Signal Amplitude and Head Geometry Measurement Accuracy Delivered by Digital and Analog Methods

October 24, 2006

1. Introduction

Guzik RWA-2000 series with D5000 Digital Signal Analyzer provides several methods for the read-back signal amplitude measurements. They are:

- Traditional RWA-2000 peak-detector TAA measurement, sometimes referred as *Analog* method, see *Appendix A* for the description of this method. It will be called ***Peak Detector*** throughout this document.
- Digital parametric measurement based on D5000 Pulse/Slope Profile algorithm. This algorithm first averages all pulse pairs (or slopes) for the whole revolution, then measures amplitude of the averaged pulse profile, see *Appendix B* for the description of this method. It will be called ***Profile*** throughout this document.
- Digital parametric measurement based on D5000 ***One-Shot*** algorithm. This algorithm measures amplitude of single pulse pairs (or slopes), then averages these "instantaneous" amplitude samples for the whole revolution. This digital method is very similar in measurement concept and results to analog peak detector, because it detects individual pulse peaks and calculates their average. It is designed to measure amplitude of a specific category of patterns – non-periodic patterns (for example, pseudo-random PRML patterns). This method is sensitive to noise, and therefore is not recommended for use. To achieve the best accuracy of amplitude measurements Guzik recommends using digital Profile method with periodic patterns.
- Traditional spectral harmonic amplitude measurement through Guzik RWA-2000 Spectrum Analyzer with resolution bandwidth 100kHz. It will be called ***Spectrum Analyzer*** throughout this document.
- Digital spectral harmonic amplitude measurement using D5000 Digital Fourier Transform (***DFT***) method. This digital method for all practical purposes is similar in measurement concept and results to RWA-2000 Spectrum Analyzer. Please note that the D5000 DFT measurements are much faster comparing to Spectrum Analyzer. Guzik recommends using DFT method to achieve maximum test execution speed.

All these methods have their own properties and unique behavior when applied to different signal types, and signals with different signal-to-noise ratios. Some methods exhibit very high immunity to noise, which means that the presence of noise does not significantly affect the accuracy of the measurements. Some methods are narrow-band, which means that they analyze the signal only in the relatively narrow frequency band. This behavior affects the accuracy of the amplitude measurements, and also the accuracy of the head geometry measurements, such as the head write width and the head read width.

The Table 1 below provides a brief summary of the measurement methods, which are reviewed and compared in this document:

Method	Hardware	Noise Immunity	Bandwidth	Description
Peak Detector	RWA-2000 (Analog)	Low	Wide Band (defined by parametric filter)	TAA measurement using peak detector. Peak detector envelope is digitized and averaged to obtain TAA, see Appendix A.
Profile	D5000 (Digital)	High	N/A	Pulse/slope positions are detected in digitized signal. Then individual transitions are averaged to obtain the averaged pulse/slope shape. The TAA is calculated as an amplitude of the averaged shape, see Appendix B.
Spectrum Analyzer	RWA-2000 (Analog)	High	Narrow Band (100kHz)	Signal is selected by spectrum analyzer with resolution bandwidth 100kHz and then supplied to the synchronous detector. The output of the synchronous detector is digitized and averaged to obtain TAA.

Table 1: Signal Amplitude Measurement Methods Comparison

The purpose of this paper is to compare the accuracy of all these methods and their influence on the head geometry measurements with different noise levels, and different types of analyzed signals, particularly, with sine-wave signal, perpendicular isolated transitions, and longitudinal isolated pulses.

Section 2 analyzes the influence of noise on signal amplitude measurements. It shows that different measurement methods deliver different accuracy on noisy signals, and analyzes the causes.

Section 3.2 analyzes the influence of the signal amplitude measurements accuracy with the presence of noise on the head geometry measurements. It will be shown, which method delivers the best head geometry measurement accuracy on noisy signals and for perpendicular recording setups.

Section 3.3 contains results acquired on the V2002 spinstand with typical perpendicular recording setup.

Section 4 provides a summary of results.

2. *Influence of Noise on Signal Amplitude Measurements*

Different signal amplitude measurement methods exhibit different sensitivity to noise, which means that the presence of noise affects the accuracy of the measurement differently. This section analyzes the dependency between the amplitude measurement accuracy and the signal-to-noise ratio for different methods and for different signal shapes.

2.1. Measurement Setup

System setup:

Guzik Tester Model	RWA-2002 with D5000
Signal Source	Guzik WG-5000
Filter	LPF Butterworth, 900MHz cutoff
D5000 Sampling Rate	10 Gsamples/s
Peak Detector Charge Time	Auto
Peak Detector Time Constant	12 μSec

The following signal shapes have been tested:

- Sine-wave signal, 250 MHz frequency
- Isolated longitudinal pulses, 1ns bitcell, 62.5 Mflux/s flux rate
- Isolated perpendicular transitions, 1ns bitcell, 62.5 Mflux/s flux rate

The arbitrary waveform generator (AWG) Guzik WG-5000 is used to generate signals with known pulse shapes and with programmable level of white noise. The noise level is changed on AWG and mixed with the signal, such that the signal parameters (amplitude and shape) remain the same at different noise levels.

The “ideal” test system should report the same actual value of the signal regardless of the noise level. The following methods are compared to understand which one is more accurate:

- Peak Detector (analog)
- Profile (digital)

The TAA and SNR are measured for each noise level. The TAA is measured by these two methods. The SNR is measured by SpiSNR test in 1-900 MHz band.

2.2. Results

Figure 1, Figure 2, and Figure 3 show how the TAA measured by different methods varies when the noise level is increased.

It can be seen that the Profile method produces very consistent TAA measurements down to 6dB SNR regardless of the pulse shape. This method provides the best accuracy comparing with all other methods.

The analog Peak Detector method tends to increase TAA result on higher noise levels. This is well known effect, when the noise spikes charge the peak detector, and the envelope amplitude exceeds the amplitude of the signal covered with noise.

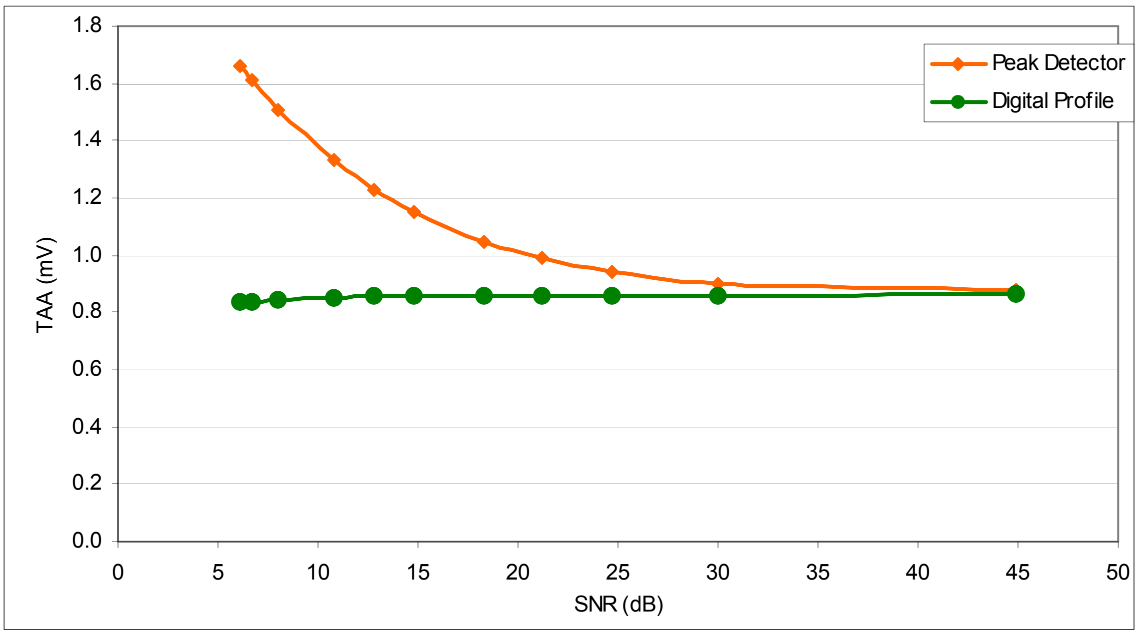

Figure 1: TAA vs. SNR. Sine-wave signal, 250 MHz, 0.85mV.

This effect manifests differently on different pulse shapes. It is especially pronounced on sine-wave and perpendicular signals. This is because these signals have prolonged high amplitude areas, where the noise spikes can charge peak detector above the signal amplitude. Contrary, the longitudinal isolated pulses have relatively short high amplitude areas, so the probability of the noise spike to occur on a top of the peak is much lower than to occur on a top of the perpendicular shape plateau. Therefore, the peak detector charge by the noise is not that big.

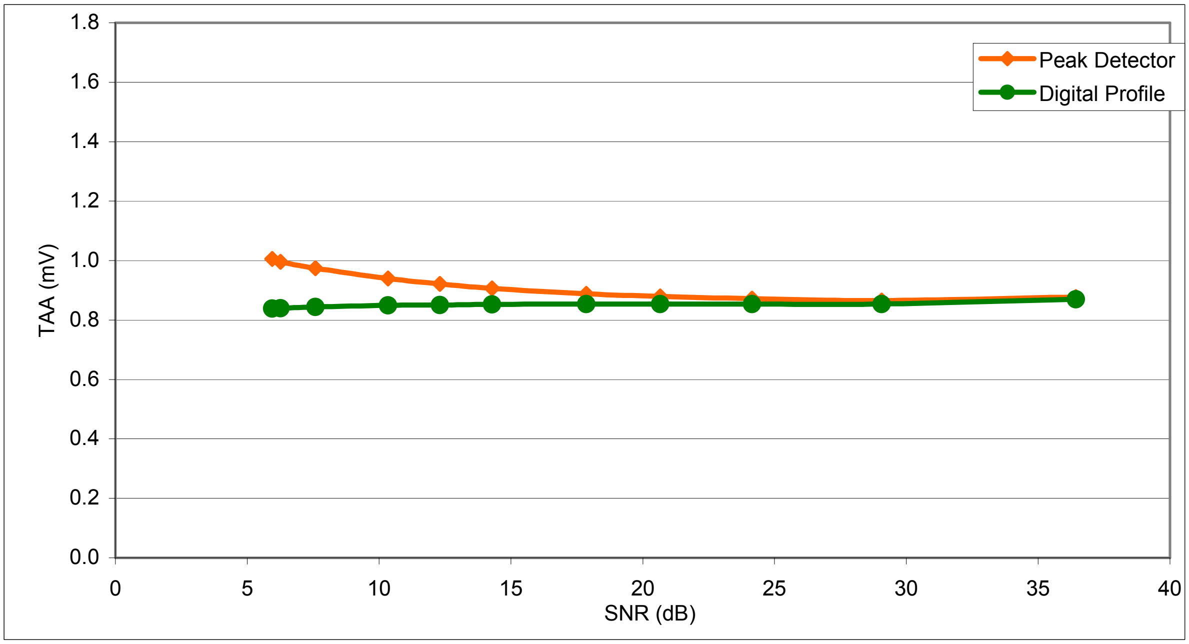

Figure 2: TAA vs. SNR. Longitudinal Signal, 0.85mV.

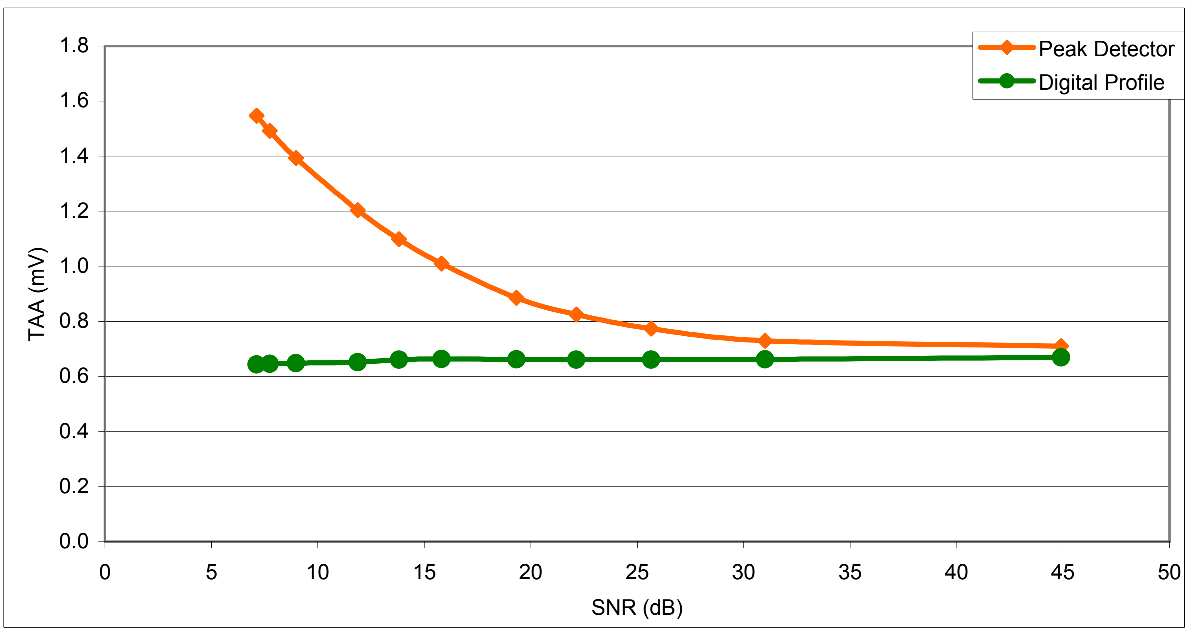

Figure 3: TAA vs. SNR. Perpendicular Signal, 0.65mV.

3. Head Geometry Measurements

As it was described above, digital Profile method can reliably detect signals with SNR ratio 6 dB or lower. This may not seem very important for on-track measurements, because the Spectral SNR values for typical PMR heads are around 15 dB. However, it becomes extremely important when the head goes off-track to build a track profile to measure head geometry, including head writer width and reader width.

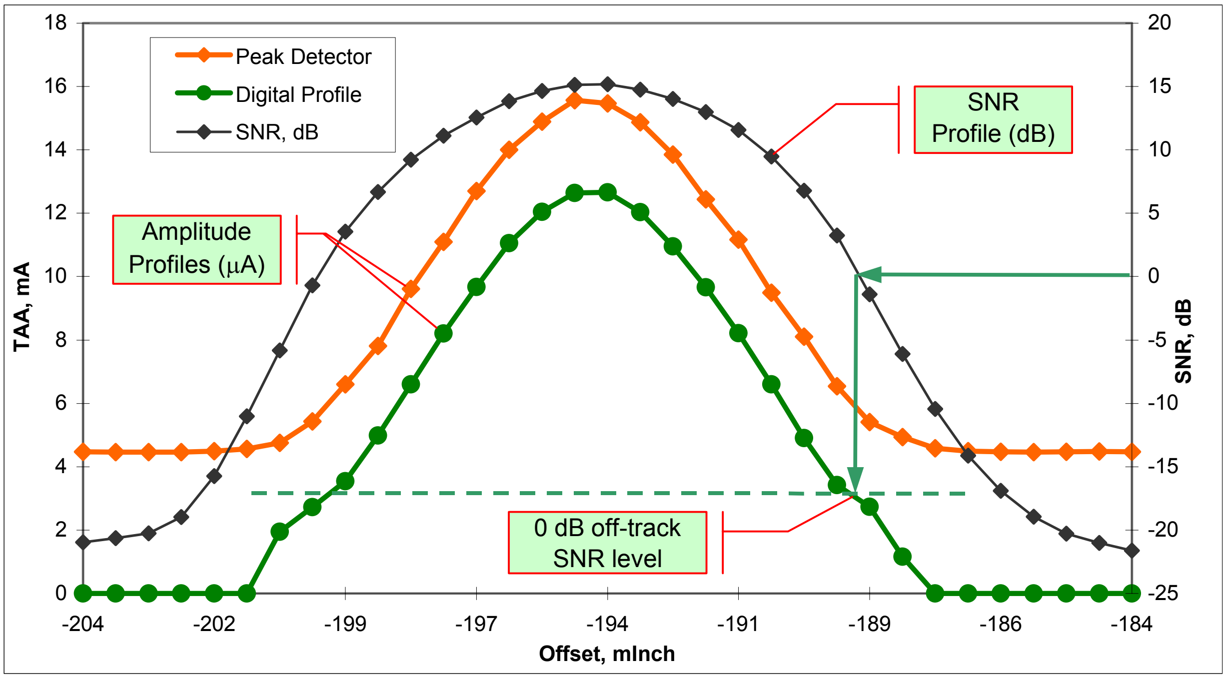

Figure 4: TAA and SNR track profiles. Isolated perpendicular transitions.

The figure above shows the Amplitude and SNR track profiles. The top black curve is the SNR profile. As you can see this head delivers reasonable 15 dB on-track SNR measured by spectral method (SpiSNR). When the head goes off-track, the SNR ratio degrades. Zero SNR point corresponds to approximately 25% amplitude level measured by the digital Profile method. Below this point the power of signal drops below the integral power of the noise, and SNR values become negative numbers. It is clear that for reliable track profile slope detection the test system must be able to measure signal with SNR levels much lower than 15 dB.

It is also very important to select appropriate threshold levels for track profile slope interpolation in order to calculate head read width and write width. Figure 4 above shows that the points below 0 dB SNR level cannot be measured reliably even by the digital Profile method. When the signal power drops below noise power, the transition detector and PLL stability degrades. Please always keep off-track SNR values in mind when selecting amplitude thresholds for track profile slope interpolation, which typically should not be lower than 25%.

3.1. Factors Affecting Head Geometry Measurement Results

There are two major factors affecting head geometry measurement results:

- SNR level decreases when head goes off-track – the signal level reduces, while the noise level remains about the same. As the result, different signal amplitude measurement methods will deliver different accuracy, as was shown in Section 2. This, in turn, affects the head geometry measurement results. Comparison of measurement methods was performed using a simulated track profile signal, provided by the Guzik WG-5000. Please refer to Section 3.2 for details.
- The read-back pulse shape changes when head stays on-track and at different off-track offsets. As a result, different methods may give different results of the head geometry measurements. Comparison of measurement methods was performed using signal coming from the head, installed on Guzik V2002 spinstand. Please refer to Section 3.3 for details.

3.2. Head Geometry Measurements on Simulated Signals

3.2.1. Measurement Setup

The measurement is performed on generated signals from the Guzik WG-5000. The setup is the same as described in Section 2.1. The following signal shapes have been tested:

- Sine-wave signal, 250 MHz frequency
- Isolated perpendicular transitions, 1ns bitcell, 62.5 Mflux/s flux rate

To simulate the track profile, Guzik WG-5000 was programmed to generate pre-defined signal levels at different offsets:

Offset	Amplitude	Offset	Amplitude
0	**0**	12	**0.39**
1	**0**	13	**0.35**
2	**0.01**	14	**0.3**
3	**0.05**	15	**0.25**
4	**0.1**	16	**0.2**
5	**0.15**	17	**0.15**
6	**0.2**	18	**0.1**
7	**0.25**	19	**0.05**
8	**0.3**	20	**0.01**
9	**0.35**	21	**0**
10	**0.39**	22	**0**
11	**0.4**		

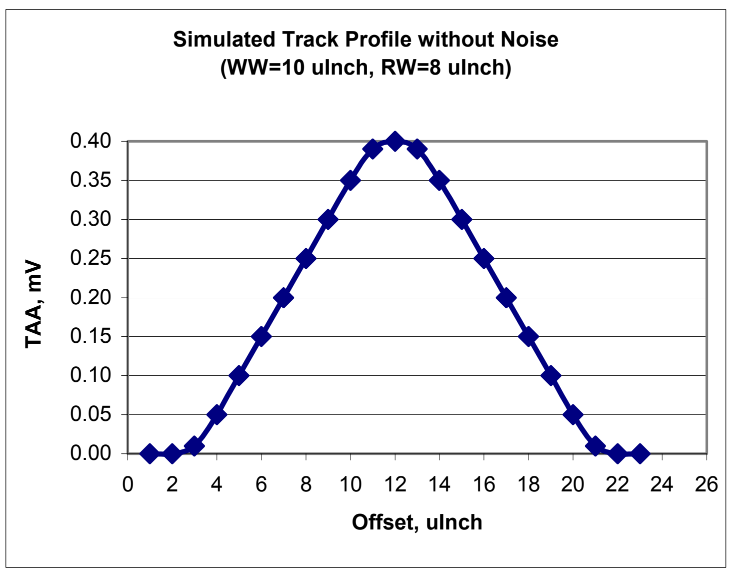

Figure 5: Simulated Track Profile.

The resulting Write Width of this profile is 10 µInch, and the Read Width is 8 µInch. Then the noise of various levels was added to the signal, simulating heads with various SNR values.

The "ideal" test system should report the same actual Write Width and Read Width regardless of noise level. The following methods are compared to understand which one is more accurate:

- Peak Detector
- Profile
- Spectrum Analyzer

3.2.2. Results

Figure 6 shows how the read width and write width varies with the noise level for the sinusoidal read-back signal.

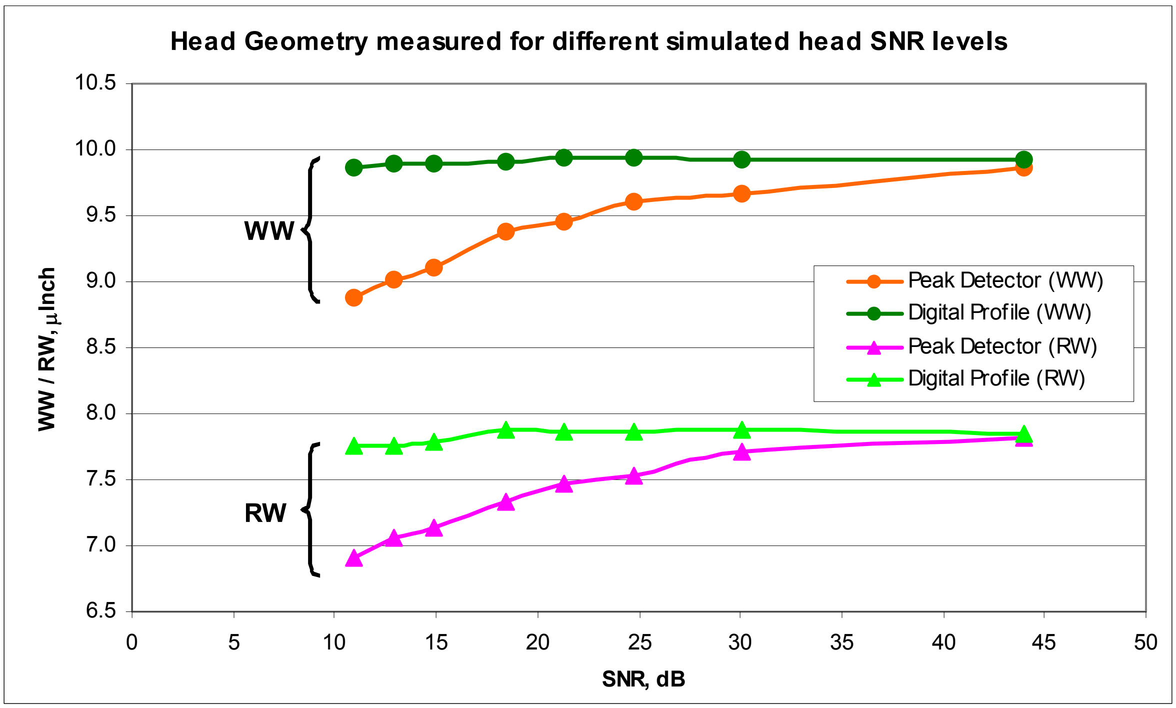

Figure 6: Head Geometry measured for 250 MHz sine-wave signal.

Figure 7 shows how the read width and write width varies with the noise level for the perpendicular shape isolated transitions signal.

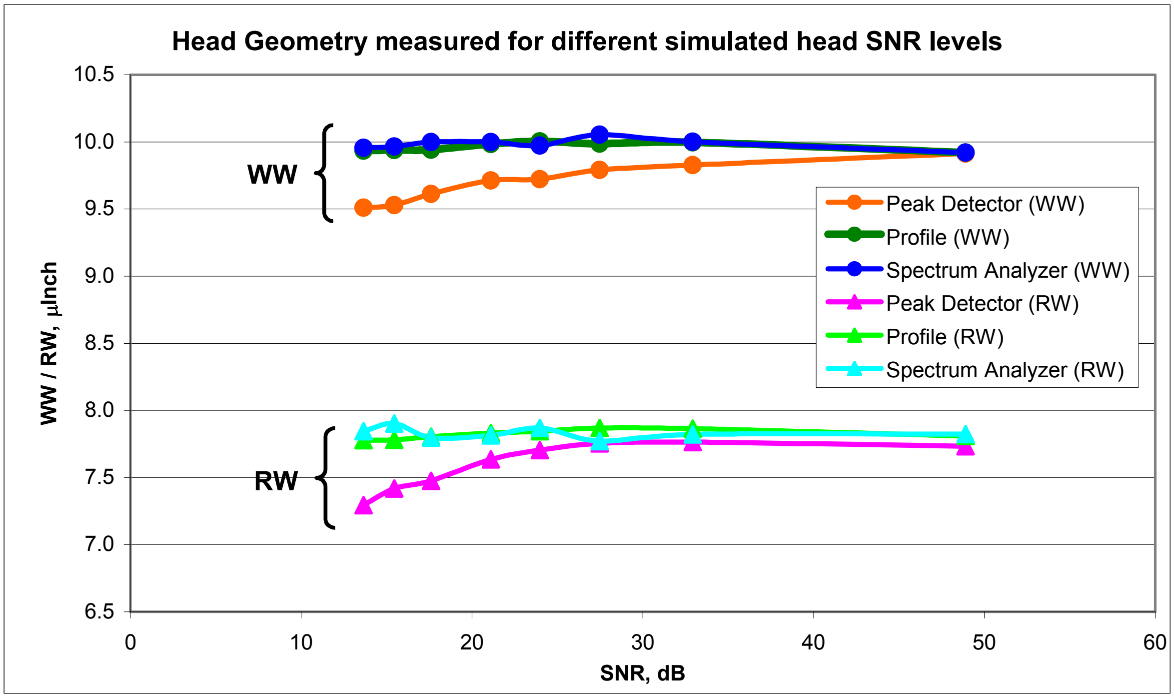

Figure 7: Head Geometry measured for isolated perpendicular transitions.

As you can see, the Profile method produces very consistent head geometry regardless of the pulse shape. This method provides the best accuracy comparing with all other methods.

3.2.3. Influence of Noise on Head Geometry Measurements

This section explains why the head write and read width measured by Peak Detector tend to be smaller than the same values measured by digital Profile method. The simplified head model is used to illustrate the effect, see Figure 8.

The red shaded area of *WW* size is the written area of the track, WW is the width of this area, which in our simple model is equal to the head write width. The green rectangles R1–R8 of *RW* size are the consequent positions of the head read element during the track profile measurement. The RW is the width of the magnetic field sensitive area of the read element, which in our simple model is equal to the head read width. For this illustration we will consider that the spinstand offset position is the middle of the read element.

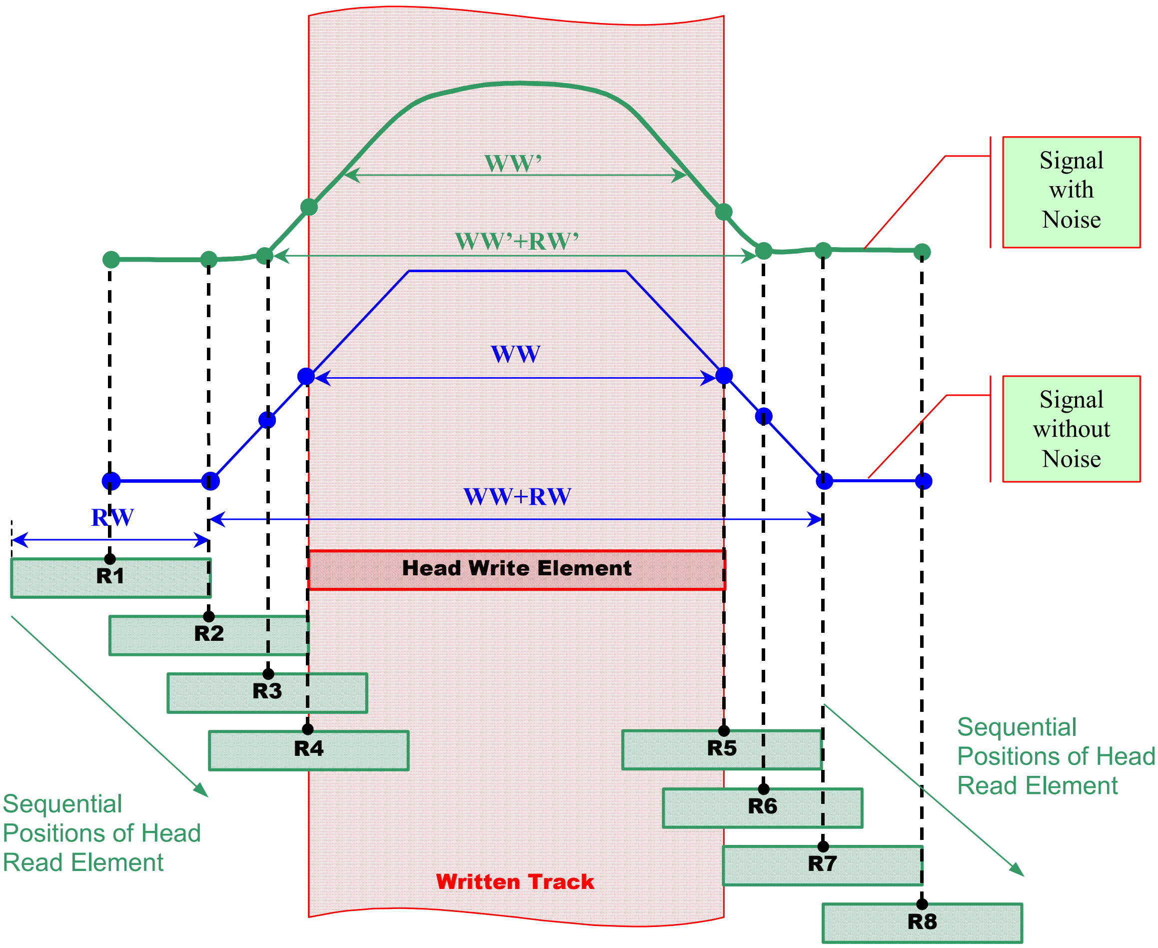

Figure 8: Head Geometry Measurement Algorithm

Lets first consider an ideal case, where no noise is present (lower blue trapezoid shape curve on the drawing). When the read element does not overlap with the written area (points R1, R2, R7, and R8), the read element measures zero. When the read element starts to overlap with the written area (point R3), the measured signal amplitude starts to increase. In our simplified model it increases linearly, proportionally to the area of the read element overlapped with the written area. It reaches the 50% level (point R4), when the read element is halfway inside the written area. On the right slope the situation is symmetrical: the amplitude starts to decrease to 50% level (point R5), reduces further when the read element goes out of the written area (point R6), and becomes zero when the read element completely leaves the track (point R7).

As seen from the figure above, the distance R4-R5 (track profile width at 50% amplitude level) is equal to WW. The distance R2-R7 (the bottom of the profile) is equal to WW+RW.

Now lets consider the situation, when the noise is present in the signal (upper green curve on Figure 8). In this case the off-track amplitudes will not be zero, but equal to some value, which depends on the noise power (points R1, R2, R7, R8). The higher the noise, the bigger this value is.

If the signal amplitude at point R3 exceeds the noise level, then the amplitude at point R3 measured by the wide-bandwidth measurement device such as peak detector will be bigger, than at points R1 and R2. But if the signal level is completely under noise level, the amplitude at point R3 *will be close to the amplitude at points R1 and R2*. The peak detector will not be able to extract the signal from the noise, and will measure the amplitude close to the noise level. This effect will reduce the width of the lower base of the trapezoid, and therefore will reduce the measured write width WW' and read width RW'. Please note that the noise-immune measurements such as Digital Profile, or narrow-band spectral measurements, do not exhibit this behavior. Therefore, these methods are more accurate for the head geometry measurements in presence of high noise, which is the case for perpendicular recording setups.

Figure 9 and Figure 10 demonstrate this effect for the signals simulated on Guzik waveform generator WG-5000. The generated sine-wave signal with the amplitude, which varies from offset to offset, produces the "ideal" profile. The noise with different power is then mixed with this signal, simulating heads with different SNR value ranging from 11dB to 30dB. The track profile via analog Peak Detector is measured for each value of the noise power, see Figure 9.

Figure 10 shows zoomed area of the left part of these track profiles. Points 1 and 2 are the first points with non-zero signal amplitude on the track profile without noise. Their measured amplitudes are clearly bigger than the amplitudes of the off-track points to the left of them. But the amplitudes at points 3 and 4, measured at the same offsets for the track profile with noise, are almost the same as the amplitudes of the off-track points. This is because the noise added to the signal exceeds the signal at these points, and the peak detector is unable to separate the noise from the signal. The lower base width of the track profile is reduced, and the write width is measured smaller than expected.

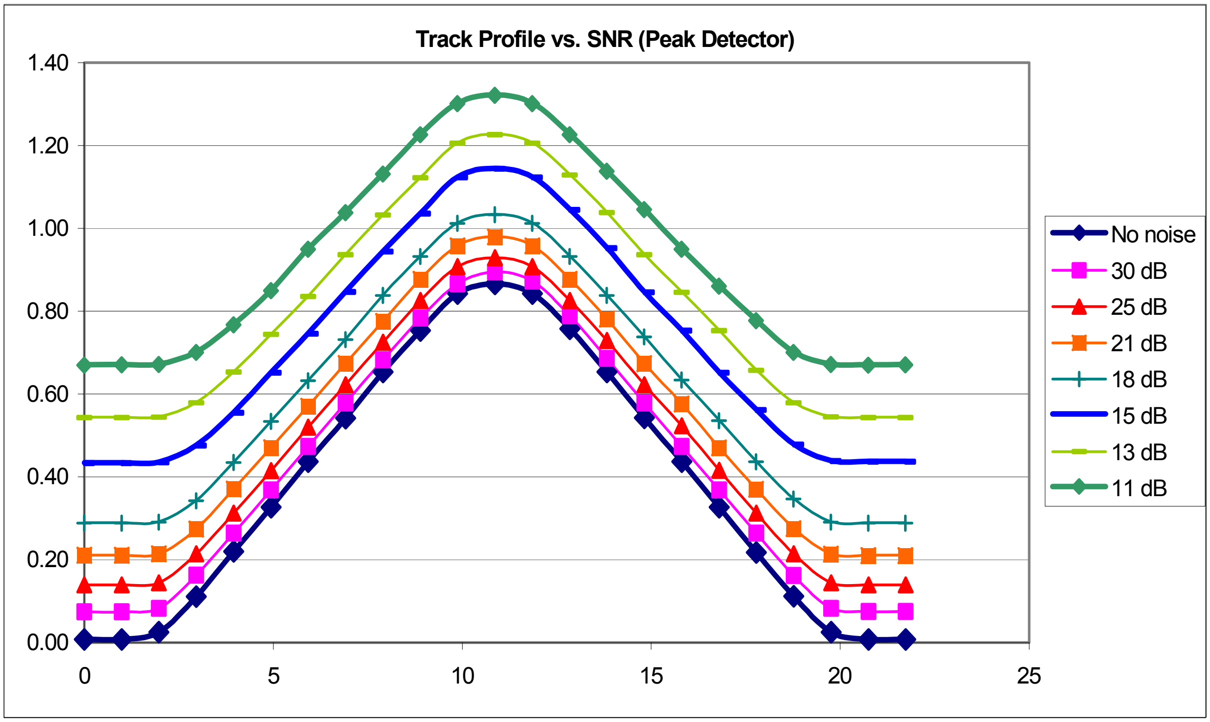

Figure 9: Track profiles shapes with different SNR

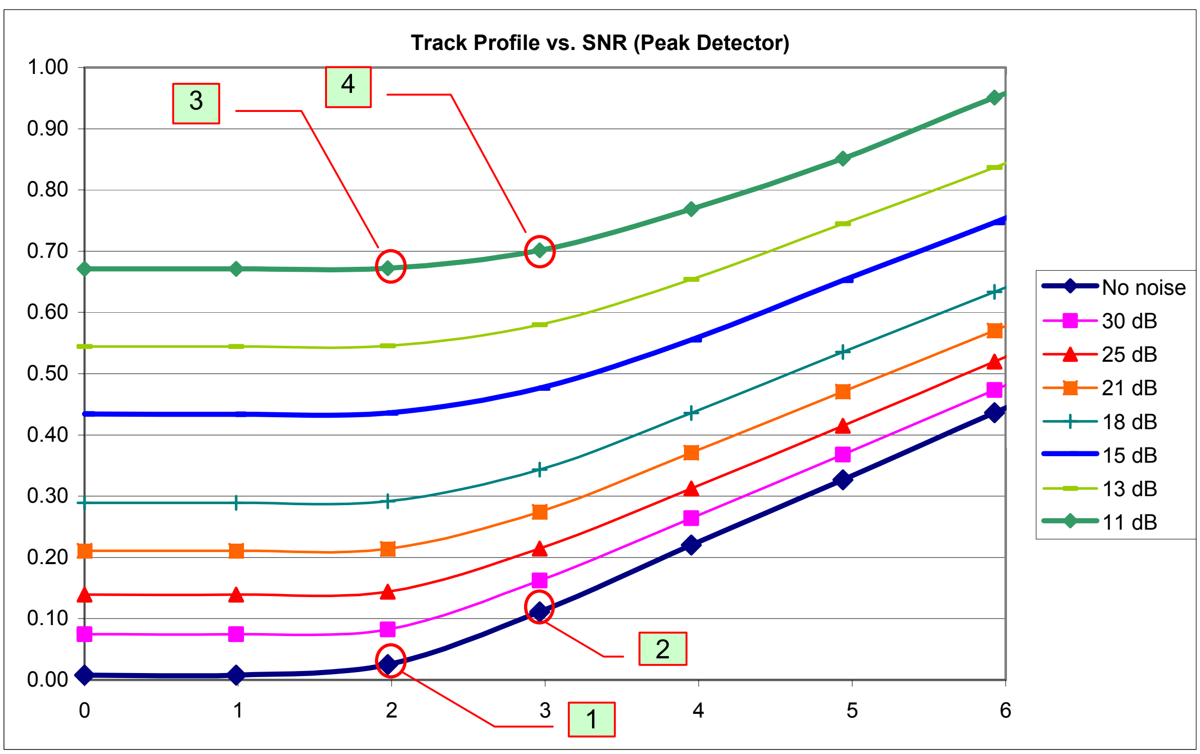

Figure 10: Track profiles shapes with different SNR (zoomed-in)

3.3. Head Geometry Measurements with Actual HGA on V2002 Spinstand

This section provides results obtained on a typical perpendicular recording configuration.

3.3.1. Measurement Setup

System setup:

Guzik Tester Model	RWA-2002 with D5000
Signal Source	Perpendicular Recording HGA
Filter	LPF Butterworth, 500MHz cutoff
Test signal	62.5 Mflux/s
Sampling Rate	10 Gsamples/s

3.3.2. Results

Figure 11 shows the average transition shapes at different offsets from the center of the track. This result demonstrates that the signal shapes, and therefore the spectral content, is different at different offsets.

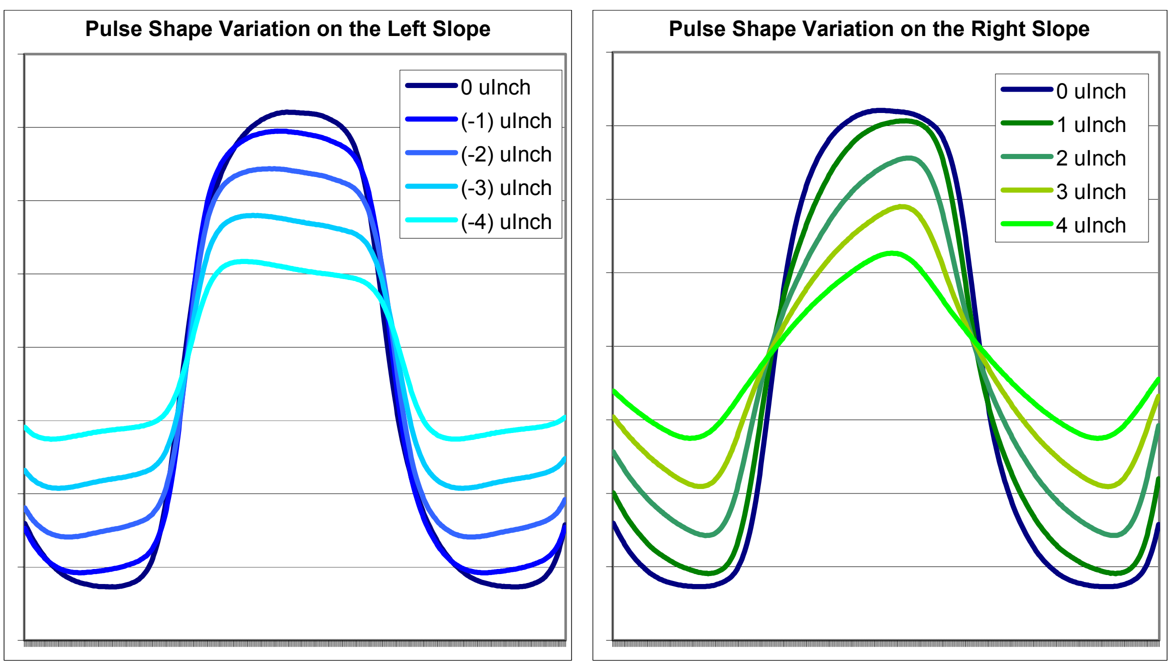

Figure 11: Pulse shapes at different offsets on the left and the right slopes of track profile

The narrow-band Spectrum Analyzer method will measure signal amplitude as amplitude of the first harmonic of the signal. Wide-band methods (Peak Detector and Profile) measure maximum amplitude, which includes all harmonics. The result reported by those methods will be different.

It is your choice what definition reflects signal amplitude for off-track measurements better. However, it is clear that one of the noise immune methods should be used, i.e. Digital Profile or Spectrum Analyzer.

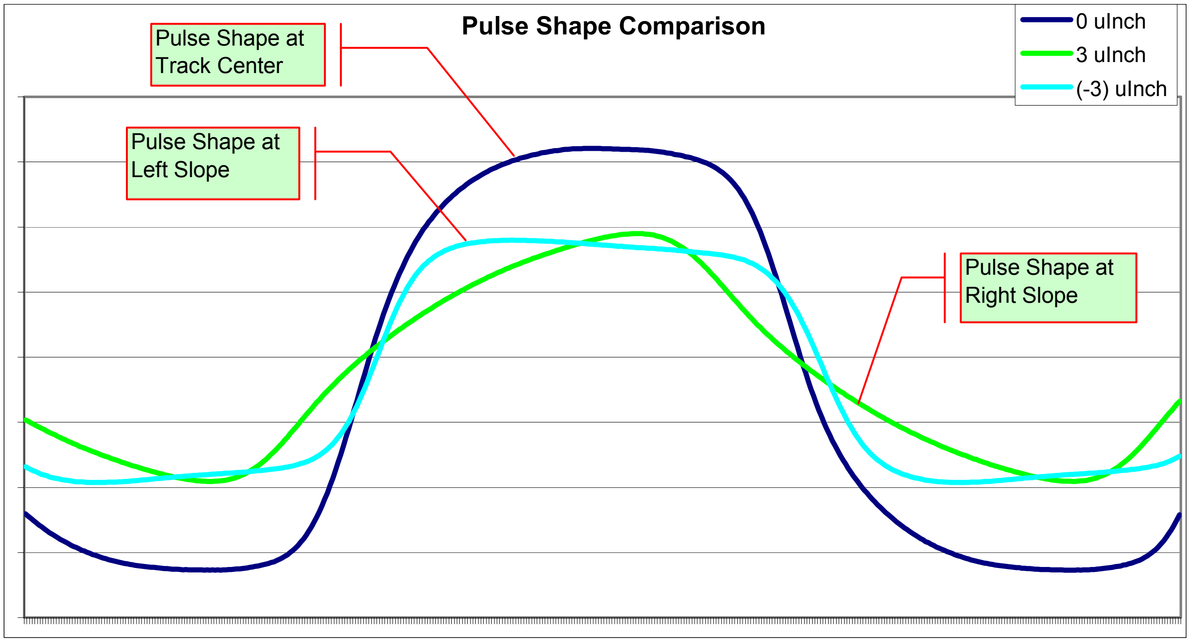

Figure 12: Pulse shape comparison

Figure 13 and Figure 14 show track profiles measured by different methods.

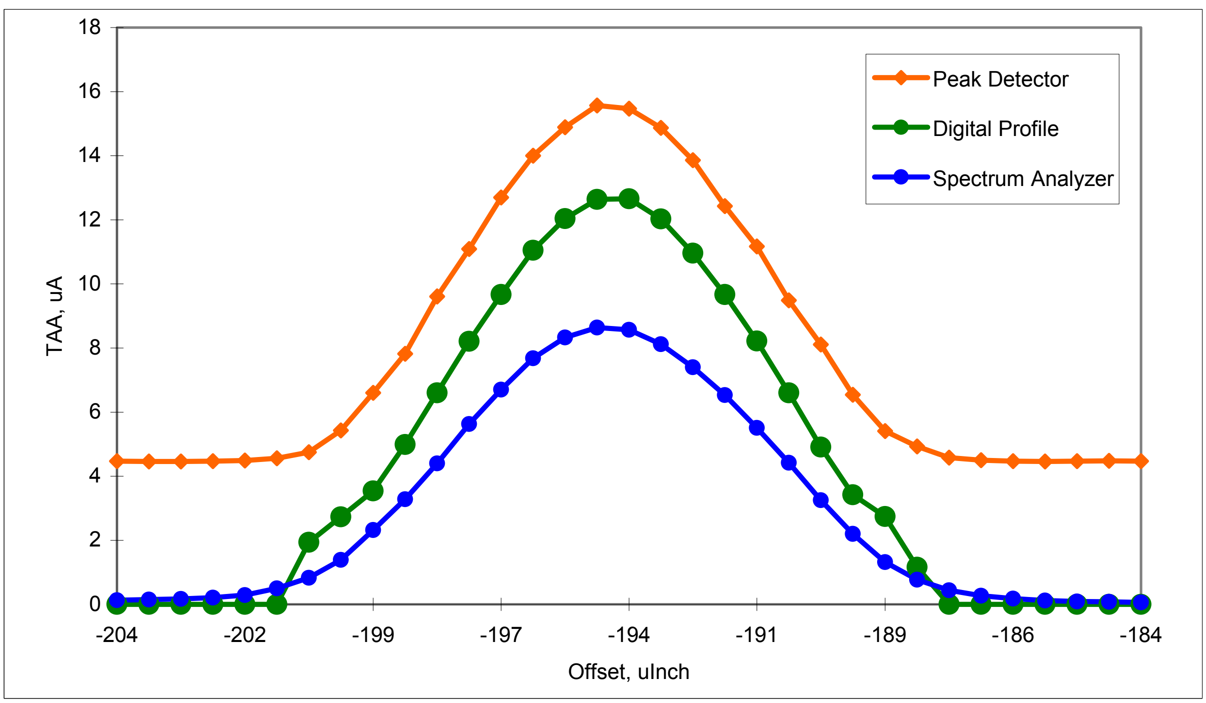

Figure 13: Track profiles for isolated perpendicular transitions.

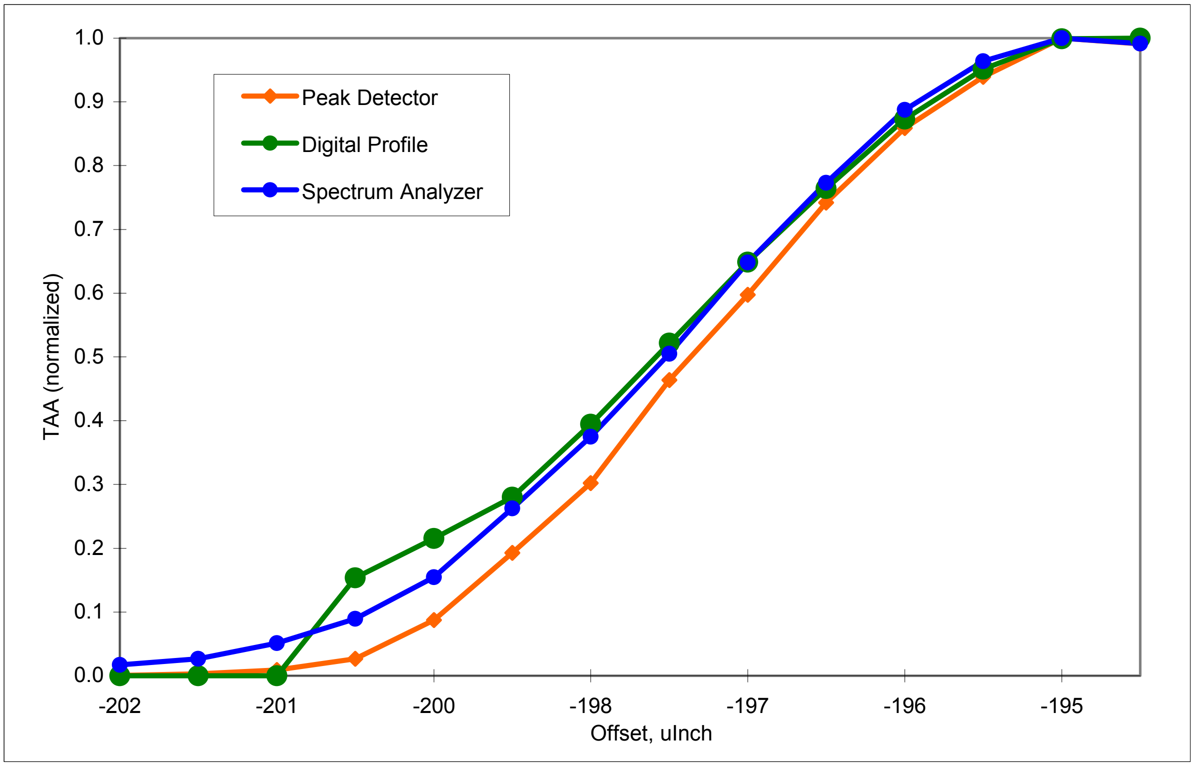

Figure 14: Normalized track profiles by different methods (zoomed-in)

The head geometry results, obtained by these track profiles are shown in Table 2.

	Peak Detector	Profile	Spectrum Analyzer
Read Width (μIn)	**4.70**	***5.74***	**5.12**
Write Width (μIn)	**6.53**	***7.29***	**7.02**

Table 2: Head geometry measured by different methods

As was explained in Section 3.2.3, the wide-band analog Peak Detector measurement tend to reduce the head geometry values. This method reports the smallest value.

The Spectrum Analyzer measurement depends on how the signal shape changes when going off-track. As shown in Figure 12, the signal shape (and therefore the spectral content) changes. As a result, the head geometry values measured by spectral method will differ from the values obtained by other methods.

The digital Profile method reports the biggest value for the head Read Width and the Write Width, when measured with the actual head and media on a spinstand. This corresponds to the model and experiments with simulated signal, provided in Section 3.2, and therefore indicates that the digital Profile method significantly reduces the head geometry measurement error due to noise.

4. Result Summary

- The accuracy of different amplitude measurement methods greatly depends on the noise level in the signal.
- The head geometry measurements based on the track profile measurement also depend on the noise level in the signal. For these measurements, this is even more important as the signal-to-noise ratio degrades when going off-track.
- The digital Profile method implemented in D5000 Signal Analyzer provides the best noise reduction and the best accuracy comparing with all other methods and recommended for use as a method of choice, especially for perpendicular magnetic recording products.

Appendix A. Analog Peak Detector Method

A typical signal from a magnetic head consists of the series of positive and negative peaks (see Figure 15). The signal amplitude is defined as *average amplitude of peaks* across selected time intervals.

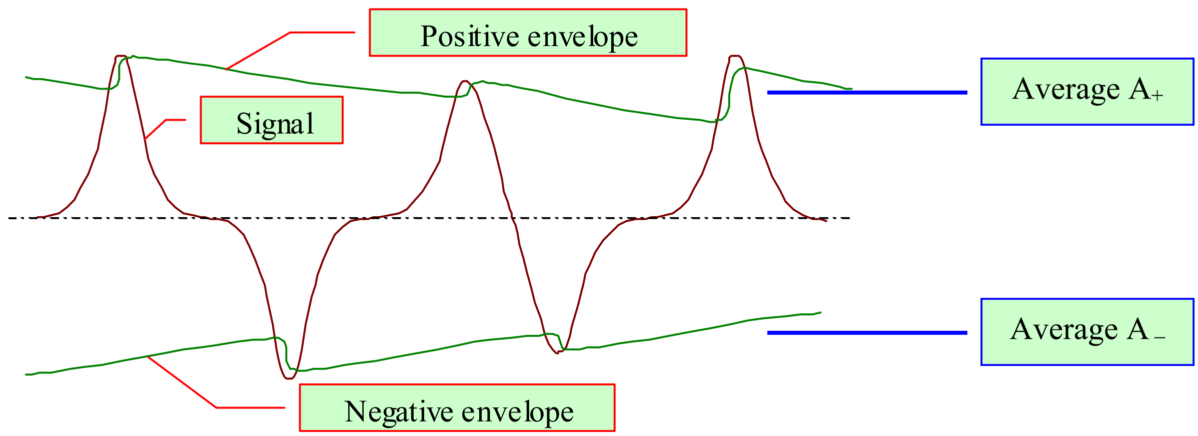

Figure 15: Read-Back Signal and Envelope Signal

RWA-2000 Series approximates the disk drive signal amplitude by the *envelope* measurements. The envelope is a low-frequency signal generated by analog peak detector circuitry of the Read Channel. This low-frequency signal follows the peaks of the signal from the head (see Figure 15).

The positive amplitude A_+ is measured as the average value of positive envelope. The negative amplitude A_- is measured as the average value of negative envelope. Software also calculates “peak-to-peak” (also called “both”) amplitude defined as $A_{\mathbf{both}} = A_+ + A_-$.

Appendix B. Digital Profile Method

The digital Profile method algorithm is slightly different for longitudinal and perpendicular recording, therefore two separate descriptions are provided below.

Profile Method for Perpendicular Recording

The pulse-profile calculation consists of the following steps:

- Locate the exact slope positions at points where the signal crosses the baseline and the derivative exceeds 50% of the running average of the derivatives of previous transitions.
- Supply the slope position to a phase-locked loop (PLL), which removes noise in the position calculation.
- Input the signal samples to a histogrammer module, which accumulates two separate slope profiles, one for the average rising slope and one for the average falling slope. The module averages over consecutive pulses, centered at the zero position.
- Calculate parameters such as TAA from the averaged signal (Figure 16).

Profile Method for Longitudinal Recording

The pulse-profile method consists of the following steps:

- Locate the exact peak positions at points where the amplitude exceeds 50% of the maximum signal power and the derivative is zero.
- Supply the peak position to a phase-locked loop, which removes noise in the peak-position calculation.
- Input the signal samples to a histogrammer module, which accumulates two separate pulse profiles, one for the average positive pulse and one for the average negative pulse. The module averages over consecutive pulses, centered at the zero position.
- Calculate parameters such as TAA from the averaged signal (see Figure 16).

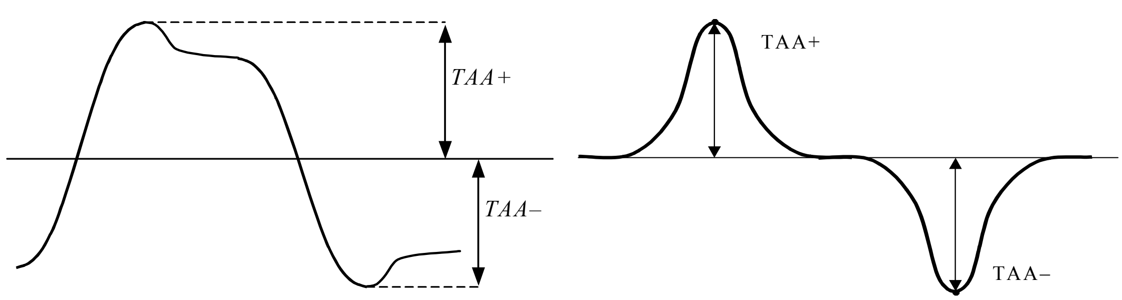

Figure 16: Profile method for Perpendicular signals (left) and Longitudinal signals (right)

Note: The Profile method can be used only with regular patterns (HF, LF, IS, *etc.*) and quasi-regular patterns. A *quasi-regular* pattern is a pattern with constant distance from each even-numbered transition to the next odd-numbered transition, and constant distance from each odd-numbered transition to the next even-numbered transition. For instance, the pattern "1001000010010000…" is quasi-regular.