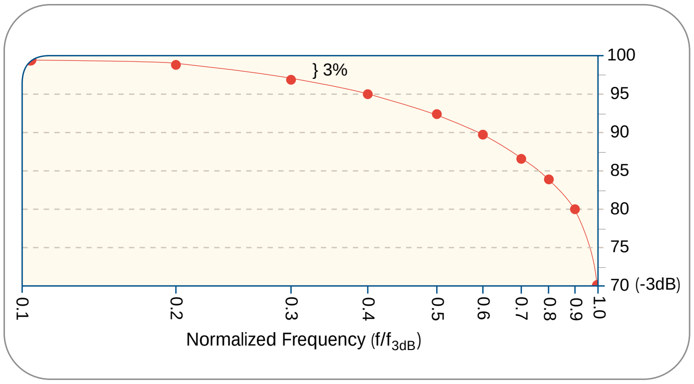

Figure 46. *Oscilloscope bandwidth is the frequency at which a sinusoidal input signal is attenuated to 70.7% of the signal's true amplitude, known as the –3 dB point.*

Performance Terms and Considerations

As previously mentioned, an oscilloscope is analogous to a camera that captures signal images that we can observe and interpret. Shutter speed, lighting conditions, aperture and the ASA rating of the film all affect the camera's ability to capture an image clearly and accurately. Like the basic systems of an oscilloscope, the performance considerations of an oscilloscope significantly affect its ability to achieve the required signal integrity.

Learning a new skill often involves learning a new vocabulary. This idea holds true for learning how to use an oscilloscope. This section describes some useful measurement and oscilloscope performance terms. These terms are used to describe the criteria essential to choosing the right oscilloscope for your application. Understanding these terms will help you to evaluate and compare your oscilloscope with other models.

Bandwidth

Bandwidth determines an oscilloscope's fundamental ability to measure a signal. As signal frequency increases, the capability of the oscilloscope to accurately display the signal decreases. This specification indicates the frequency range that the oscilloscope can accurately measure.

Oscilloscope bandwidth is specified as the frequency at which a sinusoidal input signal is attenuated to 70.7% of the signal's true amplitude, known as the –3 dB point, a term based on a logarithmic scale (see Figure 46).

Figure 47. *The higher the bandwidth, the more accurate the reproduction of your signal, as illustrated with a signal captured at 250 MHz, 1 GHz and 4 GHz bandwidth levels.*

Without adequate bandwidth, your oscilloscope will not be able to resolve high-frequency changes. Amplitude will be distorted. Edges will vanish. Details will be lost. Without adequate bandwidth, all the features, bells and whistles in your oscilloscope will mean nothing.

The 5 Times Rule
Oscilloscope Bandwidth Required = Highest Frequency Component of Measured Signal x 5

To determine the oscilloscope bandwidth needed to accurately characterize signal amplitude in your specific application, apply the "5 Times Rule."

An oscilloscope selected using the 5 Times Rule will give you less than +/-2% error in your measurements – typically sufficient for today's applications. However, as signal speeds increase, it may not be possible to achieve this rule of thumb. Always keep in mind that higher bandwidth will likely provide more accurate reproduction of your signal (see Figure 47).

Figure 48. *Rise time characterization of a high-speed digital signal.*

Logic Family	Typical Signal Rise Time	Calculated Signal Bandwidth
TTL	2 ns	175 MHz
CMOS	1.5 ns	230 MHz
GTL	1 ns	350 MHz
LVDS	400 ps	875 MHz
ECL	100 ps	3.5 GHz
GaAs	40 ps	8.75 GHz

Figure 49. *Some logic families produce inherently faster rise times than others.*

Rise Time

In the digital world, rise time measurements are critical. Rise time may be a more appropriate performance consideration when you expect to measure digital signals, such as pulses and steps. Your oscilloscope must have sufficient rise time to accurately capture the details of rapid transitions.

Rise time describes the useful frequency range of an oscilloscope. To calculate the oscilloscope rise time required for your signal type, use the following equation:

Oscilloscope Rise Time Required = Fastest Rise Time of Measured Signal ÷ 5

Note that this basis for oscilloscope rise time selection is similar to that for bandwidth. As in the case of bandwidth, achieving this rule of thumb may not always be possible given the extreme speeds of today's signals. Always remember that an oscilloscope with faster rise time will more accurately capture the critical details of fast transitions.

In some applications, you may know only the rise time of a signal. A constant allows you to relate the bandwidth and rise time of the oscilloscope, using the equation:

$$\text{Bandwidth} = \frac{k}{\text{Rise Time}}$$

where k is a value between 0.35 and 0.45, depending on the shape of the oscilloscope's frequency response curve and pulse rise time response. Oscilloscopes with a bandwidth of <1 GHz typically have a 0.35 value, while oscilloscopes with a bandwidth >1 GHz usually have a value between 0.40 and 0.45.

Some logic families produce inherently faster rise times than others, as illustrated in Figure 49.

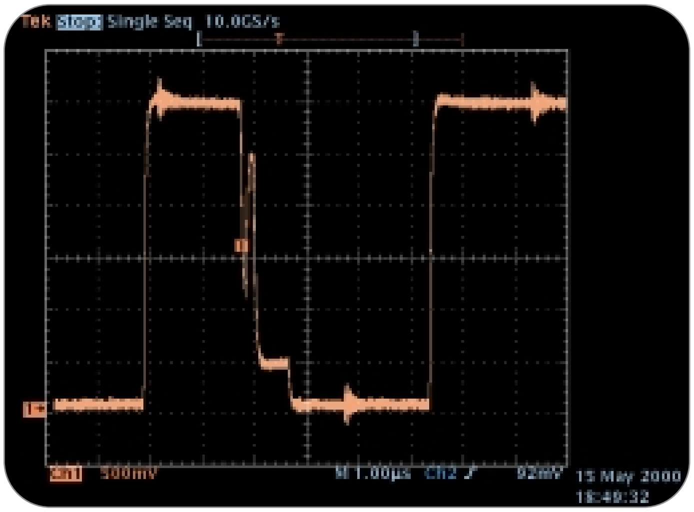

Figure 50. A higher sample rate provides greater signal resolution, ensuring that you'll see intermittent events.

Sample Rate

Sample rate – specified in samples per second (S/s) – refers to how frequently a digital oscilloscope takes a snapshot or sample of the signal, analogous to the frames on a movie camera. The faster an oscilloscope samples (i.e., the higher the sample rate), the greater the resolution and detail of the displayed waveform and the less likely that critical information or events will be lost, as shown in Figure 50. The minimum sample rate may also be important if you need to look at slowly changing signals over longer periods of time. Typically, the displayed sample rate changes with changes made to the horizontal scale control to maintain a constant number of waveform points in the displayed waveform record.

How do you calculate your sample rate requirements? The method differs based on the type of waveform you are measuring, and the method of signal reconstruction used by the oscilloscope.

In order to accurately reconstruct a signal and avoid aliasing, Nyquist theorem says that the signal must be sampled at least twice as fast as its highest frequency component. This theorem, however, assumes an infinite record length and a continuous signal. Since no oscilloscope offers infinite record length and, by definition, glitches are not continuous, sampling at only twice the rate of highest frequency component is usually insufficient.

In reality, accurate reconstruction of a signal depends on both the sample rate and the interpolation method used to fill in the spaces between the samples. Some oscilloscopes let you select either sin (x)/x interpolation for measuring sinusoidal signals, or linear interpolation for square waves, pulses and other signal types.

For accurate reconstruction using sin(x)/x interpolation, your oscilloscope should have a sample rate at least 2.5 times the highest frequency component of your signal. Using linear interpolation, sample rate should be at least 10 times the highest frequency signal component.

Some measurement systems with sample rates to 20 GS/s and bandwidths to 4 GHz have been optimized for capturing very fast, single-shot and transient events by oversampling up to 5 times the bandwidth.

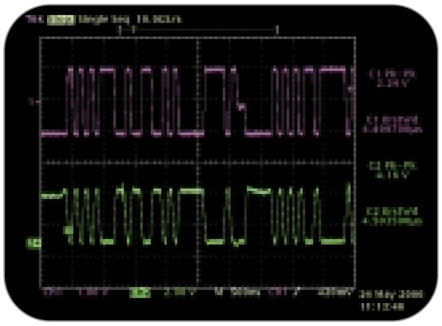

Figure 51. *A DSO provides an ideal solution for non-repetitive, high-speed, multi-channel digital design applications.*

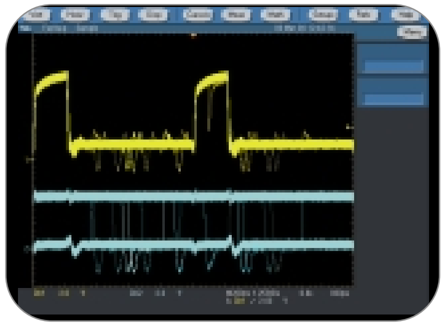

Figure 52. *A DPO enables a superior level of insight into signal behavior by delivering vastly greater waveform capture rates and three-dimensional display, making it the best general-purpose design and troubleshooting tool for a wide range of applications.*

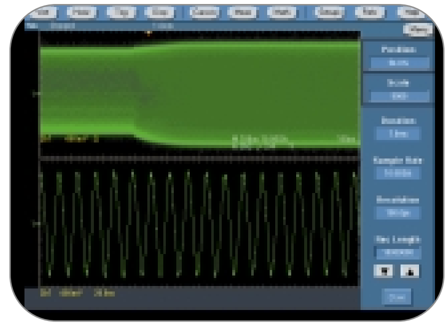

Figure 53. *Capturing the high frequency detail of this modulated 85 MHz carrier requires high resolution sampling (100 ps). Seeing the signal's complete modulation envelope requires a long time duration (1 ms). Using long record length (10 MB), the oscilloscope can display both.*

Waveform Capture Rate

All oscilloscopes blink. That is, they open their eyes a given number of times per second to capture the signal, and close their eyes in between. This is the **waveform capture rate**, expressed as waveforms per second (wfms/s). While the sample rate indicates how frequently the oscilloscope samples the input signal within one waveform, or cycle, the waveform capture rate refers to how quickly an oscilloscope acquires waveforms.

Waveform capture rates vary greatly, depending on the type and performance level of the oscilloscope. Oscilloscopes with high waveform capture rates provide significantly more visual insight into signal behavior, and dramatically increase the probability that the oscilloscope will quickly capture transient anomalies such as jitter, runt pulses, glitches and transition errors. (Refer to Figures 51 and 52.)

Digital storage oscilloscopes (DSOs) employ a serial-processing architecture to capture from 10 to 5,000 wfms/s. Some DSOs provide a special mode that bursts multiple captures into long memory, temporarily delivering higher waveform capture rates followed by long processing dead times that reduce the probability of capturing rare, intermittent events.

Most digital phosphor oscilloscopes (DPOs) employ a parallel-processing architecture to deliver vastly greater waveform capture rates. Some DPOs can acquire millions of waveforms in just seconds, significantly increasing the probability of capturing intermittent and elusive events and allowing you to see the problems in your signal more quickly. Moreover, the DPO's ability to acquire and display three dimensions of signal behavior in real time – amplitude, time and distribution of amplitude over time – results in a superior level of insight into signal behavior.

Record Length

Record length, expressed as the number of points that comprise a complete waveform record, determines the amount of data that can be captured with each channel. Since an oscilloscope can store only a limited number of samples, the waveform duration (time) will be inversely proportional to the oscilloscope's sample rate.

$$\text{Time Interval} = \frac{\text{Record Length}}{\text{Sample Rate}}$$

Modern oscilloscopes allow you to select record length to optimize the level of detail needed for your application. If you are analyzing an extremely stable sinusoidal signal, you may need only a 500-point record length, but if you are isolating the causes of timing anomalies in a complex digital data stream, you may need a million points or more for a given record length.

Triggering Capabilities

An oscilloscope's **trigger** function synchronizes the horizontal sweep at the correct point of the signal, essential for clear signal characterization. Trigger controls allow you to stabilize repetitive waveforms and capture single-shot waveforms.

Please refer to the **Trigger** section under **Performance Terms and Considerations** for more information regarding triggering capabilities.

Effective Bits

Effective bits represent a measure of a digital oscilloscope's ability to accurately reconstruct a sinewave signal's shape. This measurement compares the oscilloscope's actual error to that of a theoretical "ideal" digitizer. Because the actual errors include noise and distortion, the frequency and amplitude of the signal must be specified.

Frequency Response

Bandwidth alone is not enough to ensure that an oscilloscope can accurately capture a high frequency signal. The goal of oscilloscope design is a specific type of frequency response: **Maximally Flat Envelope Delay** (MFED). A frequency response of this type delivers excellent pulse fidelity with minimum overshoot and ringing. Since a digital oscilloscope is composed of real amplifiers, attenuators, ADCs, interconnects, and relays, MFED response is a goal that can only be approached. Pulse fidelity varies considerably with model and manufacturer. (Figure 46 illustrates this concept.)

Vertical Sensitivity

Vertical sensitivity indicates how much the vertical amplifier can amplify a weak signal – usually measured in millivolts (mV) per division. The smallest voltage detected by a general-purpose oscilloscope is typically about 1 mV per vertical screen division.

Sweep Speed

Sweep speed indicates how fast the trace can sweep across the oscilloscope screen, enabling you to see fine details. The sweep speed of an oscilloscope is represented by time (seconds) per division.

Gain Accuracy

Gain accuracy indicates how accurately the vertical system attenuates or amplifies a signal, usually represented as a percentage error.

Horizontal Accuracy (Time Base)

Horizontal, or **time base, accuracy** indicates how accurately the horizontal system displays the timing of a signal, usually represented as a percentage error.

Vertical Resolution (Analog-to-Digital Converter)

Vertical resolution of the ADC, and therefore, the digital oscilloscope, indicates how precisely it can convert input voltages into digital values. Vertical resolution is measured in bits. Calculation techniques can improve the effective resolution, as exemplified with hi-res acquisition mode. Please refer to the Horizontal System and Controls section under **The Systems and Controls of an Oscilloscope** section.

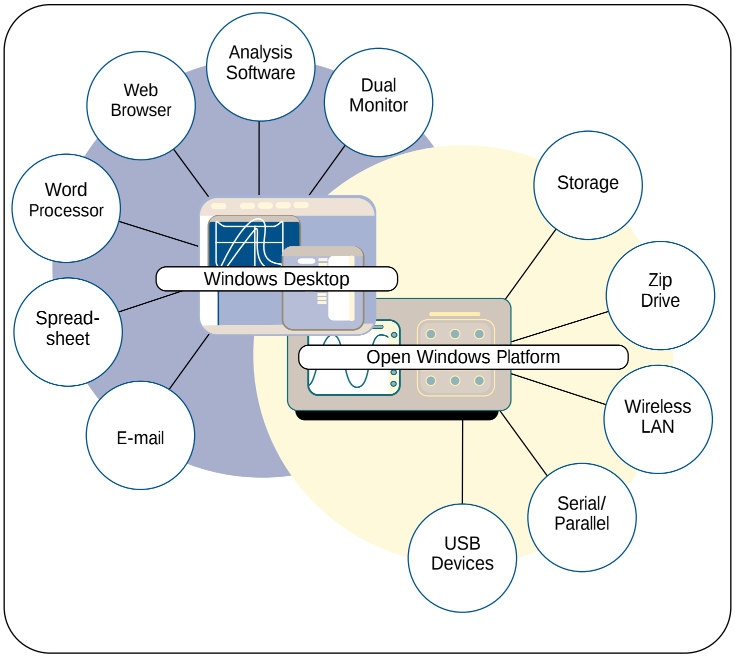

Figure 54. *A TDS7000 Series oscilloscope connects people and equipment to save time and increase total work group productivity.*

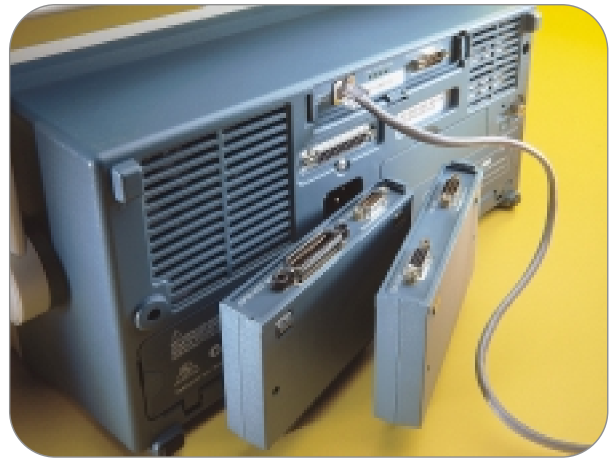

Figure 55. *A TDS3000 Series oscilloscope provides a wide array of communications interfaces, such as a standard Centronics port and optional Ethernet/RS-232, GPIB/RS-232, and VGA/RS-232 modules.*

Connectivity

The need to analyze measurement results remains of utmost importance. The need to document and share information and measurement results easily and frequently over high-speed communication networks has also grown in importance.

The connectivity of an oscilloscope delivers advanced analysis capabilities and simplifies the documentation and sharing of results. Standard interfaces (GPIB, RS-232, USB, Ethernet) and network communication modules enable some oscilloscopes to deliver a vast array of functionality and control.

Some advanced oscilloscopes also let you:

- Create, edit and share documents on the oscilloscope – all while working with the instrument in your particular environment
- Access network printing and file sharing resources
- Access the Windows® desktop
- Run third-party analysis and documentation software
- Link to networks
- Access the Internet
- Send and receive e-mail

Figure 56. *The TDSJIT2 optional software package for the TDS7000 Series oscilloscope is specifically designed to meet jitter measurement needs of today's high-speed digital designers.*

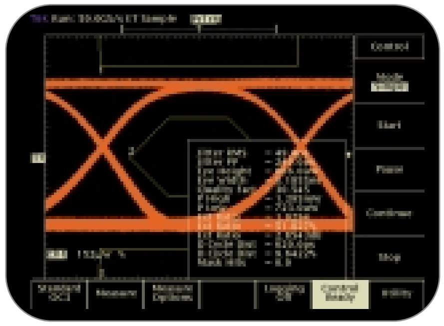

Figure 57. *Equip the TDS700 Series oscilloscope with the TDSCEM1 application module for communications mask compliance testing.*

Figure 58. *The TDS3SDI video module makes the TDS3000 Series oscilloscope a fast, tell-all tool for video troubleshooting.*

Expandability

An oscilloscope should be able to accommodate your needs as they change. Some oscilloscopes allow you to:

- Add memory to channels to analyze longer record lengths
- Add application-specific measurement capabilities
- Complement the power of the oscilloscope with a full range of probes and modules
- Work with popular third-party analysis and productivity Windows-compatible software
- Add accessories, such as battery packs and rackmounts

Application modules and software may enable you to transform your oscilloscope into a highly specialized analysis tool capable of performing functions such as jitter and timing analysis, microprocessor memory system verification, communications standards testing, disk drive measurements, video measurements, power measurements and much more.

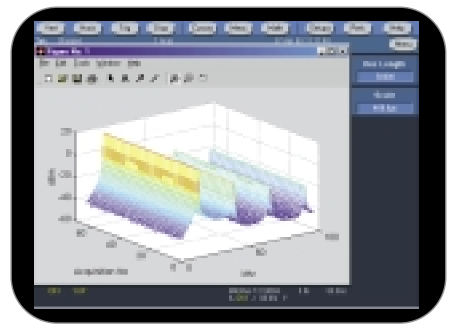

Figure 59. *Advanced analysis and productivity software, such as MATLAB®, can be installed in the TDS7000 Series oscilloscope to accomplish local signal analysis.*

Figure 60. *Traditional, analog-style knobs control position, scale, intensity, etc. – precisely as you would expect.*

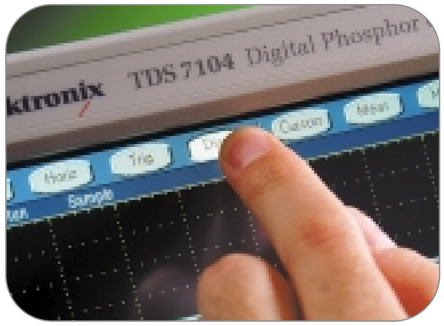

Figure 61. *Touch-sensitive display naturally solves issues with cluttered benches and carts, while providing access to clear, on-screen buttons.*

Figure 62. *Use graphical control windows to access even the most sophisticated functions with confidence and ease.*

Ease-of-Use

Oscilloscopes should be easy to learn and easy to use, helping you work at peak efficiency and productivity. Just as there is no one typical car driver, there is no one typical oscilloscope user. There are both traditional instrument users and those who have grown up in the Windows®/Internet era. The key to satisfying such a broad group of users is flexibility in operating style.

Many oscilloscopes offer a balance between performance and simplicity by providing the user with many ways to operate the instrument. A front-panel layout provides dedicated vertical, horizontal and trigger controls. An icon-rich graphical user interface helps you understand and intuitively use advanced capabilities. Touch-sensitive display solves issues with cluttered benches and carts, while providing access to clear, on-screen buttons. On-line help provides a convenient, built-in reference manual. Intuitive controls allow even occasional oscilloscope users to feel as comfortable driving the oscilloscope as they do driving a car, while giving full-time users easy access to the oscilloscope's most advanced features. In addition, many oscilloscopes are portable, making the oscilloscope efficient in many different operating environments – in the lab or in the field.

Figure 63. *The portability of many oscilloscopes makes the instrument efficient in many operating environments.*

Probes

A probe functions as a critical component of the measurement system, ensuring signal integrity and enabling you to access all of the power and performance in your oscilloscope. Please refer to The Complete Measurement System under the Systems and Controls of the Oscilloscope section, or the Tektronix' *ABCs of Probes* primer, for additional information.