## Errata

**Document Title:** Clock Rate Independent Jitter Measurements for Digital Communications Systems (AN 358-5)

**Part Number:** 5952-7999

**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 358-5
# Clock Rate Independent Jitter Measurements for Digital Communications Systems

## Description

To maintain transmission integrity and minimize errors within digital communications systems, signals are regenerated at appropriate intervals. Regeneration takes an attenuated, dispersed pulse stream and reconstructs a re-timed representation of the original signal. This regeneration process is both susceptible to and a source of jitter, a major cause of transmission errors.

Regeneration and re-timing use clock recovery circuits and phase locked loops built into devices such as line repeaters, multiplexers and digital switches.

## Problem

Jitter is a primary cause of errors in digital communications systems. It is important to verify that jitter is not excessive, to sectionalize problems and to find the source of the jitter. For example, once you know the jitter is predominantly at 60 or 120 Hz, you can start to examine power supplies.

During the current phase of evolution of the digital communications network, with for example ISDN and SONET, a wide range of clock rates are appearing for which traditional test sets are limiting.

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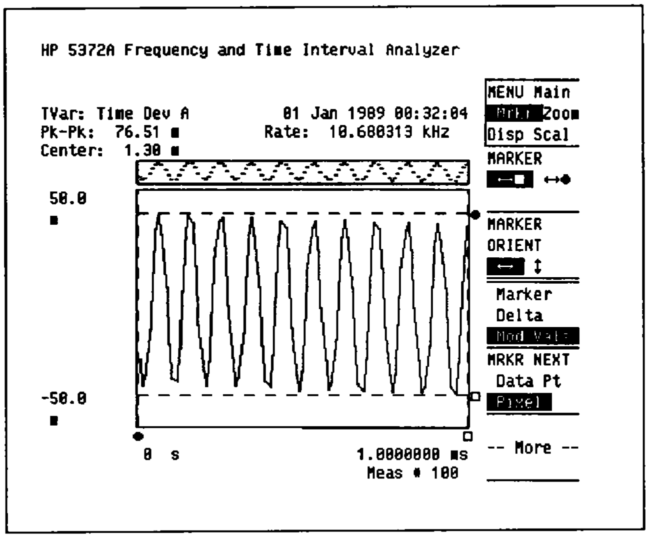



*Figure 1. Jitter as a function of time. You could call this a jitter oscilloscope. For a strong periodic element of jitter, frequency is displayed as well as peak-peak jitter in Unit Intervals.*

# HP 5372A Frequency and Time Interval Analyzer

- *Jitter Measurements at any Clock Rate*
- *Jitter can be viewed on a "Jitter Oscilloscope"*
- *Enhanced Precision*

## Solution

Using the HP 5372A Frequency and Time Interval Analyzer's Time Deviation measurement function, you can characterize jitter in several useful ways.

The technique works independently of clock rate, so as new standards evolve you are still able to use the HP 5372A to measure jitter.

Precision is often enhanced over traditional solutions — 0.00015 Unit Intervals (or 0.05 degrees) rms at 1 MHz. (Resolution is equal to 150ps× clock rate, so for example at 10 MHz it would be 0.0015 UI. Correspondingly, resolution can be enhanced by downconverting the clock.)

By displaying Time Deviation (jitter) as it varies with time (imagine a "jitter oscilloscope"), you can measure jitter amplitude, and often identify strong periodic elements of jitter. Figure 1 shows a display of jitter versus time. The vertical axis is jitter amplitude (in Unit Intervals), and the horizontal axis is time. An (x,y) pair represents the time (x) at which a jitter amplitude (y) occurred.

By creating a jitter (time deviation) histogram, you can quantify the statistics of the jitter, such as mean, standard deviation and peak jitter (see Figure 20 on page 16). By comparing jitter at the input of a device or system to jitter at the output, you can assess the jitter gain or jitter transfer function.

For a short discussion of the measurement method see Appendix A.

## Measurement Considerations

To set up the HP 5372A to make a jitter measurement, you need to select the sample rate, the number of measurements, the ideal system clock frequency and the voltage threshold to capture each clock edge.

### Sample Rate

Since you are sampling the jitter, make sure you sample fast enough to faithfully represent it. This means sampling at more than twice the maximum jitter frequency, and if practical, ten times the jitter frequency. For example, if the highest jitter frequency present is 40 kHz, sample at least at 100 kHz and if possible as high as 400 kHz.

### Number of Measurements

Make sure that you have enough measurements to see the modulation and detect the peaks when looking at a display of jitter versus time. This means a minimum of ten points per cycle of the highest frequency of jitter (to limit the error in estimating the peak jitter to less than 1%) and ten cycles of the lowest frequency of jitter (at least 100 measurements) when you are looking at a single strong periodic element).

For histograms of jitter, you will probably want several thousand measurements to get a representative distribution.

### Carrier Frequency

There are two ways the HP 5372A determines the timing of ideal clock edges. The first is to enter the clock frequency as a setup parameter. The second is to let the HP 5372A calculate the ideal clock frequency from the measured jittered clock. (Refer to Appendix A for more information.)

### Threshold (trigger)

Select the voltage level at which jittered clock edges will be timed. For a binary signal, this is generally at 50% of the peak- peak level. For a bipolar signal, there is the opportunity to measure the jitter for both positive and negative going pulses (which can be different). For positive-going pulses set the threshold at 50% of the positive peak (see Figure 2).

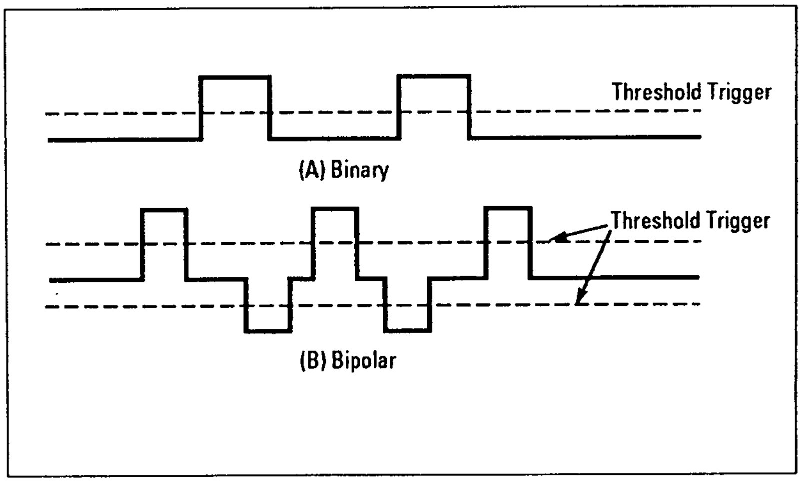



*Figure 2. The threshold (trigger) on the HP 5372A (a) is set at the 50% point on a binary signal and (b) at the 50% of the positive or 50% of the negative pulse on a bipolar signal to separate out the differences in jitter between positive and negative pulses respectively.*

### Resolution

The resolution of the jitter measurement is equal to 150ps× clock frequency. For low clock frequencies the resolution of the HP 5372A will be excellent (0.00015 UI (or 0.54 degrees) rms at 1 MHz). At 50 MHz this would be 0.0075 UI or 2.7 degrees, and at 500 MHz this would be 0.075 UI or 27 degrees. If more resolution is required, you can downconvert your clock and gain more resolution. For example, a 500 MHz clock downconverted to 1 MHz yields 0.00015 UI resolution.

## Measurement Setup

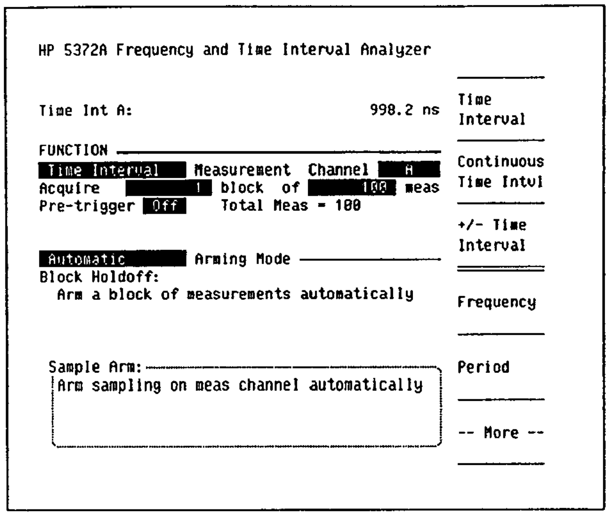
A measurement will be made on a 1 MHz clock signal with 10 kHz of sinusoidal jitter. The binary signal swings from 0 volts to 1.6 volts, so is centered on 0.8 Volts. Connect the jittered clock to channel A of the HP 5372A.

**1. Preset**

Press the green **Preset** hardkey to set the instrument to a known state. Then press the **Single/Repet** hardkey. The **Single** LED should be on.

### Function Menu

You should now be looking at the **Function** menu and the screen should appear as in Figure 3.




*Fgure 3. This is the Function screen with the HP 5372A in the Preset condition. Fields here allow you to do the primary measurement setup steps.*

## 2. Select the Measurement Function

The highlight should be on **Time Interval**. Press the **- -More- -**softkey twice. Select **Time Deviation** (Jitter) as the function (**Channel A** is the default input channel (see Figure 4).

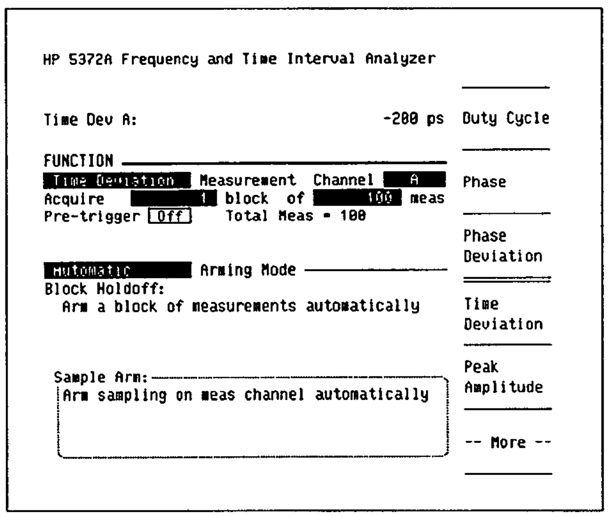



*Figure 4. With the Function field highlighted, you can cycle through many choices by pressing the - -**More**- - key. Here, Time Deviation is selected.*

### 3. Select the Number of Measurements and Arming Mode

The number of measurements should be set to 1 block of 100. This is to give you 10 points per cycle of jitter (modulation), and display ten full cycles of jitter. The measurement will terminate after 100 measurements.

For Arming Mode select **Sample** and select **Interval Sampling.** Under Sample Arm, set the sampling interval to 10 µs, which will yield 10 points per cycle for a 100 µs cycle (10 kHz jitter). See Figure 5.

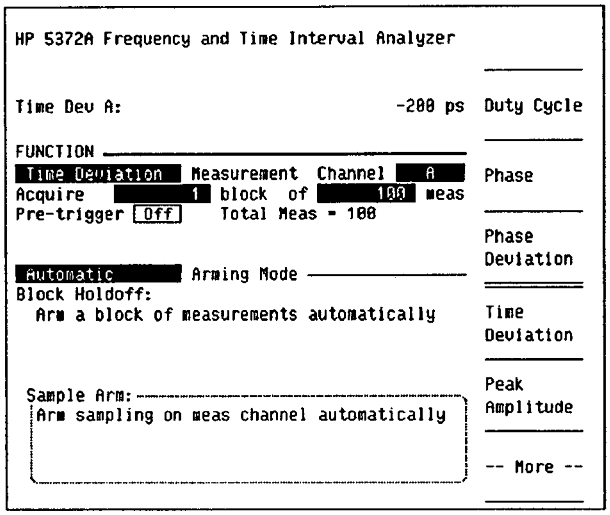



*Figure 5. You can select the arming mode after moving the highlight (with the cursor keys) to the Arming Mode field. Here Interval Sampling is selected.*

## Input Menu

### 4. Specify the Input Conditions

Press the **Input** hardkey and set Channel A trigger to **Pos, Manual** and 800mV (see Figure 6).

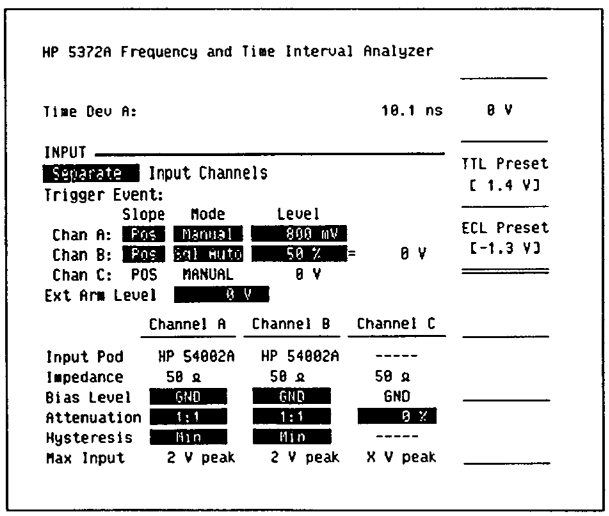



*Figure 6 - To set up the input channel hardware, press the Input hardkey, and this screen appears. Here select a Positive going edge on Channel A with the trigger level set manually at 800 mV.*

## Math Menu

**5. Determine the Carrier Frequency**
Press the **Math** hardkey.

Leave Carrier Frequency set to **Automatic** (automatic calculation of the underlying stable clock frequency).

The jitter amplitude results will normally be displayed in seconds. You can use the HP 5372A Math functions to display the results in degrees (result (seconds) × 360 / one period of the clock).

For this example we will display the results in Unit Intervals (result (seconds) × clock frequency).

Now set the Channel A Math **On**. Move the highlight to the Scale field and enter **1 M**(Hz) (the clock (carrier) frequency). See Figure 7. If the clock frequency were not known, you could measure it first, then come back and enter the Scale value and re-measure jitter.

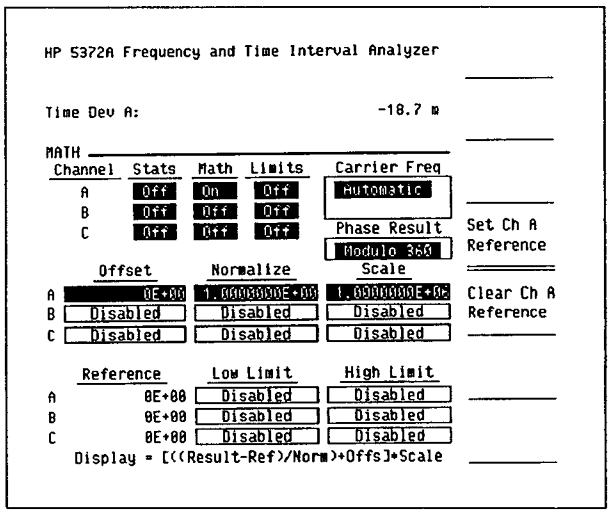



*Figure 7. Several Math functions are available to be selected on the screen presented after pressing the Math hardkey. Here Automatic calculation of the clock's frequency is selected, and the results are scaled to Unit Intervals by multiplying the measured time by the clock frequency.*

# Measurement Results

## Graphic Results

Press the **Graphic** Results hardkey. With **MENU** set to **Main** select **Time Var.**

### 1. Enhancing the display

Observe the jitter waveform as shown in Figure 8. Selecting **CONNECT DATA On** will often give a clearer picture (Figure 9). You may prefer to turn **GRID On.**

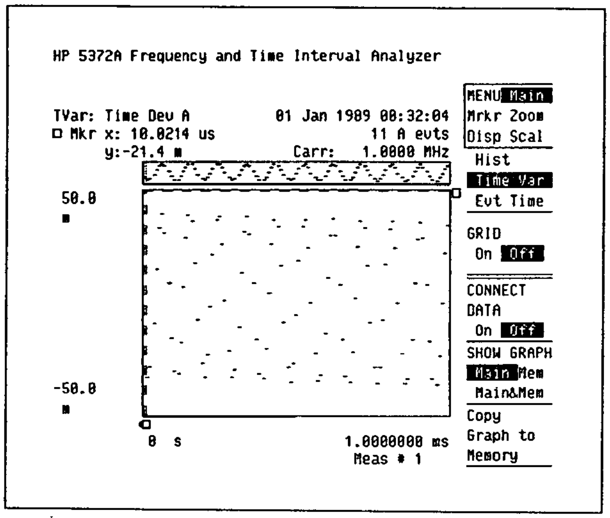



*Figure 8. The first view of the measured jitter is obtained after selecting Graphic Results and picking Time Variation as the type of analysis. A calibrated display of jitter amplitude versus time, with several menus further enhances analysis.*

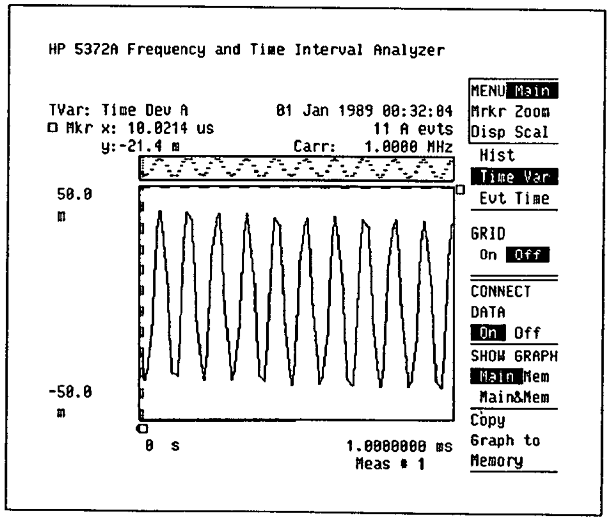



*Figure 9. A view of the jitter is first enhanced with a connect-the- dots capability. Adding a grid may also help.*

## 2. Using the HP 5372A Markers

First use the ⟷ (horizontal) markers to find the peak-peak jitter. Then use the ↕ (vertical) markers to measure the jitter (modulating) frequency.

Select **MENU Mrkr** (see Figure 10). Select **MARKER ORIENT ↕**. The active marker is the ↕□ marker. Press **- -More- -** and select **Move ↕ □ Marker to Minimum.** Select **MARKER ↕** and select **Move ↕● Marker to Maximum.** Press **- -More- -** to return to the original menu and select **Delta.** Notice that in the upper left corner of the screen the peak-peak jitter is displayed —**Δ Mkr y: 76.7 m** (Unit Intervals). See Figures 10-12.

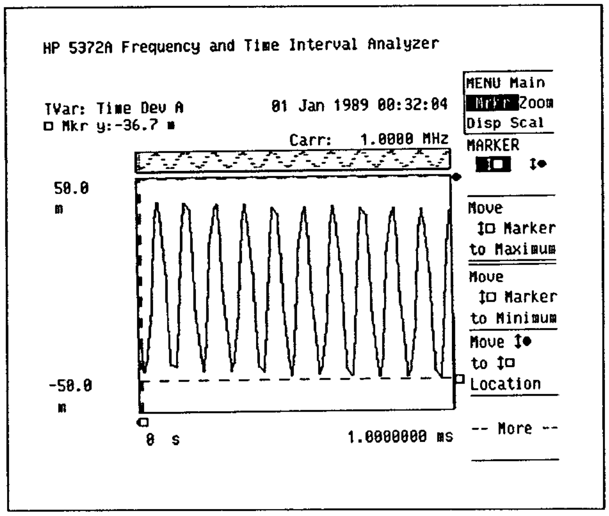



*Figure 10. The Markers further enhance analysis. First move the ↕□ marker to the minimum of the waveform.*

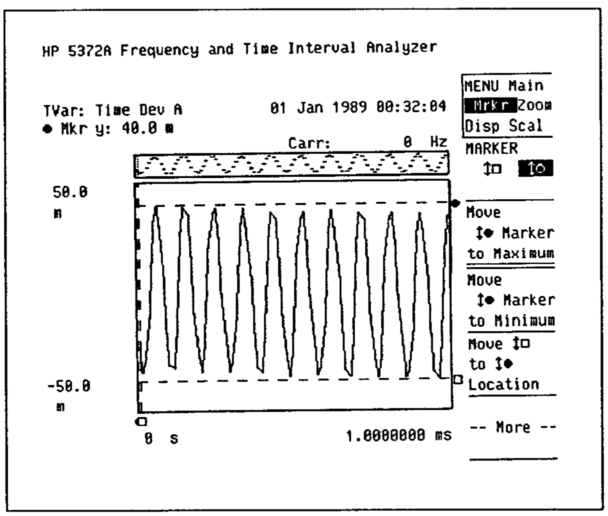



*Figure 11. The next step is to move the ↕● marker to the maximum of the waveform.*

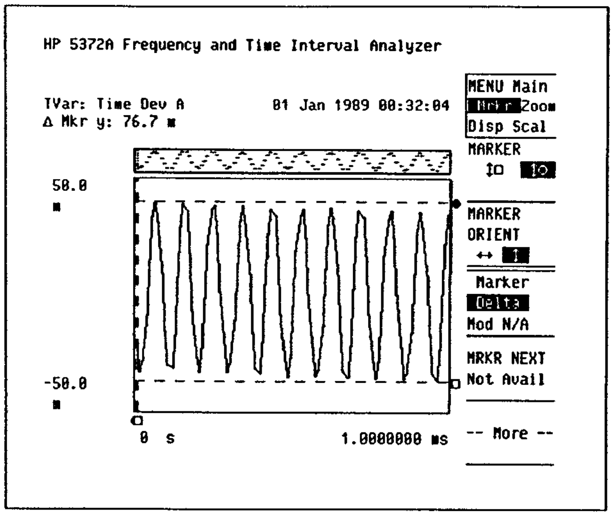



*Figure 12. The peak-peak value of jitter is measured when the Delta between cursors is selected. Note the result in the upper left corner of the display.*

### 3. Calculating Modulation Values

Select **MARKER ORIENT** ⟷. The currently active marker is the ⟷□. Using the knob, move this to the extreme right edge of the screen. Leave the ⟷● marker at the extreme left edge of the screen. Now select **Mod Vals.** Displayed at the top of the screen are the following:

**Pk-Pk: 76.51m** **Rate: 10.680313 kHz**

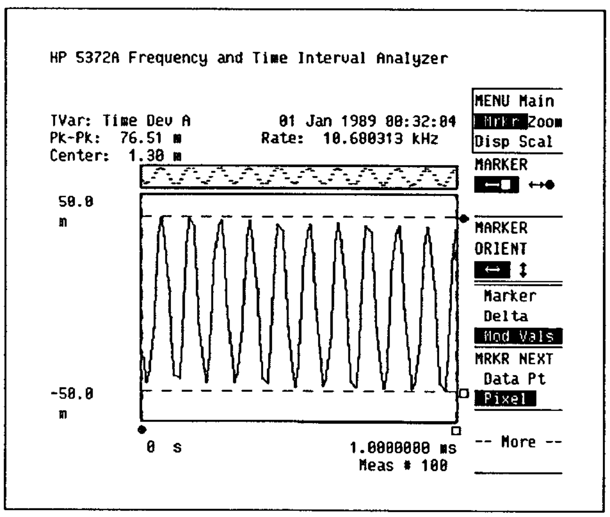



*Figure 13. The HP 5372A automatically calculates modulation values if the signal is strongly periodic. Move the ⟷ cursors to either side of the waveform section of interest and both peak-peak jitter and jitter rate (frequency) are displayed at the top of the screen.*

These are the peak-peak jitter amplitude in Unit Intervals, and the jitter frequency. This peak-peak value is different from that in the previous step. This is because the **Mod Vals** function interpolates the data to make a better estimate of the peaks.

### 4. Change the Sample Rate

Now examine what happens when the setups are changed. First you can see the effects of changing the sampling interval (sample rate). The next section will look at changing the number of samples.)

Press the Function hardkey, and move the highlight to the Sample Arm field. Enter 100 ns (the smallest value). (The instrument can actually sample no faster than every clock cycle, which in this case is 1 µs (1 MHz), so a value of 1 µs will yield the same display.) Press the Graphic results hardkey and observe that you capture only one cycle of the jitter. See Figure 14.

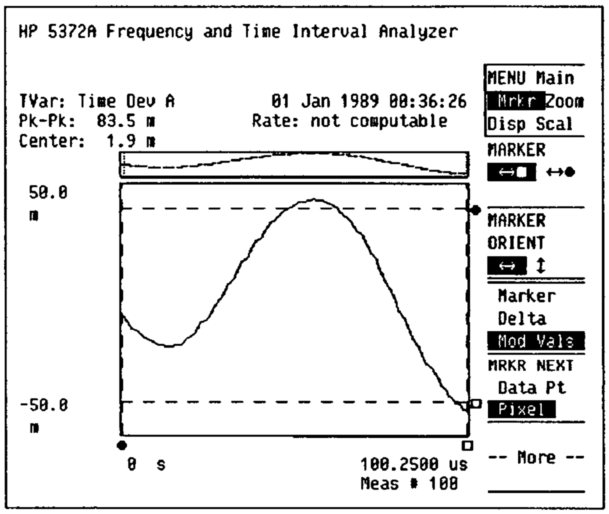



*Figure 14. If you sample too fast, you will not get results that you recognize. Here you see about one cycle of jitter. Ten times faster sampling would have shown you only a small segment of the jitter.*

If this were a 10 MHz clock with 10 kHz jitter and you were sampling at 100 ns intervals you would see 100 samples (remember you selected 1 block of 100 samples in the original setup), spaced 100 ns apart (or a total of 10 µs of captured jitter). This would only be one tenth of a cycle of the jitter (10 kHz or 100 µs period) and would not be recognizable. Therefore CAUTION. It is not always better to sample as fast as you can.

What if the sampling was slowed down to 100 µs? If you try this, using **Mod Vals** you will note that the displayed rate is in error — Rate: 717.509 Hz! See Figure 15.

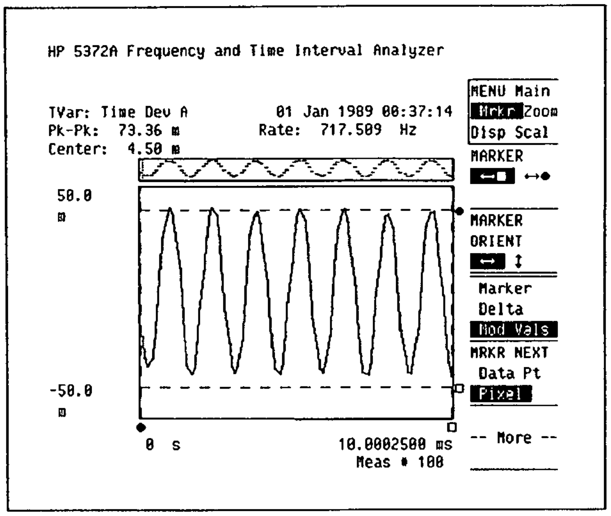



*Figure 15. If you sample too slowly, you will get erroneous results from the phenomenon of aliasing.*

You are only getting about one sample per cycle of modulation, and so you are observing the phenomenon of aliasing. Therefore, always sample at some multiple (2.5X to 10X) of the highest jitter (modulating) frequency.

### 5. Change the Number of Samples

Now look at the effect of changing the number of samples. Press the **Function** hardkey and set the acquisition to 1 block of 8000 measurements. Reset the sampling interval to **10 μs** (10 points per cycle of jitter). Press the **Graphic** results hardkey and look at the display now. See Figure 16.

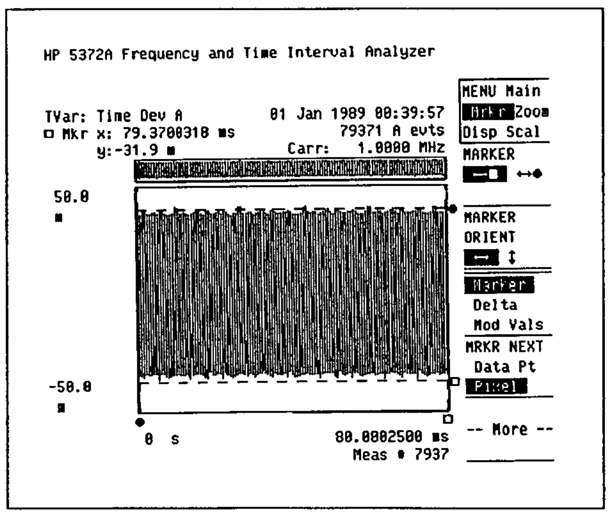



*Figure 16. Choosing the maximum number of samples is not always a good default choice to make. Here are 8000 samples of jitter versus time. It is hard to identify patterns and takes longer.*

You have 80 ms of data, or 800 cycles of the jitter--- too much to make sense of. You can certainly zoom in on the data, but you will find that the instrument response time with 8000 data points is slower than with100 points. See Figure 17.

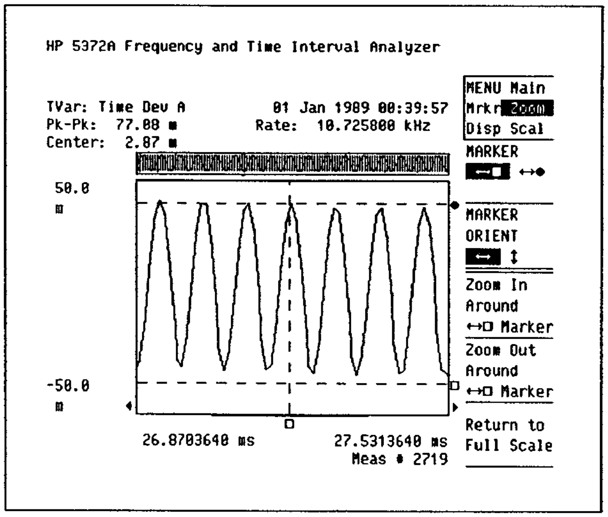



*Figure 17. Zooming allows you to take a good look at a small segment of a large number of measurements.*

If your signal has unknown jitter, you would best start with a large number of samples, say >1000, and use zoom to examine for strong periodic elements. The large number of samples would ensure a few cycles of low frequency jitter components. Try to select only enough points to get a useful display. It is not always better to gather the maximum amount of data.

## Histogram and Statistics

Return to the FUNCTION menu, and set the number of measurements to 10 blocks of 1000 measurements. See Figure 18.

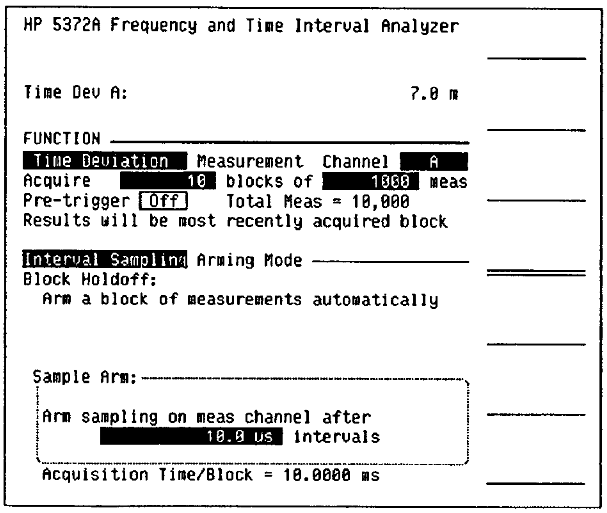



*Figure 18. For statistical analysis such as a histogram, select some large number of measurements. Here 10 blocks of 1000 or 10,000 measurements are selected.*

Return to the GRAPHICS menu and select **Hist** (ogram). Press the **Restart** hardkey and watch the histogram grow. See Figure 19.

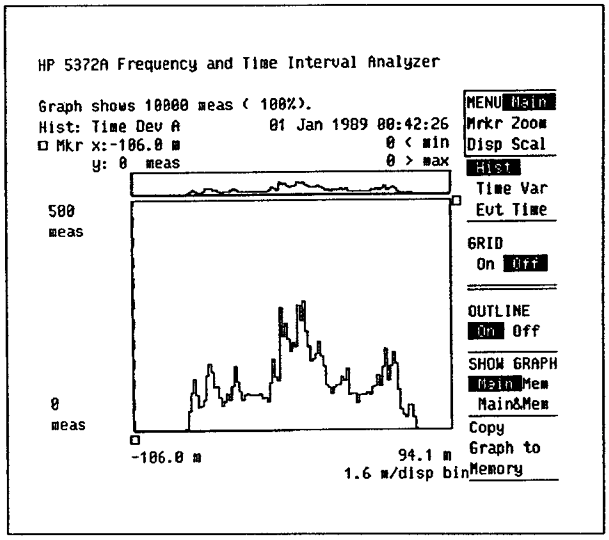



*Figure 19. The histogram allows you to visualize the variability of jitter measured over some extended period of time. Use the cursors to quantify any bin value.*

Now look at the statistics (which are always calculated on the segment of the data between the cursors). To look at all of the data, select **MENU Mrkr** and move the↔□ marker to the extreme right of the data, and put the ↔● marker at the left edge. Select **Stats** and observe across the top of the display (see Figure 20):

**Min:-71.2 m** **Mean: 1.006 m**
**Max:72.7 m** **Std Dev: 36.071 m**

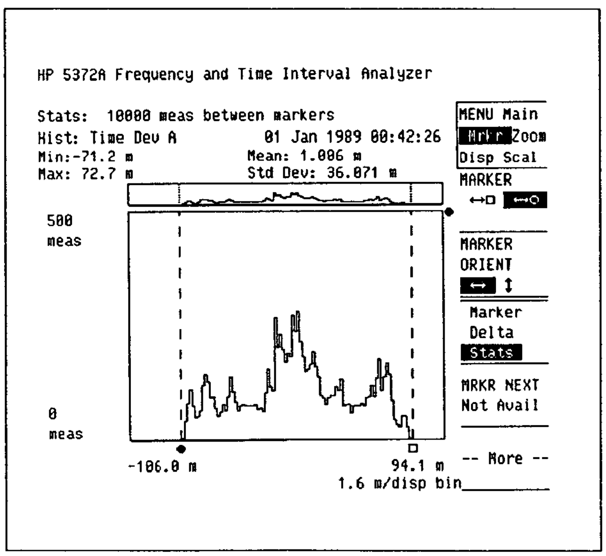



*Figure 20. You can use the Stats function to calculate peak, mean and standard deviation of the data that is between the cursors.*

## HP 5372A Advantages

- Measure jitter directly as Time Deviation in the HP 5372A
- View jitter versus time - "a jitter oscilloscope"
- Scale the jitter results as Unit Intervals, degrees or time
- Use cursors to find peak-peak jitter and modulation values
- Use a histogram to analyze the statistics of the jitter
- Technique is independent of clock rate, so it can grow with evolving standards

## For Further Information

For a more complete discussion of jitter measurement using the technique described in this note, refer to HP Application Note 358-2 "Jitter and Wander in Digital Communications" (5952-7925).

For software to perform more comprehensive measurements of jitter, refer to Technical Data Sheet number 5952-7975. This is a data sheet for the Data Physics Corporation software product numbers DP 280, DP 281 and DP 282. With this software and a computer, you can measure jitter spectrum, weighted peak-peak jitter and jitter transfer function--as described in Application Note 358-2.

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

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

HP 5372A *Getting Started Guide* (5952-8009)

## Appendix

### What is jitter/time deviation?

**A. Significant Instants**

The CCITT defines jitter as "... short term variations of the significant instants of a digital signal from their ideal positions in time". A useful "significant instant" is the rising (or falling) edge of a digital signal (Figure A).

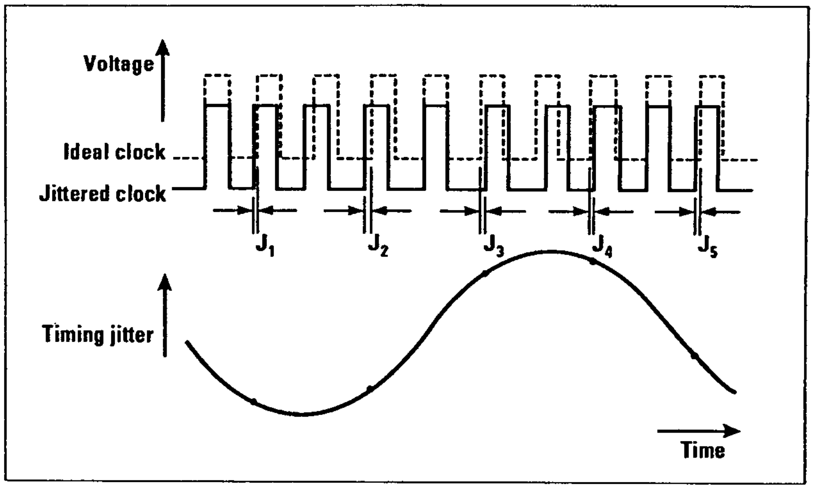



*Figure A. Jitter is the deviation of the clock edges from their ideal positions in time.*

## B. Phase/Time Deviation, Modulation

Jitter is incidental phase modulation measured as a time deviation rather than a phase deviation. If you look at a phase progression plot, (phase plotted versus time), a constant unmodulated clock would be a straight line of positive slope equal to the frequency. Modulation, or jitter is a deviation from linear (see Figure B).

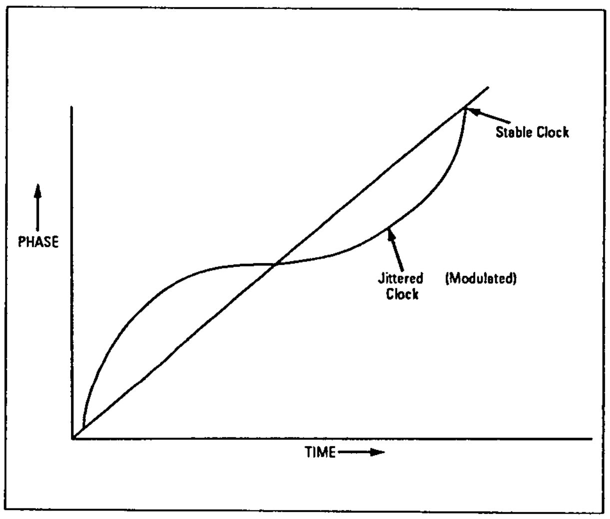



*Figure B. A stable non-jittered clock's phase is a linear progression with time, whose frequency is △phase /△time. A jittered clock's phase progression is non-linear.*

Jitter is measured as the TIME deviation - when an edge occurred relative to when it should have occurred. Phase modulation is measured as the phase deviation of the signal from its expected phase (see Figure C).

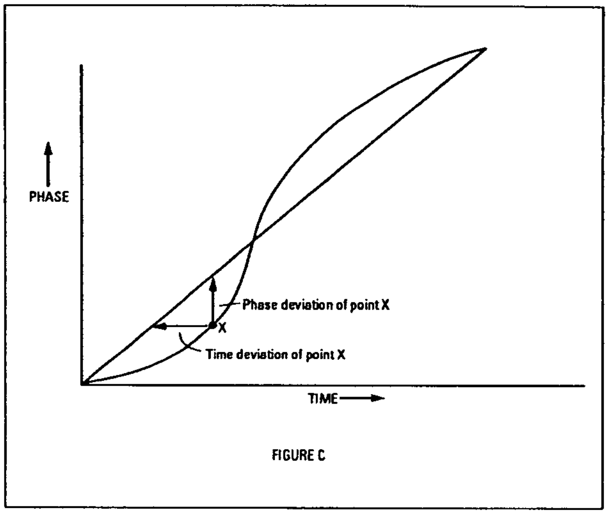



*Figure C. Jitter is defined as a digital signal's deviation in time from its ideal position. Phase modulation looks at the signal's deviation in phase from its ideal.*

## C. Single Channel Measurements

If you have access to the stable (non-jittered clock) as well as the jittered clock, you can measure the time difference between the two directly.

In most cases you will deal with only the jittered clock. For the HP 5372A to derive the time at which the clock edges should have occured, in order to calculate time deviation, you have two choices:

1. Enter the clock frequency as a setup parameter.

2. Have the HP 5372A estimate the clock frequency from the measured jittered clock. The estimation method employed is called the bi-centroid mean. See Figure D. It is close in precision to a least-squares fit and significantly faster to perform (Figure D).

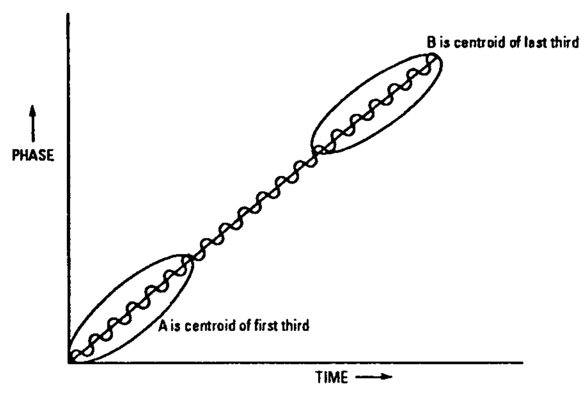



FIGURE D

*Figure D. The bi-centroid algorithm is a precise and efficient algorithm for deriving the underlying clock frequency of a modulated signal. The mean of the first and last third of the data points is calculated. The straight line joining the two means is the estimated clock frequency.*

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