Measurement Solutions for Disk Drive Design

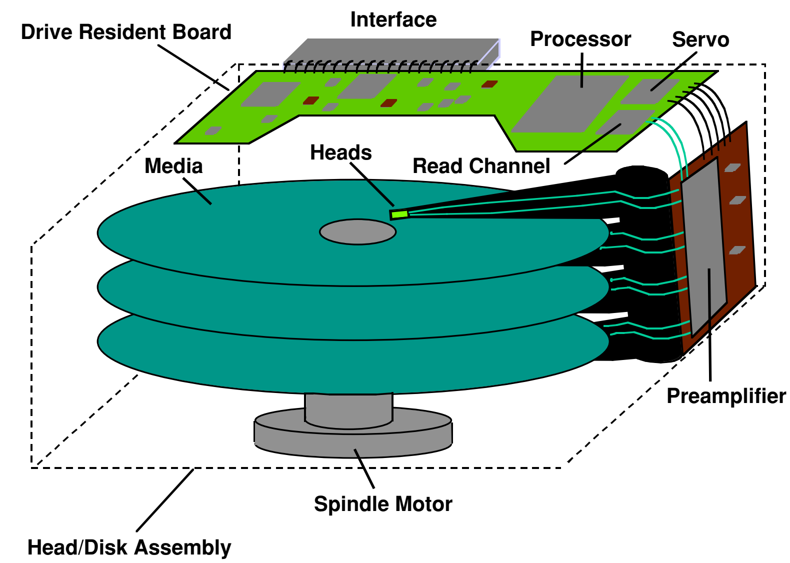


Figure 1. *Block diagram of a disk drive.*

Topics Covered:

- Heads And Media
- Preamplifier and Read/Write Electronics
- Servo Positioning
- Power Conversion Electronics
- Embedded Processors and Digital Interfaces
- Embedded System Development

Introduction

With disk drive manufacturers and their suppliers in a constant race to deliver more data capacity at the lowest possible cost, accurate and insightful analysis of disk drive performance can be challenging. Probing solutions must preserve the fidelity of very small signal characteristics so events can be examined with confidence. High-speed generation and capture of time-encoded information is required to reveal subtle waveform phenomena. Today's digital oscilloscopes, logic analyzers, arbitrary waveform generators, and high-performance differential probes provide the sophisticated processing, analysis, and display functions needed to present this array of disk drive information for effective analysis.

This application note illustrates a number of measurement techniques relevant to the following general areas of disk drive design:

– Heads and media

– Preamplifier and read/write electronics

– Spindle motors

– Servo positioning

– Embedded processors

– Digital interfaces

The goal of this application note is to provide a summary of modern instrumentation and techniques available for probing, capturing, and analyzing electronic signals that are found in disk drive systems.

Tektronix
Enabling Innovation

Heads And Media

As disk drive companies squeeze more data onto the disk, drive heads are forced to read more complex signals. Drive manufacturers have come up with a number of technological advances to solve this problem, including the development of Magneto-resistive (MR) heads, Partial Response Maximum Likelihood (PRML) data encoding, and future data encoding techniques such as Multi-Level Decision Feedback Equalization (MxDFE).

MR heads are extremely sensitive to magnetic fields, enabling them to read the small voltage variations induced into the heads by passing over the small magnetic variations of the media. In fact, it's partly due to the development of MR heads that drive designers have had to decrease magnetic strength to avoid signal interference. Since weaker magnetic fields do not conflict with each other as much, bits can be placed closer together, allowing higher densities.

PRML – a method of detecting data on a disk and making a determination as to the correctness of the bits – can handle the closely aligned signals of today's disks without reducing the signal-to-noise ratio. When combined with MR technology, drives are able to read and write faster. This, of course, makes head and media analysis even more challenging.

Typical Design Challenges

Media manufacturers typically sputter magnetic media onto a metal (aluminum) substrate. Some of their primary concerns is how evenly that media is deposited and whether or not there are any gaps or flaws in the media. Media deposited unevenly, thicker in some areas than in others, creates a greater likelihood of collision with the read/write head or the potential inability of the media to accept magnetization as a result of insufficient deposition of the magnetic medium.

Testing of the media typically occurs by placing a continuous tone on all tracks, then analyzing variations in the read signal.

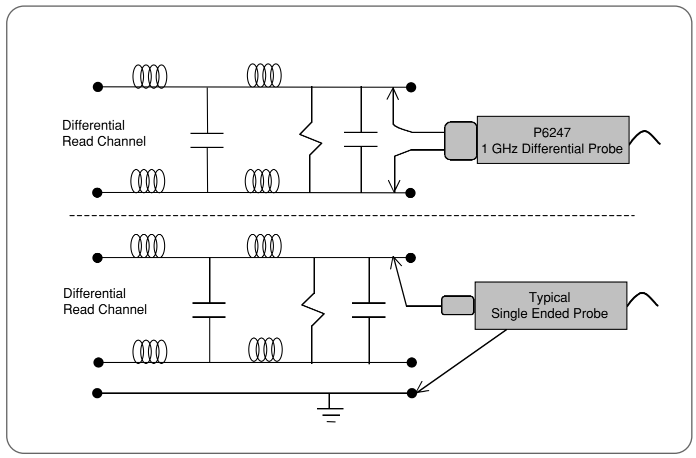
Drive head manufacturers are concerned with the physical characteristics of the head – size, weight, balance, shape – and how it is able to sense data on the media. Because these read and write heads are so small, it's difficult to manufacture them with perfectly balanced characteristics. So MR head manufacturers are particularly concerned with head asymmetries that can cause baseline shifts in read signals.

Connecting to the Low-level Differential Signals

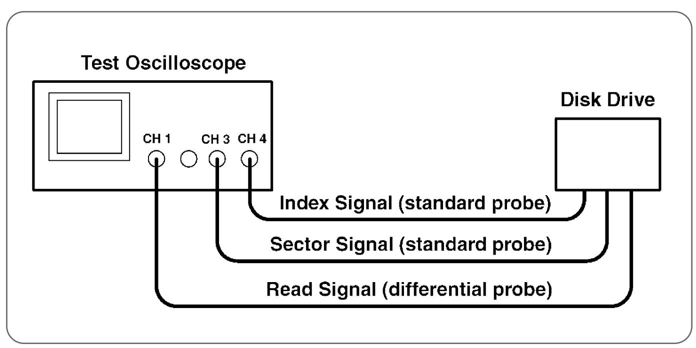
Being a magnetic interface, everything that's written onto or read from the media is done differentially. Consequently, the differential probe is the ideal tool for measuring the microvolt-level signals produced at the head as well as the millivolt-level signals after the read channel preamplifier (see Figure 2).

The P6247 is a DC to 1.0 GHz active differential probe that provides up to 1000:1 rejection of high frequency common-mode signals. This increases to 50 dB at 100 MHz and 70 dB at 1 MHz. It enables disk drive designers to make time or frequency domain measurements on the high bandwidth signals found in disk drives. The P6247 is ideal for design verification of disk drive read channel electronics.

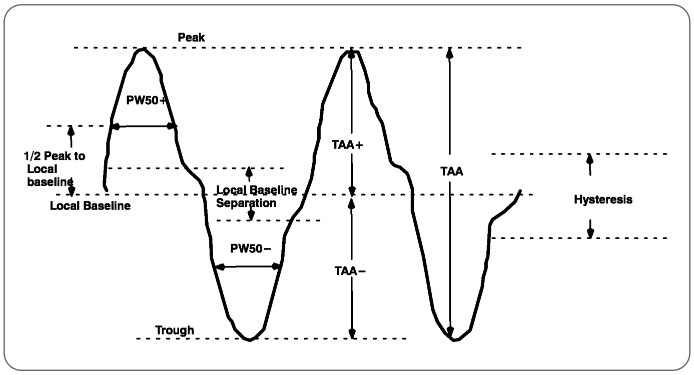
Figure 3 shows a basic test setup for disk drive measurements using the TDS794D 2 GHz Digital Phosphor Oscilloscope and the Tektronix P6247 active differential probe. In this setup,



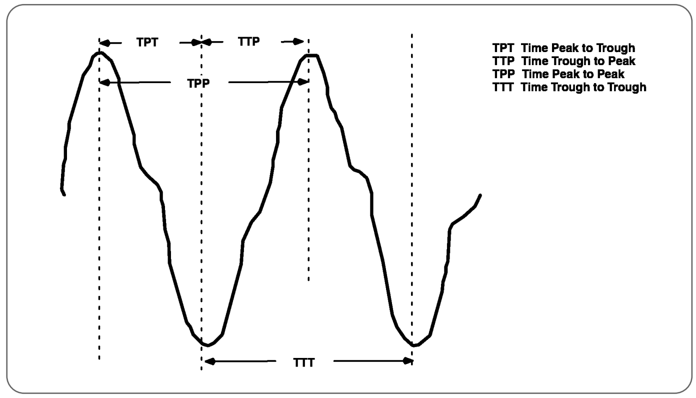
▶ ***Figure 2.*** *Tektronix P6247 active differential probe connected to differential read channel.*



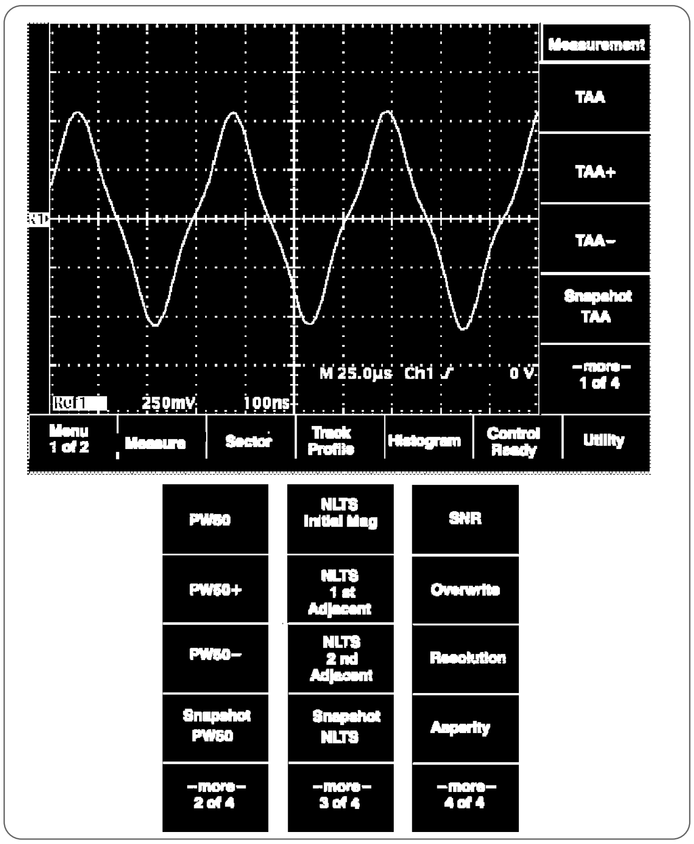
▶ ***Figure 3****. Test setup for disk drive measurements.*



▶ ***Figure 4. a)*** *Parameters for disk drive measurement.*



▶ ***Figure 4. b)*** *More parameters for disk drive measurement.*



▶ ***Figure 5.*** *Menus for disk drive measurements.*

channel 4 is connected to the index pulse, which marks the beginning of the track. Channel 3 is connected to the sector pulse, which marks the beginning of each sector on the track. Channel 2 is connected to the Read Gate signal (this connection is optional); and Channel 1 is connected to the actual data signal from the read channel amplifier.

Figures 4a and 4b show a data signal from a disk drive with typical disk drive measurement parameters.

Disk Drive Measurements

In this application note we reference the Tektronix Digital Phosphor Oscilloscopes because they provide record lengths up to 8 million points on a single channel or 2 million points on each of four channels. These oscilloscopes also offer 8-bits of amplitude resolution at up to 4 Gigasamples per second in Normal mode; 11 bits when Averaging is used; and 13 bits in the Hi-Res mode. (8 meg record lengths are available at a maximum of 8-bits resolution.)

In addition, these high performance oscilloscopes can be equipped with the Tektronix Disk Drive Measurement Software package

Digital Phosphor Oscilloscopes

A Digital Phosphor Oscilloscope has the ability to display, store, and analyze complex signals in real time, using three dimensions of signal information: amplitude, time, and the distribution of amplitude over time.

Tektronix' new DPO oscilloscopes provide disk drive designers with the ability to preserve the fine signal detail of disk drive waveforms while allowing them to see entire sectors or multiple sectors of a disk drive waveform without aliasing.

(TDSDDM1) which provides a comprehensive suite of automated measurements specifically for disk drive design and characterization (see Figure 5). IDEMA-measurements include: standard measurements for track average amplitude positive (TAA+), track average amplitude negative (TAA–), track average amplitude total (TAA), 50% pulse width positive (PW50+), 50% pulse width negative (PW50–), 50% pulse width (PW50), overwrite, and resolution; timing measurements time – trough-to-peak, and time – peak-to-trough. PRML measurements include auto-correlation non-linear transition shift, and signal-to-noise ratio. Voltage and time asymmetry measurements are available for MR head designers. Measurement statistics are also available.

When coupled with the dual time bases and a delay-by-events counter of the TDS oscilloscopes, the TDSDDM1 package can control the trigger system so that it sequences from sector to sector, acquiring only the data signals on each sector and ignoring the preamble and servo signals. This capability is especially useful for TAA and PW50 measurements since it eliminates the need to record an entire revolution and then parse out the correct information mathematically. It also reduces the need to rely on extremely long record length acquisitions.

Measuring Timing Asymmetry

The timing asymmetry test measures the ability of the head/media combination to process positive and negative transitions identically. To perform this test, a constant frequency sequence is written onto a track. Asymmetry is calculated based on timing between pulse peaks as follows:

$$A = \frac{1}{4N} \sum_{i=1}^{N} (|i - T_s|)$$

A Note On Hysteresis

Many disk drive measurements require a search for a local event called a peak-and-trough pair. It is important to set the hysteresis level of the TDSDDM1 software so that noise will not cause false identification of peaks in the Read channel waveform (see Figure 6). For a peak or trough to be captured, the signal must be greater than the hysteresis level.

Hysteresis is a global setting used in making measurements such as TAA, PW50, time asymmetry, and time between peaks.

where:

i indexes negative pulses

N is the number of measured time intervals

T_1 is the time between the prior (positive) and the current pulse

T_S is the time between the current and the next (positive) pulse

These measurements operate as other measurements – the range of sectors is defined and the measurement average and standard deviation is calculated. The amount of acquired data measured within each sector is determined by the cursors.

Overwrite

The purpose of the Overwrite test is to determine the amount of residual signal remaining from the previous write when new data is written over it. The amount of residual depends on the coercivity of the media, write current amplitude, and saturation characteristics of the head.

The basic procedure is as follows:

1) Erase the test track
2) Write data for one revolution at a low rate, f1
3) Measure the RMS amplitude (V_o) through a narrow-band filter tuned to f1
4) Overwrite the track with data at a higher frequency, f2
5) Measure residual RMS amplitude (V_r) at f1 again

Overwrite is defined as:

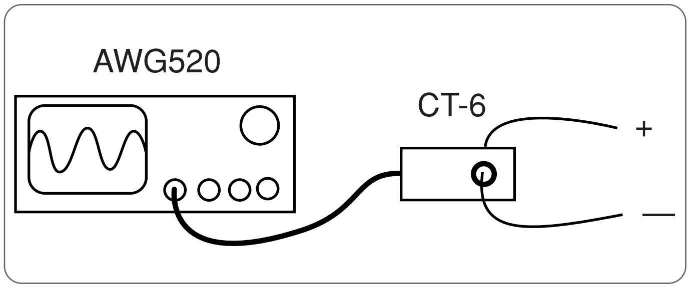
$$OW(dB) = 20 \text{ Log } \left(\frac{V_r}{V_o}\right)$$

Asperity Test

When the head strikes an aberration in the surface of the media, a large voltage spike results. The asperity test identifies these voltage spikes as thermal asperities, indicating whether the head has hit a flaw in the media surface.

The asperity test compares every peak-to-trough pair against a threshold limit defined by the user. If the signal goes above the positive threshold level or below the negative threshold level, an asperity is assumed. The TDSDDM1 software records the sector number and the time position of the asperity from the start of the data segment gated into the measurement. The asperity test will not be rearmed for another asperity until the signal crosses zero.

The total number of events checked appears in the display. An event is one positive peak followed by one negative peak. The sector number and time position of the last 10 asperities is also displayed.



▶ ***Figure 7.*** *AWG520 and CT-6 used to generate current for read channel.*

Preamplifier and Read/Write Electronics

As we move from testing the read/write heads and the media to testing the internal disk drive electronics, we move from component- to system-level testing. While many of the measurements remain the same, we now are in an environment that includes other factors, such as noise from the commutating motor and/or from the digital electronics.

Like testing of the drive head and media, analysis of the preamplifier and read/write electronics involves probing of differentially sourced low-level signals. In addition, preamplifier and read/write circuit characterization requires analysis of signals in the presence of noise and jitter, discriminating and capturing data errors, and evaluating both time and frequency-domain responses.

Differential Probes and High Frequency CMRR

Testing considerations begin at the probe tip because measurement results are only as good as the signal received from the probe. When dealing with differentially sourced signals, therefore, it's necessary to use a probe with high common-mode rejection ratio (CMRR). CMRR is a measure of how well a differential amplifier rejects signals common to both inputs. CMRR is defined as the ratio of the differential gain to the common-mode gain. In general, CMRR decreases as a function of frequency.

Reading and Writing Head Currents

Verifying write current amplitudes can be as simple as looping a head lead through a current transformer such as the CT-6. The CT-6 generates 5 millivolts per milliamp into a 50 Ω load. Of course, current transformers don't have DC response, so it is impossible to monitor DC erase currents. A subtle application of current transformers is to use them in reverse (see Figure 7). Using the Tektronix AWG510 or 520 Arbitrary Waveform Generator, with 50 Ω source impedance, the current transformer "output" can be driven to generate a current through a wire looped through the "input." The read channel front-end can be inductively coupled to make frequency response measurements.

The differential characteristics of the read/write channels of disk drives place special demands on differential probes. While many engineers use differential probes to reject line frequency noise, read channel engineers are more concerned about high frequency common-mode noise from such sources as commutating motor control circuits and digital logic. This means that the high frequency CMRR performance of the probe is a key measure of usability.

When making differential measurements, bandwidth may not be the probe's limiting factor. In read channel measurements, for example, differential probe bandwidth without commensurate CMRR performance is of little value. The P6247 probe's CMRR performance is at least 5000:1 at 1 MHz when AC-coupled. The DC-coupled performance is better, but for most 5 V read channel designs, AC-coupling should be used to obtain the probe's highest sensitivity without exceeding its common-mode voltage range.

Accurately measuring read channel signals in single-voltage designs is more challenging because the read channel and the digital logic share the same voltage supply and ground return path.

Active Probes: Handle With Care

Active probes generally use very sensitive FET input buffer amplifiers located in the probe tip to provide high sensitivity and minimal loading to the device under test. Unlike conventional passive probes, which are resistive dividers, such FET input probes can be destroyed by a brief encounter with static discharges. For such probes, it's a good idea to take a few seconds to verify voltage levels with a conventional probe before using an active FET probe.

The P6247 active differential probe is resistant to electrostatic discharge. However, it and any other active probe should always be handled with care; just as you would handle any valuable tool.

This means that the high-frequency CMRR performance of the differential probe must be carefully evaluated. For 5 V-only designs, use the P6247 in DC-coupled mode and achieve a CMRR of at least 1000:1.

Figures 8 and 9 illustrate the effect differential probing has on noise and signal accuracy when measuring read channel signals. The upper trace is the acquired time domain signal and the lower trace is the FFT of the same acquired signal. The cursor readouts are locked to the frequency domain plot on the lower trace to reflect the 50 MHz point in the spectrum displayed at 12.5 MHz per division.

In Figure 8, a single-ended ground-referenced probe was AC-coupled to measure one side of the read channel after the head preamp.

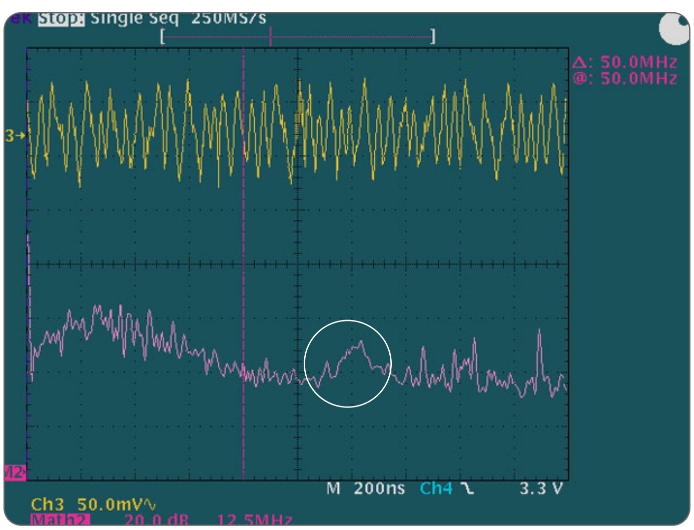
In Figure 9, the P6247 was DC-coupled to differentially measure the same point in the read channel. (Note that the signal amplitude is twice the amplitude of the single-ended measurement.) The lower trace shows the signal spectrum computed by the TDS794D. Compared to Figure 8, the differential measurement is cleaner and more accurately represents the signal (note area circled on waveforms). The spectrum computed from the single-ended probe is significantly different above 50 MHz.

Split, Noisy, and Quiet Grounds

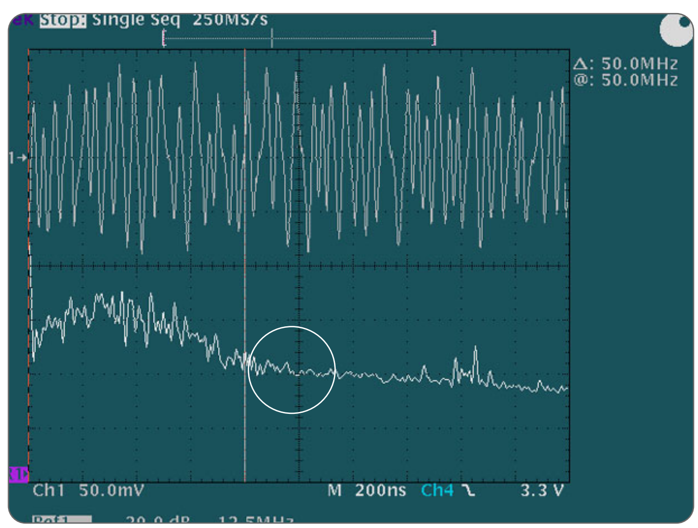
Another application requiring differential probing is the analysis of separate ground returns for analog, digital, or motor circuitry. Noisy motor drive and digital logic circuits must co-exist with sub-millivolt read-channel circuits. Isolating power return paths is a popular technique for keeping switching noise out of the read-channel.

It can be difficult to measure the effectiveness of this approach with conventional probing techniques because the user must select a reference point for a probe with a ground lead. If the ground lead is connected to any ground point on the drive, a return path is created to the scope that parallels the drive's return path(s) to the power supply. The result can be a confusing network of grounds, each at a different potential, with variations of tens of millivolts for typical drive configurations. This defeats the integrity of differential ground measurements.

The solution is to use a true differential probe which measures the voltage between two probed points. This is different from trying to force one side of a differential voltage to be at the scope's ground lead potential. The P6247 active differential probe measures true differen-



▶ ***Figure 8.*** *Measurement taken with AC-coupled, single-ended probe.*



▶ ***Figure 9.*** *Measurement taken with DC-coupled differential probe.*

tial voltages, such as those between ground nodes in a drive, with millivolt/division resolution. The P6247 presents a balanced high-impedance load to the two measured nodes. This is critical when split-path layout techniques must be accurately characterized and verified.

Accurately Simulating Read Channel Signals

As the performance criteria for successive hard drive designs become more stringent, it's important for designers to simulate precisely controlled disk drive test patterns and signals. Such waveforms are required to evaluate read channel performance and provide accurate margin testing. Designers need to have a very stable, controlled, and accurate signal source against which to reference their designs. They use Arbitrary Waveform Generators to simulate several signals; jitter effects on the device-under-test, amplifier noise, sample clock jitter, quantization error, interpolation error simulations, etc.

The Tektronix AWG510 and AWG520 Arbitrary Waveform Generators provide more than just precisely defined timing and amplitude impairments. Through the powerful graphical interface, they provide a suite of built-in tools that allows the user to define and edit a region where a violation is to occur using the cursors. Timing violations can easily be simulated using the unique Region Shift function, which allows positioning of pulses in time with 2-picosecond resolution. In addition, the Quick Edit function provides the user with "on the fly" editing of waveforms that can now be shifted to the left or right, compressed or expanded with the turn of a knob. This capability is useful to emulate such waveform impairments as inter-symbol interference, peak shift, and jitter.

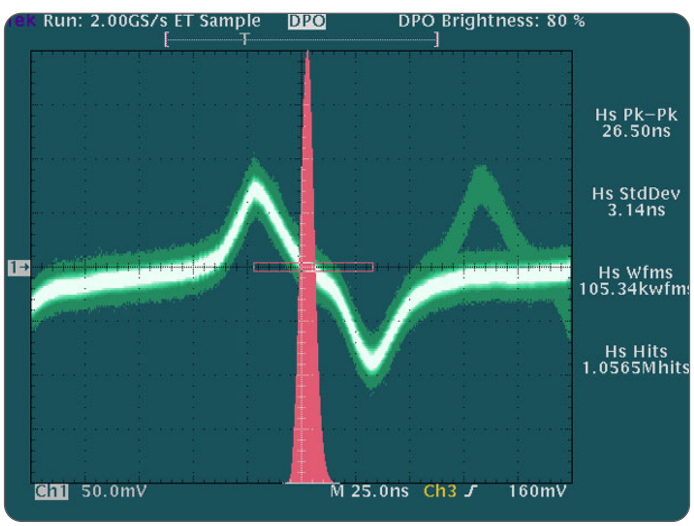


Figure 10. *The histogram shows the extent of the jitter and quantifies distribution of the signal.*

The Tektronix AWG510 and 520 also have the ability to generate a given pulse response and provide specific built-in waveforms for testing. The AWG simulates write-current transition pulse responses with bit intervals determined by the encoding technique chosen. Users can select the desired response from a menu screen that provides Lorentzian, PR4, EPR4, and E2PR4 pulse shapes. Optionally, the user may choose to download the desired shape from a software simulation tool.

The Tektronix AWG510 and 520 also have the ability to model several different write-current data patterns. To derive the final signal, the AWG first creates the pre-encoded write current which can be either an NRZ or NRZI binary pattern. Then by using the built-in code converter, the serial pattern can be translated into the desired write-current pattern with appropriate encoding. An alternative method would be to use an external simulation tool and download the simulation output to the AWG. With the push of a button the data pattern is then convolved with the desired pulse response to generate the simulated write current signal.

In addition to ideal signal generation, these high performance AWGs are equipped with a comprehensive suite of automated impairment tools specifically intended for disk drive design and characterization. Impairments include: track average amplitude positive (TAA+), track average amplitude negative (TAA–), track average amplitude total (TAA), 50% pulse width positive (PW50+), 50% pulse width negative (PW50–), 50% pulse width (PW50) and non-linear transition shift.

Read channel designs must overcome noise in the read-back signal. The AWG can be used to simulate the read-back signal and then, using the built-in analog noise generation capability, inject noise into the signal until bit error rate starts to climb. The AWG also provides a summing port for adding noise to the output from external noise sources. The ability to generate noise enables the designer to obtain a clear picture of the limits of the design, and how robust the recovery system is.

Designers will also benefit from the AWG500's ability to directly transfer a captured signal from a TDS Series oscilloscope and load it into the AWG's output. This is a useful debug tool that allows the user to compare a known good signal to a captured signal that contains a suspected impairment.

Dealing With Measurement System Jitter

The oscilloscope test system can evaluate the jitter of the device-under-test and produce accurate measurements of amplifier vertical noise, sample clock jitter, quantization error, trigger jitter, and interpolation error. Figure 10 shows the measurement of a single falling edge made with a TDS794D. The standard deviation, sigma (s), of the jitter as shown by the histogram is 3.14 ns.

The scope measurement also shows that 100% of the points fall within ±5 sigma of the mean. This statistic is further supported by the peak-to-peak jitter measurement of 26.5 ns.

Statistical confidence in measurements increases with the number of sample points collected. The Tektronix DPO oscilloscopes with the 3D database can collect statistical information at the rate of 25 million samples/second. In this example, over 100,000 acquisitions were made, providing over 1 million data points for the calculation.

Measuring Jitter

Timing jitter in index or preamble lock detection circuits makes it difficult to view waveforms from successive revolutions. The typical result is a blurred waveform because identical waveforms from successive revolutions are captured at slightly different times. The histogram function of the DPO oscilloscopes can be used, as above, to statistically determine the amount of jitter on the read signal.

Tektronix DPO oscilloscopes accurately display dynamic complex waveforms with three dimensions of waveform data in real time.

Figure 11 illustrates typical performance when viewing read signals. In the upper screen, the scope is triggered on the rising edge of the index signal. The index pulse, however, occurs at slightly different time locations because of variations in the detection comparator. The result is the jittered read signal shown on the upper trace.

TAA Measurement

Track Average Amplitude is the average peak-to-peak value of the data on the read channel signal over a specified range of sectors. Typically, the acquisition of a complete sector is required to provide enough peak-to-trough pairs for an accurate statistical measurement to be made. TAA is defined as:

$$TAA = \frac{1}{N} \sum_{i=0}^{N-1} V_{p-p}(i)$$

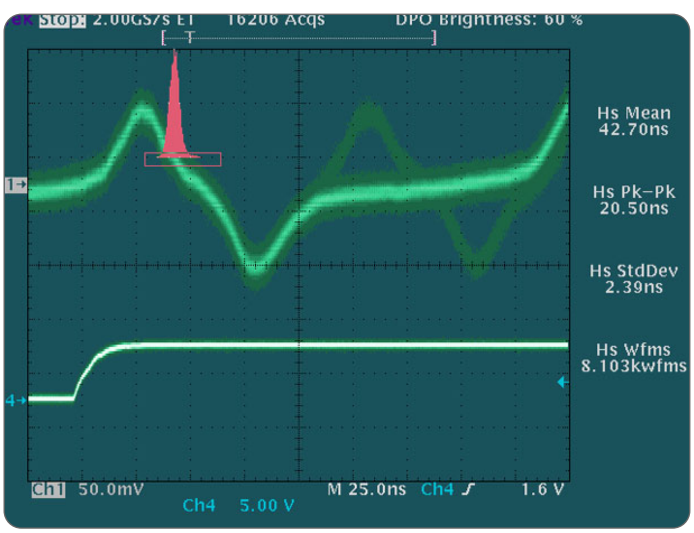
where:

i is an index for each measurement

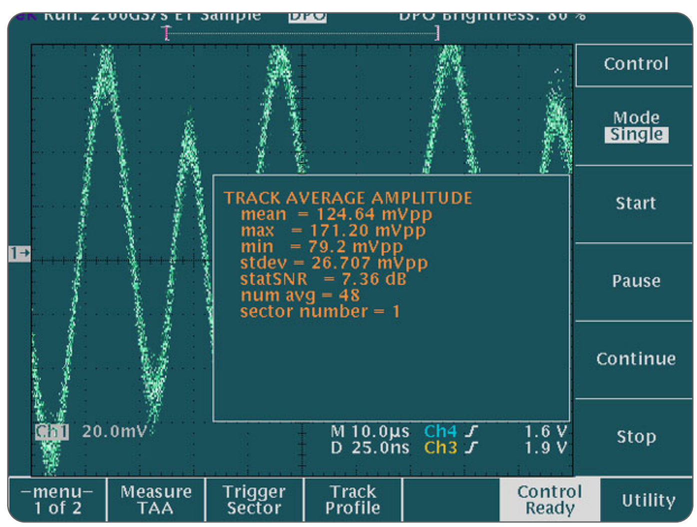
N is the number of positive and negative pulse pairs

V_{p-p} is the peak-to-peak voltage

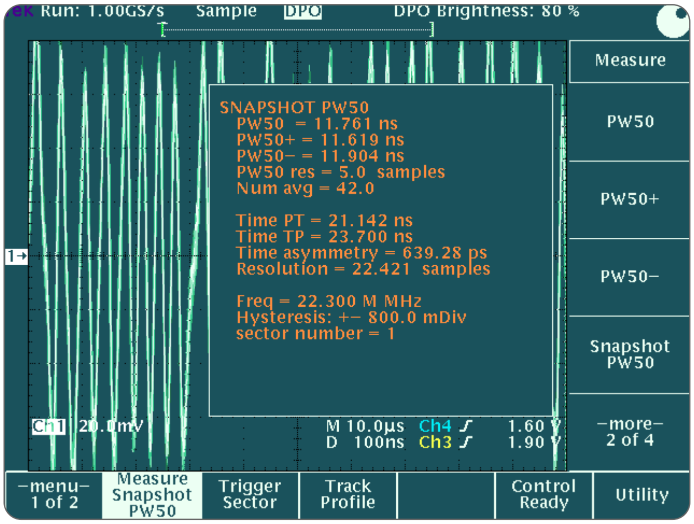
Using the basic test setup described above and the TDSDDM1 software, trigger setup is performed automatically so that the oscilloscope triggers on the index pulse. The user simply chooses the range of sectors to test. TDSDDM1 performs the measurement by acquiring the user defined sector(s). and performing the TAA measurement for the data area of that sector(s). The measurements can then be read out directly or stored into a reference memory to produce a graphic repre-



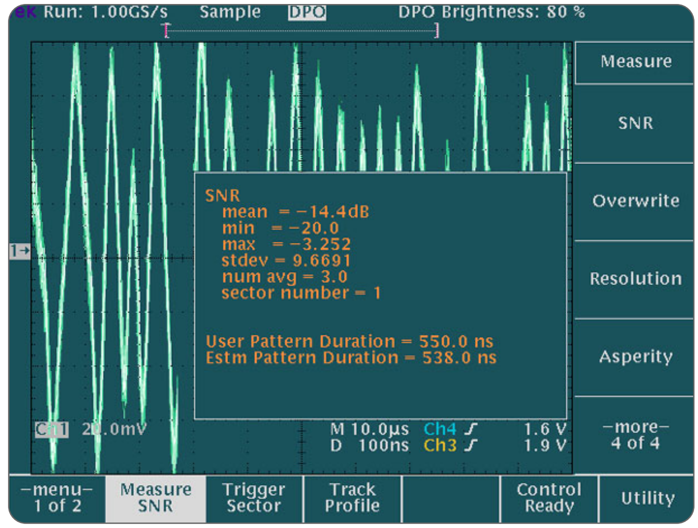
▶ ***Figure 11***. *Analog read signal captured with jitter.*



▶ ***Figure 12.*** *TAA measurement results.*



▶ ***Figure 13.*** *Results of Snapshot PW50 measurement.*



▶ ***Figure 14.*** *SNR results.*

sentation of the TAA measurement over a range of sectors. To speed up the measurement process, the user may specify a smaller region of each track segment by using the time cursors.

Figure 12 shows the results of a TAA measurement using the P6247 differential probe and the Tektronix TDS794D.

PW50 Measurement

The PW50 measurement provides the average pulse width at 50% of the peak value for both positive and negative peaks. These pulses are derived from transitions written at a spacing that minimizes pulse interaction and also creates enough pulses around the recording track to provide an adequate statistical sample from which to calculate the average. To complete this measurement, the user specifies the preamble offset time from the sector pulse to ensure that the measurement algorithm excludes all non-uniform segments such as write splices, servo gaps, header fields, etc.

As with the TAA measurement, the TDSDDM1 software performs the measurement by acquiring the data area of each sector and performing the PW50 measurements. In order to speed up the measurement process, the user may specify a smaller region of each track segment by using the cursors or by decreasing the record length. Half of the TAA value is used as the threshold level at which to measure the pulse width of each positive and negative pulse. The average pulse width for all pulses around the track are measured.

The PW50+ measurement uses only the positive peaks to determine an average pulse width, and PW50– uses only negative.

The Snapshot PW50 measurement includes the following: PW50, PW50+, PW50–, resolution, number of averages, number of measurements in the average, time peak-to-trough, time trough-to-peak, time asymmetry, period resolution, and frequency. In addition, it reads out limit test results, hysteresis setting, and filter setting (see Figure 13).

Computing SNR

The signal-to-noise ratio measurement, SNR, determines the ratio of the variance of the read-back signal to read-back noise. The measured noise may consist of media noise, crosstalk, electronic noise, and other noise characteristics to disk drive operation.

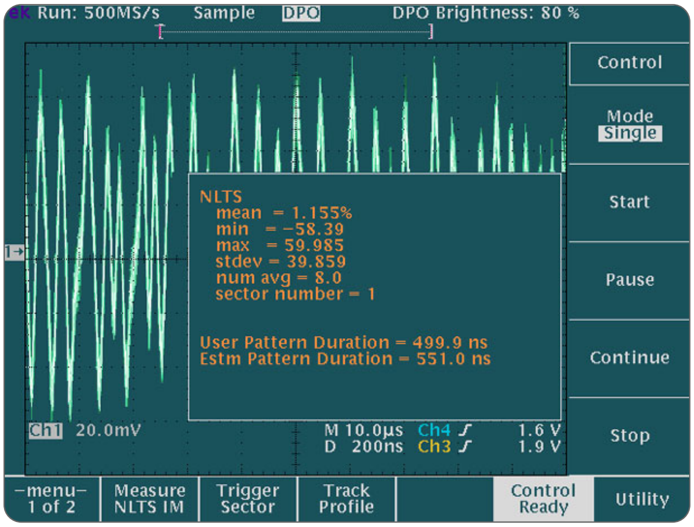
Because SNR is defined in terms of variances of the signal and noise, it is independent of DC offsets of the read-back voltage. The SNR measurement algorithm assumes that the acquired signal consists of a periodic signal and independent additive noise. The noise is assumed to be responsible for all the non-periodic behavior of the acquired waveform. Noise samples are assumed to be independent and identically distributed. The SNR measurement is defined as follows:

$$\mathrm{SNR} = 10 \,\mathrm{Log}_{10}\left(\frac{\sigma_s^2}{\sigma_n^2}\right)$$

where:

σ_s^2 is the variance of the noise-free periodic signal

σ_n^2 is the variance of the noise



▶ ***Figure 15.*** *Initial magnetization NLTS.*

In order to perform the measurement, a signal must be acquired containing at least three estimated periods of the waveform. The oscilloscope will examine the waveform using an estimated period length, supplied by the user, and then calculate a more exact period (see Figure 14). The user can specify a tolerance of up to 30% for the estimated period of the noisy periodic signal. The wide range of tolerance for the period estimation is very important because slight variations in disk rotation speed make it difficult for the user to provide an exact value for period length.

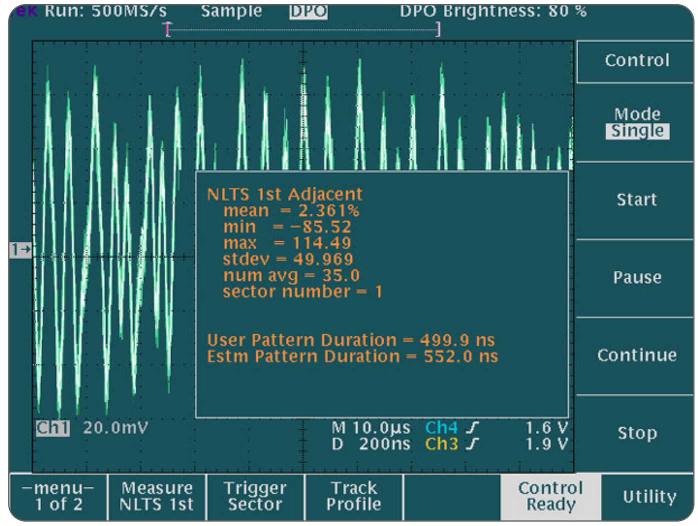
NLTS Measurement

The nonlinear transition shift (NLTS) measurement included in the TDSDMM1 software package enables the user to measure three types of NLTS on the media:

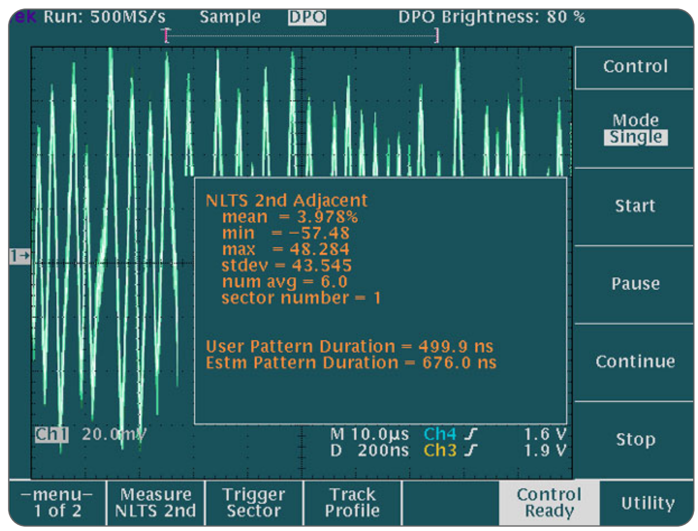
- Initial magnetization (DC erased)
- First adjacent transition
- Second adjacent transition

The initial magnetization of the media can affect the position at which transitions (reverses in magnetization) are recorded. Initial magnetization is characterized by a delay in a transition, occurring when the new transition reverses the direction of the previous magnetization (see Figure 15).

The second transition in a series of consecutive transitions is called the adjacent transition, or first adjacent transition. The first adjacent transition is characterized as follows: When write data requires transitions on consecutive data bits, the latter transition is shifted earlier in time. In other words, when one transition in a series occurs, then the following transition occurs earlier than it should (see Figure 16).



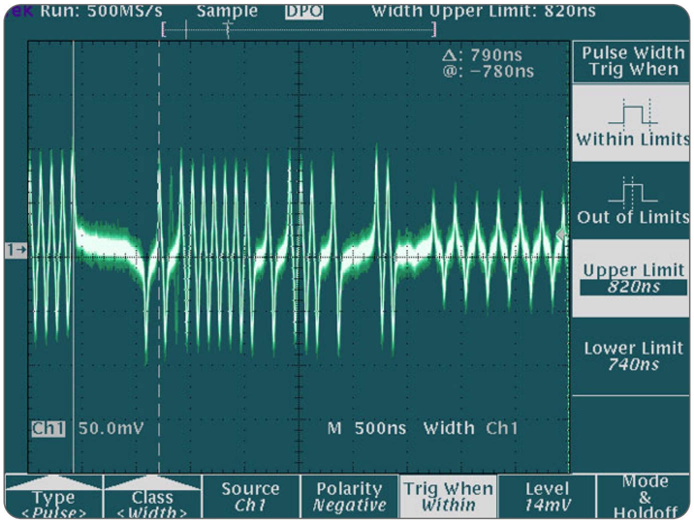
▶ ***Figure 16.*** *Adjacent transition NLTS measurement.*



▶ ***Figure 17.*** *SAT-NLTS measurement.*

Subsequent transitions in the series of consecutive transitions are grouped into the category called second adjacent transition. Second adjacent transitions are similar to first adjacent transitions. The difference is that the transitions are separated by two bit periods instead of one (see Figure 17).

In order to perform the measurement, a signal must be acquired containing at least three estimated periods of the waveform. The oscilloscope examines the waveform using an estimated period length, supplied by the user, and then calculates a more exact period. The user



▶ ***Figure 18.*** *Time qualified triggering (Pulse Width) used to discriminate portions of complex waveforms.*

can specify a tolerance of up to 30% for the estimated period of the noisy periodic signal. The wide range of tolerance for the period estimation is very important because slight variations in disk rotation speed make it difficult for the user to provide an exact value for period length, thereby causing inconsistencies in the measurement results.

When NLTS can be characterized, its effects can be mitigated with write pre-compensation.

Capturing Read-channel Errors

Since the data stored on a hard drive is not always continuous, capturing infrequent read-channel aberrations can be difficult. The solution is to selectively capture data using the advanced triggering functions of the Tektronix DPOs.

Traditional scope trigger circuits provide single level thresholds. In other words, the scope triggers if the input signal rises above or falls below the trigger voltage level. Tektronix TDS Series oscilloscopes offer this traditional single-level triggering with the Edge triggering function. In addition, the TDS Series oscilloscopes include a number of advanced triggering functions – including Pattern/State, Setup & Hold, Pulse Width, Glitch, Runt Pulse, Slew Rate, Serial Bit Pattern, and Time Out – that enable the user to isolate specific disk drive anomalies.

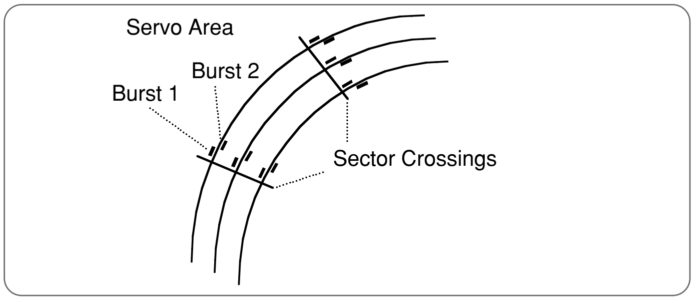
Runt pulse triggering is particularly useful for capturing read channel errors. With Runt pulse triggering, the scope triggers if a signal reaches a first voltage threshold but does not reach a second higher threshold. For example, runt triggering can be used to find only those pulses that fall between 50% and 75% of track-average-amplitude.

Time-qualified triggering functions – such as Pulse Width, Glitch, Setup & Hold, and Time Out – capture events that meet or do not meet selectable timing criteria. For example, the Tektronix DPOs can be set to capture only those pulses that fall between two pulse width thresholds. Time-qualified triggering can find missing, extra, and mistimed pulses in the data recovery channel.

In Figure 18, the Pulse Width triggering function was used to detect a predictable gap in the digital data stream. The nominal pulse width at the data output is 790 ns. The TDS794D was set to trigger on any data pulse shorter than 820 ns. Long record lengths with fast sampling rates preserve waveform details even after expansion. The pulse that initiated the trigger is clearly visible.

Read-channel Signal Spectrum

Spectral measurements in drive read channels have typically required a spectrum or network analyzer. Newer digital scopes provide built-in spectral analysis tools that increase your options. Sampling rates are now fast enough and record lengths long enough to provide sufficient frequency domain resolution. Digital signal processing techniques such as Fast Fourier Transforms (FFT) provide the basis for making spectral computations from time-domain waveforms. Skeptics of high-speed FFT analysis wonder whether or not the 8-bit A/D converters found in high-speed digital scopes provides sufficient dynamic range for frequency domain analysis. Theoretically, 8-bits provides only 48 dB of dynamic range. But when the FFT computes a magnitude, it multiplies a complex exponential by the data record and averages all the resulting samples. This results in magnitude values with resolution greater than 8-bits. In addition to the averaging inherent to the FFT function, the output magnitudes may also be averaged. This often results in additional dynamic range by lowering the noise floor by 10 to 20 dB.



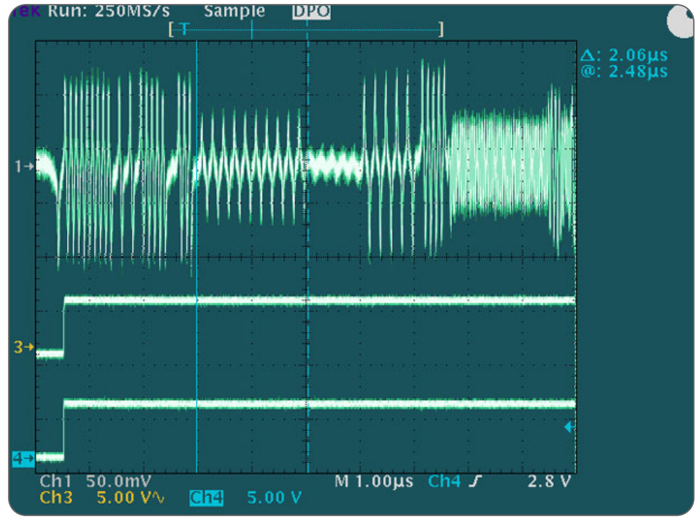
▶ ***Figure 19.*** *Block diagram of embedded servo signals.*

Servo Positioning

It's the servo positioning unit's job to keep the head centered over the track. In order to do that, disk drive manufacturers embed timing and positioning signals in each sector that provide the information the actuator needs to fine-tune the position of the read/write heads. The servo system uses the embedded positioning signals to create a position error signal that the actuator uses to dynamically reposition the heads.

Typically, embedded servo signals are placed on each side of the track at the beginning of each sector as shown in Figure 19. In this block diagram, BURST 1 is placed slightly on the outside the track; BURST 2 is placed slightly inside the track. When the read head crosses this area, the burst amplitudes are read. If the amplitudes of these two signals are the same, the read/write head is positioned correctly along the track's centerline. When the amplitude of one is larger than the other, the read/write head is positioned incorrectly and must be repositioned by applying a correctional voltage to the actuator. This correctional voltage is often referred to as the "Position Error Signal."

The TDS794D can be used to capture the position error signal for a full revolution, as shown in Figure 20. This screen shot shows both embedded servo signals: BURST 1 and BURST 2.



▶ ***Figure 20.*** *Embedded servo signals.*

Power Conversion Electronics

Disk drive designers sometimes need to analyze sources of loss in power conversion circuits to reduce unnecessary power consumption. They also need to verify that switching power supply components are operating within their safe operating areas during all phases of drive operation.

Accurately measuring dynamic parameters such as instantaneous power or transition loss requires an understanding of several measurement techniques. Since switching currents in the drive transistors have DC components, both AC and DC components must be measured. One solution, the A6302 current probe, has a DC to 100 MHz response when used with the AM503S current probe amplifier. The A6302 does not require an invasive shunt resistor in the circuit.

Measuring dynamic switching parameters such as Vc-e can be simple if the emitter is grounded on a low-side driver. But on high-side drivers or on floating voltages, you need to measure a differential voltage. In practice, the A–B or Channel 1 + Invert Channel 2 feature on most scopes can provide useful results. But to accurately characterize and measure parameters, you should use a true differential probe or a differential amplifier. This is increasingly relevant since faster switching devices challenge the matching performance of two independent scope channels or voltage probes.

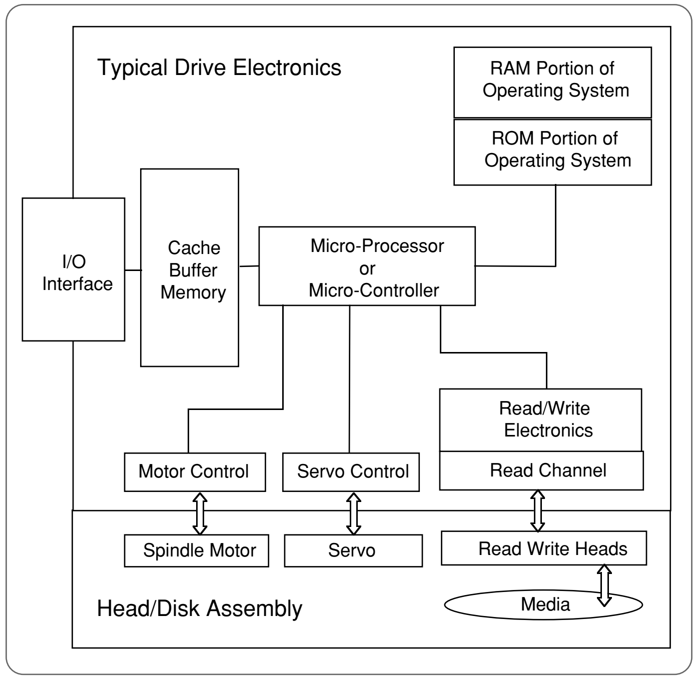
With proper probing established, how do you get accurate instantaneous power measurements when current and voltage probes are inherently different? Advanced digitizing oscilloscopes such as the Tektronix DPOs have the means to compensate for timing skews between input channels. The DPOs provide direct analysis of motor control currents, power consumption, efficiency, and other related measurements when configured with the P5200 high voltage differential probe and the AM503 current probe amplifier. A time-alignment function ensures accurate correlation of current and voltage fluctuations. This means that designers can now visualize and measure true instantaneous power waveforms without mentally adjusting for timing skews.

Digital Scopes and SOA Plots

Viewing I_c vs. V_{c-e} or I_{d-s} vs. V_{d-s} to verify transistor performance within safe operating area limits is a classic application of a scope's X-Y display mode. But check the horizontal bandwidth spec of your analog scope when it's in the X-Y mode – it's typically much less than the vertical bandwidth! This means that fast transitions that appeared to be correct in the normal Y vs. time mode will be misrepresented in Y vs. X mode.

Unlike analog oscilloscopes, digitizing oscilloscopes generally don't have this problem since both signals are captured with A/D converters up to the bandwidth of the scope. The Y vs. X display function is independent of the signal acquisition. However, timing skews introduced by probing techniques can still cause measurement errors. Digitizing oscilloscopes such as the Tektronix DPOs can correct up to 25 nanoseconds of timing skews between channels so that current vs. voltage plots are compensated for phase errors.

Instantaneous power is computed by the DPOs and displayed in real-time based on V_{c-e} and Ic with vertical units scaled in Watts. Automatic measurements track parameters such as maximum or average power through the transistor. I_c vs. V_{c-e} can be plotted in real-time with axes scaled in Amps and Volts in order to verify performance within safe operating area.



▶ ***Figure 21.*** *Block diagram of typical drive resident board.*

Startup Energy and Power Utilization

Designers working on disk drives destined for laptop computers are keenly interested in power consumption. Average active and quiescent current are readily measured using a multimeter. On the other hand, you need a DC current probe and a scope to accurately measure start-up and shutdown requirements. Scopes with built-in measurement functions can directly report peak and average current requirements. Scopes with integrated current measurement capability can directly report instantaneous power requirements in Watts.

After startup, interest turns to where the power goes. In most cases this involves magnitude relationships between signals. For example, dividing the instantaneous output power by the instantaneous input power results in a live display of conversion efficiency as a function of time Or, adding the 12 V power to the 5 V power results in a live display of total instantaneous drive power. But you need to carefully look at scale factors when combining waveforms. Digitizing oscilloscopes with integrated current probe amplifiers can greatly simplify power measurements because the scope can directly account for current probe scale factors and offsets.

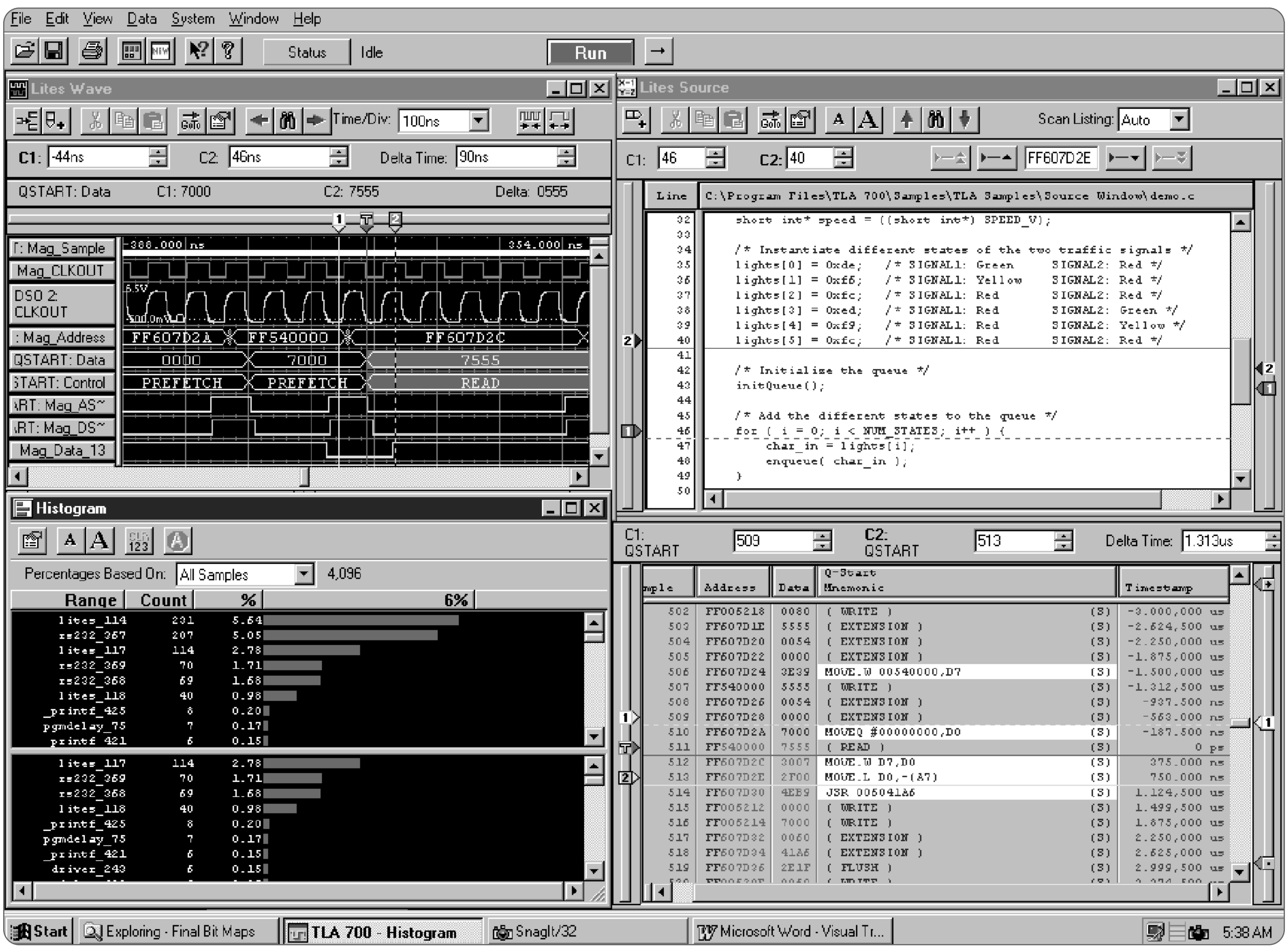
Embedded Processors and Digital Interfaces

Figure 21 shows a block diagram of a typical drive resident board showing disk drive major functional areas: heads and media; read/write electronics; servo positioning; motor-control circuitry; spindle motor; cache data buffer; an I/O section to communicate with the "outside" world via SCSI, IDE, or 1394 (Firewire); and an embedded microprocessor that controls the system.

Since a disk drive is an electro-mechanical device, there are certain performance constraints that a designer must make allowances for. This section provides an overview of the hardware/software integration task required that brings new disk designs to life.

Verifying embedded processor performance, as well as the performance of digital interfaces, requires both state and timing analysis. For example, SCSI bus state transitions are difficult to monitor by merely viewing rapidly changing bit patterns. Traffic is more easily analyzed if the changing patterns are directly decoded into meaningful displays for the designer. In addition, designers may need to measure variations in response time to interface commands or other actions that cause interrupts. This can be a difficult task unless the instrumentation directly measures and displays timing information.

Tektronix recognized this issue and equipped the TLA700 Series logic analyzers with their breakthrough MagniVu™ asynchronous over sampling architecture. This capability delivers 500 picosecond sampling



▶ ***Figure 22.** Embedded system development.*

resolution across all channels simultaneously. MagniVu provides sub-nanosecond timing information to support detailed timing verification simultaneously with state analysis on each channel without having to double-probe or use expensive timing modules.

Finding subtle timing problems – glitches, delays, or noise – is a straightforward process with sub-nanosecond resolution on all channels. Designers can determine the root causes of problems in detail across all channels precisely when they occur. The glitch detector, for example, can automatically hunt for glitches on every channel with sub-nanosecond resolution. When a glitch occurs, the detector triggers the analyzer. The designer can then see the number, width, and placement of glitches within the sample period.

Timing Verification

Asynchronous oversampling enables the TLA700 Series to produce extremely precise time stamps. This is an extremely important feature for characterizing timing relationships between channels. Time stamp values are derived by identifying the precise placement of the clock edge in the oversampled data stream of the specified clock signal.

Now designers can directly verify the design against detailed timing simulators, viewing the timing of clocks, data, and address signals with respect to each other and to asynchronous inputs. The capabilities of the TLA dramatically streamline the entire hardware/software integration process. Instead of using several instruments and having to struggle with multiple sets of probes, simply attach the TLA.

Embedded Systems Development

In embedded systems development, the designer needs to verify and troubleshoot the operation of the data, address, and control lines of the processor employed. To aid in this process, the TLA700 Series logic analyzer can be equipped with a customized processor development package designed specifically for the processor employed.

The Tektronix line of processor development packages provides support for a wide range of microprocessors, micro-controllers, DSPs, and busses from various manufacturers. Each development package speeds the process of embedded system development by allowing the designer the choice of viewing execution of the code in a high level programming language, machine code, or lower levels such as binary or hexadecimal. The development package automatically deciphers the acquired data from data, address, and control lines, then converts them into the desired format as defined by the user (see Figure 22).

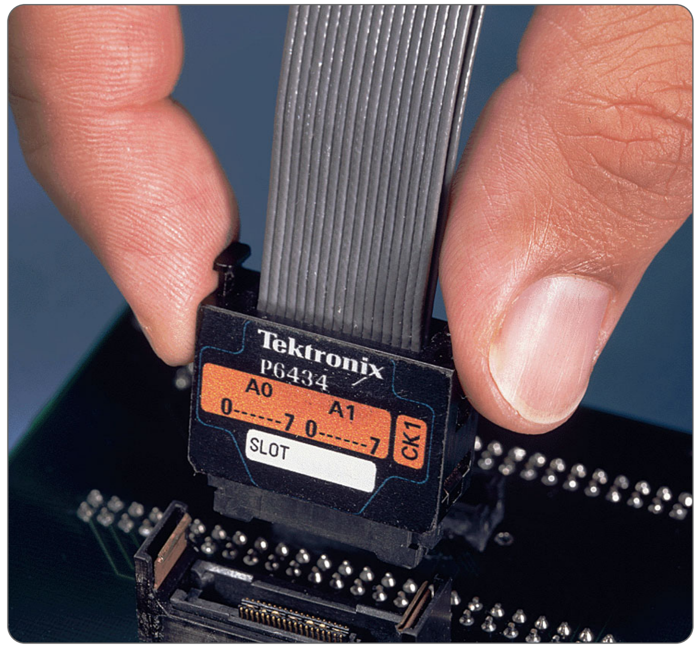


Figure 23. *High-density probe.*

Tektronix microprocessor development packages also facilitate the task of hardware/software integration. By displaying code execution as it is executed on the processor, development packages enable the TLA700 to display information that software and hardware engineers need to coordinate design activities. By using the capabilities found within the TLA, physical events can be time-correlated with the software execution in real time.

Probing Considerations

Connecting a logic analyzer to a modern processor design can be difficult without the proper probing solution. Hundreds of channels need to be attached to tiny, hair-like traces on a crowded circuit board. All it takes is one wrong connection to ruin a test.

In addition, advanced processors are less tolerant of the capacitive loads placed on them by 8 to 10 pF probes. The fast edges of today's microprocessor signals can cause reflections that noticeably distort signals.

To address these challenges, Tektronix has adopted an advanced probing solution for high-density, high-speed probing. The high-density probe incorporates a sophisticated mass-termination technology to deliver four times as many connections in the same area as traditional square-pin style probes (see Figure 23).

With a mere 2 pF capacitive load in a controlled impedance environment to minimize reflections, the high-density probe solution provides complete isolation between channels and shielding to prevent outside interference.

Conclusion

Tektronix' comprehensive combination of high-performance probes, oscilloscopes, arbitrary waveform generators, and logic analyzers gives you the ability to capture and analyze disk drive problems from the media to the read/write heads, and on to the read channel electronics, spindle motors, servo positioning circuitry, digital interfaces, and embedded processors. All Tektronix instruments work together to provide a complete disk drive measurement solution.

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