Errata

Document Title: Characterizing Barker Coded Modulation in Radar Systems (AN 358-10)

Part Number: 5952-8004

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HP References in this Application Note

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Application Note 358-10 Characterizing Barker Coded Modulation in Radar Systems

The 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 which is most often some form of Barker code.

Problem

Chirped and Barker coded 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 be provided and do not allow the study or comparison of individual pulses.

- *Capture an uncompressed pulse single shot*
- *Display either frequency or phase versus time*
- *Measure phase and time directly*

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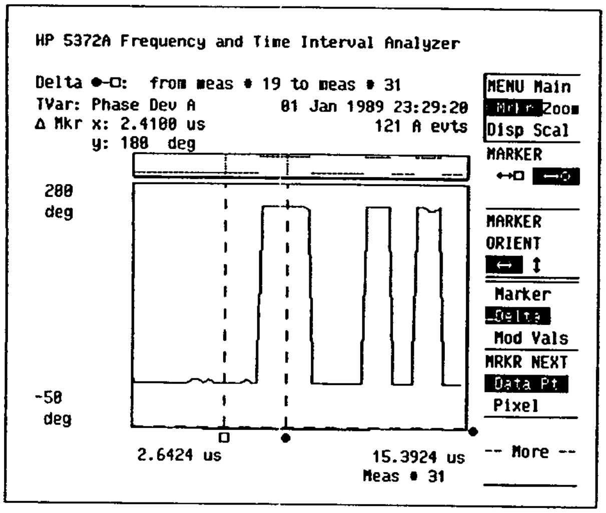

Figure 1. The HP 5372A lets you quickly and easily analyze complex radar signals, such as this 13 bit Barker modulated pulse.

The HP 5372A Frequency and Time Interval Analyzer

Solution

The HP 5372A Frequency and Time Interval Analyzer is well equipped to measure frequency and/or phase characteristics of both chirped and 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 similar to the example 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 Barker coded radar signal.

The signal used for the measurements in this note 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 acquired on a single–shot basis.

- *Capture an uncompressed pulse single shot*
- *Display either frequency or phase versus time*
- *Measure phase and time directly*

Measurement Considerations

In order to properly set up the HP 5372A to measure a Barker coded 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, 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 adapt 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 instrumentation. 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 used to decode Barker signals is not available for Channel C.) The HP 5364A can also be used to obtain improved phase resolution. This is discussed below under the subject of carrier frequency.

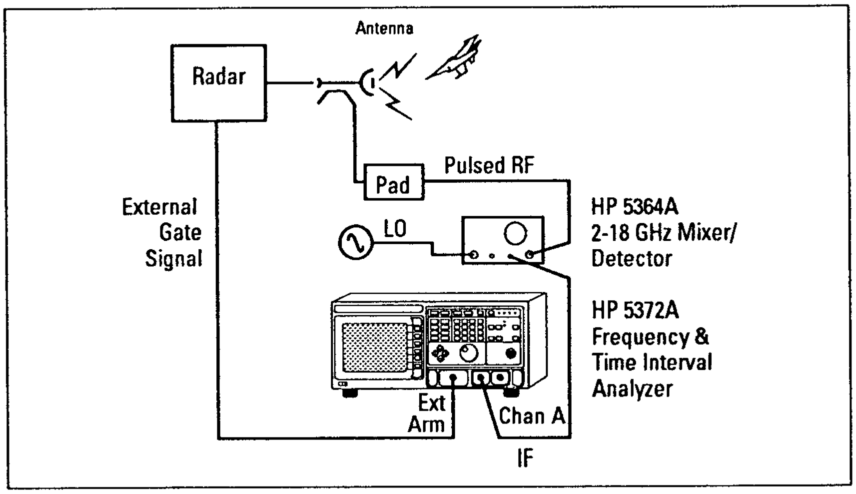

Figure 2. Typical equipment configuration for measuring Barker coded signals.

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 which would increase the time accordingly. In this example, a single 13 bit Barker coded pulse is captured and analyzed.

Sampling Rate and Number of Measurements

You will 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 Number of Measurements *

The HP 5372A is capable of collecting up to 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/100 ns < 8191

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.

Frequency Resolution

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.

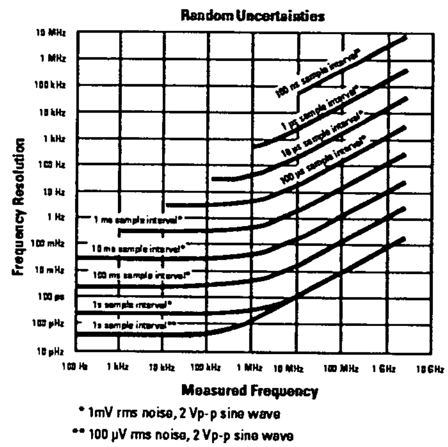

Figure 3. Frequency resolution depends primarily on sample interval and measured frequency.

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

Phase Resolution

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

Phase Resolution(LSD) = 200 ps x (Carrier Frequency) x 360°

For example, the single–shot phase resolution when measuring a 500 MHz carrier is 36°. For a 10 MHz carrier, the single–shot resolution is down to 0.7°.

Carrier Frequency

There are considerations 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 to a frequency in the vicinity of 10 to 50 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 actually going to be measured is Phase Deviation. That is, how does the phase vary from a perfect unmodulated carrier? This means that the carrier frequency must either be known or it must be measured. In either event, it must be provided to the HP 5372A prior to making a Phase Deviation measurement. The quality of the result is partly dependent on good knowledge of the carrier frequency and the stability of that frequency over the period of the measurement.

Actually, the HP 5372A can be set to automatically compute the carrier as part of making a Phase Deviation measurement. However, because of the phase discontinuities in a Barker coded signal, the algorithm used will make a slightly incorrect estimate of the carrier. An incorrect estimate of the carrier frequency degrades the phase deviation measurement by introducing a constant ramp into the result. This problem is discussed in more detail under Measurement Setup.

Input Signal Levels

A voltage level and slope need to be provided 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.

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. The rate at which data is acquired within a block is specified as sampling. The HP 5372A also allows you to specify combinations of holdoff and sampling (Hld/Samp).

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 occur on 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.

Measurement Setup

If you are working with a HP 8791 Model 10 Frequency Agile Signal Simulator, set it up to generate a 13 bit Barker coded signal at 50 MHz with a 13 μs pulse width. You will then be able to follow this procedure exactly. If you are working with a real radar (or some other source), review the measurement considerations and modify the procedure as needed. Refer to Figure 2 for guidance in connecting the equipment.

As a first step, the procedure uses the HP 5372A to measure the carrier frequency. This avoids the potential problem, referred to above, of using a frequency which is slightly in error. If you have apriori knowledge of the carrier frequency, it is not necessary to measure it. It is recommended, however, that you do so at least the first time you try this procedure. The second step is to change the setup and measure the deviations in phase exhibited by the 13 bit Barker coded signal.

1. Preset

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 set of data once the previous block has been acquired and displayed. The LED next to the key is on when **Single** is selected.

Function Menu

2. Select the Measurement Function

Figure 4 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.

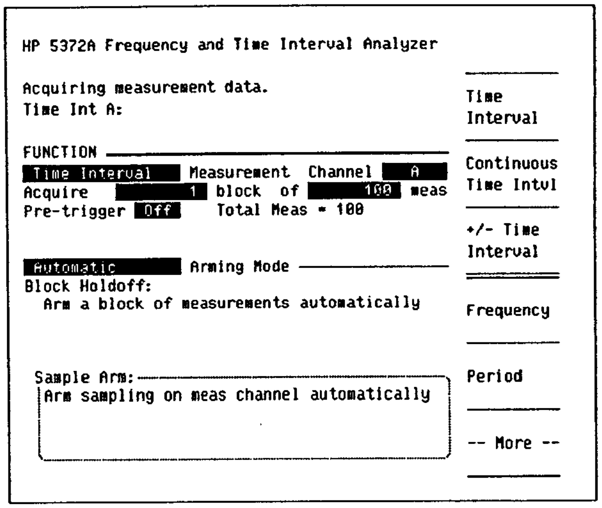

Figure 4. HP 5372A FUNCTION menu as it appears after pressing ***Preset***

3. 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. For the example signal, 80 data points will suffice. Enter 80 in the "block of" field. Use the numeric keypad to do this and be certain to terminate the entry using the **Enter** key on the pad. Next check to see that the "terminated by" field is set to **Pre-Trigger 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 80 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 (Holdoff). The second descriptor (following the "/") relates to how it will gather data once the specified condition has been met (Sampling). For example, the term Edge in Edge/Interval indicates that after the occurrence of an edge on Channel A, Channel B, or External Arm the instrument will be set 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 **Hld/Samp** 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 **200** 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 200 ns gate time (interval). The combination of 80 data points and a 200 ns interval allows capture of the entire pulse and provides good time and frequency resolution.

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.

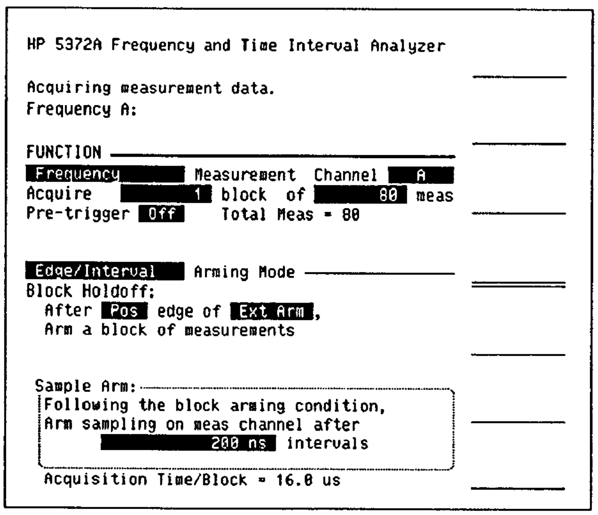

Figure 5. The completed FUNCTION menu shows selections for measurement type, number of measurements, arming, and sampling.

Input Menu

4. 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.

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.

Move to the Ext Arm Level field and set the level appropriately for the signal you intend to use. In this case, it 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 configure the input pods. If you have the standard HP 54002A 50 Ω input pods installed, these should read (for Channel A) :

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

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

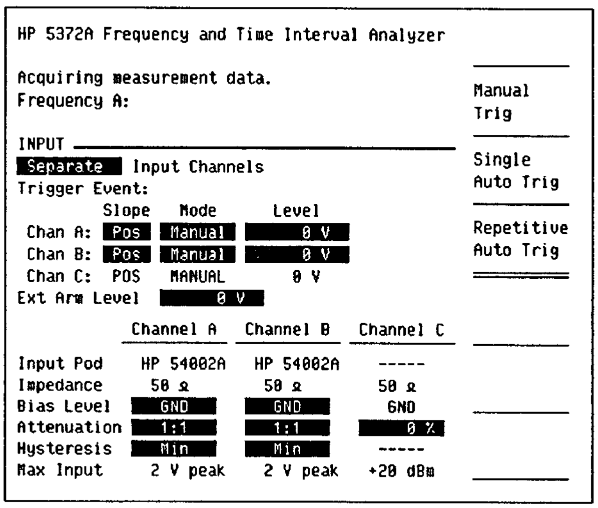

Figure 6. The completed INPUT menu shows the appropriate trigger threshold settings for Channel A and External Arm.

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 labeled **MENU**. Select **Time Var** using the second softkey. You are viewing a plot of frequency versus time. The result should appear similar to Figure 7.

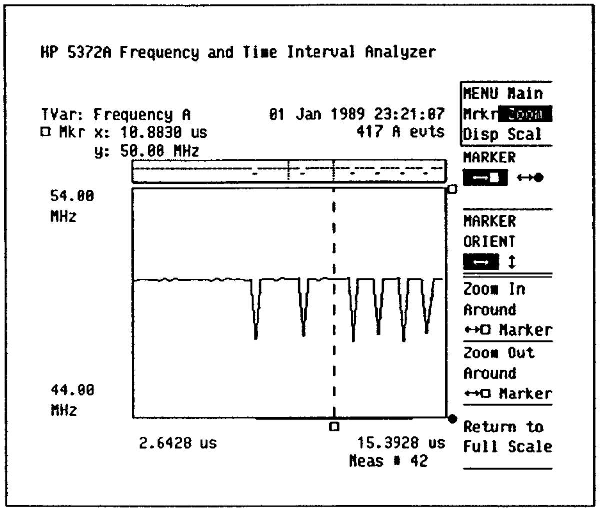

Figure 7. This plot of frequency versus time shows the effects of the Barker modulation.

Analyzing the Frequency Measurement

Note the "spikes" in frequency which occur each time the phase changes by 180 degrees. The HP 5372A has no way of distinguishing these phase changes from frequency changes. In order to measure the carrier frequency properly in the presence of phase coding, it is necessary to ignore these drop outs.

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. Use the knob to move the ↕□ marker so that it lies directly on top of the actual carrier frequency as shown in Figure 8. The idea is to use the markers to read the actual carrier frequency by ignoring the drop outs.

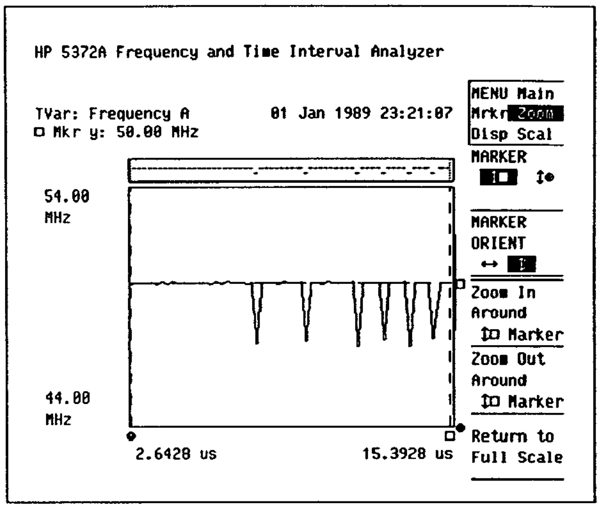

Figure 8. Positioning the ⇕□ marker to estimate carrier frequency.

Press the **MENU** softkey to highlight **Zoom**. Press **Zoom In Around ⇕□ Marker** several times to expand the display about the ⇕□ marker. Your display should now look like Figure 9. Insure that you are not in Delta Marker mode and use the knob to move the ⇕□ so that it approximates the average frequency as shown in Figure 9. You can now read the true carrier frequency with good resolution in the upper left of the display. You may wish to write this number down. It will be entered later as the carrier frequency on the MATH menu. Use **Return to Full Scale** to return to the original display.

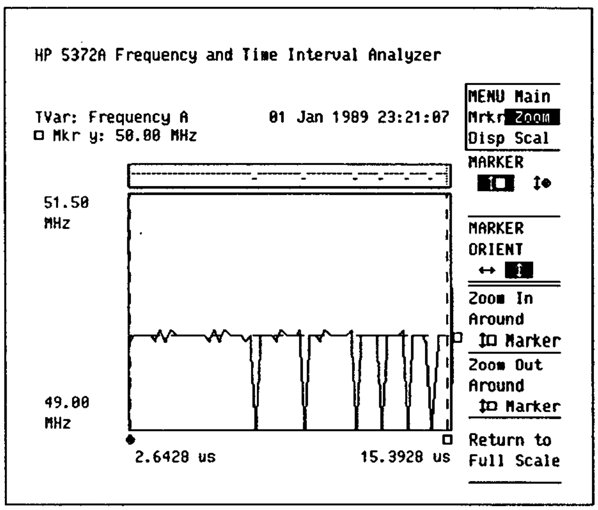

Figure 9. Zooming to get better carrier frequency resolution.

Setting Up the Phase Deviation Measurement

The next step is to modify the setup for a Phase Deviation measure-ment. 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.

The next step is to use the **Math** hardkey to bring up the MATH menu. This menu is used to enter the carrier frequency, measured above, and to choose how Phase Deviation will be displayed. The HP 5372A is capable of displaying Phase Deviation as either cumulative or modulo 360. Both methods will be demonstrated to acquaint you with the difference.

Use the arrow keys to highlight the **Carrier Frequency** field. Select the **Compute Carrier Automatic** softkey. Move to the **Phase Result** field and set it to **Cumulative** using a softkey. The MATH menu should now look like Figure 10.

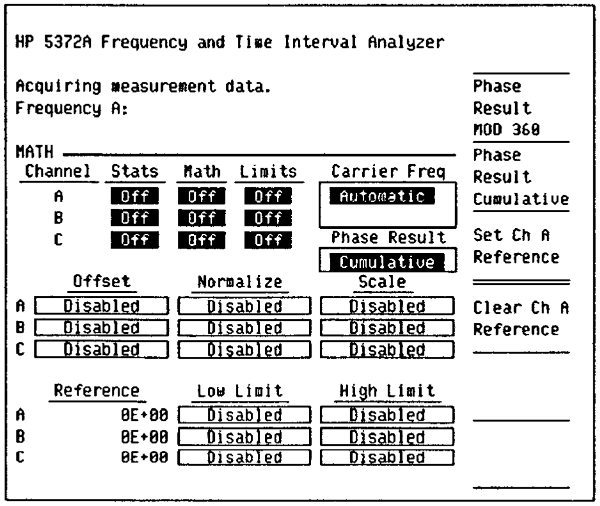

Figure 10. The MATH menu shows entries to compute the reference or carrier frequency automatically for Phase Deviation measurements. The results will be displayed as cumulative phase progression.

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 11. This is an example of a phase deviation measurement where the carrier frequency is incorrect. In general, the displayed data will exhibit a positive or negative slope depending on whether the carrier frequency value is too high or too low.

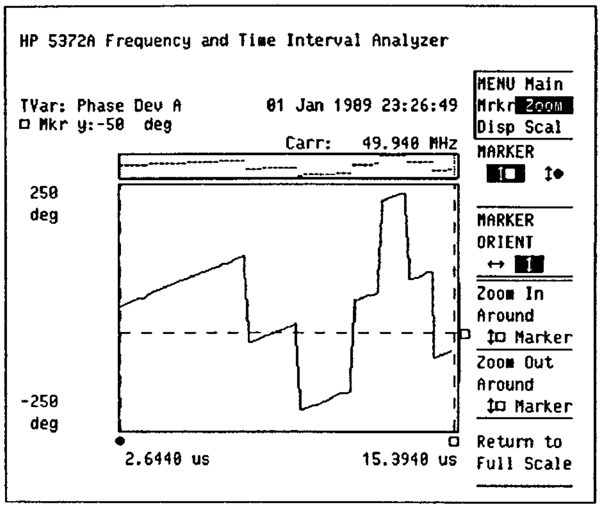

Figure 11. Example of Phase Deviation measurement with incorrect carrier frequency.

To see the carrier frequency value determined automatically by the HP 5372A, press the **Numeric** hardkey. The display is simply a list of the phase measurements in the order in which they occurred. The top softkey lists choices of **Main** and **Formats**. Select **Main** and then select **Expand On** using the third softkey. This causes the HP 5372A to list "expanded" numeric data.

Figure 12 shows the expanded numeric display. Notice that the corresponding measurement interval or gate is displayed with each measurement. Since the arming mode included Edge Holdoff, the time between this edge and the first phase measurement of the block is displayed as **Meas # T**. The second entry is the determined carrier frequency, noted as **Carr**. In this example, it is 49.940266 MHz.

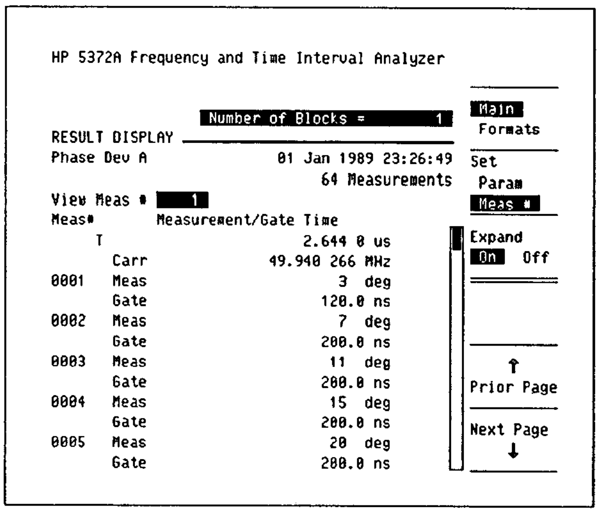

Figure 12. The numeric display is a list of phase measurement results. The "expanded" mode displays the carrier frequency used for the Phase Deviation measurement.

Compare this value with the frequency you determined above using the frequency measurement. The automatic carrier determination is actually the average frequency of the block of data. This makes it subject to any biases in frequency measurement at each phase step. For this reason, the value you determined previously and the automatic carrier value may be different. In this example, the manually determined value was exactly 50 MHz.

Now you can set the HP 5372A to use the carrier frequency you determined manually. Press the **Math** hardkey and highlight the Carrier Freq field. Press the **Compute Carrier Manual** softkey and then highlight the field below it (this field is presently set to the default 10 MHz). Enter the carrier frequency value you determined manually. Terminate your entry using the units softkeys.

Press **Restart** and the **Graphic** hardkey to view the phase deviation results. The display should resemble Figure 13. This may not be what you expect to see for a Barker coded signal because each 180 degree phase shift is plotted in a cumulative fashion. Nonetheless, the results clearly show the 5, 2, 2, 1, 1, 1, 1 pattern of the 13–bit Barker modulation.

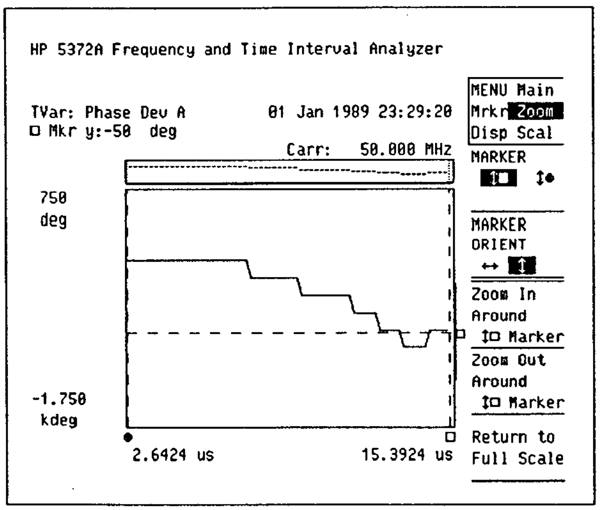

Figure 13. This plot of phase versus time shows the cumulative progression of phase through the Barker code

To acquaint yourself with this cumulative phase display use the markers to measure the total phase shift and divide by the number of steps to get the average phase shift per step. You can also use the ⟷□ and ⟷● markers in Delta mode to measure each phase shift. This is shown in Figure 14.

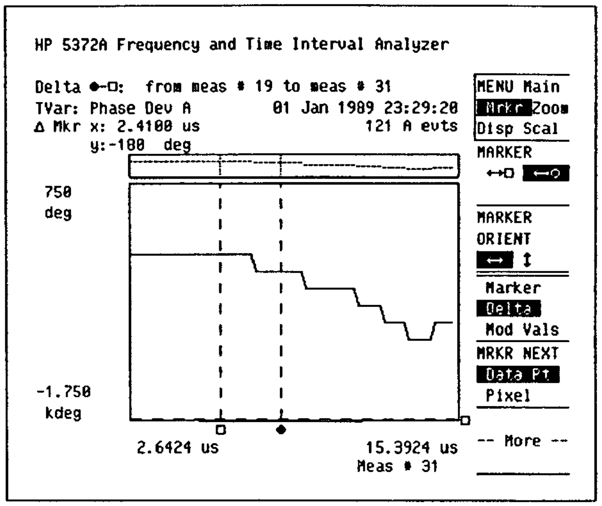

Figure 14. Using the markers in delta mode, you can determine the phase shift at each step in the code.

In order to display the results in a more familiar form, return to the MATH menu, move to the Phase Result field, and set it to **Modulo 360** using the softkey. Press **Graphic** to get the display shown in Figure 15. This result is probably more intuitive for the Barker code pattern. Depending on the objective of your measurement, you may wish to see either or both display formats.

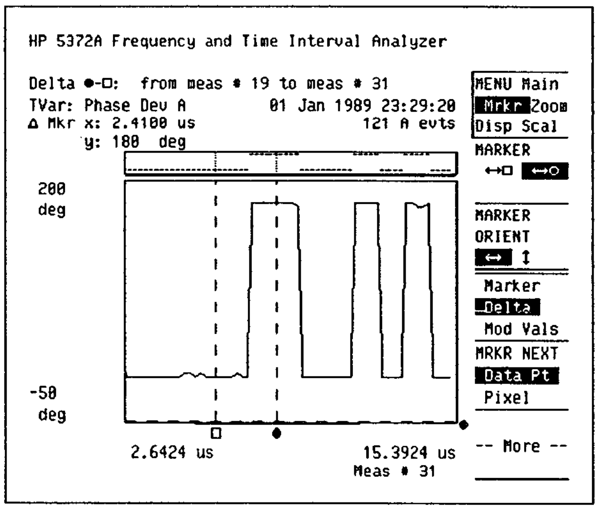

Figure 15. Phase deviation versus time using the Modulo 360 format shows the modulation in a more familiar form.

Analyzing the Phase Deviation Measurement

Items of interest in this measurement include verifying that the expected code was transmitted, that the phase shifts were 180 degrees and when the phase shifts occurred. You might also wish to look at differences in the phase shift through the pulse. You can use the vertical markers singly or together in both absolute and relative readout modes to accomplish the desired analysis. Note that this form of display makes it easier to analyze differences in phase from one shift to another than the cumulative display does. On the other hand, the cumulative display may be better suited to measuring how close, in absolute terms, each shift is to 180 degrees. An example is shown in Figure 16.

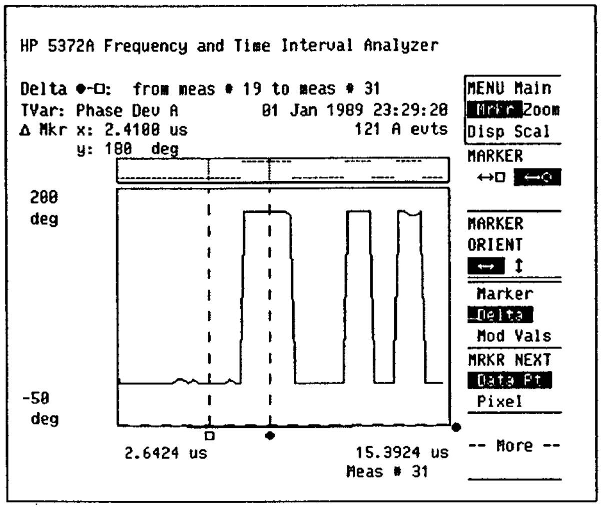

Figure 16. Using the markers to analyze a Barker modulated signal.

HP 5372A Advantages

- Using the HP 5372A, you can directly measure and analyze Barker coded radar signals on a single–shot basis.

- You can use the HP 5372A to measure the frequency of the carrier accurately and thus insure that phase modulation is properly recovered. A potential benefit is that it is not necessary to provide a coherent reference in order to recover Barker modulation.

- You can use cursors, math, and other features of the HP 5372A to analyze Barker coded pulses in a number of different ways which relate directly to the problem you are trying to solve.

- You should downconvert the radar signal to a frequency that will provide the phase resolution required for the radar in question.

For Further Information

For further information on the operation and application of the HP 5372A Frequency and Time Interval Analyzer, please reference the following publications:

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

Application Note 358–9, "Modulation Domain Techniques for Measuring Complex Radar Signals" (5952-8003)

Application Note 358-11, "Single-Shot Measurement of Chirp Coded Modulation in Radar Systems" (5952-8005)

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

HP 5372A Getting Started Guide (5952–8009)

HP 5372A Condensed Reference/Specification Guide (5952–8012)

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