Errata

Document Title: Characterizing Chirp Coded Modulation in Radar Systems (AN 358-11)

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HP References in this Application Note

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Application Note 358-11 Characterizing Chirp Coded Modulation in Radar Systems

HP 5372A Frequency and Time Interval Analyzer

Description

Pulse compression techniques are often used in modern radar systems in order to effectively increase transmitted power while, simultaneously, improving range resolution. Pulse compression is achieved by transmitting internally modulated pulses. Returns are then compressed by decoding the modulation. Among the commonly used techniques are linear FM modulation, referred to as chirp, and binary phase modulation, most commonly some form of Barker code.

Problem

Internally modulated pulsed radar signals are difficult or impossible to analyze using instrumentation such as oscilloscopes and spectrum analyzers. Vector modulation analyzers, such as the HP 8981A, are useful but they require that a repetitive signal and a coherent local oscillator be provided and do not allow the study or comparison of individual pulses. Also, it is often desirable to have data available in a digital form directly suited to advanced processing such as the study of sidelobes.

- *Single–shot capture of an uncompressed pulse*
- *Demodulates both chirp and Barker modulated signals*
- *Display either frequency or phase versus time*
- *Digital data available for advanced processing and problem solving*

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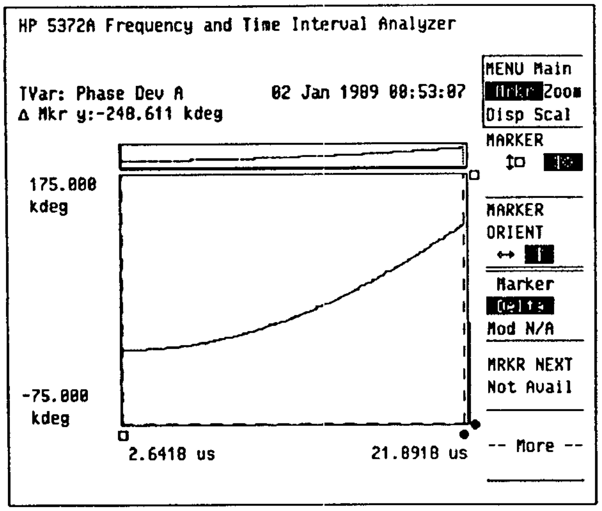

Figure 1. Phase as a function of time for a frequency–linear chirped radar pulse.

HP 5372A Frequency and Time Interval Analyzer

Solution

The HP 5372A Frequency and Time Interval Analyzer is well suited to measuring the frequency and/or phase characteristics of both chirped and phase (eg. Barker) coded radar pulses as a function of time. Many of the important characteristics of such signals are revealed in an easy to understand format on a single graphic display such as shown in Figure 1. Built–in analysis and display features allow quick quantitative measurements. More advanced analysis can be carried out using a computer.

This note explains how to measure and analyze a chirped radar signal. The signal used for the measurements was generated in minutes using the HP 8791 Model 10 Frequency Agile Signal Simulator and the HP 8791 Model 200 Radar Simulator. All of the measurements illustrated in this note were taken on a single–shot basis.

- *Single–shot capture of an uncompressed pulse*
- *Demodulates both chirp and Barker modulated signals*
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Measurement Considerations

In order to properly set up the HP 5372A to measure the frequency and phase changes over time of a chirped signal, there are several considerations. These include total measurement time, sampling rate, number of measurements, desired phase resolution, carrier frequency, input signal levels, arming mode, and the type of phase display desired.

Also, in this application note, we will assume that the radar can provide an arming signal coincident with the start of a pulse. This is not absolutely necessary because the HP 5372A provides many arming and sampling modes in order to suit the instrument to most any situation. It is, however, usually a simple matter to provide an arming signal related to the start of a pulse.

The equipment arrangement for a typical radar transmitter is shown in Figure 2. Be certain to provide sufficient attenuation to prevent damage to the HP 5372A. The HP 5364A Microwave Mixer/ Detector will normally be required since most radars operate above the 500 MHz range of the HP 5372A's A and B Channels. (The phase deviation measurement is not available for Channel C.) The HP 5364A can also be used to obtain improved phase resolution. This is discussed below.

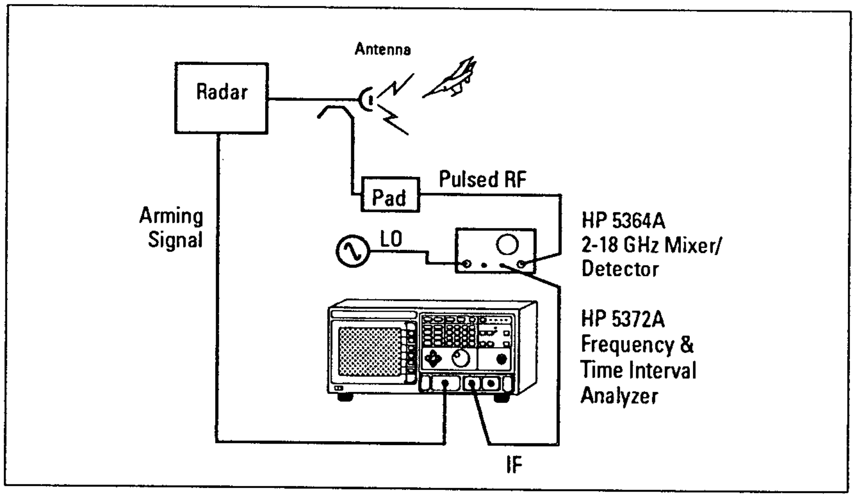


Figure 2. Typical equipment setup for measuring a chirped radar pulse.

Total Measurement Time

What is the time over which you need to measure the signal? Usually, this will be determined by the width of the transmitted pulse. You may, however, wish to capture more than a single pulse and you would increase the time accordingly. This example is based on a single chirped pulse of 20 μs duration. The start frequency is 20 MHz and the stop frequency is 60 MHz.[1]

1 Actually, we are going to introduce some intentional non-linearity so the stop frequency will be somewhat less than 60 MHz.

Sampling Rate and Number of Measurements

You need to select a sampling rate and a number of samples to be collected. These considerations are closely related to the total measurement time by the relation:

Total Measurement Time = Sampling Interval x # Of Measurements [2]

The HP 5372A is capable of collecting up to 8000 (actually 8191) continuous phase measurements. It is also capable of sampling at intervals ranging from 100 ns to 8 seconds in 100 ns increments. If you want the best time resolution possible, you will want to sample as fast as possible. In this instance, make use of the approximate relationship:

Total Measurement Time/Sampling Interval < 8000

For a sampling intereval of 100 ns, if this holds true for your required total measurement time and if time resolution is important to you, then sample at 100 ns. If the relation doesn't hold then increase the sampling interval in 100 ns steps until it does.

Time and frequency resolution can be traded off. That is, longer sample intervals sacrifice time resolution (horizontal axis) for improved frequency resolution (vertical axis). When using the Interval Sampling mode (more later) setting the sampling rate is analogous to setting the gate time on a conventional frequency counter. Frequency resolution is inversely proportional to sample rate and the frequency measured. See Figure 3.

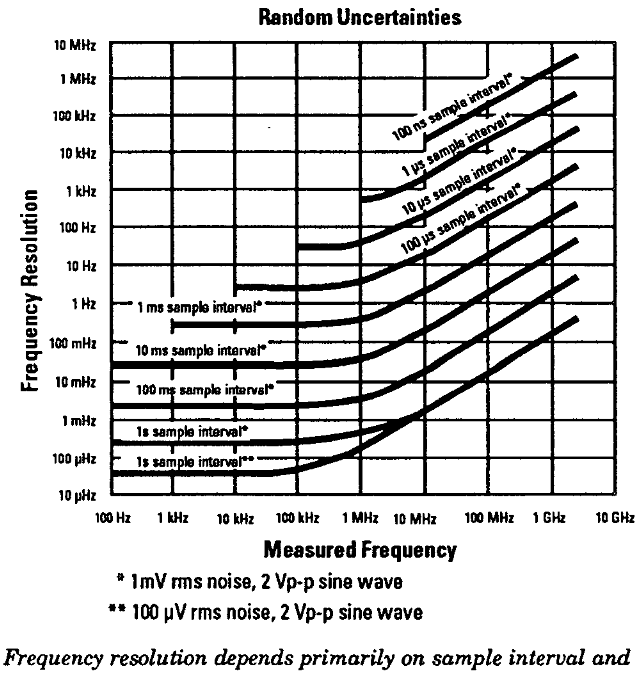


Figure 3. Frequency resolution depends primarily on sample interval and measured frequency.

2 This holds for a single pulse. The sampling technique used by the HP 5372A is paced by the signal. This means no data is collected if no signal is present. If you are looking at more than one pulse, you may need to divide by the duty cycle to get a better estimate of the total time.

Phase Resolution

Phase resolution may be very important in characterizing a chirped radar signal. The single–shot phase resolution of the HP 5372A is proportional to carrier frequency and is given by:

Phase Resolution = 200 ps x (carrier frequency) x 360 degrees

For example, the single–shot phase resolution when measuring a 500 MHz carrier is 36 degrees. For a 10 MHz carrier, the single-shot resolution is 0.72 degrees. Depending on the requirements of a particular radar system, phase resolution may determine the widest chirp which can be adequately measured on a single–shot basis.

Phase resolution can be improved using the HP 5372A's averaging features. This requires a repetitive signal and is not discussed in detail in this note. In general, averaging improves phase resolution in proportion to the square root of N where N is the number of averages. Even if it is necessary to average in order to achieve the necessary resolution on very wide chirps, the HP 5372A still offers the advantages of direct display of phase deviation and digital output for additional processing.

Carrier Frequency

There are several things to think about regarding carrier frequency. As indicated above, the lower the carrier frequency the better the single–shot phase resolution. For this reason, it is recommended that the radar signal be downconverted such that the chirp starts (or stops) in the vicinity of 10 or 20 MHz. The HP 5364A Microwave Mixer/Detector is available and well suited to this purpose.

A second consideration relates to the fact that what is going to be measured is actually phase deviation. That is, how does the phase vary from what one would expect of a perfect unmodulated carrier? This means that the carrier frequency must either be known or it must be measured prior to attempting a phase deviation measurement. In either event, it must be provided to the HP 5372A. In a very real sense, this is how the HP 5372A is able to decode phase without the need for a coherent reference source.

In the case of a chirped pulse, what is meant by the term carrier frequency? It is the frequency to which phase deviation is to be referenced. Choosing the starting frequency of a linearly increasing chirp displays phase deviation from minimum to maximum. Choosing the center frequency results in a symmetric display with minimum deviation at the center. Use the frequency which provides the display you desire.

Input Signal Levels

A voltage level and slope need to be selected in order to define the point at which the signal will be detected. The trigger level should be set to about the 50% point of the expected peak–to–peak input voltage to the HP 5372A. This level may need to be set higher particularly if you are looking at more than one pulse and there is noise present during the pulse off time.

Arming Mode

The HP 5372A provides a number of powerful arming modes. These allow you to control when the instrument starts and stops taking data. You also have control over how the data is taken. In general, you can specify when a block or group of measurements begins as a holdoff. How data is acquired within a block is specified as sampling. The HP 5372A also allows you to specify combinations of holdoff and sampling (Hold/Sample).

The measurement described in this note uses a mode referred to as Edge/Interval arming. This means that the HP 5372A will begin to gather data at the first event following receipt of a signal edge. (In the example, the edge will be specified to occur on the External Arm input, but it could also be Channel A or Channel B.) The HP 5372A will use a specified interval for each measurement. The process stops when the specified number of samples has been collected.

Phase Display

The HP 5372A can display phase as either cumulative or as modulo 360°. In the case of a chirp, cumulative phase is the most useful display.

Measurement Setup

General

If you are working with an HP 8791 Model 10 Frequency Agile Signal Simulator, set it up to generate a chirp ranging from 20 MHz to 60 MHz in 20 µs. In this example, the chirp was designed to be frequency linear over most of its range and to gradually flatten out toward the extreme so it never actually gets to 60 MHz.

If you are working with a real radar (or some other source) review the measurement considerations and modify the procedure accordingly. Refer to Figure 2 (on page 3) for guidance in connecting the equipment.

The first step is to examine the frequency profile of the pulse. This provides assurance that the signal is what's expected and allows determination of the starting frequency. The second step is to change the instrument setup and make the Phase Deviation measurement.

Function Menu

1. Setting Up the Frequency Measurement

Press the green **Preset** key in the middle right portion of the front panel. This returns the instrument to a known state and is recommended as the first step in setting up a new measurement. **Preset** automatically brings up the FUNCTION menu. You can also get this menu using the **Function** hardkey under MENU SELECTION. Press the **Single/Repet** key to set the HP 5372A for a single measurement.

Single causes the HP 5372A to acquire a single block of data and to retain it indefinitely for analysis. Pressing **Restart** will cause the instrument to collect another single block of data. Choosing **Repet** (repetitive) causes the HP 5372A to immediately acquire a new block of data once the previous block has been acquired and displayed. The LED next to the key is on when **Single** is selected.

Figure 4 (on page 8) shows the FUNCTION menu after **Preset** has been pressed. **Time Interval** will be selected as the current measurement. Change this to **Frequency** using the softkeys. If necessary press **--More--** until you see **Frequency** as an option. Move to the **Channel** field using the arrow keys and select **A** from the softkeys. You will need to press **--More--** to do this.

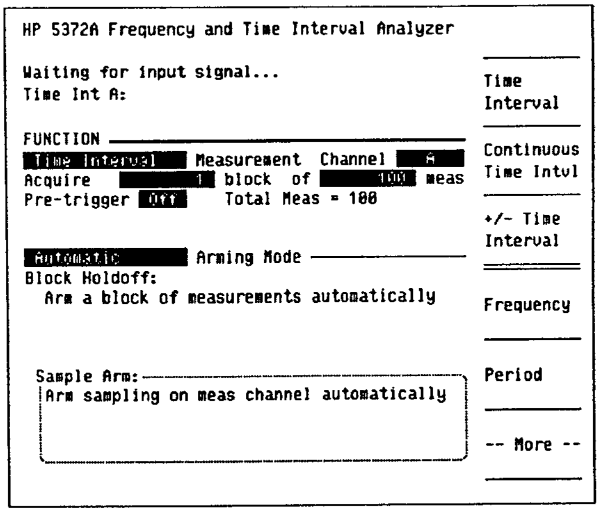


Figure 4. HP 5372A FUNCTION menu as it appears after pressing Preset.

2. Select the Number of Measurements and the Arming Mode

Insure that the **Acquire** field is set to 1 block and move to the "block of" field. Enter **160** in this field. Use the numeric keypad to do this and be certain to terminate the entry using the **Enter** key on the pad. Insure that the pre-trigger field is set to Off. Since a signal is available to synchronize the data acquisition with the beginning of a pulse, there is no need to look at data prior to this point. Therefore, pre-trigger is not required. The measurement will complete when the specified number of samples have been gathered.

Move to the Arming Mode field to specify how (when and how fast) the block of 160 measurements will be acquired. Notice the softkey selections when you highlight the Arming Mode field. The top softkey lets you select between three different groups of arming selections. You choose a group using repeated presses of the key.

The synchronizing signal edge will be specified as a holdoff arming condition to the HP 5372A. This signal is connected to the External Arm input as indicated in Figure 2.

In addition, it is necessary to pace the acquisition of frequency measurements by an interval. This is analogous to the gate time of a traditional counter. The key difference is that these sampling intervals, or "gates", are consecutive and thus provide continuous frequency profiling capability.

In general, the first word in an arming mode description which consists of two words separated by a "/" refers to the condition which will prepare the HP 5372A to take data. The second descriptor (following the "/") relates to how it will gather data once the specified condition has been met. For example, the term Edge in Edge/Interval indicates that the occurrence of an edge on Channel A, Channel B, or External Arm will set the instrument to take data.

The term Interval indicates that the HP 5372A will use the specified interval as a gate time. Single word descriptors (those not separated by a "/") such as Edge Holdoff or Interval Sampling imply that the other condition (holdoff or sampling) is automatic (as fast as possible).

Since a combination of holdoff and sampling conditions need to be specified in this example, press the top softkey until **Hold/Sample** is highlighted. You can now select **Edge/Interval** from the softkeys. You may need to press **--More--** several times to get the **Edge/Interval** choice.

Now set the Block Holdoff parameters to **Pos** and **Ext Arm** respectively. This specifies that the HP 5372A will not take data until after the occurrence of a positive edge on the External Arm input (as opposed to Channel A or B). The radar must supply an edge for this purpose. This edge must coincide with (or slightly precede) the beginning of a pulse.

Finally, in the **Sample Arm** field enter **100** using the numeric keypad. Note the choices that appear on the softkeys and terminate your entry by pressing **ns**. You have just told the HP 5372A to make all measurements using a 100 ns gate time (interval).

This completes the entries needed on the FUNCTION menu. The FUNCTION menu on your HP 5372A should now look similar to Figure 5. Note that the acquisition time for a block of data has been computed and is displayed at the bottom of the screen.

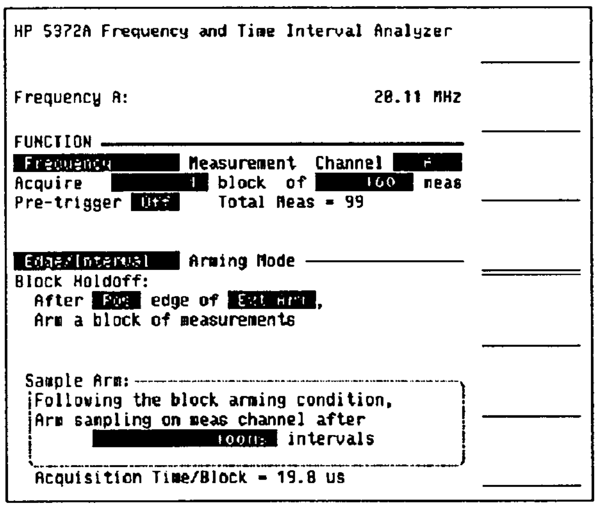
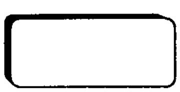


Figure 5. The completed FUNCTION menu shows selections for measurement type, block size, arming and sampling.

Input Menu



3. Specify the Input Conditions

Now set the input trigger levels, slopes and other parameters. Begin by pressing the **Input** hardkey under MENU SELECTION. Verify that the **Input Channels** field is set to separate. Move to the **Chan A** field and select **Pos** Slope, **Manual** Mode, and **0 volts** Level in that order. Since we are only going to use Channel A, the settings of Channels B and C can be ignored. You have now told the HP 5372A that you want to take data on positive zero crossings. You have set the trigger level manually to 0 volts.

For signals between 1 kHz and 200 MHz the HP 5372A can automatically determine the peak to peak signal level and set the trigger point to some specified percentage of that level. If you wish, you can use this method as an alternative to **Manual** Mode in this example. Simply select **Sgl Auto** and specify the percentage as, say, 50.

It is important to note that noise which is present during the off time of a pulsed signal can cause the HP 5372A to take data when you don't expect it to if you have the trigger level set at 0 volts. These kinds of problems can usually be solved by increasing the trigger level above 0 volts using either the manual or automatic technique. Attenuation and/or hysteresis can also be used to improve noise immunity.

Move to the Ext Arm Level field and set the level appropriately for the signal you intend to use. In our case, this can be left at 0 volts. If the LED above the Ext Arm input is not flashing, adjust the level until it does. The flashing trigger LEDs indicate that the signal is crossing the specified threshold.

Below the trigger fields are fields which set up the input pods. If you have the standard HP 54002A 50 ohm pods installed, these should read (for Channel A) :

Impedance: 50 Ω
Bias Level: GND
Attenuation: 1:1

This completes the entries in the INPUT menu. The display should resemble Figure 6. The HP 5372A is now ready to take data.

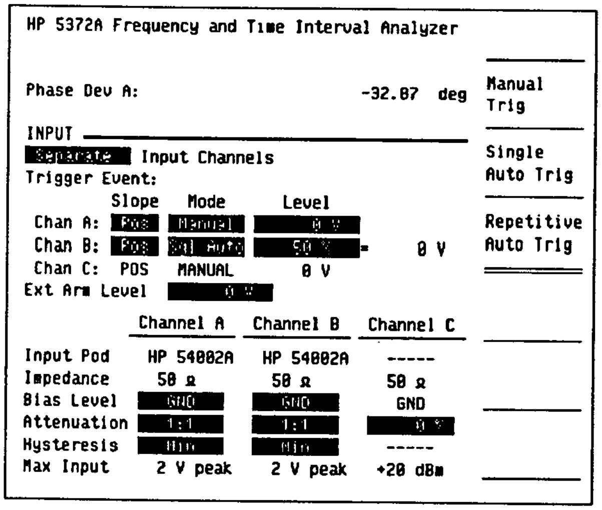


Figure 6. The completed INPUT menu shows the appropriate trigger threshold settings for Channel A and External Arm.

Measurement Results

Graphic Results

Press **Restart** to acquire a block of measurements. Press **Graphic** to get a display of the results. If you used **Preset** before setting up the HP 5372A you will see a histogram display. Set the menu to **Main** using the top softkey. Select **Time Var** using the second softkey. You are viewing a plot of frequency versus time. The result should appear similar to Figure 7.

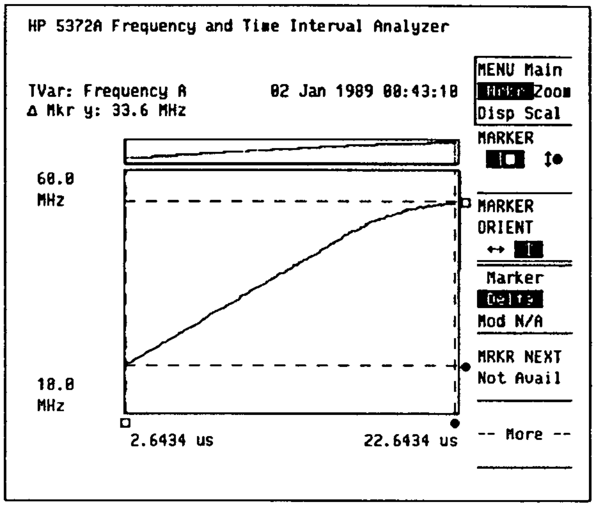


Figure 7. This plot of frequency versus time clearly shows the profile of a chirp which exhibits non-linear behavior.

Analyzing the Frequency Measurement

The next step is to use markers to measure the frequency range of the chirp.

The topmost softkey, labeled **MENU** provides access to menus which control the markers (cursors), display expansion (zoom), etc. Press this key a few times to get an idea of the options available.

Now use the key to highlight **Mrkr**. The five softkeys below the top now display some of the marker options available. Pressing **--More--** will bring up additional options. Select **MARKER ORIENT ↕** to activate the selections for the markers which can be positioned in the vertical, or up/down direction. You will notice a ↕● and ↕□ marker selection on the second softkey. Select the ↕□ marker using the second softkey. Use the knob to move the marker to the highest frequency of the chirp. Now position the ↕● marker at the lowest frequency of the chirp. Select **Delta** from the softkeys. You can now read the frequency range of the chirp in the upper left corner of the display. This is also shown in Figure 7.

Setting Up the Phase Deviation Measurement

The next step is to modify the setup for a Phase Deviation measurement. Use the **Function** hardkey to bring up the FUNCTION Menu. Use the arrow keys to highlight the measurement field and select **Phase Deviation** from the softkeys. Use **--More--** if necessary. This is the only change needed on the FUNCTION menu. There are no changes needed on the INPUT menu.

Now use the **Math** hardkey to bring up the MATH menu. This menu is used to enter the carrier frequency and to choose how Phase Deviation will be displayed. The HP 5372A is capable of displaying Phase Deviation as either cumulative or modulo 360°. In the case of a chirp, cumulative will be the proper choice as it avoids "wrap–around" on the display each time the phase progresses through 360 degrees. (See Application Note 358-10 for an example of using the modulo 360 phase display to characterize a Barker coded signal.)

Use the arrow keys to highlight the **Carrier Frequency** field. Press the **Compute Carrier Manual** softkey and enter the starting frequency of the chirp. In this example, it is 20 MHz. If necessary, move to the **Phase Result** field and set it to **Cumulative** using a softkey. Your MATH menu should now look like Figure 8.

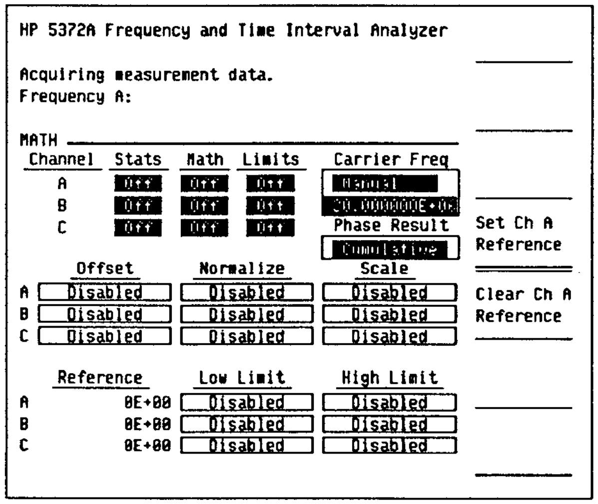


Figure 8. The MATH menu after entering carrier frequency and specifying type of phase display.

Making the Phase Deviation Measurement

Press **Restart** to acquire a block of data. Press **Graphic** to get a display of the results. You should now see a display of Phase Deviation versus time as shown in Figure 9. Since phase is the integral of frequency, the result is a parabola.

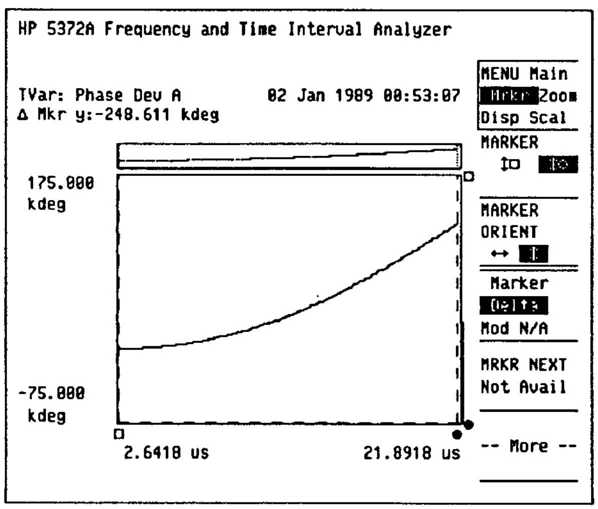


Figure 9. The phase deviation for a linear frequency chirp is a parabola.

Analyzing the Phase Deviation Measurement

You can use the markers to make simple measurements of the results. For example, you can estimate the width of the pulse using two ⟷ markers in delta mode.

The major benefit, however, is that phase deviation (from an un–modulated carrier) as a function of time is directly available for custom analysis.

Suggestions for More Advanced Analysis

If you frequently need to examine chirp modulated signals, it is worthwhile to write a short computer program to assist in the analysis. Any computer with an HP–IB (IEEE–488) interface can extract the Phase Deviation data from the HP 5372A for further processing.

The exact processing needed will depend on the nature of the chirp and the information needed to solve the problem at hand.

As an example, Figure 10 shows the result of fitting the data in Figure 9 to a parabola and then computing the difference between the fit and the actual data. The upper trace shows the actual data and the fit data overlaid. The bottom trace is a plot of the difference.

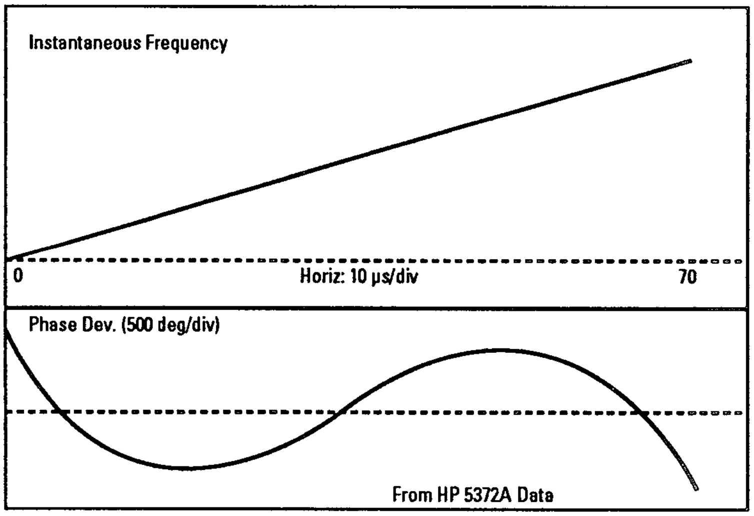


Figure 10. Result of fitting a parabola to the data and computing the difference.

This analysis may be most appropriate in cases where small deviations exist through the entire range of the chirp and the goal is to minimize phase differences over this range.

On the other hand, in this particular case, we know (or could easily determine) that approximately the first half of the chirp is linear in frequency. It might be more meaningful to determine the parabola from the data in the frequency linear portion of the chirp and compute differences from that information. This approach would avoid "distributing" phase differences over the range of the chirp.

In some situations, it may be desirable to capture more than one pulse in a single pass. This can be done by increasing the number of measurements taken.[3] By analyzing each pulse, it is possible to make comparisons and examine any intra–pulse effects which may be present.

Additional possible analysis might include using the Fourier Transform to examine the effects of phase differences on sidelobes.

[3] Remember, the HP 5372A will not waste memory taking samples between pulses when no signal is present.

HP 5372A Advantages

- Provides a solution for measuring chirp modulated signals single–shot.
- Allows rapid verification of start/stop frequencies and pulse width in a single measurement.
- Pre-processed phase deviation data is directly available for advanced analysis.

For Further Information

For more information on the HP 5372A Frequency and Time Interval Analyzer and the techniques discussed in this application note, please refer to the following publications.

Application Note 358-8 "Single-Shot BPSK Signal Characterization" (5952-8002)

Application Note 358-9 "Advanced Techniques for Measuring Complex Radar Signals" (5952-8003)

Application Note 358-10 "Characterizing Barker Coded Modulation in Radar Systems" (5952-8004)

HP 5372A Data Sheet/Brochure (5952-7997)

HP 5372A Getting Started Guide (5952-8009)

HP 5372A Condensed Reference and Specification Guide (5952-8012)

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