# Setting Up an FFT

TECHNICAL BRIEF

*May 22, 2013*


## Summary

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## Introduction

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Teledyne LeCroy offers the most flexible FFT available in any oscilloscope. The user has the choice of least prime factor or power of 2 FFT, a selection of 5 weighting windows, true frequency domain averaging of both real and imaginary components and, the ability to truncate or zero-fill the source data. All of these are in addition to a computationally efficient floating point FFT, which maximizes amplitude dynamic range.

In addition to the classical FFT controls, which we will discuss in this note, Teledyne LeCroy offers and optional Spectrum analyzer feature. Like the RF spectrum analyzer it offers the users controls for span, center frequency, resolution bandwidth, and reference level.

In the traditional setup the FFT span (Nyquist frequency) is related to the sampling rate, and the resolution bandwidth (Δf) is inversely proportional to the record length. Below, we will explain how to use these settings to control the FFT. These basic relationships for the FFT are illustrated in Figures 1 and 2.

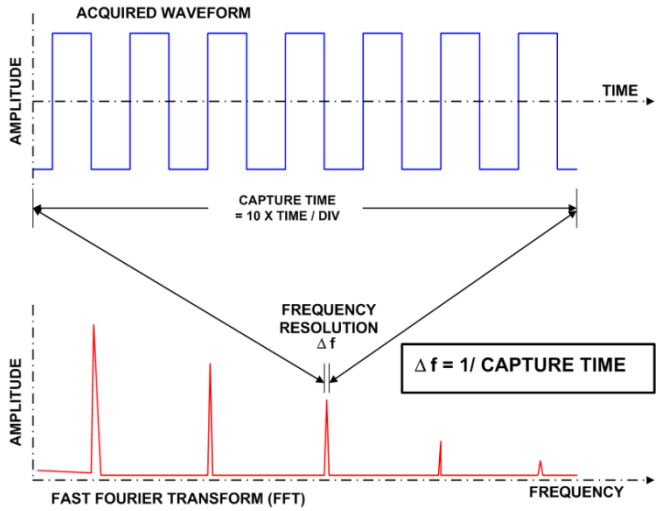


***Figure 1: Capture time determines the frequency resolution, Δf***

A logical approach to setting up an FFT starts at setting the frequency resolution, Δf. This parameter is the spacing of samples in the frequency domain display and is similar to the resolution band-width setting in an RF spectrum analyzer.

The Δf is set by the time duration of the time domain signal being input to the FFT. If an acquisition channel (channel 1 - 4) is the source, the waveform duration is the capture time, which is ten times the TIME/DIV setting. The relationship between capture time and frequency resolution is illustrated in Figure 2.

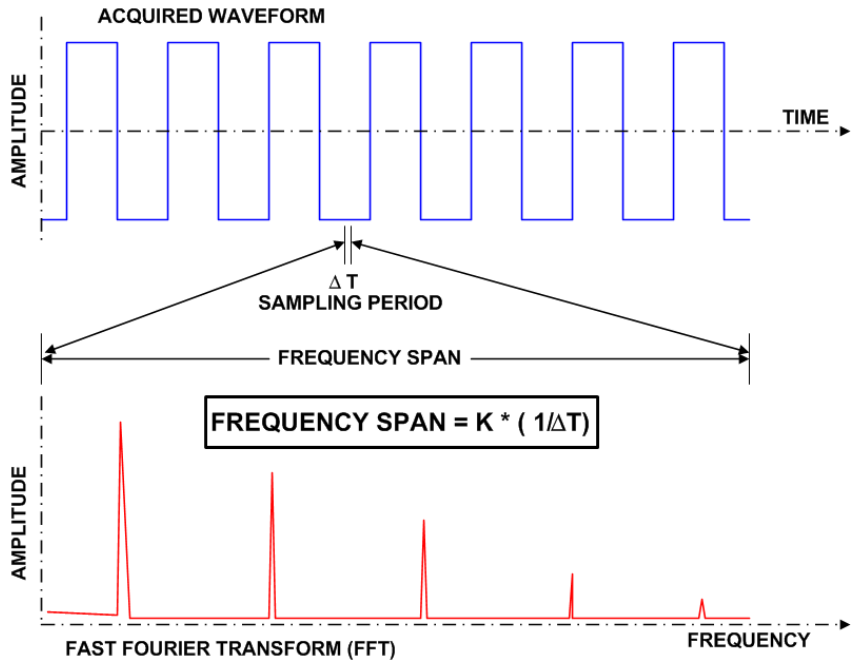


***Figure 2: The Span of the FFT is related to the sampling rate, 1/ΔT***

If the source waveform is a zoom trace, then the frequency resolution is, similarly, the reciprocal of the displayed zoom waveform's duration.

The frequency span of the FFT is called the Nyquist frequency and is one half of the effective sampling frequency of the time domain waveform. Teledyne LeCroy oscilloscopes will generally default to the highest sampling rate and therefore the longest span. In Figure 3, the sampling rate is 2 GS/s. The FFT setup in trace F1 shows a span of 1 GHz (100 MHz / division times ten divisions).


***Figure 3: Setting up the resolution bandwidth and span of the FFT in a Teledyne LeCroy HDO 6000 series scope***

If you want to decrease the span the easiest way is to use zoom. This is illustrated in figure 3, where trace F2 is a zoom expansion of the FFT in trace F1. The zoom trace has a horizontal scaling of 200 kHz/division and it is centered about a spectral peak at 248 MHz. The resolution bandwidth, set by the capture time of 1 ms, is 1 kHz and remains constant regardless of the use of zoom to expand the FFT trace.

The span can also be reduced by using less acquisition memory or by using the math sparsing function. Both of these actions lower the effective sampling rate.

Let's take a look at some of the other features of the Teledyne LeCroy FFT capabilities:

Like most FFT's, a selection of several weighting Window functions is available. If you think of the FFT as synthesizing a bank of parallel band-pass filters, then the weighting windows control the shape of the filter frequency response as shown in Figure 5. They effectively multiply the resolution bandwidth by a fixed factor, called the effective noise band-width (ENBW). Weighting functions help reduce the effects caused by performing FFT's on finite length records. They control sidelobe amplitudes and minimize scallop or 'picket fence' effect. All of these characteristics are summarized in Figure 4.

| Window Type | Highest Side Lobe (dB) | Scallop Loss (dB) | ENBW (bins) | Coherent Gain (dB) |
|---|---|---|---|---|
| Rectangular | -13 | 3.92 | 1.0 | 0.0 |
| Von Hann | -32 | 1.42 | 1.5 | -6.02 |
| Hamming | -43 | 1.78 | 1.37 | -5.35 |
| Flat Top | -44 | 0.01 | 3.46 | -11.05 |
| Blackman-Harris | -67 | 1.13 | 1.71 | -7.53 |

***Figure 4: A table of available weighting function characteristics***

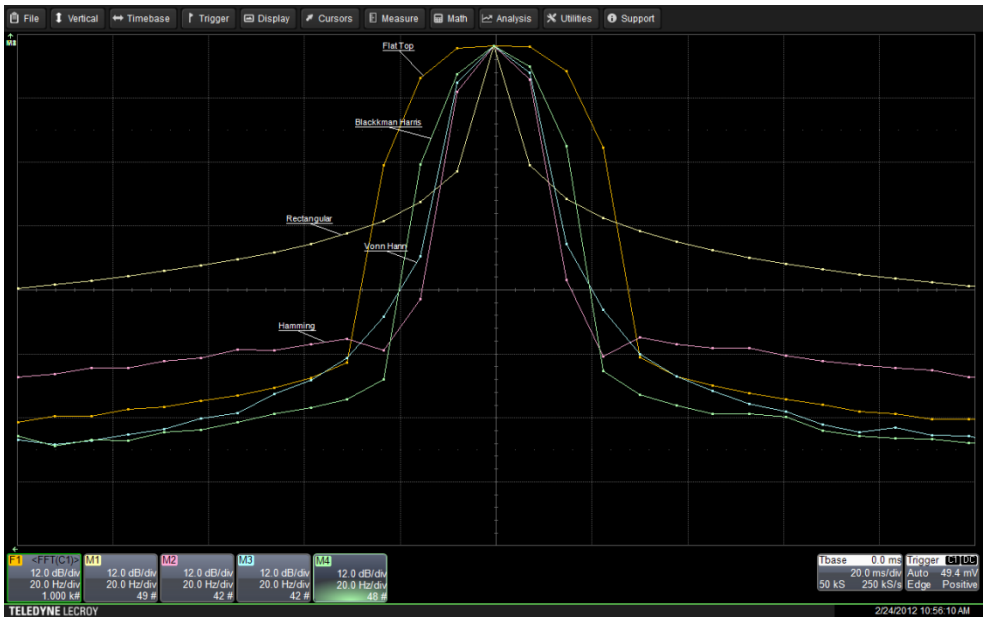


***Figure 5: The spectral "shapes" of each of the weighting functions***

Figure 6 shows the FFT setup dialog box. The Suppress DC checkbox allows the user to exclude the DC point (0 Hz) from the FFT display. This is useful if the data has a large DC offset.


***Figure 6: The FFT setup dialog box***

A feature, unique to Teledyne LeCroy oscilloscopes is the choice of FFT algorithms. The default algorithm choice is a power of two algorithm where the record lengths are in the form of $2^N$ . The power of 2 algorithm generally runs faster than the least primes algorithm. The price that is paid is a record length which is not the same as the acquired signal. The power of two FFT uses the first $2^N$ points of the record. If you acquire 500 points in your trace the power-of-two FFT would only use the first 256 points.

The other algorithm is a least primes algorithm that computes FFT's on transform sizes that have lengths that can be expressed as factors of $2^N$*5K. This is very compatible with the record lengths encountered in the oscilloscope, which are often multiples of 1, 2, 4, 5, or 10.

The last feature is the user-selected choice of how to handle FFT transform sizes that don't match the record length. Users can select to truncate the record and perform an FFT on the shorter record. This will increase the resolution bandwidth. Alternatively, the user can select zero-fill. Zero-fill is useful when the source data for the FFT comes from a math operation that shortens the record. This is commonly encountered in filtering operations like enhanced resolution. The missing data points are replaced by added data values, whose amplitudes are interpolated to fit between the last data point and the first data point in the record. This guarantees that there is not a first order discontinuity in the filled data. Since the data at the end of the record is 'filled' data, it is advisable to select a weighting window other than rectangular to minimize the effect of the fill on the resulting spectrum.

In Figure 1 note that the second math operation for trace F1 is averaging. If the FFT is the source for the averaging operation then frequency domain averaging is used. This averaging mode is synchronous with the FFT processing and not the oscilloscope trigger. Frequency domain averaging increases the dynamic range of the FFT. It is possible to obtain 72 dB dynamic range with an 8 bit scope and more with a 12 bit scope.

In summary, you should recognize that the FFT as implemented in Teledyne LeCroy oscilloscopes offers flexibility and control not equaled in the oscilloscope market today.