## Errata

**Document Title:** Modulation Domain Techniques for Measuring Complex Radar Signals (AN 358-9)

**Part Number:** 5952-8003

**Revision Date:** October 1989

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### HP References in this Application Note

This application note may contain references to HP or Hewlett-Packard. Please note that Hewlett-Packard's former test and measurement, semiconductor products and chemical analysis businesses are now part of Agilent Technologies. We have made no changes to this application note copy. The HP XXXX referred to in this document is now the Agilent XXXX. For example, model number HP8648A is now model number Agilent 8648A.

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# Application Note 358-9 Modulation Domain Techniques for Measuring Complex Radar Signals

**HP 5372A Frequency and Time Interval Analyzer**

## Description

Modern radar systems transmit and receive very complex signals. These signals are designed to achieve a variety of purposes. For example, it is often desirable that the signal be difficult to detect or intercept. Elimination of "blind spots", resistance to the effects of target motion, improved range and range resolution, and a number of additional performance characteristics of a radar system can be optimized by carefully designing the signal which is transmitted.

## Problem

Signals utilized by advanced radar systems are very difficult or impossible to measure using instrumentation such as oscilloscopes and spectrum analyzers. Even if the signals are repetitive, they are far too complex and change far too rapidly to allow meaningful interpretation using such instruments. In addition, the information of interest is often related to dynamic behavior of frequency, time, and phase parameters; data which many instruments are not well equipped to measure and display.

- *Continuous frequency measurements to 2 GHz*
- *Single-shot capture of a complete signal sequence or repetition*
- *Complex signal parameters clearly revealed in a single display*
- *Direct measurement using markers and zoom*

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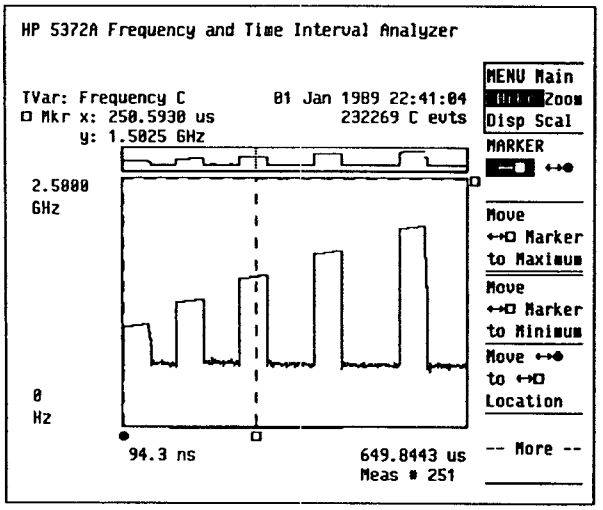



*Figure 1. The HP 5372A can reveal carrier agility, chirp modulation, PRI, and pulse width using a single display.*

# HP 5372A Frequency and Time Interval Analyzer

## Solution

Using the HP 5372A Frequency and Time Interval Analyzer, it is possible to clearly examine the most complex of radar signals. The HP 5372A reveals many of the important characteristics of radar signals in an easy to understand format on a single graphic display. Markers, combined with built–in analysis and display features, allow quick quantitative measurements.

The HP 5372A makes it possible to capture complex radar signals single-shot. This can be important when the signal does not repeat or when it is necessary to capture and analyze a particular portion of the signal.

This note utilizes a carrier agile, chirped signal with a staggered PRI to illustrate the types of analysis that can be accomplished with the HP 5372A. Five carrier frequencies ranging from 1 GHz to 2 GHz in 250 MHz steps are transmitted. Each carrier is chirped over 40 MHz in a linearly increasing fashion. The pulse width is 50 µs. Four different PRIs, ranging from 100 to 180 µs in 20 µs steps are used. Figure 1 illustrates the results.

The example signal 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 made on a single-shot basis.

- *Continuous frequency measurements to 2 GHz*
- *Single–shot capture of a complete signal sequence or repetition*
- *Complex signal parameters clearly revealed in a single display*
- *Direct measurement using markers and zoom*

## Measurement Considerations

In order to properly set up the HP 5372A to make this measurement, you should consider several things. These include total measurement time, sampling rate, number of measurements, input signal levels, and arming mode. Also, in this application, we will assume that the radar can supply an arming signal coincident with the start of a transmitted sequence. 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 sequence. (The term sequence, as used here, refers to one complete pattern of the signal transmitted by an advanced radar. For example, one complete visit to all agile frequencies, PRIs, etc.)

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 is optional. It can be used when the radar operates above the 2 GHz range of the HP 5372A's Channel C. The HP 5364A provides both an IF output with a bandwidth of 500 MHz and a detected output with a 5 ns rise time.

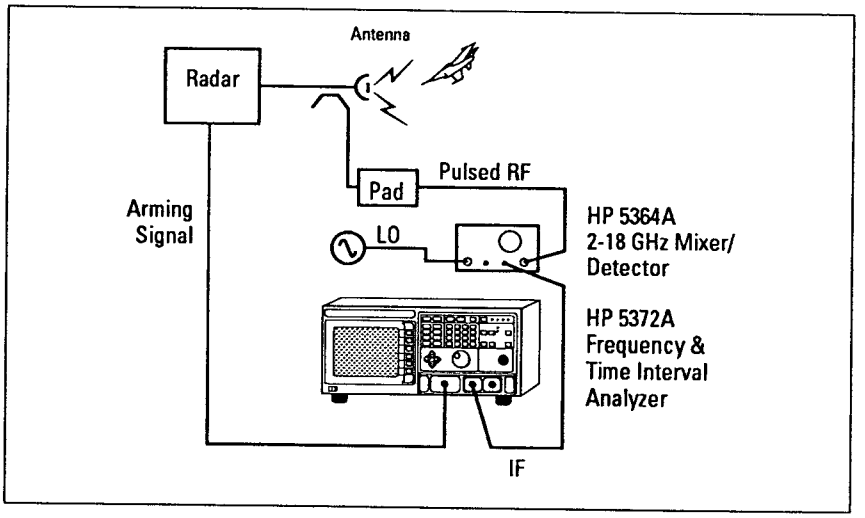



*Figure 2. Typical equipment configuration.*

Note that while we will use the HP 5372A's Channel C in this example, more accurate measurements of pulse width and PRI can be obtained using the HP 5364A's detected output and the HP 5372A's pulse width and PRI measurement functions. In other words, the measurements of pulse width and pulse repetition frequency illustrated here are intended as a means of roughly verifying that the radar is performing as expected. The HP 5372A is, however, capable of much more accurate measurements of these parameters.

### Total Measurement Time

What is the time over which you need to measure the signal? Usually, this will be determined by the time required for the signal to complete a series of frequency hops and/or a PRI sequence. In our example this is around 650 μs.

## 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 Number Of Measurements***

The HP 5372A is capable of collecting up to 8000 (actually 8191) continuous frequency 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 relationship:

**Total Measurement Time/100 ns < 8000**

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.

You may also want to consider the number of measurements as it affects display update and processing time. In general, fewer measurements imply reduced processing time and faster display updates. Also, fewer measurements mean less zooming and re–scaling to examine detailed characteristics.

Recognize that 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 arming 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.

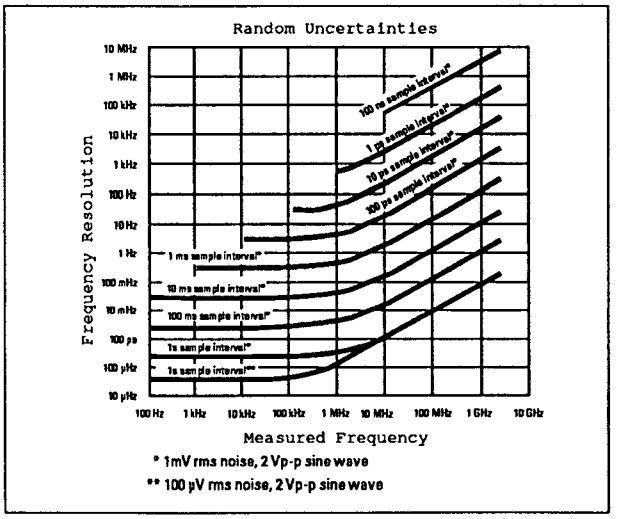



*Figure 3. Frequency resolution depends primarily on sample interval and measured frequency as shown by this graph.*

* The sampling technique used by the HP 5372A is paced by the signal. It does not take samples when no signal is present. Hence, in pulsed applications, you may need to divide by duty cycle to get a better estimate of total time.

The first measurement illustrated in this note looks at the signal for about 650 μs which is the time required to complete one sequence. After this time, the signal repeats the programmed carrier and PRI sequence. One easy combination is to take 650 measurements using a 1 μs sample rate. This will provide frequency resolution of about 1 MHz and allows observation of the entire sequence. The second measurement illustrates how to increase this frequency resolution to about 250 kHz by measuring a single pulse using a 4 μs sample rate and taking 25 measurements.

## Input Signal Levels

For Channel C, the optimum input signal level is about 0 dBm. An attenuator is provided to allow adjustment. No trigger level or slope controls are used.

As an aside, for Channels A and B, trigger levels can be determined automatically for repetitive signals between 1 kHz and 200 MHz. Simply specify the trigger level as a percentage of the peak–to–peak input voltage. The trigger point may also be specified manually as a voltage value.

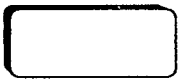
## Arming Mode

The HP 5372A provides a number of powerful arming modes which allow you to control how and when the instrument starts and stops taking data. In general, you can specify when a block or group of measurements begins as a holdoff condition, how measurements are acquired within a block by sampling, or with some combination of holdoff and sampling (hold/sample).

Two such arming modes are illustrated in this note. The first is referred to as Edge/Interval arming. This means that the HP 5372A will begin to gather data at the first event following receipt of an edge on the External Arm input. It will use a specified interval for each measurement. The process stops when the specified number of samples (a block of measurements) has been collected. The second arming mode used is referred to as Time/Interval. It is similar to Edge/Interval with the difference being that the HP 5372A will wait for a specified amount of time after the receipt of an external edge before it begins to gather data.

If you have an HP 8791 Model 10 Frequency Agile Signal Simulator, you can set it up to generate the signal described above. You will then be able to follow the procedure exactly. If you are working with an actual radar (or some other source), review the measurement considerations and modify the procedure as needed. Connect the equipment as indicated in Figure 2.

## Function Menu



### 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 to take a single block of data and stop.

**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.

### 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. Press **More** until you see **Frequency** as an option and select it. Move to the Channel field using the arrow keys and select **C** from the softkeys. You will need to press **More** to do this.

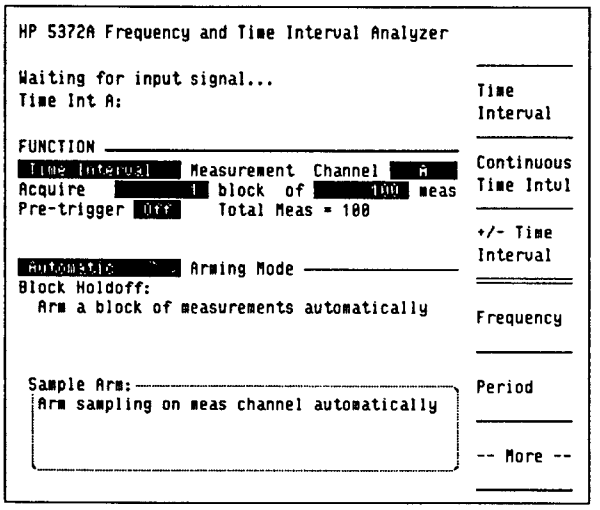



*Figure 4. The HP 5372A FUNCTION menu as it appears after pressing Preset.*

### 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. Enter **650** in this field. Use the numeric keypad to do this and be certain to terminate your entry using the **Enter** key. Insure that the Pre-trigger field is set to **Pre-Trigger Off.** Since a signal is available to synchronize the data acquisition with the beginning of the sequence, it will not be necessary to examine data prior to this signal. The acquisition will conclude when 650 measurements have been gathered after the Edge Holdoff has occurred.

Move to the Arming Mode to select how this block of 650 measurements will be acquired. Notice the softkey selections when you highlight the Arming Mode field. The top softkey lets you select between three different types of arming. You choose a type using successive presses of the top softkey.

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 shown in Figure 2.

In addition, it is also necessary to pace the acquisition of frequency data by an interval, analogous to the gate time of a traditional counter. The key difference here is that these sampling intervals or gates are consecutive, offering continuous frequency profiling capability.

In general, the first word in an arming mode description refers to the condition which will prepare the HP 5372A to make measurements. The second descriptor relates to how it will gather data once the specified condition has been met. In this case, the term Edge 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 descriptors, 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, press the top softkey until **Hld/Samp** is highlighted. You can now select **Edge/Interval** from the lower softkeys. You may need to press the **More** softkey several times to get to the **Edge/Interval** choice. The HP 5372A gives you a wide range of flexibility in acquiring measurement data.

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 the beginning of a sequence.

Finally, in the Sample Arm field enter **1** using the numeric keypad. Note the choices that appear on the softkeys and terminate your entry by pressing **μs**. You have just told the HP 5372A to make all measurements using a 1 μs gate time or sampling 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 (650 µs).

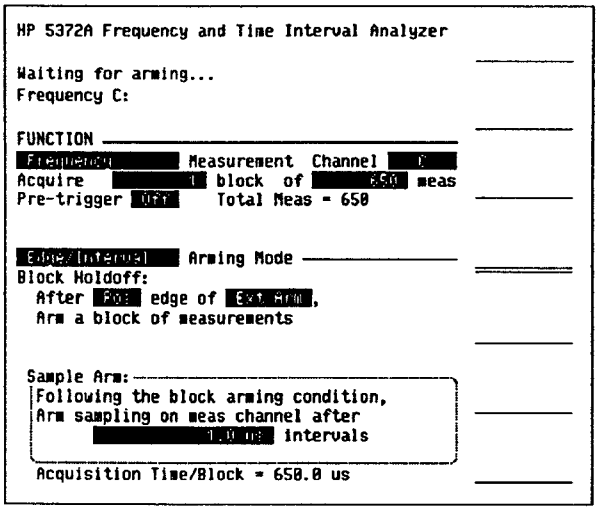



*Figure 5. The completed FUNCTION menu shows the selections for measurement type, number of measurements, and arming.*

### 4. Specify the Input Conditions

As discussed above, the input configuration generally involves specifying a signal slope and trigger voltage. For Channels A and B, the trigger voltage may be determined automatically or manually. Since this example demonstrates measurements between 1 and 2 GHz, the input channel will be C.

The Channel C input selections are limited to attenuator adjustment. Depending on the level of your input signal, you may wish to increase the attenuator setting to insure that the input circuitry is not damaged (the maximum operating input is + 10 dBm).

You may find that adjusting the attenuator value will improve performance when measuring noisy signals. That is, when no signal is present other than noise, a higher attenuator setting can prevent collecting undesired data.

## Input Menu

Press the **Input** hardkey under Menu Selection. Move to the Ext Arm Level field and set the level appropriately for the signal you intend to use. In this case, the level can probably be left at 0 volts. If the LED above the Ext Arm input is not flashing, adjust the level using the knob or numeric entry until it does. The flashing trigger LED's indicate that the signal is crossing the specified threshold.

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

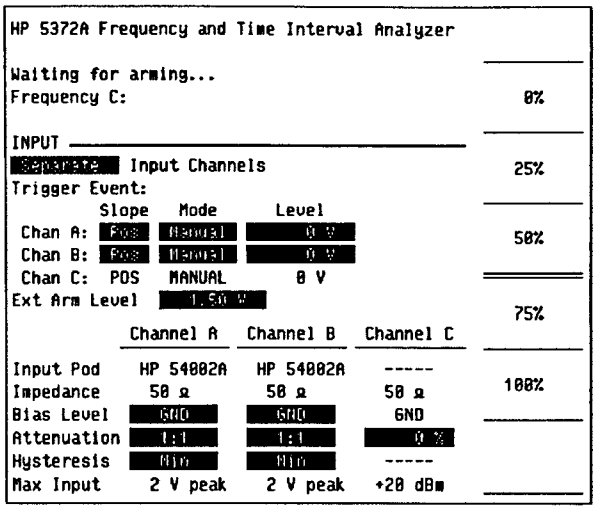
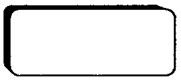



*Figure 6. The completed INPUT menu shows the settings for External Arm trigger level and Channel C.*

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

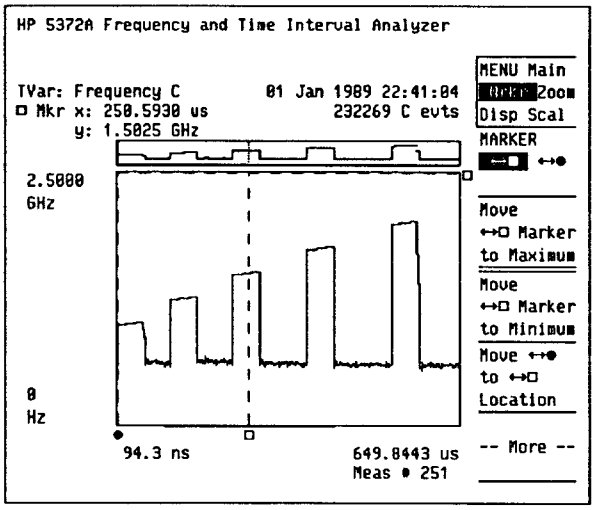



*Figure 7. The complexities of this radar signal are revealed by the HP 5372A's frequency versus time display.*

Notice the elegant simplicity of the display for such a complex signal. You can tell at a glance that the signal was pulsed and that the pulse width was constant at about 50 µs. Five carriers were transmitted between 1 and 2 GHz each higher in frequency than the last. The chirp pattern for each carrier is evident and consists of a linearly increasing frequency. Finally, four different PRIs were used.

A panorama view appears across the top of the screen. This shows all of the data collected during the measurement, albeit at low resolution. As you will see shortly, this panorama view is useful as a reference when you have expanded the display to examine your results in more detail. A quick glance at a highlighted bar reveals the portion of the data being examined on the main display area below.

### 1. Using the HP 5372A Markers

The topmost softkey 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.

Press the **MENU** softkey until **Mrkr** is highlighted. Selecting **Mrkr** allows you to choose from various options such as displaying the difference between marker coordinates, showing modulation values, or moving the marker to a particular place such as the minimum or maximum data point.

There are two sets of markers available. Each set consists of two independent markers. Markers are identified as ⟷□, ⟷●, ↕□, and ↕● on the softkeys. You can see that the second and third softkeys from the top select either marker, as well as the marker orientation. Notice that the arrow conventions describe the direction in which you can move the marker using the knob. When analyzing data on the graphic display, the knob is always connected to the currently selected marker.

Notice the softkey labeled **MRKR NEXT**. This key lets you select whether the markers move from data point to data point or from display pixel to display pixel. Generally, the pixel mode is preferred as it gives a smoother feel to the markers. The data point mode is useful when you want to be certain that the marker is on a particular data value. For the following procedures, leave the selection at **Pixel**.

Choose the ⟷□ marker using the second and third softkeys. (None of this is rigid. You could just as easily select the ⟷● marker for example.) Use the knob to move the marker to the center of the third pulse. Notice that you can read both the frequency and the time in the upper left corner of the display. (Check that the markers are not in **Delta** mode.) Your display should now resemble Figure 8.

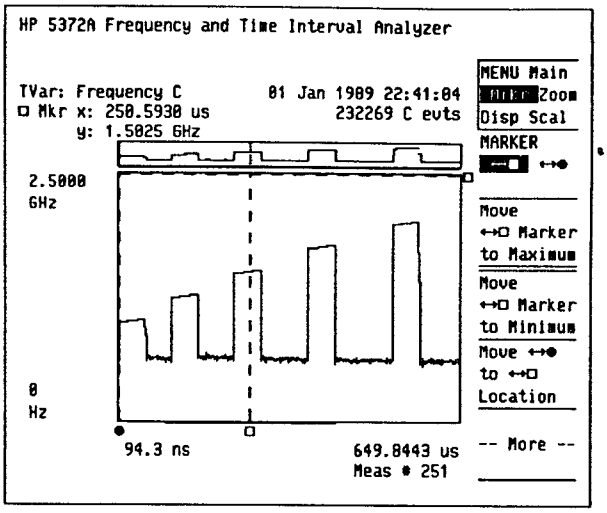



*Figure 8. The markers can be positioned on the display to retrieve detailed information.*

As a second example of the use of markers, use the knob to move the marker to the left side of the fourth pulse. Select the ↔● marker using the second softkey. Use the knob to move it to the right side of the fourth pulse. You have now identified both edges of the pulse. Use the fourth softkey to select **Delta**. Note that you can read the pulse width in the upper left corner of the display. You can also read the frequency range of the chirp as the delta frequency value. This is shown in Figure 9.

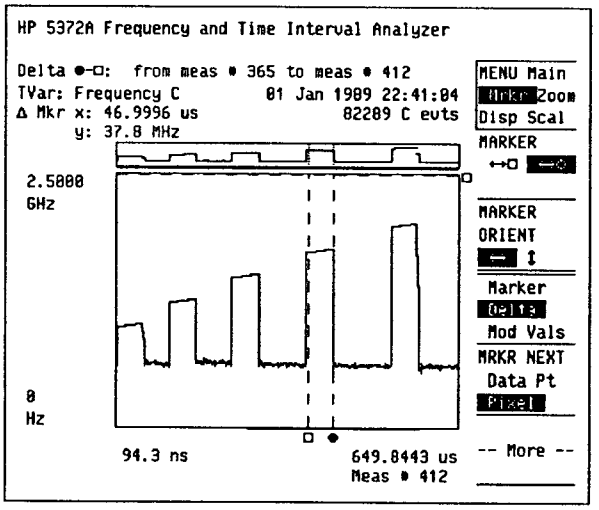



*Figure 9. Flexible marker features make it simple to determine signal parameters such as pulse width and chirp frequency range.*

## 2. Using Zoom

Position the ↔□ marker in the middle of the fourth pulse. Select "zoom" options by pressing the **MENU** softkey until **Zoom** is highlighted. Press **Zoom In Around ↔□ Marker** several times. Notice that the display expands equally about the marker as shown in Figure 10. The highlighted portion of the X axis indicates what will be displayed with the next zoom.

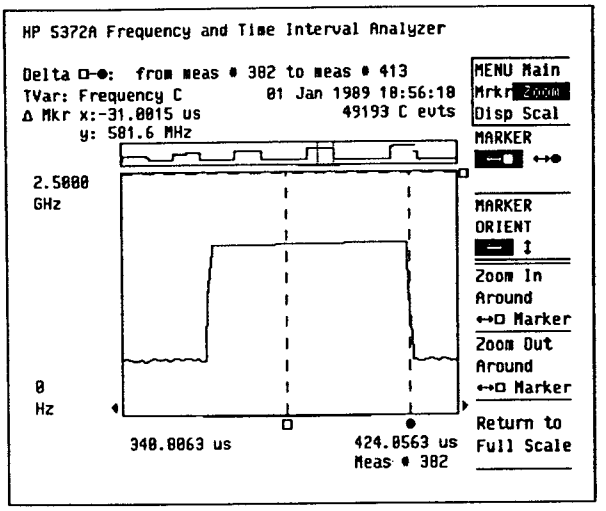



*Figure 10. You can magnify or expand any portion of the display using the zoom features with the active marker.*

Press **Zoom Out Around** ↔□ **Marker** a few times. Finally, press **Return to Full Scale** to return to the original graph and display the entire block of data.

### 3. Draw a Box Around the Data of Interest

At times, you may acquire a large block of data and then wish to study only a particular portion of it. For example, suppose the third pulse in this example is of particular interest. The zoom features can be used to magnify this data, but subsequent acquisitions cause the display to re-scale to the entire block. The markers can be used to define and hold the scale for zooming and subsequent acquisitions.

Select **Scal** using the **Menu** softkey. With the main display fully expanded to show all five pulses, position the ↔□ and the ↔● markers on either side of the third pulse. Next, select the ↕ marker orientation and position the ↕□ and the ↕● markers at the top and bottom of the third pulse. You have drawn a box with markers around the area you are interested in. The result is shown in Figure 11.

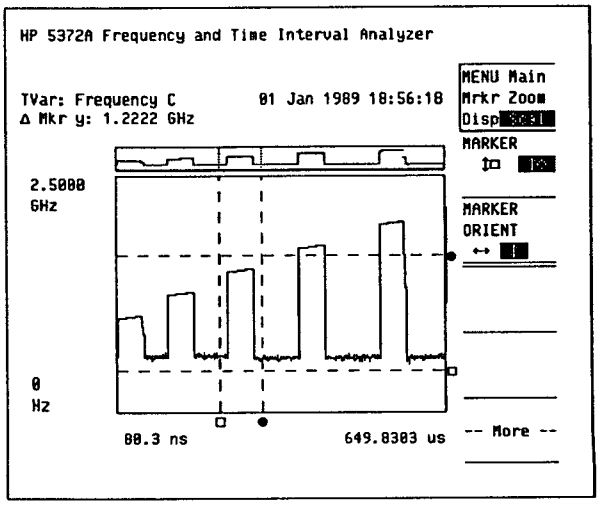



*Figure 11. You can define an area of interest using the markers.*

Press **More** and notice the selections to manually scale the X– axis, as well as the **Range Hold** softkeys. Press **Marker Range Hold X–Axis**. You have told the HP 5372A to remember the current X–axis location of the ⟷ markers.

Press **More** to bring up a similar selection of options for manually scaling the Y–axis. Press **Marker Range Hold Y–Axis**. You have told the HP 5372A to remember the current location of the ↕ markers.

Press **MAN SCALE Y-AXIS** to turn manual scaling on. You could enter numeric values for the minimum and maximum from the display, but these values have already been preset to the current marker locations. Note that the vertical scaling has been changed to match the location of the Y markers. Press **More** twice to bring up manual scaling options for the x–axis. Press **MAN SCALE X-AXIS** to turn manual scaling on. The display now shows only the third pulse and should resemble Figure 12. Subsequent acquisitions (press **Restart**) will be scaled to show only the third pulse.

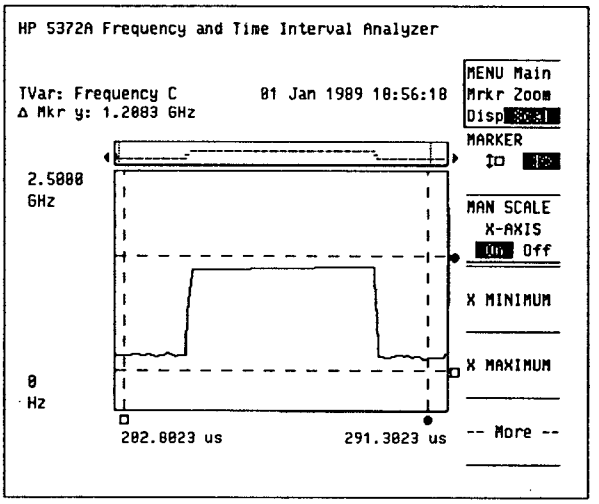



*Figure 12. Use the Marker Range Hold feature to retain marker locations for manual scaling.*

Note that even though only the third pulse is displayed, the HP 5372A is still acquiring all five pulses and must process the entire block. The following discussion shows how to use the arming and sampling modes to optimize the measurement configuration so that only a particular pulse is measured with minimal processing time and maximum resolution.

Return the display to "auto-scale" by setting both X and Y axis manual scale modes to **Off**.

## Obtaining Increased Frequency Resolution

The ability to trade–off time and frequency resolution was mentioned earlier in this note. An example is provided changing the setup to allow capturing only the fourth pulse and extending the sample (gate time) by a factor of four.

Position the ↔□ marker near the left edge of the fourth pulse and zoom until you can clearly place the marker on the first data point of the fourth pulse as shown in Figure 13. Use the marker to measure the time and write this number down. (Be certain that you are not in the delta cursor mode.)

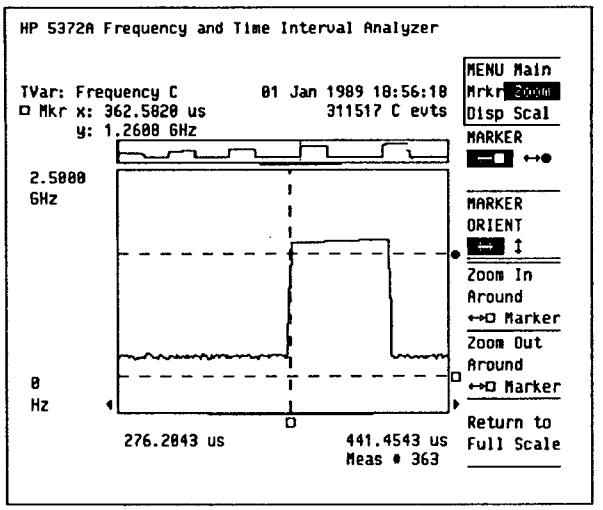



*Figure 13. Using a marker and the full display it is easy to determine delay time to the fourth pulse.*

Press the **Function** hardkey. Move to the Arming Mode field. Check that the **MENU** softkey has the **Hld/Smpl** selection highlighted. If not, press the softkey to get it. Press **More** until you find the **Time/Interval** option and select it. Notice that a new field called Delay appears. Move to this field and enter the number you measured to the left edge of the fourth pulse. Be sure to use the appropriate softkey to terminate your entry. Don't be too particular about the exact value. It is better to reduce it somewhat to insure that you don't miss data. For this example, 350 μs is appropriate.

You have changed the arming mode from **Edge/Interval** to **Time/Interval** and have specified the amount of time the HP 5372A should delay after receiving an edge on the **External Arm** input before it begins to take data. This arrangement allows you to specify that the instrument does not begin to take data until the fourth pulse begins. Note that the **Sample Arm** field is still available so you can move to it and specify an interval of 4 μs. This will improve the frequency resolution of the measurement by a factor of four.

Since only the fourth pulse is of interest, it is no longer necessary to acquire 650 data points. Reducing the size of the block reduces computation times and provides faster display updates. Move to the **meas** field and reduce the number of measurements to about 25. Your FUNCTION menu should now look like Figure 14.

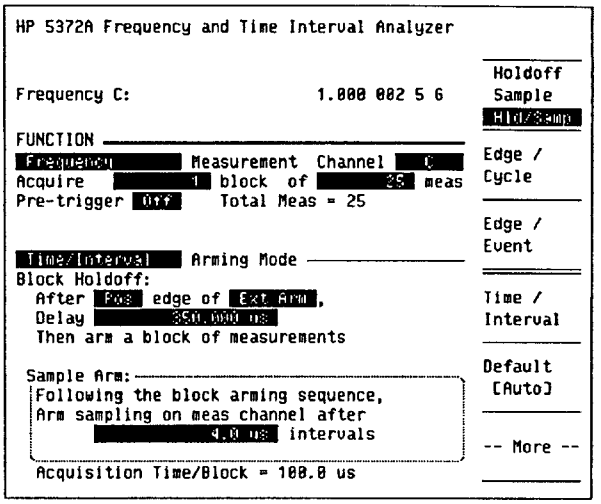



*Figure 14. FUNCTION menu to optimize frequency resolution and processing time. The fourth pulse will be captured.*

There are no changes required to the INPUT or any other menus. Press **Restart** to collect new data using the new setup. Your display should look like Figure 15.

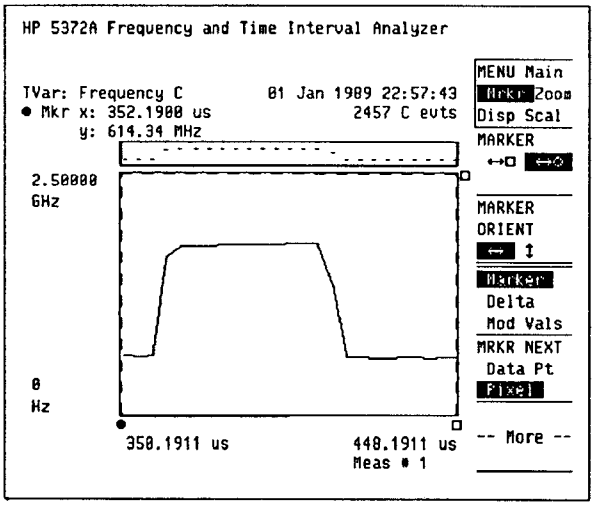



*Figure 15. Capture of a single pulse with increased frequency resolution.*

## HP 5372A Advantages

- Single–shot capture of complete signal sequences
- Simple, effective display of complex signal parameters
- Easily measure portions of interest
- Wide range of frequency and time resolution available
- Powerful marker features aid measurement and analysis
- 2 GHz input bandwidth with optional Channel C

## 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:

AN 358-10 Characterzing Barker Coded Modulation in Radar Systems (5952-8004)

AN 358-11 Characterizing Chirp Coded Modulation in Radar Systems (5952-8005)

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

HP 5372A Condensed Reference and SpecificationGuide (5952–8012)

HP 5372A Getting Started Guide (5952–8009)

HP 5364A Data Sheet (5952-7946)

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