Summary

Random noise arises from every electronic component used in your circuits. The analysis of random electrical noise requires tools which operate in the time, frequency, and statistical domains. Your LeCroy oscilloscope has the required capabilities to characterize random noise. This application brief will demonstrate these capabilities.

The Tools

Random processes are difficult to characterize because no individual measurement provides any information about the previous or next measurement. It is only by looking at cumulative measurements that you can learn about the process you are investigating. Figure 1 shows the basic tools for measuring random processes like noise. The top trace in Figure 1 is an amplitude time plot of the input on channel 2. The next lower trace is a power spectral density plot showing the frequency distribution of noise power. The next trace is a histogram of the individual noise voltage measurements. The histogram shows the distribution of the amplitude values of the individual measurements. The bottom trace is a trend of the standard deviation of each of 1000 acquisitions on channel 2. Trend functions show variations in measured values over multiple measurements. These analysis functions, combined with measurement parameters, offer a complete tool set for noise measurements.

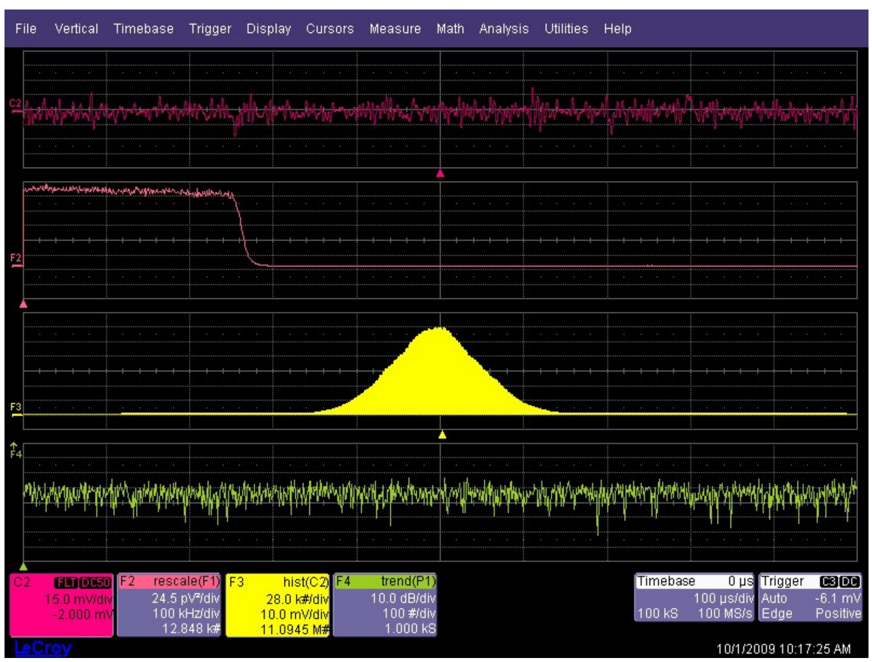

Figure 1: *The basic tools of noise analysis from top to bottom - time history, power spectral density, histogram, and measurement trend*

Time Domain Measurements

Let's start with the most basic measurement. In Figure 2 we have a time measurement of a bandlimited noise waveform. We can gain some insight into the characteristics of the noise signal by using measurement parameters. The most meaningful parameters are the mean value of the waveform, the standard deviation, and the peak to peak value. Of these measurements the standard deviation, which can also be described as the AC RMS value, is probably the most useful as it describes the effective value of the waveform. Parameter statistics show the mean, maximum, minimum, standard deviation, and number of measurements included in the statistics. The small histograms under the parameter readouts are called histicons and show the distribution of the measured values of the associated parameter.

Figure 2: *Basic time domain measurement using the mean, standard deviation (RMS), and peak to peak values of a time domain noise waveform*

Histograms

For noise, which has a Gaussian distribution, the mean and standard deviation are all that are needed to describe the probability density function (pdf) of the noise. Histograms provide a simple way of seeing the distribution of the measured values regardless of your knowledge of the distribution. In Figure 3 we show a histogram of the acquired sample values. The histogram is a plot of the number of measured values within a narrow range of values called bins plotted against the measured values. The histogram provides the user with an estimate of the probability density function of the process being measured. This data can be interpreted by using histogram parameters. In Figure 3 we show three histogram parameters, hmean, hsdev, and range. These are the mean, standard deviation, and range of the histogram distribution. Histograms can be computed on single acquisitions as shown here or over multiple acquisitions. In either case they provide a great deal of insight into the nature of the process being studied. In this example the distribution is quasi-Gaussian indicating the source as being a random process.

In Figure 4 we see a slightly different histogram. The width of the distribution has increased and there are now two major peaks. This was caused by the introduction of a small sinusoidal component to the original random noise. The distribution of a sine wave has two peaks and mixing the two waveforms convolves the distribution of the component waveforms. By observing the shape of the

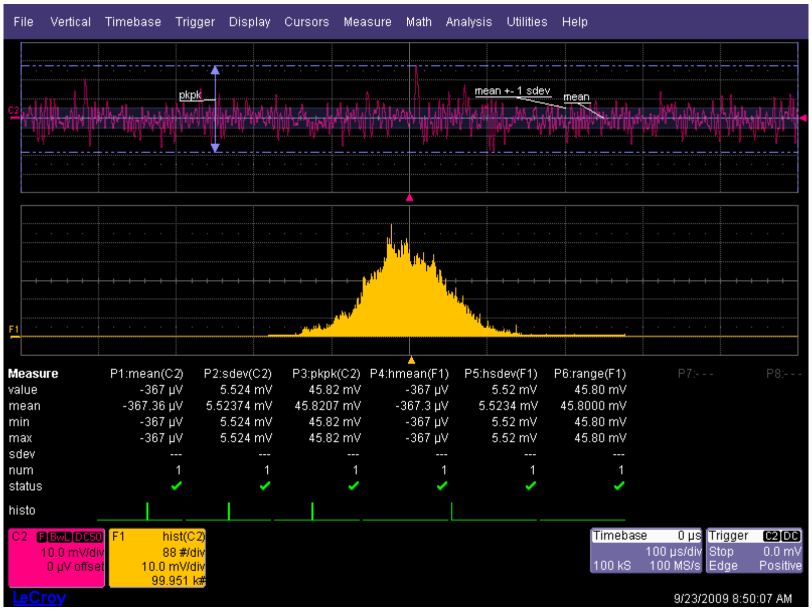

Figure 3: *Using the histogram of the acquired data allows you to view the distribution of sample values and estimate the probability density of the process being measured.*

distribution you can often gain understanding of what is happening in the process being studied. It is a good practice to look at the noise distribution before beginning any measurement.

Power Spectral Density Measurements

The frequency domain description of noise is more commonly used. The most common measurement in the frequency domain is the power spectral density. Power spectral density is usually measured in units of V^2/Hz and represents the power per unit bandwidth. In Figure 5, trace F2 is the averaged FFT of channel 2 (1000 acquisitions). Although the oscilloscope offers power spectral density as an FFT output type, it uses a logarithmic decibel scale. Instead, we have chosen the magnitude squared output type. The units here are V^2. The FFT setup is shown in Figure 6. In addition to the output type, we have chosen rectangular weighting and Least Prime Factor FFT. Note that the FFT setup reports the resolution bandwidth, 1.02 kHz in this case, as well as the effective noise bandwidth (ENBW) of the weighting function which is 1.000 for rectangular weighting.

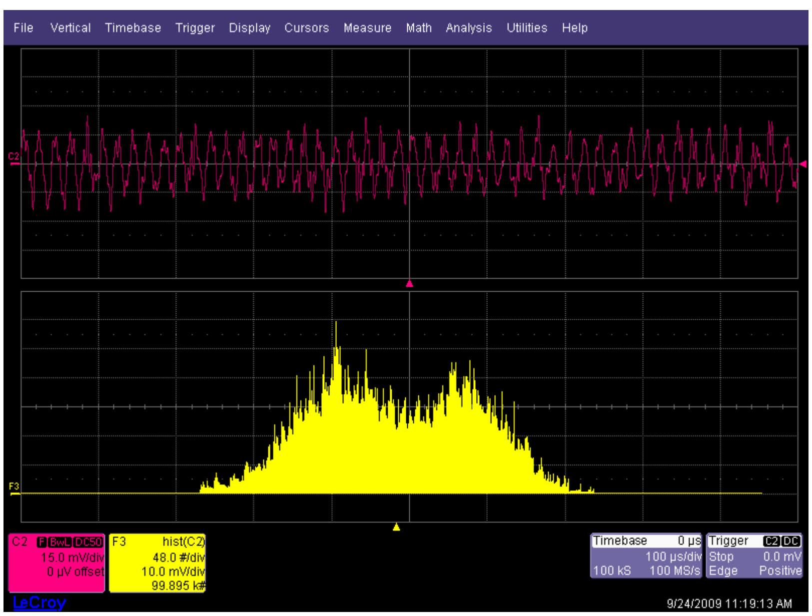

Figure 4: *The histogram of a sine contaminated noise source shows two major peaks compared to the single peak in Figure 3*

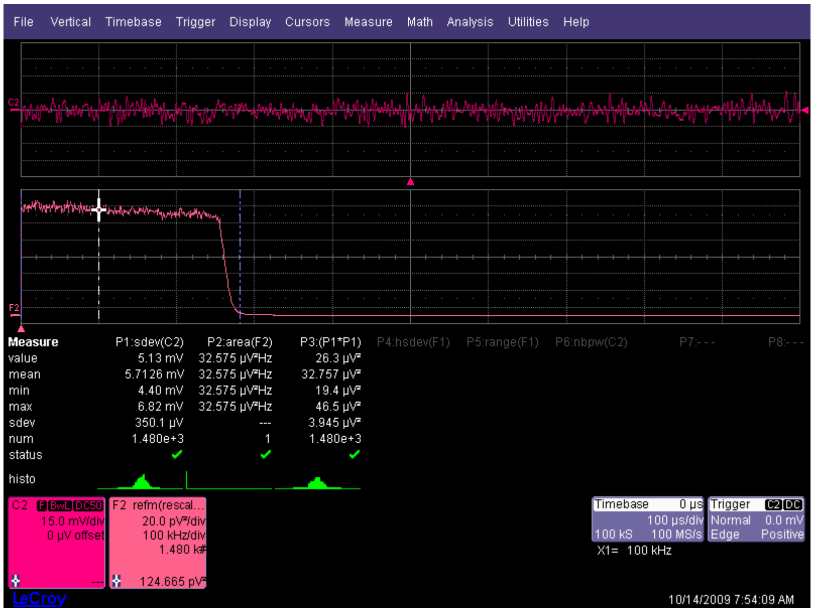

Figure 5: *Trace F2 is the averaged spectrum of the input channel (C2) normalized to read* V^2*/Hz*

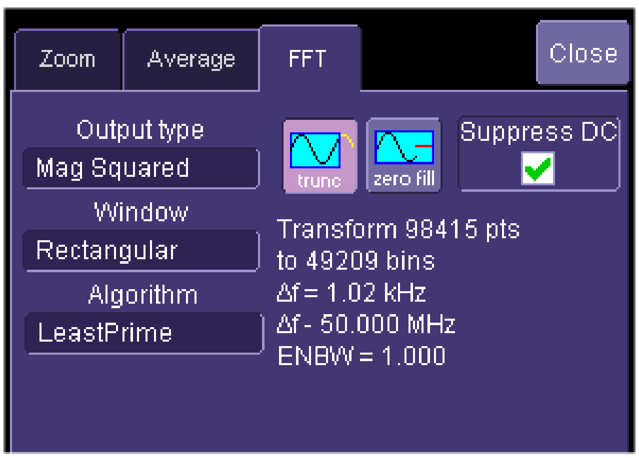

Figure 6: *The setup of the FFT.*

The averaged FFT output has to be normalized to the effective FFT bandwidth. In addition, there is one other scaling issue that has to be addressed. In LeCroy oscilloscopes the FFT outputs are calibrated to read peak values rather than RMS values. To convert back to RMS values, FFT magnitude values have to be multiplied by 0.707 and magnitude squared values are multiplied by 0.5. We also divide the FFT values by the effective bandwidth of the FFT in order to normalize the values to a unit bandwidth (1 Hz). This is done with the rescale function shown in Figure 7. The rescale function allows users to rescale by a multiplicative factor and add or subtract offset. In our case, we multiplied by 0.5/1020=490 E-6. The factor 0.5 was discussed previously. The other factor is the reciprocal of the effective FFT bandwidth, which is the Δf multiplied by ENBW shown in Figure 6. If a weighting function other than rectangular had been selected ENBW would be a higher value than 1.

Note that we have applied the reframe math function in order to optimize the mapping of the floating point FFT output into the integer math space used in parameter measurements.

After rescaling, the vertical units of the FFT in F2 are V^2/Hz. We can confirm the correctness of the rescaling by integrating the area under the FFT trace. In Figure 5 this was done using the Area parameter gated to the noise bandwidth of the filter used to bandlimit the noise source, in this case 280 kHz. The area under F2 is the mean squared value, 32.575 E-6 V^2. This can be compared to the mean squared value (variance) of the waveform in C2 of 32.757 E-6 V^2 computed in parameter P3.

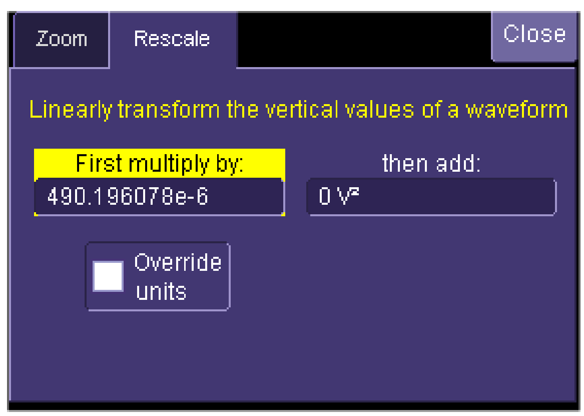

Figure 7: *The Rescale setup for normalizing the FFT output to unit (1 Hz) bandwidth*

The agreement between the time domain and frequency domain measurement is extremely good. The difference can be further reduced by integrating the area out to Nyquist (50 MHz in this case). This assumes that the noise contribution of the scope is negligible relative to the contribution from the input signal.

***Figure 8:** Use of trend functions and parameter math*

Cursor readings made on trace F2 can read the spot power spectral density directly as shown in Figure 5. The cursor is set to 100 kHz and reads 124.665 pV^2/Hz.

Trend Functions

The parameter statistics include minimum and maximum values. If you want to see the variation in a parameter value on an acquisition by acquisition basis you can use the trend function. The trend plots the value of each measurement versus a sequential event number. Examples are shown in Figure 8 where function trace F4 is a trend of parameters P1. P1 is the standard deviation of channel C2. The standard deviation parameter produces 1 value per acquisition and trace F4 shows each of those readings in the order they were measured. Trend plots can be treated like any other waveform function. You can use any of the math or measurement tools to analyze them.

Derived Parameters

Another noise parameter of interest is the crest factor. This is the ratio of the peak to the RMS value of a waveform. This parameter is of value in determining the dynamic range required to handle the peak variations in a signal. Although the scope has no bipolar 'peak' parameter, we can easily create one by taking the absolute value of the signal in channel 2. This will "'flip' the negative values into the positive region of the waveform and allow us to use the maximum value parameter (max) to read the maximum positive or negative peak of each acquisition. Note that this works because the signal has a zero means. We can then use parameter math to compute crest factor as the ratio of peak to RMS value. The parameter math setup for this is shown in Figure 9, where we compute the crest factor as the ratio of P3 to P1 as parameter P4. The crest factor readings are shown in Figure 8 with an average value of 4.3.

In Figure 8 trace F1 shows the histogram of P4 (crest factor). Observe that the distribution of the crest factor measurements is not Gaussian. This is caused by the non-linear processes associated with the absolute and maximum math functions.

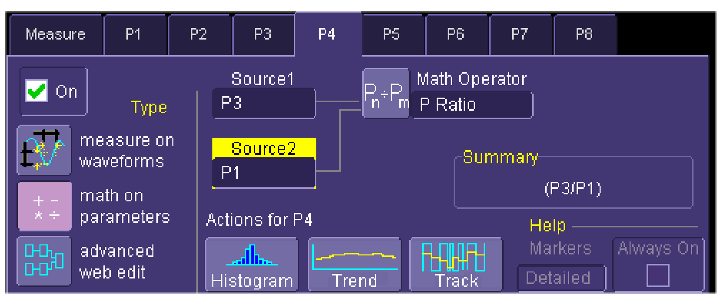

***Figure 9:** The dialog box for setting up parameter math.*

Spot noise measurements using nbpw

Another approach to making ‘spot’ measurements of noise is to adapt the optional narrow band power measurement. Narrow band power (nbpw) measures the power at a given frequency by computing the discrete Fourier Transform at that one frequency. The output units of nbpw are dBm. Not too handy for measuring noise, where we would like the measurement to be of noise power spectral density in linear units of V^2/Hz. Luckily, LeCroy oscilloscopes have the ability to apply a script using math on parameters to modify the measurement. This allows for more complex computation than the simple ratio of parameters we used for computing crest factor in Figure 9.

The result of such a measurement is shown in Figure 10.

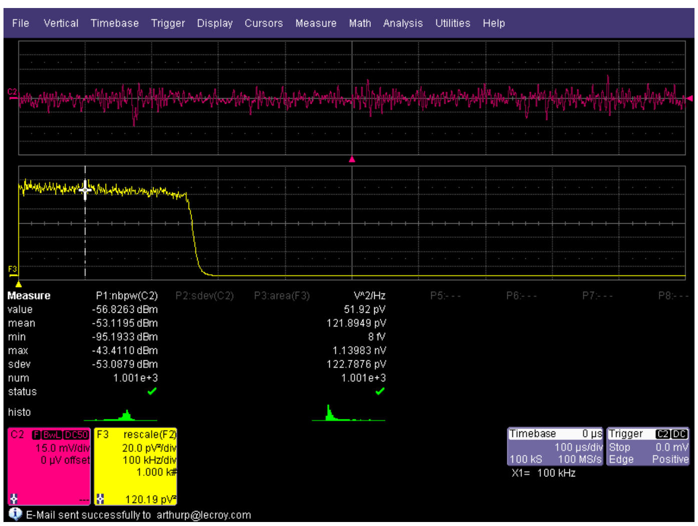

Figure 10: *Modifying the scaling of the narrow band power measurement to read out in power spectral density in units of V^2/Hz*

Parameter P4, relabeled V^2/Hz, is the power spectral density at 100 kHz.

It is based on re-scaling the nbpw measurement in parameter P1. The mean of P4 based on 1000 measurements can be compared with the equivalent measurement based on the averaged FFT being read using the horizontal absolute cursor in function trace F3. The numbers are comparable within the accuracy limits of the instrument.

Figure 11 shows the measurement dialog box used for setting up a parameter script to rescale parameter P1. The math script can be either written in Visual Basic or Java script.

Figure 11: *The measurement dialog box for setting up a parameter script to scale parameter P1 to V^2/Hz*

Figure 12 contains the Visual Basic Script used to rescale the nbpw parameter.

```
Function Update() 'VBS code
        ' TODO: Place your custom parameter math code here
        ' This example converts narrow band power from dBm to V^2/Hz
Set app=CreateObject("LeCroy.XSTreamDSO")
        'computing the resolution bandwidth
        ctime = app.Acquisition.Horizontal.HorScale * 10
        if ctime  > (960*(1/app.Measure.P1.Operator.Frequency)) then
        deltaf = 0.00105*app.Measure.P1.Operator.Frequency
        else
        deltaf                                                            =
app.Measure.P1.Operator.Frequency/(cint(ctime/(1/app.Measure.P1.Operator.Frequency)))
        end if

        OutResult.Value = (0.05*(10^(InResult1.Value/10)))/(deltaf*2) ' convert dBm to V^2
        OutResult.VerticalUnits = "V^2/Hz" 'set the custom units
        OutResult.VerticalResolution=0.00000000000001 'set out result resolution
        app.Measure.P4.Alias="V^2/Hz" 'Show parameter name as unit
End Function
```

Figure 12: *The Visual Basic script used to rescale nbpw from dBm to V^2/Hz*

The script takes the individual reading of the nbpw measurement, converts from a logarithmic to a linear scale (V^2), reads the acquisition record length, then computes the effective resolution bandwidth of the FFT and then scales to data by that value, producing the power spectral density in V^2/Hz.

LeCroy oscilloscopes have all the tools necessary to make noise measurements in the time, frequency, or statistical domain. They offer tremendous flexibility and power for those who are familiar with this type of measurement.