PULSED-RF MEASUREMENTS AND THE HP 8510B NETWORK ANALYZER

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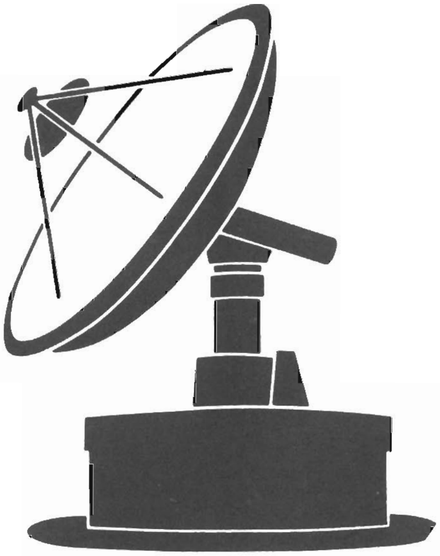

HEWLETT
PACKARD

ABSTRACT

Traditional vector network analyzers have been limited to testing with continuous wave stimulus. Previously, it has not been possible to achieve vector error correction and phase measurement capabilities under pulsed-RF conditions. Now, with new improvements in I.F. detectors, testsets and system firmware, it is possible for a vector network analyzer to make these needed measurements.

This paper will first cover the fundamentals of pulsed-RF waveforms. Then, three pulsed-RF measurement modes and their use with the HP8510B will be presented. This will include a discussion of the new detectors, testset and firmware that makes possible these pulsed-RF measurements. Measurement examples will be used to illustrate typical test results of the pulsed-RF modes and the enhanced external triggering capabilities.

AUTHORS

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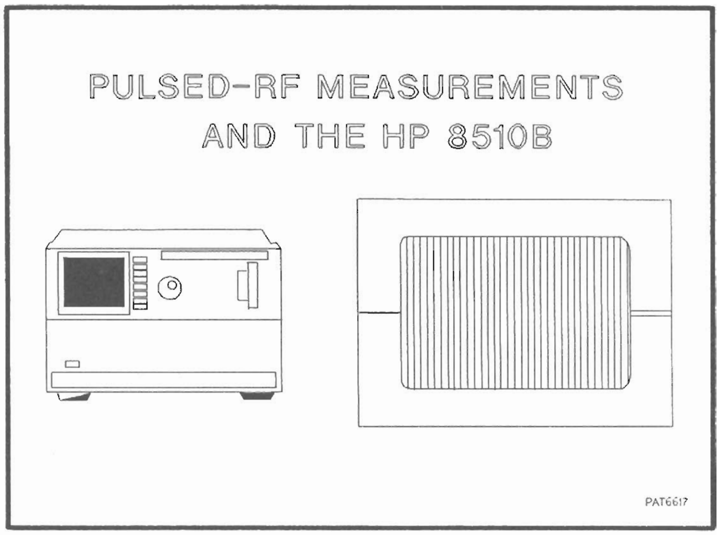
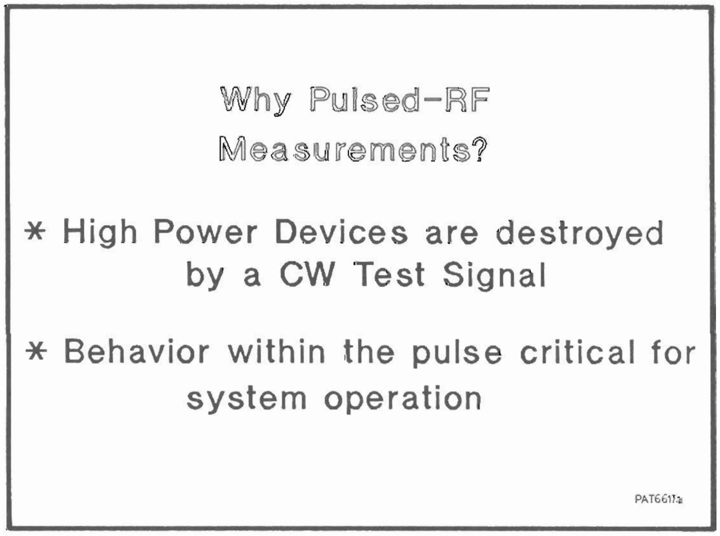


PULSED-RF MEASUREMENTS AND THE HP 8510B

PAT6617

The vector network analyzer has traditionally been limited to measuring a device-under-test (DUT) under a continuous wave (CW) stimulus. However, there are many times when a pulsed (non-CW) stimulus is desired or required. Now, with recent improvements in the HP8510B, both amplitude and phase measurements can be made on a DUT with a pulsed-RF stimulus.



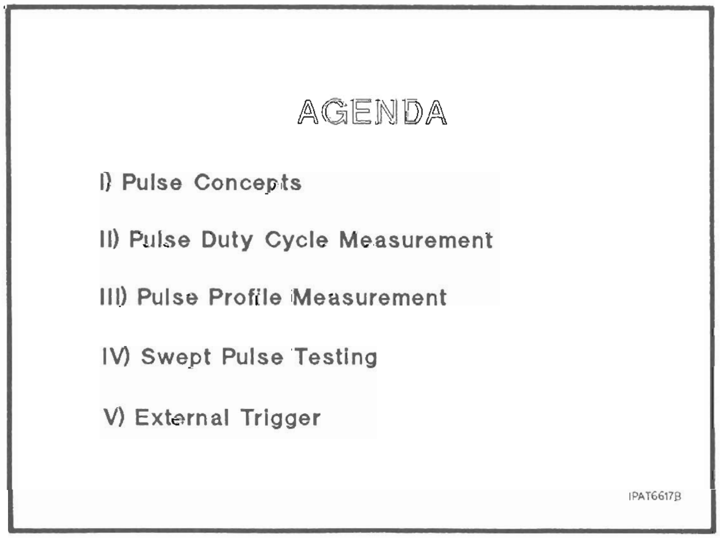
Why Pulsed-RF Measurements?

* High Power Devices are destroyed by a CW Test Signal

* Behavior within the pulse critical for system operation

PAT6617a

Pulsed-RF measurements are required in cases where continuous test power could destroy the DUT. The DUT may be damaged because it does not have sufficient heatsinking or the heatsink may not yet be attached, as in the case of an unpackaged device or a device still on the wafer. Also, the behavior of DUT during the pulse may be of some interest. For example, does the gain drop as the device heats up or does phase change with time as the power supplies run out of current storage?



AGENDA

I) Pulse Concepts

II) Pulse Duty Cycle Measurement

III) Pulse Profile Measurement

IV) Swept Pulse Testing

V) External Trigger

PAT6617B

The purpose of this paper is to address a number of different pulsed-RF measurement techniques possible with the HP8510B. First, some basic pulse concepts will be reviewed. Then three different pulse techniques will be explained: Pulse Duty Cycle, Pulse Profiling and Swept Frequency Pulse. Finally, the expanded external trigger capabilities will be discussed.

AGENDA

I) Pulse Concepts

II) Pulse Duty Cycle Measurement

III) Pulse Profile Measurement

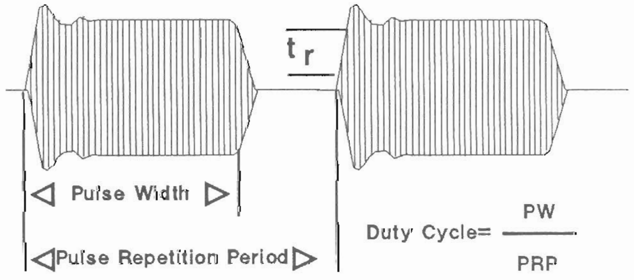
IV) Swept Pulse Testing

V) External Trigger

First, before describing the new pulse measurement capabilities, let's review some basic pulse terminology and concepts.

PULSE TERMS

TIME



$$\text{Duty Cycle} = \frac{PW}{PRP}$$

In defining any pulsed-RF waveform, there are a number of parameters.

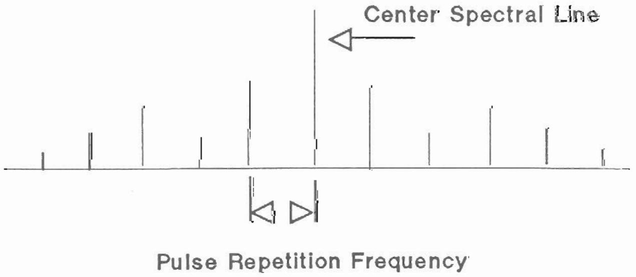
PW - pulse width - this is the ON time from 50% of the rise edge to the 50% point of the falling edge.

PRP - Pulse Repetition Period - this is the time from the start of one pulse to the start of the next. Note, the Pulse Repetition Frequency (PRF) is 1/PRP.

tr - pulse rise time - this is the time it takes for the pulse to go from the 10% ON condition to the 90% ON condition.

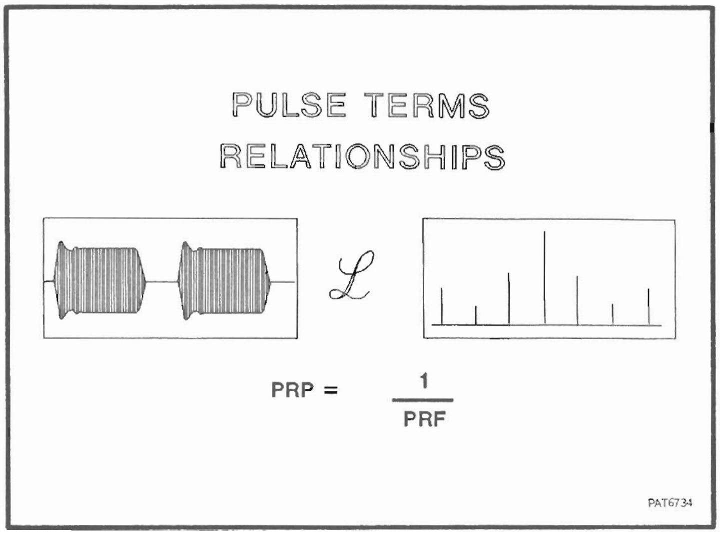
Duty Cycle - this is the ratio of pulse time ON to the total pulse period. It is this ratio, the PW and DUT characteristics that determine how much the DUT will heat up.

PULSE TERMS
FREQUENCY



Total Energy=Sum of the amplitudes of all spectral lines

When viewed in the frequency domain, such as with a spectrum analyzer, the pulsed-RF waveform has many spectral lines. There is a Central Spectral Line, at the carrier frequency. Then there are a series of additional spectral lines spaced at the PRF from the center line. The amplitudes and number of lines depend on the pulse parameters.

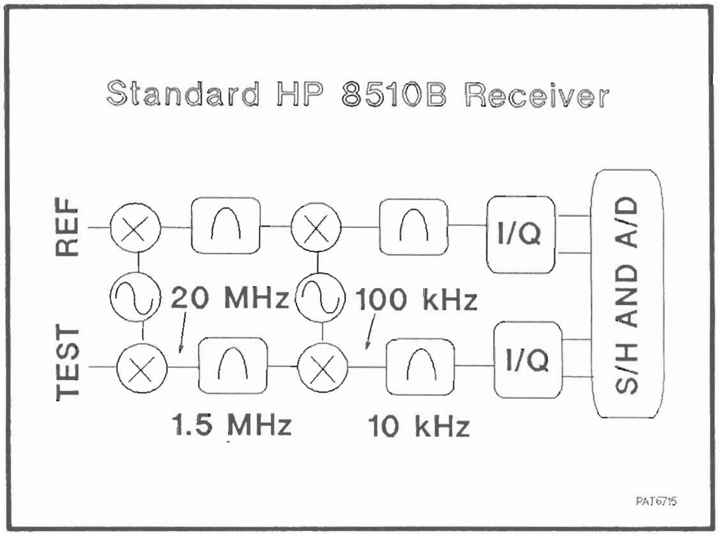


PULSE TERMS
RELATIONSHIPS

$$PRP = \frac{1}{PRF}$$

PAT6734

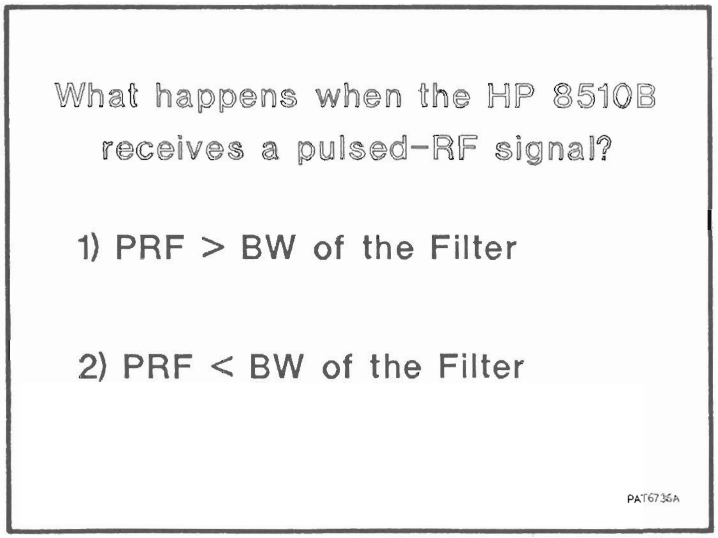
The pulsed-RF waveform can be viewed in either the time domain or the frequency domain. One fully describes the other, and the choice depends which is more convenient to observe a particular characteristic.



Standard HP 8510B Receiver

PAT6715

This functional block diagram will help explain how the standard HP8510 I.F. chain will react to a pulsed-RF waveform. The TEST and REFERENCE signals are first downconverted to 20 MHz in the testset with roughly 1.5 MHz of bandwidth. A second conversion occurs to 100 kHz followed by a synchronous detector (I/Q) with a bandwidth of 10kHz.



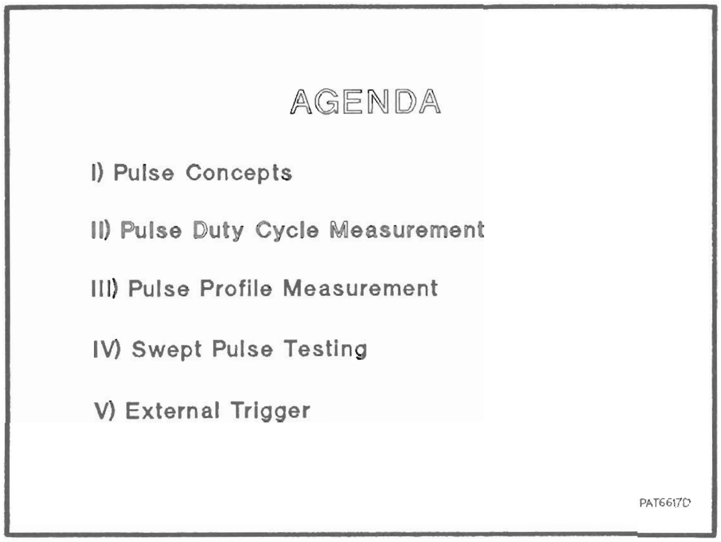
What happens when the HP 8510B receives a pulsed-RF signal?

1) PRF > BW of the Filter

2) PRF < BW of the Filter

PAT6736A

It will be the relationship between the pulse parameters and the detector bandwidth that will determine the type of pulse measurements that can be made. The two basic cases are: (1) the pulse's PRF is much greater than the detector's bandwidth or (2) the pulse's PRF is much less than the detector's bandwidth.



AGENDA

I) Pulse Concepts

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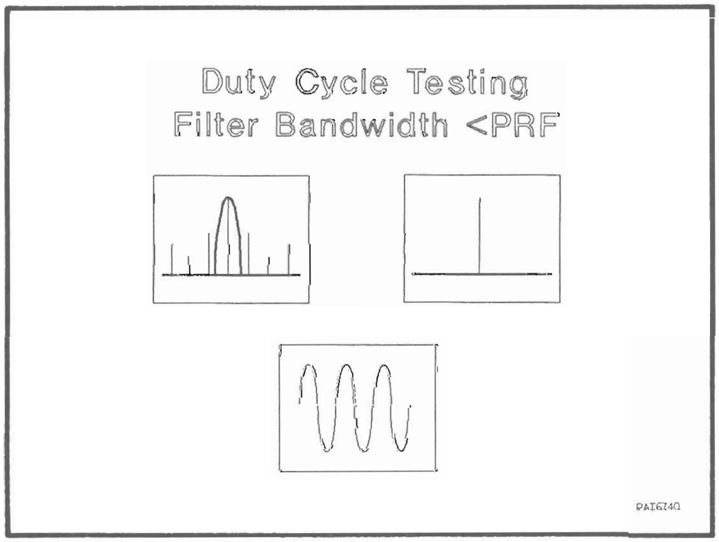
PAT6617D

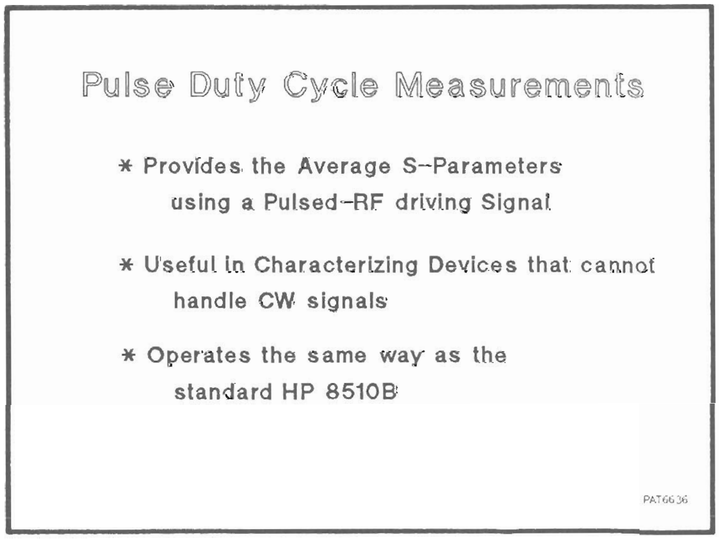
Let's first study the case where the pulse's PRF is much greater than the detector's bandwidth. This mode will be called Pulse Duty Cycle.



Duty Cycle Testing
Filter Bandwidth <PRF

PAT6740

If the pulse's PRF is much greater than the detector's bandwidth, then, as these time and frequency diagrams show, just the Central Spectral (carrier frequency) line will be measured. All the information and energy in the other spectral lines will be filtered out and lost. This means the measurement results will represent an average response of the DUT to the carrier frequency during the entire pulse period.



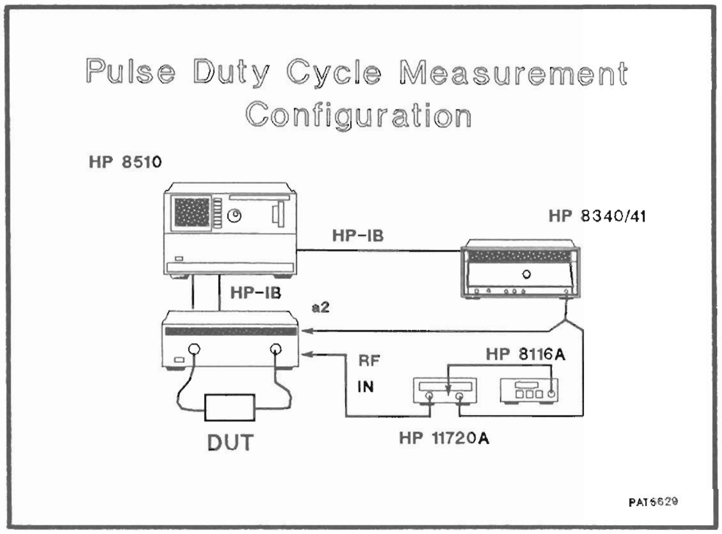
Pulse Duty Cycle Measurements

- * Provides the Average S-Parameters using a Pulsed-RF driving Signal
- * Useful in Characterizing Devices that cannot handle CW signals
- * Operates the same way as the standard HP 8510B

PAT6636

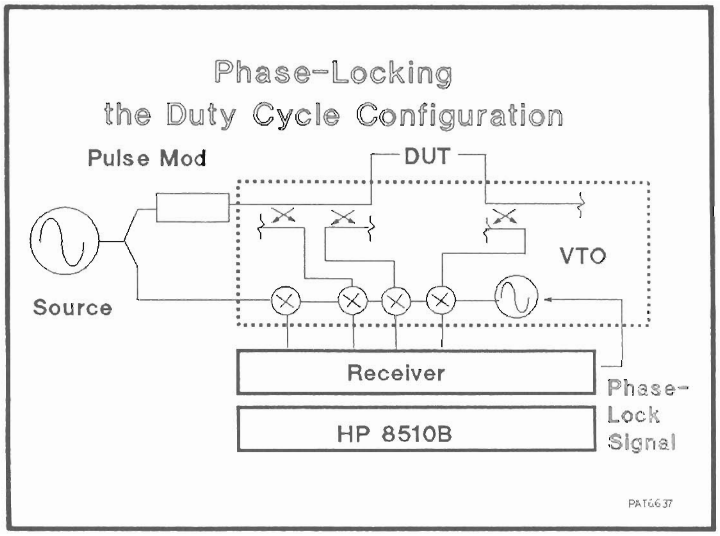
Pulsed Duty Cycle operation measures the average response of the DUT to a pulsed-RF waveform and cannot show the response at a particular point in time of the pulsed-RF stimulus. This is still very useful for testing DUTs that are unable to handle CW stimulus and the behavior during the pulse is constant. Typical uses would be for testing transistors or MMICs on wafer before packaging.

Pulsed Duty Cycle can be done with any HP8510A/B and requires PRFs of greater than 30 kHz.



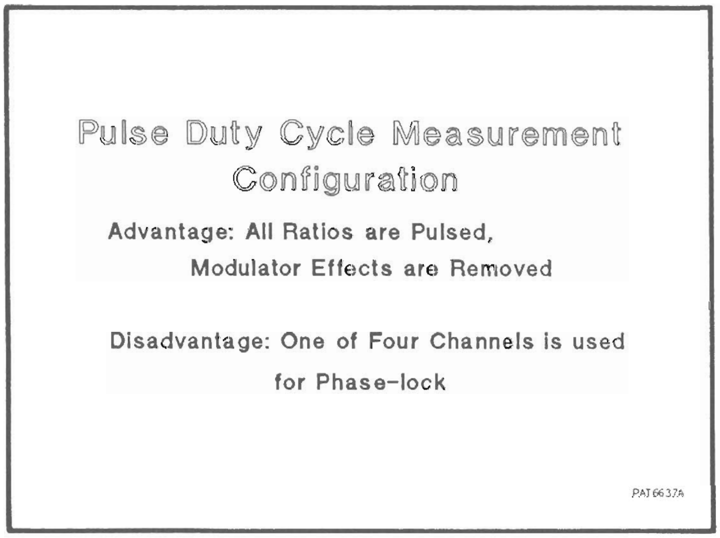
Pulse Duty Cycle Measurement Configuration

While the standard HP8510A/B can be used to do Pulse Duty Cycle, certain modifications to the measurement setup need to be made. In configuring the setup, a non-pulsed signal needs to be provided to the testset for phaselocking. It is injected into the a2 input via the rear panel coax link. An external modulator and pulse generator, such as the HP11720A and HP8116A, are used to create the pulsed-RF stimulus that is then applied to the testset via the normal RF IN port.



Phase-Locking the Duty Cycle Configuration

This detailed block diagram shows how the non-pulsed-RF is used by the testset and receiver for a phaselock reference. The other samplers and DUT measure the modulated pulsed-RF waveform.

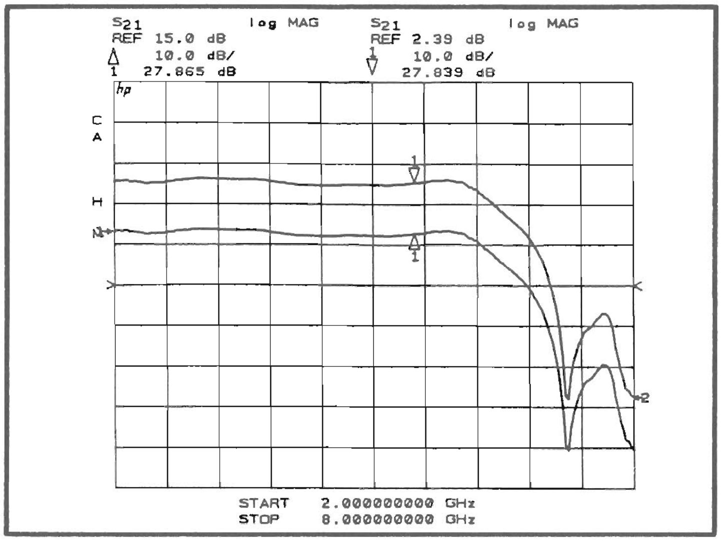


Pulse Duty Cycle Measurement Configuration

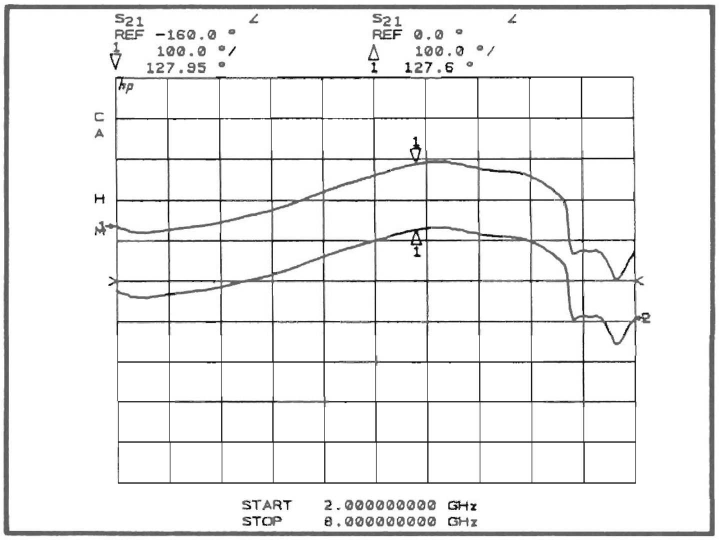
Advantage: All Ratios are Pulsed, Modulator Effects are Removed

Disadvantage: One of Four Channels is used for Phase-lock

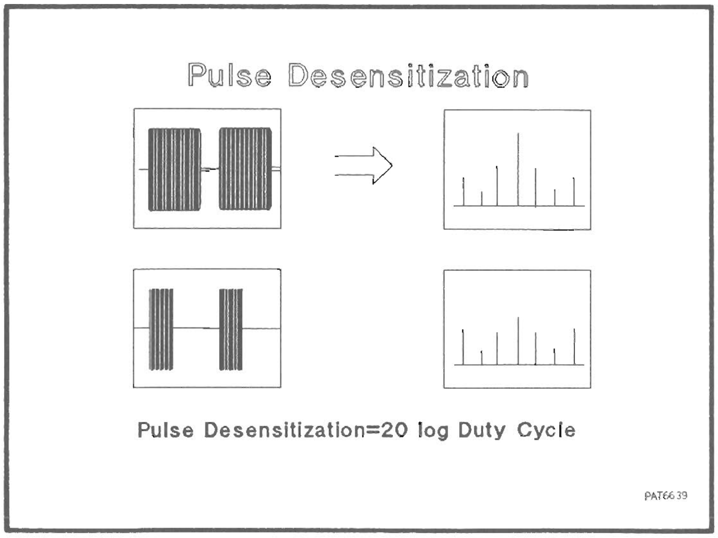
All measurements are made as ratios of pulsed-RF signals, and all modulator effects (loss and phase shift) are removed. However, with the testset reconfiguration, the S-parameter testset has been converted into a Reflection / Transmission (R/T) testset. This means that to obtain all four S-Parameters, the DUT will have to be manually reversed.



This measurement example compares the measurement of an amplifier under CW (upper trace) and Pulse Duty Cycle (lower trace) conditions (offset to better see the individual traces). In the Pulse Duty Cycle case the PRF was 100 kHz and the duty cycle was 50%. Note Error Correction is On and the results are nearly identical with perhaps a slight increase in the noise for the Pulse Duty Cycle case.



The phase responses of the previous measurements. Again, the measurements are essentially the same.

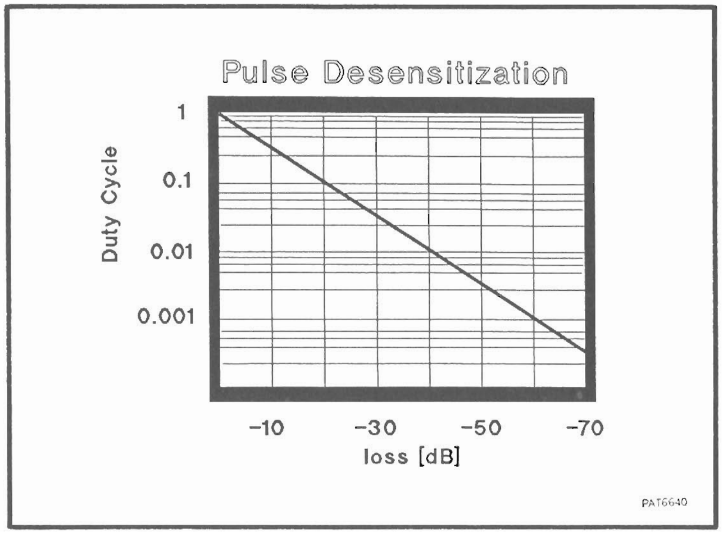


Pulse Desensitization

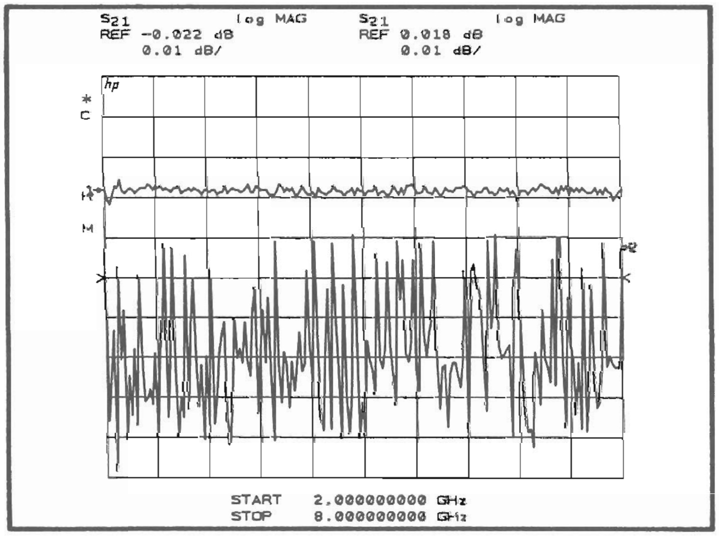
Pulse Desensitization=20 log Duty Cycle

PAT6639

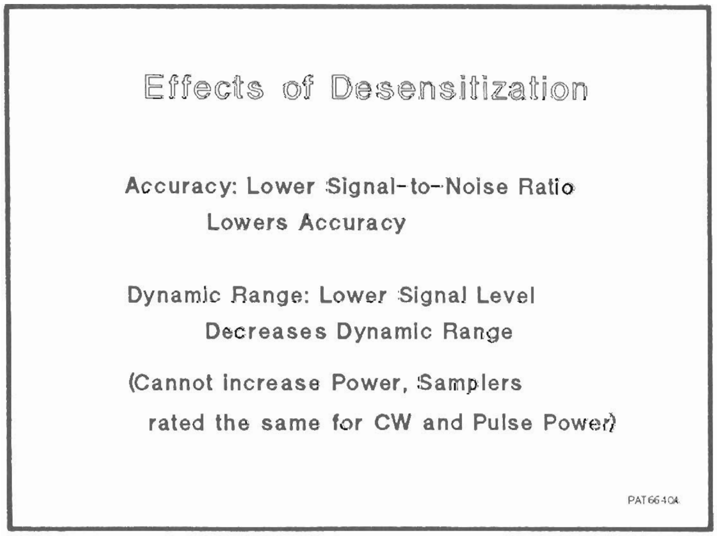
As explained earlier, a pulsed-RF waveform consist of central and additional spectral lines, and in the Pulse Duty Cycle case, only the central line is detected. As the duty cycle decreases, the total energy in the central line decreases. This causes an overall decrease in detector dynamic range and is called Pulse Desensitization.



This chart shows the effect of pulse desensitization in loss of measurement dynamic range as a function of the pulse duty cycle. A duty cycle of 10% will cause a loss of dynamic range of 20 dB.



This measurement example shows the effects of pulse desensitization in the case of 10% duty cycle (lower trace) compared to a 100% duty cycle (CW -- upper trace). Only at these very high amplitude resolutions can the increase in noise be seen.



Effects of Desensitization

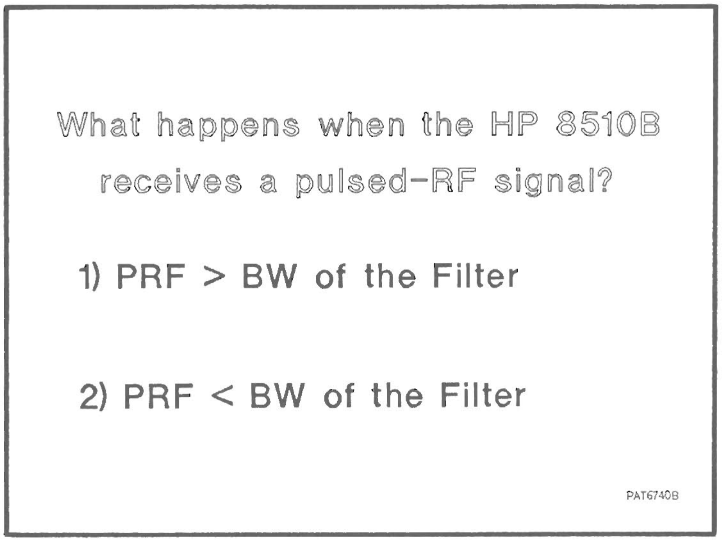
Accuracy: Lower Signal-to-Noise Ratio Lowers Accuracy

Dynamic Range: Lower Signal Level Decreases Dynamic Range

(Cannot increase Power, Samplers rated the same for CW and Pulse Power)

PAT6640A

As the previous chart shows, there is a loss dynamic range (and therefore a decrease in the measurement Signal / Noise ratio) for small duty cycles in Pulsed Duty Cycle. Signal averaging can compensate for this effect. However, increasing the RF power to reduce this effect usually cannot be done because the DUT and first I.F. of the HP8510 see the entire signal spectrum (and peak power) and may distort with increased signal power.



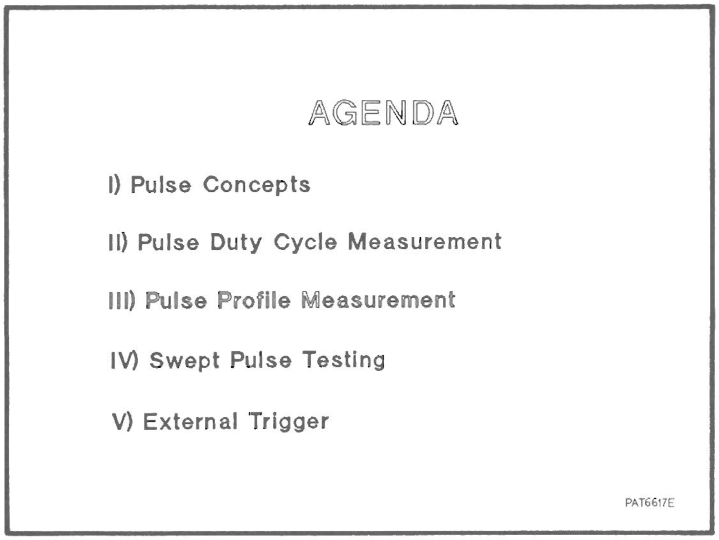
What happens when the HP 8510B receives a pulsed-RF signal?

1) PRF > BW of the Filter

2) PRF < BW of the Filter

PAT6740B

The next case to consider is where the PRF is much less than the detector bandwidth.



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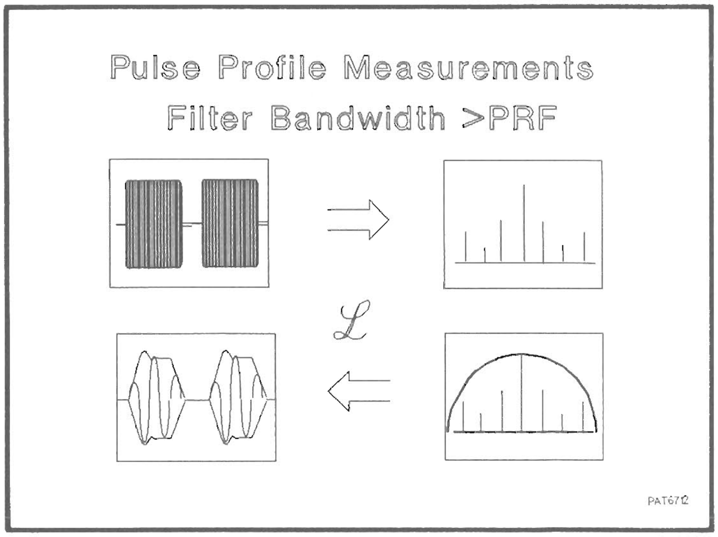
PAT6617E

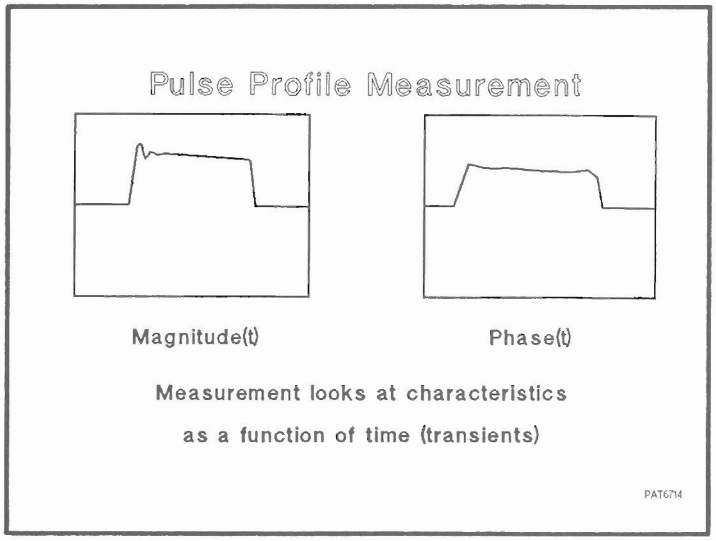
This pulse measurement technique is called Pulse Profiling.



Pulse Profile Measurements

Filter Bandwidth >PRF

To be able to fully see the dynamics of the pulsed-RF waveform, the detector bandwidth needs to be much greater then the PRF, to include a significant number of the spectral lines. This allows the detector to accurately reproduce the pulse's envelope (profile).

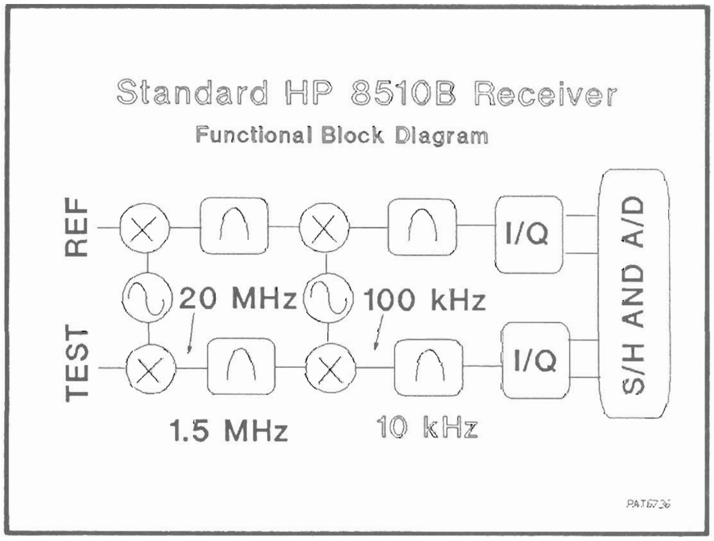


Pulse Profile Measurement

Measurement looks at characteristics as a function of time (transients)

PAT6714

With the ability to profile the pulse envelope, one can view both the magnitude and phase response as a function of time. This means under pulsed (non-CW) conditions certain DUT characteristics can be observed, such as the droop or change in the response due to DUT heating or power supply capacity limitations.

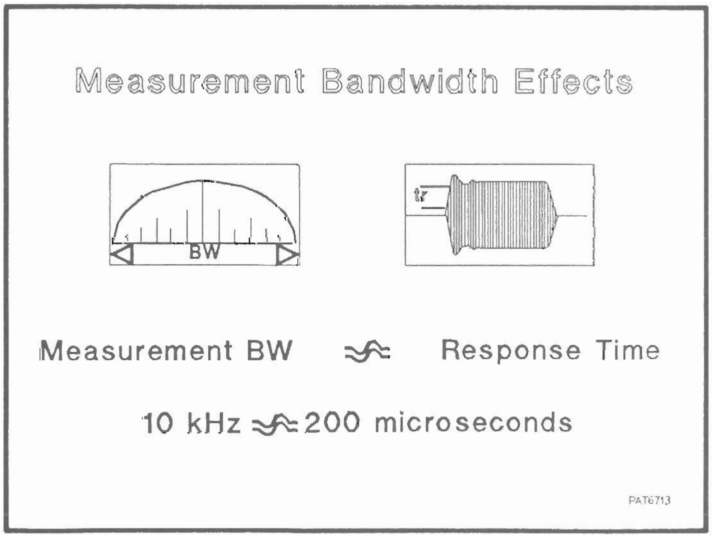


Standard HP 8510B Receiver

Functional Block Diagram

PAT6736

While Pulse Profiling could be possible with the standard HP8510, due to the low detector bandwidth, the pulse conditions needed to allow pulse profiling are not very useful.



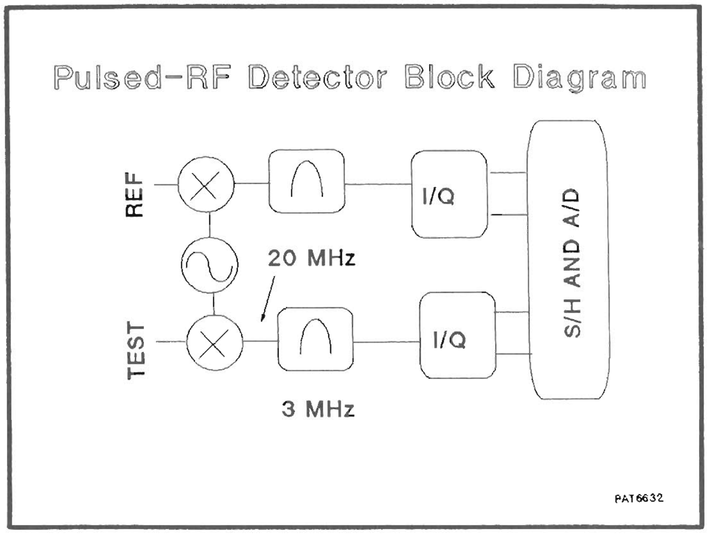
Measurement Bandwidth Effects

Measurement BW ≈ Response Time

10 kHz ≈ 200 microseconds

PAT6713

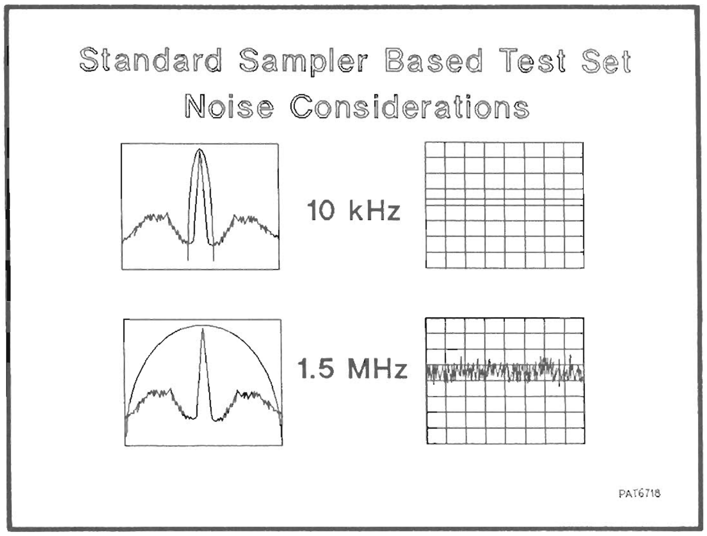
Given the limitation of a detector bandwidth of 10 kHz, it would be necessary to have a pulse width of greater than 200 microseconds with rise times of greater than 75 microseconds. So, to make useful Pulse Profiling measurements, the I.F. detector bandwidth needs to be increased.



Pulsed-RF Detector Block Diagram

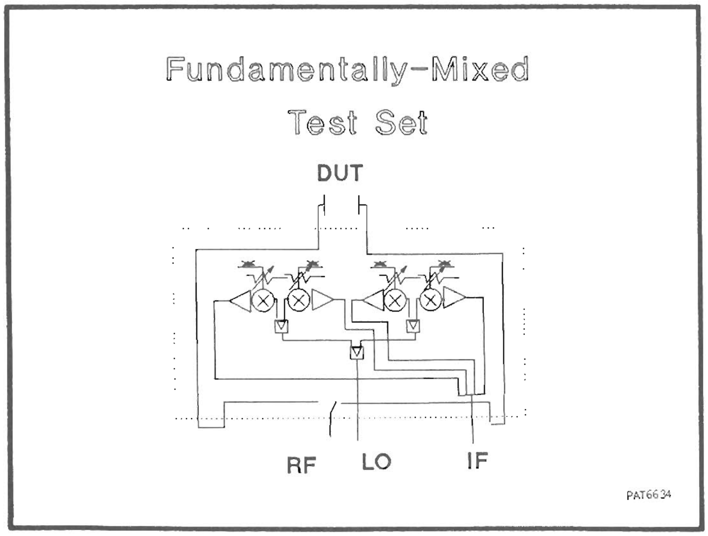
The HP8510B Option 008 provides new detectors with improved bandwidth permitting usable pulse widths as small as 1 microsecond. This allows the testing of DUT under actual operational conditions without the harmful heating effects and is even fast enough to view some transient behavior.

The new detectors operate at the 20 MHz I.F. with a 3 MHz pre-detection bandwidth (equivalent to 1.5 MHz post-detection bandwidth).



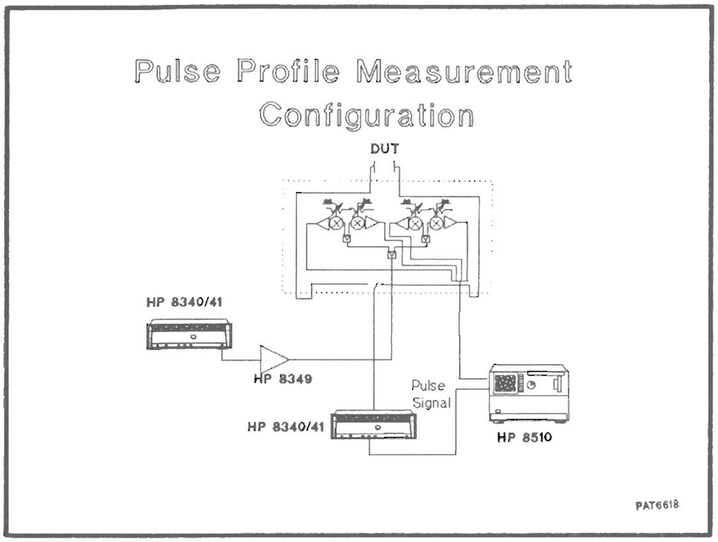
Standard Sampler Based Test Set
Noise Considerations

In addition to increasing the detector bandwidth, there are additional block diagram changes are needed to make pulsed-RF measurements. The standard HP8510s have a harmonic sampler downconvertor with a 65 to 300 MHz VTO phaselocked to the RF stimulus. As the bandwidth of the detector is increased, a larger portion of the VTO's noise is detected. For the sampler based testsets there is a significant amount of noise in the downconverter signal outside the original 10 kHz bandwidth. Even with averaging and other signal processing, the performance of the standard testset with wider bandwidth detectors is unacceptable.



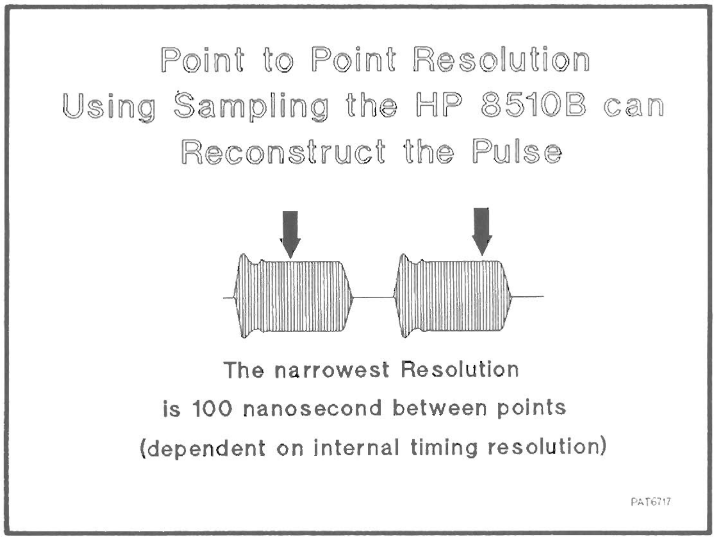
Fundamentally-Mixed
Test Set

However, by combining fundamental mixers with a careful choice of RF components, low noise RF and LO signal sources, a testset with wide I.F. bandwidth and good dynamic range can be constructed. This block diagram shows such a testset with full S-Parameter operation. The use of couplers (instead of bridges) with variable attenuators before each mixer allows operation at the high power levels typically found with pulsed DUTs. Power amplifiers to increase test port power or additional test equipment can be integrated with this testset via rear panel access links.



Pulse Profile Measurement Configuration

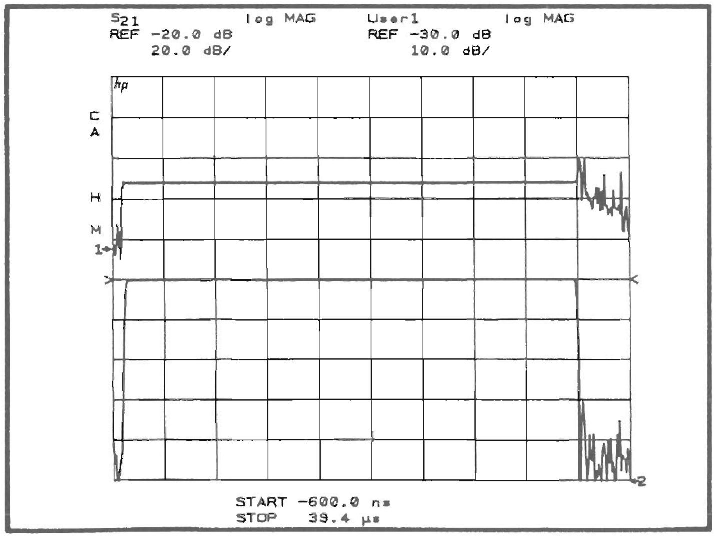
The HP85110A is fundamental mixer based testset designed for pulsed and high power DUTs. It looks much like a standard HP8510 system except for the additional HP8340/41 which provides the low noise LO. The HP8510B controls both sources using its multiple source capability. For pulsed-RF operation, the HP8510B provides a TTL output to drive the RF source internal pulse modulator.



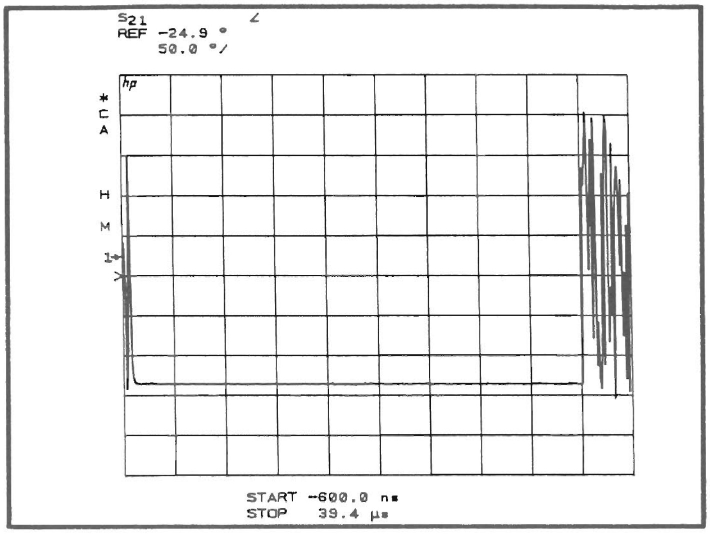
Point to Point Resolution Using Sampling the HP 8510B can Reconstruct the Pulse

The narrowest Resolution
is 100 nanosecond between points
(dependent on internal timing resolution)

The HP8510 data conversion process is not fast enough to catch all the pulse data from a single pulse. Instead repetitive sampling is used where the data is reconstructed with samples taken from a series of pulses. A single data point is taken from each pulse with the delay time from start of the pulse progressively increased in as small as 100 nanosecond intervals.



This is an example of the pulse profiling measuring capability. Shown is the S21 and the unratioed output power of our amplifier tested with a 35 microsecond pulse at 4 GHz. The S21 measurement as function of time is fully error corrected and the system has absolute accuracy specifications, both capabilities not found in previous systems.



This is the phase response of the previous measurement. Note: outside the pulse (before 0 microseconds and after 35 microseconds) there is no signal and therefore the response is just noise.

HP 8510B Pulsed-RF Testing

- * HP 8510B 1.5 MHz Bandwidth Receiver provides pulsed-RF response measurements
- * Requires Fundamentally-Mixed Test Set

PAT6728A

With increased detector bandwidth and a fundamentally mixed testset, the characteristics of a DUT to a pulsed-RF stimulus can be measured. While even wider bandwidth detectors would have permitted use of sub-microsecond pulses, the system's accuracy and stability would have been degraded. With 1.5 MHz post-detection bandwidth, DUTs can be tested with microsecond wide pulses but with accuracy similar to traditional non-pulsed measurements.

DOMAIN

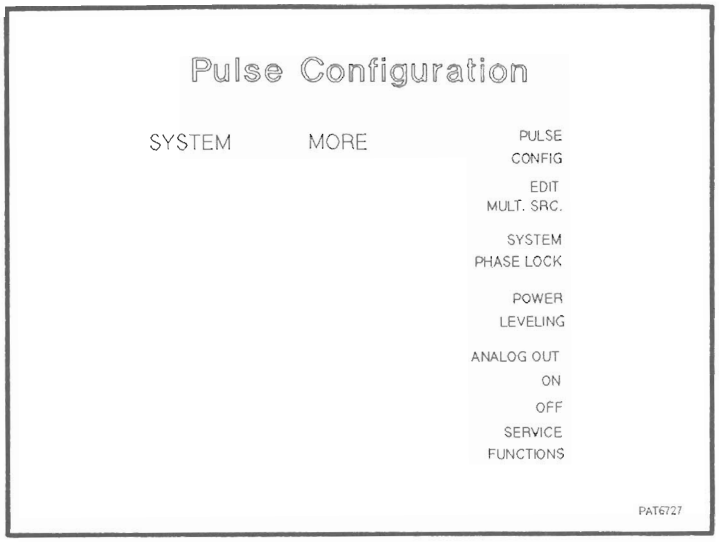
FREQUENCY
TIME LOW PASS
TIME BAND PASS
AUX. VOLT OUTPUT
PULSE PROFILE
SPECIFY TIME
SPECIFY GATE

Pulse Profile Domain

- * Turns on Wide Band Detectors
- * Sets Display for Time
- * Internal Trigger
- * Turns on Pulse OUT

PAT6726

There are new features in the HP8510B firmware to support the pulsed-RF measurements. The Pulse Profile is one the HP8510B's Domain Options. Upon selecting Pulse Profile Domain, the wide band detectors are selected with the HP8510B providing the needed drive for the RF source modulator. The display is annotated in time and the user can select with the STIMULUS START and STOP keys the portion of the pulse to view. Remember, this is not the traditional network analyzer transformed time domain but rather a true representation of the device's response to an actual pulsed-RF signal.



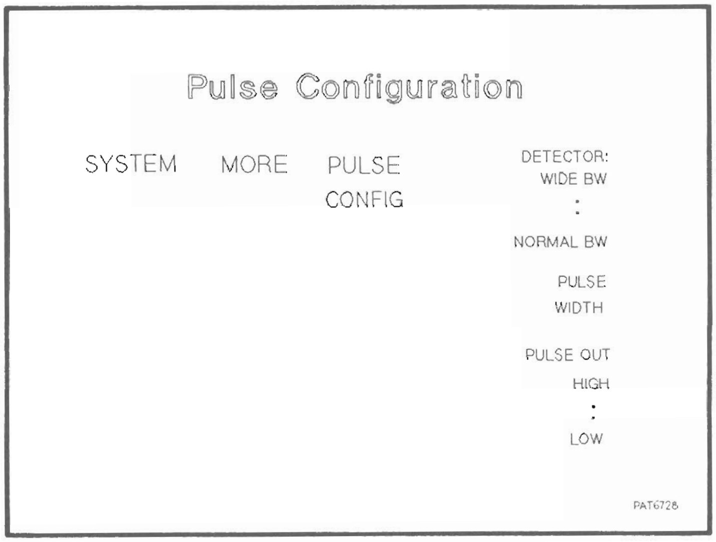
Pulse Configuration

SYSTEM
MORE

PULSE CONFIG
EDIT MULT. SRC.
SYSTEM PHASE LOCK
POWER LEVELING
ANALOG OUT
ON
OFF
SERVICE FUNCTIONS

PAT6727

There are a number of additional setup parameters for the Pulse Profile Domain. These are located under the PULSE CONFIG key found in second group of softkeys under the SYSTEM menu.



Pulse Configuration

SYSTEM
MORE
PULSE CONFIG

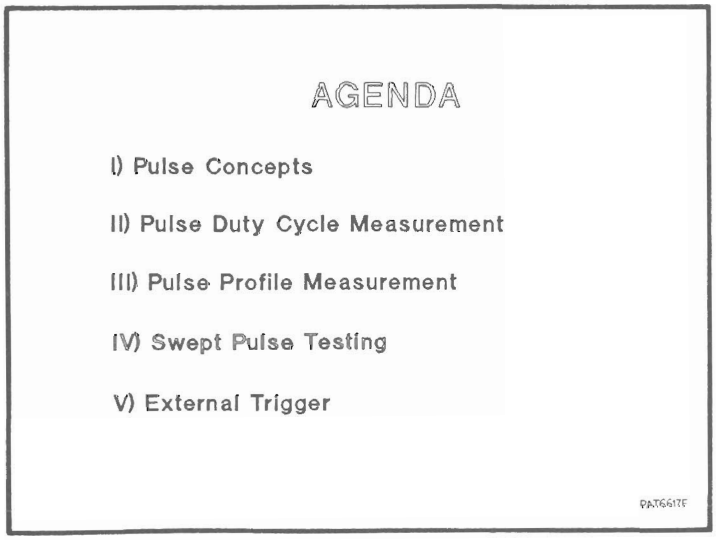
DETECTOR:
WIDE BW
:
NORMAL BW
PULSE WIDTH
PULSE OUT
HIGH
:
LOW

PAT6728

DETECTOR: Wide BW & Normal BW -- this is always set to Wide BW in Pulse Profile Domain, but other modes allow the user to select between the Wide BW detectors or the standard Normal BW detectors.

PULSE WIDTH - This controls the width of the HP8510B rear panel TTL pulse output for controlling the RF source pulse modulator. It always starts at 0 seconds and can vary from 100 nanoseconds to 40 milliseconds.

PULSE OUT: High & Low - This sets the polarity of the rear panel TTL pulse output for the ON period of the pulse.



AGENDA

I) Pulse Concepts

II) Pulse Duty Cycle Measurement

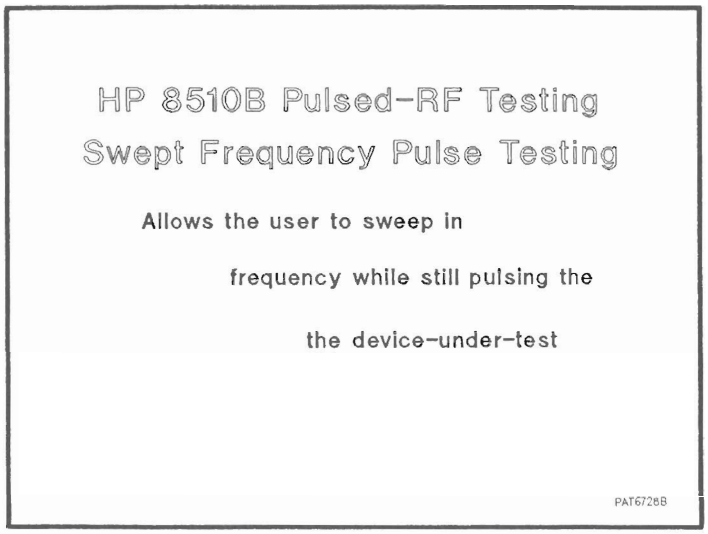
III) Pulse Profile Measurement

IV) Swept Pulse Testing

V) External Trigger

PAT6617E

Pulse Duty Cycle allows the user to view the DUT's averaged response as a function of frequency while pulsed and Pulse Profiling allows the user to view the DUTs response as a function of time during the pulse. The third and final pulsed-RF measurement techniques is called Swept Frequency Pulse testing.



HP 8510B Pulsed-RF Testing
Swept Frequency Pulse Testing

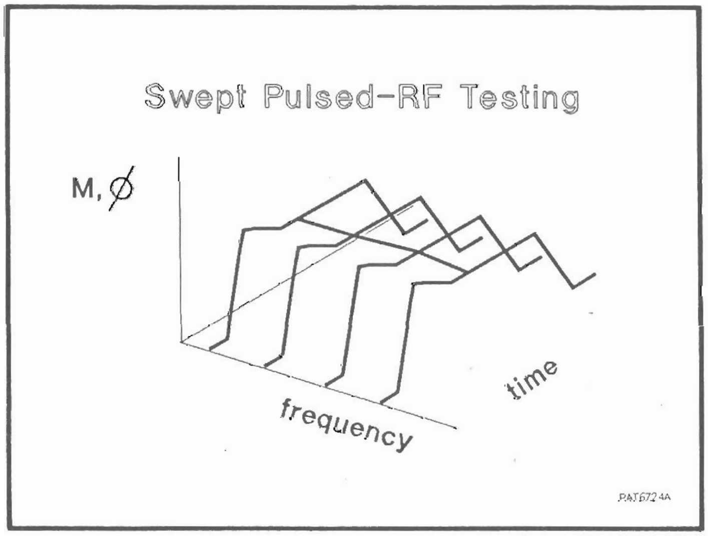
Allows the user to sweep in

frequency while still pulsing the

the device-under-test

PAT6728B

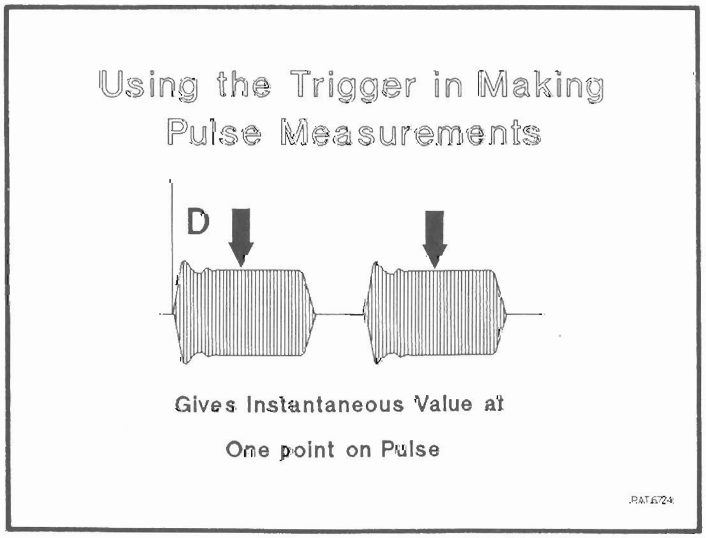
Swept Frequency Pulse testing shows the response of the DUT at a fixed point in the pulse as a function of frequency. This is a similar display to the traditional swept frequency measurement or to the Pulse Duty Cycle measurement. But with Swept Frequency Pulse testing, the data is NOT the CW or average pulse response but rather it is the response at a particular point in the pulse for range of frequencies.



Swept Pulsed-RF Testing

PAT6724A

Swept Frequency Pulse testing is another way to view the 3-dimensional world of Response, Frequency and Time. In Swept Frequency Pulse the delay from start of pulse to the sample point is held constant and the response is viewed as a function of frequency. In Pulse Profiling, the frequency is held constant and the response is viewed as a function of time. If only we had a 3-D display!!



Using the Trigger in Making Pulse Measurements

Gives Instantaneous Value at

One point on Pulse

PAT6724

Like in the Pulse Profiling measurement, a single data point is taken on a pulse, but instead of increasing the time delay, the time delay is fixed and the carrier frequency for the next measurement is changed. The value of the delay is user adjustable in 100 nanosecond intervals.

Pulsed-RF Duty Cycle vs Swept Pulse Measurement

Pulsed-RF Duty Cycle

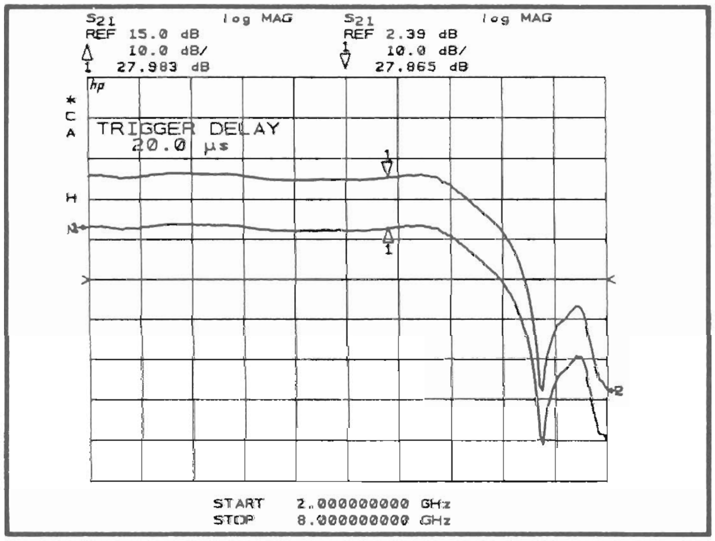
- "Averages" the S-Parameter
- Uses Standard HP 8510

Swept Pulse

- Captures the transient response
- User selects where point is taken
- Need HP 8510B pulse modifications

PAT6724B

While Pulsed-RF Duty Cycle and Swept Frequency Pulse testing have similar looking displays, the measurements are quite different and each has its benefits. Pulse Duty Cycle shows the average response during the pulse period and works with the standard HP8510 detector and testsets. Swept Frequency Pulse allows a better view of the response behavior at a specific point in the pulse but requires the new Option 008 wideband detectors and a fundamental mixer testset. Both techniques provides the non-CW power benefits of pulse testing.



In the case of our DUT amplifier, there is little difference between normal Swept Frequency and Swept Frequency Pulse testing. This Swept Frequency Pulse measurement (upper trace) was with a 80 microseconds wide pulse measured 20 microseconds into the pulse.

AGENDA

I) Pulse Concepts

II) Pulse Duty Cycle Measurement

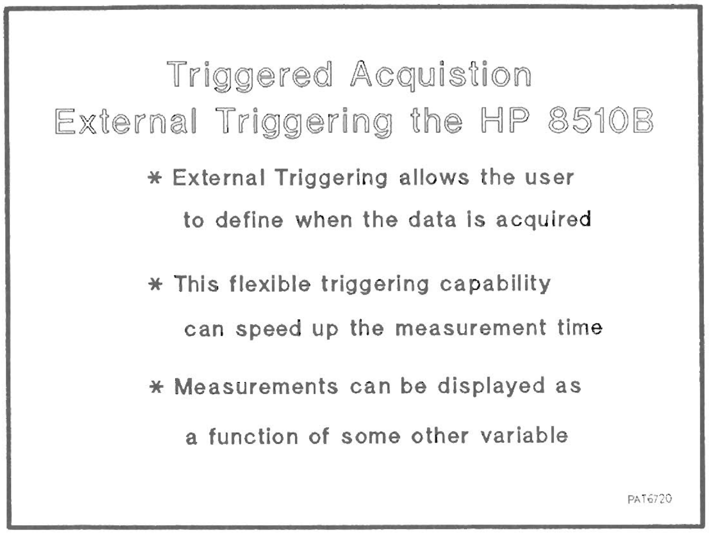
III) Pulse Profile Measurement

IV) Swept Pulse Testing

V) External Trigger

PAT6617G

While implementing the pulse functions and needed internal triggering capabilities, the external triggering capabilities of the HP8510B have also been improved.



Triggered Acquistion
External Triggering the HP 8510B

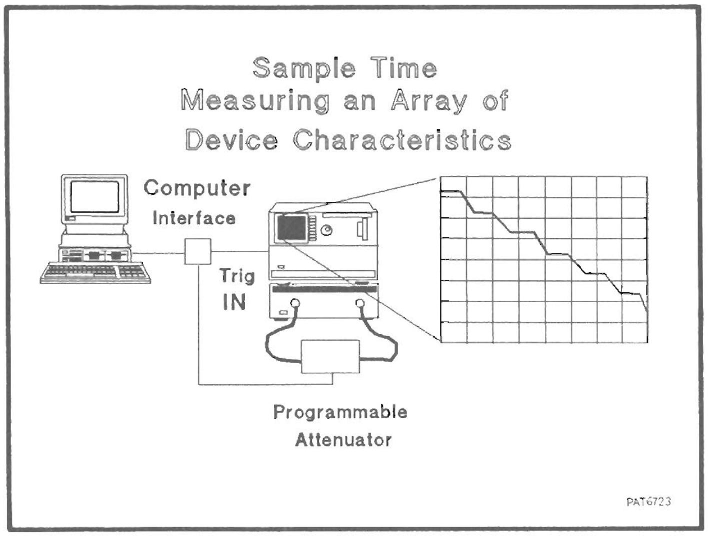
∗ External Triggering allows the user to define when the data is acquired

∗ This flexible triggering capability can speed up the measurement time

∗ Measurements can be displayed as a function of some other variable

PAT6720

With the new external triggering capabilities the measurements of the HP8510B can be better coordinated with external DUT events. In STEP and FREQ LIST sweep modes, frequency changes can now be triggered externally. Since only a single data point need be taken instead of a full sweep the total time needed for many measurements will be reduced. In addition, the x-axis can now be a function of some external state, such as antenna angular position or phase shifter setting.



Sample Time
Measuring an Array of Device Characteristics

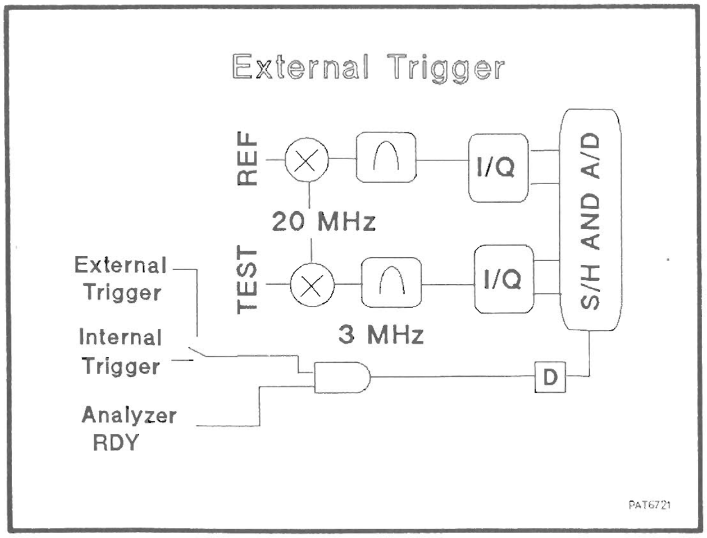
Computer Interface

Trig IN

Programmable Attenuator

PAT6723

This example shows the coordination of the stepping of a programmable attenuator with the HP8510B measurement process. Here in a single data trace the response of the DUT at multiple control states can be seen.



External Trigger

REF

TEST

20 MHz

3 MHz

I/Q

I/Q

S/H AND A/D

External Trigger

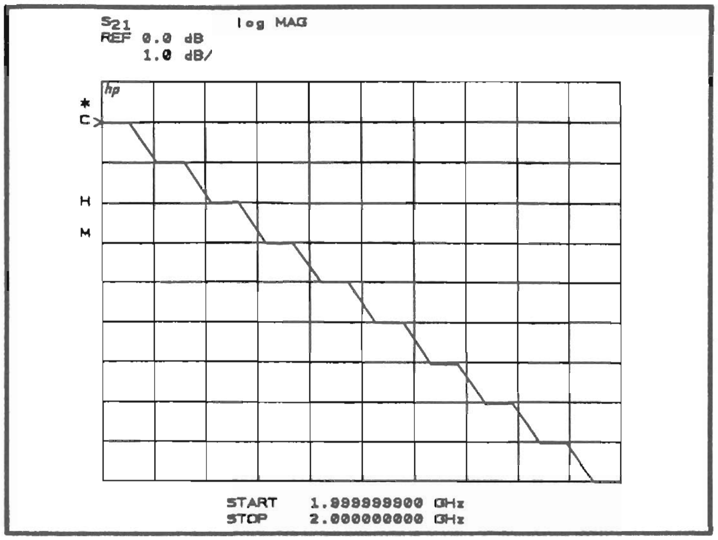
Internal Trigger

Analyzer RDY

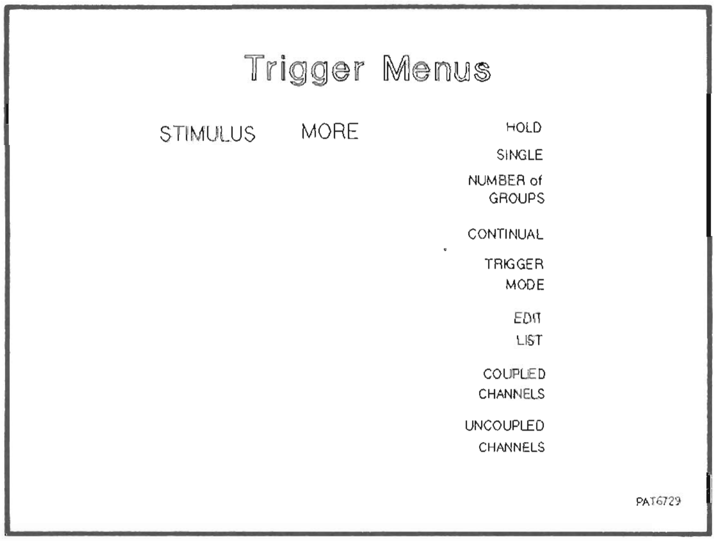
D

PAT6721

The external trigger is a TTL input on the rear panel of the HP8510B. It is edge triggered and will be ignored if the analyzer is not yet ready to be triggered. The Analyzer RDY signal is also available on the rear panel (Stop Sweep) for the user. The external trigger is usable with both detectors. In case of the wide bandwidth detectors, there is an user adjustable trigger delay. External trigger is particularly useful in pulse testing, when a particular duty cycle or PRF is desired.



This is the measurement of a 10 dB step attenuator with two measurements at each attenuator level. Each measurement was made in response to an external trigger.



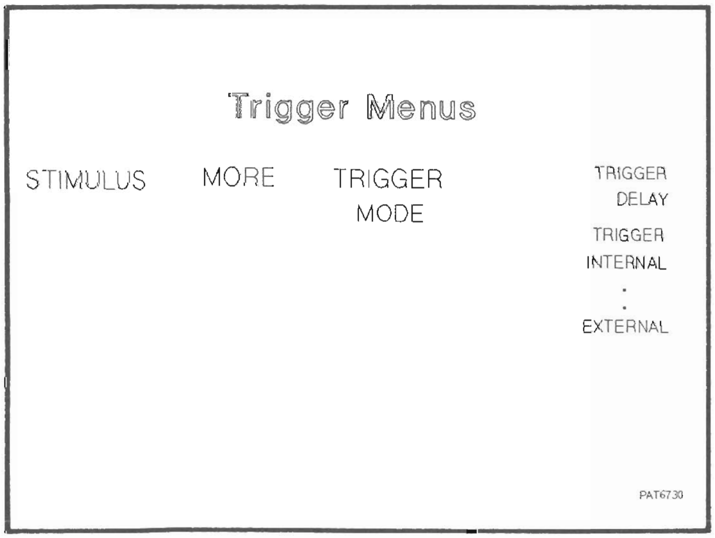
Trigger Menus

STIMULUS
MORE

HOLD
SINGLE
NUMBER of GROUPS
CONTINUAL
TRIGGER MODE
EDIT LIST
COUPLED CHANNELS
UNCOUPLED CHANNELS

PAT6729

To access the new trigger functions, press the TRIGGER MODE softkey which appears in the second level of softkeys under the STIMULUS menu. The external trigger is part of the standard system (with firmware revision HP 8510B.05.00) and does not require the Option 008.



Trigger Menus

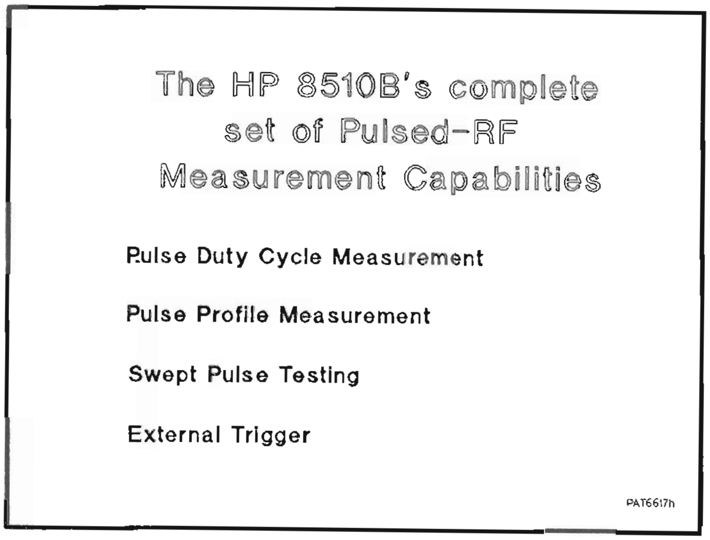
STIMULUS
MORE
TRIGGER MODE

TRIGGER DELAY
TRIGGER INTERNAL
.
.
EXTERNAL

PAT6730

TRIGGER DELAY -- When using Wideband Detectors, with either Internal or External Triggering, the actual measurement point can be delayed up to 40 milliseconds after the trigger.

TRIGGER: Internal or External -- this selects the trigger mode, Internal is the default setting.



The HP 8510B's complete set of Pulsed-RF Measurement Capabilities

Pulse Duty Cycle Measurement

Pulse Profile Measurement

Swept Pulse Testing

External Trigger

PAT6617h

The ability to measure both amplitude and phase under pulsed-RF conditions will enable the designers and manufacturers of microwave systems to better understand their devices. The choice of Pulsed-RF Duty Cycle, Pulse Profile and Swept Frequency Pulse testing plus all the traditional HP8510B measurement capabilities allows the user to select the optimal mode for their measurement problem.

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Naegeli, A. H.; "Simulation and Analysis of I*Q Vector Modulation for Testing of Modern Microwave Systems", HP RF & Microwave Measurement Symposium, April 1987.

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