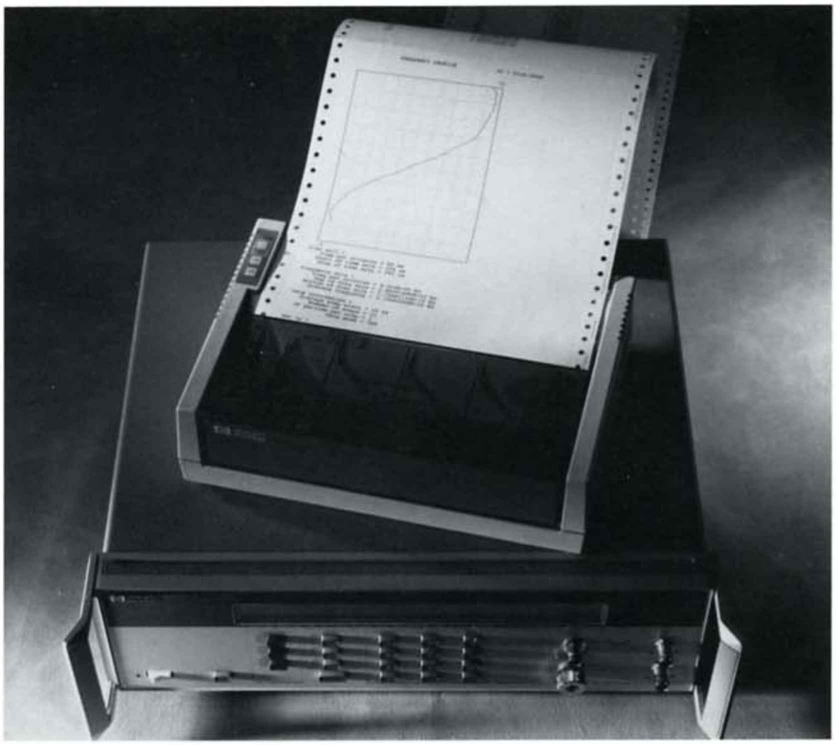
HEWLETT PACKARD

Application Note 377-4

Frequency and Phase Profiling Simplified with the HP 5361B Pulse/CW Microwave Counter



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Introduction

The HP 5361B Pulse/CW Microwave Counter is a multi-function microwave counter used to quickly and easily measure both static signals such as a signal from a stable local oscillator and dynamic signals found in pulsed radars. Other dynamic signals include VCO/DTO settling time, modulation on transponders, and frequency agile communications. Previously, characterizing these signals has been expensive and difficult because this could only be done with a custom solution involving several instruments and much custom software. Now the HP 5361B provides a much easier way to characterize your dynamic signals.

Frequency Profiling

Frequency profiling is useful in applications such as measuring the unintentional frequency modulation that degrades performance. This could be a radar pulse that is modulated by a switching power supply, or the switching transient of a voltage controlled oscillator (VCO). Frequency profiling shows you the change in frequency vs. time for a signal with respect to a reference mark in time. This reference is usually the beginning of the pulse for a pulsed microwave signal.

When a printer is added to the HP 5361B, frequency profiling is easy. Just connect the printer (see figure 1), your signal and press the PROFILE key. The complete instructions for this procedure are on the Quick Reference Guide, which can be attached to the top of the counter.

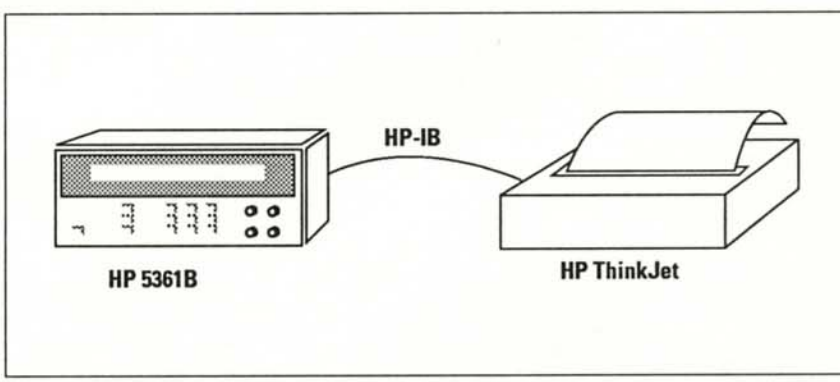


Figure 1: Setup for frequency profiling.

Single Channel Phase Profiling

Phase profiling is useful in applications such as measuring the phase response of components, or the linearity of a radar chirp. The phase response of a bandpass filter can be measured by sending a microwave pulse through the filter and profiling the phase. A radar chirp should have the inverse phase characteristics of the matched filter. A linear chirp will produce a parabolic phase progression, which can be measured with phase profiling. This is sometimes a more direct method of analyzing your radar chirp than measuring the frequency profile or side range lobes.

Phase profiling shows you the change in phase vs. time with respect to a reference mark in time. This computation requires a phase reference, and is easier to perform if the reference is derived, rather than using an external reference. The HP 5361B can perform this measurement on a single channel (single channel phase profiling), with a computer and a program, that derives the phase reference from the measured signal. The program can be requested free of charge with the enclosed reply card.

The HP 5361B, HP 9000 series 200/300 computer and the program are all that is needed to make single channel phase measurement from 500 MHz to 40 GHz (see figure 2). This measurement capability is often all the phase accuracy and resolution you need. For more demanding applications, a modulation domain analyzer (such as the HP 5372A) or network analyzer may be needed. The modulation domain analyzer can provide single shot data and the network analyzer provides higher phase resolution.

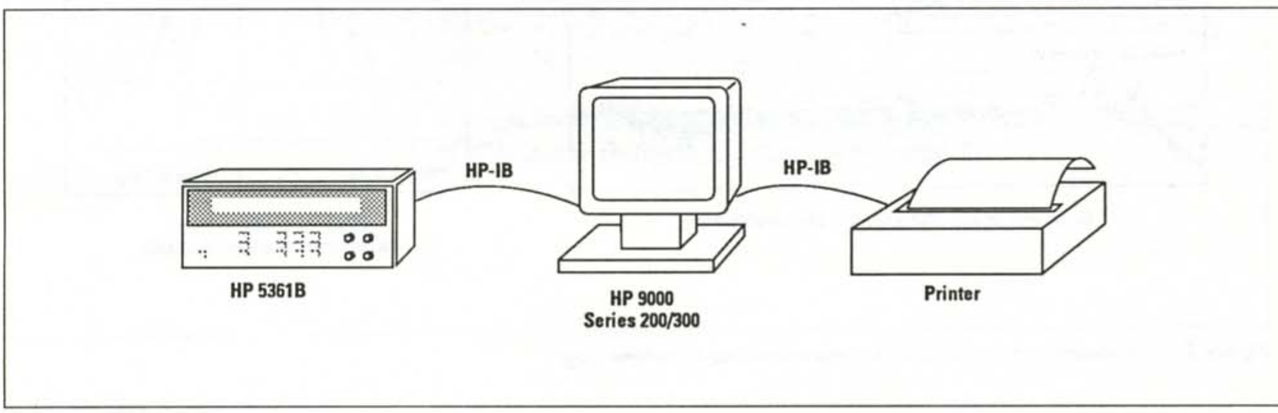


Figure 2: Setup for phase profiling.

Get More Insight into Your Signals with the Sample Program

This note describes the operation of the HP 5361B and how to take advantage of its added measurement capability for more insight into your signals. The BASIC language program that can be ordered with the reply card, demonstrates an implementation of measuring phase. It illustrates the basic procedure for calculating phase and can be used as a starting point for more focused applications. The program should be modified to take full advantage of the measurement capability and flexibility needed in your application.

Profiling Shortens Troubleshooting Time and Design Cycles

Profiling is becoming more important as demands increase on radar, EW, transponder, and communication equipment. Unwanted frequency/phase modulation on a pulse (UMOP, UFMOP or UPMOP) degrades performance. For example, if the linearity of a chirp deviates too much from the desired characteristics, the range side lobes will be out of spec (see figure 3). Characterizing frequency transients, modulation, and linearity is key to lowering costs and increasing performance in future systems.

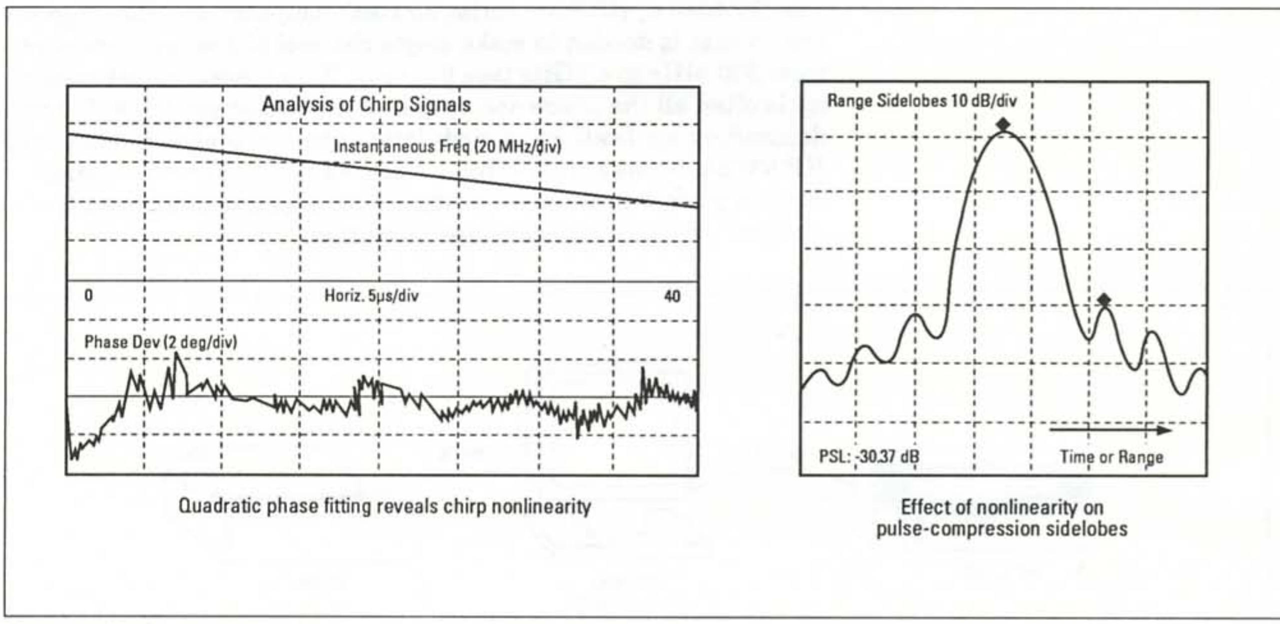


Figure 3: Nonlinearities in a chirp cause range sidelobes to become larger.

Standard pulse microwave counters measure the average frequency of a microwave pulse, but extra equipment and a program are required to determine the change in frequency as a function of time inside the burst (frequency profile). Also, the traditional pulse microwave counter can not phase profile.

When frequency or phase profiling is not done, you may not be getting the most from your design. Unfortunately, measuring frequency transients has always been a slow and difficult process. Today, the HP 5361B eliminates extra equipment for frequency profiling, and reduces the process to the simple press of a button. Measuring phase has been possible, but it has required an expensive network analyzer. Phase profiling is now possible with a counter and a computer, reducing the cost drastically.

Testing Phase Delay Is Quick and Easy
(Phase Profiling Example)

Testing a device such as a bandpass filter is simplified with the HP 5361B and a computer. A microwave pulse that is centered in the middle of a bandpass filter has no phase transient when it is sent through the filter. The center plot in figure 4 shows the signal changing less than 2.5 degrees. When it is slightly off center, it will have a phase transient, as shown in the top and bottom plot in figure 4. The initial phase transient in the top plot overshoots to 28 degrees, then settles to 22 degrees of phase change.

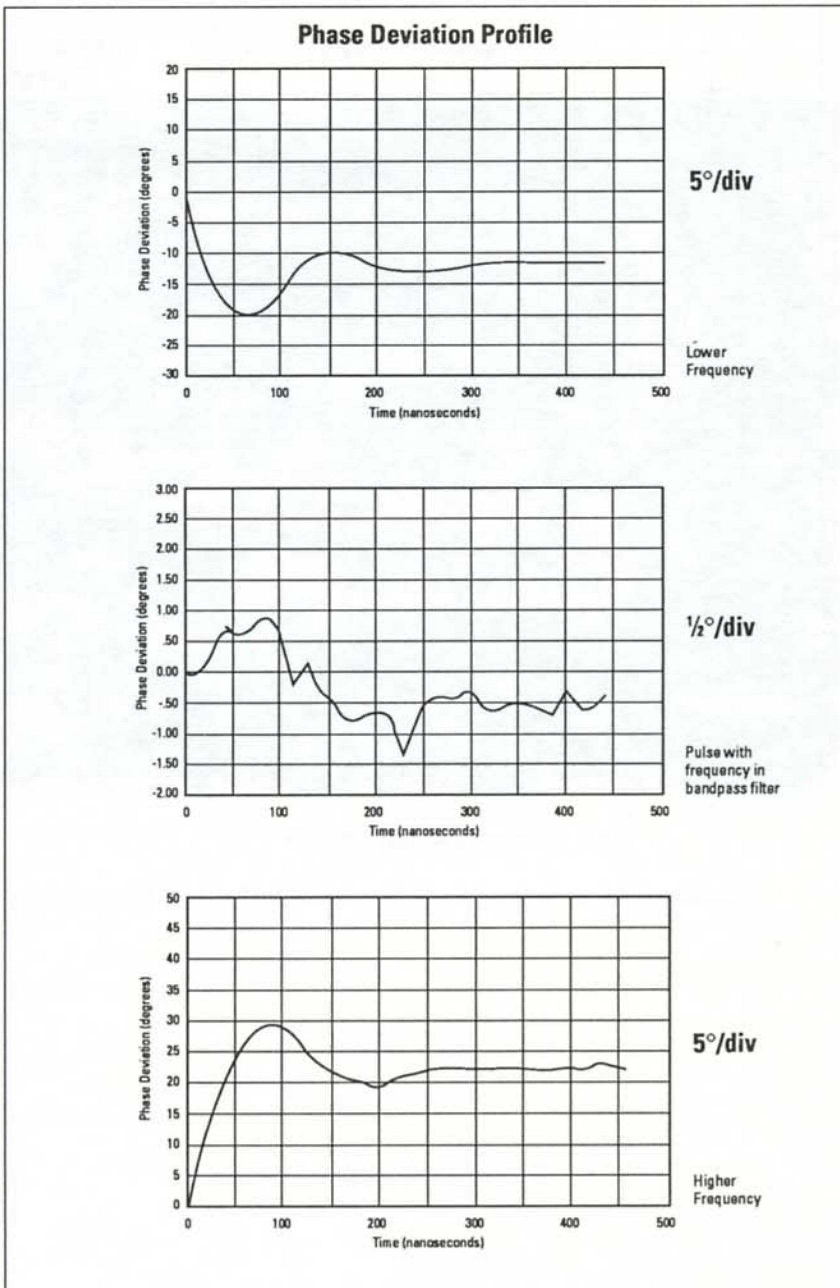
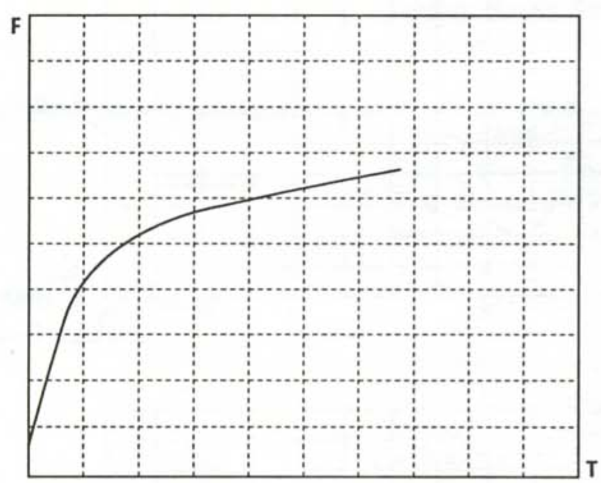


Figure 4: Phase profiling a filter excited with three different microwave pulses.

Troubleshooting Older Designs Is Quick

(Frequency Profile Example)

Turn on transients can be discovered quickly with the aid of the HP 5361B's built-in profiling. Frequency profiling is as easy as connecting the printer, connecting your pulse microwave signal, and pushing the profiling key. CW signals still need an external gate to define the boundaries of the profile. Figure 5 shows an actual turn on transient of a 13.45 GHz oscillator as measured and recorded by the HP 5361B. The pulse drifts 450 kHz within 2 µs, a difficult measurement to make without frequency profiling.



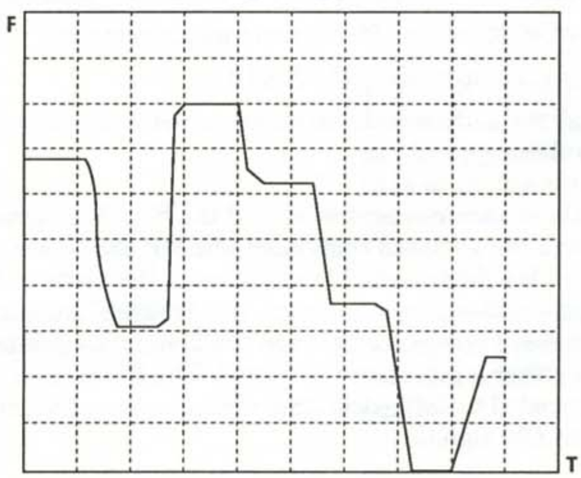
Time per Division = 1000 ns
Freq per Division = 1.0E+05 Hz

Time axis:	
Start of time axis	= 0 ns
Stop of time axis	= 10000 ns
Frequency axis:	
Top of freq axis	= 1.3451578825E+10 Hz
Bottom of freq axis	= 1.3450578825E+10Hz
Average frequency	= 1.3451101900E+10 Hz
Gate Information:	
Average step width	= 127 ns
Number of steps	= 51
IF periods per step	= 9
Starting IF period	= 0
Gate mode	= INT
Number of averages	= 3000
Set up: Resolution	= 1 Hz
Offset	= OFF
Scale	= OFF
Filter status	= ON

Figure 5: Single key measurement made by an HP 5361B showing a turn on transient.

Innovative New Designs Are Easy to Measure
(Frequency Profile Example)

Built-in profiling makes it easy to experiment with new designs. For example, we know that various parts of a target reflect radar pulses differently. These differences can be used to identify a target (Radar Cross Section, RCS). But measuring the intentional Frequency Modulation on the Pulse (FMOP) on a signal with intra-pulse frequency hopping can be a tedious, expensive task. With the HP 5361B, pulses with this FMOP are easy to measure and graph. Figure 6 shows the output of the HP 5361B when measuring a 5 µs pulse with hopping frequency modulation.



Time per Division = 500 ns
Freq per Division = 5.0E+06 Hz

Time axis:

Start of time axis	= 0 ns
Stop of time axis	= 5000 ns

Frequency axis:

Top of freq axis	= 7.29985837E+08 Hz
Bottom of freq axis	= 6.79985837E+08 Hz
Average frequency	= 7.02340149E+08 Hz

Gate Information:

Average step width	= 97 ns
Number of steps	= 48
IF periods per step	= 7
Starting IF period	= 0
Gate mode	= INT
Number of averages	= 3000

Set up: Resolution	= 1 Hz
Offset	= OFF
Scale	= OFF
Filter status	= OFF

Figure 6: Measuring a pulse with agile modulation is easy with the HP 5361B. This signal was created on an HP 8791 Model 200 Frequency Agile Signal Simulator (FASS).

A Useful Tool for Frequency and Phase Characterization

The HP 5361B is the first full function microwave counter that is designed for today's dynamic signals and measurement needs. From precision 1 Hz resolution in the CW Mode to high resolution pulsed RF measurements, it exceeds the requirements of most of today's radars and components. But more importantly, it adds capability that addresses measurement needs for future products. The HP 5361B frequency profiles a pulsed RF signal with no additional equipment and then outputs a plot and tabular data to a printer. It also provides data over HP-IB to a computer for phase deviation measurements. This new measurement capability provides the following features that make these measurements easy and cost effective:

- Single command to complete phase and frequency profiles.
- Single command for up to 100 separate measurements.
- Only one instrument needed (HP 5361B).
- High throughput, only completed measurements are transferred to the computer.

Window Your Profile with Programming and the External Gate

When used with an external controller and the BASIC program available through the enclosed reply card, the HP 5361B automatically acquires all the data needed to reconstruct the phase of a signal over a programmed time interval. For example, the counter can be programmed to measure between the 2 and 5 µs points. This can be done on either a pulsed or CW signal. The External Gate Mode input is needed to define the time window over which the profile occurs on CW signals.

When either the PROF (Profile Frequency) or PROFTIME (Profile Time) command is invoked, the counter will begin a process of measuring and accumulating the time of the zero crossings of the Intermediate Frequency (IF). The signal being measured is down-converted to the IF inside the HP 5361B. These series of measurements are stored in memory and later used for calculating frequency versus time when PROF is issued. When PROFTIME is sent to the counter, the raw unprocessed data is transferred back to the computer. The phase of the original signal can be reconstructed in the computer with a few more parameters such as the number of averages, and IF periods per step. These are readily available at the end of the measurement.

Built-in Profiling Improves Accuracy

Accuracy for frequency measurements is impacted by both random and non-random errors. Typically non-random error is by far the largest. Built-in profiling greatly reduces non-random error in the gating process, providing improved accuracy over an externally gated measurement. You will find in some cases that accuracy can be ten times better than the specification indicates in the datasheet.

The Measurement Process for Phase Profiling

This section will provide you with more knowledge of the HP 5361B measurement process. The focus will be on making and understanding phase profiling measurements. Frequency profiling is much simpler and is covered adequately in the manual, although most of the following information will be applicable.

An internal digital counter generates the gate that opens on the 2nd IF period. The end of the gate is variable and is increased to measure larger and larger segments of the signal (see figure 7). The actual measurement is the duration on an integral number of IF periods. Up to 100 separate measurements are made, which are sent to the computer for phase calculations. After the data has been collected, the phase of the original signal can be reconstructed inside the computer.

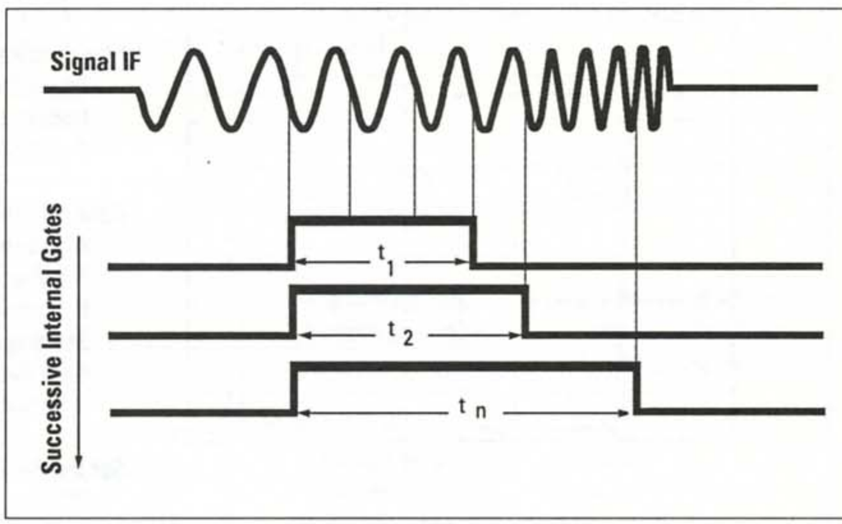


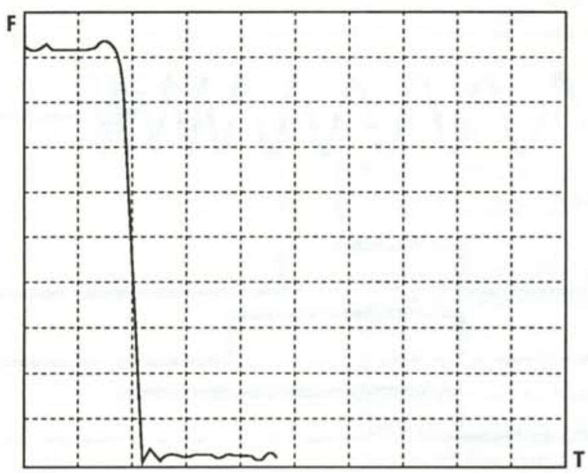
Figure 7: The internal gate is stepped through the measurement window, measuring integral IF periods.

Phase Resolution Is Increased by Averaging

The data stored in counter's memory are the values of time for each step (an integral number of IF periods), using the beginning of the pulse or external gate as a reference. For example, 50 steps will yield 50 time values in memory. Measurements are averaged to achieve higher resolution, and averaging is set easily by increasing the requested frequency resolution of the measurement. The HP 5361B will automatically average up to 3000 measurements for each data point. The time in memory is not the actual time of the zero crossing, but the actual time multiplied by the number of averages. The counter nominally takes 50 data points over the profile interval, and the average IF period is typically 14 ns. If the profile interval is larger than 700 ns (50 x 14 ns) there may be more than one IF period per data point. This means that the values in memory are: (average IF period) x (# of IF periods per step) x (# of averages).

Average Time Resolution Can Be 14 ns, Even on Long Measurements

The HP 5361B has the capability of stepping one IF period per data point. The period of the IF can vary from 10 to 22 ns, and is typically 14 ns. This allows resolving phase changes over very small time intervals. If fine time resolution is required, the stop and start times can be adjusted so that (stop time - start time) ≤ 700 ns. This means each step will be a single IF period. Figure 6 (page 9) shows an agile intra-pulse signal, measured with a 97 ns average step width. Figure 8 shows the capability of the HP 5361B and how you can zoom in on the transition of an agile frequency inside a pulse and receive a 14 ns average step width.



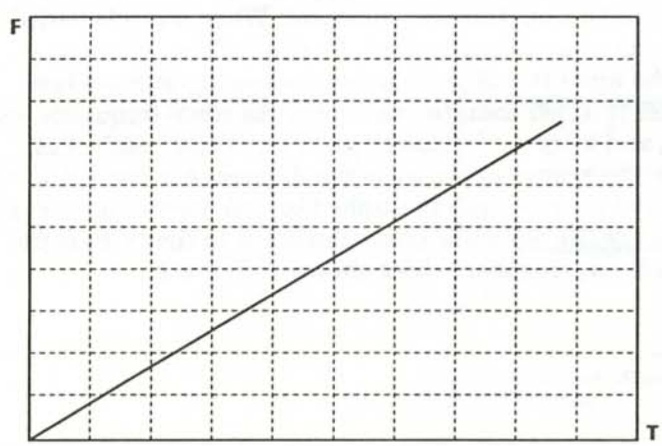
Time per Division = 100 ns
Freq per Division = 2.0E+06 Hz

Time axis:	
Start of time axis	= 499 ns
Stop of time axis	= 1499 ns
Frequency axis:	
Top of freq axis	= 7.15579578E+08 Hz
Bottom of freq axis	= 6.95579578E+08 Hz
Average frequency	= 7.02643039E+08 Hz
Gate Information:	
Average step width	= 14 ns
Number of steps	= 36
IF periods per step	= 1
Starting IF period	= 41
Gate mode	= INT
Number of averages	= 3000
Set up: Resolution	= 1 Hz
Offset	= OFF
Scale	= OFF
Filter status	= OFF

Figure 8: Zoom in on a frequency transition in a pulse, from 499 ns to 1499 ns by setting the start and stop times.

Single Channel Phase Deviation Measurements

Most instrumentation that measures phase uses a reference to compare against the test signal. The technique in this program can derive the phase reference from the test signal itself and therefore works even when a reference is not available. When the reference is known, it can be entered. The program determines the average frequency of the signal, and uses this to derive the phase reference. For example, a linearly chirped pulse that starts low in frequency and goes high will have an average frequency that is midway between the high and low frequencies. When this is used as a reference, frequencies below the midpoint will appear to have a negative slope on the plot. The phase plot will decrease, while the slope becomes more positive, until the signal reaches the average frequency. At the average frequency (middle of the pulse) the slope will be zero (the phase deviation of the average signal zero), and the slope will go positive. Figure 9 shows the frequency profile of a linear chirp and figure 10 (next page) shows the phase profile of this signal, as it was just described.



Time per Division = 500 ns
Freq per Division = 2.0E+06 Hz

Time axis:	
Start of time axis	= 0 ns
Stop of time axis	= 5000 ns
Frequency axis:	
Top of freq axis	= 2.010443782E+09 Hz
Bottom of freq axis	= 1.990443782E+09 Hz
Average frequency	= 1.998063151E+09 Hz
Gate Information:	
Average step width	= 73 ns
Number of steps	= 54
IF periods per step	= 5
Starting IF period	= 0
Gate mode	= INT
Number of averages	= 3000
Set up: Resolution	= 1 Hz
Offset	= OFF
Scale	= OFF
Filter status	= ON

Figure 9: Frequency vs. time plot of a linear chirp.

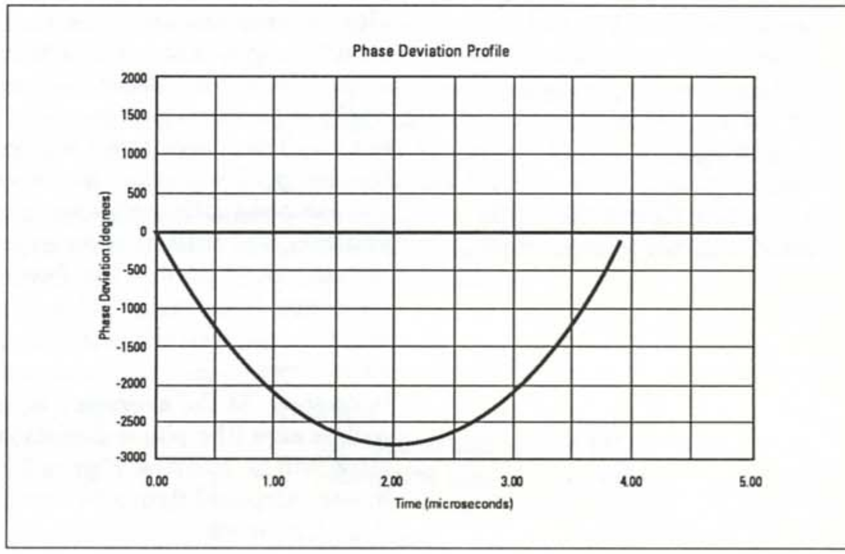


Figure 10: Phase vs. time plot of a linear chirp.

As discussed earlier, the time of integral periods is measured, and phase is computed from this measurement. When a single period of a lower frequency is subtracted from a period of the reference frequency, the number will be negative, indicating that the test signal's phase is larger than the reference. An equal frequency will yield a zero, and a higher frequency gives a positive result. Put another way, the phase difference is the difference in time, divided by the period of the reference multiplied by 360 degrees (or 2 Pi for Radians). Notice the parabolic phase deviation in figure 10 is the result of the linear frequency chirp shown in figure 9.

Limitations

Phase Change Must Be Band-limited

A phase change can also be looked at in the frequency domain. Frequency is the derivative of the phase with respect to time ($d\phi/dt$ = Frequency). The phase of the test signal is measured reliably so long as the rate of change of the phase doesn't produce frequencies greater than the IF bandwidth of the counter. The IF bandwidth in the auto-acquisition mode is 10 MHz, and 50 MHz in the manual-acquisition mode.

This is not a problem in most linear applications. Certain types of phase shift keying may give inconsistent results if the transition time from one phase to another is too abrupt.

Phase Error Increases with Frequency

Phase measurements require precise time measurements and coherent phase noise degrades the quality of the measurement. The HP 5361B down-converts the signal by sampling, so any phase noise associated with the down conversion process is multiplied by the harmonic number. The higher the frequency, the greater the effect of the noise. At the highest frequencies (40 GHz) the error in phase can be approximately 40 degrees rms. Lower frequencies and small time or profile windows will reduce these errors substantially. As a general rule, you can expect about 1 degree rms of error per 1 GHz.

Maximum and Minimum Profile

The minimum profile is 100 ns. The maximum profile is 10 ms, but larger profiles can be measured by stepping the external gate through the pulsed/CW signal under test. Note, the external gate must be terminated before the end of the pulse, or an error will result.

Advanced Applications

Identically to the frequency profiling function, phase profiling can use Extended Functions to set up the data collection. A review of these functions will help in tailoring the measurement to your needs.

Ext Funct 81	Set Start Time Of Profile
Ext Funct 82	Set Stop Time of Profile
Ext Funct 83	Set Data Points to Coarse (10 Nom) or Fine (50 Nom)
Ext Funct 87	Set Number of Data Points (1 to 99)
Ext Funct 88	Set Start by IF Period
Ext Funct 89	Set Step Size by IF Period(s)

Extended Function 82 will not let the stop time be set beyond the end of the pulse. This may restrict your ability to measure all the way to the end of the pulse. This can be circumvented by setting the stop time limit by using Extended Function 90, which allows the stop edge to be set closer to the end of the pulse.

Monitoring the Gating Process with an Oscilloscope (Optional)

As the HP 5361B goes through the measurement process, the changing gate width can be monitored on an oscilloscope by connecting the Scope-View output from the counter to any 100 MHz oscilloscope (see figure 11). This provides you with visual feedback of the measurement process. If the process happens too rapidly, increase the resolution of the measurement to 1 Hz. This will make the counter take more measurements at a particular gate width.

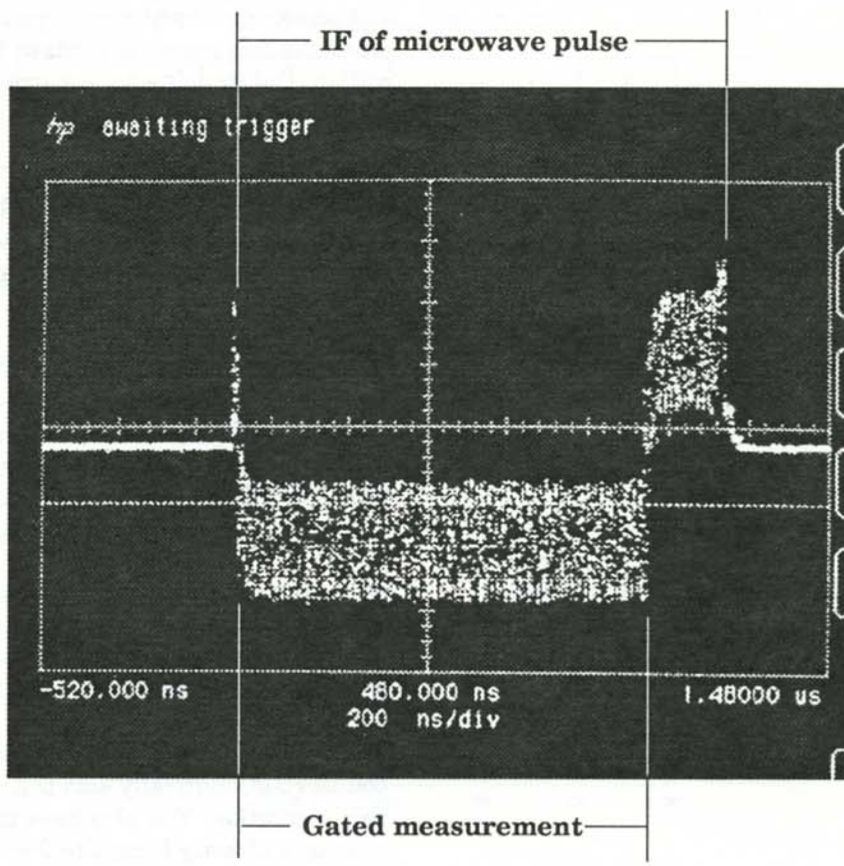


Figure 11: Scope-View output, showing IF of pulse and gated measurement.

Program Description

This program is designed as a starting point for a detailed solution. But for many applications, the program will be a useful tool for gathering quick phase information on your microwave signal. It prompts you for setup conditions that make the measurement more meaningful. Here is a description of the options and how they can be customized for your measurements.

The Graph

The program asks if you are using a series 300 computer. This information is required so that the plot will be properly scaled for the screen and hardcopy. If you are using a series 300 computer and want the full screen to contain the plot, you can select the "N" option. But in doing so, the printer will not be able to reproduce the full plot.

The Frequency Band

If you are using an HP 5361B Option 040, you will see the prompt, "Hi freq band is 12 GHz to 40 GHz, Low freq band is 0.5 GHz to 29 GHz". You will need to input the band of operation as "L" or "H". The standard HP 5361B and Option 026 do not give you this prompt.

Extending Your Bandwidth

The next prompt will ask, "Do you want to set the manual center frequency?" This may be needed if the frequency deviation exceeds 10 MHz peak to peak. The default is to program the counter to AUTO mode, and it will acquire and center the signal for subsequent profile measurements. Responding "Y" (yes) to this prompt will allow you to enter the center frequency in GHz.

Profiling CW Signals

"Do you want to set the 5361B to EXTERNAL gate mode?" CW signals require the EXTERNAL gate mode on. The externally applied gate will define the time window for the profile. For pulsed signals, an external gate is not needed but can still be used.

Setting the Resolution

"Select Resolution" requests you to set the desired resolution. The counter automatically sets the number of averages needed to obtain this resolution. You also have the option of setting the number of averages directly from 1 to 9999.

Profile a Segment of Your Signal

"Do you want the entire width to be profiled?" A "Y" answer to this prompt causes the counter to profile the entire pulse width for pulsed signals or the entire time window for externally gated signals. A "N" answer will allow you to set the start and stop times for the profile. Time zero is defined as the beginning of the pulse or the external gating signal. The times are in microseconds, and the actual measurement is generally within 20 ns of the programmed time.

The Reference Frequency

"Do you want to enter a reference frequency?" A "N" causes a reference to be internally generated from the average frequency. This generally causes the initial and final phase measurements to be close to zero. For measurements with known carrier frequencies, you can input this value. This is valuable when characterizing the phase settling of a phase locked loop or an agile source. A slope to the phase deviation plot illustrates the difference between the reference frequency and the measurements.

After plotting the data, you can press continue to run the program again. The program will give you the opportunity to change the start and stop time for the phase profile measurement. Pressing run after the plot will cycle back to the top of the program and will allow you to re-enter new data.

References

Phase Digitizing: A New Method for Capturing and Analyzing Spread Spectrum Signals, by David Chu. HP Journal, February 1989, page 28, vol. 80 number 1.

Intrapulse and ELINT System Design, by P. Michael Gale. Journal of Electronic Defense, October 1989, page 87.

Software Request

Please send me a free 3-1/2" diskette containing the three HP BASIC Software programs:

Profiling Radar Pulses
Characterizing VCO's
Phase Profiling

My immediate concern is:

- ☐ Radar Pulse Characterization
- ☐ VCO Characterization
- ☐ Frequency Profiling
- ☐ Phase Profiling

NAME	*TITLE*
COMPANY	*DIVISION*
ADDRESS	*BLDG. & MAILSTOP*
CITY	*STATE* *ZIP*
PHONE	*EXT.*

My primary areas of responsibility are:

- ☐ Research and Design
- ☐ Production / Manufacturing
- ☐ Service
- ☐ Test / Inspection
- ☐ Other ____________________

I am personally involved with:

- ☐ Radar
- ☐ Ground Support
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- ☐ Communications
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- ☐ Other ________________

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