

## HARD DISKS - MR & PRML

Since its advent in 1955, the magnetic recording industry has constantly and dramatically increased the performance and capacity of hard disc drives to meet the computer industry's insatiable demand for more and better storage. Applications like multimedia, real-time video and audio, and graphical user interfaces, along with ever-increasing program sizes, are driving the need for ever-greater storage capacity.

**Magnetoresistive (MR) Heads :** The most economical and practical method for increasing hard disk drive capacities is to increase areal density — fit more bits of data onto the surface of the disk, as opposed to adding disks and heads to the drive. But as density increases, the bit patterns recorded on the disk necessarily grow smaller. This weakens the signal generated by traditional inductive technology read heads, making it difficult to properly identify the patterns.

Several methods have been used to combat this. For example, the head can be made to fly closer to the surface of the disk or the disk can be made to spin faster to increase the strength of the signal. Turns, or coils of thin copper conductors, can also be added around the head to boost the read signal (which increases proportionally to the number of turns).

Each of these solutions, however, has its drawbacks. Flying the head closer increases the risk of crashes. Speeding the disk strengthens the signal, but also increases data frequencies; and today's inductive heads cannot perform at very high frequencies. (An inductor resists high frequencies or AC and allows DC) Meanwhile, adding turns helps with

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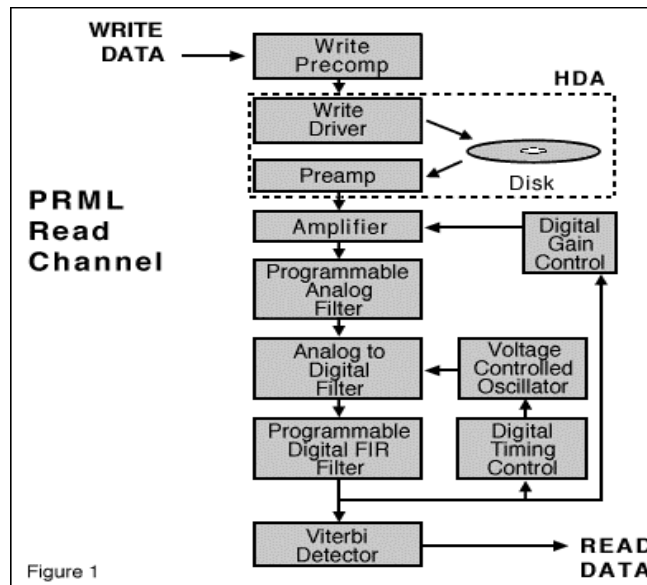
the read process but hinders the write process by limiting the frequency with which current reversal can occur for write operations.

MR heads, on the other hand, employ independent read and write elements, using an inductive element (with few turns relative to inductive heads) for write operations, and an independent MR element for read operations. The separate

read element can also be made narrower to better read tightly spaced data tracks, thus sidestepping the dangers of misalignment.

MR heads also produce a strong signal when reading extremely closely spaced bits, regardless of linear disk speed. This means that disks do not have to spin faster in order to accommodate increased density. But, if they do (in order to maximize data rates in high-performance drives), the write head can be optimized for high-frequency write operations without degrading readback performance.

**PRML Read Channels: Bringing Higher Densities and Performance:** PRML (Partial Response Maximum Likelihood) read channels are enabling users'



requirements for new drive products: higher data densities, improved drive performance, and high data integrity. PRML

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read channels represent a major technological advance over traditional peak detector read channels, where increased data densities or transfer rates may adversely affect data integrity.

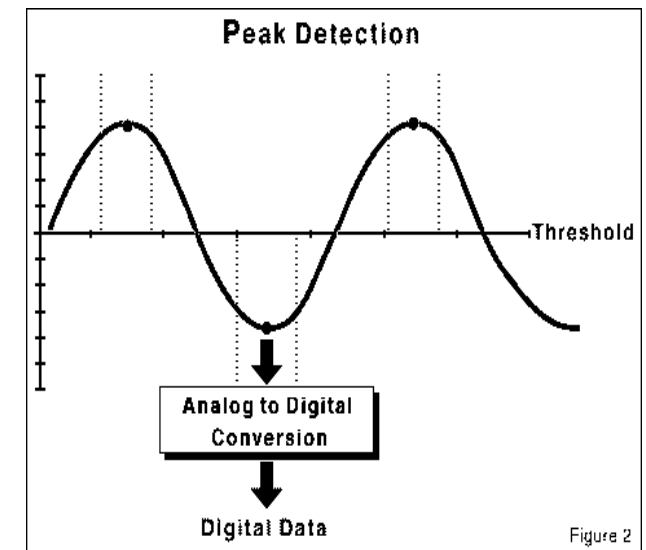
To understand PRML read channels, one must first consider the basic workings of traditional read channel designs.

Essentially, the read channel performs the data encoding and conversions needed to "write" information on a magnetic

medium (the disk), and then read that information with a high degree of accuracy. During a write operation, the encoded data is converted into an analog signal, which the drive's read/write head uses to cause magnetic flux changes, or changes in the magnetic patterns, on the drive's disks, hence "writing" data to the disk.

During a read operation, the read/write head "senses" the magnetic flux changes on the disk sector(s) to be read, then generates an analog readback signal that is transmitted to the read channel. The read channel detects the signal's peaks (each of which represents one bit), converts the data back into digital information, and finally decodes the data into its original sequence of 1s and 0s (see Figure 2 below).

**RLL and the Density Factor:** Central to a discussion of PRML read channels versus peak detection read channels is



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the particular data encoding scheme employed during write operations to facilitate data readback. Both types of read channels use a scheme called RLL, which stands for "Run Length Limited."

RLL encoding imposes constraints on the user data that will be written to the disk. For peak detection, these constraints are typically denoted as (1,7). Here, "1" means there must be at least one digital 0 between every digital 1 in the sequence

of bits in a data stream. This translates into at least two encoded-bit time periods between every magnetic flux change. It also means that the peaks in the analog readback signal will occur at least two encoded time periods apart.

The "7" in the (1,7) constraints means there can be no more than 8 of these encoded-bit time periods between magnetic flux changes. The peaks in the readback signal thus will occur no later than eight encoded time periods apart.

The RLL 1,7 constraints, then, are what separate the peaks in a peak detector read channel and reduce ISI during readback of user data. (At high data rates, the analog signal

"peaks" that are detected during read operations tend to stream through a drive's read/write head. There is a possibility that the signal peaks will significantly overlap - i.e., create ISI -Inter Symbol Interference) These constraints ward against bit errors very effectively; the downside is that the requirement for two encoded time periods between flux changes eats up disk space. The result: for hard drives that use peak detection, the ratio of user data to stored data on the drives' disks is only 2-to-3.

**A More Efficient RLL Encoding Scheme :** In today's most advanced PRML read channels, (0,4,4) constraints replace the (1,7) constraints during data write operations. Here, the "0" means that the digital 1s in a data stream can occur right next to each other. Hence the magnetic flux changes on the disk can occur with just one encoded-bit time period between them, and the peaks in the analog readback signal are not separated.

The first "4" in the encoding constraints means there can be no more than four digital 0s between digital 1s in a data stream, or no more than six encoded-bit periods between flux changes. (The latter "4" refers to the maximum number of 0s

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between 1s that can occur in certain data subsequences, a constraint that simplifies implementation of digital data-sequence detection.)

The result of this more efficient PRML encoding scheme is that the user data to stored data ratio is increased to 8-to-9.

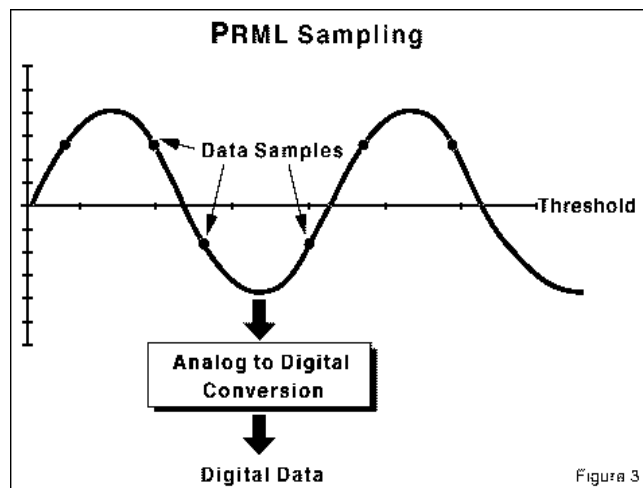
**PRML Read Channel Operations:** Now the question becomes: how can a PRML read channel deliver the same low bit error rate as a peak detector read channel if its encoding

scheme does not separate the peaks in the analog readback signal? The answer rests with the PRML read channel's advanced digital filtering, data processing, and data feedback techniques, which "shape" the readback signal so that the data written to the disk can be accurately detected by the read channel's Viterbi detection circuitry.

PRML read channel operations (simplified) include the following key steps, which occur prior to Viterbi detection:

- Ongoing sampling of the analog readback signal to extract various points along the waveform (peak detection, by contrast, looks only for the peaks) (see Fig 3). Analog

signals are sampled at various points and then converted to digital data.



- Conversion of these analog values into digital data samples.

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- Filter equalization of the digital data samples. The filter modifies the data samples so that they cluster around three target values: zero, a negative value, and a positive value.

The filter also modifies the sine wave components of the analog readback signal in order to produce a particular signal shape. (This step is analogous to the functions of a stereo system's equalizer, which modifies sine wave components - bass and treble - to produce a particular "shape" or desired sound.)

- Ongoing processing and feedback of the filter's output to several of the read channel's front-end analog components, while analog-to-digital conversion continues to take place. These operations ensure that the analog signal will exhibit the needed characteristics for analog-to-digital conversion, and that sampling of the signal will take place during a specified timing window.

As a result of these steps, the digital data samples will exhibit the frequency domain and time domain characteristics required by the Viterbi detector.

**Viterbi Detection :** The essential difference between peak detection and Viterbi detection is that peak detector circuitry detects one data bit at a time, while the Viterbi algorithm detects an entire sequence of bits at a time.

When the digital circuitry that performs Viterbi detection receives a data sample, it doesn't have to decide immediately whether the sample represents a "1" or a "0" in the original write data. Instead, it compares sequences of samples with sequences of possible samples. It then uses the comparison to determine what an entire sequence of data bits must be.

After Viterbi detection, the PRML read channel decodes the data into the original user data sequence that the host system had transferred to the hard drive.