and from there to the measurement system. If S21 is the desired parameter, a power splitter supplies a reference signal to a1 and a test signal to the device-under-test. This provides a pulse reference and test signal. The output of the device-under-test then is connected to b2. (To understand why a pulsed signal is used in both the reference and test, refer to the special tutorial on "Pulsing both the Test and Reference Signals.")

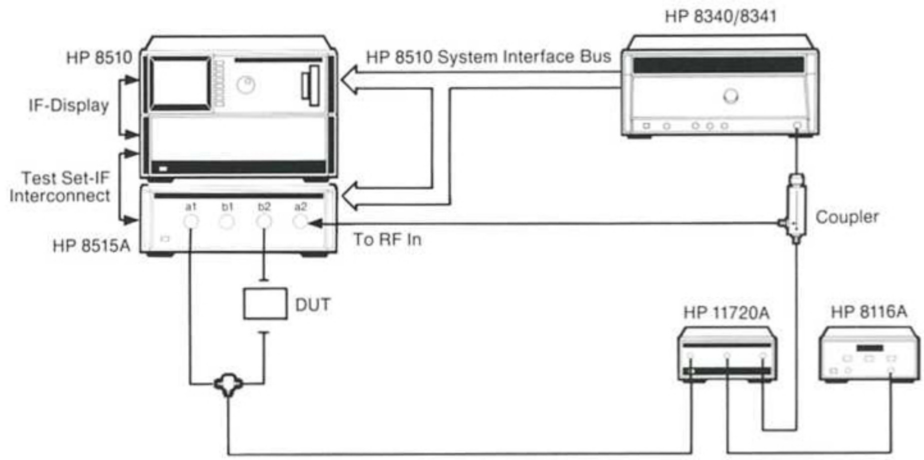


Figure 3. Pulsed-RF HP 8510/8511A Configuration

Pulsed network analysis may also be easily configured using a standard test set (Figure 4). As with the HP 8511A system, the source power is split to provide a CW signal for locking the receiver. This can be inserted into extension A (J2 connection) in the back of the test set (See Figure 5) and the measurement parameters are all redefined to phase lock to a2.

The other signal from the power splitter is then pulse modulated and is routed directly to the test set in the RF IN back panel connection to supply the pulsed test signal. Although this pulse signal is available to drive both test ports, the a2 sampler is directly connected to the CW signal. This will effect the operation of the S-parameter test set.

The reverse parameters will be a ratio of a pulsed signal to a non-pulsed reference. Although all four S-parameters can be displayed, only S11 and S21 will be a ratio of pulsed signals where S12 and S22 will be the ratio of a pulsed signal to a nonpulsed reference. The performance degradation of a pulsed test to non-pulsed reference is discussed in Appendix A.

Another limitation to the standard S-parameter test set operation is the inability to calibrate using the reverse S-parameters. This calibration is not available since the drive to Port 2 and the signal measured by the a2 channel are not the same, either in match or drive level. This will result in invalid error coefficients. The approach for S21 and S11 measurements would be to use an eight-term error-correction model (response and isolation cal). This calibration does not use the reverse S-parameters in the error-correction model.

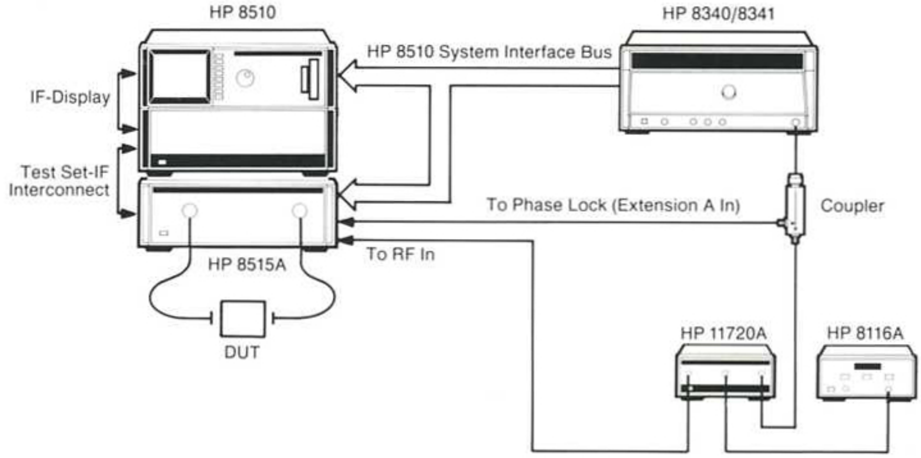


Figure 4. Pulsed-RF HP 8510/Test Set Configuration

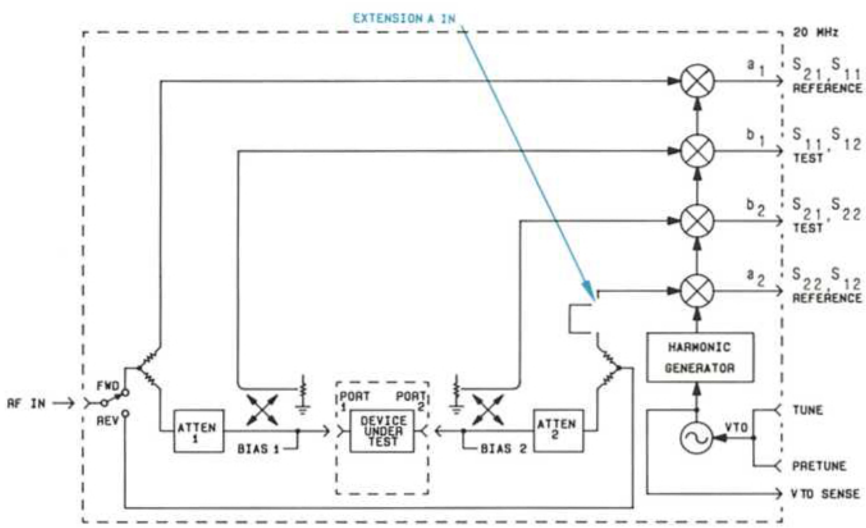


Figure 5. Test Set Block Diagram

Calibration

The calibration sequence for pulsed-RF measurements using PRFs of greater than 30 kHz are similar to the standard non-pulsed measurement system. However, two-port calibrations are not available because of the configuration limitations discussed previously. Also, calibrate with the pulse modulator turned on and set to the correct PRF and duty cycle.

Results

Several devices were measured to verify the performance of the pulsed-RF HP 8510 system. These measurements were made using the configuration shown in Figure 4. Figure 6 compares the measurement of the gain of a semiconductor device in both CW and pulse mode (PRF-100 kHz). Figure 7 shows a comparison of a measurement of the phase shift through a phase control component. Both of these measurements show excellent correlation between pulsed-RF and non-pulsed measurements, as predicted by examining how the HP 8510 is effected by the additional pulse requirement.

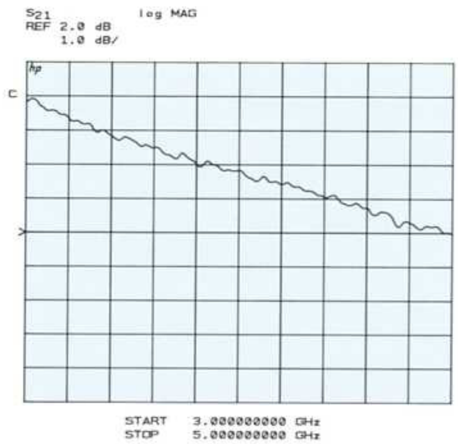


Figure 6A. Gain Measurement in CW Mode

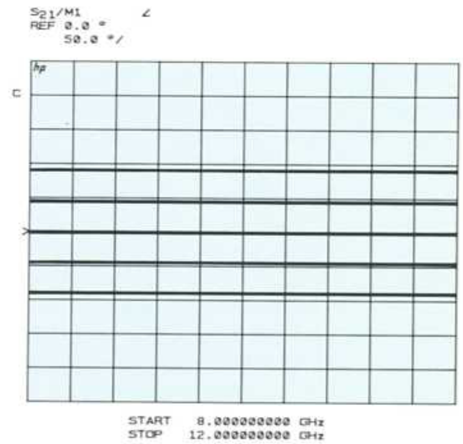


Figure 7A. Phase Measurement in CW Mode

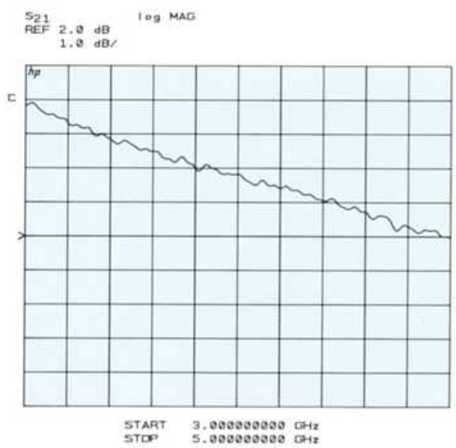


Figure 6B. Gain Measurement in Pulsed-RF Mode (PRF=100 kHz)

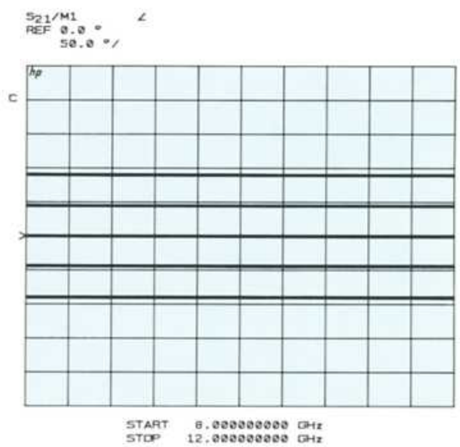


Figure 7B. Phase Measurement in Pulsed-RF Mode (PRF=100 kHz)

The only difference in the pulsed-RF measurement and the standard CW measurement would be the decrease in signal-to-noise ratio caused by the pulse desensitization factor. Figure 8 illustrates this effect on a measurement. Here the increase in the trace noise at decreasing pulse duty cycles illustrates the decrease in the signal-to-noise ratio predicted by the pulse desensitization factor.

The amount of this trace noise will be dependent on the peak power level of the pulse and the duty cycle, and can be predicted. If the sensitivity of the system is −73 dBm (typical HP 8515A test set performance, 13 dB signal-to-noise ratio, at 20 GHz), the peak power into the test set port +2 dBm (maximum allowed into the test set), and the duty cycle at 10% (a 20 dB pulse desensitization factor), the signal-to-noise ratio would be 55 dB. Looking at the noise caused by a signal 55 dB below the carrier would predict (by changing the dB to linear voltage terms and looking at the worst case distortion) 0.03 dB peak trace noise in magnitude and 0.1 degree phase trace noise. If these levels prove unsatisfactory, they could be decreased using averaging.

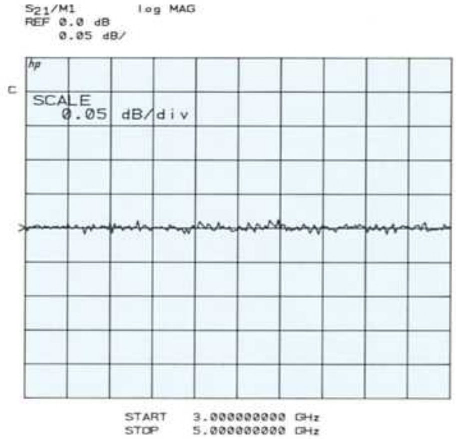


Figure 8A. Trace in CW Mode

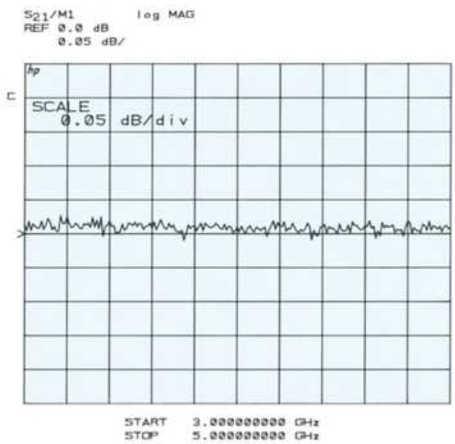


Figure 8B. Trace in Pulsed-RF Mode (Duty Cycle = 50%)

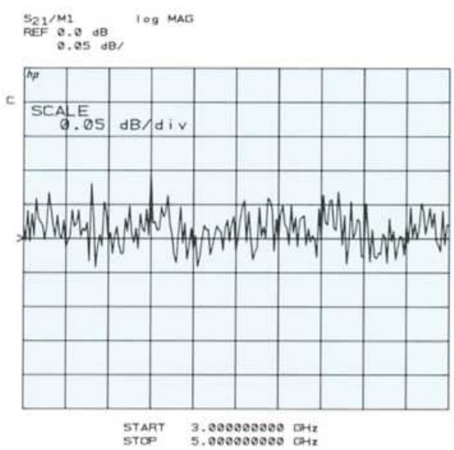


Figure 8C. Trace in Pulsed-RF Mode (Duty Cycle = 10%)

Applications with PRFs<30 kHz

Configuring a Test System

For pulsed-RF measurements with PRF's below 30 kHz the pulses do appear in the IF. This requires triggering the HP 8510 when data is valid. This external triggering capability is available in the HP 8510B. This requirement does restrict the HP 8510B measurement system to measuring at a single frequency, since the HP 8510B cannot sweep in frequency and use the external trigger.

In this configuration, the HP 8510B will be used in ramp sweep mode, however, the actual frequency sweep will be set to the minimum value. The HP 8510B will use the external trigger to update the measurement, instead of the sweep ramp. Thus the display of the HP 8510B will show an array of measurement points made at the same frequency. Each of these points will represent one data point on each pulse. Where this data point is taken can be adjusted by adjusting the delay on the pulse generator.

To configure a system to make pulsed-RF measurements with PRFs less than 30 kHz, first configure the system as shown for PRFs >30 kHz (Figure 9). Then continue with the following additional steps:

1. Set the HP 8510B to **RAMP** sweep mode. Set the HP 8510B's **CENTER** frequency to the desired measurement frequency. Set the frequency **SPAN** to 100 Hz if an HP 8340B or 8341B is the source. If the HP 8350B is the source, set the frequency span to 0 Hz. Set the **SWEEP TIME** on the HP 8510B to 100 seconds.
2. Disconnect the sweep ramp on the back of the HP 8510B. Connect the external trigger output on the pulse modulator to the **EXTERNAL TRIGGER** input on the HP 8510B.

Figure 9 illustrates the system configuration using the HP 8511A as the test set. Any of the previously discussed test configurations could be used by disconnecting the sweep ramp and connecting the external trigger of the pulse generator.

This configuration now uses the external trigger from the pulse generator to trigger the HP 8510B to take data. The display will be updated using the external trigger pulses.

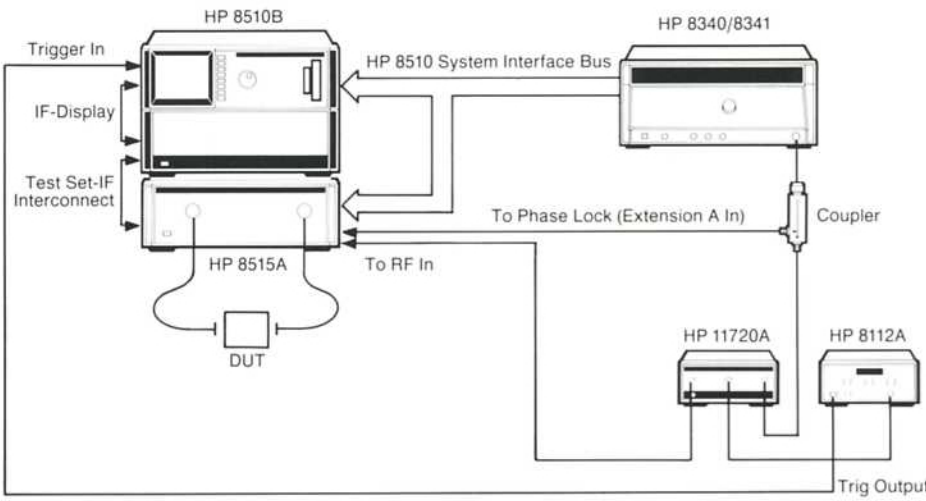


Figure 9. Pulsed-RF Testing Configuration using the HP 8510 (External Trigger)

3. Set the automatic gain control of the IF on the HP 8510B to prevent the **IF OVERLOAD** error messages. These messages result from overloads caused by the automatic gain control contained in the IF signal path. This automatic gain control circuit normally maximizes the dynamic range by varying the IF gain in the standard HP 8510B configuration. However, since the actual IF level in this configuration is varying, the magnitude can be sampled at the wrong time resulting in an inaccurate gain setting. This automatic gain circuit can be set from the front panel using the following procedure:

   Press the **SYSTEM** hard key.

   Press the **MORE** soft key.

   Press the **SERVICE FUNCTIONS** soft key.

   Press the **IF GAIN** soft key.

   Press the **REF AMP GAIN** soft key.

   This selection will set the gain of the IF amplifier in the reference channel. Fix this gain while pulsing and check for an **IF OVERLOAD** message. Maximize this gain while checking to see that no **IF OVERLOAD** condition occurs.

   Once the **REF AMP GAIN** is set, repeat the procedure for **TEST AMP GAIN.**

4. Set the proper delay on the external trigger so that the measurements are taken at the maximum power level. For pulse widths greater than 200 microseconds, the trigger can simply be set to 125 microseconds (there is a built-in 75 microsecond delay on the Trigger-In line of the HP 8510B). This delay will be something less for narrower pulses. To set the correct delay, monitor the magnitude of a1 and vary the trigger until a maximum level is reached. The trigger input to the HP 8510B is triggered on the falling edge, so this should be taken into account when calculating the delay.

Now the HP 8510B should be displaying the actual measured values. Each time a trigger comes from the pulse generator, the HP 8510B will display that measurement point on the display.

Calibration

This configuration can also be calibrated using most of the standard calibration techniques contained in the HP 8510B. The limitations are the same as those for the PRFs greater than 30 kHz (two-port calibration is not available).

One important point to note. When using error correction in the ramp sweep mode, the display is only updated every four display sweeps.

Results

Figure 10 shows the result of a measurement of the amplifier with a PRF=10 Hz. Here the screen is updated using the external trigger pulses. The information shown is the magnitude of S21 of a 400 microsecond wide pulse with an external trigger delay of 125 microseconds. Each point is the measurement of the magnitude of the response 200 microseconds into the pulse.

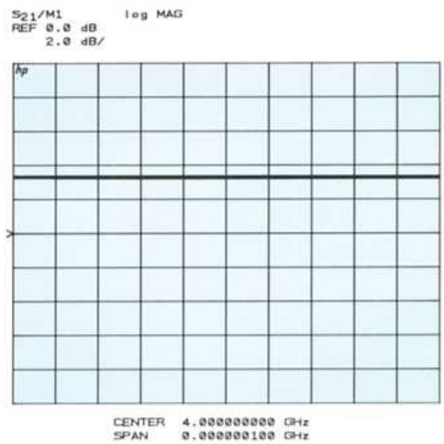


Figure 10. Gain Measurement in Pulsed-RF Mode (PRF=10 Hz, Pulse Width=400 microseconds)

Why Pulse both the Reference and Test Channels

There are several advantages to pulsing both the reference and the test channels. The first is the removal of any effects of the modulator itself. These effects will be seen in both the test and reference channels and will be ratioed out. Another advantage is that the offset caused by the pulse desensitization will occur in both channels and again be ratioed out.

One of the major disadvantages of comparing a pulse-RF test signal with a non-pulsed reference is the noise levels that occur when a standard test set is used in the configuration. This noise can be attributed to the samplers that are used in the first down conversion stage of the HP 8510. The figures at right illustrates this noise. In this case, the major noise component effects only the phase measurement.

Figure A shows the trace noise on the phase measurement of standard CW network analyzer measurement. Figure B shows the noise that may be present with a measurement made with a pulsed-RF test signal with PRF=100 kHz and a CW reference signal. Figure C shows the same response with a PRF=300 kHz and Figure D shows the same measurement for a PRF of 1 MHz. As these figures illustrate, the noise that appears on the phase measurement decreases as the PRF increases. Figures E, F, G, and H show the trace noise on the magnitude measurement for the same corresponding conditions, which effectively remains unchanged.

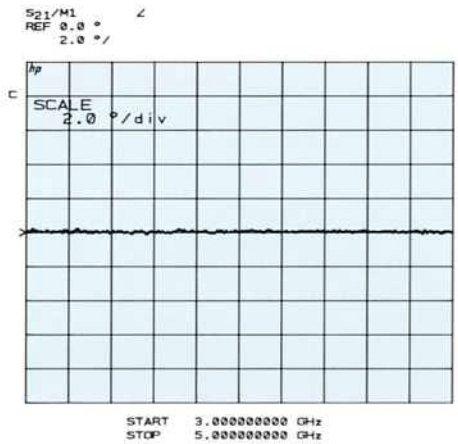


Figure A. Phase Trace Noise on a CW Measurement

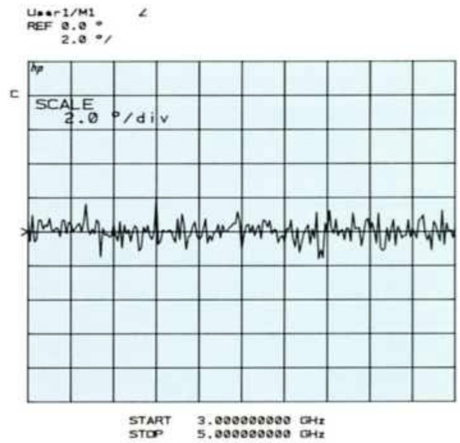


Figure C. Phase Trace Noise on a Pulsed-RF Measurement (PRF=300 kHz)

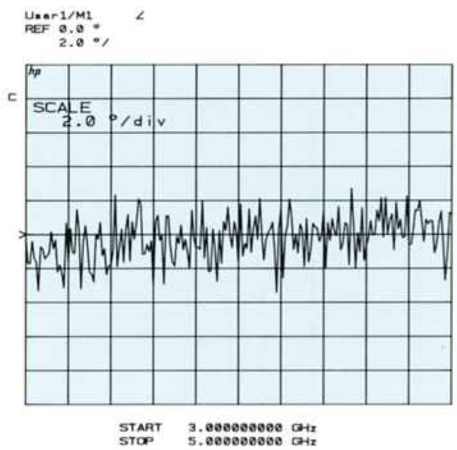


Figure B. Phase Trace Noise on a Pulsed-RF Measurement (PRF=100 kHz)

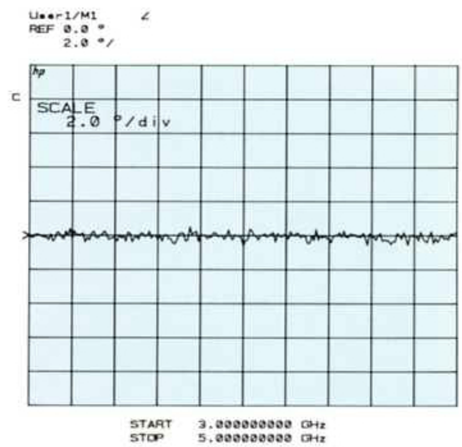


Figure D. Phase Trace Noise on a Pulsed-RF Measurement (PFR=1 MHz)

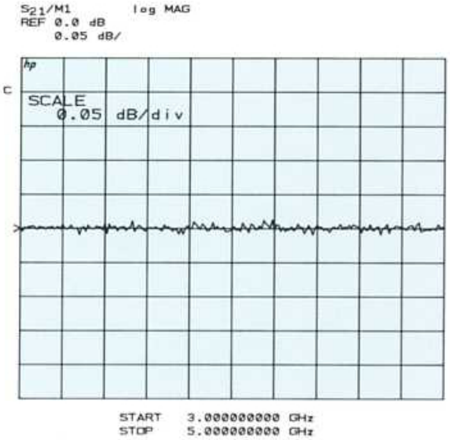


Figure E. Magnitude Trace Noise on a CW Measurement

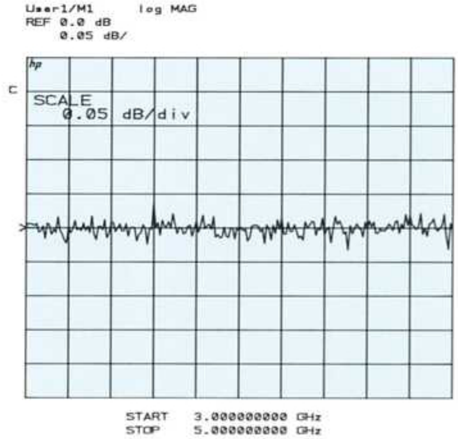


Figure G. Magnitude Trace Noise on a Pulsed-RF Measurement (PRF=300 kHz)

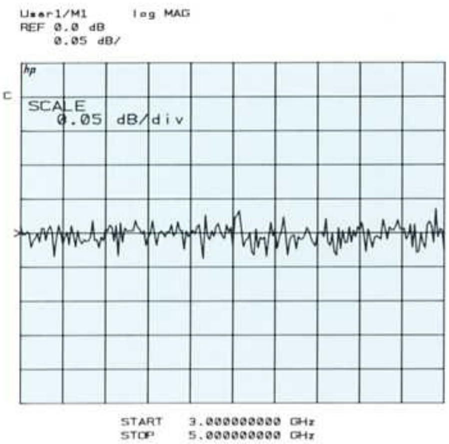


Figure F. Magnitude Trace Noise on a Pulsed-RF Measurement (PRF=100 kHz)

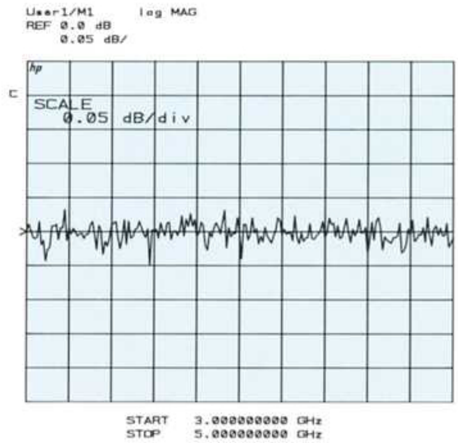


Figure H. Magnitude Trace Noise on a Pulsed-RF Measurement (PRF=1 MHz)

Summary

The HP 8510 can lend the same excellent performance in measurement accuracy and error correction to pulsed-RF network measurements as it has in the past to CW measurements. These measurements require only an understanding of the configurations needed and the effects of the pulsed signal on the test system.

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