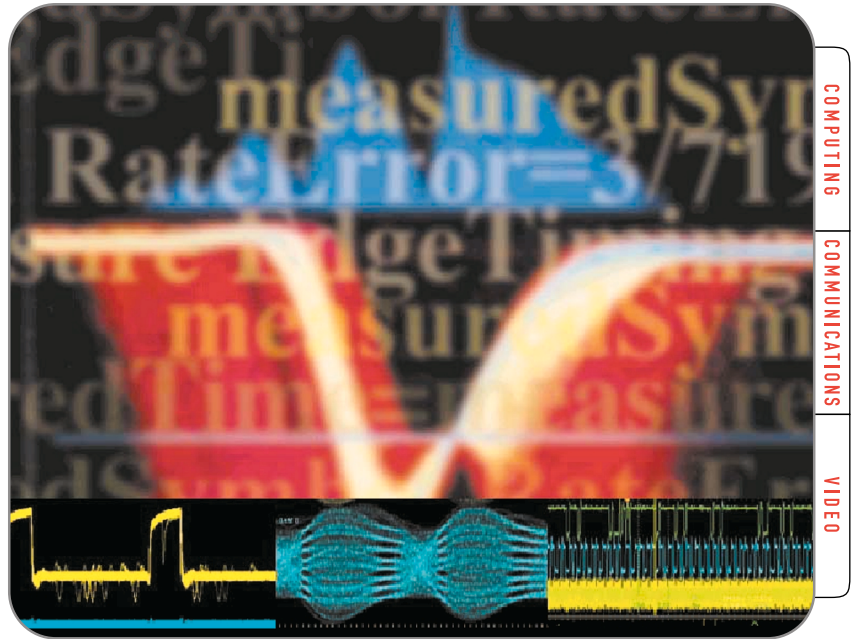


Analyzing Clock Jitter Using Excel



▶ Easy data connectivity using the TDS 7000 Series.

Characterizing jitter, whether in the 100 picoseconds (ps) or 100 microseconds (μ s) range, can be a time consuming effort requiring detailed analysis of waveform data. Automating this analysis can result in increased accuracy, improved efficiency and significantly improve test repeatability as compared to a manual process.

The TDS7000 Series digital phosphor oscilloscopes, with open Windows®, offers the unique advantage of enabling industry-standard analysis and database applications, such as Excel, Mathcad® and MATLAB®, to reside within the instrument itself.¹ The waveform data in the oscilloscope's acquisition memory can be exported, then imported to the analysis application, processed, and displayed—all on the same platform.

This document will describe the process of using the TDS7000 Series digital phosphor oscilloscopes and Excel to capture signal data and then to conduct simple jitter analysis of an NRZ (non-return-to-zero) clock signal. This includes:

- ▶ How to determine the sample resolution for accurate results
- ▶ How to move waveform data from the TDS7000 to Excel
- ▶ How to build a simple jitter analysis worksheet
- ▶ How to use Excel to graph the results

¹ The TDS7000 supports a second Windows monitor output which will greatly enhance the oscilloscope's functionality as an analysis system. The second monitor is not required but enables you to actively use the scope while simultaneously running a separate application on the second monitor.

Analyzing Clock Jitter Using Excel

► Application Note

Overview of Jitter

What is Jitter?

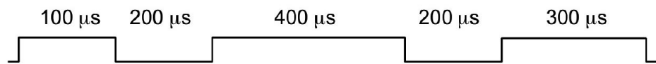
Jitter has two overlapping definitions:

1. The deviation of a signal transition from its ideal position in time, or...
2. The timing variation from transition to transition

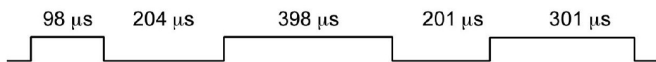
Jitter intervals often fall in the range from tens of ps to a few hundreds of ps. As clock frequencies reach the 1 GHz range, this seemingly small amount of jitter error can become a significant portion of the "timing budget," that is, the time allotted for a series of logical operations. For example, at the standard SONET/SDH bit rate of 2.5 Gbits/sec, one unit interval (one data bit) is only 400 ps. The transmitter and receiver components consume most of this budget. Jitter can make too much of the remaining time unavailable (or at least uncertain) for necessary operations.

Jitter Characteristics

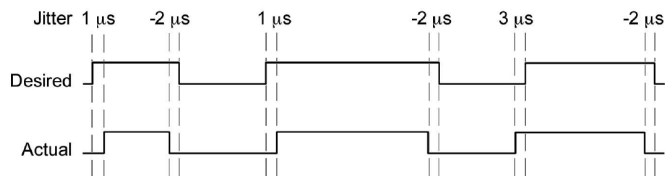
Let's take an illustrated look at jitter. Consider the following waveform:



Every time the waveform goes positive above a specified threshold, the data is a logical one. When the waveform is below the threshold, the data is a logical zero. Now suppose that when this waveform is sent and received, its timing is affected as shown below:

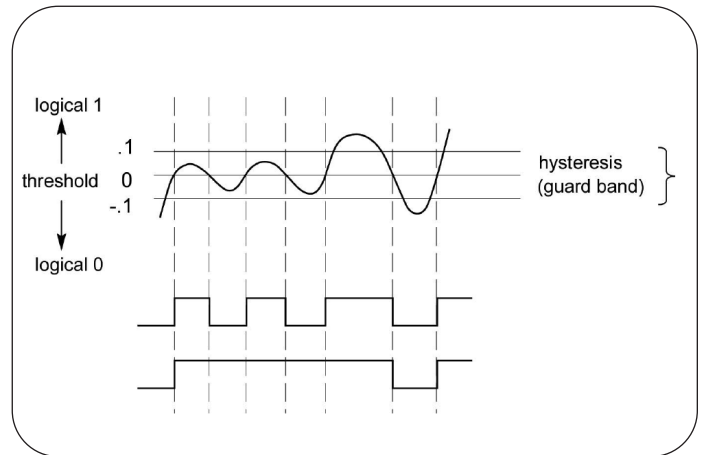


Here the signal transition deviates from its ideal position in time and it varies from transition to transition—the definition of jitter. Where the location of the edges has changed, because of factors such as noise or other error sources, the amount of change is the jitter figure, expressed in microseconds (μs), nanoseconds (ns), or picoseconds (ps) depending on the magnitude of the jitter.



Hysteresis Effects and Guard bands

When detecting and evaluating jitter, threshold crossings and hysteresis must be considered. It is common practice to use a "guard band" (essentially a margin that widens the ideal threshold). Figure 1 shows the threshold to be crossed and the guard band around it. To avoid registering noise as an actual change in logic level, a threshold crossing is not considered a valid transition unless the waveform first goes outside the guard band. Enforcing this rule ensures that only the true edges (bottom trace in Figure 1) are detected.



► **Figure 1:** The threshold and hysteresis in clock jitter analysis

Jitter and Your Design

It's an acknowledged fact in the industry: jitter can affect the stability of any high-speed circuit design. Increasingly, this realization is reflected in standards, specifications and compliance guidelines.

A case in point is the USB 2.0 Specification promulgated by the USB Implementer's Forum. This document exists to ensure interoperability among USB-based products from diverse manufacturers, and, like other standards, is essential to the continued success and health of the platform. Consumers will demand USB 2.0 capability as the amount of readily accessible multimedia content grows in the coming years.

USB 2.0 has a data rate of up to 480 Mbits/sec., which is sufficient to deliver video and other bandwidth-intensive content. It is also fast enough to be susceptible to jitter. Therefore the Compliance Suite for USB 2.0 Certification includes jitter specifications. Any new platform that includes USB 2.0 (an increasing number of consumer and office products) must meet these guidelines in order to qualify for the certification.

The USB 2.0 Specifications are just one example that demonstrates how a few ps of timing inaccuracy can affect not only the technical functionality, but also the market viability of a new product.

Terminology

The clock jitter example will make use of the following terms:

Table 1: Terminology used in the clock jitter problem

Term	Meaning
Symbol Rate	The frequency at which the communication system is sending data. (In RS232 this would be the baud rate.)
Sample Rate	The frequency at which the oscilloscope is sampling data (measured in samples/second).
Sample Interval	The time difference between samples (measured in seconds/sample). The oscilloscope user interface calls this resolution. Mathematically the <i>Sample Interval = 1/ Sample Rate</i> .
Threshold	The voltage used to determine if a voltage value is a logical zero (0) or a logical one (1).
Edge	A place where the waveform crosses the threshold. We are interested in the time when this occurs. Since an edge usually occurs between samples, we must use a technique called linear interpolation to find it accurately.
Hysteresis	Defines a guard band around the threshold that is used to make the algorithm less sensitive to small amounts of noise. For each edge there must be at least one point outside the guard band.

Analyzing Clock Jitter Using Excel

▶ Application Note

The Algorithm

The algorithm we'll use is as follows:

- ▶ Measure the timing of the edges
- ▶ Derive the clocks using the edges and the symbol rate
- ▶ Determine the average measured symbol rate
- ▶ Calculate the error in the average measured symbol rate
- ▶ Reconstruct the timing of the edges using the derived clock and the average measured symbol rate
- ▶ Calculate the jitter from the measured timing of the edges and the reconstructed timing
- ▶ Plot the jitter

Determining the Best Sample Interval

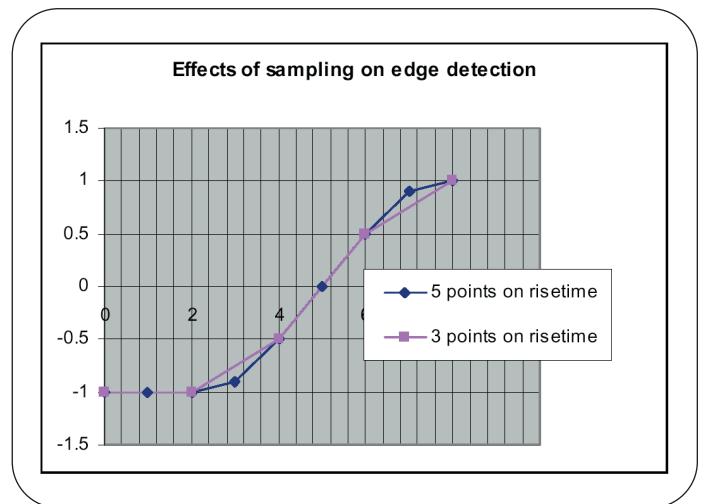
Before acquiring the waveform data, it is necessary to decide on the best sample interval to use. In trying to measure jitter, we must balance two things:

- ▶ Capturing as many edges as possible (or desired)
- ▶ Locating each edge as accurately as possible

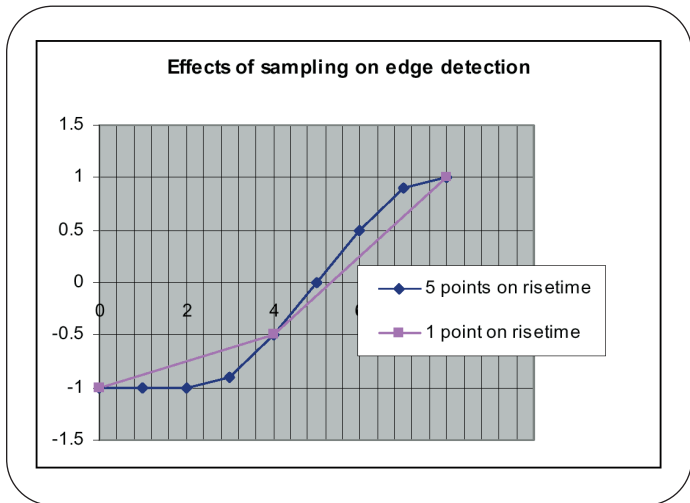
To achieve this, we want to sample the data with enough resolution to locate the edges, but not so much that we begin to limit the number of edges that we can reasonably capture. There are two tradeoffs:

- ▶ Record length versus the time it takes to process the data
- ▶ The number of edges we can capture in a given record length versus the accuracy of finding the edges

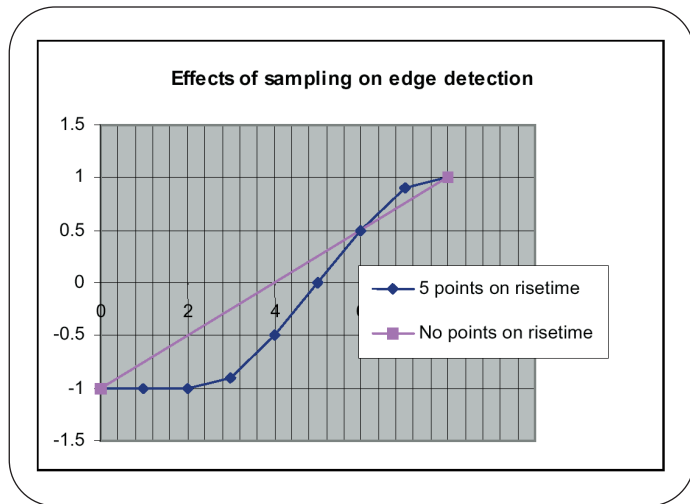
Let's explore this last tradeoff. The following graph shows an edge sampled with both three and five points on the rise time. Both pass through 0 at the horizontal value of 5. So we'll say that the edge occurs at 5.



The next graph shows the situation with five points versus a single point on the rise time. In this case, the line with a single point on the rise time passes through 0 at the horizontal value of 5.3. The data is undersampled and this undersampling has led to an error of 0.3. The result will look like jitter, but it's just an error in our measurement.



The final graph shows the situation with no points on the rise time. In this case, the line with no points on the rise time passes through 0 at a horizontal value of 4. The data is severely undersampled and this problem has led to an error of -1. Again, the result will look like jitter, but it's just an error introduced by undersampling our data in the measurement.



From the above, we can see that a sample interval (horizontal resolution) that gives us between three and five samples on the waveform rise time will allow us to accurately find the edges. Higher resolution will just limit the number of edges in whatever record length we choose.

This first step is critical in assuring that the waveform acquisition and the subsequent analysis yield accurate results, since the error induced by undersampling will be indistinguishable from the jitter present in the signal.

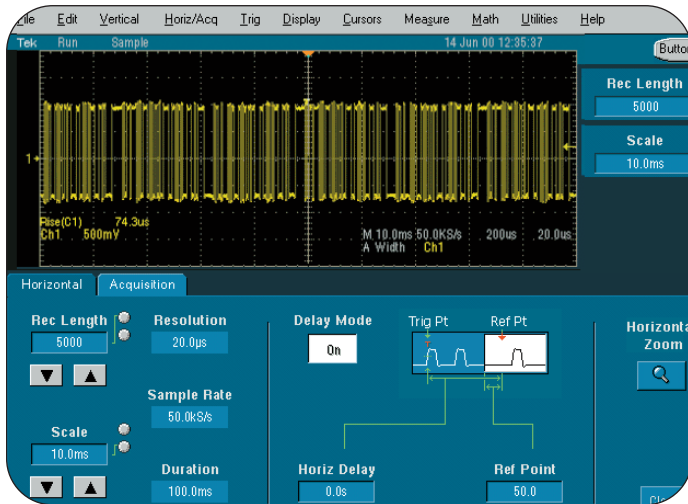
Having determined the sample interval (the sample rate setting to be used for the acquisition), the waveform is captured using normal oscilloscope methodology.

Analyzing Clock Jitter Using Excel

► Application Note

Setting Up the TDS7000

Set up the TDS7000 to capture 5000 point records, with the horizontal resolution set to 20 μ s, channel 1 vertical scale set to 500 mV/div, or a setting that provides multiple divisions of amplitude deflection, as in the example display below (Figure 2).

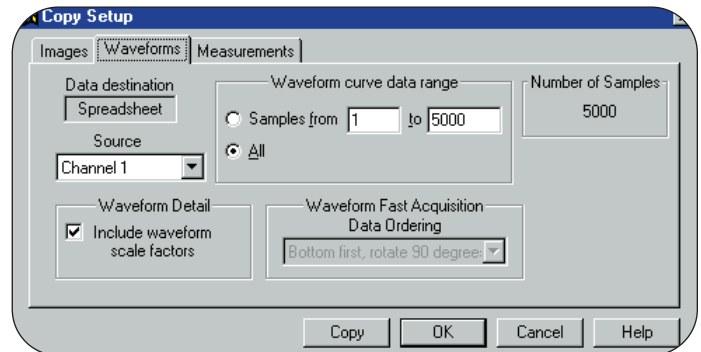


► **Figure 2:** Set up of the TDS7000 to capture waveform data.

For convenience, we'll be working with relatively small waveforms in this example. Actually, Excel itself imposes a practical limitation on waveform size. Since the program has a physical limit of 65,536 rows, it will truncate any waveform record larger than that number.

Copy and Past Waveform Data into Excel

The copy-and-paste method is the most direct method of transferring the waveform data to the spreadsheet. This simple method is available because the TDS7000 Series' open Windows architecture allows the user to run Excel directly on the oscilloscope platform.



► **Figure 3:** Copy Setup dialog box.

Selecting the Copy Setup menu option on the oscilloscope causes the above dialog box (Figure 3) to appear, providing the user with save setup options that quickly enable the transfer of waveform data and all the required instrument setup parameters for entry into the jitter analysis *spreadsheet*.

Note that the Waveform tab has been selected, *Spreadsheet* is the Data Destination, *Channel 1* is the Data Source, *All* waveform curve data range and *include waveform scale factors* have been selected. With the above selections completed, all the user needs to do is simply click the Copy button.

The next step is to start up Excel and open a new, empty spreadsheet, select cell E6 (for this example), and paste (or Ctrl-V) to complete the transfer of the data to the spreadsheet.

In Figure 6, on page 9, Column I is the raw waveform data that you just entered. This column in the sheet has 5,000 data values. Columns E, F, G, and H contain related information supplied with the waveform, where:

- Record Length = 5,000 points (cells in column H)
- Sample Interval = 1/Sample Rate
- = 1/50,000
- = 0.00002 seconds

Column H contains the time when each sample was taken relative to the Trigger Point. Now the input waveform can be graphed using the Chart Wizard (Figure 4).

With the waveform data and related instrument information entered into the spreadsheet we now can begin entering the data variables into the spreadsheet including: Input data, symbol rate, threshold, and hysteresis shown in Figure 6 (column C, rows 4 through 8, titled Input Data).

The next step is to generate the array of measured timing of the edges in the raw input waveform, as in Column K in Figure 6. Excel has no built-in function that can easily be used to find the edges in the input waveform. When this situation occurs, one way to solve the problem is to write a user-defined function using Excel's built-in Visual Basic Editor. The formulas in column K are generated by a user-defined function called Measure Edge Timing in this example, using the built-in VB Editor.

Derive the Clocks Between Edges

There is always *n* number of clocks between each pair of edges. By subtracting the measured edge times between adjacent edges (in column K) and then multiplying that value by the supplied symbol rate (in cell C6), we get a noninteger value of the number of clocks between edges. When we round the number to the nearest integer, we then get a value we store in column L. Column L is the cumulative derived symbol clocks; that is, the cumulative number of clocks since the first edge.

Note: Recall that the *symbol rate* is the frequency at which the communication system is sending data. In RS232 communications, this would be the *baud rate*.

Calculate the Average Measured Symbol Rate

Now we can find the best fit of the measured edges (column K) and the derived clocks (column L) to a straight line. To do this, we'll use linear regression using Excel's SLOPE and INTERCEPT functions. The formula for a straight line is:

$$y = a + bx$$

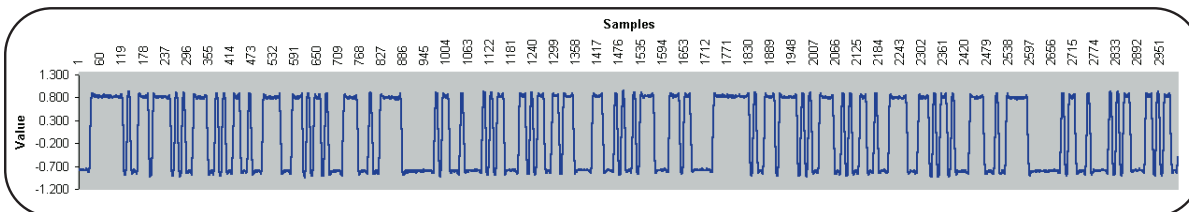
where:

- a* = the intercept (the point where a line will intersect the y-axis)
- b* = the slope (the rate of change along the line)

We want a formula that will give us the reconstructed time of an edge if we know the clock number. So we use:

- y* = the reconstructed time of an edge (to appear in column M)
- x* = the clock number of an edge (column L)

The value of *a* is returned by Excel's INTERCEPT function. The value of *b* is returned by Excel's SLOPE function.



► **Figure 4:** The clock jitter input waveform graphed in Excel

Calculate the Symbol Clock Error Rate

Now that we know the average measured symbol rate, we can calculate the symbol clock error rate, which is the average error in the symbol clock when spread across all the sampled values. We arrive at this result by subtracting the supplied symbol rate from the average measured symbol rate and dividing the difference by the supplied symbol rate.

Calculate the First Edge

The time of the first edge of the reconstructed timing of the edges (which will appear in cell M6) is the intercept of the best-fit line to the y-axis. Use Excel's INTERCEPT function to calculate the first edge.

Reconstruct the Timing

Column M is the reconstructed timing of edges. Here we apply the formula $y = a + bx$. To reconstruct the timing of all the edges (that is, solve for y), we add the previously calculated intercept a (in cell C21) to the slope b (which is $1/\text{cell C18}$), times the derived clocks between edges (in column L, which corresponds to x in the formula).

Calculate the Jitter

Column N is the jitter, calculated by finding the difference in timing between the reconstructed edge timing (in column M) and the measured edge timing (in column K). Then extend the calculation to RMS jitter (in cell C14).

Graph the Solution

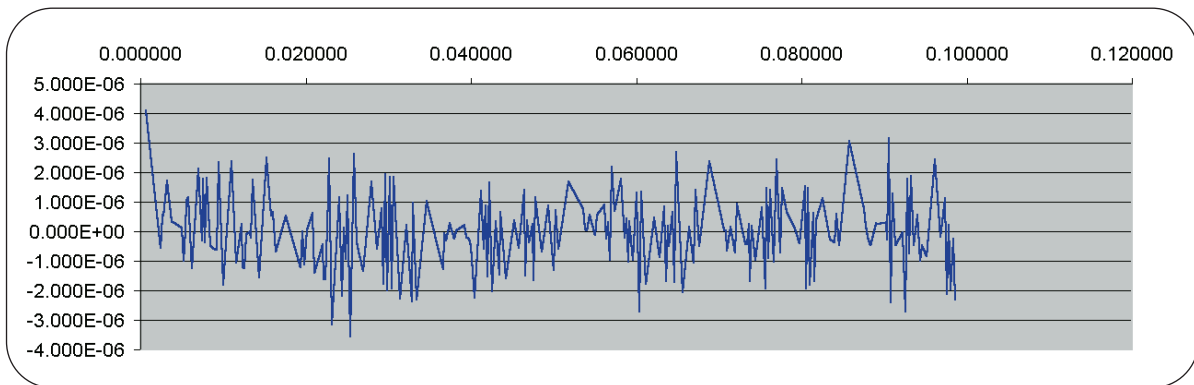
Now you can plot the using the built-in VB Editor, and on the x-axis in a scatter plot against the jitter on the y-axis (Figure 5).

Communicating the Results

Once you have completed the analysis you may need to communicate the results to coworkers, vendors, your management team, or customers. Because the TDS7000 Series offers the unique advantage of enabling Windows-compatible applications, such as Power Point and Word, to run on the oscilloscope platform, this becomes a very simple task.

Any and all data, spreadsheets, screen shots and graphs generated as part of your analysis can be quickly and easily transferred to other windows applications for development of reports or presentations. Those in turn can then be transferred to network drives on your company intranet, printed on network resources, or even sent via email to anywhere in the world.

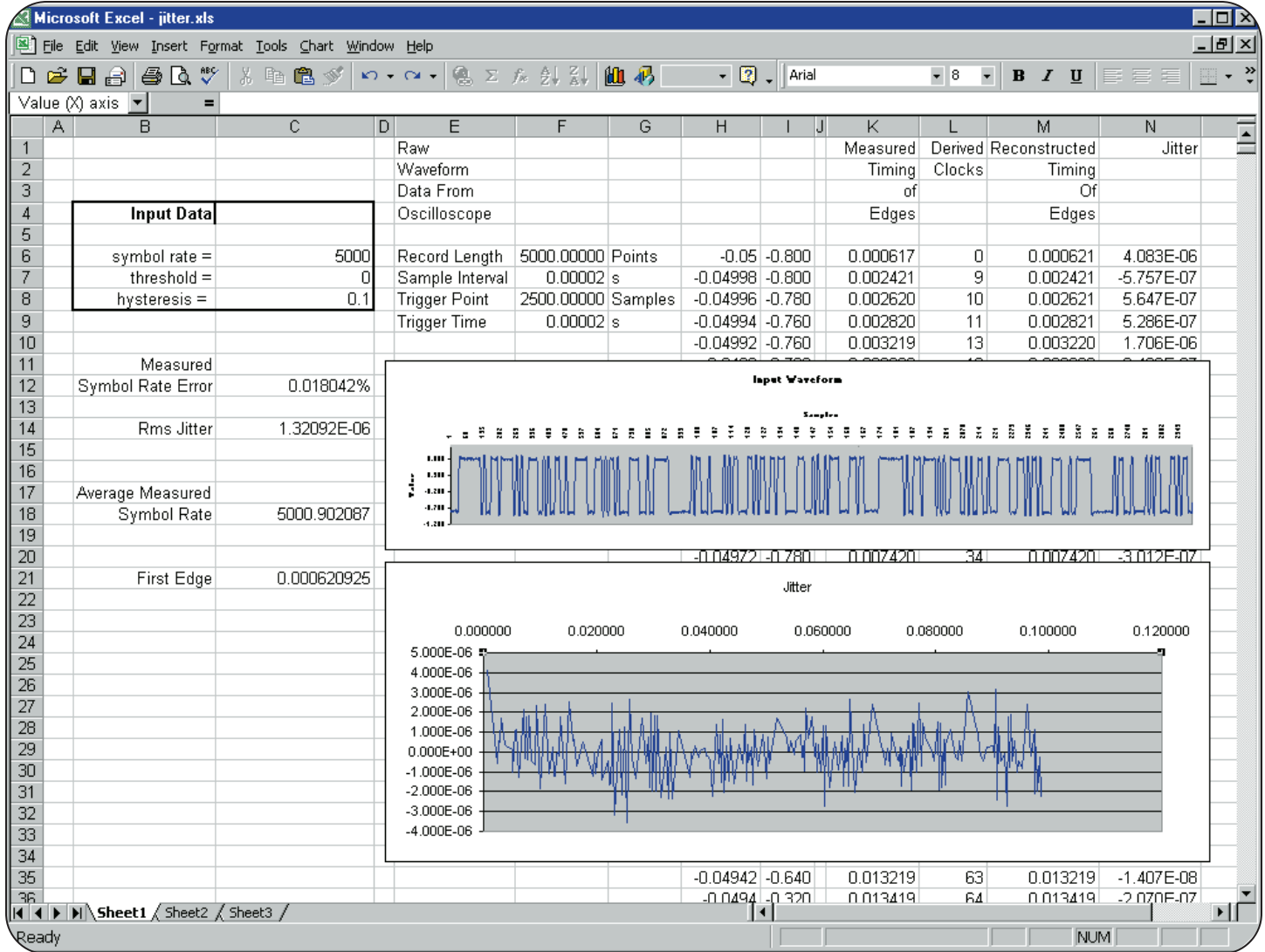
This efficient transfer and analysis of your results to a broad audience can significantly increase the speed and efficiency of communicating information in the time-critical environment that engineers work in today.



► **Figure 5:** The clock jitter solution graphed in Excel

Analyzing Clock Jitter Using Excel

► Application Note



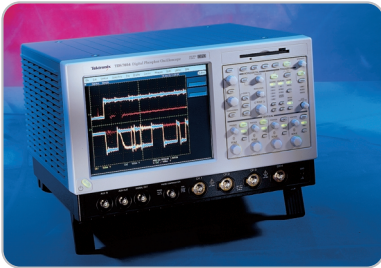
► **Figure 6:** Clock jitter analysis Excel spreadsheet example

¹ Figure 6 is an example Excel spreadsheet that contains the algorithm described earlier in this document. We will be referring to this figure throughout this document

² A functioning sample of this spreadsheet and a complete explanation of developing a clock jitter analysis application, including programming instructions, macros and a functional Excel spreadsheet, are included in *Oscilloscope Connectivity Made Easy* and its accompanying CD-ROM, published and sold by Tektronix at www.tektronix.com/accessories.

Analyzing Clock Jitter Using Excel

► Application Note



► TDS7054



► TDS7104



► TDS7404

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