Tilt Analysis of Readback Signals from DVD-ROM Media

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ABSTRACT

Tilt is a major source of distortion for the DVD channel. This paper is aimed at understanding the effect of tilt on the readback signal. Equalized signals were collected from DVD-ROM media on an optical spin stand with a variable tilt stage. A simulated version of duty cycle correction (DCC) was applied to each signal to cancel the baseline drift. The pulse response, which characterizes the signal under the linear superposition assumption, was extracted for each signal. The pulse response of the DVD-ROM channel is shown to be highly affected by tangential tilt while the effect of radial tilt is minimal.

Keywords: optical data storage, disk tilt, DVD, signal processing, channels

1. INTRODUCTION

Although not considered a major problem for CDs, tilt is now being looked on as one of the major sources of distortion for the DVD mainly due to the smaller feature size and track pitch. For future generations of optical disk products, the tilt problem will even be more critical and therefore needs to be addressed. Understanding the consequences of this problem can provide more insight into the design of reliable and robust equalizers and detectors.

In this paper, we consider the effect of tilt on the readout signal, particularly on the pulse response of the channel. We collected signals from DVD-ROM media on an optical spin stand with a 650 nm, 0.6 NA optical head and a tilt stage that allowed the tilt to be varied between -1.0 and 1.0 degrees. All reading conditions were set to optimum values. The RF signals were taken after equalization from the same location on the disk. Only the amount of tilt was varied. Data-to-clock jitter measurements were also taken for each signal.

One way to assess the effect of any type of distortion on the channel characteristics is to examine its impact on the pulse response of the channel. Assuming linear superposition holds, we extracted the pulse response from each signal using a least-squares approach. To get rid of the baseline offset in the signal, we employed a simulated version of duty cycle correction (DCC) before the pulse extraction procedure. Our results show that the in-track component of tilt has a significant impact on the shape of the pulse response.

The organization of the paper is as follows: In Section 2, we provide a brief description of the tilt problem. Section 3 is devoted to the effects of tilt on the readback signal. After providing an overview of the essential blocks in the channel architecture, we qualitatively analyze the readout waveforms and discuss the data-to-clock measurements. A short description of the DCC operation is given in Section 4. The pulse response extraction results are presented in Section 5.

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2. TILT

Ideally, the scanning read beam should be at right angles to the disk. Any misorientation in the head-media interface that causes the scanning beam to hit the disk surface at a tilted angle leads to coma [1]. Fig.1a shows the situation where there is disk tilt present. With the help of a tilt stage, it is possible to introduce head tilt artificially by rotating the head slightly with respect to the disk. Since disk tilt is equivalent to head tilt, the amount of tilt introduced can be thought to represent both head and disk tilt that can exist in a particular system. In general, tilt can also be introduced if the lens is tilted slightly or the media isn't perfectly flat (due to irregularities in the manufacturing process, the media layer may have a "potato chip" shape).

The angle between the normals (or the tangentials, as shown in Fig.1a) of the disk and the head can be decomposed into two components; tangential and radial. Assuming only a fixed amount of head (or disk) tilt, these two components are independent of the location on the disk (this is not true, however, if the media has significant tangential tilt). In Fig.1b we illustrate how the optical spot on the disk might look. Ideally, with no tilt, the optical spot has a circular shape with a Gaussian-like intensity profile. Radial tilt, which is the cross-track component, is expected to increase the intertrack interference (ITI). Similarly, tangential tilt (the in-track component) is likely to cause intersymbol interference (ISI).

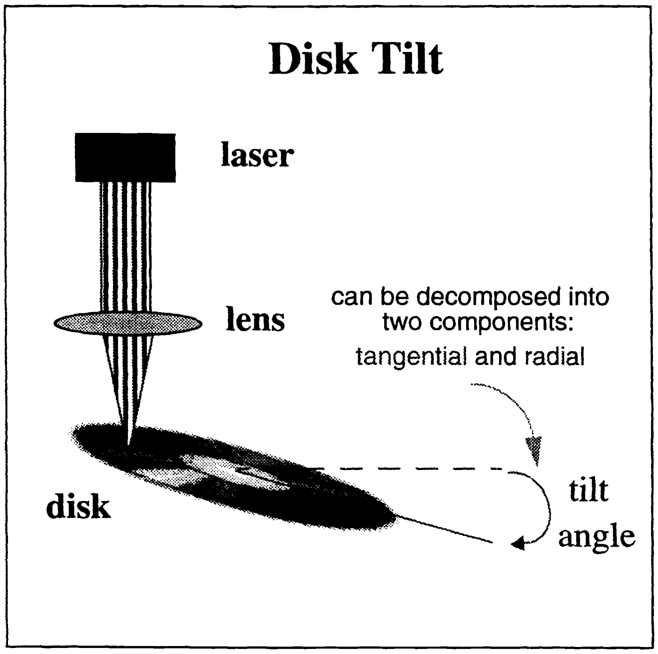

Fig.1a **Schematics of the head media interface in the presence of disk tilt.**

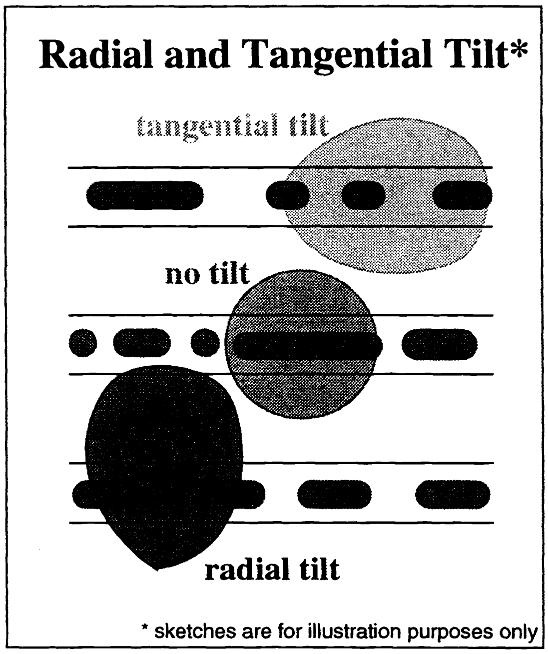

Fig.1b **The shape of the optical spot for the cases of tangential, radial and no tilt.**

3. EFFECTS OF TILT ON THE READBACK SIGNAL

3.1. The Optical Disk Channel Architecture

Before proceeding with the discussion of the effects of tilt on readout, it is helpful to have a look at the main blocks of typical channel circuitry for DVD. In Fig.2, a simplified channel architecture is presented. The first main block is the equalizer which also serves as a low pass filter. The high boost at the high frequency end of the equalizer is needed to slim the pulse response, i.e., to sharpen the transition response. The gain of the equalizer was set to 4.8 dB for all the signals we collected.

The second block is where the duty cycle correction (DCC) is accomplished. The DCC process can be viewed as a feedback loop where an offset to be subtracted from the signal is calculated in conjunction with a zero-level slicer. The output of the slicer is a binary-valued signal with a series of rectangular pulses. The details of the DCC procedure are given in Section 4.

Finally, the last main block in the readback channel is the detector. The detector makes its decisions based on a clock recovered from the signal.

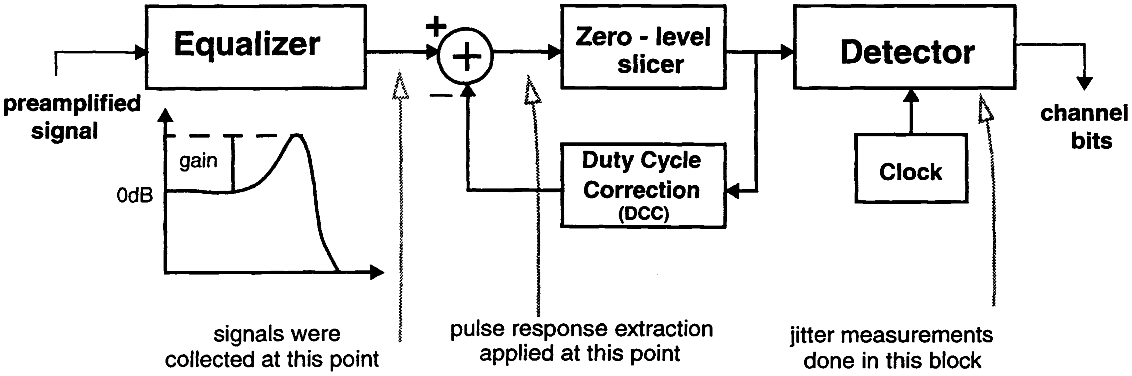

Fig.2 The blocks of a simplified DVD channel architecture.

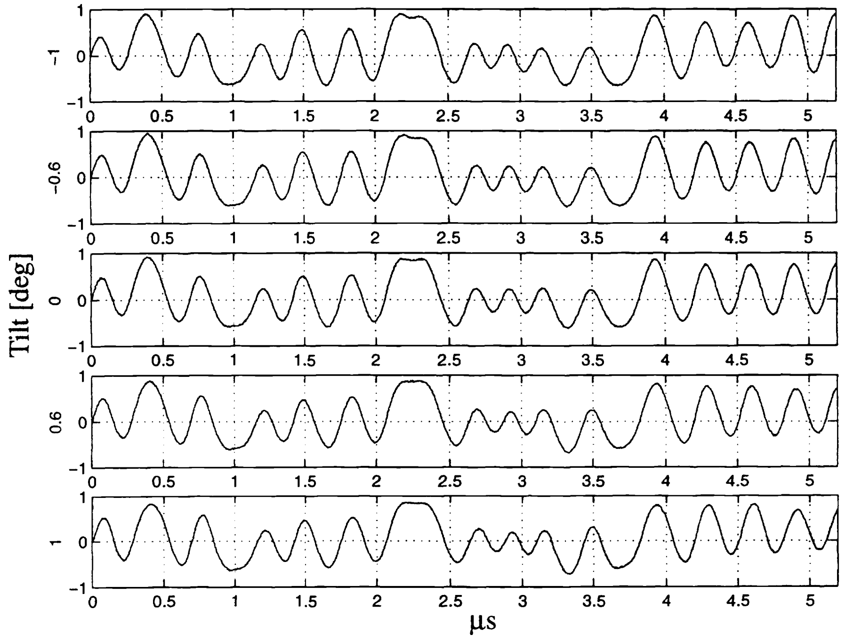

Fig.3a Readout signal waveforms with radial tilt.

3.2. Readout Waveforms

As shown in Fig.2, readout signal waveforms were collected after equalization. The channel bit interval was approximately 38.13 ns with the disk spinning at a velocity of 3.49 m/s. For the convenience of having many samples per bit interval, a sampling interval of 4 ns was chosen which amounts to roughly 9.5 samples per bit. Each signal collected was 2 ms long, which translates to 500,000 samples or 52,500 bits approximately.

The signals in the presence of radial tilt are displayed in Fig.3a. No significant change in the general shape of the signal is observed. The differences between the waveforms reveal a random, noise-like nature. Some of the amplitude fluctuations may in part be due to insufficient servo tracking because of excessive jitter.

However, as shown in Fig.3b, waveforms with tangential tilt show a clear non-random change in the signal shape as the degree of tilt is increased. Also, the signal distortion displays a symmetry as tilt is varied from negative to positive values.

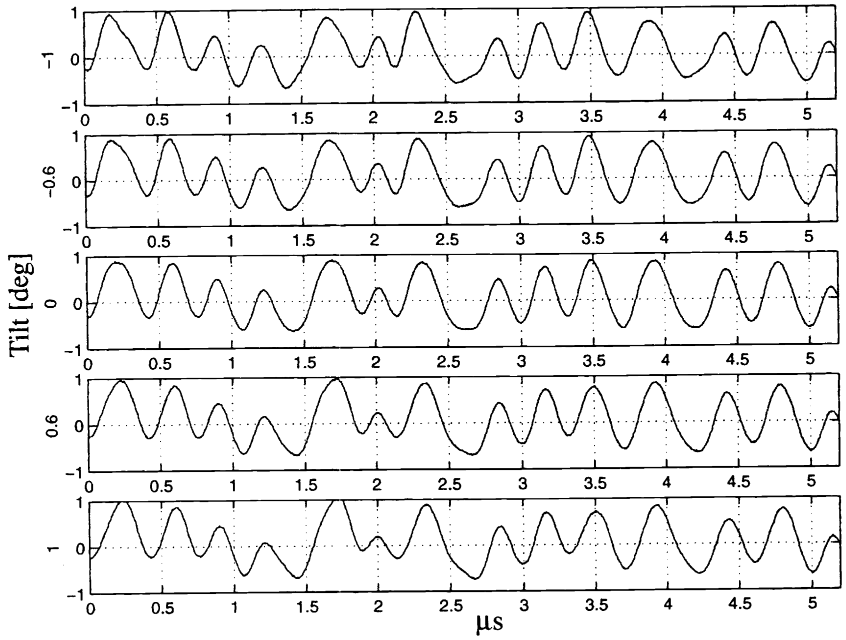

Fig.3b Readout signal waveforms with tangential tilt.

3.3. Data-to-clock jitter

In current DVD systems, data-to-clock jitter is the system parameter used to quantify system performance. Jitter is defined as the mean square distance between the transitions in the data and the corresponding clock edges. In other words, jitter provides insight on how the zero-crossings of the signal deviate around their nominal positions. If these deviations are plotted as a histogram, the jitter value represents the standard deviation of the resulting distribution. The zero-crossings in the optical readback signal (and, therefore the mark edges) can move away from their nominal position for a variety of reasons. The stronger the system perturbations are, the higher the jitter. As shown in Fig.2, the measurement of jitter is performed between the recovered clock and rectangular data waveform during the detection process, after DCC.

In Fig.4, the amount of jitter (measured) is plotted as a function of tangential and radial tilt. The y-axis represents the percentage of the jitter relative to the size of the detection window, i.e., to the channel bit interval. Even for a small jitter increase significant errors might occur, since the tails of the distribution may extend out of the detection window. A value of 20% jitter is unacceptable in terms of the bit error rate it indicates. From the jitter plot, it is seen that both radial and tangential tilts increase jitter considerably, although tangential tilt is more adverse. We have observed that in case of radial tilt, the tracking signal is affected as well (also see [2]).

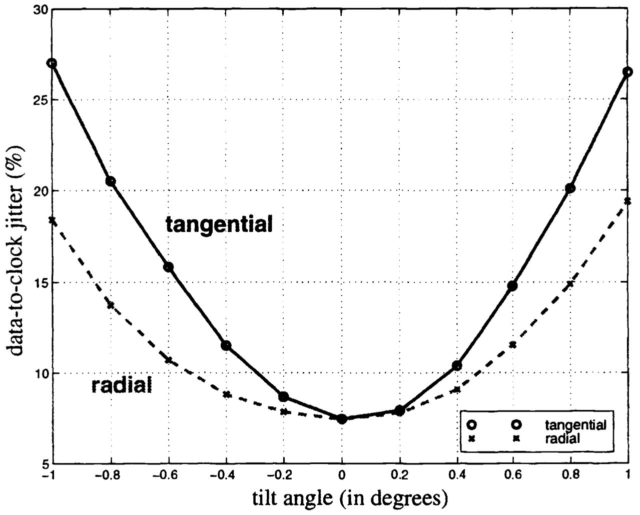

Fig.4 Data-to-clock jitter versus tangential and radial tilt.

4. DUTY CYCLE CORRECTION (DCC)

As opposed to magnetic recording, the optical recording channel is not DC free. The detection process is based on locating the zero-crossings and is, therefore, sensitive to their position. Any change in the baseline (zero-level) of the signal changes all the locations of the transitions in the signal in an adverse manner. This is best quantified by the use of feature histograms.

Fig.5a shows the feature histogram of the no tilt signal before the DCC operation. The upper graph displays the histogram of the marks and lands together. Note the two peaks in the 3T feature distribution. The lower graph separates the marks and lands by denoting the land features as negative. The 3T marks are centered around a value less than 3 whereas the center of the 3T land distribution is larger than 3, hence the two peaks observed in the upper graph. The same remarks can also be made for the higher length features. This clearly indicates a baseline drift in the signal.

Similar histograms are presented in Fig.5b for the feature lengths after DCC. Notice how well the combined (upper graph) and the separate (lower graph) mark/land distributions are centered. It is interesting to note that this is the result of a rather small adjustment in the baseline level of the signal as shown in Fig.5c.

DCC in the DVD channel can be accomplished because of the DC-free EFM+ code. DCC can be explained by the feedback loop structure as shown in Fig.6. The signal is first binarized by the use of a zero-level slicer. Then the DC value of this rectangular waveform is calculated. By way of a feedback, this DC level is subtracted from the signal out of the equalizer. If the correct value of the DC level is subtracted, the signal will have no baseline drift and the output of the slicer will have no DC component. Note that the sharp transitions in the rectangular data waveform allows the timing recovery circuit and the detector to exactly locate the zero-crossings.

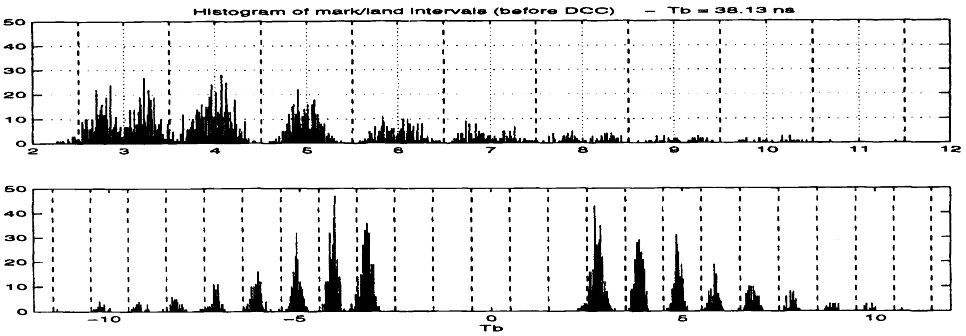

Fig.5a Feature histograms before DCC. The upper graph shows marks and lands together whereas the lower graph shows them separately.

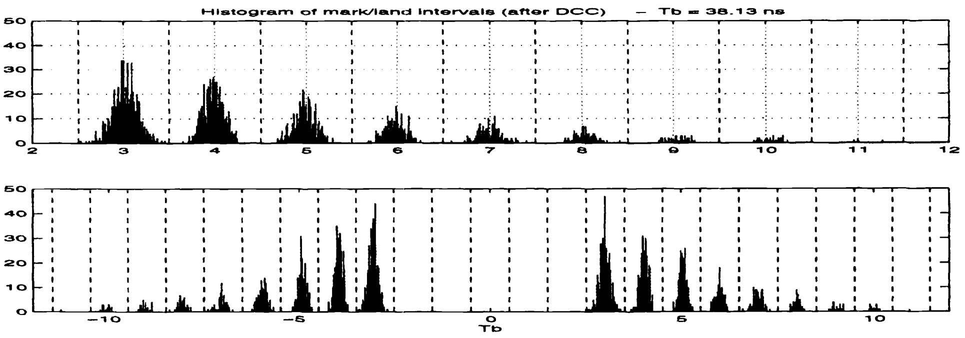

Fig.5b Feature histograms after DCC. The upper graph shows marks and lands together whereas the lower graph shows them separately.

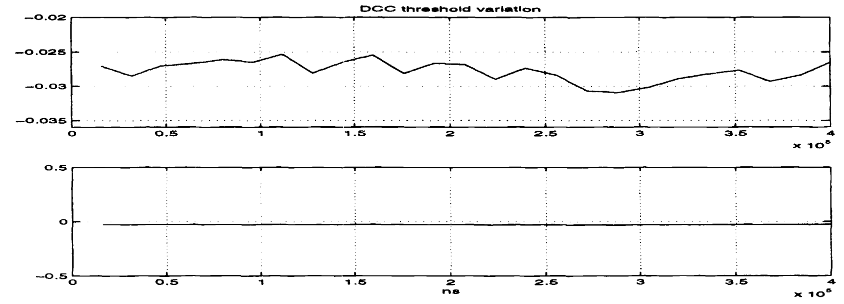

Fig.5c DCC threshold variation. The upper graph is the enlarged version of the lower graph. Note that the DCC threshold is very small compared to the maximum amplitude of the signal.

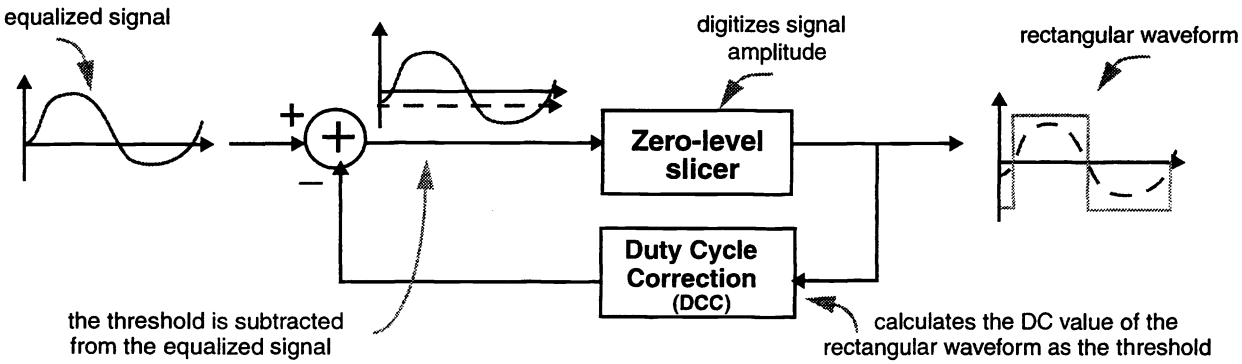

Fig.6 Block diagram of the duty cycle correction (DCC) procedure.

5. PULSE RESPONSE EXTRACTION

From a channels perspective, jitter reflects a cumulative effect, and may not provide detailed information needed for channel design. Besides jitter, it is desirable to examine the effects of tilt in other ways when considering equalization and detection strategies. The pulse response, which characterizes the signal under the linearity assumption, is one such alternative.

To obtain the pulse responses we adopted the following procedure: First, a simulated version of a duty cycle corrector was applied to each readback waveform. Then, from the signal with no tilt, we determined the zero-crossings and from the interval between subsequent zero-crossings deduced the length of the features. Having determined the channel bits, the next step was to obtain the pulse response for each signal (with tilt) assuming

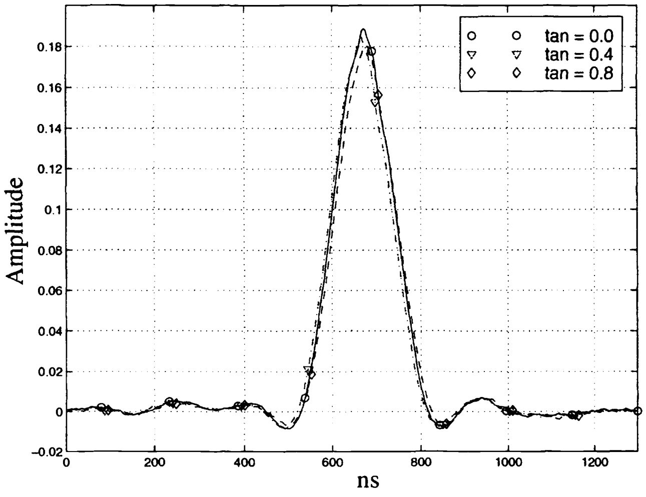

Fig.7a Pulse responses from signals with positive radial tilt (bit interval is 38.2 ns).

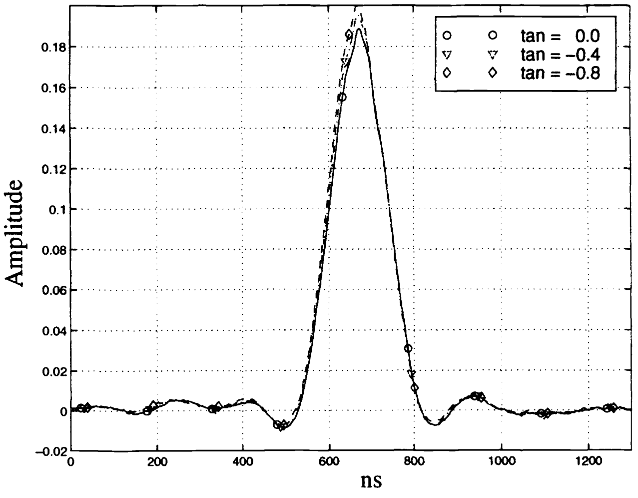

Fig.7b Pulse responses from signals with negative radial tilt (bit interval is 38.2 ns).

linear superposition holds. To accomplish this, we made use of least squares channel identification [3] to find the pulse response which would produce a readback signal as close as possible to the original in the minimum square error sense. Obviously, the pulse response thus estimated represents an average entity.

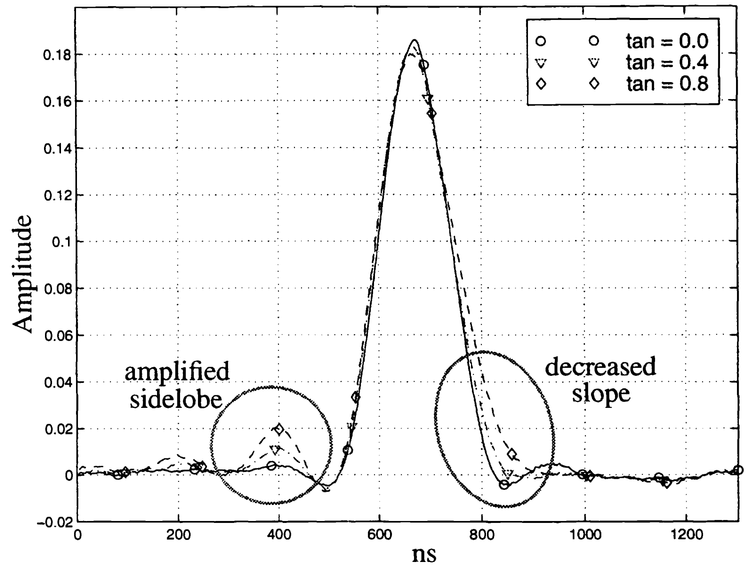

Fig.8a Pulse responses from signals with positive tangential tilt (bit interval is 38.2 ns).

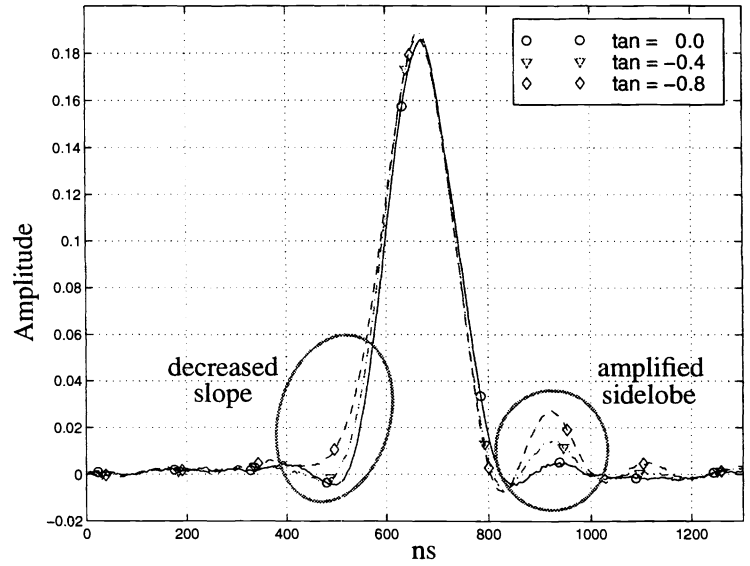

Fig.8b Pulse responses from signals with negative tangential tilt (bit interval is 38.2 ns).

In Fig.7a and Fig.7b, the extracted pulse responses from signals with radial tilt are shown. Although radial tilt causes a considerable amount of jitter, its effect on the pulse response is not significant. This might be due to the fact that the ITI introduced by radial tilt is a random effect that appears as noise in the readback signal. Since pulse response extraction is an averaging process, only systematic rather than random effects show up in the pulse response. Notice the under and overshoots around the baseline due to equalization.

Fig.8a and Fig.8b show the extracted pulse responses from signals with tangential tilt. As expected, without tilt, the pulse response is almost symmetric. For readback signals with tangential tilt, the pulse response becomes asymmetric; the sidelobes on one side of the pulse are flattened out and on the other side amplified. When the sign of tangential tilt is reversed, this asymmetric effect also reverses (compare Fig.8a and Fig.8b).

On the side where smoothing occurs, we also observe a change in the slope of the center pulse and an increase in its width that will cause a considerable increase in jitter (note that the bit period is approximately 38 ns). The amplified overshoot on the opposite side, which is 4-5 bits away, will also have an effect on the zero-crossing in that location.

Fig.9 shows the spectrum of the pulse responses for positive tangential tilt. For negative tilt angles, the behaviour of the spectrum is nearly identical. With the introduction of tilt, an increase in the low and a decrease in the high frequency content of the channel is observed. Such spectral changes can affect the performance of equalizers and suggest the use of an adaptive equalizer [4].

6. CONCLUSIONS

Our analysis showed that tilt has a considerable impact on the quality of the readback signal. Besides causing jitter, the in-track component of tilt changes the shape of the pulse response significantly. Assuming the media tilt and the head tilt to have a slowly changing nature, an adaptive equalizer may be appropriate for dealing with tangential tilt. Other than providing an insight on the jitter mechanism, this information is valuable when considering advanced detection methods. For example, partial response equalization that is based on shaping the pulse response to a predetermined shape is likely to suffer from the asymmetry introduced by tangential tilt.

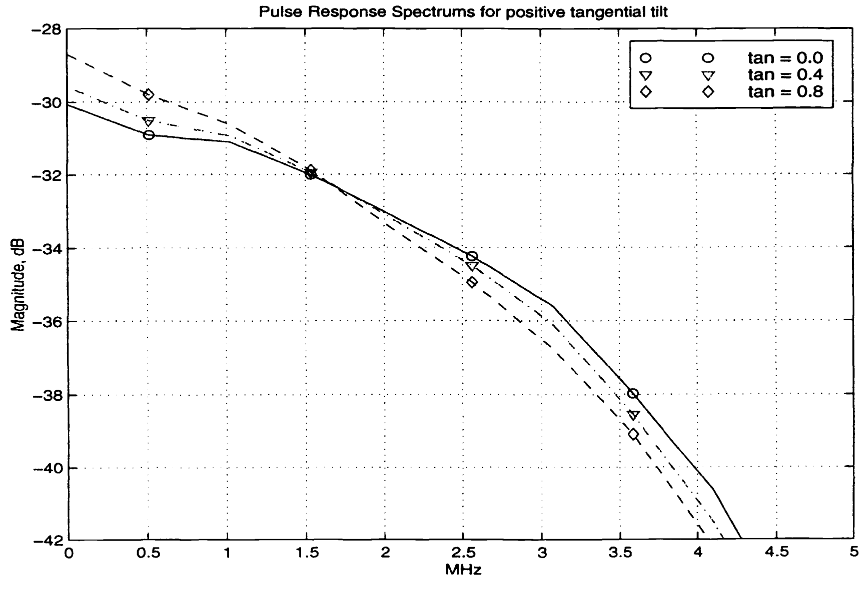
Pulse Response Spectrums for positive tangential tilt

Fig.9 Spectrum of the pulse responses with tangential tilt.

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