
FFT Measurement

Operating System Requirements

Refer to "Oscilloscope Compatibility" on page 1-2 for operating system requirements for FFT operation.

FFT (Function 2) is used to compute the fast Fourier transform using vertical inputs (1 and 2), or the Function 1 waveform. This function takes the digitized time record of the specified source and transforms it to the frequency domain. When the function is selected, the FFT spectrum is plotted on the oscilloscope display as **dBV** (dBV or dBm for 54610 and 54615/54616) versus **frequency**. The readout for the horizontal axis changes from time to Hertz and the vertical readout changes from volts to dBV (dBV or dBm for 54610 and 54615/54616). For the 54610 and 54615/54616, when 50Ω input is selected, readout is in dBm; when 1MΩ input is selected, readout is in dBV. dBV is a unit of measure that is referenced to 1 Vrms. If the display of the **54600**, 54601, 54602, 54603, or 54645 is needed to be in dBm, the operator must apply an external 50Ω load (10100C or equivalent), and then perform the following conversion:

$$dBm = dBV + 13.01$$

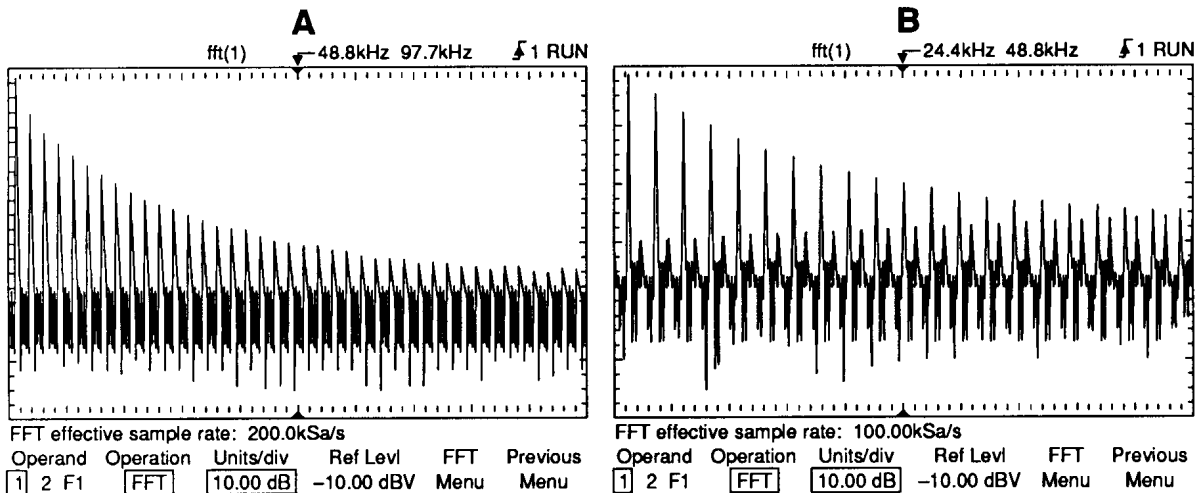
DC Value The FFT computation produces a DC value that is **incorrect**. It does not take the offset at center screen into account and is 1.41421 times greater than its actual value. The DC value is not corrected in order to accurately represent frequency components near DC. **All DC measurements should be performed in normal oscilloscope mode.**

Aliasing When using FFT's, it is important to be aware of aliasing. This requires that the operator have some knowledge as to what the frequency domain should contain, and also consider the effective sampling rate, frequency span, and oscilloscope vertical bandwidth when making FFT measurements. **Effective sample rate is briefly displayed when the \pm key is pressed.**

Aliasing happens when there are insufficient samples acquired on each cycle of the input signal to recognize the signal. This occurs whenever the frequency of the input signal is greater than the Nyquist frequency (sample frequency divided by 2). When a signal is aliased, the higher frequency components show up in the FFT spectrum at a lower frequency.

The following figure illustrates aliasing. In waveform A, the sample rate is set to 200 kSa/s, and the oscilloscope displays the correct spectrum. In waveform B, the sample rate is reduced by one-half (100 kSa/s), causing the components of the input signal above the Nyquist frequency to be mirrored (aliased) on the display.

Figure 2-2



Aliasing

Since the **frequency span goes from ≈ 0 to the Nyquist frequency**, the best way to prevent aliasing is to make sure that the frequency span is greater than the frequencies present in the input signal.

Spectral Leakage The FFT operation assumes that the time record repeats. Unless there is an integral number of cycles of the sampled waveform in the record, a discontinuity is created at the end of the record. This is referred to as leakage. In order to minimize spectral leakage, windows that approach zero smoothly at the beginning and end of the signal are employed as filters to the FFT. The Measurement/Storage Module provides four windows: rectangular, exponential, hanning, and flattop. For more information on leakage, see Agilent Application Note 243, "The Fundamentals of Signal Analysis" (Agilent part number 5952-8898.)

FFT Operation

- 1 Press $\boxed{\pm}$.
- 2 Toggle the **Function 2 On Off** softkey to enable math function number 2.
- 3 Press the **Function 2 Menu** softkey.
- 4 Toggle the **Operand** softkey until the desired source is selected.
F1 uses the result waveform in function 1.
- 5 Press the **Operation** softkey until **FFT** is selected. Results (F2) are displayed on the screen.
- 6 Press the **Units/div** softkey and rotate the knob closest to the $\boxed{\text{Cursors}}$ key to set the **vertical sensitivity** of the resulting waveform.
- 7 Press the **Ref Lev** softkey and rotate the knob closest to the $\boxed{\text{Cursors}}$ key to set the **reference level (top graticule line)** of the resulting waveform.

The ~~**Autoscale FFT** softkey~~ will automatically set Units/div and Ref Lev to bring the FFT data on screen. Frequency Span is set to maximum. Steps 6 and 7 could be replaced to say:

6 Press **FFT Menu** softkey.

~~**7** Press **Autoscale FFT** softkey.~~ Rotate Time/Div knob until freq span is around the frequencies of interest.

- 8 Press the **FFT Menu** softkey.

A softkey menu with six softkey choices appears. Five of them are related to FFT.

- **Cent Freq** Allows centering of the FFT spectrum to the desired frequency. Select and rotate the knob closest to the **Cursors** key to set the center frequency to the desired value.
- **Freq Span** Sets the overall width of the FFT spectrum (left graticule to right graticule). Select and rotate the knob closest to the **Cursors** key to set the center frequency to the desired value. See FFT Measurement Hints (next page) for information on using frequency span to magnify the display.
- **Move 0Hz To Left** Pressing this key changes the center frequency so that the left most graticule represents 0 Hz.
- ~~**Autoscale FFT** The Autoscale FFT softkey will automatically set Units/div and Ref Lev to bring the FFT data on screen. Frequency Span is set to maximum.~~
- **Window** Allows one of four windows to be selected. Select and rotate the knob closest to the **Cursors** key to set the desired window. The **rectangular** window is useful for transients signals and signals where there are an integral number of cycles in the time record. The **hanning** window is useful for frequency resolution and general purpose use. It is good for resolving two frequencies that are close together or for making frequency measurements. The **flattop** window is the best window for making accurate amplitude measurements of frequency peaks. The exponential window is the best window for transients analysis.
- **Previous Menu** Returns you to the previous softkey menu.

FFT spectrum (F2) is available for viewing, measurement, or storage.

- 9 The **Cursors** key contains two additional selections that can be used to measure or move the FFT spectrum. Press **Cursors** , then set the **Source** softkey to **F2**.

Find Peaks Pressing this key sets Vmarker1 and the start marker (f1) on the peak with the highest amplitude and sets Vmarker2 and the stop marker (f2) on the peak with the next highest amplitude. Marker values in dBV/dBm or frequency (dependent on the active cursor) are automatically displayed at the bottom of the oscilloscope screen. The difference in dBV/dBm (ΔV) or frequency (Δf) between the two peaks is also displayed.

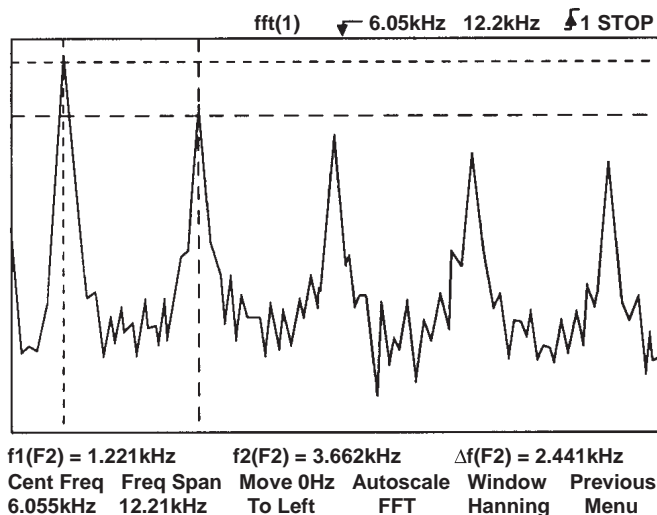
Move f1 To Center Pressing this key changes the center graticule (or center frequency) to the current f1 marker frequency. If f1 cannot be found, a message is displayed on the screen.

Operating the Measurement/Storage Module

FFT Measurement

The following FFT spectrum was obtained by connecting the front panel probe adjustment signal to input 1. Set Time/Div to 500 s/div, Volts/Div to 100 mV/div, Units/div to 10.00 dB, Ref Level to -10.00 dBV, Center Freq to 6.055 kHz, Freq Span to 12.21 kHz, and window to Hanning.

Figure 2-3



FFT Measurements

FFT Measurement Hints

It is easiest to view FFT's with Vectors set to On. The Vector display mode is set in the Display menu. Note that on the 54615/54616, when Vectors is set from Off to On, the frequency span is halved, and when Vectors is set from On to Off, the frequency span is doubled.

The number of points acquired for the FFT record is normally 1024 (see FFT "Operating Characteristics" in Chapter 3 for specifics,) and when frequency span is at maximum, all points are displayed. Once the FFT spectrum is displayed, the frequency span and center frequency controls are used much like the controls of a spectrum analyzer to examine the frequency of interest in greater detail. Place the desired part of the waveform at the center of the screen and decrease frequency span to increase the display resolution. As frequency span is decreased, the number of points shown is reduced, and the display is magnified.

FFT Measurement Hints – Continued

While the FFT spectrum is displayed, use the and Cursor keys to switch between measurement functions and frequency domain controls in FFT menu. See the end of the manual for display menus.

Decreasing the effective sampling rate by **selecting a slower sweep speed will increase the low frequency resolution** of the FFT display and also **increase the chance that an alias** will be displayed. The resolution of the FFT is one-half of the effective sample rate divided by the number of points in the FFT. The actual resolution of the display will not be this fine as the shape of the window will be the actual limiting factor in the FFT's ability to resolve two closely spaced frequencies. A good way to test the ability of the FFT to resolve two closely spaced frequencies is to examine the sidebands of an amplitude modulated sine wave. For example, at 2 MSa/sec effective sampling rate, a 1 MHz AM signal can be resolved to 2 kHz. Increasing the effective sampling rate to 4 MSa/sec reduces the resolution to 5 kHz.

For the best vertical accuracy on peak measurements:

- Make sure the source impedance and probe attenuation is set correctly. The impedance and probe attenuation are set from the Channel menu if the operand is a channel.
- Set the source sensitivity so that the input signal is near full screen, but not clipped.
- Use the flattop window.
- Set the FFT sensitivity to a sensitive range, such as 2 dB/division.

For best frequency accuracy on peaks:

- Use the Hanning window.
- Use cursors to place f1 cursor on the frequency of interest.
- Press **Move f1 to Center** softkey.
- Adjust frequency span for better cursor placement.
- Return to the Cursors menu to fine tune the f1 cursor.

For more information on the use of window please refer to Agilent Application Note 243, "The Fundamentals of Signal Analysis" Chapter III, Section 5 (Agilent part number 5952-8898.) Additional information can be obtained from "Spectrum and Network Measurements" by Robert A Witte, in Chapter 4 (Agilent part number 5960-5718.)

Operating Characteristics

Operating Characteristics are specified with the Measurement/Storage Module installed on an Agilent 54600-Series Oscilloscope.

Measurements

Voltage	Vamp, Vavg, Vrms, Vpp, Vpre, Vovr, Vtop, Vbase, Vmin & Vmax
Time	Delay, Duty Cycle, Frequency, Period, Phase Angle, Rise Time, Fall Time, +Width, & -Width
Thresholds	User-selectable among, 10%/90%, 20%/80% or voltage levels
Cursor Readout	Voltage, time, percentage, and phase angle.
Waveform Math Functions	Addition, subtraction, multiplication, differentiation, integration, and FFT.

Fast Fourier Transforms

Test Region	Each pixel is selectable to be tested or not.
Inputs	On either ch1, ch2, or F1
Freq Cursor Resolution	From 1.22 mHz (milliHz) to 9.766 MHz (1.22 mHz to 48.828 MHz for 54615/54616)
Points	Fixed at 1024 for all models except 54615/54616 Fixed at 1024 for 54615/54616 with vectors off Fixed at 512 for 54615/54616 with vectors on
Peak Find:	Find Peak automatically snaps cursor to the two largest peaks located anywhere in the displayed frequency span. Measurement information is automatically displayed at the bottom of the screen together with the difference in frequency between the two selected peaks.
Variable Sensitivity and Offset	Sensitivity and vertical offset (position) are controlled from the front panel to display an optimum view of the spectrum. Sensitivity is calibrated in dB per divisions; vertical offset is calibrated in dBV.
Time Record Length	10x main sweep speed.
Horizontal Magnification and Center Frequency Control	As the frequency span is changed, the display is magnified about center frequency so that you get a closer view.

Reference Information

Operating Characteristics

Selectable Windows Four windows are selectable: **Hanning**, for best frequency resolution and general purpose use; **flattop**, for best amplitude accuracy; **rectangular**, for single-shot signals such as transients and signals where there are an integral number of cycles in the time record, and exponential for best transient analysis.

Window Characteristics

Window	Highest Side Lobe (dB)	3dB Bandwidth(b ins)	6dB Bandwidth(b ins)	Scallop Loss (dB)
Rectangular	-13	0.89	1.21	3.92
Hanning	-32	1.44	2.00	1.42
Flattop	-70	3.38	4.17	0.005

FFT Freq Range dc to 100 MHz (54600/54601/54645)
 dc to 150 MHz (54602)
 dc to 60 MHz (54603)
 dc to 500 MHz (54610/54615/54616)

Freq Span Control This control allows you to specify the frequency span of the FFT display. When the Span is adjusted the display will expand or contract about the center frequency as set by the Center Frequency control. Refer to Figure 3-1 for the limits of the Frequency Span control.

Center Freq Control This control allows you to specify the frequency at the center of the FFT display. When the Frequency Span is changed, the FFT display will expand or contract about the frequency at the center of the display. Refer to Figure 3-1 for the limits of this control.

Move 0 Hz to Left Pressing this soft key will move the FFT display so that the left hand edge of the display will be 0Hz.

FFT Vector display **When the time domain display is turned off the FFT display will be displayed in vector drawing mode.** The time domain display can be turned off by pressing the Channel # key twice

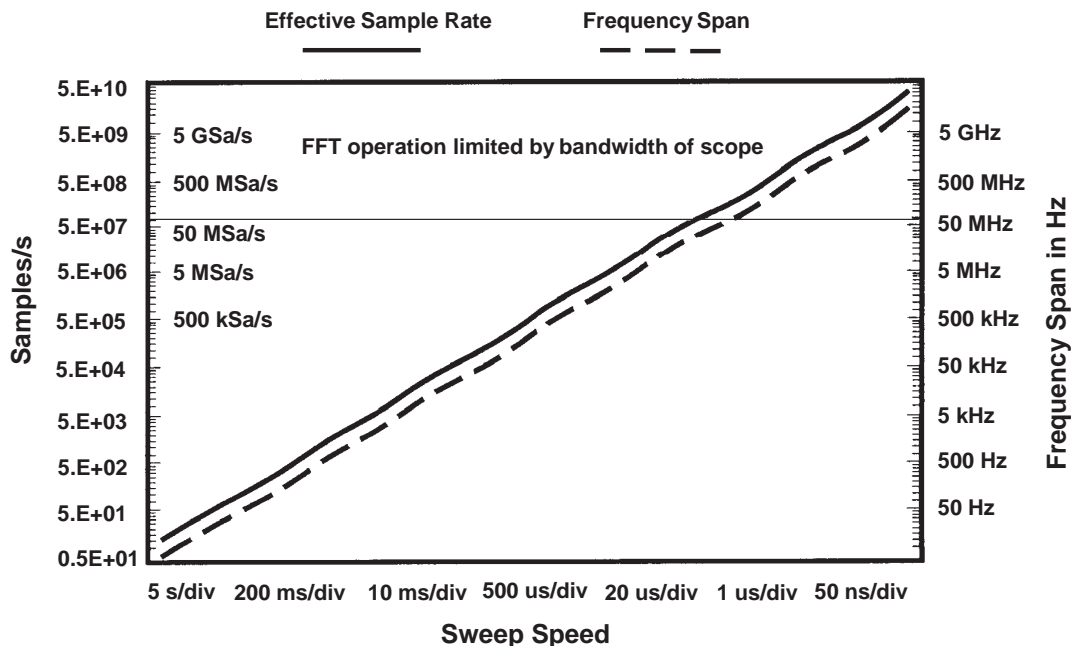
Display FFT vertical units in dB.

Units/Div This control allows you to adjust the vertical scaling of the FFT display in a 1-2-5 sequence from 1 dB/div to 50 dB/div.

Reference Level This control allows adjustment of the reference level of the FFT display across a range of 400 dBV. The minimum setting is -196 dB at 1 dBV/div decreasing to 0 dBV at 50 dBV/div. The maximum setting is 400 dBV at 50 dB/div, decreasing to 204 dB at 1 dBV/div.

Programmability All front-panel controls are fully programmable over **GPIB (54657A)** or RS-232 (54658A and 54659B)

Figure 3-1



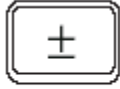
Sweep Speed	Effective Sample Rate	Maximum Frequency Span	Sweep Speed	Effective Sample Rate	Maximum Frequency Span
5 s/div	20 Hz	9.75 Hz	50 μ s/div	2 MHz	975k kHz
2 s/div	50 Hz	24.4 Hz	20 μ s/div	5 MHz	2.44 MHz
1 s/div	100 Hz	48.85 Hz	10 μ s/div	10 MHz	4.885 MHz
500 ms/div	200 Hz	97.5 Hz	5 μ s/div	20 MHz	9.75 MHz
200 ms/div	500 Hz	244 Hz	2 μ s/div	50 MHz	24.4 MHz
100 ms/div	1 kHz	488.5 Hz	1 μ s/div	100 MHz	48.85 MHz
50 ms/div	2 kHz	975 Hz	500 ns/div	200 MHz	97.5 MHz
20 ms/div	5 kHz	2.44 kHz	200 ns/div	500 MHz	244 MHz
10 ms/div	10 kHz	4.885 kHz	100 ns/div	1 GHz	488.5 MHz
5 ms/div	20 kHz	9.75k Hz	50 ns/div	2 GHz	975 MHz
2 ms/div	50 kHz	24.4 kHz	20 ns/div	5 GHz	2.44 GHz
1 ms/div	100 kHz	48.85 kHz	10 ns/div	10 GHz	4.885 GHz
500 μ s/div	200 kHz	97.5 kHz	5 ns/div	20 GHz	9.75 GHz
200 μ s/div	500 kHz	244 kHz	2 ns/div*	50 GHz	24.41 GHz
100 μ s/div	1 MHz	488.5 kHz			

* 2 ns/div FFT valid only on 54615/54616

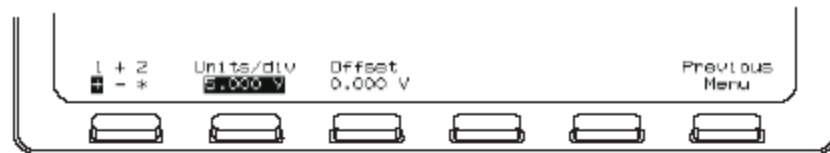
**FFT Operation
Frequency Span and Effective Sampling Rate vs Sweep Speed**

Press this key ...

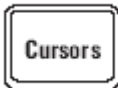
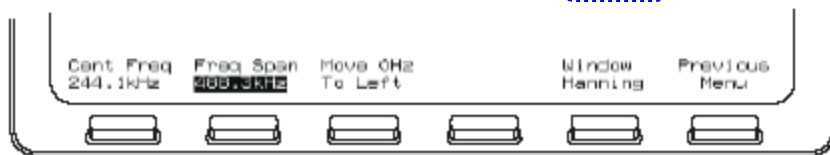
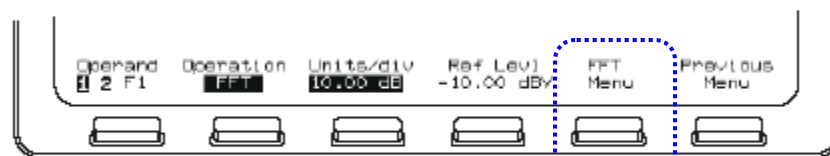
... to obtain this menu



Function 1 Menu



Function 2 Menu



Source

