Errata

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HP References in this Manual

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User's Guide

HP 5372A Option 040
Jitter Spectrum Analysis

Notice

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User's Guide

*This guide describes how to use the Jitter Spectrum Analysis, Option 040, for the HP 5372A Frequency and Time Interval Analyzer. This information applies to instruments having HP 5372 firmware revision: **3127**.*

The firmware revision number is listed on the System menu at the bottom of the display.

If the number on this page does not match your firmware revision number, refer to the Manual Updating Changes included with this guide.

HP 5372A Option 040
Jitter Spectrum Analysis

In This Book

What is Jitter Spectrum Analysis, Option 040?

Jitter Spectrum Analysis, Option 040 (also referred to as the FFT in this guide), extends the capabilities of the HP 5372A by adding spectral analysis of modulation-domain results. This feature performs an FFT on the results first captured in the Time Variation graph (this graph plots measurement results, such as frequency or time interval, versus time). The resulting FFT graph displays the spectral content of the waveform displayed on the Time Variation graph.

How this option is documented

This user's guide describes the added capabilities of the FFT and how to use them. This guide does not take the place of the HP 5372A Operating Manual and Programming Manual, in fact this guide builds on the information presented in those books. Use them to learn about the details of the operating and programming characteristics of the HP 5372A.

How this guide is organized

This user's guide is organized to make different levels of information as accessible as possible, depending on what your needs are. Read the summaries below to help determine where to go from here.

Chapter 1, Getting Started Start here to read about what the Jitter Spectrum Analysis option is showing with the FFT graph. Here you will find procedures for enabling the FFT and displaying the FFT graph results. A short example of making a measurement for FFT analysis is presented.

Chapter 2, Using Jitter Spectrum Analysis This chapter builds on Getting Started and explains how to optimize the FFT analysis using a three-step process. This is followed with three application examples demonstrating how to measure clock jitter, phase noise, and data jitter.

Chapter 3, Features The FFT features are grouped on the Math menu. This chapter describes how to use the features such as windowing, averaging, and resampling. A chart is included that summarizes the functions and arming modes that support the FFT. The FFT graph and its labels are explained and the two measurements added with the option (Phase Deviation Data and Time Deviation Data) are described.

Chapter 4, Programming Information This chapter describes the commands used for computer control of the Jitter Spectrum Analysis option and includes example programs.

Chapter 5, Concepts This chapter defines in greater detail some of the topics introduced in other parts of this guide. The first topic is a description of an FFT. The following topics are covered as well: the relationship between the Time Variation graph and the FFT graph, the FFT graph spectral resolution, resampling, aliasing, windowing, and averaging.

Appendix A This is a generic presentation on how to set the HP 5372A to make measurements.

Appendix B This appendix contains graphs to help you estimate the number of measurements and the sample interval to provide the desired FFT spectral resolution and frequency span.

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Getting Started

1

Getting Started

Jitter Spectrum Analysis (FFT) Overview

To help describe what Option 040 adds to the HP 5372A, this overview compares the option with the information a spectrum analyzer can add to a signal displayed on an oscilloscope. The spectrum analyzer displays the spectrum of the oscilloscope signal. Each sine wave line on a spectrum analyzer is a component of the total signal. Similarly, the Jitter Spectrum Analysis option shows the spectrum of the modulation that the HP 5372A measures. The modulation includes both intended modulation, such as frequency modulation in radio broadcasting, and unintended modulation, such as clock jitter in a telecommunications network.

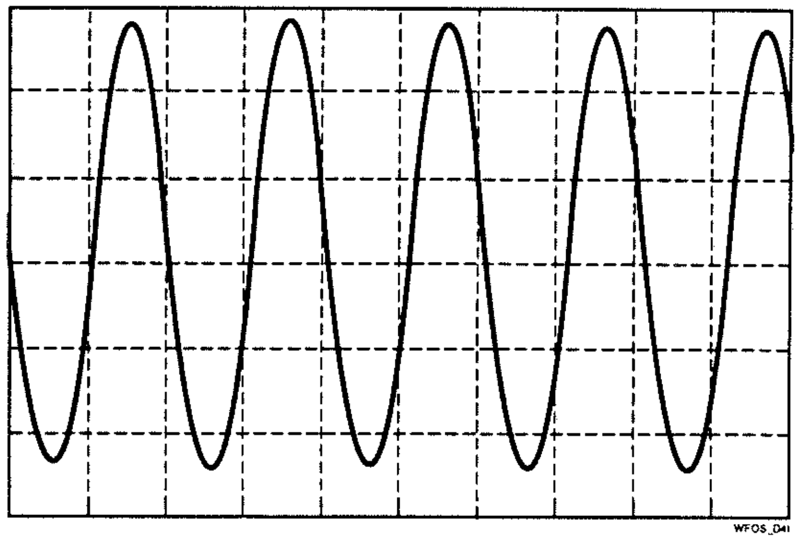
Spectrum of the modulation

The spectrum is presented on the FFT (fast Fourier transform) graph. The graph plots the results of an FFT performed on the data from the HP 5372A Time Variation graph. The spectral components are displayed. The amplitude of the components indicates the magnitude of the deviation from the carrier, and the x-axis position shows the frequency of the modulation.

Sine Wave on an Oscilloscope

If a 1-MHz sine wave signal is connected to an oscilloscope, the signal will appear as shown below. This is the voltage amplitude of the input signal versus time.

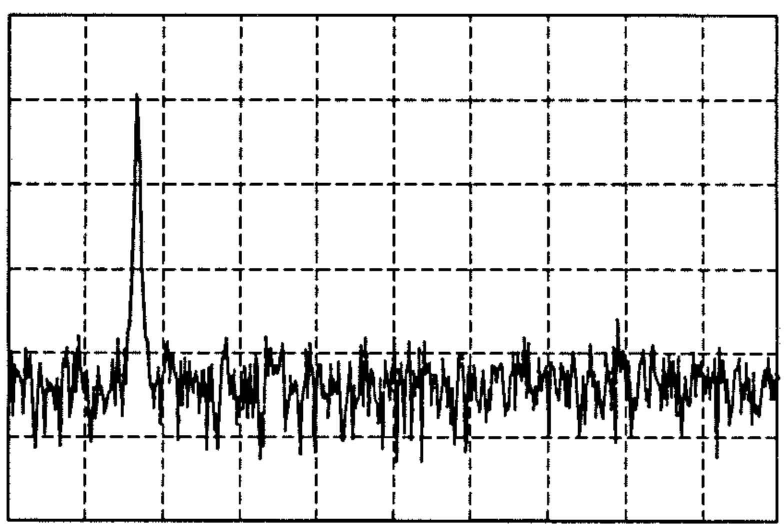
The oscilloscope displays the voltage of the input signal as it changes over time.



Sine Wave on a Spectrum Analyzer

The spectrum analyzer represents a signal as amplitude versus frequency. If the signal from the oscilloscope is connected to a spectrum analyzer, you would see a display as shown. The spectrum analyzer shows that most of the energy is at one frequency. The amplitude indicates the power of the signal.

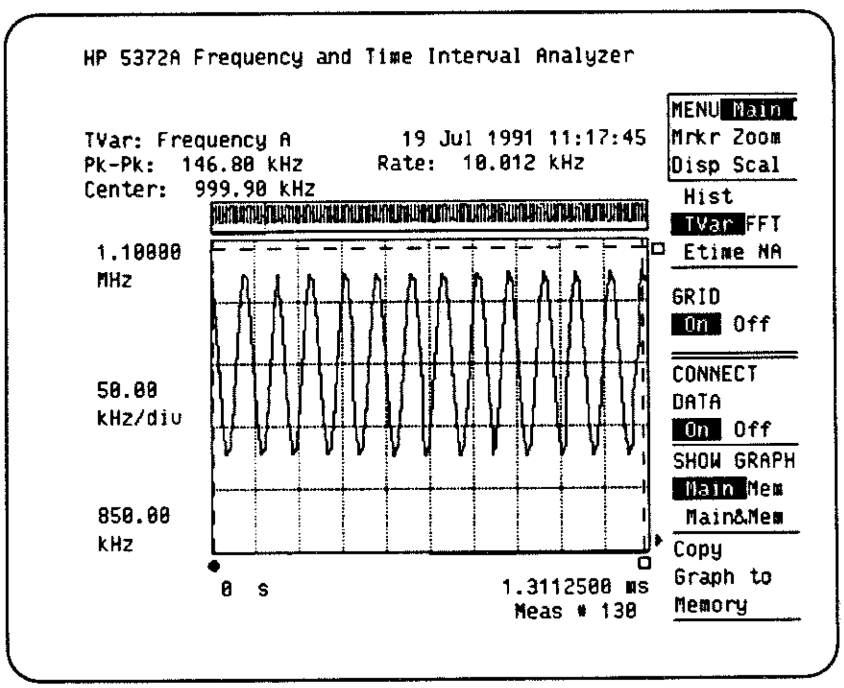
The spectrum analyzer transforms the time-domain waveform into a magnitude display of its frequency components. This is the frequency spectrum of the input signal.



Modulated Sine Wave on the HP 5372A Time Variation graph

In the display below, a 1-MHz carrier with a 10-kHz sine wave modulation rate is applied to the HP 5372A. A frequency measurement is made and the resulting data is displayed on the Time Variation graph. This data is the result of measuring frequency and displaying it versus time to reveal the modulating signal. The Modulation Values feature is enabled here to display the modulation rate, peak-to-peak deviation, and the center frequency. Again, this display shows the frequency of the input signal as a function of time. From the display, you can see that the frequency of the input signal is changing sinusoidally at a rate of 10.012 kHz.

The HP 5372A's Time Variation graph displays the changing frequency of the input signal over time.



SC1_3D4

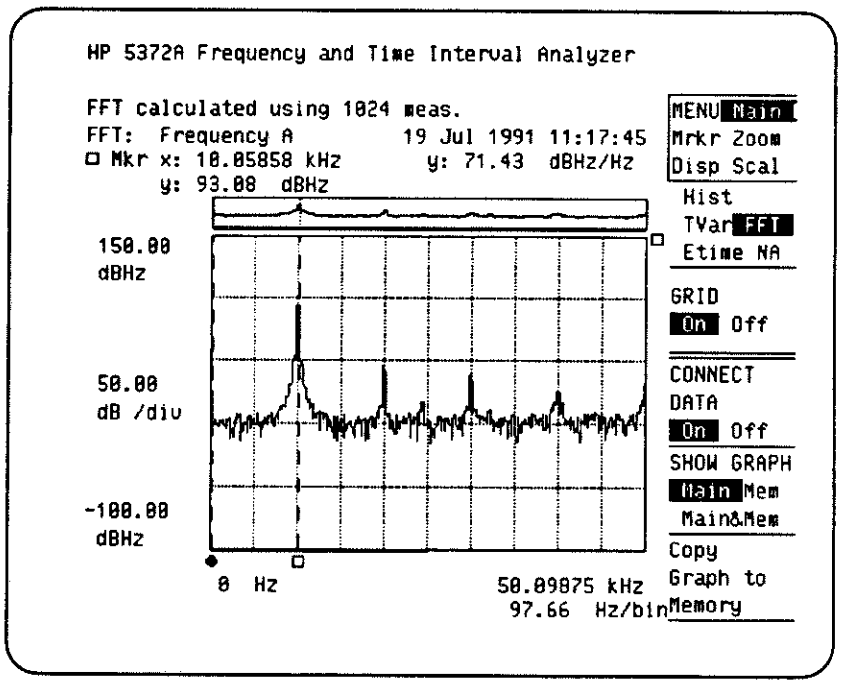
Modulated Sine Wave on the HP 5372A FFT Graph

The data that is first acquired and displayed in the Time Variation graph is input to the FFT algorithm. The result reveals the spectral content of the modulating signal. The main spur is at 10 kHz on the x-axis, and some harmonics of that signal are visible as well. The y-axis scale indicates the magnitude of the deviation from the carrier. Note that in this case, most of the deviation is due to the modulation at 10 kHz. It is scaled logarithmically relative to a unit amount, 1 Hz. It is important to realize that you are looking at an FFT of the Time Variation graph waveform (the frequency vs. time graph shown on the previous page).

NOTE

For more information on how to relate the amplitude of FFT modulation components to deviation on the Time Variation graph, see chapter 5 of this guide under, "Interpreting the Time Variation and FFT Results."

The FFT feature transforms the Time Variation graph waveform into a magnitude display of the frequency components of the modulation. This is the frequency spectrum of the modulation on the input signal.



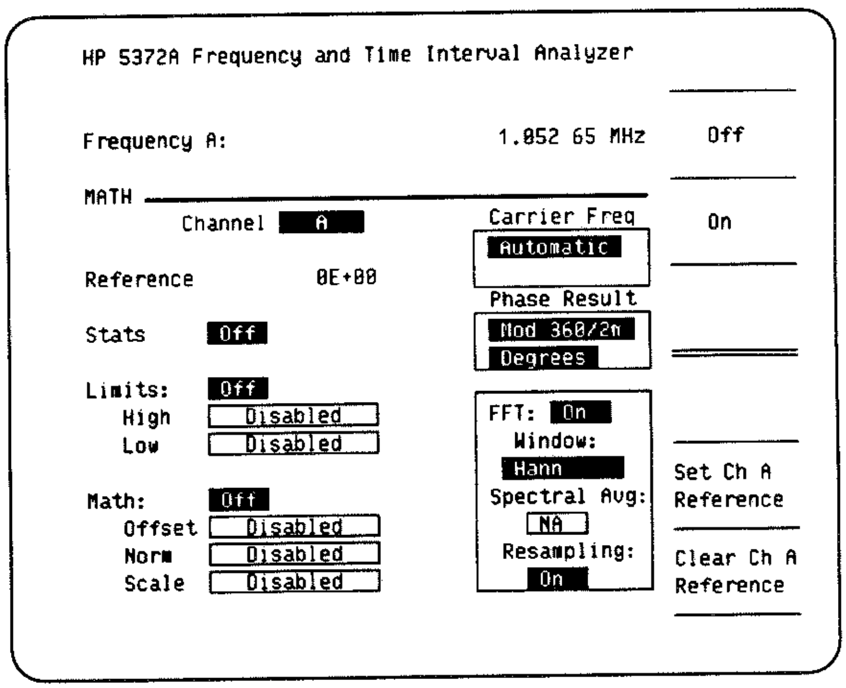
SCI_4DR

To enable the FFT feature

The FFT feature is enabled on the Math menu.

1. **Press the Math hardkey.**
2. **Move the menu cursor to the FFT field.**
3. **Press the On softkey.**

The Math menu contains the FFT controls.



SC1_5D4

NOTE

*When the HP 5372A is preset using the Preset hardkey or the *RST command over the HP-IB, the FFT feature is disabled. Off is the default state for FFT because execution of the FFT algorithm does add to the time it takes the HP 5372A to acquire and display data.*

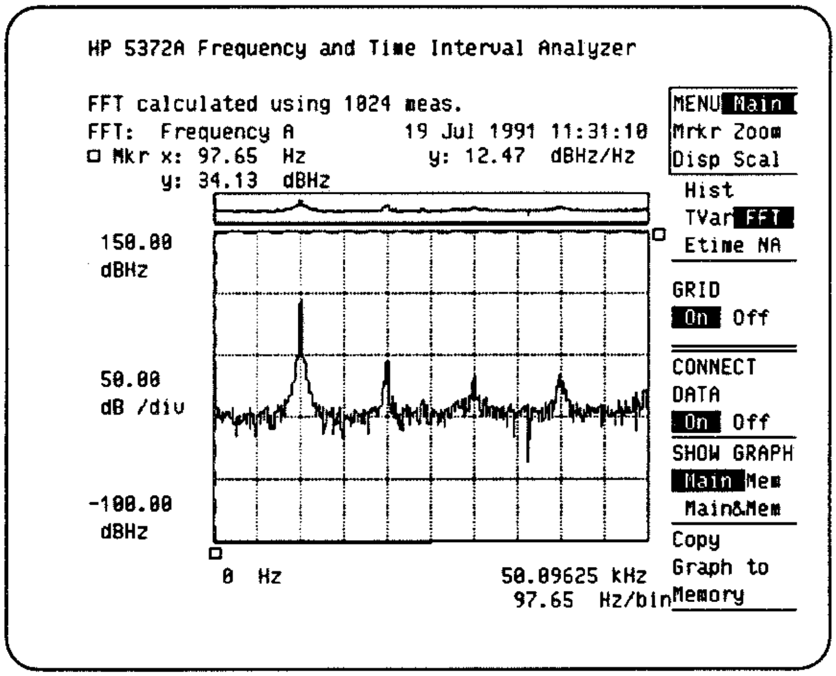
Spectral Averaging for the FFT graph is available whenever the number of blocks is set greater than one on the Function menu.

To display the FFT graph

Once the FFT is enabled on the Math menu, the FFT graph can be selected on the Graphic menu.

1. **Press the Graphic hardkey.**
2. **Select the Main menu with the top softkey.**
3. **Select the FFT graph with the second softkey from the top.**

The FFT graph is accessed in the same way as the other standard graph displays. The Grid background is set to On.



SCI_6D4

To make a measurement for FFT analysis

For the most part, preparing to make an FFT measurement is no different from the way you would normally set the HP 5372A to measure. Because the FFT algorithm is applied to the data displayed in the Time Variation graph, which displays measurement data vs. time, your first consideration is to configure a measurement setup that makes sense in terms of that graph display.

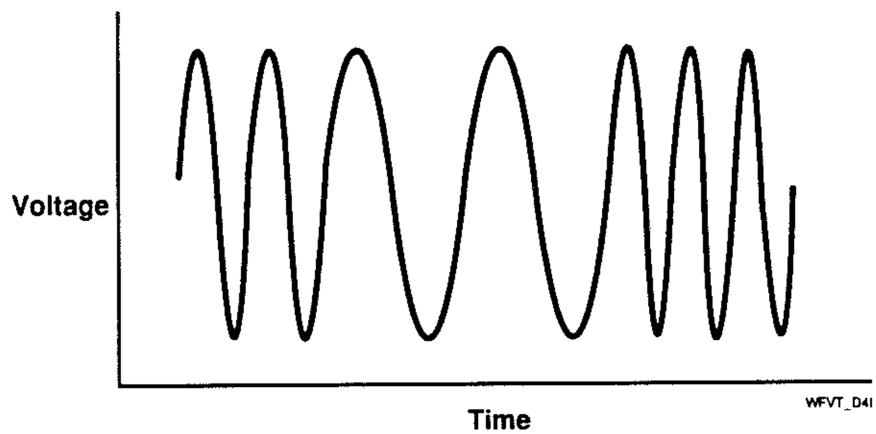
Once you feel comfortable with what the Time Variation graph is showing you, check the FFT graph and then, if necessary, modify the number of measurements or the sample interval to optimize the FFT display for your needs.

The following procedures show how to set up the HP 5372A to acquire data and then use the FFT feature to analyze that data. Use these procedures as a guide when making your first FFT measurements.

Signal to be measured

The signal used for this example is a 1.544-MHz carrier with frequency modulation. The task here is to determine the characteristics of the modulation using the FFT feature. As you can see below, an oscilloscope view of the signal indicates a changing frequency condition.

A time-domain view of a carrier with FM. The FFT will analyze the modulation on the carrier.



Preliminary setup steps

It is recommended that you begin every setup with a preset of the HP 5372A. This sets the instrument's features to their default condition. Since the FFT defaults to Off, enable the FFT feature as part of the preliminary setup.

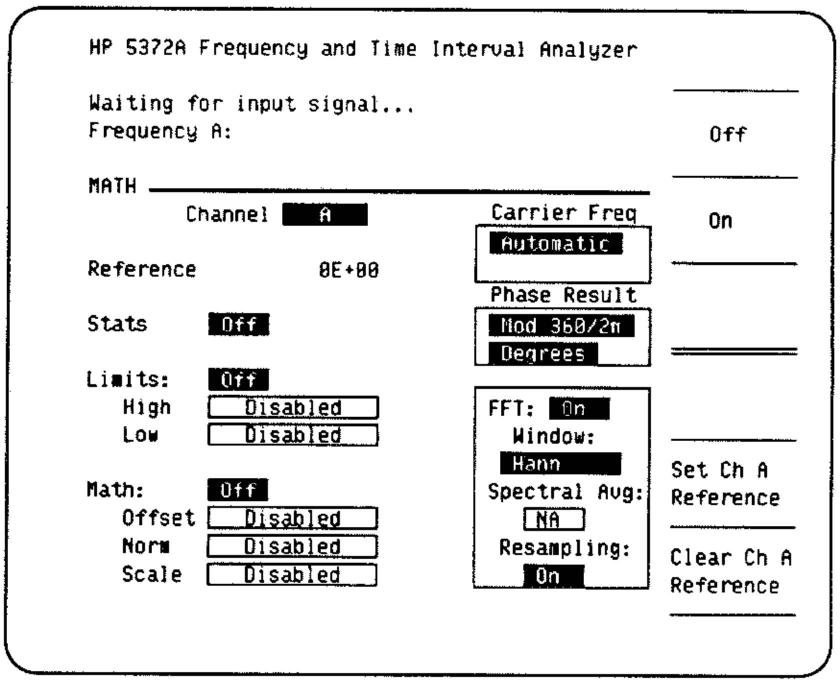
1 **Press the Preset hardkey.**

2 **Press the Math hardkey.**

3 **Move the menu cursor to the FFT field on the Math menu.**

4 **Press the On softkey.**

FFT is turned off by a preset of the HP 5372A. Don't forget to enable the FFT before making measurements.



SC1_7D4

Set measurement function and input channel

Always start with the Function menu. On it you select measurement function, input channel, and sampling conditions.

1 **Press the Function hardkey.**
2 **Select Frequency to measure a signal with frequency modulation.**
3 **Select input channel A or B for this kind of measurement.**

Setup Hints

The measurement function that you use to produce results for the Time Variation graph will most often be the same one to use for FFT analysis.

NOTE

The FFT is not supported for the following measurement functions:

- *Rise Time*
- *Fall Time*
- *Positive Pulse Width*
- *Negative Pulse Width*
- *Duty Cycle*
- *Peak Amplitude*
- *Histogram Time Interval*
- *Histogram Continuous Time Interval*
- *Histogram ± Time Interval*

The FFT does not operate with the following channel selections:

- *Ratio measurements, such as B / A*
- *Difference measurements, such as A – B*
- *Sum measurements, such as A + B*
- *Two-result measurements, such as A & B*

Set number of measurements

✓ The preset condition of 1 block of 100 measurements is used here to demonstrate why the number of measurements is important in order to obtain valid FFT results.

Setup Hints Make one block of measurements to begin. This will produce quick results and usually provide enough information to indicate what needs to be investigated more closely.

When the number of measurements field is highlighted, power-of-two softkey choices are available.

```
HP 5372A Frequency and Time Interval Analyzer

Waiting for input signal...
Frequency A:                                          128

FUNCTION ____________________________________________
Frequency     Measurement  Channel   A                256
Acquire             1 block  of      100 meas
Pre-trigger Off     Total Meas = 100
                                                      512
Automatic     Arming Mode ___________________
Block Holdoff:
  Arm a block of measurements automatically          1024


 Sample Arm:                                          2048
 Arm sampling on meas channel automatically

                                                      4096
```

SC1_6D4

Use Pre-trigger?

✓ Although an FFT can be produced for a Single block pre-triggered acquisition, Pre-trigger is not used for this measurement example.

Setup Hints

Use Pre-trigger when you want the HP 5372A to collect measurement data until a specified time interval value is measured or a signal on the External Arm input is detected to end the acquisition. The HP 5372A can collect data before and after the specified event. Refer to chapter 10, "Pre-trigger Menu," in the *HP 5372A Operating Manual* for more information.

NOTE

For measurements using Pre-trigger, the FFT is only supported for the Single block selection. No FFT is produced for Multiple block Pre-trigger measurements.

Set arming and sampling

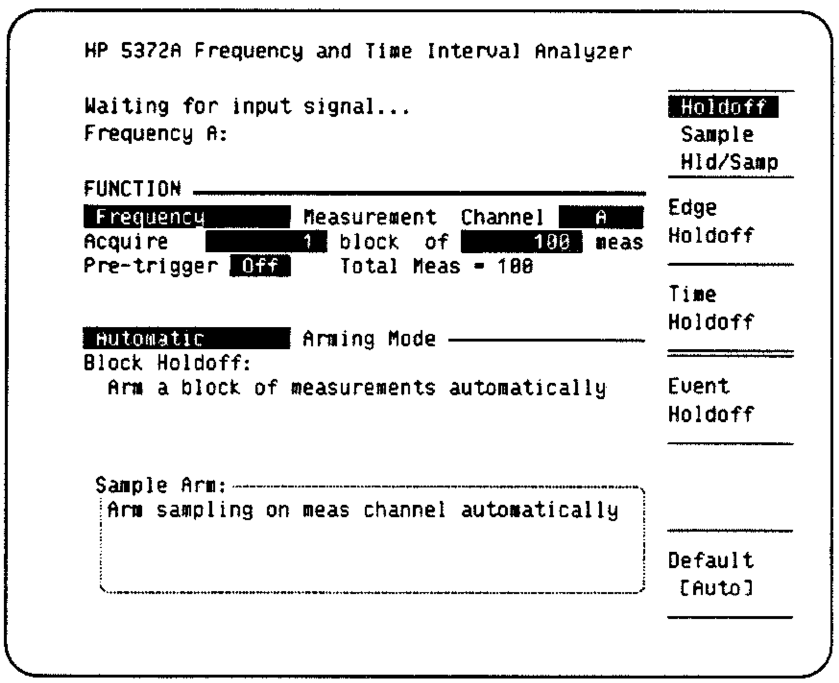
✓ Use the Automatic arming mode when investigating an unfamiliar signal.

Setup Hints

Whenever possible use Automatic arming as a starting point. This normally provides the fastest sampling rate and the widest frequency span for the FFT in the shortest acquisition time. Once you have determined the FFT graph characteristics of interest, the number of measurements and the sample interval can be modified to achieve the needed span and resolution. The tradeoff for wide frequency span is a fairly coarse spectral resolution. This example demonstrates how this works.

The FFT is compatible with the majority of the HP 5372A's arming choices. Refer to chapter 5, "Arming," in the *HP 5372A Operating Manual* for information on the complete set of arming modes and how they work.

Your choice of arming mode determines how the input signal is sampled. Automatic arming provides the fastest sampling.



SC1_904

NOTE

The FFT is not supported for the following continuous arming mode:

- *Externally Gated*

The FFT is not supported for all non-continuous arming modes:

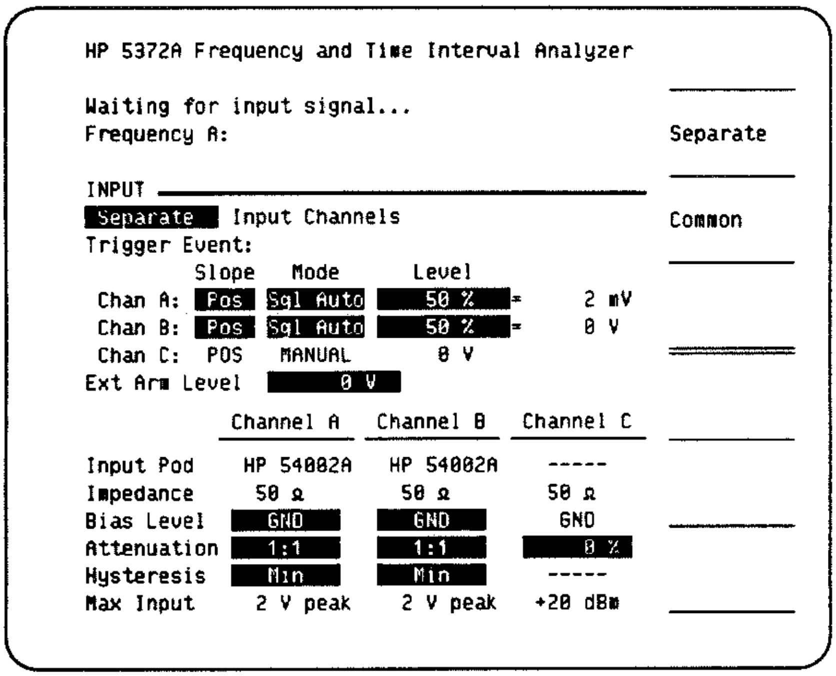
- *Time Sampling*
- *Edge/Time*
- *Edge/Event*
- *Time/Time*
- *Event/Event*
- *Manual*

Set the input conditioning features

1 **Press the Input hardkey.**
2 **Configure the settings as needed for the input signal.**

Setup Hints The preset conditions are usually acceptable for most signals. Refer to chapter 8, "Input Menu," in the *HP 5372A Operating Manual* for a full description of the input features.

The Input menu controls how the HP 5372A will detect the input signal. The default settings provide detection on the rising edge and the 50% amplitude level.



SC1_1004

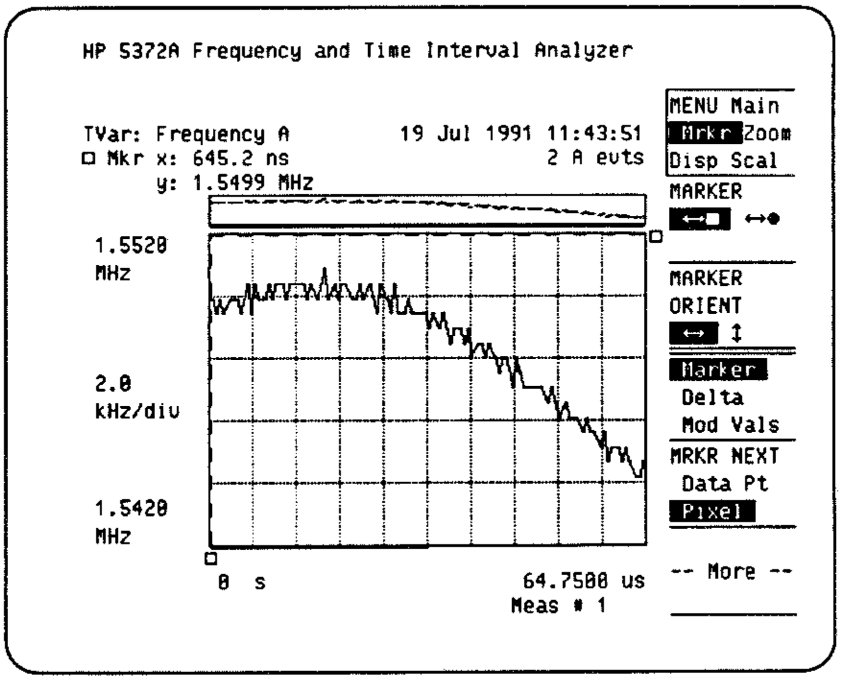
Make a measurement and view the Time Variation graph

1 **Press the Single/Repet hardkey.**
2 **Press the Graphic hardkey.**
3 **Select the Time Variation graph (TVar) using the second softkey from the top.**
4 **Set Connect Data to On using the fourth softkey from the top.**

Observations

One glance at the Time Variation graph below indicates that not enough data was acquired. Less than one period of the modulating signal can be seen. The number of measurements should be increased to provide more data for analysis. It is recommended that at least several cycles of the modulation be acquired to produce a more easily interpreted FFT.

This is an example of insufficient measurements on the Time Variation graph for an accurate FFT analysis.



SC1_11D4

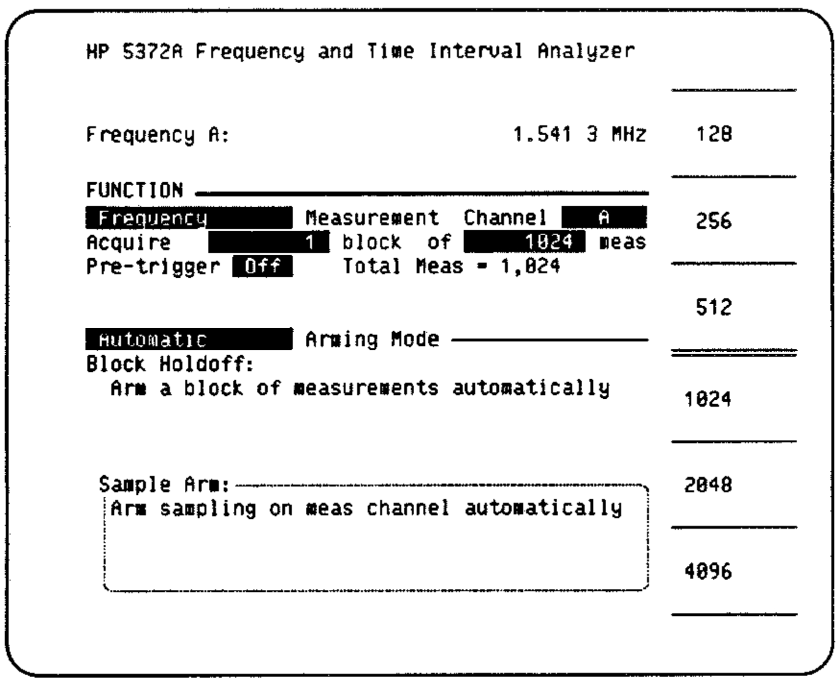
Acquire more data

1. **Press the Function hardkey.**
2. **Move the menu cursor to the number of measurements field (set to 100 for the first measurement acquisition).**
3. **Press the 1024 softkey.**

Setup Hints

When the menu cursor is highlighting the measurement field, power-of-two measurements per block are presented as softkey choices. Although measurement sizes that are not powers of two can be entered, the FFT algorithm operates faster with a power-of-two selection.

The measurement size is increased and a new acquisition is started when the 1024 softkey is pressed.



SC1_1204

NOTE

The FFT can operate on measurement sizes that are not powers of two, but processing time will be slightly longer.

In most cases if an odd number of measurements is entered, the FFT is based on the entered number of measurements minus one.

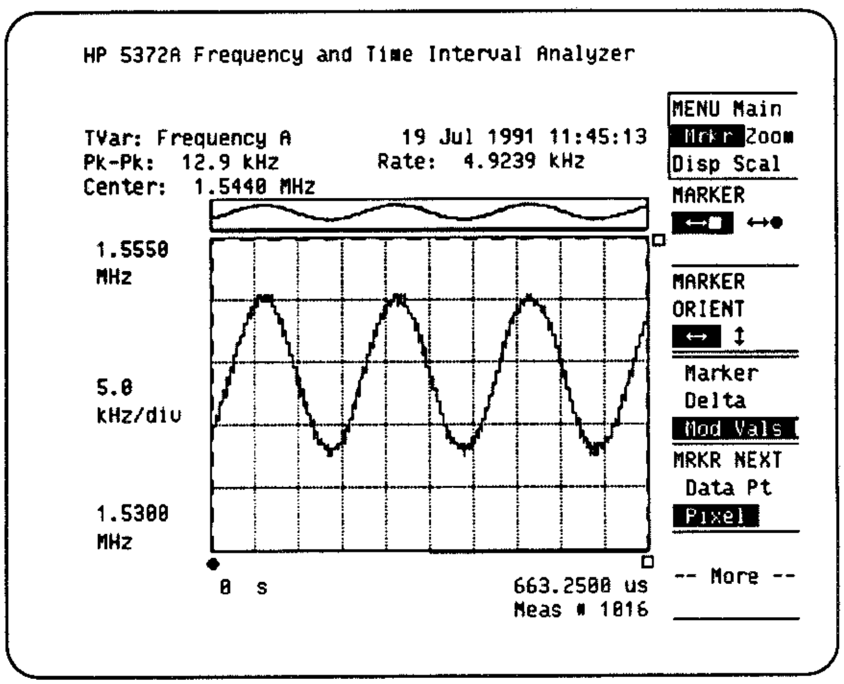
Check the modulation values on the Time Variation graph

1 **Press the Graphic hardkey.**
2 **Select the Mrkr (Marker) menu using the top softkey.**
3 **Rotate the knob to move the marker to the right edge of the display.**
4 **Select Mod Vals using the fourth softkey from the top.**

Observations

Above the graph is displayed the peak-to-peak deviation, the carrier frequency (Center), and the modulation rate. The main modulation is at 4.9 kHz. The data looks a little noisy indicating there may be other modulation components involved. The Time Variation graph cannot reveal specific characteristics of any additional modulation elements. The next step is to observe the FFT analysis.

The Time Variation graph shows several cycles of the modulation. The FFT will transform this data to produce the frequency spectrum of the modulation.



SCI_1304

View the FFT graph

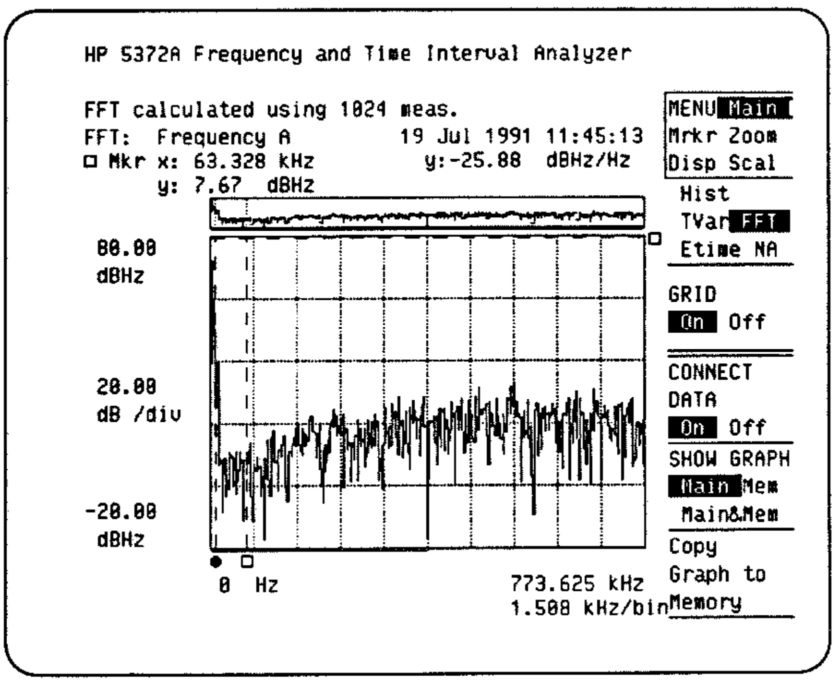
1 **Select the Main menu using the top softkey.**
2 **Select the FFT graph using the second softkey from the top.**

Observations

The FFT analysis is performed on the Time Variation graph data. As a result, a spectral line, indicating the main source of the modulation, can be expected on the x-axis at approximately 4.9 kHz. Its y-axis magnitude is a function of the peak-to-peak deviation of the sine wave on the Time Variation graph.

The x-axis values show a frequency span of approximately 770 kHz. The only portion of interest looks to be close to the carrier (near 0 Hz at the left edge of the display). Using the Zoom feature this area can be expanded to provide a better look at the close-in modulation.

The FFT graph shows the frequency content of the modulation out to 773 kHz from the carrier. A closer look near the carrier is needed.



SC1_14D4

NOTE

The FFT graph does not display the carrier. It shows the jitter or modulation components offset from the carrier.

Zoom on the data

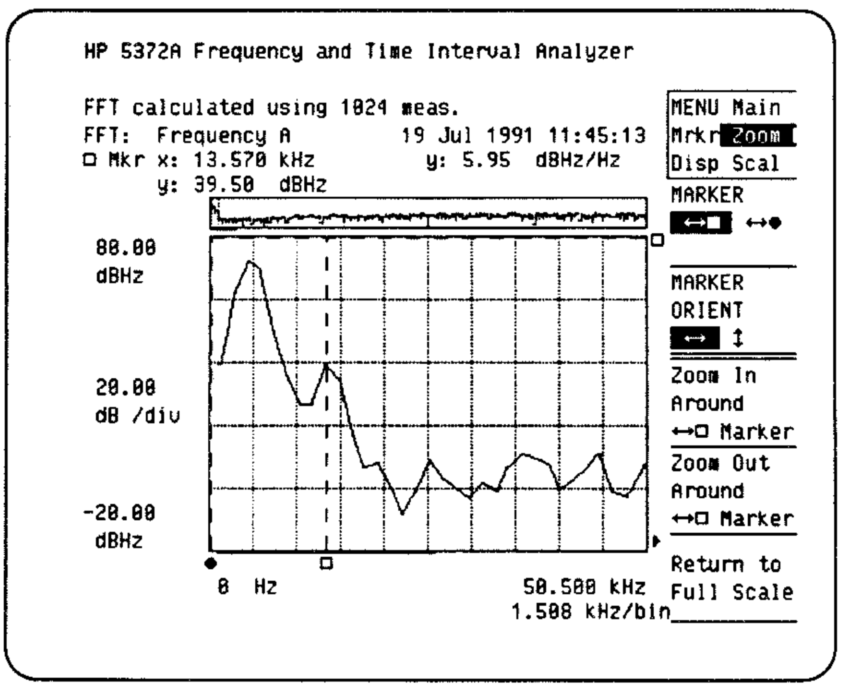
1 **Select the Mrkr (Marker) menu using the top softkey.**
2 **Press the More softkey.**
3 **Press the Move Marker to Maximum softkey.**
4 **Select the Zoom menu using the top softkey.**
5 **Press the Zoom In softkey several times.**
6 **Move the marker over the secondary spur and identify its frequency and amplitude.**

Observations

This action magnifies the area of interest at the position of the active marker. The main spur is the modulating signal identified on the Time Variation graph, but there is another modulation spur close to the main spur.

The FFT graph reveals that two signals are modulating the carrier. The secondary spur is at a modulation rate of approximately 13.5 kHz. Depending on the application that involves this signal, this secondary modulation signal may be causing unacceptable behavior. The FFT graph allows characterization of this "interference" modulation. This information was not available on the Time Variation graph.

Zooming on the FFT shows a secondary modulation component near the one identified on the Time Variation graph at 4.9 kHz.



SC1_15D4

To more precisely characterize the modulation spur

In this example, the main modulation is at approximately 5 kHz. In order to precisely characterize the modulation, the resolution of the FFT graph should be about ten times better than the resolution of the signal of interest. So, if you are looking for a 5-kHz spur, you would like to have a resolution of 500 Hz. Resolution on the FFT graph is expressed as a measure of Hertz per bin. The graph label below the x-axis values shows a resolution of 1.5 kHz per bin (on the previous page). One way to increase spectral resolution is to make the sample interval longer (slower sample rate). This is demonstrated in the following procedure.

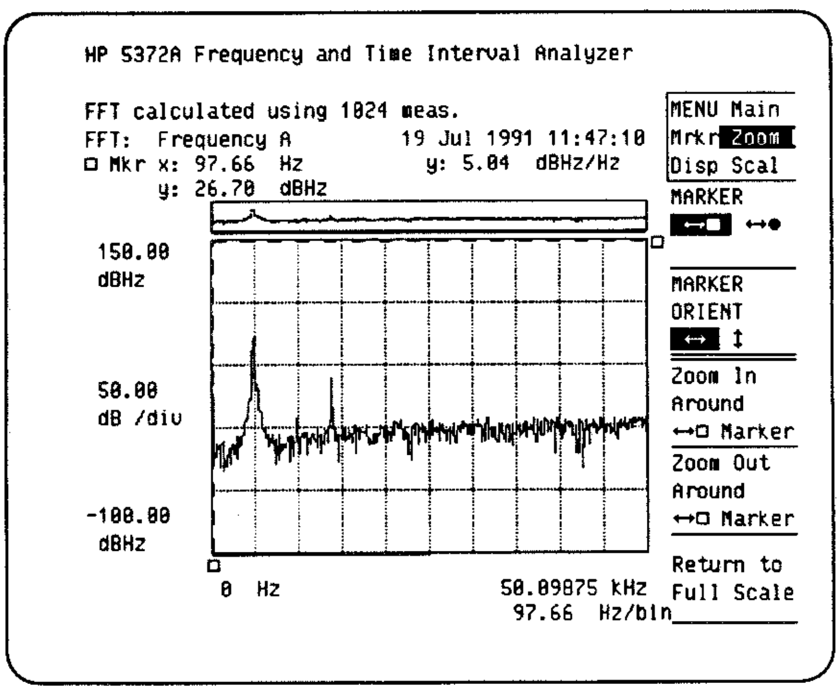
Another way to increase spectral resolution is by increasing the number of measurements. A change to the number of measurements does not affect the frequency span.

1 **Press the Function hardkey.**
2 **Move the menu cursor to the Arming Mode field.**
3 **Select Sample arming modes with the top softkey.**
4 **Select Interval Sampling with the second softkey.**
5 **Press the Graphic hardkey.**

Observations

The display shows another acquisition made using a sample interval value of 10 µs. Now the frequency span is 50 kHz (was 770 kHz) and the resolution is about 100 Hz/bin (this is better than the minimum improvement to 500 Hz/bin that was desired).

The spectral resolution of the FFT graph (indicated by the Hz/bin label below the graph) has been improved by changing the sample interval. The two modulation components are displayed with better spectral resolution.



SC1_16D4

To make a relative deviation measurement

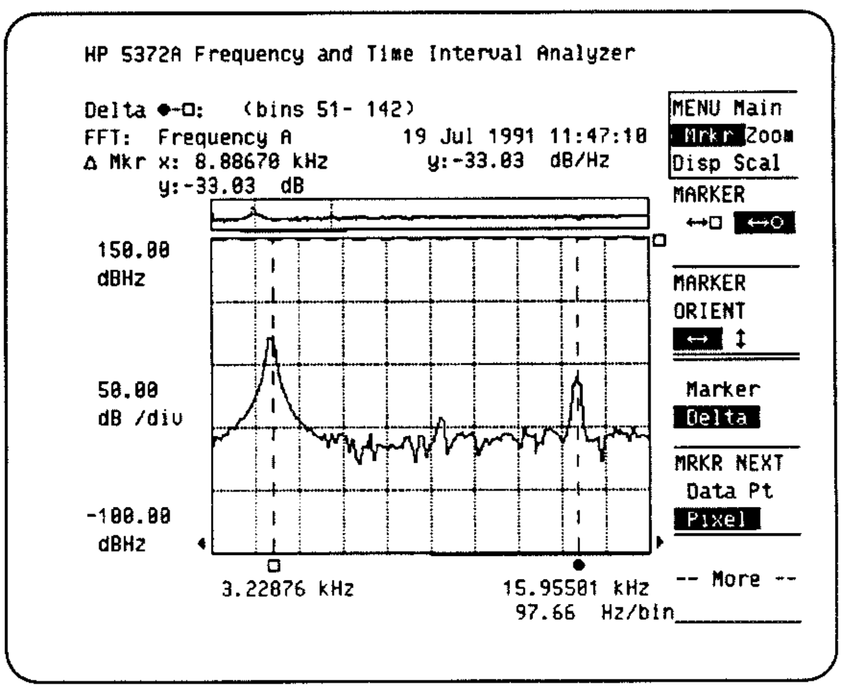
1. **Rotate the knob to move the active marker between the two spurs of interest.**
2. **Use the Zoom softkeys to provide a close-up while keeping both spurs on the display.**
3. **Set the marker on the peak of one spur.**
4. **Select the Mrkr menu with the top softkey.**
5. **Press the More softkey once.**
6. **Press the Move to Location softkey.**
7. **Move the marker to the other spur peak.**
8. **Press the More softkey once.**
9. **Select Delta with the fourth softkey from the top.**

Observations

The y-axis scale of the FFT graph indicates the modulating signal's contribution to the deviation from the carrier. The difference in relative amplitude here is approximately 33 dB.

At this point, a determination would need to be made as to whether or not the secondary spur is enough to cause problems with the intended application.

The amplitude difference of the two modulation components can be used to help determine if the cause of the secondary modulation requires attention.



SC1_1704

Conclusions

1. Similar to how a spectrum analyzer shows the spectrum of a signal, the Jitter Spectrum Analysis option shows the spectrum of the modulation or jitter on a signal.

2. This option performs an FFT of the Time Variation graph results.

3. The FFT can extract information about complex modulation on a signal that cannot be easily determined any other way. This chapter demonstrated how the FFT can help characterize a signal being modulated by two sources.

Using Jitter Spectrum Analysis

2

Using Jitter Spectrum Analysis

In this chapter

This chapter builds on the procedures introduced in chapter 1. It is assumed that you already know how to set up the HP 5372A to make measurements and display the results in the FFT graph as described in chapter 1. This chapter concentrates on the following topics:

- A three-step process to help you produce meaningful FFT graphs.
- The issues you must consider to avoid making incorrect conclusions based on your observations of the FFT graph.
- Several applications that illustrate the tradeoffs and considerations required for Jitter Spectrum Analysis (FFT). The applications cover how to measure and analyze clock jitter, phase noise, and jitter on a data signal.

Guidelines for using Jitter Spectrum Analysis

Obtaining maximum benefit from the FFT means making tradeoffs based on what you are interested in seeing on the graph. You can increase the FFT spectral resolution by increasing the number of measurements or by lengthening the sample interval. The price you pay when raising the number of measurements is an increase in the measurement processing time. Lengthen the sample interval and the effect is a reduction in the frequency span of the FFT graph. This may be what you want, but now the input signal is sampled less often, increasing the possibility of signal components being aliased into your FFT graph. This chapter focuses on these issues and suggests ways to handle the tradeoffs in order to increase the value you can gain from the FFT graph.

Three-step process for FFT analysis

The guidelines for using FFT analysis are presented as a series of three main steps. These general recommendations should help you produce an FFT graph that meets your needs. All the steps should be considered, but not all three may be appropriate for every measurement situation. These steps build on the procedures introduced in chapter 1.

Step one. See the big picture.

✓ Use Automatic arming for a maximum frequency span.

Automatic arming produces the smallest possible sample interval, which results in the widest possible frequency span. Automatic arming also minimizes the possibility of aliasing higher frequency components into your frequency span of interest (aliasing is discussed later in this chapter). Aliasing should always be a concern.

Use the Time Variation graph

The FFT algorithm transforms the measurement data that you see on the Time Variation graph. Use this graph to help interpret the FFT graph.

Zoom on the data

Use the zoom feature, if necessary, to see the close-in frequency components on the FFT graph. Note that the data is not changed by zooming. Zooming only produces a close-up view of the components of interest.

For better resolution

If you require better spectral resolution, increase the number of measurements. Increasing the number of measurements effectively divides the FFT graph's x-axis into more frequency bins producing better resolution without affecting the span.

The spectral resolution of the FFT graph is expressed as Hz/bin. This value appears below the bottom right corner of the graph. Bin is the name for a segment of the x-axis frequency span. The value assigned to a bin depends on the frequency span and the number of bins across the span. (The number of bins is one-half the number of measurements used to calculate the FFT.)

The FFT spectral resolution value is the result of dividing the span by the number of bins. Additional bins divide the frequency span into smaller increments providing better resolution per bin. When the number of measurements is already set to its maximum value, greater resolution can only be achieved by lengthening the sample interval as explained in the second step.

Step two. Fine tune the FFT graph for your needs.

✓ If the resolution is not sufficient when the number of measurements is set to the maximum value, you must change the arming mode to one that lets you increase the sample interval. Use one of the arming modes that provides continuous interval sampling. Those arming modes are:

- Interval Sampling
- Edge / Interval
- Time / Interval
- Event / Interval

For a full description of the arming modes, refer to chapter 5, "Arming," in the *HP 5372A Operating Manual.*

Automatic sampling interval

If you want to determine the interval that is used when Automatic sampling is selected for Frequency or Period measurements, follow this short procedure:

1 **Press the Numeric hardkey.**
2 **Select Main with the top softkey.**
3 **Set Expand to On with the softkey third from the top.**

Note that the Gate value on the Numeric screen is the sample interval for each measurement. When this value is increased on the Function menu, the time over which each measurement is made is increased.

Increasing the sample interval with no change to the number of measurements will produce a reduced frequency span with an associated increase in resolution because the same number of bins will be divided over a smaller span. At this point you might want to reduce the number of measurements if the resolution is greater than you need. The more measurements, the longer the measurement acquisition and FFT calculation will take. When the number of measurements is doubled, the resolution per bin is divided by two.

Calculate the sample interval

If you want to limit the frequency span of the FFT graph (x-axis), use the formula below to calculate the sample interval.

The formula for calculating the sample interval to produce a specific frequency span is:

$$Sample\ Interval = \frac{1}{(FFT\ frequency\ span \times 2)}$$

For example, if the desired span is 50 kHz, the sample interval should be 10 µs.

Calculate # of measurements

If you want a particular spectral resolution, use the formula below to calculate the number of measurements.

The formula for calculating the number of measurements to produce a spectral resolution (bin width) based on a particular sample interval is:

$$\text{Number of measurements} = \frac{1}{(\text{sample interval} \times \text{bin width})}$$

For example, if the sample interval is 1 μs, and the desired resolution is 1 kHz, then the number of measurements required is 1000.

See "More on fine tuning your FFT" later in this chapter for information on selecting the appropriate sample interval and number of measurements for a desired spectral resolution and frequency span.

Step three. Check for aliased components in your FFT graph.

✓ Check your FFT graph results for aliased frequency components.

You must always be concerned about the possibility of aliased modulation components in the FFT graph. To minimize the possibility of aliasing, it is recommended that the modulation components of interest be sampled at least 10 points per cycle to produce an accurate FFT transformation. The HP 5372A samples signals at their zero crossings, so the maximum sample rate is equal to the carrier frequency (or less, if the signal is above 10 MHz). Any modulation components sampled less than two points per cycle will produce aliasing in the FFT graph.

Here is an example to show the relationship between sampling of the input signal and valid sampling of the modulation. You have a 1-MHz signal being modulated at a 10 kHz rate. When the HP 5372A measures this signal using Automatic arming, a sample is collected every 1 μs (1/1 MHz). This produces 100 samples per cycle of the 10-kHz modulation, which has a period of 100 μs. Therefore, this 10 kHz spur would not be aliased. Since in most situations the full range of the modulation is not known, include a check for aliased modulation components every time you use the FFT graph. Checking for aliased modulation components is described on the next page. Chapter 5 includes a more detailed explanation of aliasing.

Check for aliased spurs

Once you have adjusted the setup to give you the desired frequency span and resolution, check for unexpected, or unusual spurs.

FIRST, eliminate those spurs that are of no importance to you:

- Ignore those spurs outside your frequency span of interest.
- Ignore those spurs below an amplitude level that does not cause concern for your application.

SECOND, individually check the spurs that do not pass these tests. The following procedure describes how you can verify the existence of spurs. This procedure requires making a new acquisition.

1. **Move the marker to the suspected spur.**
2. **Select the Scal (Scaling) menu using the top softkey.**
3. **Press the More softkey until the MAN SCALE X-AXIS On/Off softkey is displayed.**
4. **Press the Autoscale Range Hold softkey.**
5. **Set the MAN SCALE X-AXIS option to On.**
6. **Go back to the Function menu and alter the sample interval by a small amount. (For example, if set to 10 µs, use 9.5 µs.)**
7. **Go to the FFT graph and observe if the spur has changed position. If it changed position (moved to a different frequency), it is an aliased component and should be ignored.**
8. **Continue to check every spur that looks suspicious by first moving the marker to the spur, and then following steps 6 and 7.**

Convert spur amplitude to deviation

At times it is helpful to convert the spur amplitude to the equivalent peak-to-peak deviation contributed by the modulation component. The formula for this conversion is:

$$Deviation, pk\text{-}pk = 2\sqrt{2} \times 10^{\frac{spur\ (dB\ units)}{20}}$$

For example, a spur with an amplitude of −152.09 dBsec equals 70.31 ns of peak-to-peak deviation.

More on fine tuning your FFT

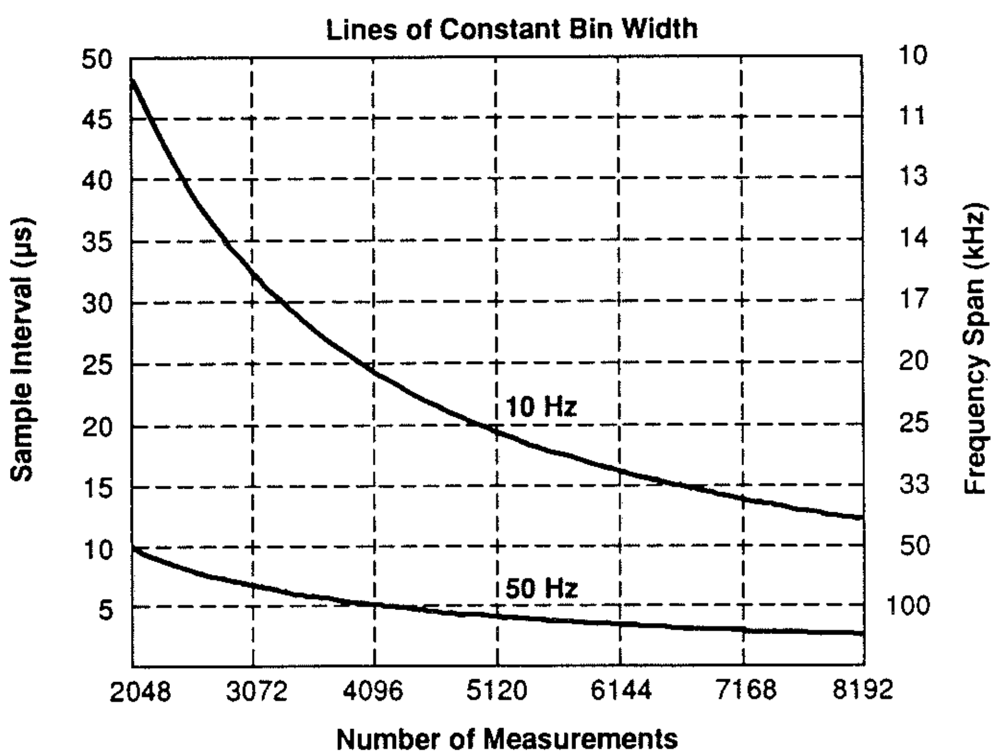
There is a set of graphs in appendix B that provides you with a convenient way to estimate the number of measurements and the sample interval necessary to produce an FFT graph of a specific spectral resolution and frequency span. An example of how to use these Bin Width and Span graphs is included here. Graph 2 from appendix B is used for this example.

Bin Width and Span graphs

The graph shown below is copied from appendix B. The sloping lines represent a constant bin width. Frequency span is at the right edge of the graph. Sample interval is along the left edge of the graph.

To use the graph, pick a bin width and a span. See where the bin width line crosses the span line. Look to the left edge for the sample interval and to the bottom for the number of measurements required to provide the selected bin width and frequency span. Use appendix B graphs 1 through 4 for longer record lengths and wide frequency spans. Use graphs 5 through 8 for reduced frequency spans and shorter record lengths.

This graph can help you select a number of measurements and sample intervals based on your desired FFT spectral resolution and frequency span.



For example, suppose you want a resolution of 10 Hz per bin and a frequency span of 20 kHz. The graph (see previous page) shows that you need to select a sample interval of 25 μs and 4096 measurements. Now, if you wanted to increase the span to 25 kHz, while maintaining the 10-Hz bin width, you would need to set the number of measurements to 5120 and set the sample interval to 20 μs.

Use the appendix B graphs as a guide for selecting a sample interval and a number of measurements based on your desired resolution and frequency span.

Application Examples

Here are three examples that help illustrate the methods for using Jitter Spectrum Analysis to investigate:

- clock jitter,
- phase noise, or
- jitter on a data signal.

It is anticipated that you will read through these examples and learn about the ways to apply Jitter Spectrum Analysis to your particular measurement needs.

• Clock Jitter

Clocks are critical to all kinds of digital and telecommunications systems. Excessive clock jitter can limit performance in digital systems and cause timing-related errors in communications systems.

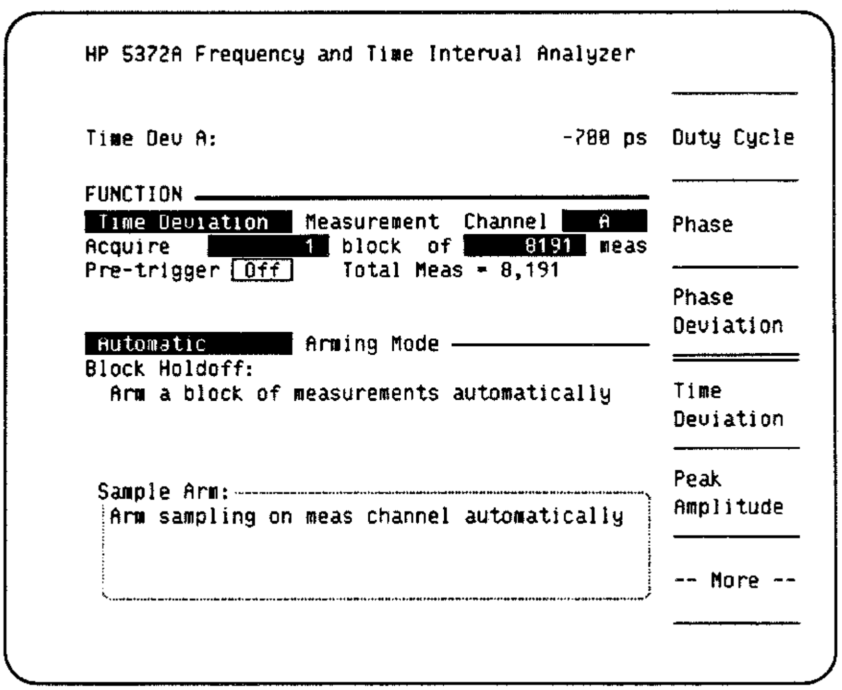
The FFT extends the analysis of clock jitter by revealing any periodic frequency components in the jitter. In order to measure jitter on a clock signal, you need to compare the clock to a "perfect" signal. The perfect signal here can be a value that you enter on the Math menu, or the HP 5372A will calculate a mean value and use that as the reference. The appropriate HP 5372A measurement function for this application is phase deviation or time deviation. The difference between the two is in the type of units used to express the measurement results. Phase deviation results can be displayed in degrees or radians, and Mod 360 or cumulative phase deviation. Time deviation expresses the results in units of seconds. These functions are described in more detail in chapter 3, "Special-Purpose Measurements," in the *HP 5372A Operating Manual.*

Measurement needs

A telecommunications designer needs to look at the jitter on a T1 1.544-MHz carrier.

Setup

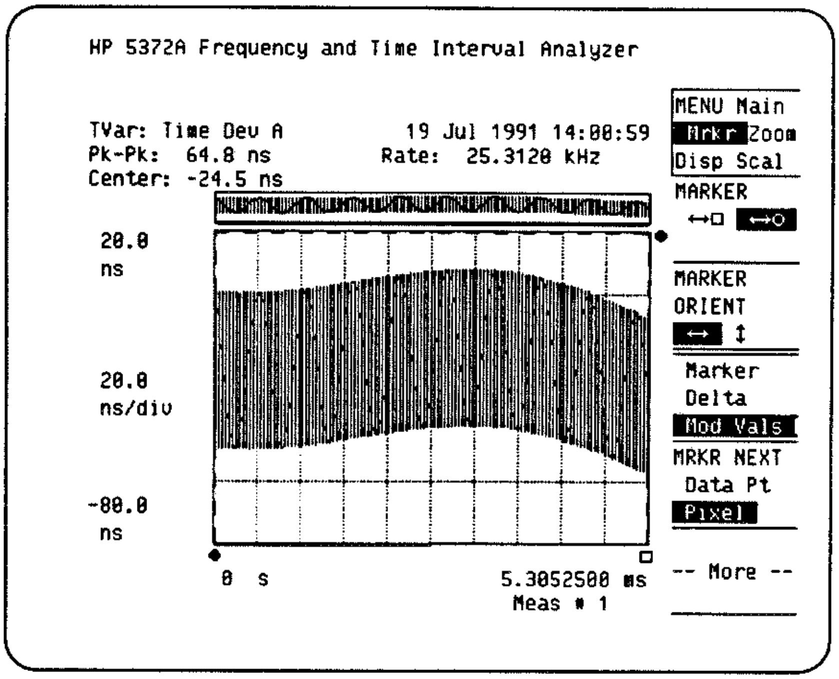
Time Deviation measures the amount of time by which the input signal deviates from the carrier value over time. The maximum number of measurements is set for good FFT graph resolution. Automatic arming will provide the widest frequency span for the FFT graph.



SC2_1D4

Time variation results

The Time Variation graph shows some wander in the time deviation results. This is an indication that there may be another frequency component of the jitter in addition to the 25 kHz component identified with the modulation values feature (see values above the graph).



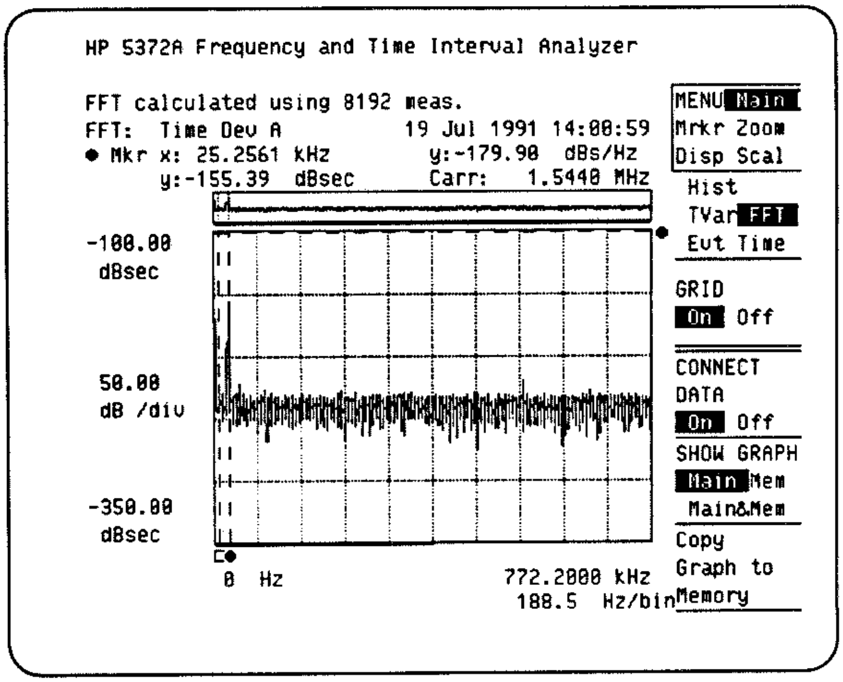
SC2_2D4

Observations

On the Time Variation graph above, the Mod Vals feature shows about 65 ns of peak-to-peak deviation at a 25.3-kHz rate. You can see some wander in the signal that might indicate some lower frequency sources of jitter are present. The FFT graph of this data should reveal these and any other frequency components of the jitter.

FFT results

The FFT graph shows no jitter components outside of the 25 kHz spur identified with the marker. Zooming on the spur will allow a better evaluation of it.



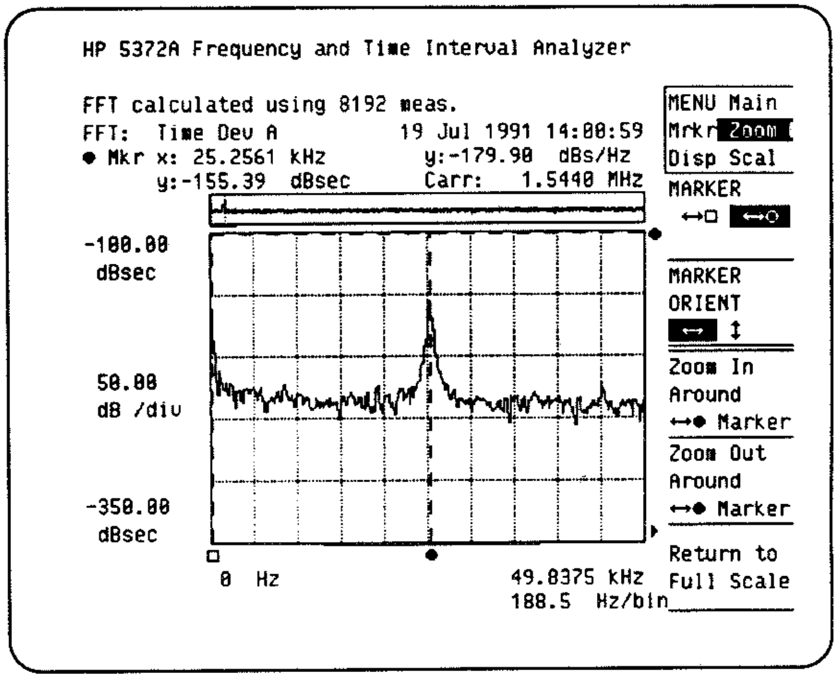
SC2_3D4

Observations

The FFT graph shown above reveals any modulation components out to an offset of 772 kHz from the carrier. The frequency span is produced by using Automatic sampling on an input signal of 1.544 MHz. The HP 5372A is able to sample every edge of the input signal at this frequency so the sample interval becomes the period of the input signal. This interval produces the frequency span shown above.

Zoom on FFT graph

Zooming on the jitter component gives a better look at the spur. Calculating its contribution to the deviation provides a clue that there is something else causing jitter on the carrier.



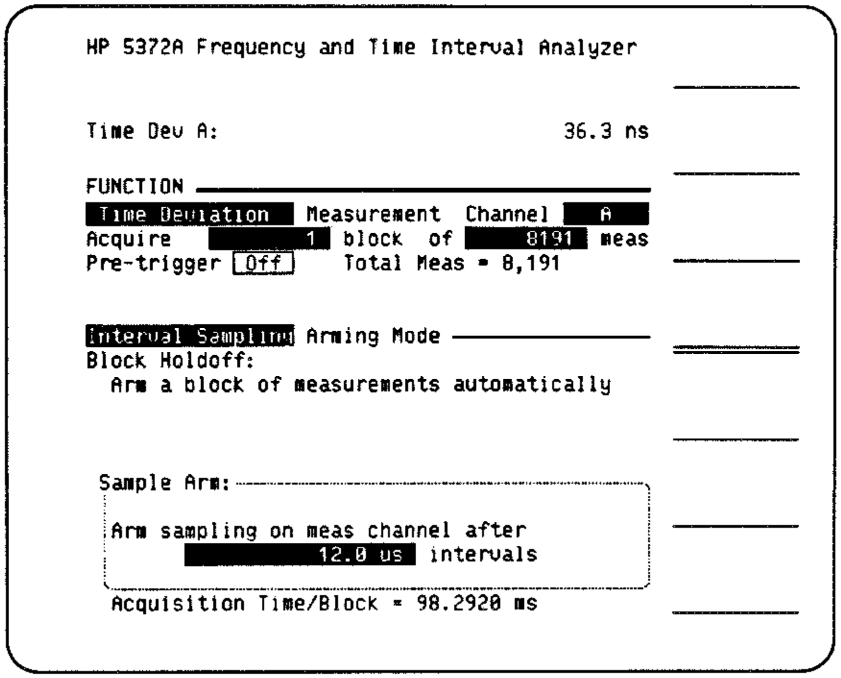
SC2_4D4

Observations

In the graph on the previous page, a jitter component was evident at the left side of the display. Taking a close-up look at the amplitude of the spur is the first step in determining the contribution of this frequency component of the jitter to the deviation of the carrier. Using the formula for converting this amplitude value to the equivalent peak-to-peak rms value (see formula under "Convert spur amplitude to deviation" earlier in this chapter) shows it equal to 48.09 ns peak-to-peak. Compare this to the Pk-Pk value on the Time Variation graph of 64.8 ns and you realize that there is probably another component contributing to the jitter on the carrier.

Increase the spectral resolution

In order to look at the low-frequency components of the jitter, a new acquisition is needed with increased spectral resolution. The sample interval is lengthened from 647 ns with Automatic arming to 12 µs using Interval Sampling.



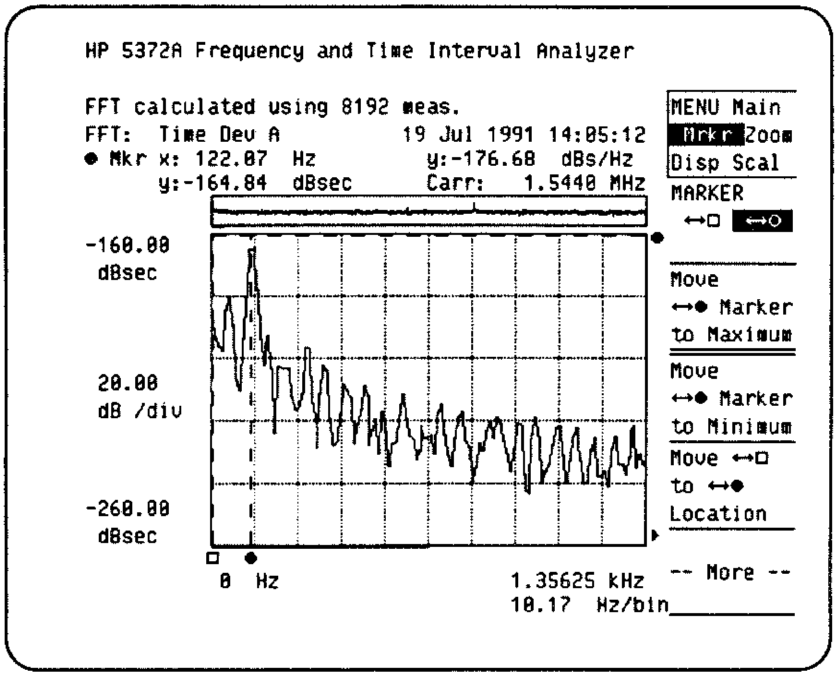
SC2_504

Observations

In order to see the lower frequency components of the jitter, a narrower bin width is needed. From the Bin Width and Span graph earlier in this chapter, you can see that a 10-Hz/bin resolution at 8,191 measurements requires a sample interval of 12 µs. A new measurement acquisition is made with this longer sample interval and shown on the next page.

FFT graph with increased spectral resolution

Zooming on the new acquisition shows a spur at 120 Hz. The spectral resolution is 10 Hz/bin.



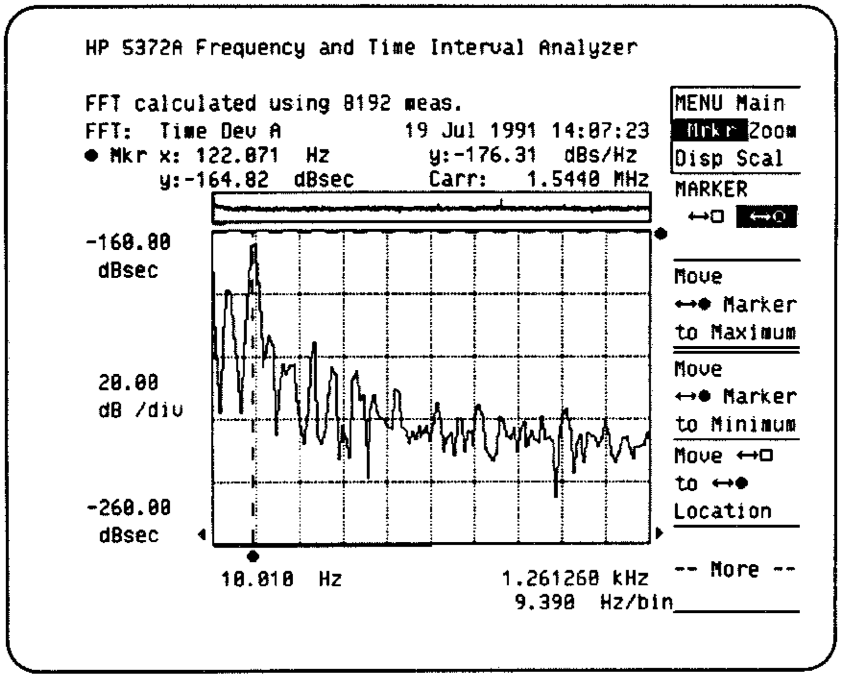
SC2_6D4

Observations

Once the zoom feature is used to look more carefully at the low frequency area of the FFT graph, a signal at 120 Hz is revealed. The amplitude reading indicates that it is definitely large enough to influence the carrier. One more check remains. Since a much slower sample rate was used for this measurement acquisition, the chances of aliasing are increased. This spur should be subjected to the aliasing test to verify that it is not a higher frequency component of the jitter that has been aliased down into the observed frequency span.

Checking for an aliased spur

To ensure that the 120 Hz spur is not aliased, the sample interval is changed and a new acquisition is made. If the frequency of the spur changes, it is aliased.



SC2_7D4

Observations

The sample interval was altered slightly to 13 µs. The spur did not change frequency so it is an actual spur at 120 Hz. Aliasing is covered in more detail in chapter 5, "Concepts."

Conclusions

The Time Variation graph indicated jitter was present on the T1 clock. The FFT graph revealed the two major frequency components of the jitter: one at 120 Hz and one at 25 kHz.

• Phase Noise

To characterize phase noise performance, an FFT of a phase deviation measurement is needed. The phase deviation function indicates by how much the phase of the input signal varies from the "ideal" carrier. This carrier reference value can be entered on the Math menu or the HP 5372A will calculate and use the mean measured value as the reference. Phase deviation is described in more detail in chapter 3, "Special-Purpose Measurements," in the *HP 5372A Operating Manual.*

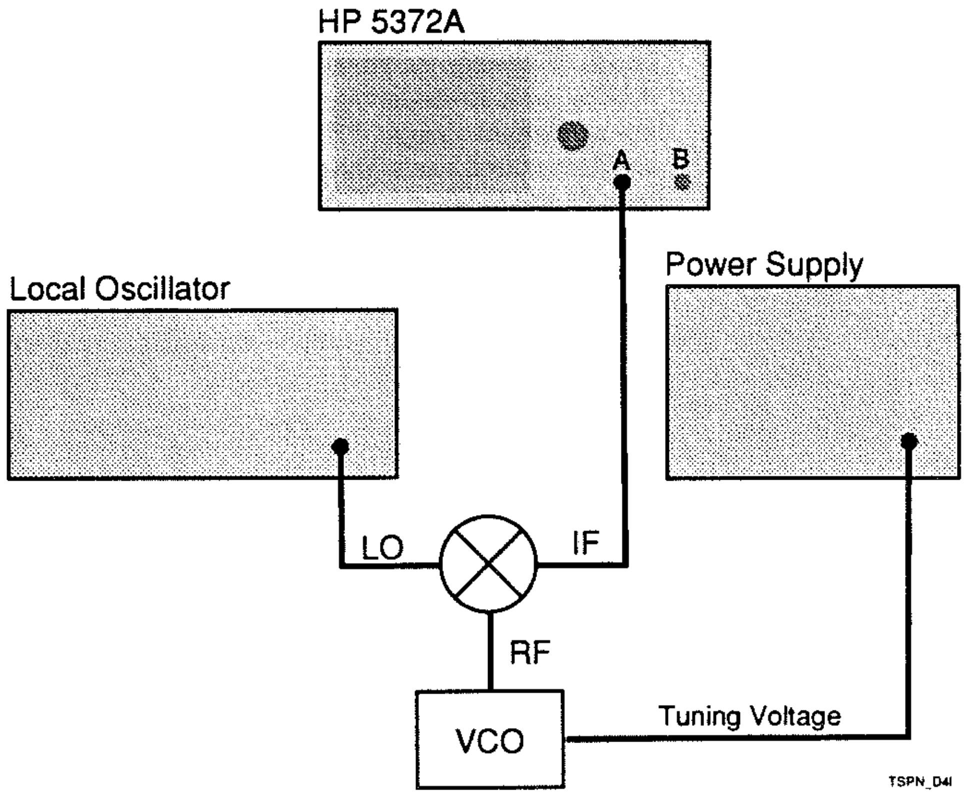
Measurement needs

The designer of a high-frequency voltage controlled oscillator (VCO) needs to specify its phase noise performance. The VCO operates at 9 GHz, so a down-converter is required to bring the VCO signal into the measurement range of the HP 5372A. It is important to use a local oscillator that has a phase noise performance better than the VCO under test. If one is not available, use another VCO slightly offset from the test VCO. The phase noise plot (FFT) will show the combined phase noise of the two VCOs, but at least it will provide an idea of the worst-case phase noise of the VCO under test.

Assuming the use of a low-noise synthesizer as the local oscillator, a mixer with an IF down to dc is recommended. This will allow you to take advantage of the improved resolution of the HP 5372A at lower frequencies.

In this example, the VCO is tuned to 9.005 GHz and the local oscillator is set to 9.000 GHz producing an IF of 5 MHz. The amplitude of the input signal to the HP 5372A should be as close as possible to the maximum input voltage of 2 V (p-p) for the best results. A sine wave is acceptable, but a very stable square wave from a low-noise squaring circuit is preferred. The equipment setup is shown below.

Phase noise measurement setup.

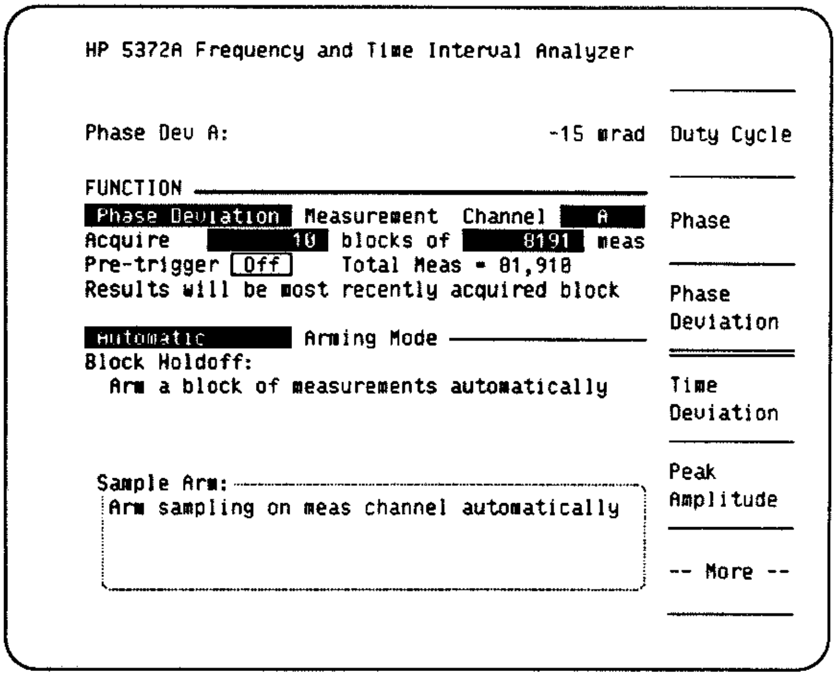


Filtering

There are advantages to filtering the IF. A low-pass filter would help reduce the chances of aliasing. Ideally, a bandpass filter centered around the IF with a bandwidth equal to the carrier offset of interest would be used. A customized bandpass filter reduces the effects of aliasing, but is more difficult to build.

Setup

Phase Deviation measures the amount of phase difference between the input signal and the carrier value over time. The maximum number of measurements is set for a reasonable FFT graph resolution. The number of blocks is set to ten to take advantage of the spectral averaging feature. Automatic arming is used to produce a wide frequency span for the FFT graph.



SC2_6D4

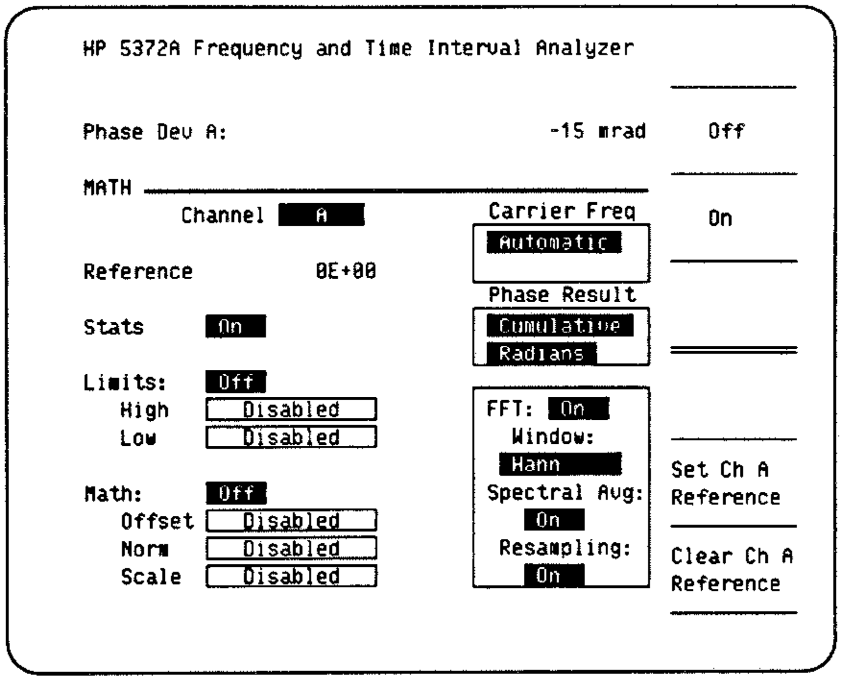
Observations

Automatic arming is used to produce the widest frequency span. This wide span will show all the spurs, while minimizing aliasing. The maximum number of measurements is entered (8,191) for the best spectral resolution and noise floor.

Additionally, to ensure that you are measuring the true noise of your system, the FFT graph data should be spectrally averaged. This feature is enabled on the Math menu. As you can see on the Function menu, ten blocks of 8,191 will be collected and averaged. This will reduce the variance to a level that will reveal most spurs.

Phase Deviation Math menu

Spectral averaging will average out the variance in the FFT graph of the phase noise measurement.



SC2_904

Observations

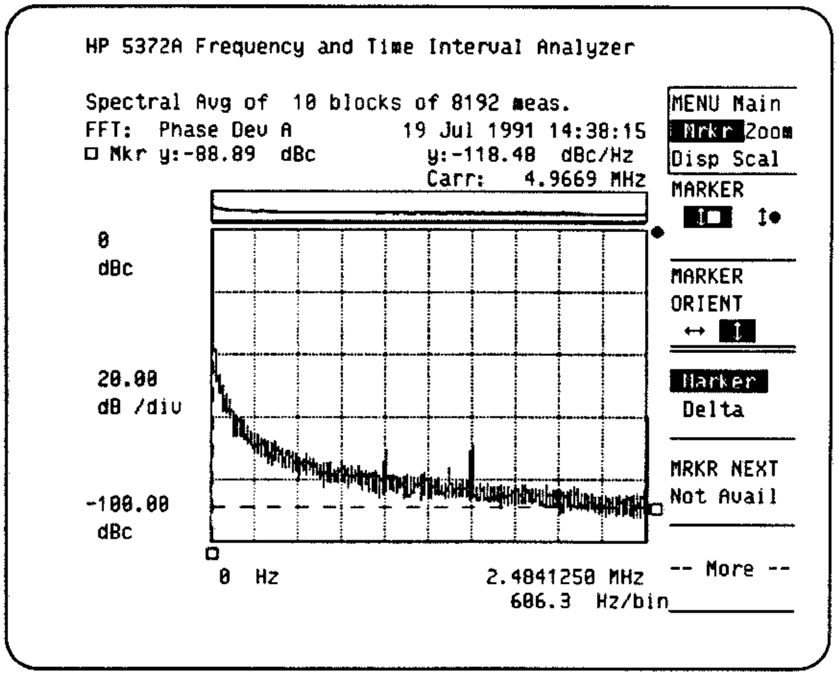
The Math menu shows:

- Carrier Frequency set to Automatic.
- Phase Result set to Cumulative, Radians.
- Window selection set to Hann.*
- Spectral Averaging set to On.
- Resampling set to On.

* FFT windows are discussed in chapter 3.

FFT results

A phase noise plot of a VCO is produced by making an FFT of the phase deviation results. The graph shows the results from ten blocks averaged together to show the true noise floor of the system.



SC2_1004

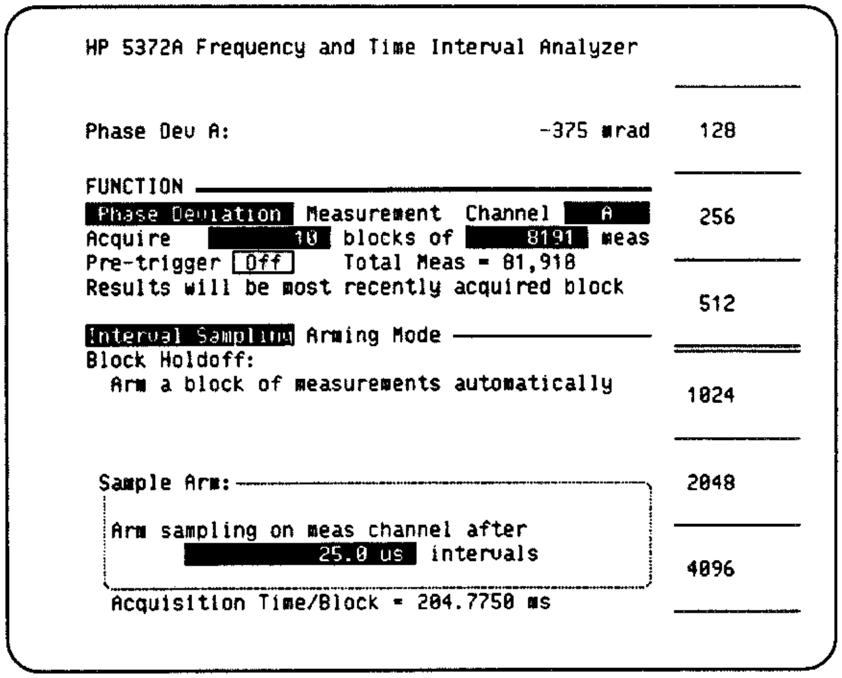
Observations

You can see the phase noise plot at offset frequencies up to one-half the IF, which in this example is 2.48 MHz. The noise floor is measured by scrolling the horizontal marker to near the lowest average level and reading the y-axis value from the upper right corner of the display. The noise floor is –118 dBc/Hz at high offset frequencies. This value is located just above the carrier value on the display. This is the power spectral density value (PSD). It is normalized to a one Hz bandwidth and takes into account the type of window used. See chapter 3 under, "FFT y-axis scale," for information on use of PSD.

Use the PSD marker value only for measuring the noise floor in a phase noise measurement. The y-axis value on the left side of the display should be used to measure spurs.

New acquisition for increased spectral resolution

To see the low-frequency jitter components, the FFT spectral resolution is increased from 600 Hz/bin to 5 Hz/bin by lengthening the sample interval to 25 µs.



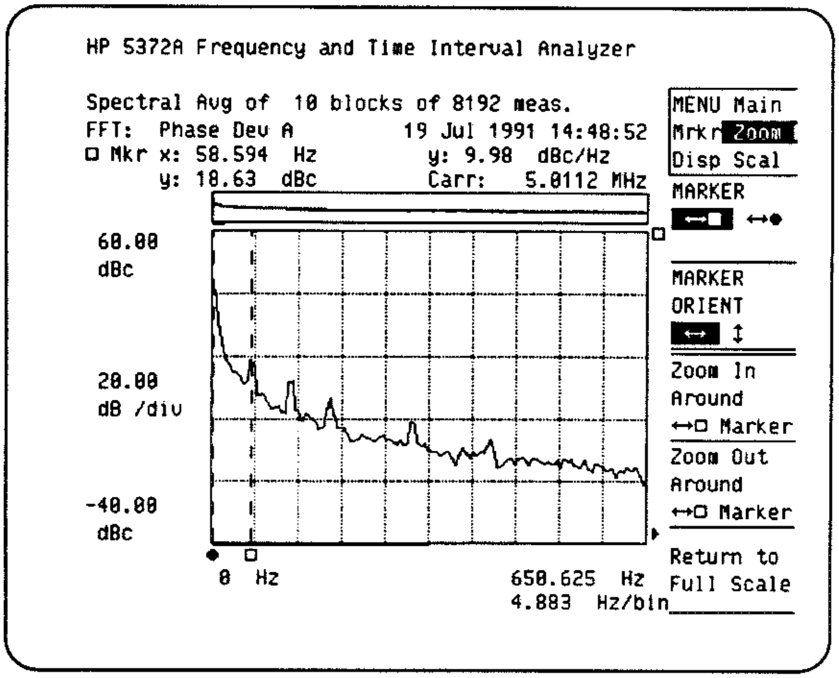
SC2_12D4

Observations

Improving spectral resolution requires making another acquisition with a longer sample interval. A bin width of 5 Hz should be adequate to examine spectral components close to the carrier. You can use Graph 1 in appendix B to determine the appropriate sample interval. For 8,191 measurements and 5 Hz bins, the graph indicates a sample interval of approximately 25 µs.

Close-in phase noise

Zooming on the FFT graph shows a 60 Hz power line spur.



SC2_13D4

Observations

Now with a spectrally averaged acquisition of ten blocks of 8,191 measurements at 25 μs, the bin width is 4.88 Hz. Notice that the display shows a message stating that 10 blocks of 8192 measurements were spectrally averaged. A "zero" measurement is added to each block to maintain a power-of-two number for faster processing.

The zoom feature has been used to look very close to the carrier. Still, it would be a good idea to test for aliasing. This is described earlier in this chapter under, "Step three. Check for aliased components in your FFT graph."

Conclusions

The FFT graph can be used to examine phase noise. There is a small spur at 60 Hz, but aside from that, the display shows no unexpected, or unusual spurs.

• Data Jitter

The HP 5372A with Option 040 can measure the jitter on data signals. Data is defined here as a non-repetitive signal that is related to a known clock (see the next page for an illustration). For example, a data stream on a disk drive or a digital telephone transmission. There are two measurement functions to measure a data signal, Time Deviation Data or Phase Deviation Data. This example uses the Time Deviation Data function.

Concerns about measuring data jitter

The data signal is not periodic, so the time interval between adjacent edges is not the same. Because a data signal is not periodic, it is not sampled uniformly in time. The FFT algorithm requires that the measurements be spaced uniformly in time. This requirement is met by curve-fitting the collected data and resampling so that the FFT receives data sampled uniformly in time.

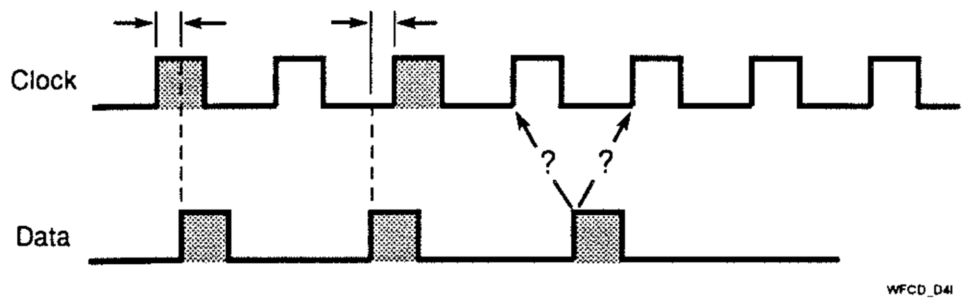
The result is a new set of measurement points that represents the original data. This resampled data is plotted on the Time Variation graph and used by the FFT algorithm. The number of measurement points is identical to the original acquisition, but the original data is not available. See chapter 5, "Concepts," for more on resampling.

Too much jitter on the data signal

Another concern when measuring a data signal is that every edge be associated with the proper clock edge. The HP 5372A Data functions can handle data streams where there are consecutive zeros between ones.

There is no problem associating an edge on the data line with the associated clock edge unless the data jitter is so severe that it causes more than a one-half clock period slip between adjacent samples. When this occurs, the correct clock edge cannot be determined and an erroneous measurement might occur. Fortunately, this amount of jitter is usually far more than can be expected in most signals in use today.

Severe jitter on the data can produce a situation where the measurement algorithm can have difficulty matching the data edge with its associated clock edge.



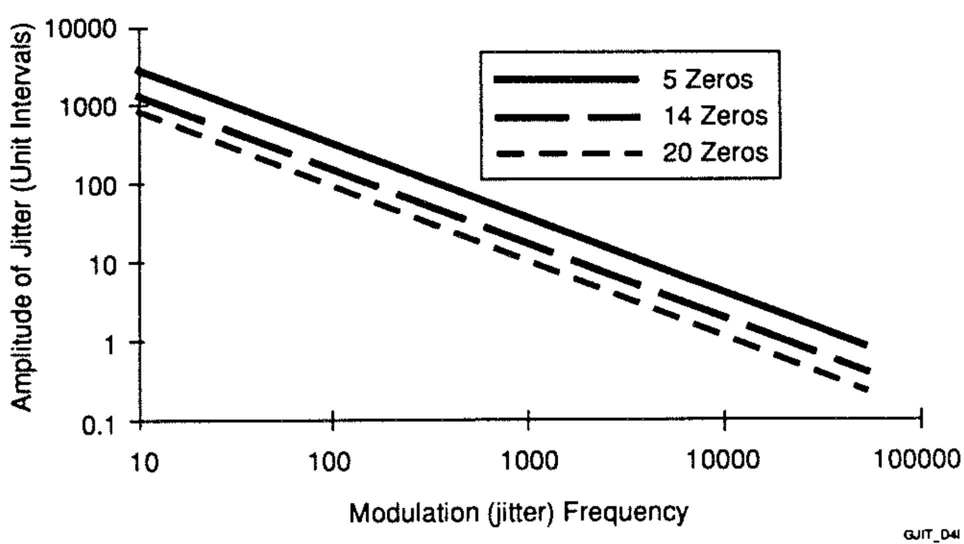
How much jitter is too much?

The table here provides a guide to the maximum amount of jitter that can be tolerated by the Data measurement functions. The maximum jitter is described in terms of Unit Intervals. To express the FFT results in Unit Intervals, enable Math (on the Math menu) and either scale the results by the frequency of the clock or normalize the results by the period of the clock.

An example using the graph should be helpful. Suppose you had a signal that had up to 14 consecutive zeros between data ones. At a sinusoidal jitter frequency of 10 kHz, the data can slip up to approximately two Unit Intervals peak-to-peak and still be correctly matched to its associated clock edge.

This graph can be used to determine the maximum data edge slippage with regard to its related clock edge. 5, 14, 20 Zeros refers to the maximum number of consecutive zeros.

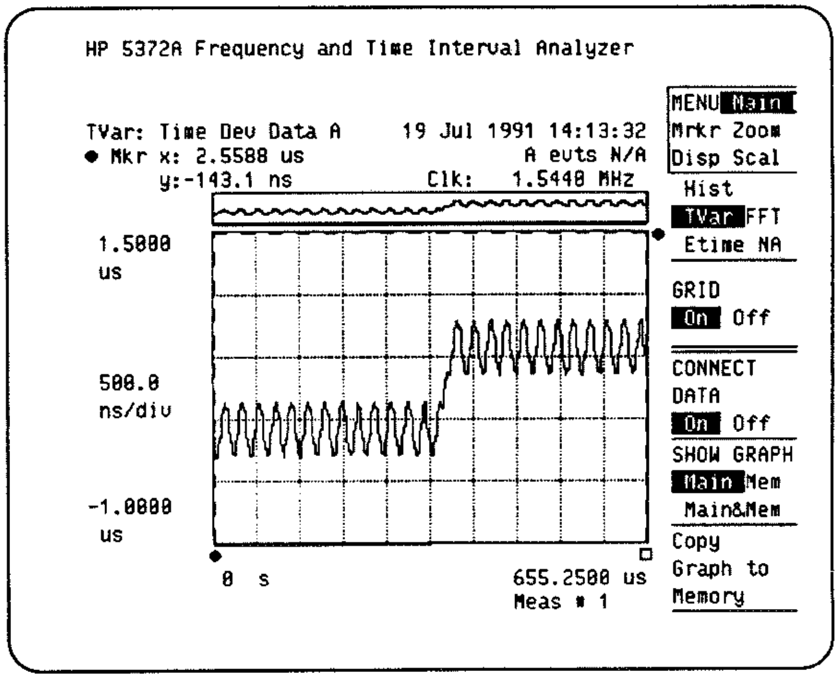
Maximum Jitter



A view of excessive jitter

This display shows the Time Variation graph of a data signal with too much jitter. Note the discontinuity. This happened because a data edge was associated with the wrong clock edge.

SC2_14D4



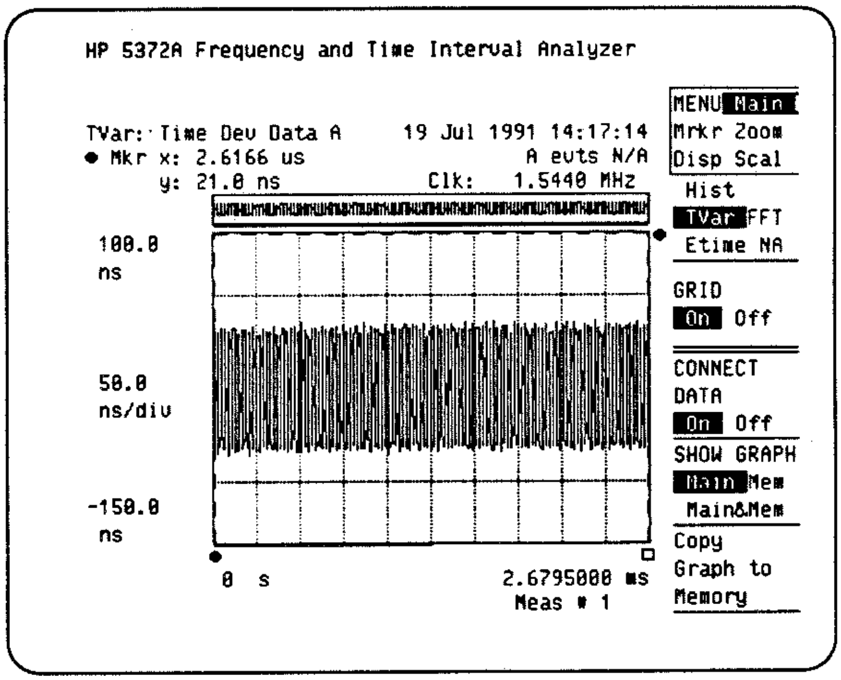
Observations

Looking at the Time Variation graph is a good way to determine if you have too much jitter on a data signal.

The clock frequency

The clock frequency must be known very precisely, or else the noise floor will be excessively high and data edges may not be associated with the correct clock edges. The clock frequency is entered on the Math menu as the Carrier Frequency. The HP 5372A uses this entered value as the reference against which it will measure any deviation of the data. The Time Variation graph can be used to verify that the appropriate clock frequency was entered. If the display slopes up or down, the clock frequency is incorrectly set.

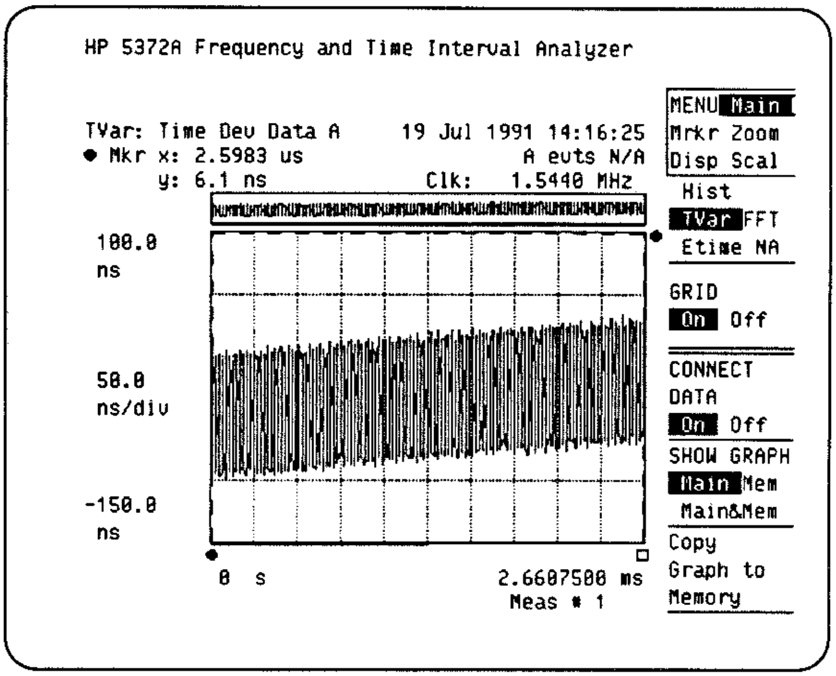
The overall slope of the graph is flat. This indicates that the manually entered carrier frequency is correct. When measuring data jitter, you must enter the clock frequency on the Math menu.



SC2_15D4

Evidence of an incorrectly entered clock frequency

The slope indicates that the frequency of the manually entered carrier is too low in this Time Deviation Data measurement.



SC2_16D4

Observations

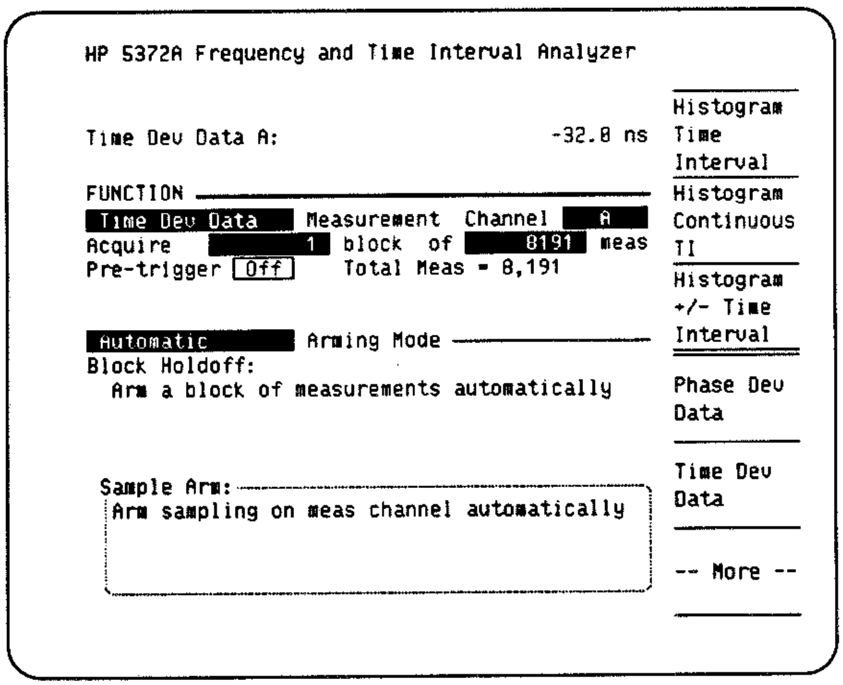
The slope of the Time Variation graph results is a good indicator that an incorrect clock frequency value was entered as the carrier frequency on the Math menu.

Measurement needs

A telecommunications designer wants to measure the jitter on a T1 data stream. The Time Deviation Data function is used. As already discussed, knowing the precise frequency of the carrier is critical to the success of this measurement. The frequency must be entered manually on the Math menu as the Carrier Frequency. There is no automatic method to measure and then select the frequency of the carrier.

Setup

Time Deviation Data measures the time variation between the data edges and their associated clock edges. The maximum number of measurements is selected and Automatic arming is used to provide the widest frequency span for the FFT graph.



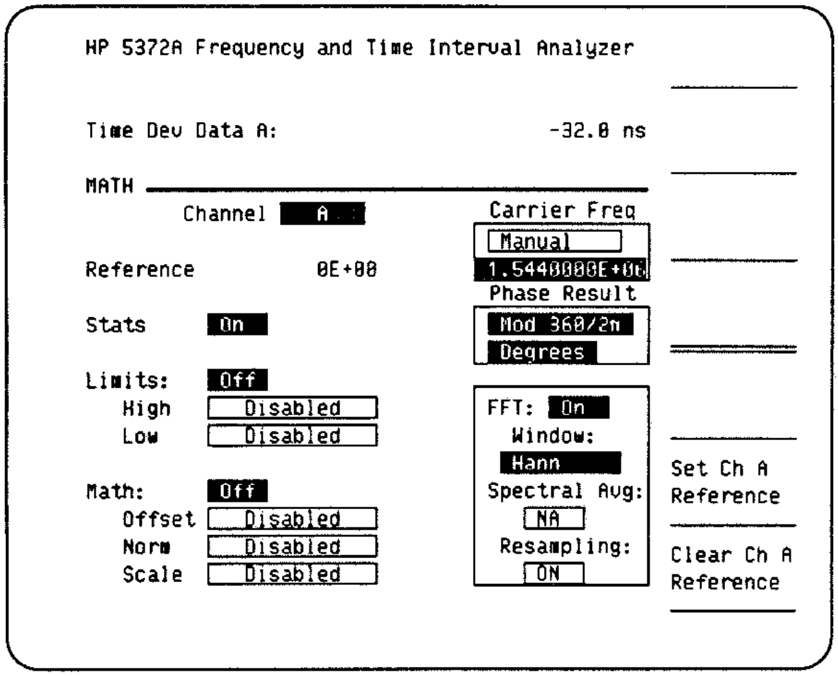
SC2_17D4

Observations

Automatic sampling is used to produce the widest frequency span and minimize aliasing. The spectral resolution at this span is optimized by specifying the maximum number of measurements (8,191).

Time Deviation Data Math menu

It is very important that the correct clock frequency be manually entered as the carrier frequency.



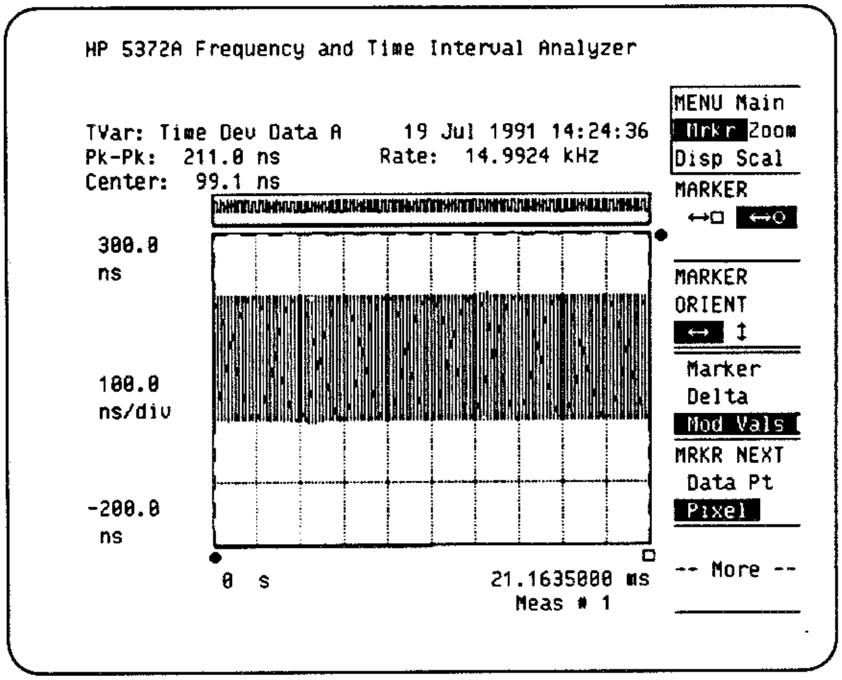
SC2_18D4

Observations

It is important to correctly enter the carrier frequency on the Math menu. Note that the resampling feature defaults to On for Data measurements (Time Deviation Data and Phase Deviation Data). It cannot be disabled for these measurements.

Time Variation results

The Time Variation graph provides a good indication of how closely the entered clock frequency matches the actual clock.



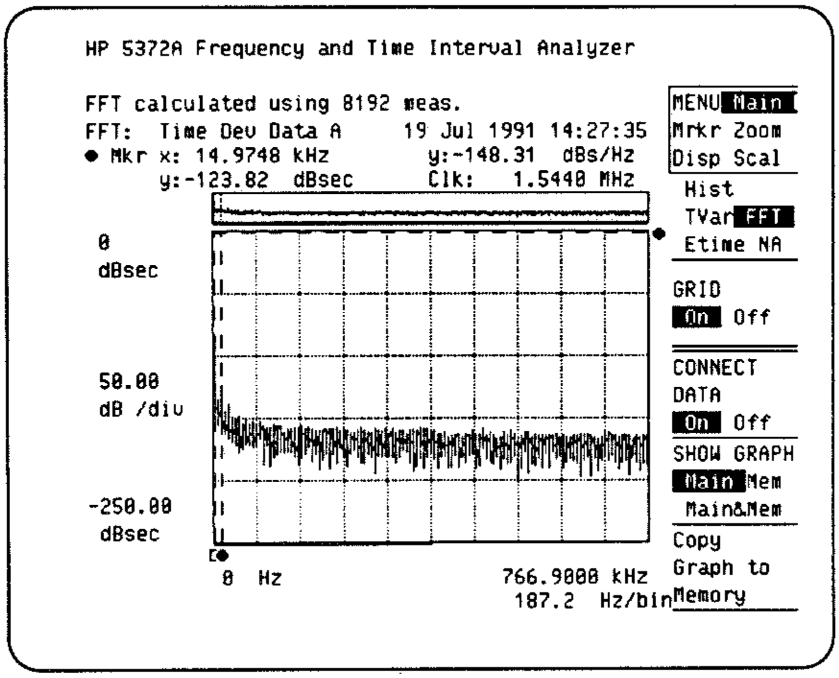
SC2_19D4

Observations

Flatness of plotted results indicates that the entered carrier frequency is very close to the correct value. Also, the absence of discontinuities in the results verifies that the data jitter is within the bounds measurable by the Time Deviation Data function.

FFT results

The FFT graph shows a frequency component of the jitter at approximately 15 kHz.



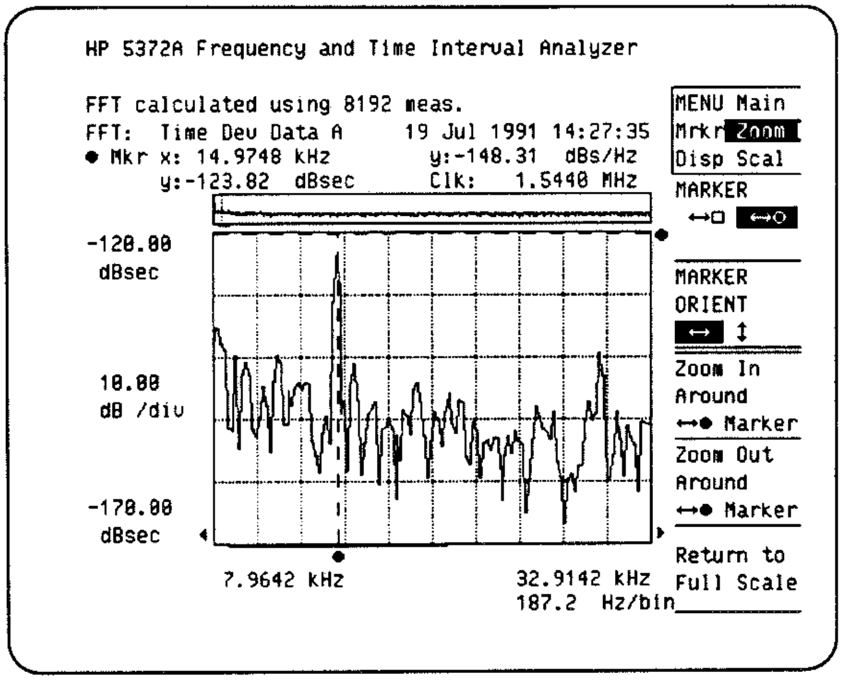
SC2_20D4

Observations

There are spectral components close to the carrier that should be investigated more closely. The simplest way to do this is with the Zoom feature as shown on the next page. There appear to be no jitter components beyond those at about 15 kHz.

Close-in jitter on data

The main spur indicates a jitter frequency of 14.9 kHz. A harmonic of this spur is also evident.



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Observations

The Zoom feature is used to show the close-in jitter of the data. The main spur is identified with the marker. You can see a harmonic of the main spur as well. The source of the 15 kHz modulation will need to be identified. When it is eliminated, most likely the harmonic will also disappear.

Conclusions

The Time Deviation Data and Phase Deviation Data functions provide the capability to measure the jitter on data signals. This is done by measuring the extent to which each edge on the data line deviates from the perfect time represented by the manually entered carrier frequency (clock).

The FFT of the deviation of the data provides a frequency spectrum of the data jitter. This information is very useful when troubleshooting the existence and cause of jitter on your data.

Features

3

Jitter Spectrum Analysis Features

In this chapter

This chapter describes the features that are part of the Jitter Spectrum Analysis (FFT) Option 040 for the HP 5372A. This chapter discusses the following topics:

- Measurement configurations that are compatible with FFT.
- FFT options on the Math menu.
- Measurement acquisition size.
- FFT graph description.
- New measurement functions.

FFT measurement configurations

The FFT algorithm operates on most measurement and arming modes of the HP 5372A. The chart on the next page shows the FFT measurement functions and arming modes and uses shading to highlight setups that are not compatible with FFT.

✓ In addition to the chart items, FFT is not available for measurements using pre-trigger to monitor Multiple blocks of measurements, but FFT is supported for pre-trigger measurements on Single blocks.

✓ No FFT is produced when the number of measurements is set to three or less, or when a partial acquisition occurs that collects less than four measurements.

Refer to the *HP 5372A Operating Manual* for details on the measurement functions and arming modes.

HP 5372 Jitter Spectrum Analysis Function and Arming Summary

ARMING MODE	MEASUREMENT FUNCTION: TIME INTERVAL OR HISTOGRAM TI		CONTINUOUS TIME INTERVAL OR HISTOGRAM CTI	± TIME INTERVAL OR HISTOGRAM ± TI		FREQUENCY, PERIOD		TOTALIZE		POS WIDTH NEG WIDTH RISE TIME FALL TIME DUTY CYCLE	PHASE	PEAK AMPLITUDE	PHASE DEVIATION/ PHASE DEVIATION DATA	TIME DEVIATION/ TIME DEVIATION DATA
	A	A→B	A	A	A→B	A	DUAL[1]	A	DUAL[1]	A	A rel B	A	A	A
	B	B→A	B	B	B→A	B	RATIO[2]	B	RATIO[2]		B rel A	B	B	B
						C	SUM[3]		SUM[3]					
							DIFF[4]		DIFF[4]					
AUTOMATIC														
AUTOMATIC	C*	C*	C*		C*	C*	C*			C*	C*	N*	C*	C*
HOLDOFF														
EDGE HOLDOFF	C	C	C		C	C					C		C	C
TIME HOLDOFF	C	C	C			C								
EVENT HOLDOFF	C	C	C			C								
SAMPLING														
INTERVAL SAMPLING	C	C	C		C	C	C	C*	C*		C		C	C
TIME SAMPLING						N								
CYCLE SAMPLING						C								
EDGE SAMPLING						C	C	C	C					
PARITY SAMPLING					C									
REPET EDGE SAMPLING	C	C	C		C									
REPET EDGE-PARITY SAMPLING					C									
RANDOM SAMPLING	C	C			C									
HOLDOFF/SAMPLING														
EDGE/INTERVAL	C	C	C		C	C	C	C	C		C		C	C
EDGE/TIME						N								
EDGE/EDGE						C		C	C					
EDGE/CYCLE						C								
EDGE/EVENT				N	N	N								
EDGE/PARITY					C									
EDGE/RANDOM	C	C			C									
TIME/INTERVAL						C		C						
TIME/TIME				N	N	N								
EVENT/INTERVAL						C								
EVENT/EVENT				N*	N	N								
EXTERNALLY GATED						C		C	C					
MANUAL								N	N					

[shaded box] Indicates measurement functions and arming modes that do not produce an FFT graph.

Symbol C or N indicates that a measurement can be made using the corresponding combination of Function, Channel, and Arming selections.

- C = Continuous Arming, (Block/Sample Arming)
- N = Non-Continuous arming, (Start/Stop Arming), setups are limited to M blocks of 1 measurement.
1. DUAL. Simultaneous Dual-channel, (2 results). Frequency and Period options are: A&B, A&C, B&C. Totalize option is: A&B.
2. RATIO. Frequency and Period ratio options are: A/B, A/C, B/A, B/C, C/A, C/B. Totalize ratio options are: A/B, B/A.
3. SUM. Frequency and Period sum options are: A+B, A+C, B+C. Totalize sum option is: A+B.
4. DIFFERENCE. Frequency and Period difference options are: A–B, A–C, B–A, B–C, C–A, C–B. Totalize difference options are: A–B, B–A.
- * = Default Arming

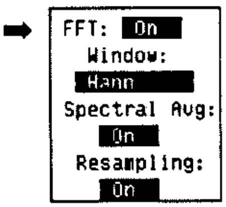
ARMING CATEGORIES

CATEGORY	CONTINUOUS ARMING MODES	NON-CONTINUOUS ARMING MODES
Automatic	Block Holdoff is Automatic Sample Arm is Automatic	none
Holdoff Modes	Block Holdoff is User-defined Sample Arm is Automatic	none
Sampling Modes	Block Holdoff is Automatic Sample Arm is User-defined	Start Arm is Automatic Stop Arm is User-defined
Holdoff/Sampling Modes	Block Holdoff is User-defined Sample Arm is User-defined	Start Arm is User-defined Stop Arm is User-defined

Setting FFT features

All FFT controls are contained on the Math menu. They include the following settings:

- **FFT:** On/Off
- **Window:** Rectangle, Hann, or Flat-top
- **Spectral Averaging:** On/Off
- **Resampling:** On/Off



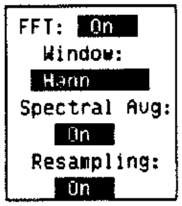
FFT On/Off

The FFT function is enabled on the Math menu. When the instrument configuration does not support FFT, the letters "NA," for Not Available, appear alongside the FFT choice.

Because of the additional processing time required by the FFT algorithm, especially for large acquisitions, the FFT function is disabled whenever the HP 5372A is preset. Pressing the Preset hardkey or sending the *RST command over the HP-IB presets the HP 5372A and will disable the FFT. This default to Off is done so that those not interested in the FFT will not have to wait through the additional measurement processing time required by the FFT. The regular FFT user should make the step of turning on the FFT a part of every measurement setup.

If you forget to turn on FFT before making an acquisition

As long as the HP 5372A has completed an acquisition and is idle (use the Single/Repet hardkey), and the acquisition fits in memory (up to 4,096 or 8,191 total measurements; number depends on measurement function), you can enable FFT after the acquisition and still have the HP 5372A generate an FFT from the the collected measurements.



Window: Rectangle, Hann, or Flat-top

Each of the window functions has a specific purpose. Your selection of the window type depends on your input signal and on what you are most interested in learning from the FFT graph. The issues are summarized in the next three paragraphs.

Rectangle

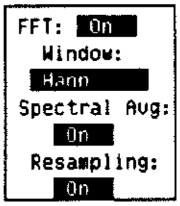
The choice of Rectangle window is appropriate if you are measuring a transient event, that is, the signal starts and stops entirely in the capture time, or the signal is perfectly periodic with an exact number of cycles in the Time Variation display. The Rectangle window will provide better amplitude and spectral resolution for these special situations than either of the other two window choices. If the signal is neither a transient nor periodic within the window, there will be excessive leakage and the FFT will not produce useful results.

Hann

The Hann window is valuable for reducing leakage and providing good spectral resolution for most signals that are neither transients nor perfectly periodic. This window trades off amplitude accuracy for better spectral resolution. The Hann window is a very good choice for most measurements. It is the default window setting.

Flat-top

The Flat-top window is particularly good at amplitude accuracy with a tradeoff in its ability to resolve two different modulating frequencies that are closely spaced.



Spectral Averaging

Spectral averaging for the FFT graph is available whenever the number of blocks is set greater than one on the Function menu. This averaging of multiple FFT acquisitions is valuable in order to reduce the variance in the displayed spectrum. This technique can reveal low-amplitude spurs otherwise difficult to detect.

Spectral averaging is enabled on the Math menu. When the instrument configuration does not support spectral averaging, the letters "NA", for Not Available, appear on the Math menu below this averaging option.

What is spectral averaging?

The method of averaging used is a simple bin-to-bin average of FFT results.* For example, if you are collecting 4 blocks of 1024 measurements (set on the Function menu), an FFT is computed for each of the blocks, then the FFT results for each block are averaged together in the following way: the first FFT bin of the first block is averaged with the first FFT bin of the second block, the second FFT bin of the first block is averaged with the second FFT bin of the second block, and so on for four blocks of 1024 measurements. The final results on the FFT graph are the averaged FFT results.

There is an additional averaging feature in the HP 5372A. It averages multiple blocks of measurement results for plotting on the Time Variation graph. This is called, "block averaging." An FFT can be performed on block averaged results. The next several paragraphs describe what to expect from the FFT results when using both types of averaging, one or the other, or no averaging.

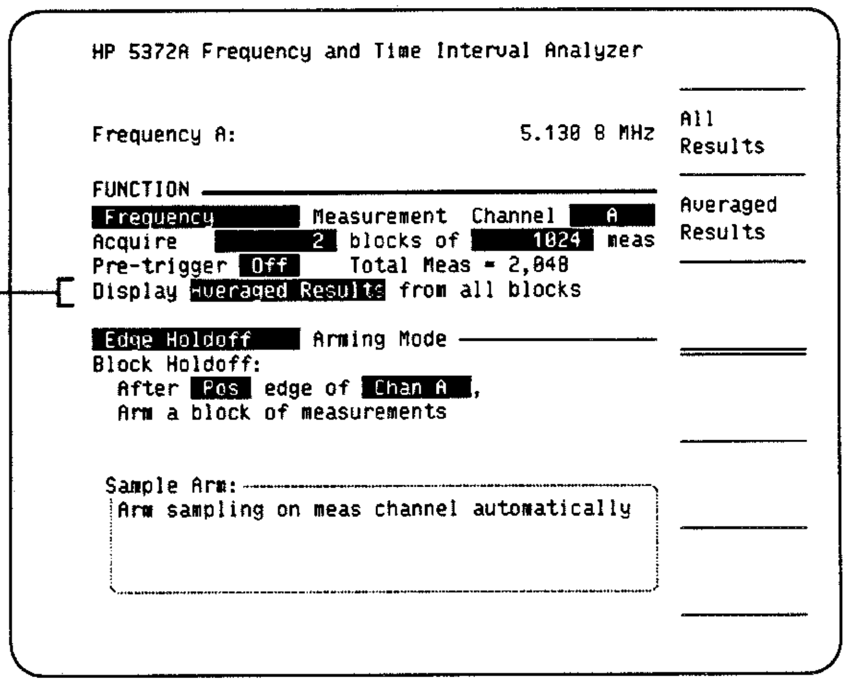
* This type of averaging reduces the variance and provides a better indication of the noise floor, but does not improve the signal-to-noise ratio.

What is block averaging?

Block averaging is the averaging together of multiple blocks of time-domain measurements. These results are displayed on the Time Variation graph.* Block averaging is supported for a limited combination of measurement functions and arming modes that are described in chapter 7, "Function Menu" (see Averaged Results), of the *HP 5372A Operating Manual.*

Block averaging is enabled on the Function menu by first selecting a measurement function and arming mode that supports block averaging; second, by setting the number of blocks to a value greater than one; and third, changing the Function menu Display option from "All Results" to "Averaged Results," as shown below.

Block averaging is available for certain combinations of functions and arming modes.



Enable block averaging

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* This type of averaging improves the signal-to-noise ratio of the result. However, it requires a trigger signal that is synchronous with any modulation, to start each block.

Measurement functions and arming modes that support block averaging and FFT

The following combinations of functions and arming modes can produce block-averaged results on the Time Variation graph for multiple blocks.

Frequency and Period functions support block averaging with the following arming modes:

- Edge Holdoff
- Time Holdoff
- Event Holdoff
- Edge/Interval
- Edge/Cycle
- Time/Interval
- Event/Interval

Continuous Time Interval function supports block averaging with the following arming modes:

- Edge Holdoff
- Time Holdoff
- Event Holdoff
- Edge/Interval

Phase Deviation or Time Deviation functions support block averaging only when using a manually entered value for the Carrier on the Math menu, along with the following arming modes:

- Edge Holdoff
- Edge/Interval

FFT results with spectral averaging and without block averaging

The FFT of each block is computed, and then the spectral average of all the FFT blocks is computed and displayed.

FFT results with block averaging and without spectral averaging

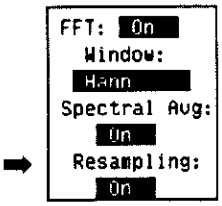
The FFT algorithm is applied to the the block-averaged results that appear on the Time Variation graph, not the individual blocks of measurements.

FFT results with spectral averaging and block averaging

The FFT spectral averaging operates on the individual blocks of measurements and does not use the block-averaged results that appear on the Time Variation graph. This is the same behavior as for spectral averaging without block averaging.

FFT results for multiple blocks without either spectral averaging or block averaging

The FFT is calculated using the most recently acquired block.



Resampling

Resampling is an additional processing step that minimizes the error in the FFT caused by nonuniform sampling of the input signal. Resampling On is the default setting. Almost all measurements benefit from resampling.

Why do you need resampling?

The HP 5372A collects samples and produces measurement results versus time on the Time Variation graph. The FFT algorithm uses these measurement results and assumes they are uniformly spaced along the time axis. Because the HP 5372A samples edge crossings of the input signal, and these edge crossings typically have jitter, the time between edges will vary. When the sampling is extremely nonuniform and Resampling is disabled, the FFT produced from the samples may have an elevated noise floor.

What causes nonuniform sampling?

The HP 5372A samples only when a trigger-level crossing occurs that satisfies the trigger-event conditions specified on the Input menu. Only when an input signal is a constant frequency does it cause sampling at perfectly regular intervals. More often, the input signal's frequency varies, and this variation causes sampling at irregular intervals.

Any time the sampling rate is close to the input signal's carrier frequency, the sampling interval may toggle between two values which are integer multiples of one another. For example, a 1-MHz signal being sampled with a 1-µs interval may, if the frequency is varying slightly above and below 1 MHz, cause sample intervals to bounce between 1 µs and 2 µs. This occurs because the sample interval clock is not synchronous with the input signal, so the sample interval can lead or lag the input signal.

How does resampling work?

The acquired measurements in the Time Variation graph are subjected to a resampling process that creates a new set of measurements spaced uniformly in time.

As long as the entire acquisition fits in memory, the resampling feature can be toggled off/on to see what effect resampling has on the FFT graph results. In this case, no re-acquisition will occur.

When does resampling not help?

Nonuniform sampling for the Continuous Time Interval or Totalize measurement functions cannot always be corrected by the resampling process. By the nature of these measurement functions, the individual results are coupled to the sampling interval determined by the input signal. Resampling the results cannot always be expected to improve the FFT.

FFT Acquisition Size

The FFT is calculated from the data displayed on the Time Variation graph. The acquisition size is specified on the Function menu. Two numbers can be entered. One sets the number of blocks, the other sets the number of measurements for each of the blocks. The higher the number of measurements, the greater the resolution (or ability to see small changes on the FFT graph). The tradeoff for increased resolution is a longer time required to collect data and process results.

The text on the Function display reads as follows:

Acquire _____ blocks of _____ meas

Number of blocks

The number of blocks can be set from 1 to 99,999,999. Whenever the number of blocks is set greater than one, spectral averaging of the FFT graph is available. Spectral averaging is enabled on the Math menu.

Number of measurements

To produce FFT results, the number of measurements can be set from 4 to 8191, depending on the selected measurement function. With the FFT feature set to On, power-of-two softkey choices for the number of measurements are available on the Function menu. The FFT algorithm operates most quickly on the following power-of-two choices, although the FFT will run on other choices as well:

- 128
- 256
- 512
- 1024
- 2048
- 4096
- 8191*

* In the cases where 8191 is the maximum value that can be entered as the number of measurements, a "zero" result is added so the FFT still operates on a power-of-two number (8192).

The number of measurements used by the FFT

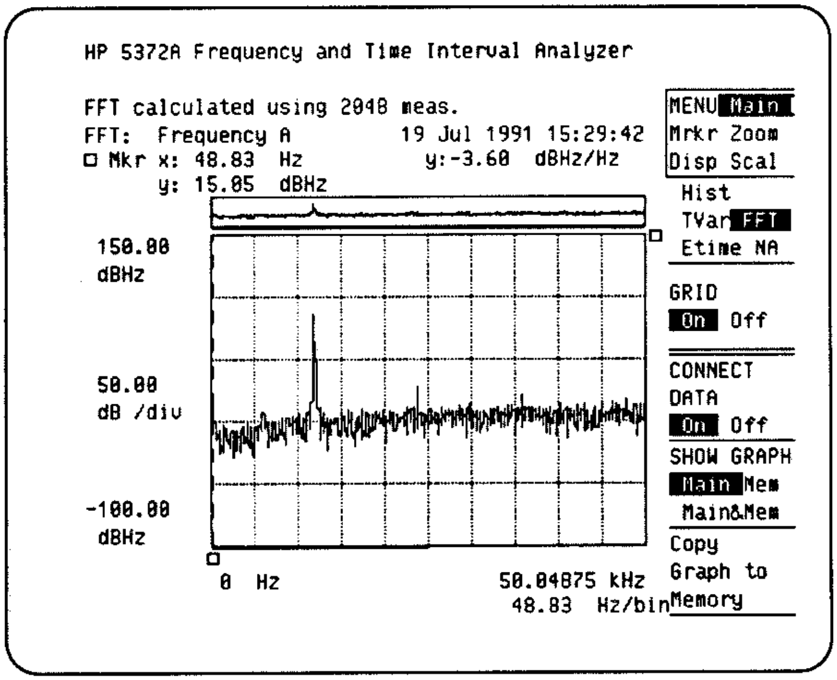
The number of measurements used for the FFT calculation is always displayed above the FFT graph. This number can vary depending on the following conditions:

- In most cases, if an odd number of measurements is entered, the FFT algorithm ignores the last measurement when computing the FFT graph.
- When the maximum allowed number of measurements for a function is odd (for example, 8191 for Frequency or 4,095 for Totalize), the FFT algorithm adds a "zero" result to the acquired measurements so the FFT operates on a power-of-two number of measurements. For most other odd number entries, the last result is ignored to maintain an even number of measurements for FFT processing.
- In some cases, several measurements are discarded from the end of the acquisition. This is done to maintain an acceptable processing time.

FFT Graph Described

The Jitter Spectrum Analysis option performs an FFT on the results from the Time Variation graph. The FFT graph shows the spectral content of the waveform displayed on the Time Variation graph. The left edge of the FFT graph represents the carrier. As you look towards the right edge, you are seeing the spectral content of the signals that are modulating the carrier. The graph shows the magnitude of the deviation from the carrier versus frequency offset from the carrier.

The FFT graph is the result of applying the FFT algorithm to the results displayed on the Time Variation graph.



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FFT y-axis scale

The y-axis of the FFT graph has a logarithmic scale. The units are appropriate for the measurement function selected and are expressed in dB. The following table summarizes the y-axis units for the FFT measurement functions:

Table of FFT Units

Measurement Function	Units
Frequency	dBHz (dB with respect to 1 Hz)
Time Interval Continuous Time Interval ±Time Interval Period	dBsec (dB with respect to 1 sec)
Time Deviation Time Deviation Data	dBsec (dB with respect to 1 sec)
Phase Deviation Phase Deviation Data	dBdeg (dB with respect to 1 degree) dBc (dB with respect to 1 radian, when Radians set on the Math menu)
Phase	dBdeg (dB with respect to 1 degree) dBrad (dB with respect to 1 radian)
Totalize	dBevt (dB with respect to 1 event)

To convert amplitude to deviation

The amplitude of each spectral component is a measure of the magnitude of the modulation component and its contribution to the deviation on the carrier. Here is the formula to convert the amplitude of the spectral components to their equivalent peak-to-peak deviation values.

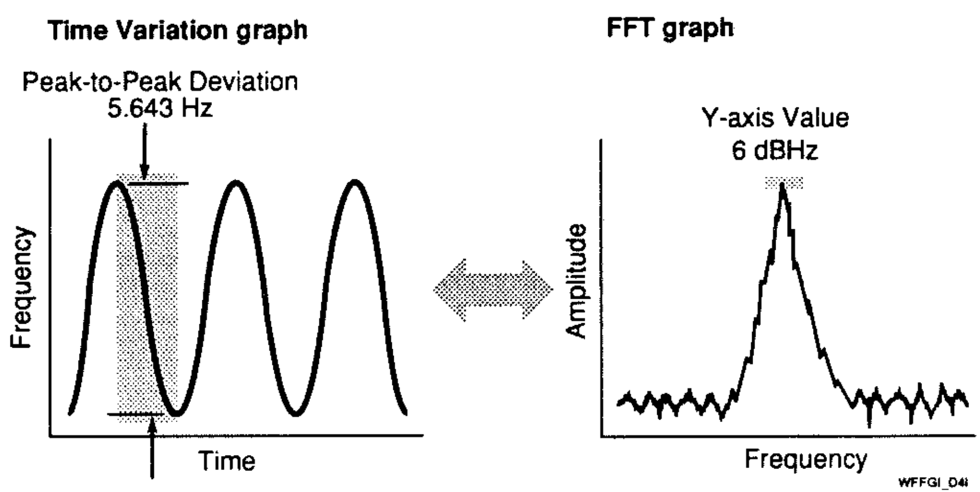
$$\textit{Amplitude (measurement units) p–p} = 2\sqrt{2} \times 10^{\frac{spur\ (dB\ units)}{20}}$$

Amplitude value examples

The following table shows some examples of FFT amplitude values converted to rms, peak, and peak-to-peak values.

dB units	rms value	peak	peak-to-peak
0 dBHz	1.0 Hz	1.414 Hz	2.828 Hz
6 dBHz	2.0 Hz	2.822 Hz	5.643 Hz
60 dBHz	1000.0 Hz	1414.214 Hz	2828.427 Hz
0 dBsec	1.0 sec	1.414 sec	2.828 sec
–60 dBsec	1.0 msec	1.414 msec	2.828 msec
–181.5 dBsec	841 psec	1.190 nsec	2.380 nsec
–33.45 dBc	21.257 mrad	30.062 mrad	60.124 mrad
11.43 dBdeg	3.728 deg	5.272 deg	10.544 deg
10 dBevt	3.162 events	4.472 events	8.944 events

This illustration shows the relationship between the peak-to-peak deviation on the Time Variation graph and the amplitude of the deviation on the FFT graph.



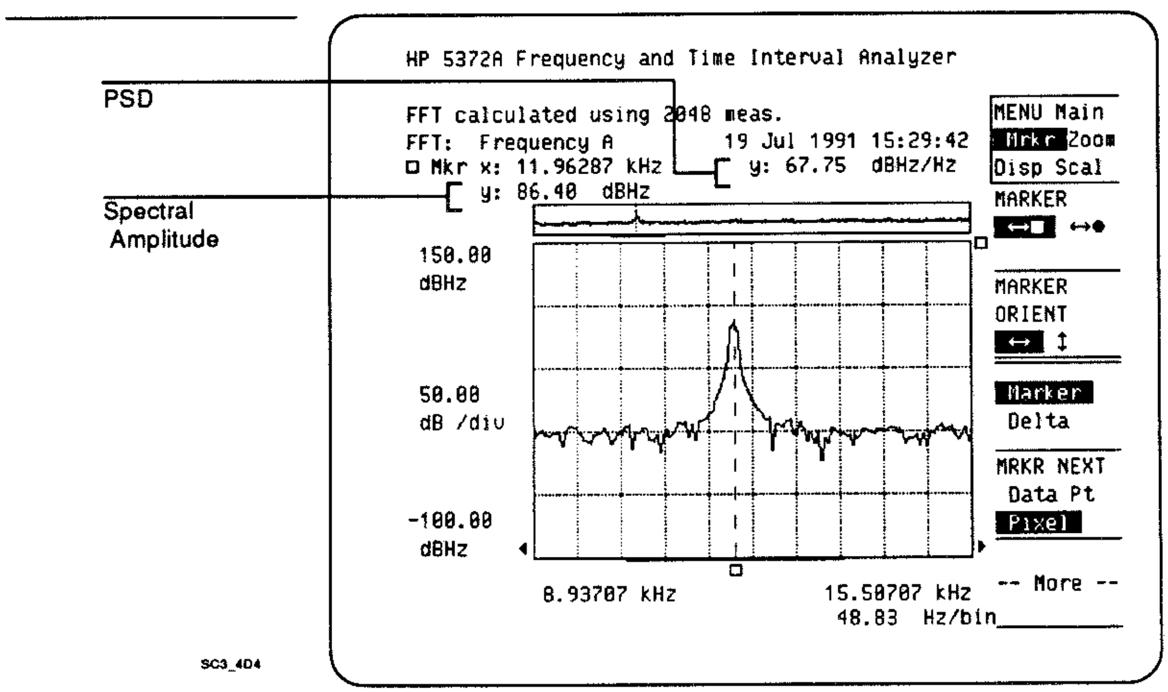
Marker readouts for the y-axis

There are two values presented on the display for the FFT y-axis; one is on the left below the x-axis readout and one is opposite the x-axis readout below the date and time. These values are intended to be used for two different kinds of FFT analysis. It is very important that the difference is understood and that the appropriate value is used for FFT analysis.

These values are related but used for different purposes. The y-axis readout on the left is for measuring the spectral amplitude of the modulation components. The readout on the right is used for measuring the Power Spectral Density (PSD) of phase noise measurements.

The PSD readout represents the power spectral density at the position of the active marker. The value is normalized to a one-Hz bandwidth.

To convert from the spectral amplitude value to the PSD value, a number is subtracted from the spectral amplitude that is based on the bin width and the type of window used for the acquisition of the FFT. In the display shown below, the spectral amplitude readout is expressed in dBHz which can be converted to frequency deviation from the carrier in Hz. The PSD value is an expression of the phase noise spectral density per Hz of bandwidth at the cursor. The conversion factor to determine the PSD here is 86.40 – 67.75 or 18.65 dB.



The PSD value is not provided directly over the HP-IB. To determine the PSD value over the bus, you would send the "PSDS?" query to return the power spectral density conversion factor. This value is to be subtracted from the original FFT results. In this example you would receive a value of 18.65. This value could then be used to convert the non-spur value to the PSD value. The same conversion factor applies to the entire FFT acquisition.

Note

The conversion factor should not be applied to spurs. You should identify portions of the FFT graph that are considered part of the noise floor. Then, apply the conversion factor selectively to those values.

Summary

Use the spectral amplitude value to measure a modulation spur of jitter on a clock or data stream. Use the PSD value to measure the noise floor for a phase noise measurement. The phase noise example in chapter 2 shows how to use the PSD value to evaluate the noise floor.

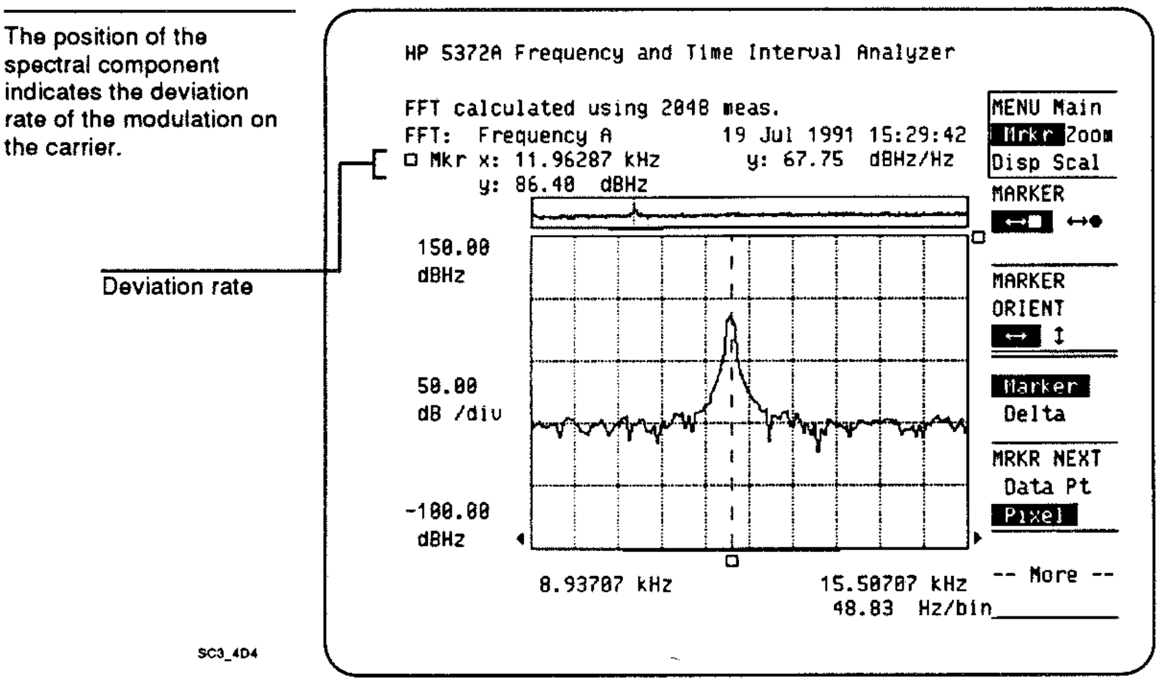
FFT x-axis scale

The x-axis of the FFT graph shows the frequency span of the FFT. Before any zooming or manual scaling takes place on the graph, the left edge of the graph is always 0 Hz and the right edge is the frequency span. Just below the span value at the right edge of the graph is the bin width. The bin width is a measure of the resolution for the FFT graph. It is computed by taking the reciprocal of the time over which measurements were acquired. The longer the time, the greater the resolution.

Marker readout for the x-axis

There is only one value for the x-axis position of the marker. It is located on the left above the graph and the y-axis spectral amplitude value. The value is the offset from the carrier at the position of the active marker.

The position of the spectral component indicates the deviation rate of the modulation on the carrier.



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Data Signal Measurements

The Jitter Spectrum Analysis option adds two measurement functions to the HP 5372A. These two functions are for measuring jitter on data signals. Data here is a non-repetitive signal that is related to a known clock. For example, a data stream on a disk drive or a digital telephone transmission.

To measure a data signal, either Phase Deviation Data or Time Deviation Data can be used. The function you select depends on your desired results. If you want to see the jitter spectrum in terms of Unit Intervals, use Time Deviation Data and use Math to either scale the results by the frequency of the clock, or normalize by the period of the clock. If you are more interested in the phase noise, select Phase Deviation Data. The data signal input is compared to a clock frequency that must be entered on the Math menu under Carrier Frequency. If no value is entered, the default value of 10 MHz is used.

What is being measured?

For every edge on the data signal, there is a corresponding edge of an ideal clock. The Deviation Data functions measure the extent to which each edge on the data signal deviates from the ideal time represented by the entered clock value. Refer to the data jitter example in chapter 2.

Measurement concerns

Since data is a series of ones and zeros, there will not always be a data edge for every edge of the clock. The Deviation Data algorithm has been designed to correctly associate each data edge with the appropriate clock edge.

The association of a data edge with its corresponding clock edge may not hold up if there is too much slip between the data signal and the clock. Three factors determine if the slippage is too great:

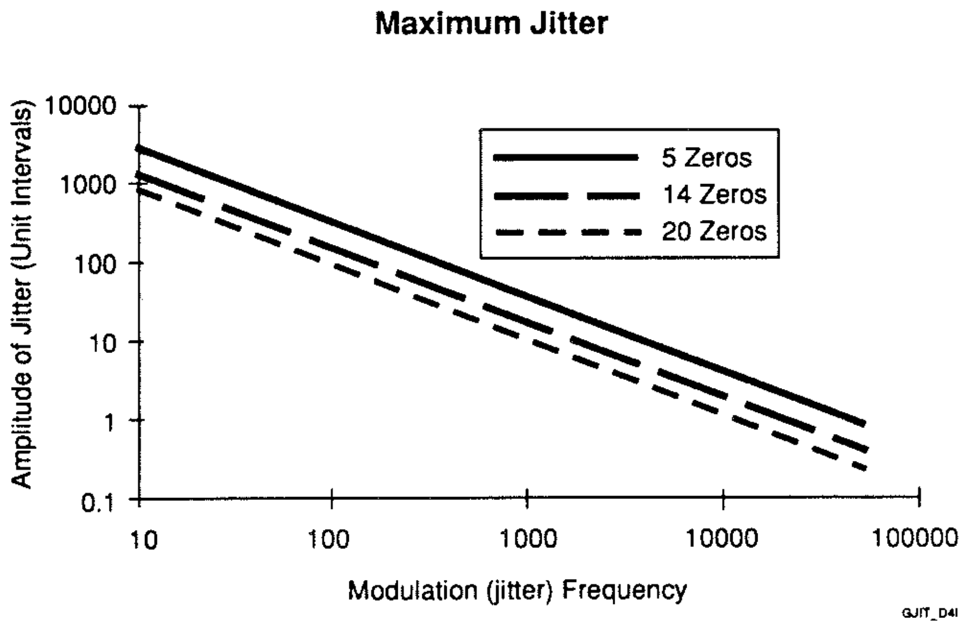
- The extent of deviation between the data signal and the clock.
- The duration of time between sampled data edges.
- The clock frequency.

How much jitter is too much?

The table here provides a guide to the maximum amount of jitter that can be tolerated by the Data measurement functions. The maximum jitter is described in terms of Unit Intervals. To express the FFT results in Unit Intervals, enable Math (on the Math menu) and either scale the results by the frequency of the clock or normalize the results by the period of the clock.

A graph for determining maximum allowable jitter is included here. It indicates the amount of data jitter (expressed in Unit Intervals) that can occur and still have the data edges matched with their associated clock edges.

This graph helps determine the maximum allowable data edge slippage with reference to its related clock edge. 5, 14, 20 Zeros refers to the maximum number of consecutive zeros.



Resampling to produce uniformly sampled results

After a series of Deviation Data results have been measured, they are subjected to a resampling algorithm to produce uniformly sampled results. The characteristics of resampling are presented here:

- The Time Variation graph displays the resampled data.
- The Numeric screen displays the resampled data.
- The FFT algorithm uses the resampled data.
- Any results requested over HP-IB are resampled results, except the binary output results.

Arming modes

The arming modes available for the Deviation Data functions are:

- Automatic
- Edge Holdoff
- Interval Sampling
- Edge/Interval

Incompatibilities

The Inhibit, Pre-trigger, and block averaging features are not available when using the Deviation Data functions.

Measurement suggestion

In a system where the data signal is modulated, and the clock is modulated to compensate, make a Phase A rel B measurement to measure jitter on the data. Refer to chapter 3, "Special-Purpose Measurements," in the *HP 5372A Operating Manual* for more on the Phase measurement function.

Phase Deviation Data

This measurement function is a specialized version of the Phase Deviation function. It measures the phase variation between the data edges and the clock. It includes the option of displaying the results in degrees or radians. Just as with the Phase and Phase Deviation functions, there is also a Modulo 360 option that can be used to keep the range of phase results limited to a total span of 360°.

Modulo 360 implementation

Refer to chapter 3, "Special-Purpose Measurements," in the *HP 5372A Operating Manual* for the description of Modulo 360 included as a Technical Comment. The behavior here is identical.

Modulo 360 displays the phase results in a 360° span from −180° to +180° with 0° at the middle of the span. With Mod 360 and Degrees selected, the Math value, "Offset" can be used to move the boundaries of the 360° span so the mid-point no longer is equal to 0°. The new range will be from (−180° − Offset) to (180° − Offset). The mid-point will always equal (−1) × Offset. Similar scaling occurs when Mod 360/2π and Radians are enabled.

Cumulative phase result

The phase results will reflect the cumulative phase deviation of the data signal from the reference clock.

Math features

When Cumulative is selected for Phase results, the Math features, Offset, Normalize, and Scale, can be used to modify the results.

Time Deviation Data

This measurement function is a specialized version of the Time Deviation function. It measures the time deviation between the data edges and the clock.

Math features

The Math features, Offset, Normalize, and Scale, can be used to modify the results.

Useful graphic features

This section lists some of the graphic features useful for FFT analysis and where they can be found under the Graphic hardkey.

Main Menu

This menu contains softkeys for selecting the graph to display, enhancing the display of data, and saving a graph to allow later comparison with another.

- Histogram graph, Time Variation graph, FFT graph, Event Timing graph.
- Grid On/Off.
- Connect Data On/Off.
- Copy graph to memory.

Marker Menu

This menu allows you to identify specific graph data, measure between markers, and scroll the graph data.

- Delta values between markers.
- Modulation values on Time Variation graph.
- Move marker to maximum, minimum, or location of other marker.

Zoom Menu

Zoom features make it possible to expand a portion of the graph for a more detailed view.

- Zoom on graph data.

Scaling Menu

This menu allows you to manually scale the x- and y-axis of the FFT graph.

- Manually scale x- or y-axis.
- Use current values of x- or y-axis values for new acquisitions.
- Use current marker locations as the x- or y-axis values for new acquisitions.

Programming Information

4

Programming Information

In this chapter

This chapter describes the commands used to program the Jitter Spectrum Analysis (FFT) capability (Option 040) of the HP 5372A Frequency and Time Interval Analyzer.

The information is organized as follows:

- Overview of the new commands.
- A detailed description of each command.
- Programming examples for the FFT-related HP-IB commands.

This information supplements the information contained in the *HP 5372A Programming Manual.*

Overview of Option 040 (FFT) Commands

New commands (or additional parameters to existing commands) are present in the following subsystems. The commands are listed in alphabetical order with brief definitions. Refer to the next section of this chapter for details of the FFT command functions.

- Commands with a question mark "?" are query only: for example "OFFT?",
- Commands with a question mark in parentheses "(?)" are either command or query: for example "GDISplay(?)",
- Commands without a question mark "?" are command action only.

NOTE

The Command subsystems are presented in the same order in the HP 5372A Programming Manual.

System commands

FFT Bin Width (FBINwidth?),
Return the FFT bin width

FFT Length (FLENgth?),
Return the number of results provided when the "OFFT?" query is used

Options Installed (*OPT?),
Identify all installed options

Output FFT (OFFT?),
Return FFT measurement data

Power Spectral Density Scale Factor (PSDScale?),
Return FFT power spectral density scale factor

GRAPhic subsystem

Graphic Display (GDISplay(?)),
Select or Return display as HISTogram/TVARiation/ETIMe/FFT

X-axis Auto Range Hold (XARHold),
Copy X-axis values to manual scale parameters

X-axis Maximum Value (XMAXimum(?)),
Set or Return X-axis maximum value for Manual Scaling

X-axis Minimum Value (XMINimum(?)),
Set or Return X-axis minimum value for Manual Scaling

X-axis Manual Scale (XMSCale(?)),
Set or Return X-axis Manual Scaling as On/Off

X-axis Marker Range Hold (XMRHold),
Copy vertical marker values to X-axis manual scale parameters

Y-axis Auto Range Hold (YARHold),
Copy Y-axis values to manual scale parameters

Y-axis Maximum Value (YMAXimum(?)),
Set or Return Y-axis maximum value for Manual Scaling

Y-axis Minimum Value (YMINimum(?)),
Set or Return Y-axis minimum value for Manual Scaling

Y-axis Manual Scaling (YMSCale(?)),
Set or Return Y-axis Manual Scaling as On/Off

Y-axis Marker Range Hold (YMRHold),
Copy horizontal marker values to Y-axis manual scale parameters

MEASurement subsystem

Function (FUNCtion(?)), Set or Return function choices available for the HP 5372A. The Jitter Spectrum Analysis option adds the new choices of DPDeviation (Phase Deviation Data function) or DTDeviation (Time Deviation Data function)

PROCess subsystem

Fast Fourier Transform (FFT(?)),
Set or Return FFT computation as On/Off

Phase Angle Units (PAUNits(?)),
Set or Return the phase-angle units setting as DEGrees or RADians

Resample Data (RDATa(?)),
Set or Return data resampling as On/Off

Spectral Averaging (SAVG(?)),
Set or Return spectral averaging as On/Off

Window Type (WINDow(?)),
Set or Return FFT window as FLATtop/HANN/RECTangle

System Commands

System commands control general instrument functions. A complete explanation of the structure and use of System commands is contained in the *HP 5372A Programming Manual.* The following paragraphs describe the new system commands for the FFT option:

FBIN?
FFT Bin Width? *(query only)*

Shortform: FBIN? [FFT BIN width]
Longform: FBINwidth?

The FBINwidth? query returns the FFT bin width (in Hertz) provided an FFT has been calculated.

Example: OUTPUT 703;"FBIN?" - Queries the FFT bin width (in Hertz).

FLEN?
FFT Length? *(query only)*

Shortform: FLEN?
Longform: FLENgth?

The FLENgth? query returns the number of results provided by the HP 5372A when the "OFFT?" query is used.

Example: OUTPUT 703;"FLEN?" - Queries for the number of FFT results.

***OPT?**
Options Installed *(query only)*

Shortform: *OPT? [Options (Installed)]
Longform: *OPT?

The *OPT? query returns a string indicating which options are installed. For example, "040," (Option 040 Jitter Spectrum Analysis option installed), or "030,040" (Option 030 Channel C option installed, and 040 Jitter Spectrum Analysis option installed) are valid responses to this query.

Example: OUTPUT 703;"*OPT?" - Returns the currently installed options.

OFFT?
Output FFT Measurement Data Results *(query only)*
Shortform: OFFT?
Longform: OFFT?

The OFFT? query returns the FFT measurement data.

Example: OUTPUT 703;"OFFT?" - Queries for FFT measurement data.

PSDScale?
Power Spectral Density Scale? *(query only)*
Shortform: PSDS? [Power Spectral Density Scale factor]
Longform: PSDScale?

The Power Spectral Density Scale? query returns the FFT Power Spectral Density Scale factor expressed in dB.

This number is to be subtracted from the numbers provided by the "OFFT?" query or from the numbers read from the y-axis marker callout. The performed subtraction expresses "OFFT?" results normalized to a one-Hertz bandwidth. (This is the same value as appears on the Graphic display's PSD y-axis callout. Refer to chapter 3 for more on PSD.)

Example: OUTPUT 703;"PROC,PSDS?" - Queries the FFT Power Spectral Density Scale factor expressed in dB.

Graphic Subsystem Commands

The GRAPhic subsystem commands control display of measurement results. A complete explanation of the structure and use of the GRAPhic subsystem commands is contained in the *HP 5372A Programming Manual.* The following paragraphs describe the new commands for the FFT option:

GDIS(?)

Graphic Display *(command/query)*

Shortform: GDIS(?) [Graphic DISplay]
Longform: GDISplay(?)

Use GDISplay(?) to set or return the displayed graph type as HISTogram, TVARiation, ETIMe, or FFT.

Parameters: {HISTogram | TVARiation | ETIMe | FFT}

Examples: OUTPUT 703;"GRAP;GDIS,FFT" - Selects FFT as the displayed graph.

OUTPUT 703;"GRAP;GDIS?" - Queries for the currently displayed graph type.

FFT

Fast Fourier Transform *(command)*

Shortform: FFT
Longform: FFT

The FFT command is required to select the FFT sublevel. Additional sublevel commands described in this subsection can be used to control the FFT graphic display.

Example: OUTPUT 703;"GRAP;FFT;YMSC,ON" - Enables Y-axis Manual Scaling.

NOTE

The x- and y-axis min/max queries return the entered manual scale value(s) provided to the instrument for its scaling process. The results of this process are the displayed axis minimum and maximum values. If you want to query the displayed axis minimum or maximum values, use one or more of the following queries: MGRaph YMIN?, MGRaph YMAX?, MGRaph XMIN?, or MGRaph XMAX?.

XARH

X-axis Auto Range Hold *(command)*

Shortform: XARH [X-axis Auto Range Hold]
Longform: XARHold

Use XARHold to copy the current X-axis min/max values to Manual Scaling values. The current values are retained if X-axis manual scaling is then enabled.

Example: OUTPUT 703;"GRAP;FFT;XARH" - Copies the current X-axis min and max values to the Manual Scaling values.

XMAX(?)

X-axis Maximum *(command/query)*

Shortform: XMAX(?) [X-axis MAXimum (value)]
Longform: XMAXimum(?)

Use XMAXimum(?) to set or return the FFT X-axis maximum value used by Manual Scaling.

Range: 0 to 1E8

Examples: OUTPUT 703;"GRAP;FFT;XMAX,1000" - Sets X-axis maximum value to 1 kHz.

OUTPUT 703;"GRAP;FFT;XMAX?" - Returns the current X-axis maximum value used by Manual Scaling.

XMIN(?)
X-axis Minimum *(command/query)*

Shortform: XMIN(?) [X-axis MINimum (value)]
Longform: XMINimum(?)

Use XMINimum(?) to set or return the current FFT X-axis minimum value used by Manual Scaling.

Range: 0 to 1E8

Examples: OUTPUT 703;"GRAP;FFT;XMIN,1E6" - Sets the X-axis minimum value to 1 MHz.

OUTPUT 703;"GRAP;FFT;XMIN?" - Returns the current X-axis minimum value used by Manual Scaling.

XMRH
X-axis Marker Range Hold *(command)*

Shortform: XMRH [X-axis Marker Range Hold]
Longform: XMRHold

Use XMRHold to set the manual scale XMINimum and XMAXimum to the current vertical marker values.

Example: OUTPUT 703;"GRAP;FFT;XMRH" - Copies the vertical marker values to the X-axis Manual Scaling values.

XMSC(?)
X-axis Manual Scale *(command/query)*

Shortform: XMSC(?) [X-axis Manual SCale]
Longform: XMSCale(?)

Use XMSCale(?) to set or return X-axis Manual Scaling as On or Off.

Parameters: {ON | OFF}

Examples: OUTPUT 703;"GRAP;FFT;XMSC,ON" - Sets X-axis Manual Scaling On.

OUTPUT 703;"GRAP;FFT;XMSC?" - Returns the current X-axis Manual Scaling status as On or Off.

YARH
Y-axis Auto Range Hold *(command)*

Shortform: YARH [Y-axis Auto Range Hold]
Longform: YARHold

Use YARHold to copy the current Y-axis min and max values to the Manual Scaling values. The current values are retained if Y-axis manual scaling is then enabled.

Example: OUTPUT 703;"GRAP;FFT;YARH" - Copies Y-axis min and max values to the Manual Scaling values.

YMAX(?)
Y-axis Maximum *(command/query)*

Shortform: YMAX(?) [Y-axis MAXimum (value)]
Longform: YMAXimum(?)

Use YMAXimum(?) to set or return the FFT Y-axis maximum value after Manual Scaling has been turned On.

Range: –10E12 to 10E12, and 0dB.

Examples: OUTPUT 703;"GRAP;FFT;YMAX,-50" - Sets Y-axis maximum value to -50 dB.

OUTPUT 703;"GRAP;FFT;YMAX?" - Queries for the current Y-axis maximum Manual Scale value.

YMIN(?)
Y-Axis Minimum *(command/query)*

Shortform: YMIN(?) [Y-axis MINimum (value)]
Longform: YMINimum(?)

Use YMINimum(?) to set or return the FFT Y-axis minimum value used by Manual Scaling.

Range: –10E12 to 10E12 and 0dB

Examples: OUTPUT 703;"GRAP;FFT;YMIN,-150" - Sets the Y-axis minimum value to -150 dB.

OUTPUT 703;"GRAP;FFT;YMIN?" - Queries for the current Y-axis Manual Scale minimum value.

YMRH
Y-axis Marker Range Hold *(command)*

Shortform: YMRH [Y-axis Marker Range Hold]
Longform: YMRHold

Use YMRHold to set the Manual Scale YMINimum and YMAXimum to the current horizontal marker values.

Example: OUTPUT 703;"GRAP;FFT;YMRH" - Copies the horizontal marker values to the Y-axis Manual Scaling values.

YMSC(?)
Y-axis Manual Scaling *(command/query)*

Shortform: YMSC(?) [Y-axis Manual Scaling]
Longform: YMSCale(?)

Use YMSCale(?) to set or return the Y-axis Manual Scaling as On or Off.

Parameters: {ON | OFF}

Examples: OUTPUT 703;"GRAP;FFT;YMSC,ON" Sets Y-axis Manual Scaling On.

OUTPUT 703;"GRAP;FFT;YMSC?" - Returns the current Y-axis Manual Scaling status as On or Off.

Measurement Subsystem Commands

The MEASurement subsystem commands control the measurement modes, arming modes, measurement sizes, and measurement holdoff (start) and sampling (stop) conditions. A complete explanation of the structure and use of the MEASurement subsystem commands is contained in the *HP 5372A Programming Manual.* The following paragraphs describe the new parameters added to the FUNCtion command for Option 040:

FUNC(?)
Function *(command/query)*

Shortform: FUNC(?) [FUNCtion]
Longform: FUNCtion(?)

The FUNCtion(?) command selects or returns the measurement function.

NOTE *The DPDeviation and DTDeviation functions are added for Option 040.*

The function selections for which an FFT is offered are listed below:

FREQuency
PERiod
TOTalize
TIMe or TINTerval (Time Interval)
PMTinterval (Plus or Minus Time interval)
CTINterval (Continuous Time Interval)
PHASe
PDEViation (Phase Deviation)
TDEViation (Time Deviation)
DPDeviation (Phase Deviation Data)
DTDeviation (Time Deviation Data)

Examples: OUTPUT 703;"MEAS;FUNC,DPD" - Selects Phase Deviation Data as the measurement function.

OUTPUT 703;"MEAS;FUNC?" - Returns the current measurement function.

NOTE

Changing the function can modify other instrument states, although this only happens if the current setting is not supported for the new function. Refer to tables D-1 and D-2 in appendix D of the HP 5372A Programming Manual for the default arming and measurement source settings for each measurement function.

NOTE

When using DPD or DTD, Manual Carrier Frequency is enabled and the appropriate carrier value must be provided by your program. For example: "PROC;CFR,1.544E6".

Process Subsystem Commands

The PROCess (MATH) subsystem commands control math functions, statistical functions, test limits, and enable or disable the FFT. A complete explanation of the structure and use of the PROCess (MATH) subsystem commands is contained in the *HP 5372A Programming Manual.* The following paragraphs describe the new commands for Option 040:

FFT(?)

Fast Fourier Transform ***(command/query)***

Shortform: FFT(?) [Fast Fourier Transform]
Longform: FFT(?)

Use FFT(?) to set or return FFT analysis as On or Off. If FFT is unavailable, "FFT NA" appears on the Math Menu. The query then returns the FFT state when FFT measurement was last available. For example, if FFT was On, the query return will be "ON".

Parameters: {ON | OFF}

Examples: OUTPUT 703;"PROC;FFT,ON" - Enables the FFT.

OUTPUT 703;"PROC;FFT?" - Queries for the current status of the FFT.

PAUN(?)

Phase Angle Units ***(command/query)***

Shortform: PAUN(?) [Phase Angle UNits]
Longform: PAUNits(?)

Use PAUNits(?) to set or return the phase angle unit setting as DEGrees or RADians.

Parameters: {DEGrees | RADians}

Examples: OUTPUT 703;"PROC;PAUN,RAD" - Selects radians as the phase angle units.

OUTPUT 703;"PROC;PAUN?" - Queries for the current phase angle units.

RDATa(?)
Resample Data *(command/query)*

Shortform: RDAT(?) [Resample DATa]
Longform: RDATa(?)

Use RDATa(?) to set or return resampling as On or Off. The default setting for RDATa is On.

Parameters: {ON | OFF}

Examples: OUTPUT 703;"PROC;RDAT,OFF" - Sets resampling Off.

OUTPUT 703;PROC;RDAT? - Returns the status of resampling.

SAVG(?)
Spectral Averaging *(command/query)*

Shortform: SAVG(?) [Spectral AVeraGing]
Longform: SAVG(?)

Use SAVG(?) to set or return spectral averaging as On or Off.

Parameters: {ON | OFF}

Examples: OUTPUT 703;"PROC;SAVG, ON" - Enables spectral averaging.

OUTPUT 703;"PROC;SAVG?" - Queries for the current status of spectral averaging.

WIND(?)
Window Type *(command/query)*

Shortform: WIND(?) [WINDow type]
Longform: WINDow(?)

Use WINDow(?) to set or return the window type.

Parameters: {FLATtop | HANN | RECTangle}

Examples: OUTPUT 703;"PROC;WIND,HANN" - Selects the Hann window.

OUTPUT 703;"PROC;WIND?" - Queries for the current window type.

Programming Examples

The programs listed here make the same types of measurements as the front-panel procedures explained in chapters 1 and 2.

Examples in HP BASIC are included for all four measurement tasks. Additional examples are given in Microsoft® QuickBASIC (version 4.5)* for an FFT of a Frequency Measurement, and one in Turbo C (version 2.0)** for Clock Jitter. The programming examples are:

- FM Signal Spectral Content (HP BASIC),
- Clock Jitter (HP BASIC),
- Phase Noise (HP BASIC),
- Data-Signal Jitter (HP BASIC),
- FFT of a Frequency Measurement (QuickBASIC),
- Clock Jitter (Turbo C).

Before you begin programming:

- Ensure that the HP 5372A is in the "Talk/Listen" addressing mode by,
  (a) Pressing the SYSTEM hardkey, and
  (b) Selecting TALK/LISTEN as the active addressing mode, then
- Select the HP-IB address as 03,
- Load the applicable measurement program into your controller, and
- Run the program.

* Microsoft is a U.S. registered trademark of Microsoft Corporation.
** Turbo C is a product of Borland International, Inc.

To Measure FM Signal Spectral Content

This is an example program to measure the spectral content of an FM signal.

- HP BASIC example program:

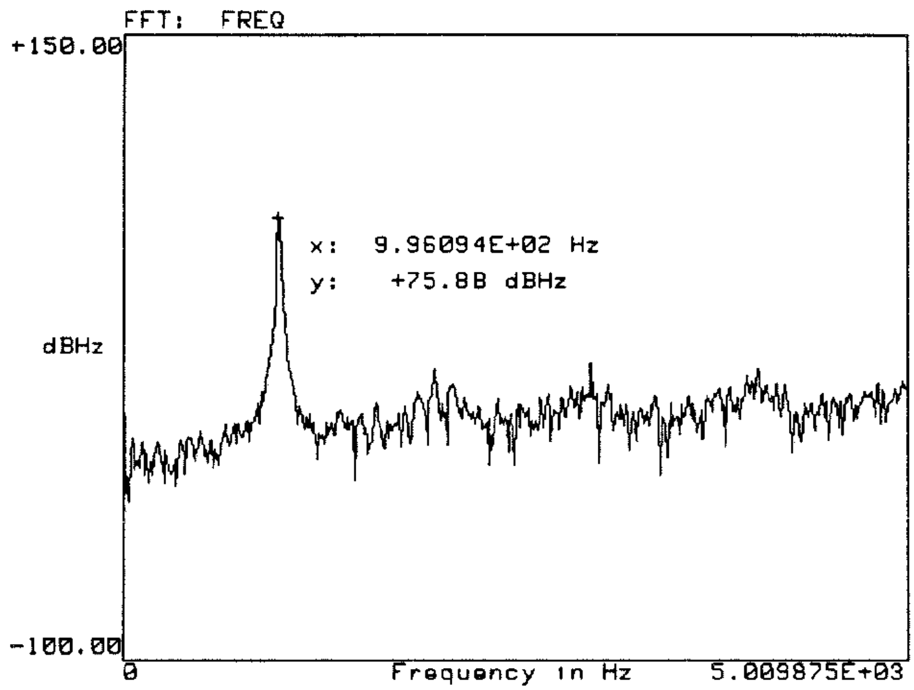
```
10     ! This program sets up the HP 5372A Option 040 to make an FM
20     ! measurement, perform an FFT, transfer the data and plot it on
30     ! the computer's CRT. It assumes a signal with some frequency modulation
40     ! is attached to channel A. The sample interval of 100 usec means
50     ! that any modulation present above 5 kHz will be aliased. Change the
60     ! sample interval if you suspect higher modulation rates.
70     !
80     OPTION BASE 1
90     GCLEAR
100    DIM Fft(4096) BUFFER
110    DIM Header$[8]
120    INTEGER I,Num_meas,Flength
130    Func$="FREQ"
140    Samp_int=1.E-4                   ! Sample interval for measurement
150    Num_meas=1024                    ! Number of measurements
160    CLEAR 7                          ! Reset the HP-IB
170    ASSIGN @Hp5372 TO 703            ! Setup I/O path for HP 5372A
180    ASSIGN @Buff1 TO BUFFER Fft(*)   ! Assign path to data array
190    OUTPUT @Hp5372;"PRES"            ! Preset the instrument
200    OUTPUT @Hp5372;"SMOD,SINGLE"     ! Set to single measurement mode
210    OUTPUT @Hp5372;"INT;OUTP,FPO"    ! Data format floating point
220    OUTPUT @Hp5372;"PROC;FFT,ON"     ! Enable the FFT function
230    OUTPUT @Hp5372;"MEAS;FUNC,";Func$! Set measurement to frequency
240    OUTPUT @Hp5372;"MEAS;BLOCK,1"    ! Set to 1 block
250    OUTPUT @Hp5372;"MEAS;SSIZ,";Num_meas     ! Set number of measurements
260    OUTPUT @Hp5372;"MEAS;ARM,ISAM"           ! Set arming to interval sampling
270    OUTPUT @Hp5372;"MEAS;SAMP;DEL,";Samp_int  ! Set the sample interval
280    S=SPOLL(@Hp5372)                 ! Make sure no status is pending
290    OUTPUT @Hp5372;"*SRE 2"          ! Enable SRQ when measurement complete
300    DISP "Waiting for measurement to complete"
310    OUTPUT @Hp5372;"REST"            ! Start a new measurement
320    ON INTR 7 GOTO Get_data          ! Go get the data when SRQ enabled
330    ENABLE INTR 7;2                  ! Enable the interrupt
340 Loop_here:  !                       ! Loop here while waiting for
350    GOTO Loop_here                   ! measurement to complete
360    !
370    !
380 Get_data:                           ! Start of measurement process
390    S=SPOLL(@Hp5372)                 ! Read the status of the HP 5372A
400    GOSUB Get_fft                    ! Go get the data
410    GOSUB Get_markers
420    GOSUB Plot_data
430    STOP
440    !
450    !
460 Get_fft:                            ! Start of routine to transfer data
470    DISP "Transferring and processing data"
```

FM Spectral Content (HP BASIC)

```
480   OUTPUT @Hp5372;"OFFT?"               ! Request data
490   ENTER @Hp5372 USING "#,8A";Header$    ! Get the header which has the number
500                                          ! of bytes to be transferred
510   Flength=VAL(Header$[3])/8            ! Flength is the number of FFT bins
520   REDIM Fft(Flength)
530   TRANSFER @Hp5372 TO @Buff1;COUNT VAL(Header$[3]),WAIT !Transfer the data
540                                        ! The data can now be accessed via
550                                        ! the FFT(*) array
560   RETURN
570   !
580   !
590 Get_markers:                           ! Start of routine to get marker values
600   OUTPUT @Hp5372;"MENU,GRAP"           ! Use the graphics menu
610   OUTPUT @Hp5372;"GRAP;GDIS,FFT"       ! Show the FFT graph
620   OUTPUT @Hp5372;"GRAP;CDAT,ON"        ! Connect the dots on the graph
630   WAIT 2                               ! Must wait a bit for graph
640   OUTPUT @Hp5372;"GRAP;MMAX"           ! Move the marker to max of the graph
650   OUTPUT @Hp5372;"GRAP;YVAL?"          ! Ask for the y_value of marker
660   ENTER @Hp5372;Y_value
670   OUTPUT @Hp5372;"GRAP;XVAL?"          ! Ask for x_value of marker
680   ENTER @Hp5372;X_value
690   DISP
700   RETURN
710   !
720   !
730 Plot_data:                             ! Start of routine to plot data
740   VIEWPORT 13,100,22,92
750   OUTPUT @Hp5372;"GRAP;MGR;XMIN?"      ! Get the graph axis values for graph
760   ENTER @Hp5372;Xmin
770   OUTPUT @Hp5372;"GRAP;MGR;XMAX?"
780   ENTER @Hp5372;Xmax
790   OUTPUT @Hp5372;"GRAP;MGR;YMIN?"
800   ENTER @Hp5372;Ymin
810   OUTPUT @Hp5372;"GRAP;MGR;YMAX?"
820   ENTER @Hp5372;Ymax
830   OUTPUT @Hp5372;"FBIN?"               ! Ask for the FFT bin width
840   ENTER @Hp5372;Fbin
850   WINDOW Xmin,Xmax,Ymin,Ymax           ! Set up computer graphics window
860   FRAME
870   FOR I=1 TO Flength
880     PLOT I*Fbin,Fft(I)                 ! Plot the data
890   NEXT I
900   CLIP OFF
910   CSIZE 3
920   LORG 1
930   MOVE Xmin,Ymax
940   LABEL "FFT:  ";Func$
950   LORG 3
960   MOVE Xmin,Ymin                       ! Label the axes
970   LABEL USING "D";Xmin
980   LORG 9
990   MOVE Xmax,Ymin
1000  LABEL USING "D.6DE";Xmax
1010  LORG 7
1020  MOVE Xmin,Ymin
1030  LABEL USING "SDDD.DD";Ymin
1040  LORG 9
```

FM Spectral Content (HP BASIC) (Continued)

```
1050  MOVE Xmin,Ymax
1060  LABEL USING "SDDD.DD";Ymax
1070  LORG 8
1080  MOVE Xmin,Ymax-(Ymax-Ymin)/2
1090  LABEL "dBHz "
1100  LORG 6
1110  MOVE Xmax-(Xmax-Xmin)/2,Ymin
1120  LABEL "Frequency in Hz"
1130  MOVE X_value,Y_value              ! Move to max of graph
1140  LORG 5
1150  LABEL "+"                         ! Put + at max of graph
1160  LORG 2
1170  LABEL USING "2X,2A,2X,D.5DE,3A";"x:";X_value;" Hz"
1180  MOVE X_value,Y_value-.1*(Ymax-Ymin)
1190  LORG 2
1200  LABEL USING "2X,2A,2X,SDDD.DD,5A";"y:";Y_value," dBHz"
1210  RETURN
1220  END
```



FM Spectral Content (HP BASIC) (Continued)

To Measure Clock Jitter

This is an example program to measure clock jitter using HP BASIC.

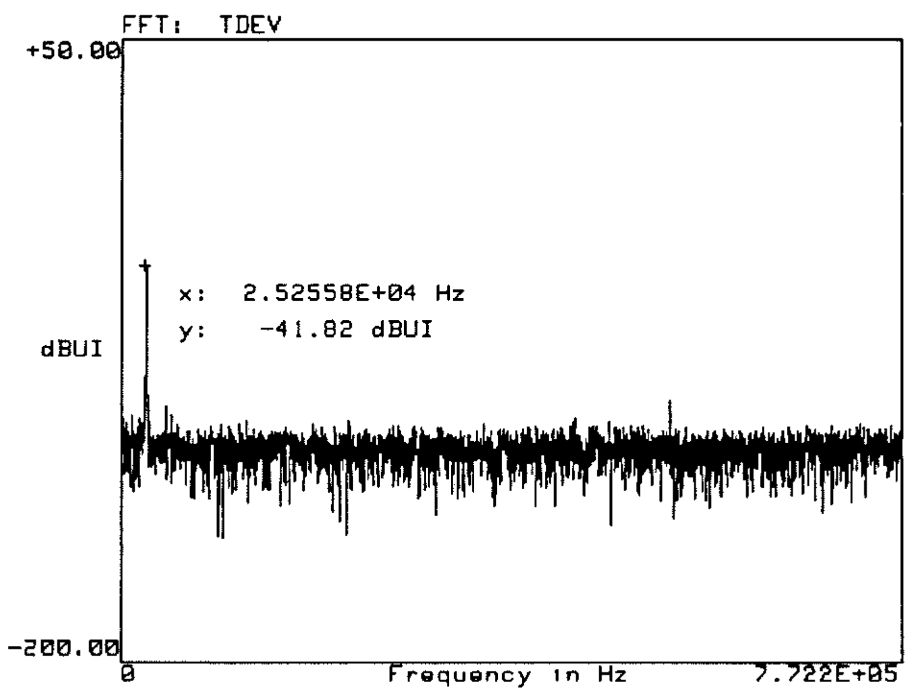
```
10    ! This program sets up the HP 5372A Option 040 to make a Time Deviation
20    ! measurement, perform an FFT, transfer the data and plot it on
30    ! the computer's CRT. It assumes a signal with some jitter is
40    ! attached to channel A and that the clock frequency is 1.544 MHz.
50    ! Auto sampling is used to minimize the possibility of aliasing.
60    !
70    OPTION BASE 1
80    GCLEAR
90    DIM Fft(4096) BUFFER
100   DIM Header$[8]
110   INTEGER I,Num_meas,Flength
120   Func$="TDEV"                     ! Measurement function
130   Clock=1.544E+6                   ! Frequency of clock to be measured
140   Num_meas=8191                    ! Number of measurements
150   CLEAR 7                          ! Reset the HP-IB
160   ASSIGN @Hp5372 TO 703            ! Setup I/O path for HP 5372A
170   ASSIGN @Buff1 TO BUFFER Fft(*)   ! Assign path to data array
180   OUTPUT @Hp5372;"PRES"            ! Preset the instrument
190   OUTPUT @Hp5372;"SMOD,SINGLE"     ! Set to single measurement mode
200   OUTPUT @Hp5372;"INT;OUTP,FPO"    ! Data format floating point
210   OUTPUT @Hp5372;"PROC;FFT,ON"     ! Enable the FFT function
220   OUTPUT @Hp5372;"MEAS;FUNC,";Func$! Set measurement to frequency
230   OUTPUT @Hp5372;"MEAS;BLOCK,1"    ! Set to 1 block
240   OUTPUT @Hp5372;"MEAS;SSIZ,";Num_meas    ! Set number of measurements
250   OUTPUT @Hp5372;"MEAS;ARM,AUTO"          ! Set arming to Auto
260   OUTPUT @Hp5372;"PROC;SOUR,A;MATH,ON"
270   OUTPUT @Hp5372;"PROC;SOUR,A;SCAL,";Clock ! Convert to Unit Intervals
280   S=SPOLL(@Hp5372)                 ! Make sure no status is pending
290   OUTPUT @Hp5372;"*SRE 2"          ! Enable SRQ when measurement complete
300   DISP "Waiting for measurement to complete"
310   OUTPUT @Hp5372;"REST"            ! Start a new measurement
320   ON INTR 7 GOTO Get_data          ! Go get the data when SRQ enabled
330   ENABLE INTR 7;2                  ! Enable the interrupt
340 Loop_here:  !                      ! Loop here while waiting for
350   GOTO Loop_here                   ! measurement to complete
360   !
370   !
380 Get_data:                          ! Start of measurement process
390   S=SPOLL(@Hp5372)                 ! Read the status of the HP 5372A
400   GOSUB Get_fft                    ! Go get the data
410   GOSUB Get_markers
420   GOSUB Plot_data
430   STOP
440   !
450   !
460 Get_fft:                           ! Start of routine to transfer data
470   DISP "Transferring and processing data"
480   OUTPUT @Hp5372;"OFFT?"           ! Request data
490   ENTER @Hp5372 USING "#,8A";Header$  ! Get the header which has the number
500                                       ! of bytes to be transferred
510   Flength=VAL(Header$[3])/8        ! Flength is the number of FFT bins
520   REDIM Fft(Flength)
```

Clock-Jitter Spectral Content (HP BASIC)

```
530   TRANSFER @Hp5372 TO @Buff1;COUNT VAL(Header$[3]),WAIT !Transfer the data
540                                   ! The data can now be accessed via
550                                   ! the FFT(*) array
560   RETURN
570   !
580   !
590 Get_markers:                      ! Start of routine to get marker values
600   OUTPUT @Hp5372;"MENU,GRAP"      ! Use the graphics menu
610   OUTPUT @Hp5372;"GRAP;GDIS,FFT"  ! Show the FFT graph
620   OUTPUT @Hp5372;"GRAP;CDAT,ON"   ! Connect the dots on the graph
630   WAIT 2                          ! Must wait a bit for graph
640   OUTPUT @Hp5372;"GRAP;MMAX"      ! Move the marker to max of the graph
650   OUTPUT @Hp5372;"GRAP;YVAL?"     ! Ask for the y_value of marker
660   ENTER @Hp5372;Y_value
670   OUTPUT @Hp5372;"GRAP;XVAL?"     ! Ask for x_value of marker
680   ENTER @Hp5372;X_value
690   DISP
700   RETURN
710   !
720   !
730 Plot_data:                        ! Start of routine to plot data
740   VIEWPORT 13,100,22,92
750   OUTPUT @Hp5372;"GRAP;MGR;XMIN?" ! Get the graph axis values for graph
760   ENTER @Hp5372;Xmin
770   OUTPUT @Hp5372;"GRAP;MGR;XMAX?"
780   ENTER @Hp5372;Xmax
790   OUTPUT @Hp5372;"GRAP;MGR;YMIN?"
800   ENTER @Hp5372;Ymin
810   OUTPUT @Hp5372;"GRAP;MGR;YMAX?"
820   ENTER @Hp5372;Ymax
830   OUTPUT @Hp5372;"FBIN?"          ! Ask for the FFT bin width
840   ENTER @Hp5372;Fbin
850   WINDOW Xmin,Xmax,Ymin,Ymax      ! Set up computer graphics window
860   FRAME
870   FOR I=1 TO Flength
880     PLOT I*Fbin,Fft(I)            ! Plot the data
890   NEXT I
900   CLIP OFF
910   CSIZE 3
920   LORG 1
930   MOVE Xmin,Ymax
940   LABEL "FFT:  ";Func$
950   LORG 3
960   MOVE Xmin,Ymin                  ! Label the axes
970   LABEL USING "D";Xmin
980   LORG 9
990   MOVE Xmax,Ymin
1000  LABEL USING "D.DDDE";Xmax
1010  LORG 7
1020  MOVE Xmin,Ymin
1030  LABEL USING "SDDD.DD";Ymin
1040  LORG 9
1050  MOVE Xmin,Ymax
1060  LABEL USING "SDDD.DD";Ymax
1070  LORG 8
1080  MOVE Xmin,Ymax-(Ymax-Ymin)/2
1090  LABEL "dBUI "
```

Clock-Jitter Spectral Content (HP BASIC) (Continued)

```
1100  LORG 6
1110  MOVE Xmax-(Xmax-Xmin)/2,Ymin
1120  LABEL "Frequency in Hz"
1130  MOVE X_value,Y_value              ! Move to max of graph
1140  LORG 5
1150  LABEL "+"                         ! Put + at max of graph
1160  LORG 2
1170  LABEL USING "2X,2A,2X,D.5DE,3A";"x:";X_value;" Hz"
1180  MOVE X_value,Y_value-.1*(Ymax-Ymin)
1190  LORG 2
1200  LABEL USING "2X,2A,2X,SDDD.DD,5A";"y:";Y_value," dBUI"
1210  RETURN
1220  END
```



Clock-Jitter Spectral Content (HP BASIC) (Continued)

To Measure Phase Noise

This is an example program to measure phase noise.

- HP BASIC example program:

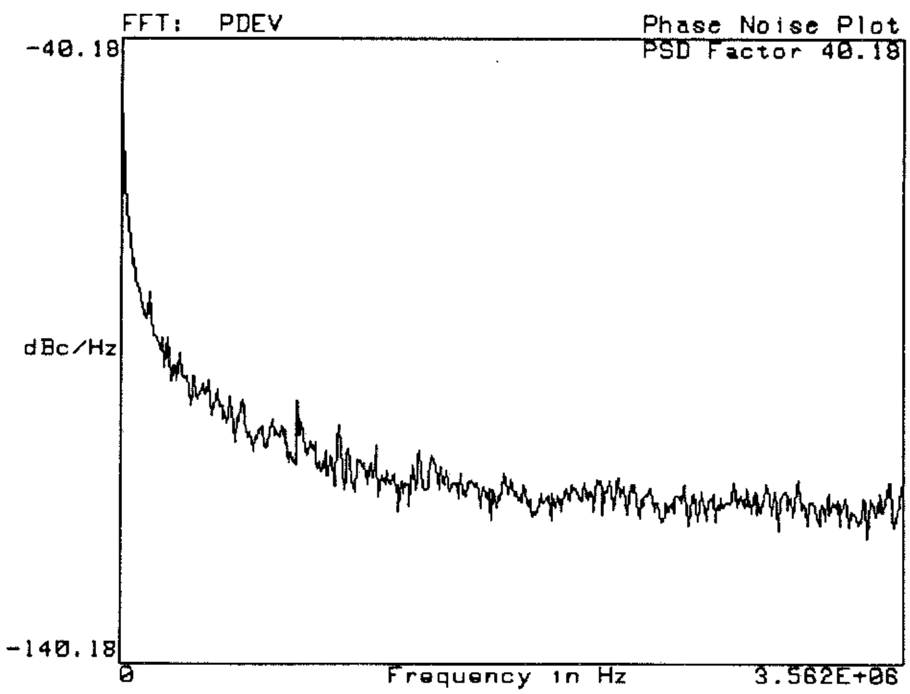
```
10     ! This program sets up the HP 5372A Option 040 to make a phase deviation
20     ! measurement, perform an FFT, transfer the data and plot it on
30     ! the computer's CRT. This plot shows the phase noise of the unit under
40     ! test.
50     ! Auto sampling is used to minimize the possibility of aliasing and
60     ! show the greatest span. To look at phase noise close in, interval
70     ! sampling must be used.
80     !
90     OPTION BASE 1
100    GCLEAR
110    DIM Fft(4096) BUFFER
120    DIM Header$[8]
130    INTEGER I,Num_meas,Flength,Num_blocks,X
140    Func$="PDEV"                      ! Measurement function for phase noise
150    Num_meas=1022                     ! Number of measurements
160    Num_blocks=8                      ! Reduces variance to give a better
170                                      ! estimate of true phase noise floor
180    ! Using 8 blocks of 1022 measurements allows all of the data to be
190    ! captured in the internal HP 5372A memory. The total acquisition time
200    ! is kept to a minimum, reducing the effects of drift in the device
210    ! under test.
220    !
230    CLEAR 7                           ! Reset the HP-IB
240    ASSIGN @Hp5372 TO 703             ! Setup I/O path for HP 5372A
250    ASSIGN @Buff1 TO BUFFER Fft(*)    ! Assign path to data array
260    OUTPUT @Hp5372;"PRES"             ! Preset the instrument
270    OUTPUT @Hp5372;"SMOD,SINGLE"      ! Set to single measurement mode
280    OUTPUT @Hp5372;"INT;OUTP,FPO"     ! Data format floating point
290    OUTPUT @Hp5372;"PROC;FFT,ON"      ! Enable the FFT function
300    OUTPUT @Hp5372;"MEAS;FUNC,";Func$! Set measurement to phase deviation
310    OUTPUT @Hp5372;"MEAS;BLOCK,";Num_blocks ! More blocks reduces variance
320    OUTPUT @Hp5372;"MEAS;SSIZ,";Num_meas    ! Set number of measurements
330    OUTPUT @Hp5372;"MEAS;ARM,AUTO"          ! Set arming to Auto
340    OUTPUT @Hp5372;"PROC;PAUN,RAD"    ! Use radians for proper scaling
350    OUTPUT @Hp5372;"PROC;PCOM,CUM"    ! Use cumulative phase results
360    OUTPUT @Hp5372;"PROC;SAVG,ON"     ! Enable spectral averaging
370    OUTPUT @Hp5372;"MENU,GRAP"        ! Display the graphics menu
380    OUTPUT @Hp5372;"GRAP;GDIS,FFT"    ! Show the FFT graph
390    OUTPUT @Hp5372;"GRAP;CDAT,ON"     ! Connect the dots on the graph
400    WAIT 2                            ! Must wait a bit for graph
410    S=SPOLL(@Hp5372)                  ! Make sure no status is pending
420    OUTPUT @Hp5372;"*SRE 2"           ! Enable SRQ when measurement complete
430    DISP "Waiting for measurement, be patient for ";Num_blocks;" blocks to
complete"
440    OUTPUT @Hp5372;"REST"             ! Start a new measurement
450    ON INTR 7 GOTO Get_data           ! Go get the data when SRQ enabled
460    ENABLE INTR 7;2                   ! Enable the interrupt
470 Loop_here:  !                        ! Loop here while waiting for
480    GOTO Loop_here                    ! measurement to complete
```

Phase-Noise Spectral Content (HP BASIC)

```
490   !
500   !
510 Get_data:                           ! Start of measurement process
520   S=SPOLL(@Hp5372)                  ! Read the status of the HP 5372A
530   GOSUB Get_fft                     ! Go get the data
540   GOSUB Plot_data                   ! Go plot the data
550   LOCAL @Hp5372
560   STOP
570   !
580   !
590 Get_fft:                            ! Start of routine to transfer data
600   DISP "Transferring and processing data"
610   OUTPUT @Hp5372;"OFFT?"            ! Request data
620   ENTER @Hp5372 USING "#,8A";Header$  ! Get the header which has the number
630                                       ! of bytes to be transferred
640   Flength=VAL(Header$[3])/8         ! Flength is the number of FFT bins
650   REDIM Fft(Flength)
660   TRANSFER @Hp5372 TO @Buff1;COUNT VAL(Header$[3]),WAIT !Transfer the data
670                                     ! The data can now be accessed via
680                                     ! the FFT(*) array
690   RETURN
700   !
710   !
720   !
730 Plot_data:                          ! Start of routine to plot data
740   DISP
750   VIEWPORT 13,100,22,92
760   OUTPUT @Hp5372;"GRAP;MGR;XMIN?"   ! Get the graph axis values for plotting
770   ENTER @Hp5372;Xmin
780   OUTPUT @Hp5372;"GRAP;MGR;XMAX?"
790   ENTER @Hp5372;Xmax
800   OUTPUT @Hp5372;"GRAP;MGR;YMIN?"
810   ENTER @Hp5372;Ymin
820   OUTPUT @Hp5372;"GRAP;MGR;YMAX?"
830   ENTER @Hp5372;Ymax
840   OUTPUT @Hp5372;"FBIN?"            ! Ask for the FFT bin width
850   ENTER @Hp5372;Fbin
860   OUTPUT @Hp5372;"PSDS?"            ! Ask for power spectral density
870   ENTER @Hp5372;Psds                ! conversion factor. Subtracting this
880   MAT Fft= Fft-(Psds)               ! number from the data gives the power
890   Ymin=Ymin-Psds                    ! spectral density in a one Hz bandwidth
900   Ymax=Ymax-Psds
910   WINDOW Xmin,Xmax,Ymin,Ymax        ! Set up computer graphics window
920   FRAME
930   FOR I=1 TO Flength
940     PLOT I*Fbin,Fft(I)              ! Plot the data
950   NEXT I
960   CLIP OFF
970   CSIZE 3
980   LORG 1
990   MOVE Xmin,Ymax
1000  LABEL "FFT:  ";Func$
1010  LORG 7
1020  MOVE Xmax,Ymax
1030  LABEL "Phase Noise Plot"
1040  LORG 9 1050  MOVE Xmax,Ymax
1060  LABEL USING "10A,X,DD.DD";"PSD Factor";Psds
```

Phase-Noise Spectral Content (HP BASIC) (Continued)

```
1070  LORG 3
1080  MOVE Xmin,Ymin                    ! Label the axes
1090  LABEL USING "D";Xmin
1100  LORG 9
1110  MOVE Xmax,Ymin
1120  LABEL USING "D.DDDE";Xmax
1130  LORG 7
1140  MOVE Xmin,Ymin
1150  LABEL USING "SDDD.DD";Ymin
1160  LORG 9
1170  MOVE Xmin,Ymax
1180  LABEL USING "SDDD.DD";Ymax
1190  LORG 8
1200  MOVE Xmin,Ymax-(Ymax-Ymin)/2
1210  LABEL "dBc/Hz"
1220  LORG 6
1230  MOVE Xmax-(Xmax-Xmin)/2,Ymin
1240  LABEL "Frequency in Hz"
1250  RETURN
1260  END
```



Phase-Noise Spectral Content (HP BASIC) (Continued)

To Measure Data-Signal Jitter

This is an example program to measure data-signal jitter.

- HP BASIC example program:

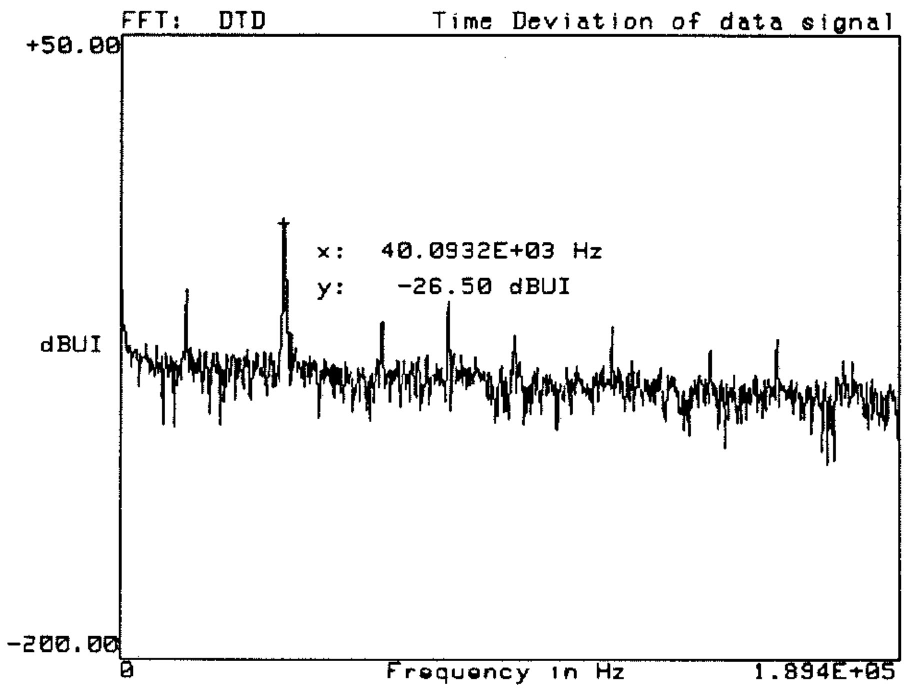
```
10    ! This program sets up the HP 5372A Option 040 to make a Time Deviation
20    ! Data measurement, perform an FFT, transfer the data and plot it on
30    ! the computer's CRT. It assumes a data signal with some jitter is
40    ! attached to channel A and that the clock frequency associated with
50    ! the data is 1.544 MHz. Auto sampling is used to minimize the
60    ! possibility of aliasing.
70    !
80    OPTION BASE 1
90    GCLEAR
100   DIM Fft(4096) BUFFER
110   DIM Header$[8]
120   INTEGER I,Num_meas,Flength
130   Func$="DTD"                       ! Function is Time Deviation Data
140   Clock=1.544E+6                    ! Frequency of manual carrier
150   Num_meas=2048                     ! Number of measurements
160   CLEAR 7                           ! Reset the HP-IB
170   ASSIGN @Hp5372 TO 703             ! Setup I/O path for HP 5372A
180   ASSIGN @Buff1 TO BUFFER Fft(*)    ! Assign path to data array
190   OUTPUT @Hp5372;"PRES"             ! Preset the instrument
200   OUTPUT @Hp5372;"SMOD,SINGLE"      ! Set to single measurement mode
210   OUTPUT @Hp5372;"INT;OUTP,FPO"     ! Data format floating point
220   OUTPUT @Hp5372;"PROC;FFT,ON"      ! Enable the FFT function
230   OUTPUT @Hp5372;"MEAS;FUNC,";Func$! Set measurement to frequency
240   OUTPUT @Hp5372;"MEAS;BLOCK,1"     ! Set to 1 block
250   OUTPUT @Hp5372;"MEAS;SSIZ,";Num_meas    ! Set number of measurements
260   OUTPUT @Hp5372;"MEAS;ARM,AUTO"          ! Set arming to Auto
270   OUTPUT @Hp5372;"PROC;CARR,MAN"
280   OUTPUT @Hp5372;"PROC;CFR,";Clock ! Must enter the manual carrier frequency
290   OUTPUT @Hp5372;"PROC;SOUR,A;MATH,ON" ! Enable math
300   OUTPUT @Hp5372;"PROC;SOUR,A;SCAL,";Clock ! Convert to Unit Intervals
310   S=SPOLL(@Hp5372)                  ! Make sure no status is pending
320   OUTPUT @Hp5372;"*SRE 2"           ! Enable SRQ when measurement complete
330   DISP "Waiting for measurement to complete"
340   OUTPUT @Hp5372;"REST"             ! Start a new measurement
350   ON INTR 7 GOTO Get_data           ! Go get the data when SRQ enabled
360   ENABLE INTR 7;2                   ! Enable the interrupt
370 Loop_here:  !                       ! Loop here while waiting for
380   GOTO Loop_here                    ! measurement to complete
390   !
400   !
410 Get_data:                           ! Start of measurement process
420   S=SPOLL(@Hp5372)                  ! Read the status of the HP 5372A
430   GOSUB Get_fft                     ! Go get the data
440   GOSUB Get_markers
450   GOSUB Plot_data
460   STOP
470   !
480   !
490 Get_fft:                            ! Start of routine to transfer data
500   DISP "Transferring and processing data"
```

Data-Signal Jitter Spectral Content (HP BASIC)

```
510   OUTPUT @Hp5372;"OFFT?"              ! Request data
520   ENTER @Hp5372 USING "#,8A";Header$   ! Get the header which has the number
530                                        ! of bytes to be transferred
540   Flength=VAL(Header$[3])/8           ! Flength is the number of FFT bins
550   REDIM Fft(Flength)
560   TRANSFER @Hp5372 TO @Buff1;COUNT VAL(Header$[3]),WAIT !Transfer the data
570                                       ! The data can now be accessed via
580                                       ! the FFT(*) array
590   RETURN
600   !
610   !
620 Get_markers:                          ! Start of routine to get marker values
630   OUTPUT @Hp5372;"MENU,GRAP"          ! Use the graphics menu
640   OUTPUT @Hp5372;"GRAP;GDIS,FFT"      ! Show the FFT graph
650   OUTPUT @Hp5372;"GRAP;CDAT,ON"       ! Connect the dots on the graph
660   WAIT 2                              ! Must wait a bit for graph
670   OUTPUT @Hp5372;"GRAP;MMAX"          ! Move the marker to max of the graph
680   OUTPUT @Hp5372;"GRAP;YVAL?"         ! Ask for the y_value of marker
690   ENTER @Hp5372;Y_value
700   OUTPUT @Hp5372;"GRAP;XVAL?"         ! Ask for x_value of marker
710   ENTER @Hp5372;X_value
720   DISP
730   RETURN
740   !
750   !
760 Plot_data:                            ! Start of routine to plot data
770   OUTPUT @Hp5372;"GRAP;MGR;XMIN?"     ! Get the graph axis values for graph
780   ENTER @Hp5372;Xmin
790   OUTPUT @Hp5372;"GRAP;MGR;XMAX?"
800   ENTER @Hp5372;Xmax
810   OUTPUT @Hp5372;"GRAP;MGR;YMIN?"
820   ENTER @Hp5372;Ymin
830   OUTPUT @Hp5372;"GRAP;MGR;YMAX?"
840   ENTER @Hp5372;Ymax
850   OUTPUT @Hp5372;"FBIN?"              ! Ask for the FFT bin width
860   ENTER @Hp5372;Fbin
870   VIEWPORT 13,100,22,92
880   WINDOW Xmin,Xmax,Ymin,Ymax          ! Set up computer graphics window
890   FRAME
900   FOR I=1 TO Flength
910     PLOT I*Fbin,Fft(I)                ! Plot the data
920   NEXT I
930   CLIP OFF
940   CSIZE 3
950   LORG 1
960   MOVE Xmin,Ymax
970   LABEL "FFT:  ";Func$
980   LORG 3
990   MOVE Xmin,Ymin                      ! Label the axes
1000  LABEL USING "D";Xmin
1010  LORG 9
1020  MOVE Xmax,Ymin
1030  LABEL USING "D.DDDE";Xmax
1040  LORG 7
1050  MOVE Xmin,Ymin
1060  LABEL USING "SDDD.DD";Ymin
1070  LORG 9
```

Data-Signal Jitter Spectral Content (HP BASIC) (Continued)

```
1080  MOVE Xmin,Ymax
1090  LABEL USING "SDDD.DD";Ymax
1100  LORG 8
1110  MOVE Xmin,Ymax-(Ymax-Ymin)/2
1120  LABEL "dBUI "
1130  LORG 6
1140  MOVE Xmax-(Xmax-Xmin)/2,Ymin
1150  LABEL "Frequency in Hz"
1160  MOVE X_value,Y_value               ! Move to max of graph
1170  LORG 5
1180  LABEL "+"                          ! Put + at max of graph
1190  LORG 2
1200  LABEL USING "2X,2A,2X,2D.4DE,3A";"x:";X_value;" Hz"
1210  MOVE X_value,Y_value-.1*(Ymax-Ymin)
1220  LORG 2
1230  LABEL USING "2X,2A,2X,SDDD.DD,5A";"y:";Y_value," dBUI"
1240  LORG 7
1250  MOVE Xmax,Ymax
1260  LABEL "Time Deviation of data signal"
1270  RETURN
1280  END
```



Data-Signal Jitter Spectral Content (HP BASIC) (Continued)

To Compute Spectral Content of a Frequency Measurement

This is an example program to compute the FFT of a frequency measurement. The program requires QuickBASIC 4.5 and an HP 82335 HP-IB card. The select code is 7 and the HP 5372A address is 03.

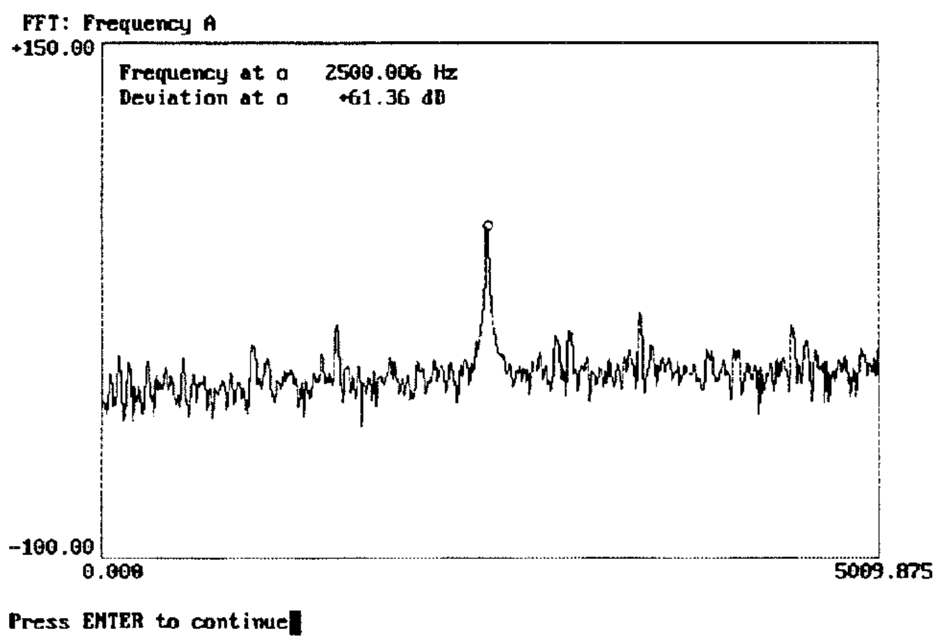
```
'This program sets up the HP 5372A to make a frequency measurement,
'compute an FFT, send the FFT result to the computer and plot it on the
'computer CRT.
'It requires the HP 82335A HPIB card and assumes the select code is 7
'and the HP 5372A address is 03.

DECLARE FUNCTION gethp (answer#)            'function to return HP 5372A queries
DECLARE SUB sendhp (code$)                  'SUB to send HPIB commands

REM $INCLUDE: 'QBSETUP.BAS'                 'Required by HP 82335A
DIM SHARED source AS LONG                   'address of HP 5372A
DIM i AS INTEGER                            'used for indexing
DIM processed AS INTEGER                    'check for process complete
DIM counter AS SINGLE                       'used in wait loop
DIM nummeas AS INTEGER                      '# of measurements
DIM status AS INTEGER                       'status byte value
DIM func AS STRING * 4                      'measurement function
DIM sampinterval AS SINGLE                  'sample interval
DIM swapbytes AS INTEGER                    'swap bytes used in ioenterb
DIM maxbytes AS LONG                        'maximum bytes transferred
DIM actualbytes AS LONG                     'actual bytes transferred
DIM flength AS STRING * 23                  'string for # of FFT measurements
DIM fft(0 TO 4096) AS DOUBLE                'array for data
DIM flen AS DOUBLE                          'number of FFT measurements

source = 703                                'address of HP 5372A
isc& = 7                                    'select code 7
priority% = 0                               'priority for interrupt
state% = 1                                  'variable used in some subprograms
SCREEN 11                                   'screen is VGA
func = "FREQ"                               'measure frequency
nummeas = 1024                              'number of measurements
sampinterval = .0001                        'sample interval

CALL IOEOI(isc&, state%)                    'make sure EOI enabled
CALL sendhp("*RST")                         'clear the HP 5372A HPIB
CALL sendhp("PRES")                         'preset the HP 5372A
CALL sendhp("SMOD,SINGLE")                  'single measurement mode
CALL sendhp("INT;OUTP,FPO")                 'floating point data format
CALL sendhp("PROC;FFT,ON")                  'enable FFT
CALL sendhp("MEAS;FUNC " + func)            'set to frequency
CALL sendhp("MEAS;BLOCK,1")                 'make 1 block
CALL sendhp("MEAS;SSIZE " + STR$(nummeas))   'of nummeas
CALL sendhp("MEAS;ARM,ISAM")                   'interval sampling
CALL sendhp("MEAS;SAMP;DEL, " + STR$(sampinterval))  'of this sample interval
CALL sendhp("*SRE 2")                       'pull SRQ on measurement complete
PRINT "Waiting for measurement to complete."
CALL sendhp("*CLS")                         'clear all pending activity
CALL sendhp("REST")                         'start the measurement
processed = 0                               'have not made a measurement yet
ON PEN GOSUB getdata                        'get data when SRQ is high
```

Spectral Content of a Frequency Measurement (QuickBASIC)

```
PEN ON                                   'enable interrupt
CALL IOPEN(isc&, priority%)              'look for service requests

loophere:                                'loop while waiting for measurement
IF processed GOTO endprog                'if measurement processed, leave
GOTO loophere
endprog:                                 'program is complete
STOP                                     'program is all done
getdata:                                 'get the HP 5372A FFT data
PEN OFF                                  'don't respond to any more SRQs
processed = 1                            'data has been processed
swapbytes = 8                            '8 bytes per measurement
maxbytes = 23
actualbytes = 0
CALL iospoll(source, status)             'Spoll to check and clear status
CALL sendhp("flen?")                     'get length of FFT
CALL ioenters(source, flength, maxbytes, actualbytes)
flen = VAL(flength)
maxbytes = swapbytes * flen + 8          'determine max number of bytes
CALL sendhp("offt?")                     'ask for FFT data
CALL ioenterab(source, SEG fft(0), maxbytes, actualbytes, swapbytes) 'enter
PRINT "Data transferred. Configuring for plot."

CALL sendhp("menu,grap")                 'enable graphics menu
CALL sendhp("grap;gdis,fft")             'show FFT graph
CALL sendhp("grap;cdat,on")              'connect data
CALL sendhp("grap;mmax")                 'move marker to maximum
FOR counter = 1 TO 20000                 'wait for graph to process
NEXT counter
CALL sendhp("grap;yval?")                'ask for y value of maximum
yval# = gethp(answer#)
CALL sendhp("grap;xval?")                'ask for x value of maximum
xval# = gethp(answer#)

CALL sendhp("grap;mgr;xmin?")            'ask for x-axis minimum label
xmin# = gethp(answer#)
CALL sendhp("grap;mgr;xmax?")            'ask for x-axis maximum label
xmax# = gethp(answer#)
CALL sendhp("grap;mgr;ymin?")            'ask for y-axis minimum label
ymin# = gethp(answer#)
CALL sendhp("grap;mgr;ymax?")            'ask for y-axis maximum label
ymax# = gethp(answer#)
CALL sendhp("fbin?")                     'ask for FFT bin width
fbin# = gethp(answer#)

CLS 0
SCREEN 11
VIEW (60, 20)-(572, 350)
WINDOW (xmin#, ymin#)-(xmax#, ymax#)    'set up graphics window

LINE (xmin#, ymax#)-(xmax#, ymin#), , B 'draw a rectangle
FOR i = 1 TO flen - 1                   'plot the data
LINE (i * fbin#, fft(i))-((i + 1) * fbin#, fft(i + 1))
NEXT i
CIRCLE (xval#, yval#), 25               'mark the maximum point
LOCATE 1, 2
PRINT "FFT: Frequency A"                'label the graph
LOCATE 22, 1
PRINT USING "+###.##"; ymin#
```

Spectral Content of a Frequency Measurement (QuickBASIC) (Continued)

```
LOCATE 2, 1
PRINT USING "+###.##"; ymax#
LOCATE 23, 5
PRINT USING "###.###"; xmin#
LOCATE 23, 67
PRINT USING "######.###"; xmax#
LOCATE 3, 10
PRINT USING "Frequency at o ######.### Hz"; xval#
LOCATE 4, 10
PRINT USING "Deviation at o +#####.## dB"; yval#
LOCATE 25, 1
INPUT "Press ENTER to continue", a$     'press enter to continue program

RETURN

FUNCTION gethp (answer#)
'This function returns the value from an HP 5372A query.
'All queries are entered as strings and then converted to
'DOUBLE precision values

DIM parameters AS STRING * 23
maxbytes% = 23
actualbytes% = 0
CALL ioenters(source, parameters, maxbytes%, actualbytes%)
gethp = VAL(parameters)
END FUNCTION

SUB sendhp (code$)
'This SUB sends an HPIB command

CALL iooutputs(source, code$, LEN(code$))
END SUB
```



Spectral Content of a Frequency Measurement (QuickBASIC) (Continued)

To Measure Clock Jitter

This is an example program to measure clock jitter. It requires Turbo C 2.0 and an HP 82335 HP-IB card.

The program may be compiled from the command line as: TCC program_name clhpib.lib graphics.lib. The program_name is the name of the file to be compiled and clhpib.lib is a library included with the HP 82335A command library. The graphics.lib is part of the Turbo C libraries needed for graphics routines. The select code is 7 and the HP 5372A address is 03.

- Turbo C example program:

```
/* This program causes the HP 5372A to make 7 blocks of time deviation
measurements, compute a spectrally averaged FFT of these 7 blocks, send the
FFT to the computer, and then plot it on the computer CRT.
This program requires an HP 82335A HPIB card at select code 7. It assumes
that the HP 5372A is at address 03 (the factory default). */

#include <string.h>  /* used for strcpy() and strcat() */
#include <stdio.h>   /* used for printf() */
#include <dos.h>     /* used for delay() */
#include <stdlib.h>  /* used for exit() */
#include <graphics.h> /* used for graphics */
#include "CHPIB.H" /* HPIB library constant declarations */
#include "CFUNC.H" /* HPIB library function prototypes */
void sendhp(char *);   /* function to send command to HP5372A */
void write_crt(int x,int y, int numdigits,char *text,float result);
/* function to put text on graphics screen */
/* global data */
long ctr=703;      /* HP 5372A is at address 03. HPIB is at select code 7 */
int  error;
void main()
{
    float gethp();              /* Function to get results from HP 5372A */
    double *fft,*data_array;  /* Arrays to hold data */
    long isc=7;                 /* Select code 7 */
    int condition=1;            /* Used in IOSTATUS */
    int status;                 /* Used in IOSTATUS */
    int state=1;                /* Used in IOEOI    */
    int driver=DETECT;          /* Detect video system */
    int clip=0;                 /* Do not clip viewport */
    int mode;                   /* Used in initgraph() */
    float maxx,maxy,tempmaxx,tempmaxy,left,right,top,bot; /* Used in graph */
    int swapped;                /* Used to swap bytes from HP 5372A */
    int numbytes;               /* Number of bytes to be transferred */
    float loopctr;              /* loop counter variable */
    char function[15]="Time Deviation"; /* Measure time deviation */
    char textout[30];           /* String to place on graphics */
    float flen,fbin,yval,xval,xmin,xmax,ymin,ymax; /* HP 5372A parameters */
    clrscr();                   /* Clear the computer CRT */
 IORESET(isc);                          /* Reset the HPIB interface */
 IOEOI(isc,state);                      /* Enable use of EOI */
```

Clock Jitter Spectral Content (Turbo C)

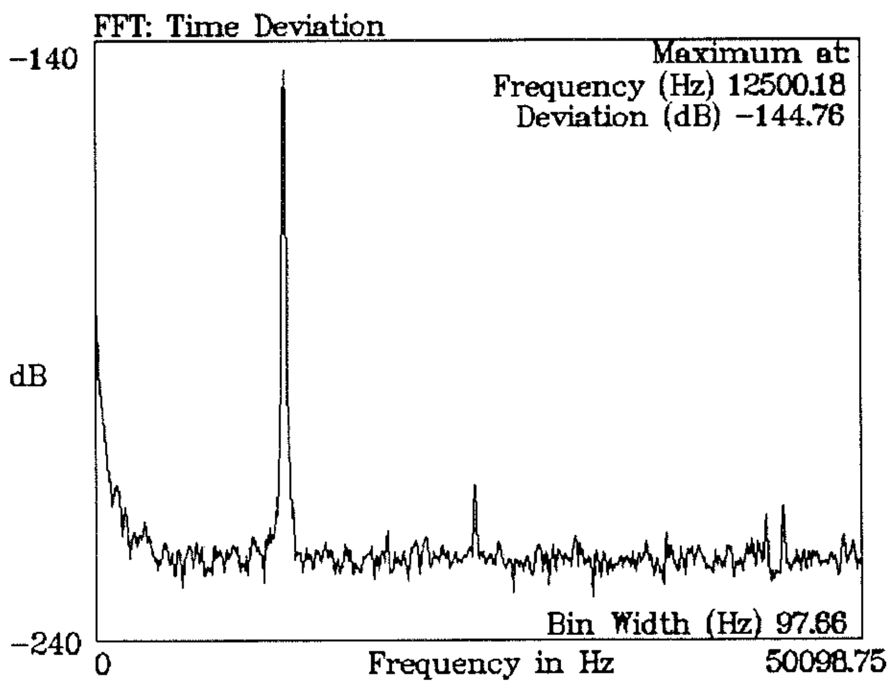
```
sendhp("pres");                       /* Preset the HP 5372A */
sendhp("smod,sing");                  /* Set mode to single */
sendhp("int;outp,fpo");               /* Use floating point output */
sendhp("proc;fft,on");                /* Enable the FFT */

sendhp("proc;savg,on");               /* Enable spectral averaging */
sendhp("meas;func,tdev");             /* Make a time deviation measurement */
sendhp("meas;msiz,1024");             /* Take 2048 measurements */
sendhp("meas;block,7");               /* Take 7 blocks to spectral average */
sendhp("meas;arm,isam");              /* Use interval sampling */
sendhp("meas;samp;del,.00001");       /* Use 10 us sample intervals */
sendhp("*sre 2");                     /* SRQ when measurement is complete */
sendhp("*cls");                       /* Clear all activity */
sendhp("rest");                       /* Start the measurement */

/* Waiting for the measurement to complete */
puts("Waiting for measurement to complete");
do
{
IOSTATUS(isc,condition,&status);  /* Check status byte */
  delay(200);
}
while (status!=1);                  /* if =1 then measurement complete */
/* Measurement is complete, get the data */
IOSPOLL(ctr,&status);               /* Serial poll HP 5372A for status */
puts("Transferring and processing data");
sendhp("flen?");                    /* Get number of FFT results */
flen=gethp();
sendhp("OFFT?");                    /* Ask for FFT data */
numbytes=flen*sizeof(double);       /* numbytes is total # of bytes */
fft= malloc(flen*sizeof(double)); /* allocate array for results */
data_array=malloc(flen*sizeof(double)); /* allocate array for graphing */
swapped=sizeof(double);
IOENTERAB(ctr,fft,&numbytes,swapped); /* Get the data from HP 5372A */
sendhp("menu,grap");          /* Enable graphics HP 5372A graphics */
sendhp("grap;gdis,fft");      /* Display FFT */
sendhp("grap;cdat,on");       /* Connect data points */
sendhp("grap;mmax");          /* Move marker to maximum */
delay(1000);                  /* Wait 1 second for graphics to process */
sendhp("grap;yval?");         /* Get y value of maximum */
yval=gethp();
sendhp("grap;xval?");         /* Get frequency value of maximum */
xval=gethp();
sendhp("grap;mgr;xmin?");     /* Get the scale values */
xmin=gethp();
sendhp("graph;mgr;xmax?");
xmax=gethp();
sendhp("grap;mgr;ymin?");
ymin=gethp();
sendhp("grap;mgr;ymax?");
ymax=gethp();
sendhp("fbin?");              /* Get the FFT bin width */
fbin=gethp();
sendhp("*sre 0");             /* No more service requests from HP 5372A */
sendhp("local");              /* Put HP 5372A in local */
/* Beginning of plot routine */
initgraph(&driver,&mode,"c:\\tc\\lib");
```

Clock Jitter Spectral Content (Turbo C)(Continued)

```
    maxx=getmaxx();              /* Get the max and min CRT coordinates */
    maxy=getmaxy();
    left=.1*maxx;                /* Set up a nice coordinate system */
    top=.05*maxy;
    right=.9*maxx;
    bot=.9*maxy;
    rectangle(left,top,right,bot);
    setviewport(left,top,right,bot,clip);

    /* Convert the FFT data so it can be easily plotted */
    data_array[0]=((top-bot)/(ymax-ymin))*(fft[0]-ymax);
    for (loopctr=1;loopctr<flen;loopctr++)  /* Plot the data */
    {
    data_array[loopctr]=((top-bot)/(ymax-ymin))*(fft[loopctr]-ymax);

line((loopctr-1)*(right-left)/flen,data_array[loopctr-1],(loopctr)*(right-left)/fle
n,data_array[loopctr]);
    }
    settextstyle(TRIPLEX_FONT,HORIZ_DIR,2);
    strcpy(textout,"FFT: ");
    strcat(textout,function);
    settextjustify(2,2);
    /* Annotate the graph */
    write_crt(.88*right,.01*bot,0,"Maximum at:",0);
    write_crt(.88*right,.06*bot,8,"Frequency (Hz) ",xval);
    write_crt(.88*right,.11*bot,5,"Deviation (dB) ",yval);
    write_crt(.88*right,.90*bot,4,"Bin Width (Hz) ",fbin);
    setviewport(0,0,maxx,maxy,clip);
    settextjustify(0,2);
    moveto (.09*maxx,1);
    outtext (textout);
    write_crt(.09*maxx,.91*maxy,1,"",xmin);
    write_crt(.8*maxx,.91*maxy,7,"",xmax);
    write_crt(0,.05*maxy,6,"",ymax);
    write_crt(0,.88*maxy,6,"",ymin);
    write_crt(.38*maxx,.91*maxy,0,"Frequency in Hz",0);
    write_crt(0,.5*maxy,0,"dB",0);
    getch();                        /*Press a key to end the program */
    closegraph();
    /* End of main program */
}

/* Function to put text and numbers onto CRT */
void write_crt (int x,int y,int numdigits,char *text,float result)
{
char textstring[30],newtext[30];
moveto(x,y);
strcpy(textstring,text);
if (numdigits==0)
outtext(textstring);
else
{gcvt(result,numdigits,newtext);
strcat(textstring,newtext);
outtext(textstring);
}
}
/* Function to get single results from HP 5372A */
```

Clock Jitter Spectral Content (Turbo C)(Continued)

```
float gethp()
{
char reply[24];                       /* Set up variables */
double answer;
int length=23;
error=IOENTERS(ctr,reply,&length);    /* Get string from HP 5372A */
if (error!=0)
printf("Error during HPIB query");
sscanf(reply,"%lf",&answer);         /* Convert to double precision */
return (answer);
}

/* Function to send command to HP 5372A */
void sendhp(hpib_cmd)
char *hpib_cmd;
{
char hpcmd[80];                /* Variables used by function */
int length;
strcpy(hpcmd,hpib_cmd);
length=strlen(hpcmd);

error=IOOUTPUTS(ctr,hpcmd,length);  /* Send command to HP 5372A */
if (error!=0)
printf("Error during HPIB: %d Command %s\n",error,hpcmd);
}
```



Clock Jitter Spectral Content (Turbo C)(Continued)

Concepts

5

Concepts

In this chapter

This chapter describes the concepts that are part of the Jitter Spectrum Analysis (FFT) Option 040 for the HP 5372A. This chapter discusses the following topics:

- Description of the FFT.
- FFT relationships to the HP 5372A.
- FFT graph spectral resolution.
- Time Variation graph vs. FFT graph deviation.
- Resampling
- Aliasing
- Windowing
- Averaging

What is the FFT?

Please note that this description is very much an overview. There is much left out in this summary. We recommend that you refer to the bibliography at the end of this chapter for reference material that describes the FFT in greater detail. This subject matter is very complex and there is no intention here to cover all the critical issues involved.

In the nineteenth century, Jean Baptiste Joseph Fourier developed a method, using a series of sine and cosine terms, to analyze periodic waveforms. It was from his early work with this trigonometric series that he later evolved the Fourier integrals for the study of nonperiodic waveforms, that is, waveforms that do not repeat themselves. While the Fourier series transforms time-domain periodic waveforms to the frequency domain at only specific frequencies, the Fourier integral takes nonperiodic waveforms and transforms them to a continuous frequency spectrum.

One of the limitations of the Fourier integral is that it can only operate on waveforms that can be mathematically described. This is a severe limitation for complex waveforms. To address this problem, a different approach was taken. The combination of windowing a portion of the signal and sampling the waveform at equally spaced intervals turns out to closely approximate the analog waveform. This sampled version of the windowed waveform can now be evaluated by a derivation of the Fourier integral. It is know as the *discrete Fourier transform (DFT)*. The DFT transforms a time-domain series of samples to a series of frequency-domain samples. The *fast Fourier transform (FFT)* is a very fast, efficient method for calculating the DFT.

Where does the FFT come from?

Fourier was able to show that, under certain conditions, a time-domain waveform x(t) could be represented as series of sine and cosine waveforms:

$$x(t) = a_0 + \sum_{n=1}^{\infty} \left(a_n \cos(n\omega_0 t) + b_n \sin(n\omega_0 t) \right)$$

The coefficients for the sine and cosine terms are found by performing several integrals.

An integral form as a function of a continuous frequency variable is:

$$x(t) = \int_{-\infty}^{\infty} X(f)\, e^{j2\pi ft} df$$

From this equation, Fourier showed that the Fourier transform X(f) can be determined as follows:

$$X(f) = \int_{-\infty}^{\infty} x(t)\, e^{j2\pi ft}\, dt$$

What this means is, given x(t), by evaluating the integral it is possible to determine X(f), the Fourier transform. The effect is a transformation of the waveform from the time domain to the frequency domain.

Notice that these equations all use integrals that indicate waveforms are continuous and exist from minus infinity to plus infinity. This is not the case in the real world. If a band-limited waveform is sampled, the discrete Fourier transform (DFT) can be used to Fourier transform the sampled waveform.

The DFT can be expressed as follows:

$$X(k) = \frac{1}{N} \sum_{n=0}^{N-1} x(n) e^{\frac{-j2\pi kn}{N}}$$

or

$$X(k) = \frac{1}{N} \sum_{n=0}^{N-1} x(n) \left(\cos \frac{2\pi\, kn}{N} - j \sin \frac{2\pi\, kn}{N} \right)$$

These expressions let you transform a series of time-domain samples to a series of frequency-domain samples. The variables are defined as follows:

N = the number of time-domain samples
n = the time sample index, from 0 to N-1
k = the frequency component index, from 0 to N-1
x(n) = the time-domain samples, value of signal at n
X(k) = the Fourier coefficient, value of frequency at k
j = the imaginary portion of a complex number

FFT and the HP 5372A

The FFT capability in the HP 5372A adds spectral analysis of modulation-domain signals. The modulation domain displays frequency, time interval, phase, etc. versus time. It is this result (viewed on the Time Variation graph) that is subjected to the FFT algorithm.

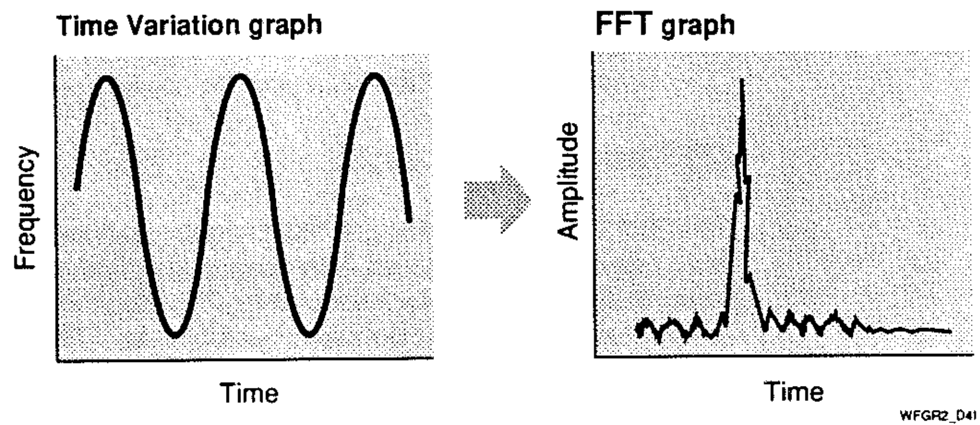
Jitter Spectrum Analysis is an FFT of the Time Variation results

The Time Variation graph plots measurements versus time. The FFT graph shows the spectral content of those results. To emphasize what this means, the next two illustrations compare the Time Variation results with the FFT graphs of the same results.

FFT of sine wave modulation

In the illustration below, the Time Variation graph displays the result of measuring a signal with sine wave modulation. The FFT of the Time Variation results shows a single frequency component of the sine wave modulation at the modulating frequency.

Time Variation graph and FFT graph showing views of sine wave modulation.



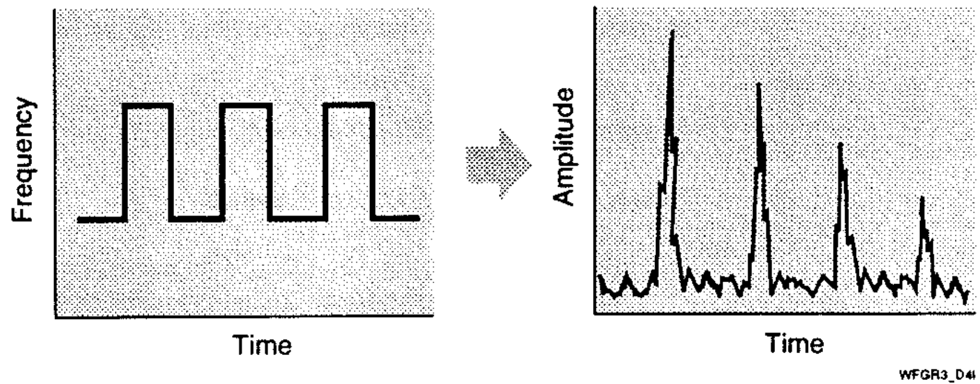
FFT of square wave modulation

The next illustration shows an example of square wave modulation. The Time Varation graph reveals the wave shape of the modulation on the carrier. The FFT shows a main spur at the frequency of the modulation along with the odd harmonics of the modulating signal.

Time Variation graph and FFT graph showing views of square wave modulation.

Time Variation graph

FFT graph



FFT Relationships to the Time Variation graph

The relationships between the modulation-domain results on the Time Variation graph and FFT graph results are best described with the use of an example. Suppose that the HP 5372A measured a 25-MHz signal that had some sinusoidal modulation on it. If you take 256 measurements, at a sample interval of 0.1 milliseconds, the following is true:

Number of points (N) = 256

Sample interval (t) = 0.1 millisecond

> *Because of the way the HP 5372A samples zero crossings, the sample interval will not always be exactly 0.1 ms when there is jitter on the signal.*

Time record length (T) = 25.6 milliseconds (approximate)

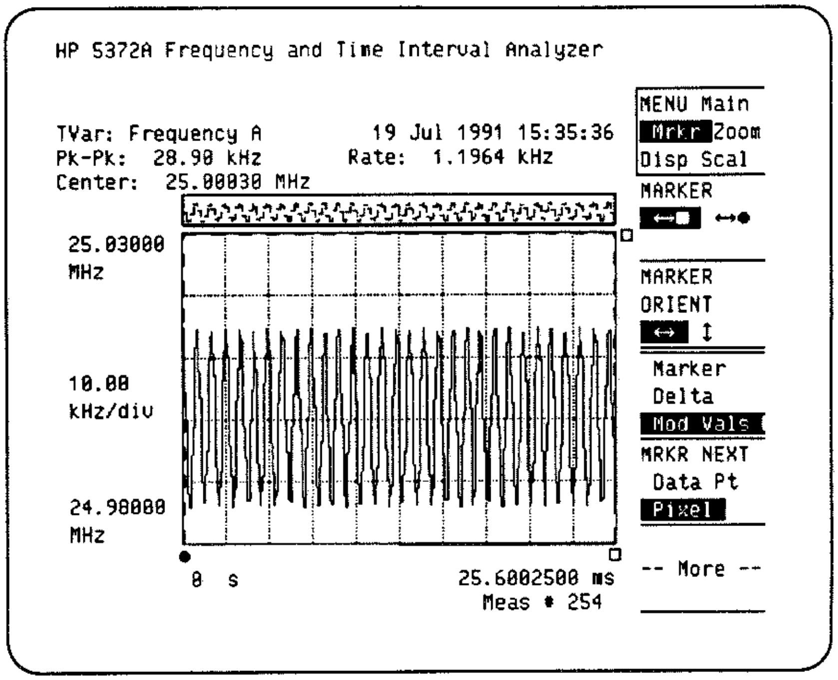
Number of FFT bins (N/2) = 128

FFT bin width (1/T) = 39.06 Hz (approximate)

FFT frequency span (N/(2T)) = 5 kHz

The Time Variation graph shows the modulation-domain plot of frequency versus time. The graph shows the total acquisition time to be about 25.6 milliseconds. Using the modulation values feature shows the frequency deviation is 28.9 kHz peak-to-peak at a 1.19-kHz rate.

Time Variation graph showing modulation on a carrier.

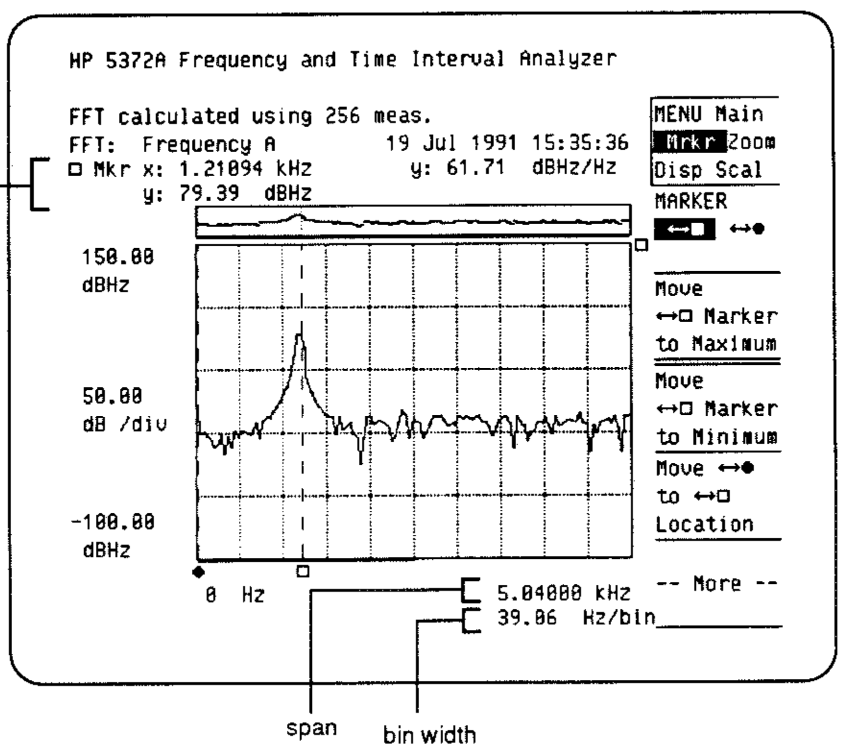


SC5_1D4

The FFT graph shows the FFT of the Time Variation graph results. A 1.2-kHz spur with deviation is easily seen. At the lower right of the plot, you see the frequency span and the bin width. These values match the calculations from the previous page.

FFT graph showing the spectral content of the modulation.

x: Deviation Rate
y: Magnitude of Deviation



SC5_2D4

Mathematical relationships

Both the calculation for bin width and frequency span begin with data from the Time Variation graph and calculate parameters for the FFT graph. What follows is a list of mathematical relationships between the two graphs to show how they are linked so you can better interpret what the FFT graph shows.

These relationships are shown graphically in appendix B.

Sample interval

The selection of the sample interval on the Function menu directly determines the FFT frequency span.

$$sample\ interval = \frac{1}{(FFT\ frequency\ span \times 2)}$$

FFT bin width

The bin width represents the spectral resolution of the FFT graph. It is a function of the total time over which the measurements were acquired (obtained from the Time Variation graph).

$$bin\ width = \frac{1}{(number\ of\ meas \times sample\ interval)}$$

Number of measurements

The number of measurements can be selected to specify a spectral resolution for the FFT graph (FFT bin width).

$$number\ of\ measurements = \frac{1}{(sample\ interval \times bin\ width)}$$

FFT frequency span

The frequency span is a function of the number of measurements and the time record length (the time over which measurements are collected). This time is accessible on the Time Variation graph.

$$frequency\ span = number\ of\ FFT\ bins \times bin\ width$$

The number of bins is always half the number of measurements used to calculate the FFT.

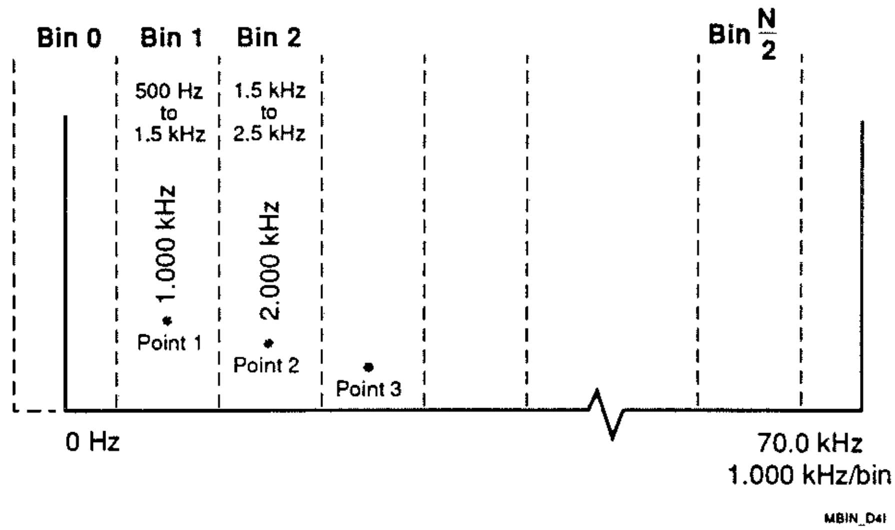
Summary

- The FFT is just a faster algorithm for a DFT.
- Collecting N points in the time domain yields N/2 points in the FFT.
- The location of a spur on the x-axis of the FFT is the deviation rate.
- The amplitude of a spur is the peak-to-peak deviation of the modulation from the carrier.

FFT Spectral Resolution Details

The x-axis of the FFT graph is segmented into divisions called *bins*. The width of the bins is the spectral resolution of the graph. The details described here will clarify some of the characteristics of results plotted on the FFT graph.

The rest of this page describes the details of the FFT bins shown in the illustration.



For a case where the frequency bin width is 1.000 kHz/bin:

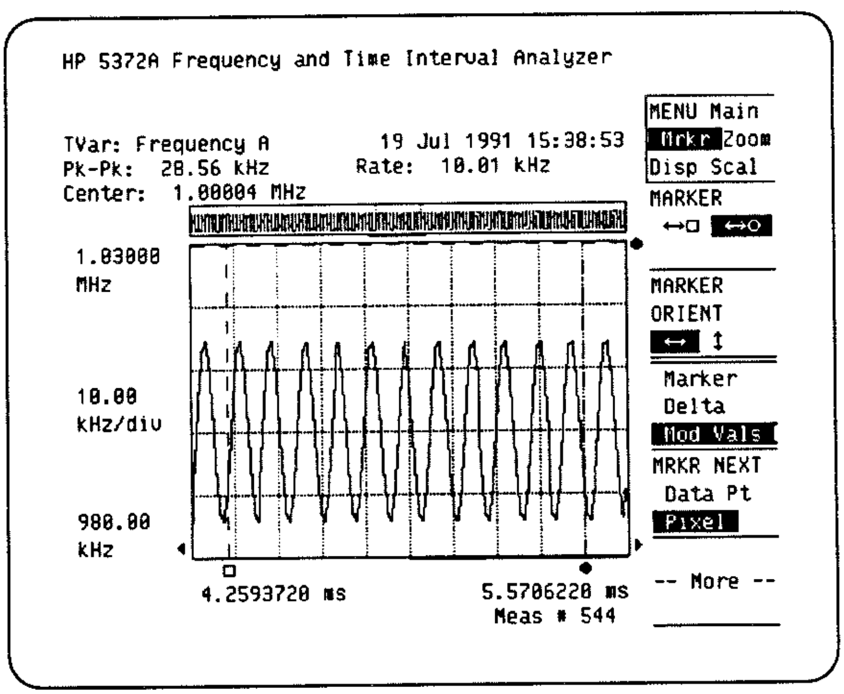
- Bin 0 — The contents of bin #0 are not displayed.
- Bin 1 — This bin spans the frequencies 500 Hz to 1.5 kHz. The x- axis marker readout is "1.000 kHz" when the marker is anywhere from the leftmost edge of the graph to the second data point.
- Bin 2 — This bin spans the frequencies 1.5 kHz to 2.5 kHz. The x-axis marker readout is "2.000 kHz" when the marker is between the second and third data points.
- Bin N/2 — This bin is the rightmost bin. Its frequency value is equal to the sampling frequency (reciprocal of sample interval) divided by 2. This value is the frequency span. The right edge of the graph is beyond this value and is identified by the x-axis label (above the bin width). The number of bins is equal to the number of measurements divided by 2. There is always one point per bin.

Interpreting the Time Variation and FFT Results

Both the Time Variation graph and the FFT graph display modulation as one of their parameters. Comparing the two values is instructive in understanding the advantage of having an FFT of the modulation-domain data from the Time Variation graph.

Time Variation graph deviation

The Time Variation graph below shows frequency versus time. Using modulation values to characterize the modulation on the input signal shows a modulating signal of 10 kHz on a 1-MHz carrier. The deviation is approximately 28.6 kHz peak-to-peak. This peak-to-peak deviation value is computed by taking the difference between the maximum value and the minimum value of the displayed results.



Time Variation graph showing a frequency measurement made on a 1-MHz carrier with FM. This plot of frequency vs. time reveals the modulation on the carrier.

SC5_3D4

FFT graph deviation

The FFT graph below shows the value of the main modulation spur to be 78.84 dBHz. This amplitude is a measure of the magnitude of the modulation component and its contribution to the deviation on the carrier. The FFT value can be converted to a peak-to-peak frequency value with the following formula:

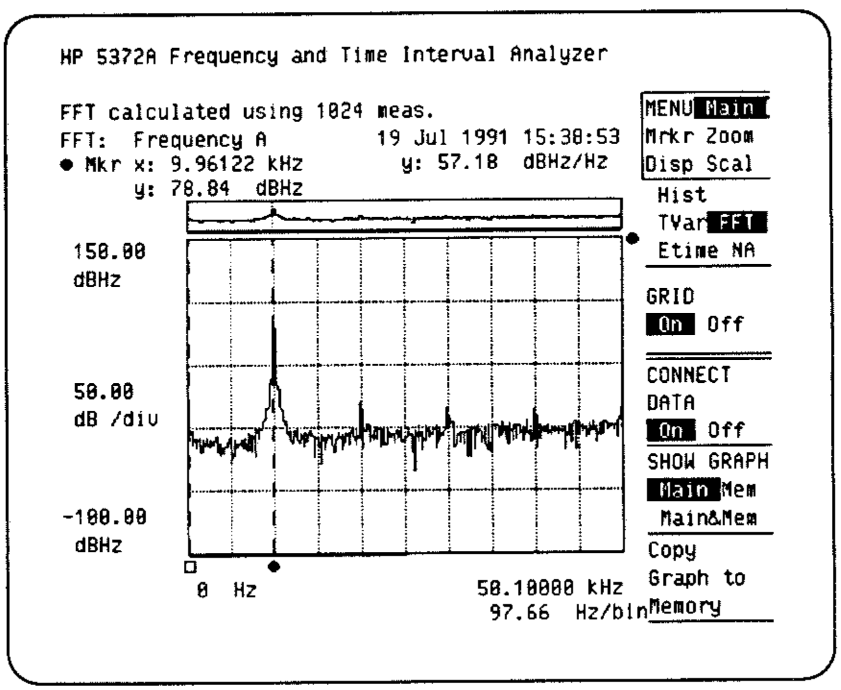
$$Amplitude\ (Hz)\ p\text{-}p = 2\sqrt{2} \times 10^{\frac{spur\ (dBHz)}{20}}$$

The resulting peak-to-peak amplitude of the 78.84 dBHz spur is 24.75 kHz. This does not equal the deviation value on the Time Variation graph. The reason is that the main spur is not the only modulation component in the spectrum. As you can see on the FFT graph, there are other modulation components contributing to the modulation deviation. The Time Variation graph with its single modulation rate is not capable of revealing this.

NOTE

For more examples of FFT graph amplitude/deviation comparisons, see chapter 3 under, "FFT Graph Described."

FFT graph showing the spectral content of the modulation.



SC5_4D4

Resampling

The FFT algorithm requires data points that have been uniformly sampled in time to make an accurate transformation of the data to the frequency domain. One of the principles of operation of the HP 5372A is that it can only sample when there are signal edges received at its input. Only CW signals without modulation and using Automatic sampling will produce samples taken at uniform time intervals. It is more the norm for data to be collected at nonuniform intervals. How is this potentially serious problem solved for the FFT? With a feature called "Resampling." It is enabled on the Math menu, and its default setting is On.

The problem

Any signal measured by the HP 5372A can be non-uniformly sampled in time. If non-uniformly sampled data is operated on by the FFT, the resultant data will be in error. For example, if a 1-MHz signal is input to the HP 5372A, and a 1-μs sample interval is used, every once in a while, the sample interval will be 2 μs, twice the expected value. This occurs because the sample interval clock is not synchronous with the input signal, so at times it can lead or lag the signal. If these results are used by the FFT algorithm to produce the FFT graph, the discontinuities will cause significant errors in the FFT. Resampling greatly reduces the effects of sampling non-uniformly.

The preset state of the HP 5372A includes Resampling On. Resampling can be disabled for most measurement functions, but disabling it is not recommended. For the Time Deviation Data and Phase Deviation Data functions, which by their nature are not sampled uniformly in time, Resampling cannot be disabled.

The solution

For all measurement functions, the samples are acquired normally (nonuniformly sampled based on the occurrence of edges at the input). The Time Variation, Histogram, and Event Timing graphs use the samples as is. The Numeric screen and the results over the HP-IB present the normally sampled data. However, if the FFT is enabled and Resampling is enabled, additional processing is performed on the data before the FFT is calculated. A curve is fit to the sampled data using a cubic spline interpolation algorithm. After the interpolation, the data is resampled at uniform time intervals, using the interpolated y-axis values as FFT input. This new data is only used for the FFT calculation and is not available as a graph or over the HP-IB.

If Resampling is not enabled, the data sent to the FFT algorithm is not uniformly sampled, but the FFT is still performed. The only time not to use resampling is if you can be sure that the jitter on your signal is small enough that the variation in your sample intervals are less than 1%.

Time Deviation Data and Phase Deviation Data functions

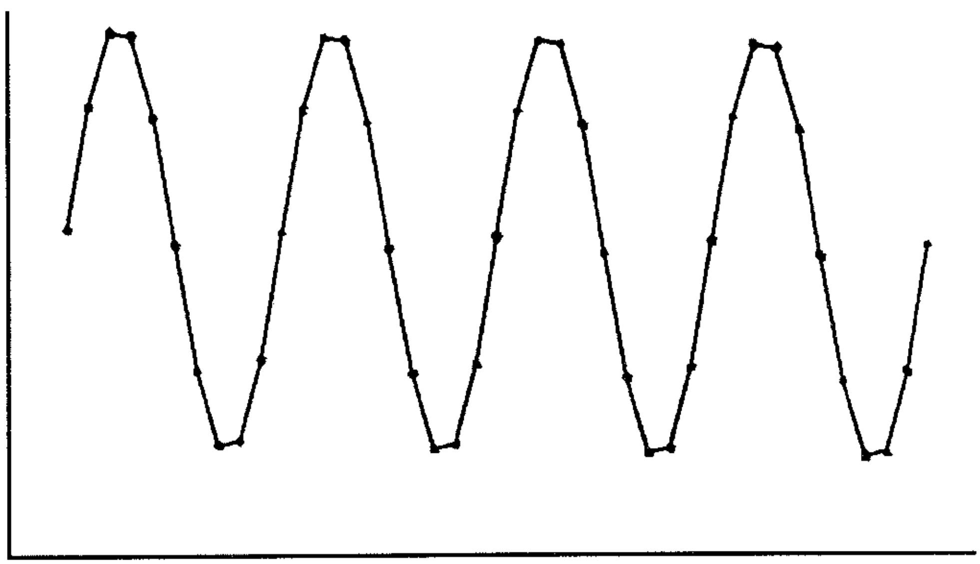
For the two Data functions, the data is resampled as soon as the acquisition is complete. The resampling algorithm is the same as above. All measurement results are resampled. This resampled data is shown on the Numeric display and the Time Variation graph. If you look at the Numeric screen and enable Expanded Data, you will notice that all of the gate times are identical. The same is true if you scroll through the Time Variation graph. The only way to get the non-resampled data after a Time Deviation Data or Phase Deviation Data measurement is to use the binary output format over the HP-IB or collect the data from the optional FastPort outputs.

Aliasing

Aliasing is one of the most confusing and potentially misleading side effects of any sampling system. It occurs because signals that enter measuring instruments have bandwidths much higher than these instruments can adequately sample. Consequently, the high frequency components get "folded down" to within the bandwidth of interest. In fact, due to the nature of sampling in the HP 5372A, lower frequency components get "folded up" to the bandwidth of interest.

This can be demonstrated with an oscilloscope analogy. Suppose you have a 1-kHz sine wave. The Nyquist sampling rate to reproduce this signal is 2 kHz. This means the signal has to be sampled every 500 μs, or two samples per cycle. Usually, to get a better visual idea of the reconstructed signal, you would sample at 10 points per cycle. This is shown below.

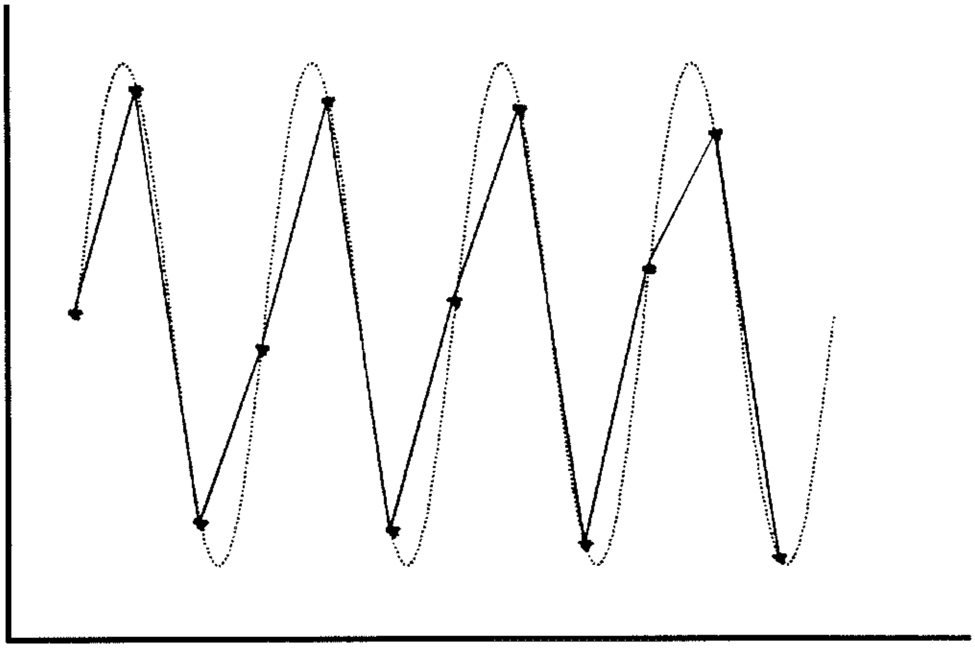
This is a sine wave sampled at 10 points per cycle. The signal is easily recognizable and is more than sufficiently sampled.



SIN10_D4

The next illustration shows a sine wave sampled at about 3 points per cycle, not enough to recognize the sine wave but enough to satisfy the Nyquist sample rate.

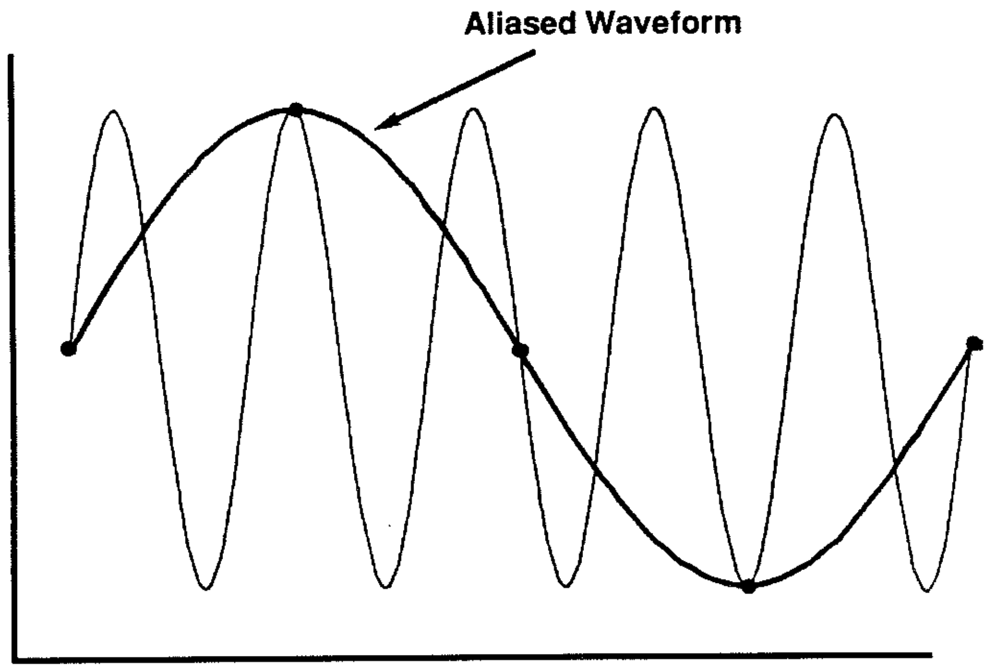
This sine wave is sampled at 3 points per cycle.



SIN3_D4

Now look at a sine wave that has not been sampled often enough. You can see that connecting the sample points yields a much lower frequency signal that looks like a sine wave. This is aliasing. You cannot always know if you have undersampled a signal just by looking. More analysis will usually help.

This under-sampled sine wave will be incorrectly characterized as being a lower frequency than it really is.

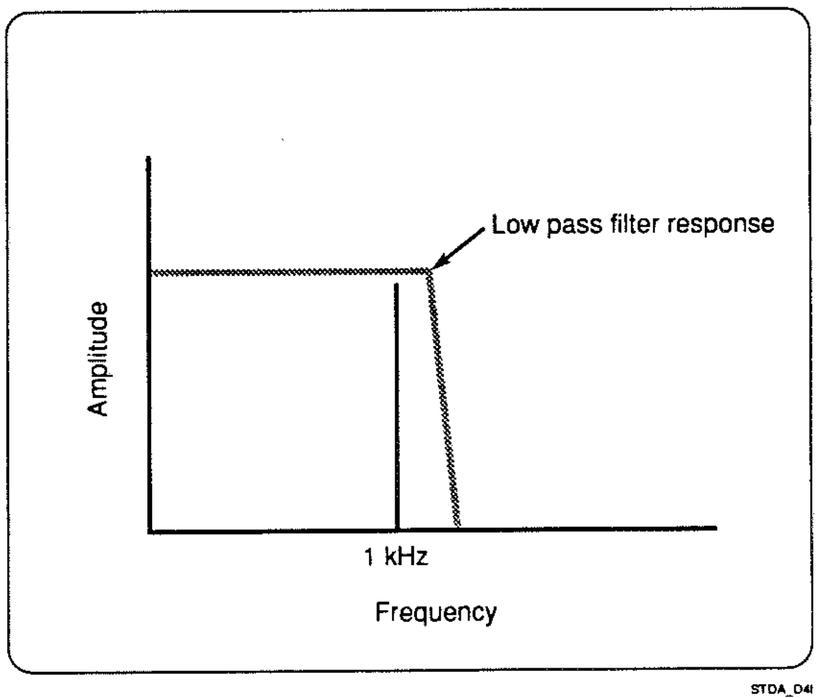


SINALS_D4

Dealing with time-domain aliasing

The previous illustration shows an obvious example of aliasing. Now suppose you wanted to look at a 1-kHz sine wave using an oscilloscope. The Nyquist theorem says you should sample at 2 kHz, or above, to correctly reproduce the signal. The problem is that there are probably higher frequency components present in the environment, and the 2-kHz sampling rate on those high frequency signals will cause aliasing. In an oscilloscope, this is usually no problem. Just low-pass filter the signal to eliminate the high-frequency components. If you put a steep 1-kHz low-pass filter on the sine wave and sampled at 2 kHz, you will eliminate high-frequency components that can be aliased. This is shown in the frequency-domain view below.

A frequency-domain view of how to avoid aliasing with an oscilloscope by using a low-pass filter.

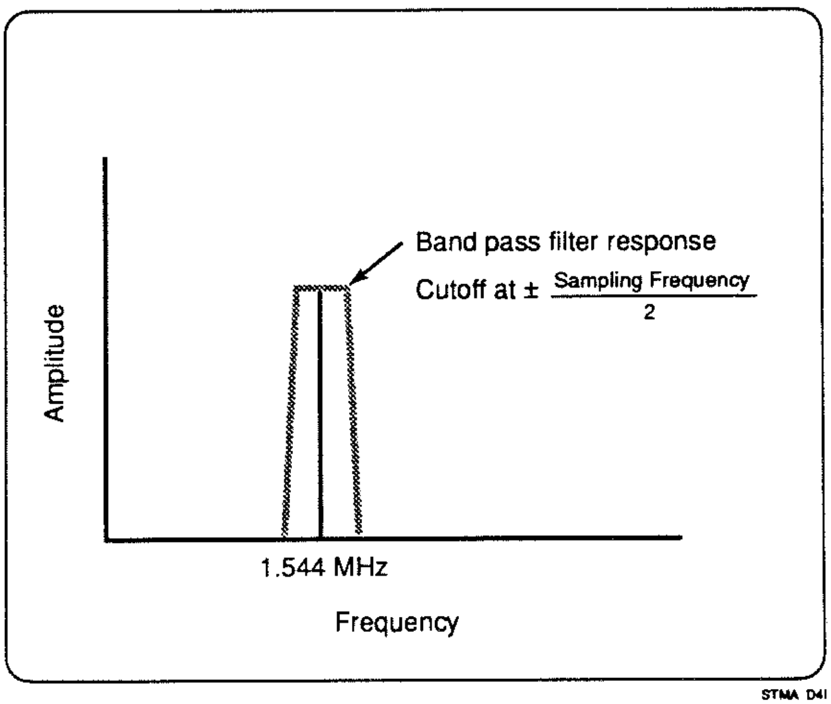


Dealing with modulation-domain aliasing

The modulation domain is a bit more complex. Remember that the FFT of the Time Variation graph shows the modulation spectrum with respect to the carrier. The left edge (0 Hz) of the FFT graph actually represents the carrier. As you look out towards the right of the graph, you are looking at the spectral content of the signals that are modulating the carrier. The right edge of the screen is limited by the sample rate, and is equal to the sample frequency divided by 2.

Aliasing is a problem in the modulation domain. The HP 5372A samples signals at their zero crossings, so the maximum sample rate is equal to the carrier (or less, if the signal is above 10 MHz). There is no way to sample faster to minimize aliasing of higher frequency modulations. Also, because the FFT looks at the spectral content offset from the carrier, a low-pass filter to get rid of high frequency components will not usually be sufficient. A band-pass filter must be used to eliminate aliasing. The illustration below shows what this would look like in the frequency domain. The width of the filter is equal to the sample frequency, and it is centered about the carrier.

A frequency-domain view of how to avoid aliasing with a modulation domain analyzer by using a band-pass filter.



Unfortunately, it is very difficult to construct a good frequency-selectable, band-pass filter. This means that you must be very careful when measuring signals. A good rule is to suspect every spur and test for aliasing by changing the sample rate and watching for spurs changing frequency. (This is demonstrated in chapter 2, "Step three. Check for aliased components in your FFT graph.")

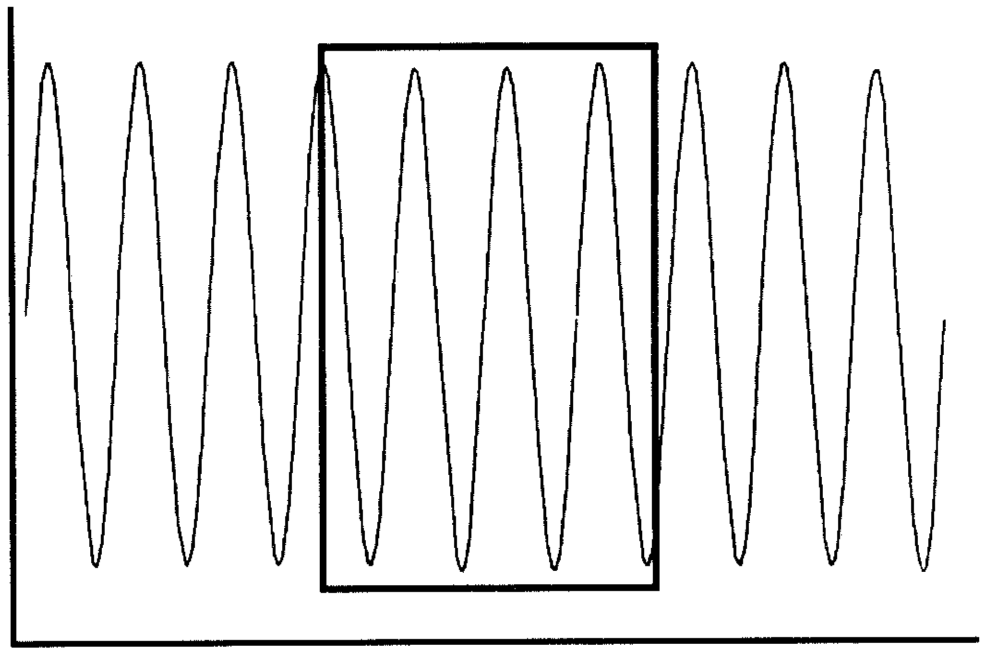
Summary

You should try to keep the sample rate at least ten times the frequency of the highest modulation component. For example, if the highest frequency component of the modulation on the signal is expected to be 100 kHz, the sample interval should be 1 µs or faster. This equates to a sample rate of 1 MHz. This may not provide the spectral resolution you desire. To achieve the desired resolution you may need to sample less often. This lengthens the time over which the HP 5372A makes each measurement, producing results with more significant digits.

Windows

A waveform can only be sampled for a finite period of time. This time-limited waveform sampling is, in effect, looking at just a portion of the entire waveform. The illustration below shows this.

The effect of sampling a waveform for a finite period of time. The FFT requires that the portion of the signal it operates on start and stop at the same position on the waveform. Otherwise, the FFT can produce misleading results.



SINWIN_D4

The FFT assumes that the data in this region is duplicated for all time. However, the discontinuities that exist at the end points yield undesirable results in the FFT. The purpose of a window is to eliminate the discontinuities at the end points. The replicated waveform then appears continuous to the FFT.

Jitter Spectrum Analysis Windows

There are three window types included:

- Rectangle
- Hann
- Flat-top

The appropriate window eliminates the discontinuities by forcing the endpoints to the same value. The waveform then appears continuous for the purposes of the FFT.

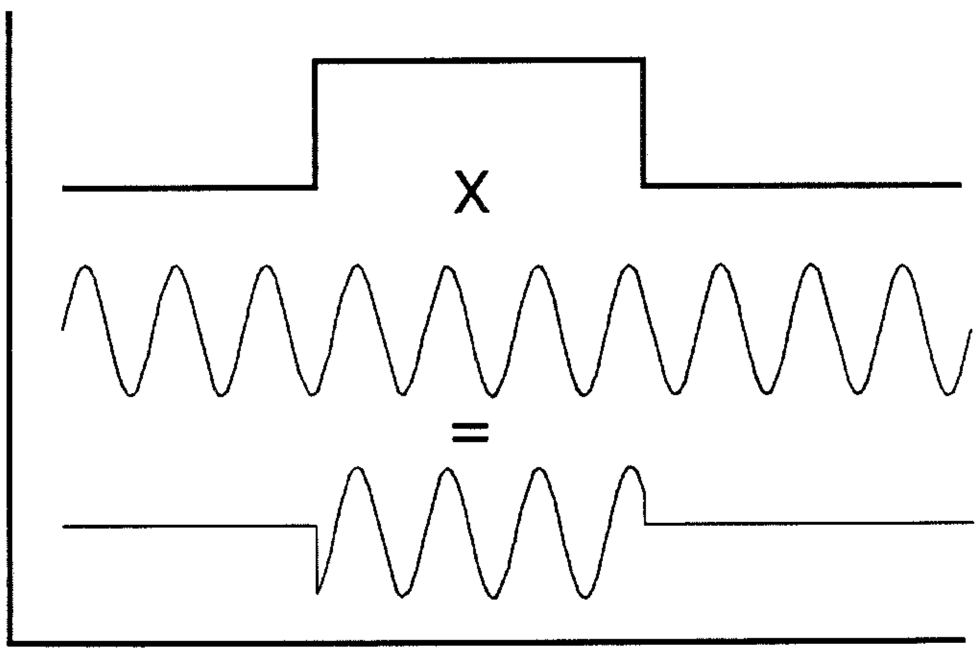
The main tradeoff when using windows is between amplitude accuracy and frequency selectivity. If you want to precisely know the amplitude of the spur, you will not be able to discriminate close frequency components. Conversely, if you want to emphasize frequency differentiation, you will have to give up some amplitude accuracy. The Hann and Flat-top windows balance these two tradeoffs.

Rectangle

Rectangle is discussed first because as you will see, it is really no window at all. It should be used for only particular kinds of applications. An example is a function that occurs completely within the time record, such as a transient that is zero at the beginning and end of the time record. Another example is a signal composed of an integer number of cycles within the time of the acquisition. Acquisitions that meet either of these criteria generate no leakage in the FFT and so need no window.

In the case of the rectangular window, imagine the window to be a square pulse of magnitude one and duration equal to the length of time shown in the previous illustration. If you multiplied the sine wave by this pulse, you would get a waveform like that below.

The effect of applying a rectangular window to a sine wave. The start and stop points are forced to zero.

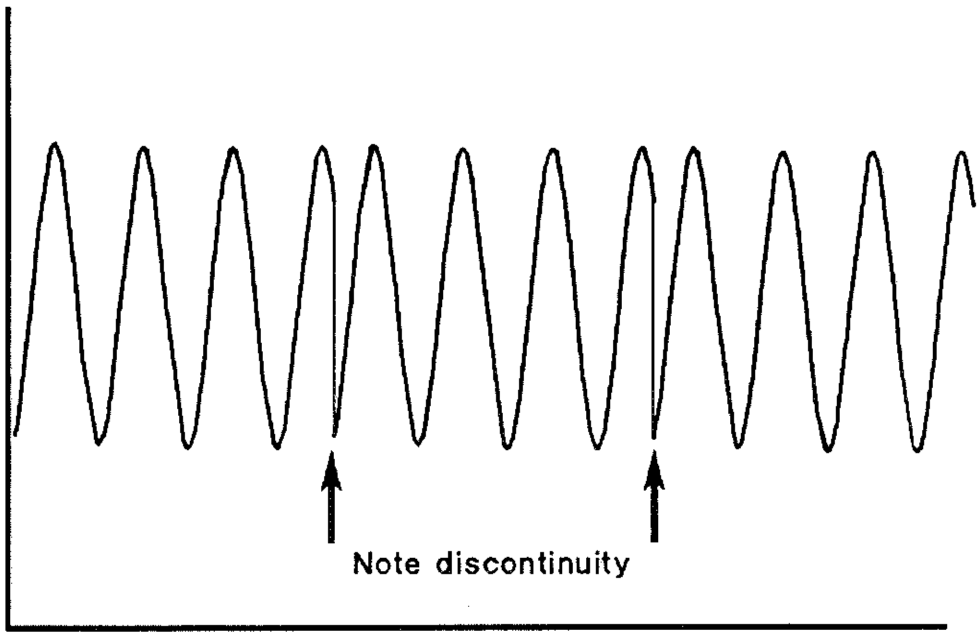


SINRECT_DR

The illustration shows a sine wave as seen through a rectangular window. You can see that this waveform now has a start and stop. On either side of the sine wave, the waveform has a value of zero.

The well-defined waveform is operated on by the FFT algorithm. Unfortunately, there are some side effects resulting from windowing waveforms. If you were to take the windowed waveform and reconstruct a signal that existed for all time, you would see a signal that looked something like the illustration below. Note the discontinuities where the individual waveforms meet. These discontinuities exist because a non-integer number of sine wave cycles were windowed. If an integer number of cycles had been windowed, the signal would be smooth and indistinguishable from the original waveform.

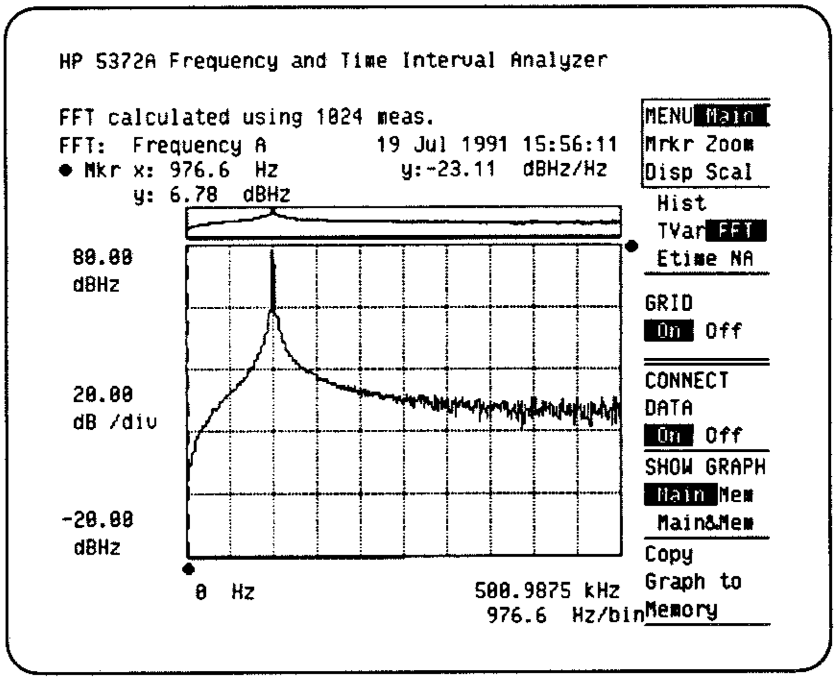
If the windowed waveform was replicated, the discontinuities at the meeting points would not correctly represent the original signal.



SINDISC_D4

The problem with discontinuities is they cause leakage in the FFT. That is, the primary component leaks power into adjacent frequencies. The display below shows an FFT of a non-integer number of cycles using a rectangular window.

The FFT graph shows an example of leakage that can occur when a non-integer number of cycles are analyzed with the rectangular window option.

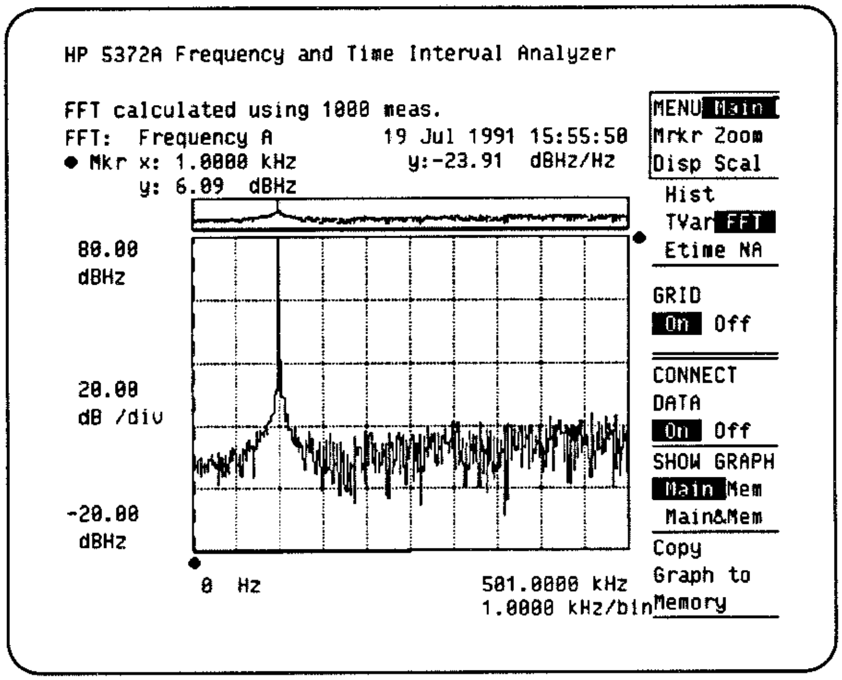


SC5_5D4

The following illustration also uses a rectangular window, but an integer number of cycles was captured.

The advantage of the rectangular window is that it provides the best frequency selectivity. It is not easy, or always practical to capture an integer number of cycles. This is where the Hann or Flat-top windows are important.

The FFT graph shows the result of using a rectangular window to analyze an integer number of cycles. Notice how leakage is no longer a problem (compare to previous display).



SC5_6D4

Hann

This is the window of choice for most applications. It provides good amplitude accuracy and is reasonably narrow for good frequency resolution. For this reason, it is the default window selection in the HP 5372A. The formula for the Hann window is as follows:

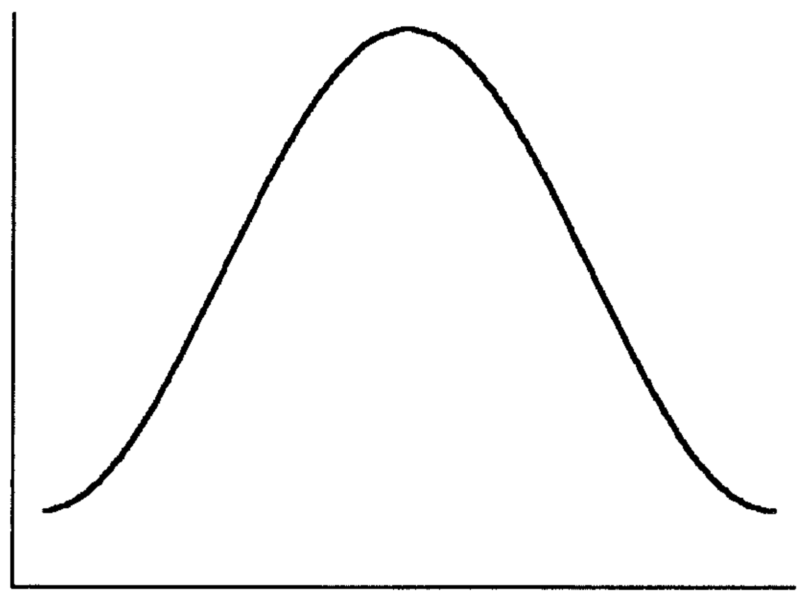
$$W_i = 0.5 \times \left(1 - \cos \frac{2 \times \pi \times i}{n}\right)$$

where:

Wi = the ith element in the window;
n = the number of points in the time record.

The illustration shows the time-domain representation of the Hann window. The next illustration shows the window as it is applied to a sine wave.

The shape of the Hann window.

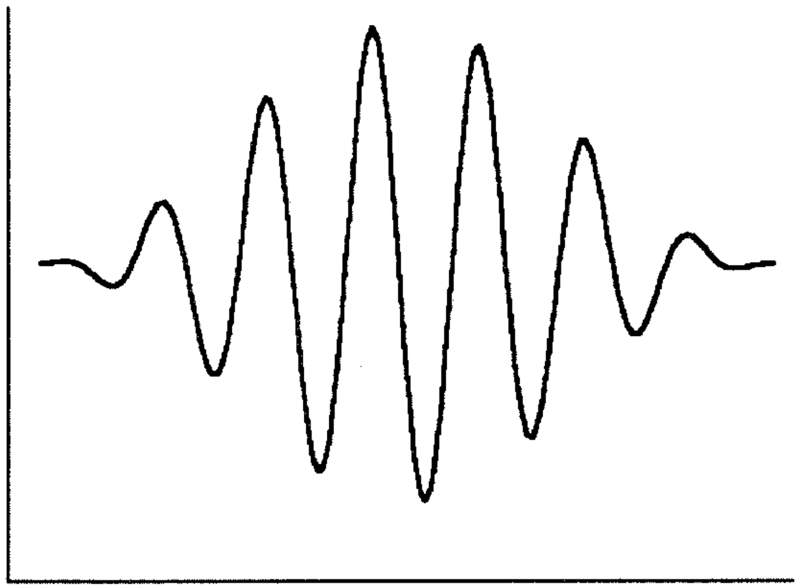


SIN2H_D4

As you can see, the Hann window forces the endpoints of the sine wave to zero (which means they are equal). Although it appears to distort the original waveform, most of the amplitude information is still intact and the frequency information is virtually unchanged. The Hann window offers a good compromise between amplitude accuracy and frequency selectivity.

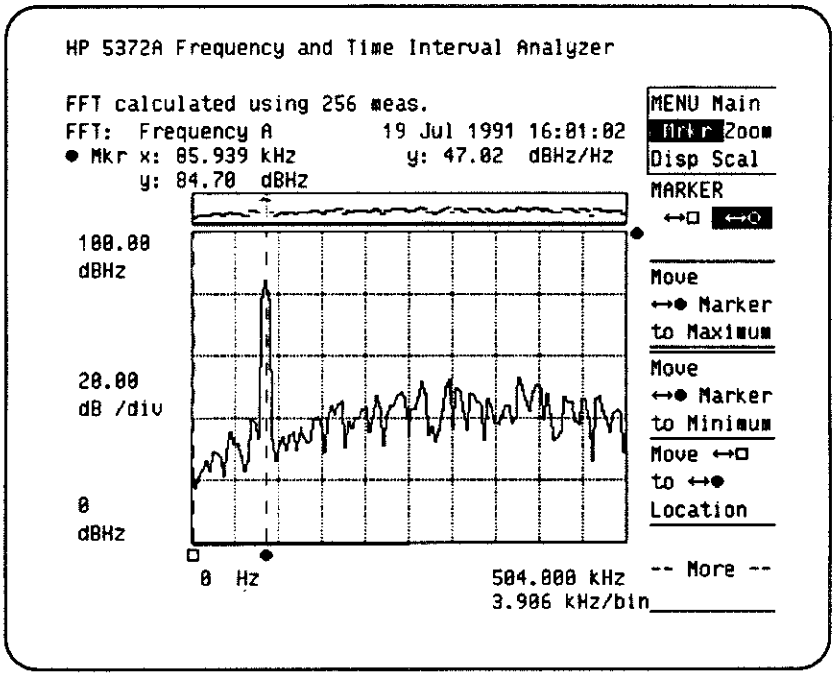
This illustration shows the result of applying the Hann window to a sine wave. The endpoints of the sine wave are forced to zero. The amplitude and frequency information remain unaltered.

HAN2_D4



The following example illustrates the effect of the Hann window. Suppose you want to look at the FM on a 16-MHz carrier. For this example, you will sample at a 1-MHz rate and use a block length of 256 measurement points. The FFT span will be about 500 kHz and the bin width will be 3.9 kHz. The carrier has some modulation present around 85 kHz and you need to determine its magnitude. You use the Frequency function and use the Hann window. The result is shown in the following display.

An example of the FFT using the Hann window. It provides the best tradeoff between spectral resolution and amplitude accuracy.



SC5_7D4

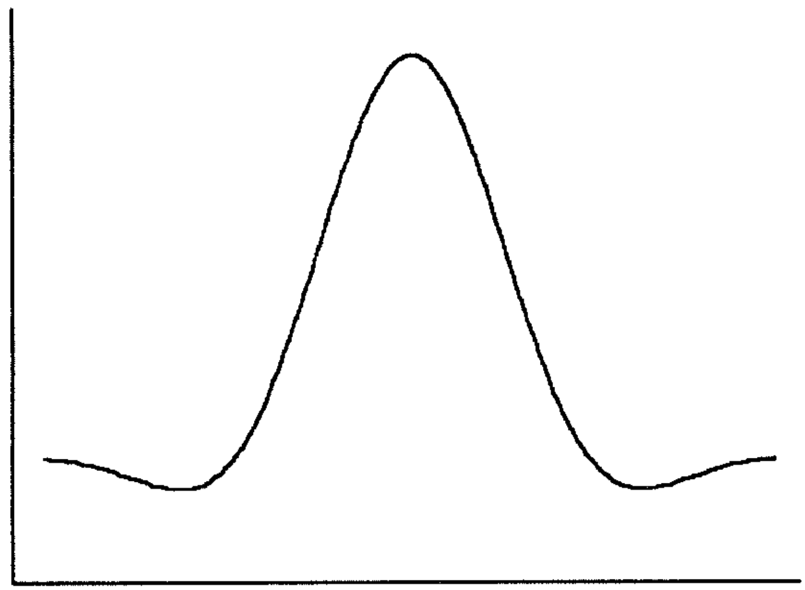
Note that the peak amplitude is 84.70 dBHz at a frequency of 85.939 kHz. Going through the calculations to convert from dBHz to modulation deviation, you see the peak frequency deviation is about 24.295 kHz. (The conversion calculation is described in this chapter under, "Interpreting Time Variation and FFT results.") This seems about right, but think about what the FFT is showing. Each bin is 3.9 kHz wide. All we know is that the spur is somewhere inside the bin that is centered at 85.939 kHz, but where? (For an explanation of bin width, see the discussion earlier in this chapter.) This is important because the Hann window does roll off somewhat if the modulation component is not in the center of the bin. In fact, if the component is one half bin off center, then the window has a 15.1% amplitude rolloff. This means the spur's amplitude measurement could be off by that much. To check for this, you could increase the number of measurements, or increase the sample interval, to decrease the bin width and provide a better idea of exactly where the spur is.

Flat-top

If the application requires better amplitude accuracy, then the Flat-top window must be used. The formula for the Flat-top is:

$$W_i = 0.9994484 - \left(1.911456 \cos \frac{2\pi i}{n}\right) + \left(1.078578 \cos \frac{4\pi i}{n}\right) - \left(0.183162 \cos \frac{6\pi i}{n}\right)$$

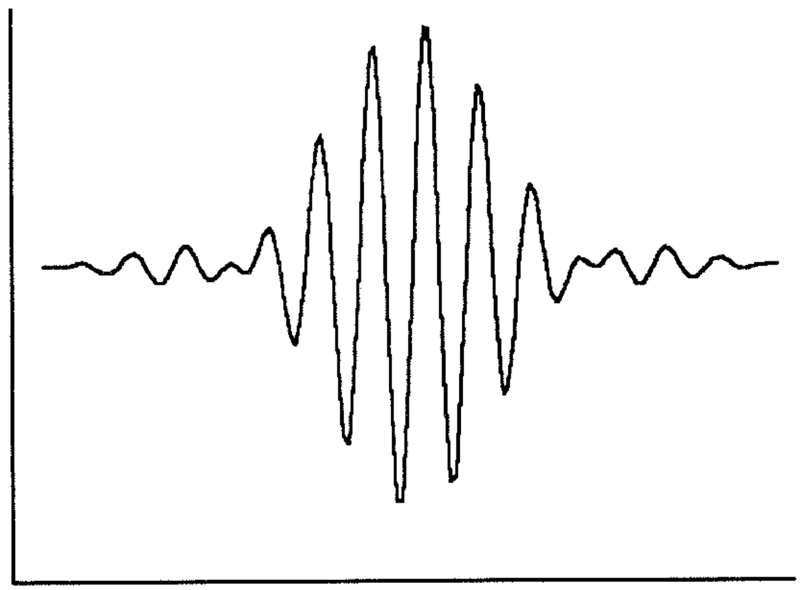
The shape of the Flat-top window.



FLAT2_D4

The Flat-top window is applied to a sine wave.

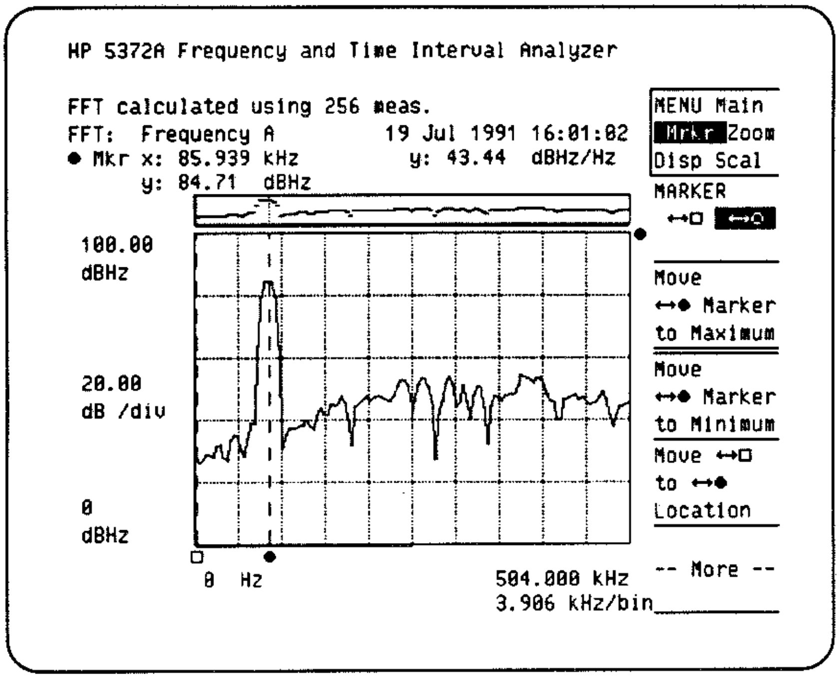
This illustration shows the result of applying the Flat-top window to a sine wave. The endpoints are at zero. The amplitude information is unaffected, but the frequency content is slightly altered when compared to the original sine wave.



SIN2F_D4

The following example uses the same measurement as for the Hann window example, only changing the window to Flat-top. The display shows the measurement with the modulation still set to 85 kHz. Note that the spur is somewhat wider than with the Hann window example. This means you have a slightly reduced frequency selectivity (a tradeoff for amplitude accuracy). The spur is at 85.939 kHz and has an amplitude of 84.71 dBHz. Rolloff is less than 0.1% across the bin.

An FFT example using the Flat-top window. When compared to the Hann window, the spur amplitude value is more accurate here because of the flat amplitude response across the width of the FFT bin. Frequency selectivity is slightly reduced.



SC5_8D4

Summary

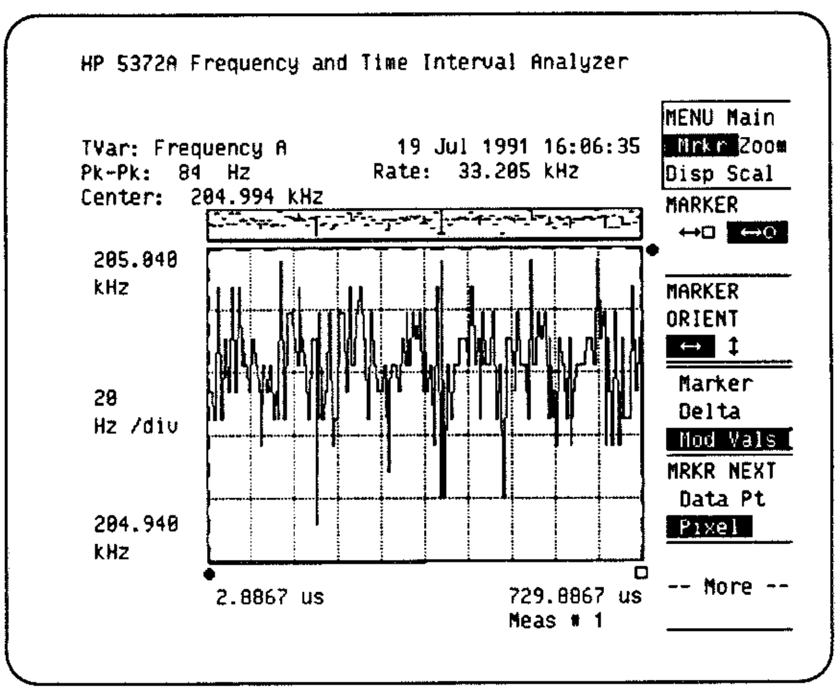
For most applications, the Hann is the best window to use. It provides the best tradeoff between resolution and amplitude accuracy. If you need very good amplitude accuracy, and you do not have spurs that may be separated by only a couple of bins, then use the Flat-top. The only time to use Rectangle is if the signal is composed of an exact integer number of cycles, or it is a transient that starts and stops at the same point on the y-axis of the Time Variation graph.

Averaging

Quite often, applications require more information than is present in a single acquisition. This information can be lacking because it is buried in noise or the acquired results just do not have enough resolution to satisfy your measurement needs. A common method for extracting more information is to average a signal over multiple acquisitions.

Block averaging

The standard HP 5372A has one form of averaging called *block averaging*. This averaging requires M blocks of N measurements to be averaged together to form one averaged block of N measurements. This averaging improves resolution and can be used to bring out a pattern of modulation that may not have been readily apparent in a single acquisition. There is one major drawback to this type of averaging. It requires a reference edge at the start of each block that is synchronous with the modulation in the block. For example, if you are looking at a 1-MHz carrier with 10 Hz of deviation at a 10-kHz rate, the reference edge must be synchronous with the 10-kHz rate in order for the averaging to be effective. There are applications where such a reference edge is not available, but when you can block average, the benefits are quite apparent. The illustration below shows a one block measurement of a carrier with a small amount of modulation. Notice that the display shows no recognizable modulation.

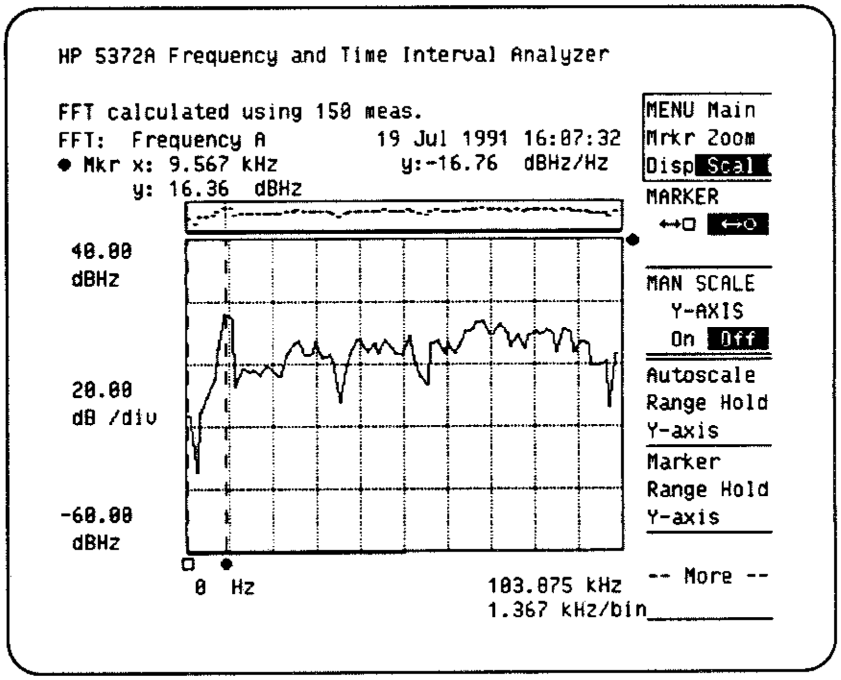


Time Variation graph (without averaging) showing 1 block of 150 measurements.

SC5_9D4

Note that the FFT of one block (shown in the next display) does indicate the correct modulation. Even though the measurement record is a short one (150 meas.), the FFT can extract the dominant frequency modulation component. An FFT of longer records and averaged measurements would have far better spectral resolution and amplitude accuracy.

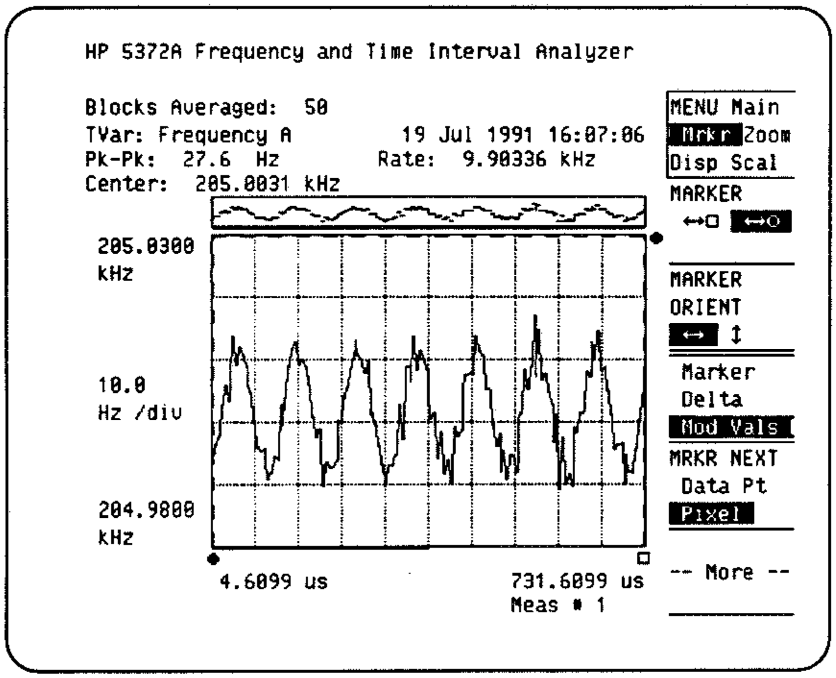
FFT graph of 1 block of 150 measurements. The signal-to-noise ratio is not very good, but the frequency component of the modulation is revealed.



SC5_11D4

The next display shows the same signal averaged over 50 blocks, using a reference edge that is synchronous with the modulation. Not only is the modulation easy to see, but there is more frequency resolution. The resolution increases with the square root of the number of averages.

Time Variation graph showing 50 blocks of 150 measurements using block averaging.



SC5_10D4

Block averaging is an excellent method for extracting signals and improving resolution. It can significantly improve the signal-to-noise ratio of the final result. This is apparent in both the Time Variation graph results and the FFT. If an edge synchronous with the suspected modulation is available, block averaging is the preferred method. Refer to chapter 3 for a list of the function and arming modes that support block averaging.

Spectral averaging

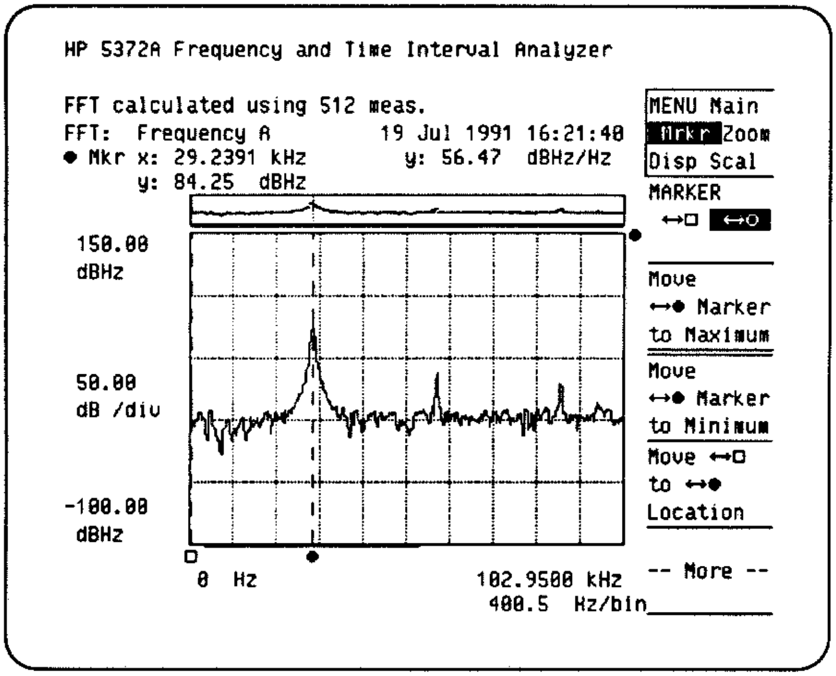
The Jitter Spectrum Analysis option allows you to average successive FFTs. For example, if you take 50 blocks of 128 measurements, block 2 will be averaged with block 1, block 3 with the average of blocks 1 and 2, and so on. This type of averaging does not improve the signal-to-noise ratio. It does reduce the variance on the FFT and make it easier to see very low level spurs. This is the only type of averaging available when no synchronous edge is available as a reference for successive blocks (see Block Averaging). In fact, the FFT average does not require any type of time-domain synchronization.

FFT spectral averaging works by taking bin 1 of the first block and averaging it with bin 1 of the second block. This process assumes that each bin width in each block is the same, or nearly so. If the bin width of the most recent block is significantly different from the current average bin width, the HP 5372A will display a warning message indicating that the sampling should be changed. Try increasing the sample interval to produce usable results.

On the FFT graph, spectral averaging takes precedence over block averaging. So if you have 100 blocks of 512 measurements and have block averaging enabled on the Function menu and spectral averaging enabled on the Math menu, the result on the FFT graph will be a spectral average of 100 blocks. The Time Variation graph will show the block average of 100 blocks.

The display below shows an FFT of 1 block of 512 measurements. Compare this with the next illustration showing a spectral average of 100 blocks of 512 measurements. The variance has significantly decreased and it is much easier to estimate the noise floor of the measurement. However, the signal-to-noise ratio has not changed, as compared to the previous display.

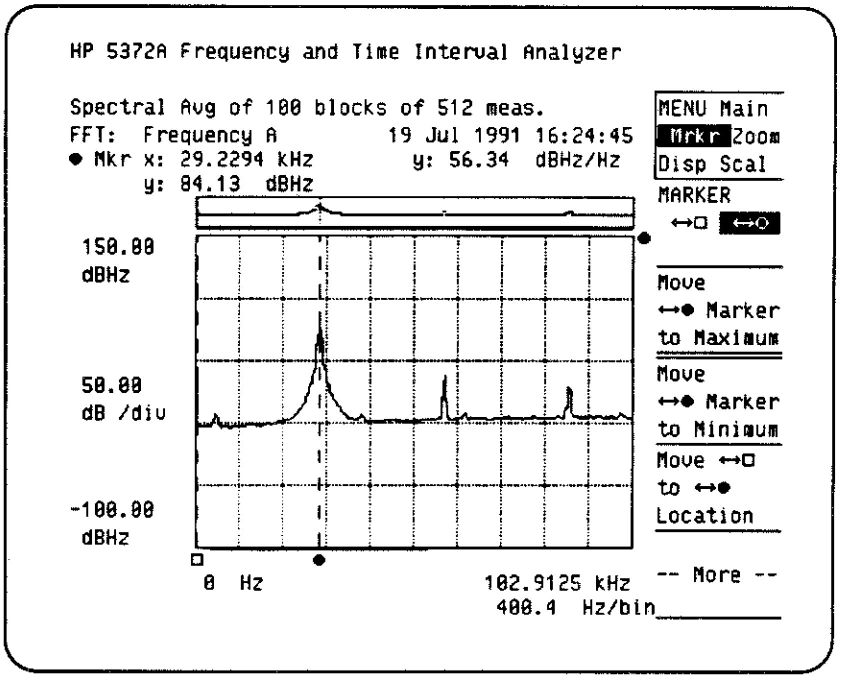
FFT graph showing 1 block of 512 measurements.



SC5_12D4

The FFT here shows a spectral average of 100 blocks of 512 measurements.

FFT graph showing 100 blocks of 512 measurements using spectral averaging.



SC5_13D4

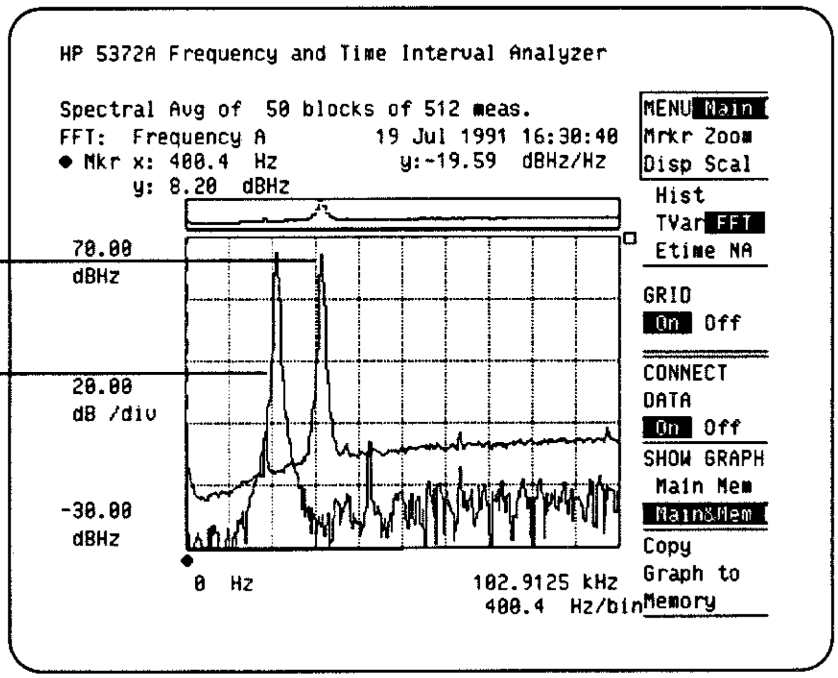
Block averaging and spectral averaging compared

To compare the two types of averaging, the next display shows a block average FFT and a spectral average FFT overlayed. You can see that the spectral average has a much smaller variance, but the signal-to-noise ratio is not as good as the block average. The block average has a much higher variance, but the noise level is almost 20 dB lower. The modulating frequencies have been offset slightly so you can see the differences.

A comparison of 2 averaged FFT graphs. One shows the spectral average of 50 blocks, the other the block average of 50 blocks.

FFT of spectral averaged results

FFT of block averaged results



SC5_14D4

Summary

If you need the best signal-to-noise ratio, use block averaging and then take the FFT of that result. If no reference is available, use spectral averaging and take as many averages as you are willing to wait for. After about 100 averages, there is not much more to be gained in terms of a smaller variance.

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The Fundamentals of Signal Analysis, HP Application Note 243

Bingham, E.O., and R.E. Morrow, "The Fast Fourier Transform," *IEEE Spectrum*, December 1967, pp 63-70.

Bracewell, R., *The Fourier Transform and Its Applications*, McGraw-Hill, 2nd ed., 1986.

Papoulis, A., *The Fourier Integral and Its Applications*, New York: McGraw-Hill, 1962.

Ramirez, Robert W., *The FFT, fundamentals and concepts*, Prentice Hall, Inc., Englewood Cliffs, N.J. 07632, 1985.

Appendixes

Appendix A

HP 5372A Setup Quick Reference

All measurements require you to make some decisions as part of a general measurement process. Regardless of the measurement type, you'll probably think about:

- **FUNCTION:** *Measurement function, sample size, and arming*
- **INPUT:** *Input signal conditioning and event triggering*
- **MATH:** *Math value inputs, statistics, FFT On / Off*
- **SINGLE/REPET - RESTART:** *Repetitive or single measurements*
- **GRAPHIC/NUMERIC:** *Results output as numeric or graphic displays*

These areas correspond to seven front-panel keys. You'll be using these keys when setting up and making front-panel measurements.

Front-Panel Key Sequence

The following pages (*Starting on page A-3*) show a general relationship between the HP 5372A measurement process and associated front-panel keys.

Depending on the nature of your signal and measurement complexity, one or more of these keys and associated variables may need to be changed. (Some functions limit these choices.)

Step through these keys and variables, making changes where needed by using the:

- *Softkeys* (right side of display) to select screen options,
- *Cursor / Scroll keys* to move the cursor within each screen, and
- *Data entry keypad* to change current or default numeric settings.

Front-Panel Checklist

If you get unexpected results, consider these possibilities:

- Is your input signal active at the 5372A front-panel input?
- Are the event triggering settings causing event counts?
- Are the input signal conditioning choices correct?
- Is the selected arming mode appropriate for your signal?
- Are the sample size parameters of **m** blocks of **n** measurements sufficient (or too many?) to display your signal in a meaningful way?

Analyzer Preset

Press the *Preset* key to set the analyzer to its default state.

Pressing the Preset key at any time brings you back to the default instrument state. Use the Preset key to quickly reset the Analyzer parameters to their default settings:

- If you should ever press the Preset key by mistake, your last instrument setup can be retreived by pressing the Recall key and 0 on the data entry keypad. The instrument setup at the time Preset is selected is saved in storage register 0.
- Automatic storage of the current instrument setup to register 0 also occurs when you use the Default Measurement Setup feature. The Default Measurement Setup (selected by the Shift key and Preset key) automatically configures the HP 5372A to make measurements and display results for the current measurement function.

Measurement Reference Information

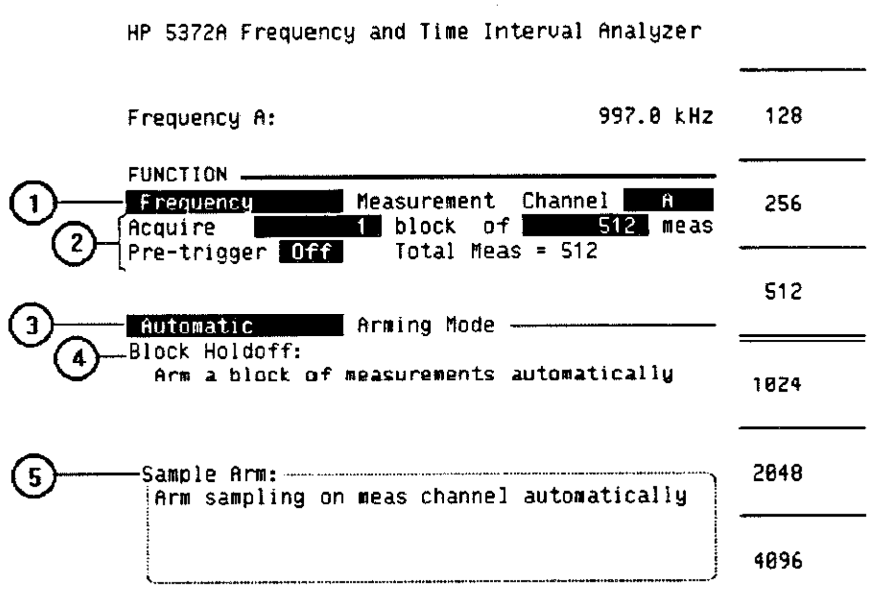
If you want more information on making measurements, start with chapter 2 of the *HP 5372A Getting Started Guide*.

Preset Reference Information

Refer to chapter 11 in the *HP 5372A Operating Manual* for more information on saving and recalling instrument setups. Refer to chapter 6, "Front Panel/Rear Panel", in the *HP 5372A Operating Manual* for a listing of the parameters selected by the Preset function.

Step 1: Function Screen Setup

Function: *Select measurement function, channel, sample size, and arming.*



1. Choose the *Measurement* function and channel **A, B,** or **C**. (**More** key displays more function choices.)

NOTE

If your measurement task requires Jitter Spectrum Analysis, go to the **Math** *screen now, enable the FFT, and return to this screen.*

2. Acquire **m** blocks of **n** measurements.

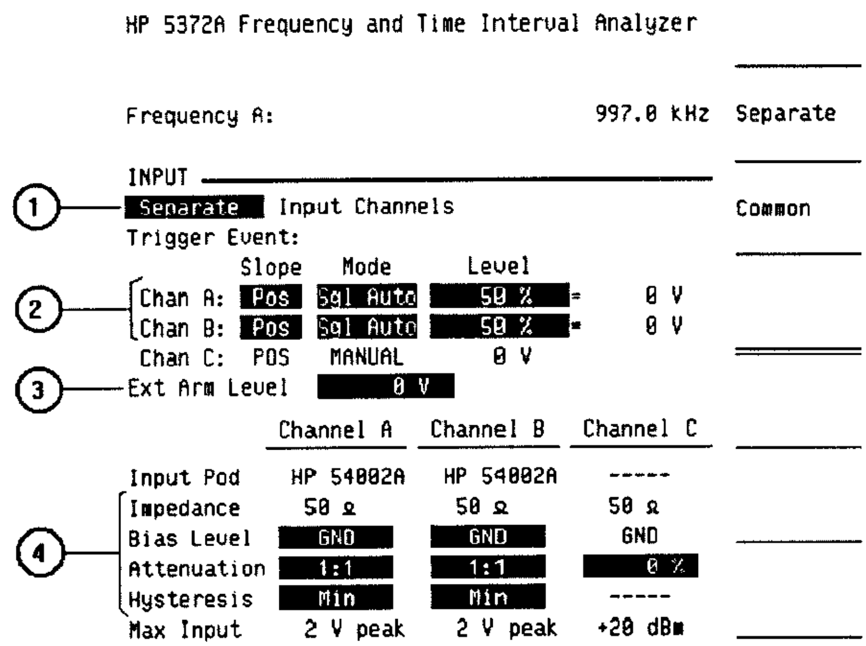
3. Select *Arming Mode* from the **Holdoff, Sample,** or **Default [Auto]** arm categories.

4. Set *Block Holdoff:* This condition is met prior to each block of measurements. For example, with **Edge/Interval** arming, the specified edge must be detected before a block begins.

5. Set *Sample Arm:* This condition is met prior to each measurement. For example, with **Edge/Interval** arming, a measurement is made after each elapsed interval.

Step 2: Input Screen Setup

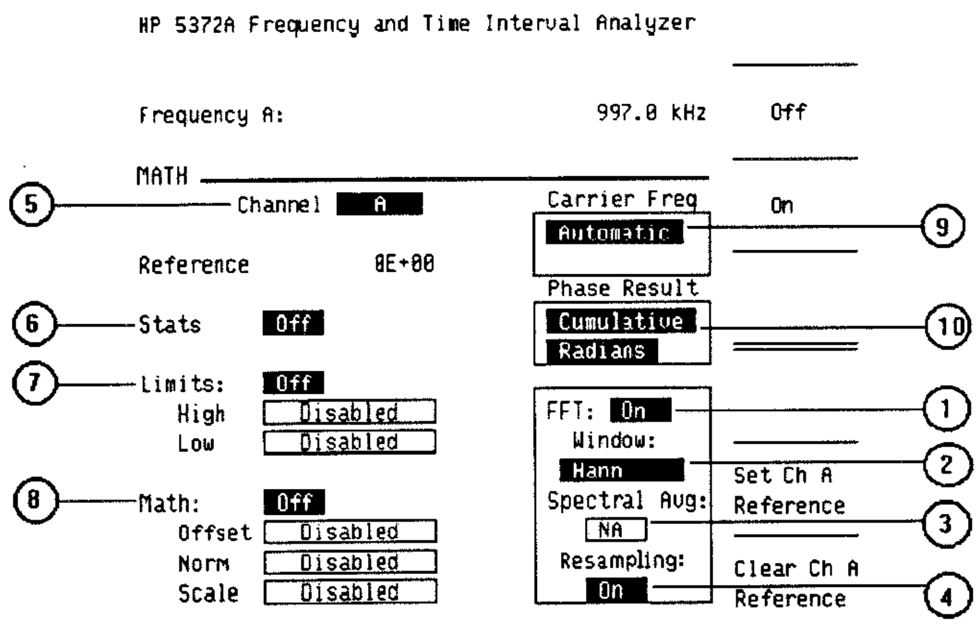
Input: *Getting your input signal to trigger the Analyzer.* (Flashing Channel LEDs)



1. Set **Separate** or **Common** Input Channels.
2. Set Trigger Event: *Slope, Mode,* and *Level* for channels **A** or **B**.
3. Set *External Arm Level:* select **0 V, TTL Preset[1.4V],** or **ECL Preset[-1.3V]**.
4. Set *Impedance, Bias Level, Attenuation,* and *Hysteresis* settings. (Input Pod selection determines input impedance.)

Step 3: Math Screen Setup

Math: *Set up math operation, enable statistics, and enable FFT.*



1. Set *FFT* **On** or **Off**.
2. Select FFT *Window* as **Rectangle, Hann,** or **Flat-top**.
3. Set *Spectral Averaging* as **On** or **Off** for multiple block measurements.
4. Set *Resampling* as **On** or **Off**. This choice is NOT selectable (default is On) for Phase Deviation Data and Time Deviation Data measurements.
5. Select channel **A, B,** or **C** prior to setting up items 6 through 8 below.
6. Set *Statistics:* **On** or **Off**.
7. Set *Limits:* **On** or **Off**, set *High* or *Low* limits.
8. Set *Math:* **On** or **Off**, set *Offset, Norm,* or *Scale*.
9. Set *Carrier Frequency* as: **Automatic** or **Manual**.
10. Set *Phase Result* as **MOD 360/2π** or **Cumulative**, set **Radians** or **Degrees**.

Step 4: Single or Repetitive Measurements

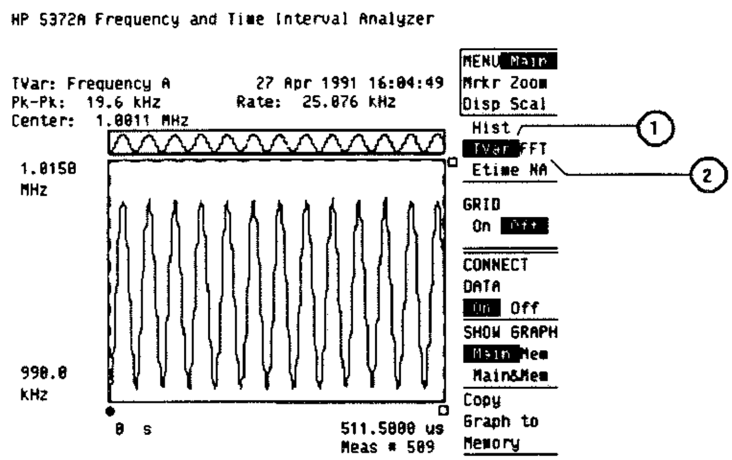
Single/Repet: *Select measurement execution as Single or Repetitive.*

Restart: *Restart the acquisition process.*

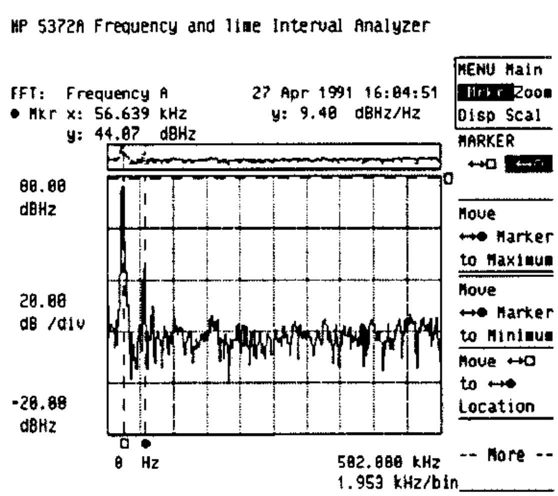
Step 5: Graphic Screen Display

Graphic: *Display results.*

1. **Time Variation:** Function vs. Time

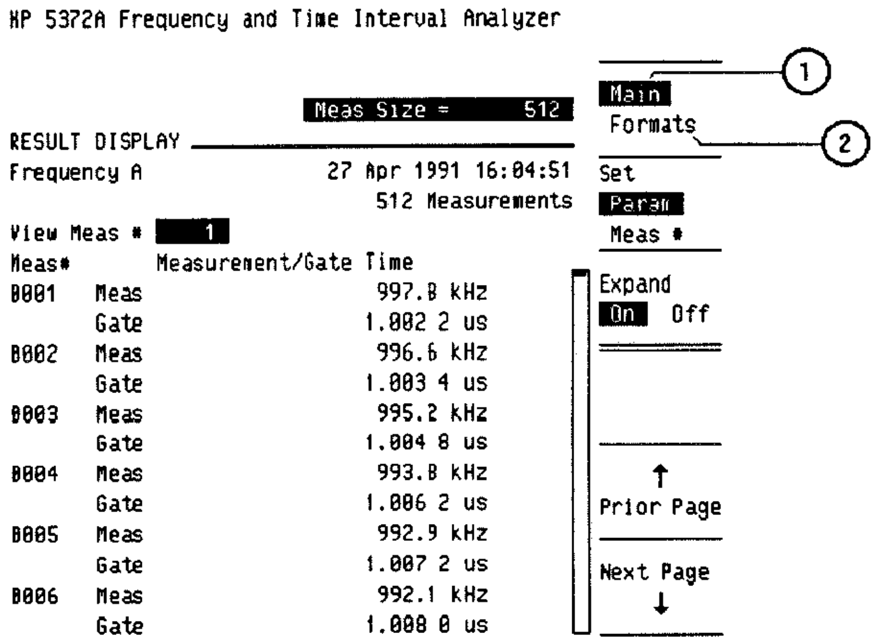


2. **FFT:** FFT spectrum of time-variation data



Step 6: Numeric Screen Display

Numeric: *Display numeric results.*



The Numeric display shows the individual measurements that are plotted on the TVar display.

1. *Measurement Data:* Examine individual results.

2. *Statistics:* Examine summary values: Press the Formats softkey, then Statistics.

NOTE

You must enable Statistics via the Math menu before summary values can be displayed.

Appendix B

Bin Width and Span Graphs

Use the eight graphs in this appendix to help you select the number of measurements and the sample interval for an FFT measurement. The graphs indicate a number of measurements and a sample interval for a measurement setup based upon your desired FFT spectral resolution (bin width) and frequency span. An example of how to use these graphs is presented in chapter 2 under "More on fine tuning your FFT."

There are three steps to using these graphs:

1 **Select a graph based on your requirements for FFT spectral resolution (bin width) and frequency span.**

Graph 1.	1 Hz and 5 Hz bin width 1 kHz to 10 kHz frequency span
Graph 2.	10 Hz and 50 Hz bin width 10 kHz to 100 kHz frequency span
Graph 3.	100 Hz and 500 Hz bin width 100 kHz to 1 MHz frequency span
Graph 4.	1 kHz and 5 kHz bin width 1 MHz to 10 MHz frequency span
Graph 5.	1 Hz and 5 Hz bin width 250 Hz to 2.5 kHz frequency span
Graph 6.	10 Hz and 50 Hz bin width 2.5 kHz to 25 kHz frequency span
Graph 7.	100 Hz and 500 Hz bin width 25 kHz to 250 kHz frequency span
Graph 8.	1 kHz and 5 kHz bin width 250 kHz to 2.5 MHz frequency span

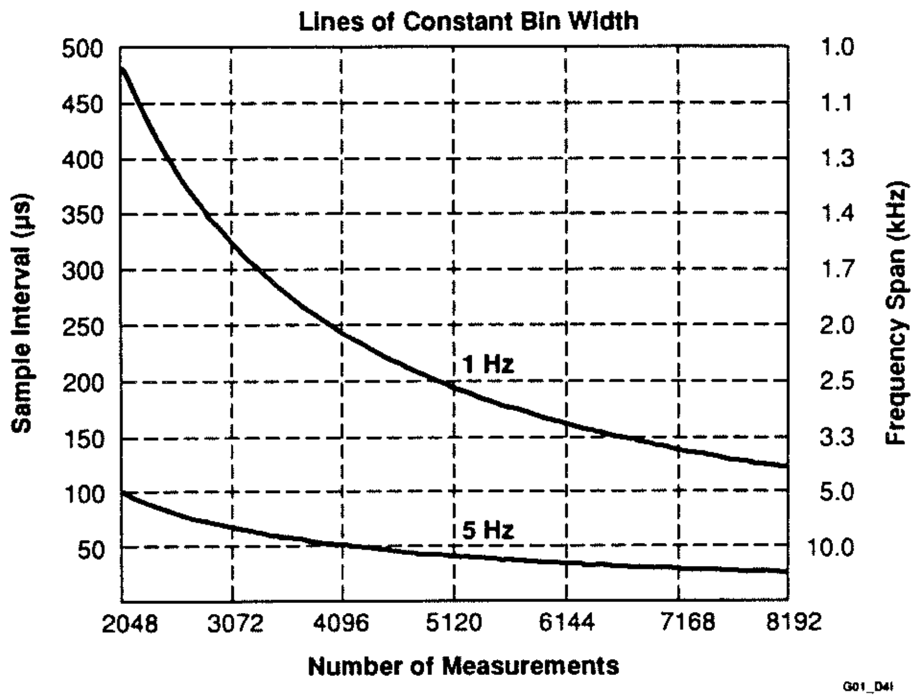
2 **Pick a bin width and a span.**

3 **At the point where the frequency span line intersects the bin width curve, look to the left edge for the sample interval and to the bottom for the number of measurements.**

Graph 1.

1 Hz and 5 Hz bin width

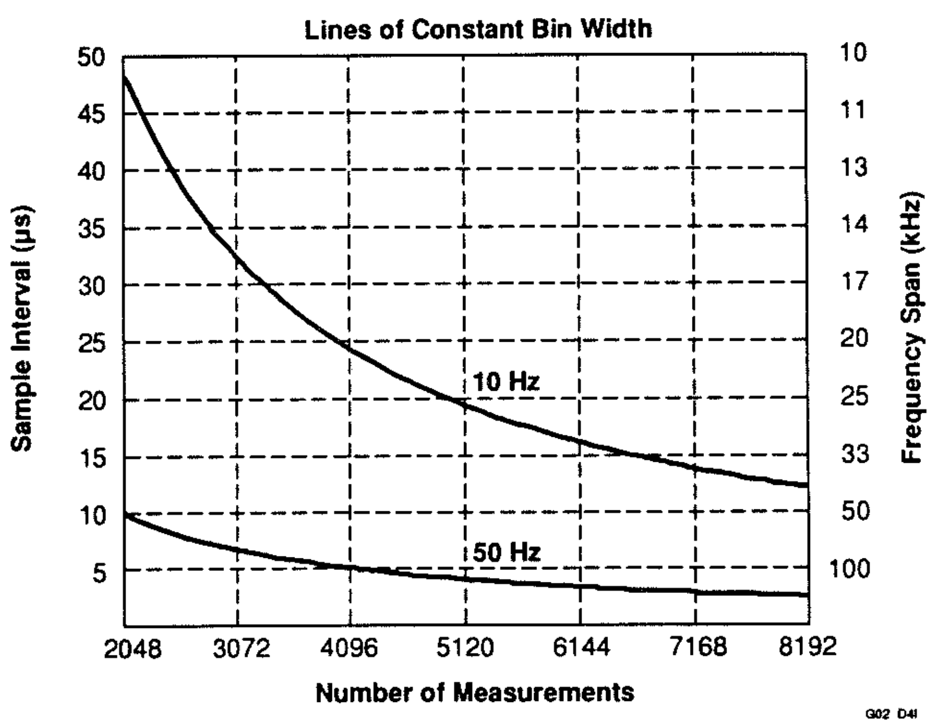
1 kHz to 10 kHz frequency span



Graph 2.

10 Hz and 50 Hz bin width

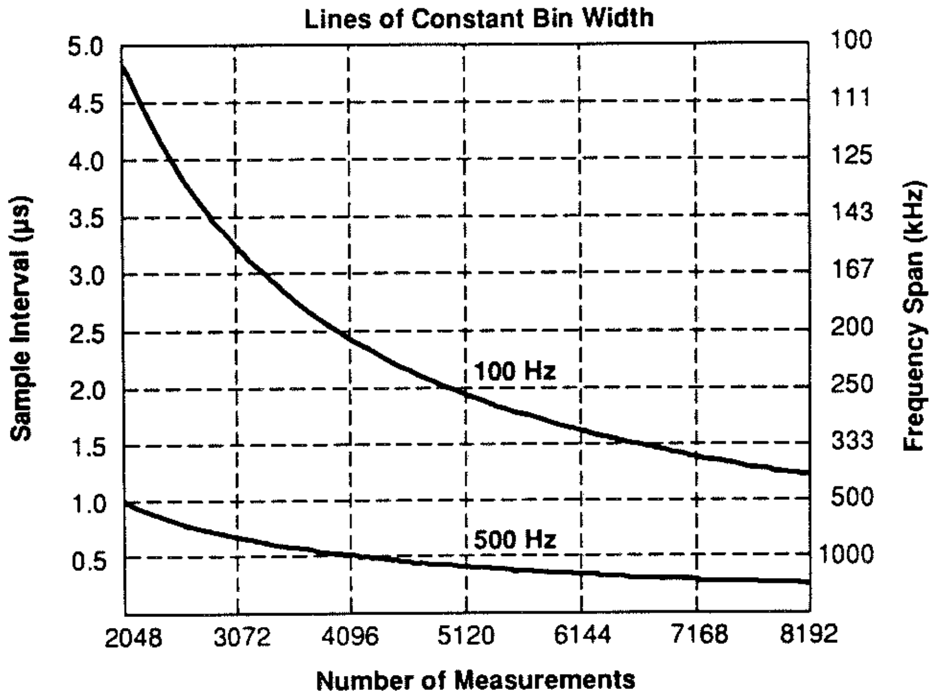
10 kHz to 100 kHz frequency span



Graph 3.

100 Hz and 500 Hz bin width

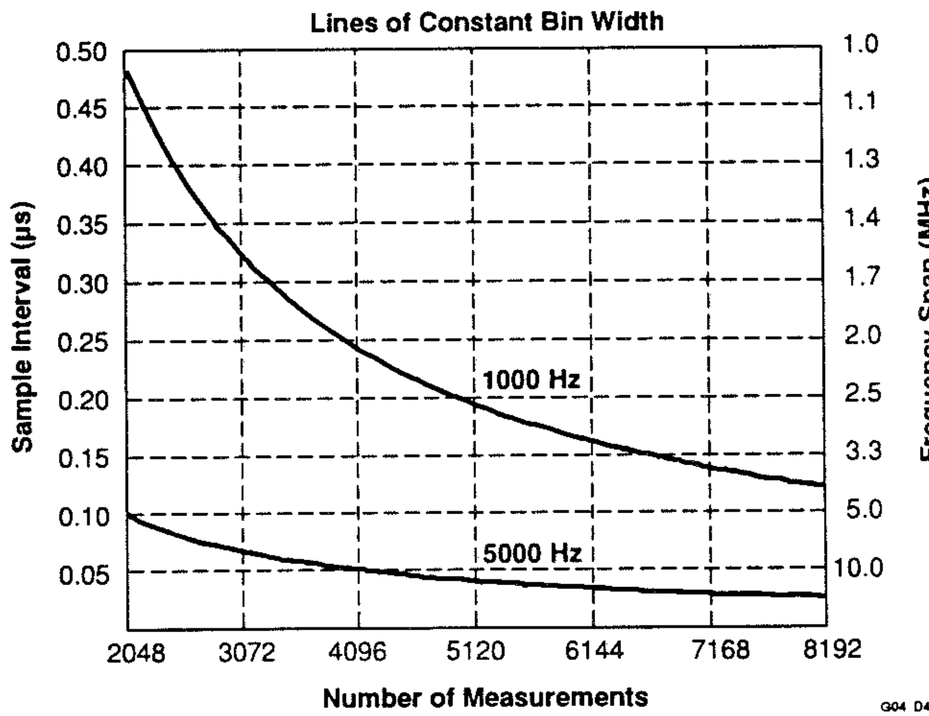
100 kHz to 1 MHz frequency span



Graph 4.

1 kHz and 5 kHz bin width

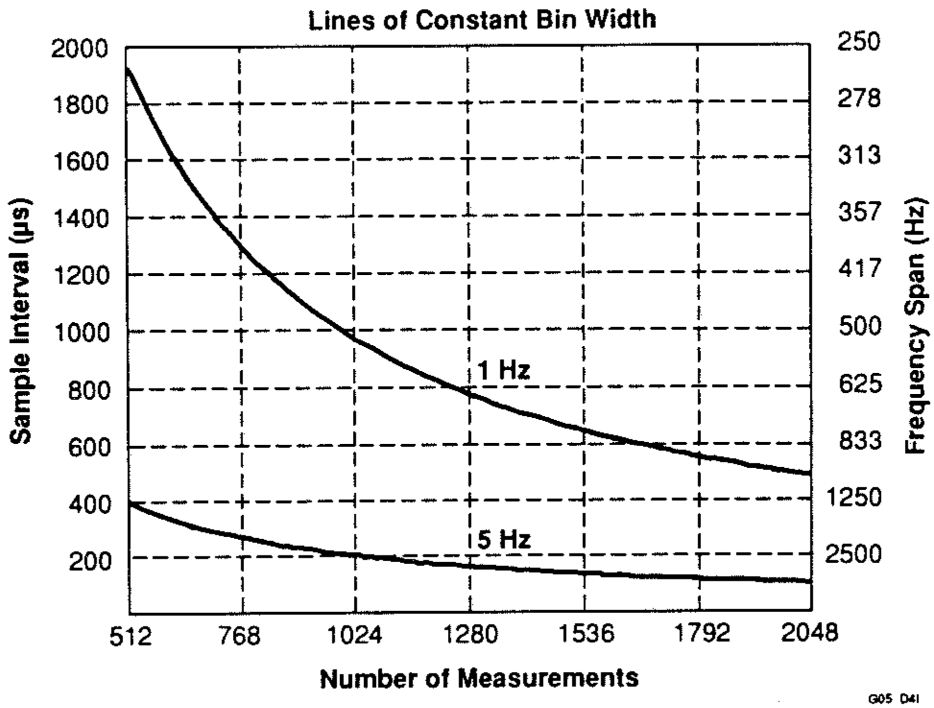
1 MHz to 10 MHz frequency span



Graph 5.

1 Hz and 5 Hz bin width

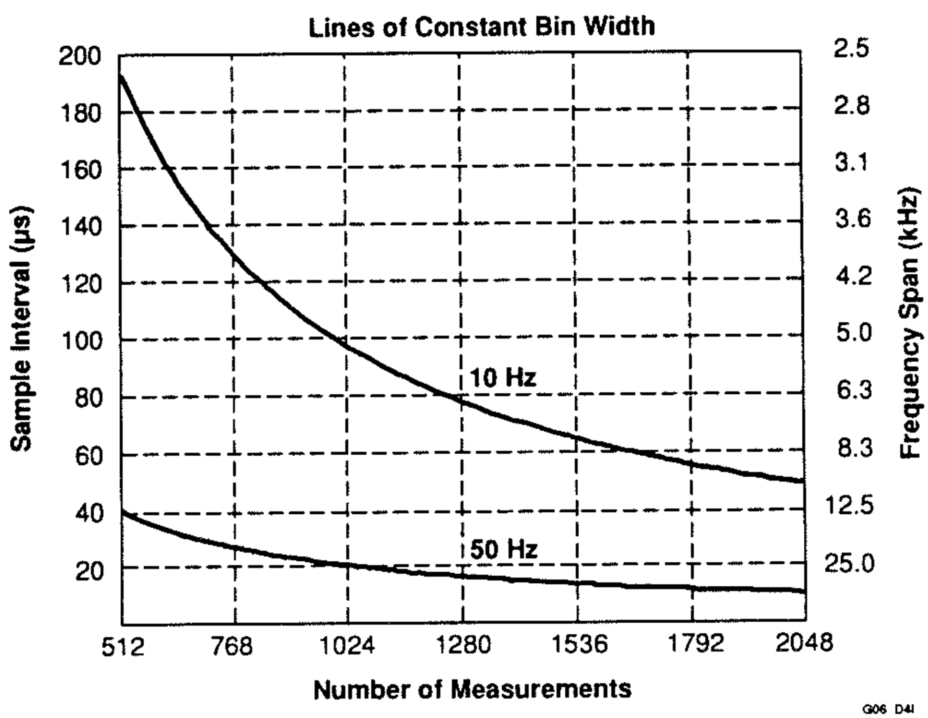
250 Hz to 2.5 kHz frequency span



Graph 6.

10 Hz and 50 Hz bin width

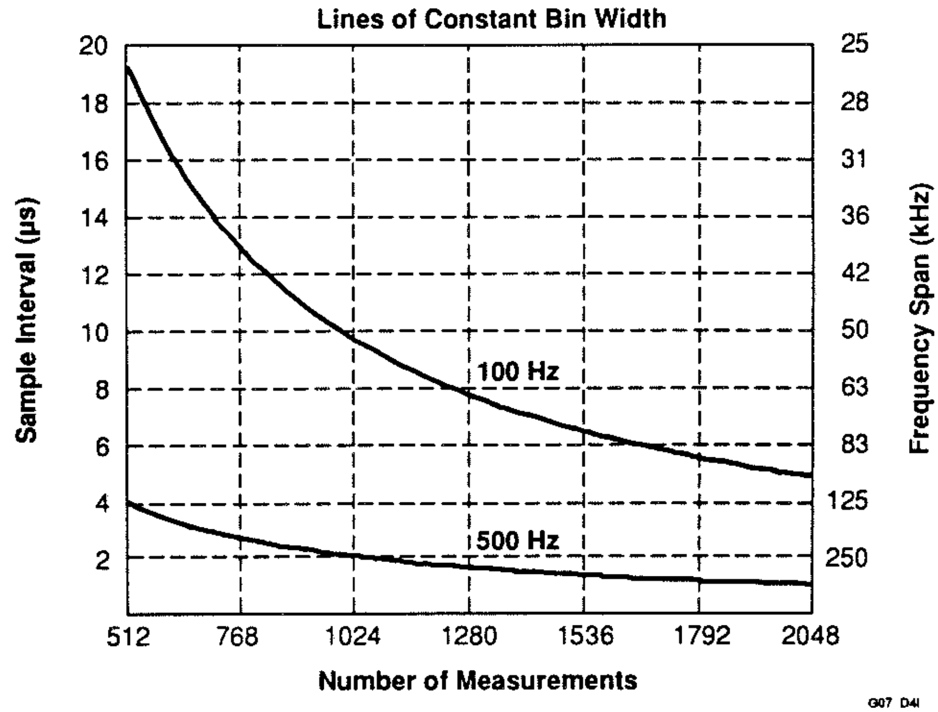
2.5 kHz to 25 kHz frequency span



Graph 7.

100 Hz and 500 Hz bin width

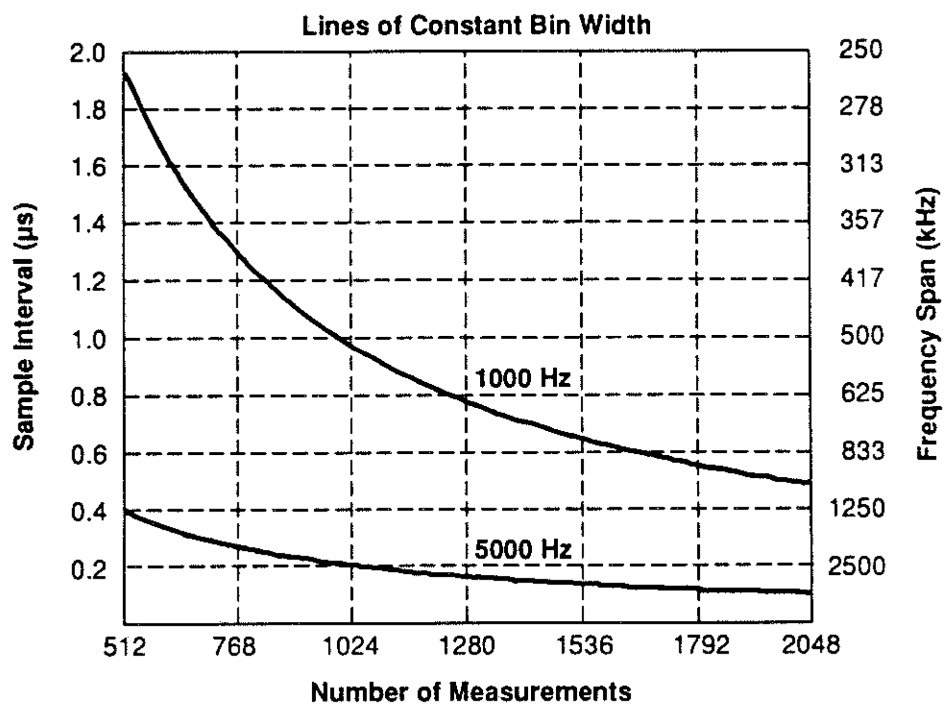
25 kHz to 250 kHz frequency span



Graph 8.

1 kHz and 5 kHz bin width

250 kHz to 2.5 MHz frequency span



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