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High Frequency Wobbles: A Write Clock Generation Method for Rewritable DVD That Enables Near Drop-In Compatibility with DVD-ROMs

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ABSTRACT

This paper describes a write clock generation scheme for rewritable DVD which eliminates a major issue for drop-in compatibility with DVD-ROMs. The method used is to co-locate a high frequency clock reference next to the data using a wobble groove. This enables bit accurate edits on rewritable DVD media.

Keywords: High Frequency Wobbles, DVD-ROM Compatibility, Optical Recording, Write Clock Generation

1. MOTIVATION

This paper presents an overview of a new method of write clock generation on rewritable DVD drives that eliminates many of the problems associated with reading rewritable disks in DVD-ROM drives. It is believed that such a format will provide tremendous benefits to the end user, making it possible to edit content on a rewritable DVD disk and then play that same disk in a conventional DVD-ROM player. From a large set of potential problems, it appears that the real issues can be reduced to two:

- smaller changes in reflectivity on phase-change media and
- a much tighter clocking requirement caused by the need to eliminate edit gaps.

Of these, the first is an issue for roughly half of the commercial DVD players in the world today. This issue can be overcome in the remainder with a simple circuit change in the AGC of the reader. It is the latter issue which is a problem. As shown in the bottom drawing of Figure 1, DVD-ROM disks have no edit gaps or physical sector marks. This is in contrast to conventional rewritable formats (the top two drawings of Figure 1) which need these gaps to accommodate imprecision in the write clock which would otherwise cause data loss at the end of data fields.[1–5] In order to match the DVD-ROM format,[6] a rewritable format must move away from what is depicted in the top two drawings to the bottom drawing of Figure 1.

2. HIGH FREQUENCY WOBBLE CLOCK

In order to eliminate edit gaps and other in line sector information in a rewritable format, a new clocking scheme was devised that uses high spatial frequency groove edge oscillations (wobbles) to generate clock signals. This has the advantage that it co-locates clock reference with data, yielding a high fidelity, high frequency clock reference, as shown schematically in the left half of Figure 2. Using this, one can lock a narrow band phase-locked loop (PLL), as shown in Figure 3, to the oscillation frequency to generate the write clock. Addressing information can be encoded into the wobble itself using a variety of methods to eliminate the need for physical sector marks.

Having a continuous clock co-located with the data is more precise and robust than intermittent clocks. The PLL can average over many clock cycles to ignore defects more easily. Furthermore, spindle runout, disk eccentricity and thermal variations have far less effect on the write clock. This means that there is virtually no drift between clock samples, allowing for the elimination of edit gaps. By encoding address information in the wobble itself, the

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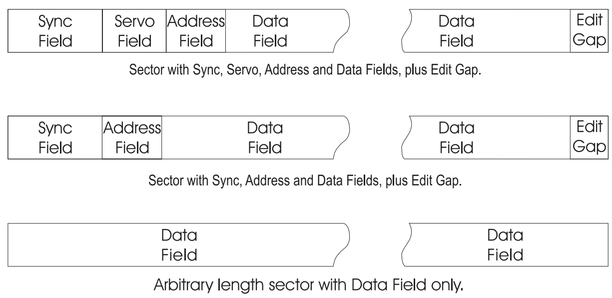

Figure 1. Optical disk formats on rewritable and ROM media. The top diagram represents sector formats on drives where synchronization, servo, and address fields as well as an edit gap are time multiplexed down the track with the data. This is the current norm in both sampled servo magnetic and optical disk drives. The middle diagram represents sector formats on drives which do not obtain their servo information from the sector header, but still time multiplex the remaining fields with the data. This was common in dedicated servo magnetic drives, which have fallen out of favor, and is the norm in optical drives where the grooves or pits provide a continuous pattern for the tracking servo. The top two formats are the prevalent methods used in rewritable magnetic and optical media. The bottom digram represents a typical format for ROM media. Because the media is mastered once at the factory, no physical sector marks are needed. Instead, logical synchronization and address fields are included within the data.

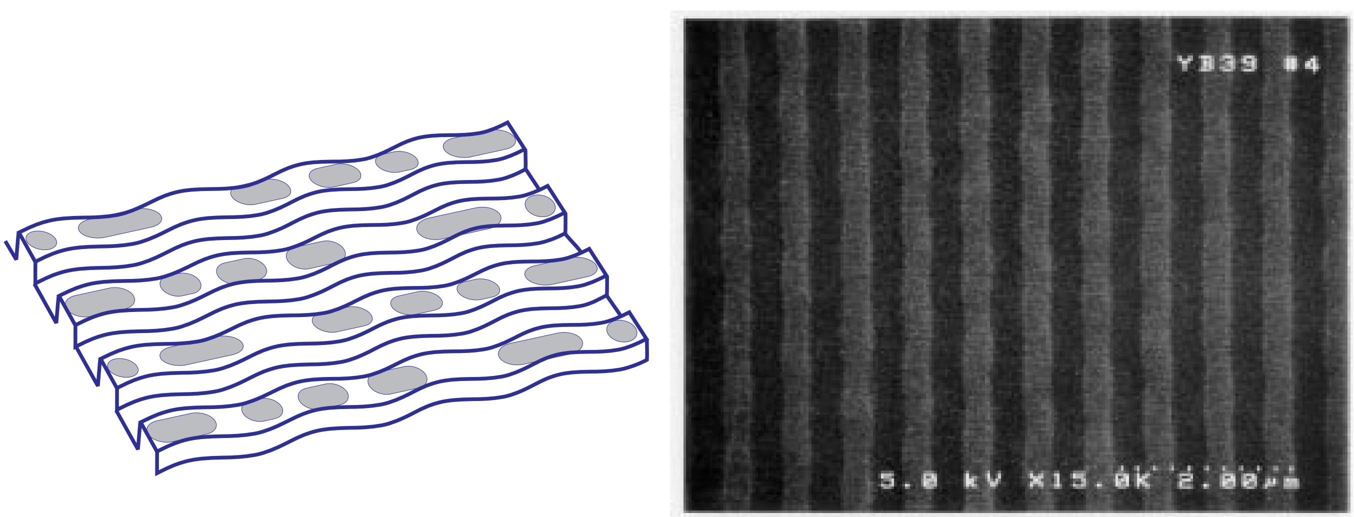

Figure 2. High frequency wobbles. On the left is a perspective schematic of high frequency wobbles. On the right is an SEM image of 4.7 GB, 30 nm peak to peak wobble disk. Wobbles with amplitudes of up to 50 nm peak to peak have been tested.

embossed sector information leaves the entire track available for the data. This clears the way to make the data sector continuous, as in the DVD-ROM format.[6]

The design of the PLL is linked to the design of the clock reference signal. The shape of the modulation transfer function (MTF)[7] of the optical system is typically falling off at higher frequencies. This means that higher frequency signals are attenuated more than lower frequency signals, finally reaching 0 at the optical cutoff frequency. Thus, there is both an absolute and a practical limit on the spatial frequencies that can be resolved, leading to a upper limit on the clock reference frequency that can be encoded on the disk. Generally speaking, the lower the reference clock frequency, the higher the signal to noise of the signal at the detector.

The write clock, on the other hand, typically requires a clock frequency that is higher than the allowable clock

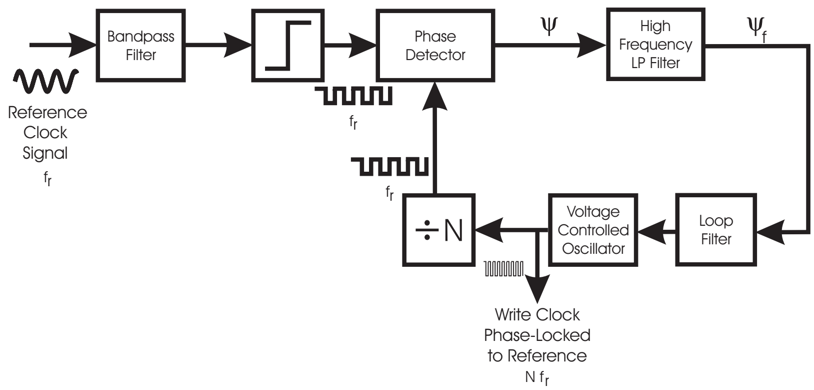

Figure 3. A Harmonic Locking PLL is used to generate the write clock.

reference frequency. A relatively standard solution to this problem is what is known in the PLL field as a *harmonic locking PLL* or simply a *harmonic locking loop*, shown in Figure 3. A harmonic locking loop has the property that while it is phase locked to the reference signal, it generates a clock signal at N × reference clock frequency. Variants of this are available that allow N to be a non-integer number. However, a consequence of using such a loop is that it boosts the clock jitter by N. Thus, for a given desired write clock, one would want to minimize N for a given write clock frequency. To do this, one would wish to maximize the reference clock frequency. A practical choice for a reference clock frequency must trade off between the lower signal to noise of a higher frequency reference and the increased jitter of a lower frequency reference.

3. IMPLEMENTATION ISSUES

While there are many possibilities for implementing such a scheme, the choice of the specific physical encoding method depends upon the available spatial frequencies, the available signal detection methods, and a desire to avoiding interference between clock and data/servo signals.

This format was aimed at a consumer application of computers and digital video. In such markets, cost is a critical factor and therefore minimizing the cost of parts by using industry standard optical components was seen as the path with the highest probability of success as a product. Once it was decided that an industry standard set of optics (0.6-0.65 NA lens, 635-650 nm laser) would be used, the possibility of putting the clock frequency above the data frequencies was eliminated. Putting the clock frequency below the frequency range at which there is substantial data content would have resulted in a write clock with too much jitter to eliminate the edit gaps.

The solution is a high frequency wobble groove – an in-phase oscillation of the groove walls – as the method for encoding the reference clock. This has the advantage that it is nominally invisible to data detection in the central aperture mode (CAD), but yet easily detectable in the radial push pull (RPP) servo signal outside of servo bandwidth. This allows the wobble signal to be encoded within the range of data frequencies with little interference between the two signals. Some spectra of typical signals are shown in Figure 4.

These choices provide near bit accurate editing. However, it has been noticed that linkless editing must take into account issues with the preheating of the media at the edit in and edit out points. As shown in Figure 5, a typical write strategy used in phase change recording tends to make single bit errors when used in linkless editing. At edit in, the first mark is too short, while the first space is too long. At edit out, both the mark and space are too long, albeit by different amounts. The solution is to make slight adjustments to write strategy at edit in and edit out bits. The length of the start and stop pulses are adjusted to compensate for the initial and final thermal effects, as shown in Figure 6. These final adjustments provide bit accurate editing without any bit errors.

4. RESULTS

The signal read back from the high frequency wobble becomes the reference clock signal for the system. The write clock is generated by using a harmonic locking PLL[8,9] as shown in Figure 3 to boost the reference clock frequency to

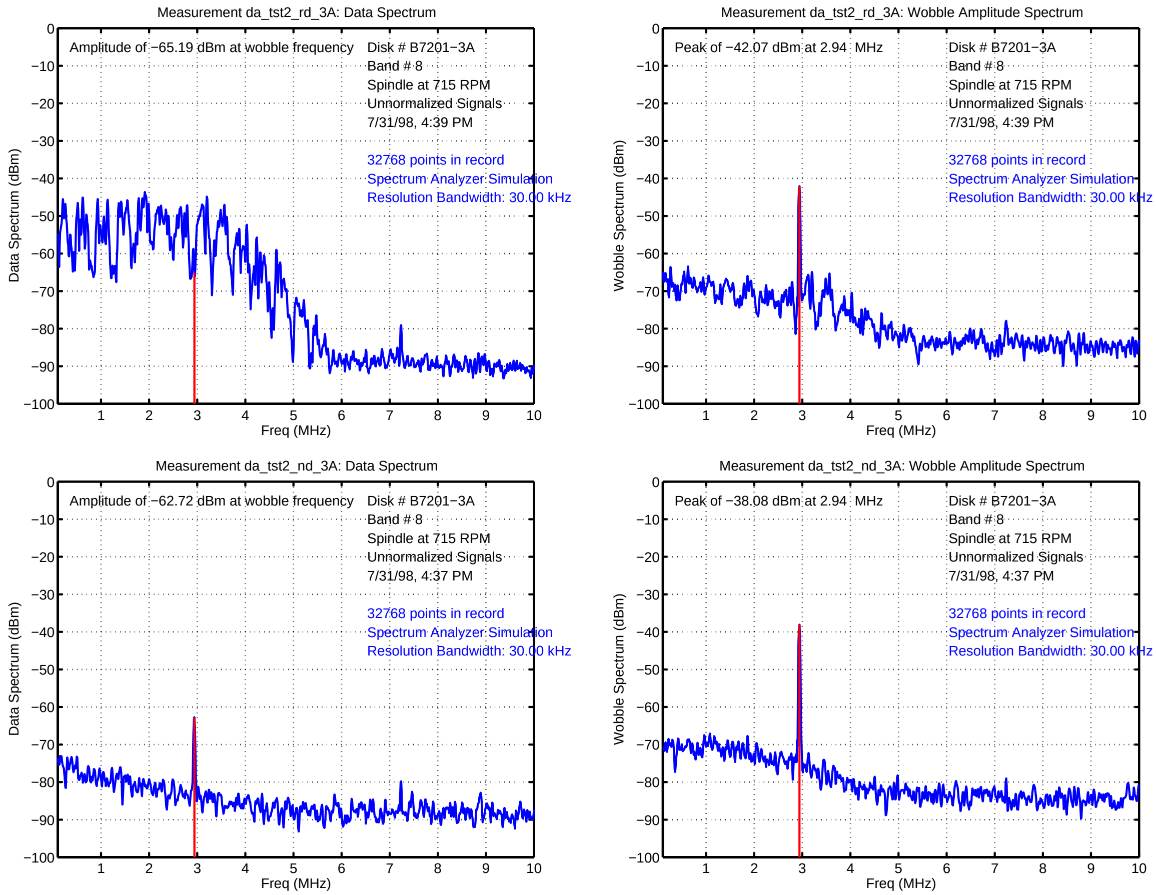

Figure 4. Crosstalk between data and wobbles is small as shown in this example. The left side column of plots contains spectrums taken from the data channel (sum signal). The right side column of plots contains spectrums taken from the wobble channel (radial push-pull). The top two plots are spectrums when random data is recorded on the track. The bottom two plots are spectrums with no data recorded on the track. Note that the wobble signal is visible in the data channel when no data is present, but the signal level of random data is far higher. This results in the wobble having no significant effect on the data channel. Likewise, random data can be seen in the wobble channel, but its signal level is far below that of the wobble, leading to no significant effect on the write clock. These results are robust to offtrack, defocus, beam walk, and tilt.

Offtrack:	$\pm$ 30 nm
Defocus:	$\pm$ 0.8 μm
Beam Walk:	$\pm$ 6% of beam
Radial Tilt:	$\pm$ 0.3°
Tangential Tilt:	$\pm$ 0.6°

Table 1. Summery of wobble clock and data jitter margins from measurements.

that of a write clock. The limiter preceding the loop makes it insensitive to amplitude changes resulting from laser power changes when switching between reading and writing.

The resulting write clock is very accurate with jitter $<$ 300 pS. This is $<$ 1 % of a data clock bit (for T $\approx$ 38 nS and for wobbles with a period of 9T). Furthermore, the clock is orthogonal to the data; that is, the data and the wobble are detected in different ways, as noted in Section 3.

The resulting system is one that makes bit accurate editing a reality. A few typical examples of this are shown

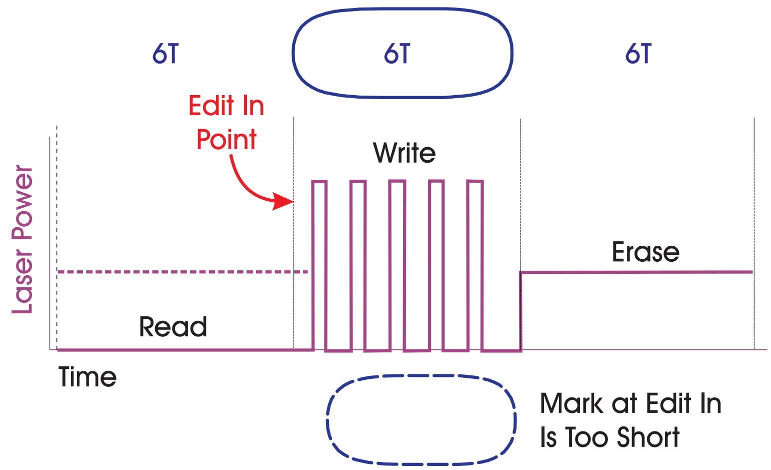

Figure 5. Due to the heating of the media, there are problems with a typical write strategy when used in linkless editing. At edit in, the first mark is too short, while the first space is too long. At edit out, both the mark and space are too long, albeit by different amounts.

in Figures 7, 8, and 9, where a 6T pattern (6T mark, 6T space) is spliced into a 4T-8T (4T mark, 4T space, 8T mark, 8T space) pattern with negligible phase error. Figure 7 shows a measurement of an edit which is centered on the edit in position. Note the lack of bit errors or distortion of the data signal at the edit point. Figure 8 shows similar results, albeit centered at the edit out point. Figure 9 shows an edit in of 2 6T bits.

Finally, the clock is very robust to a variety of conditions as shown in Table 1, which summarizes the margins from the measurements in Figures 10 and 12. Furthermore, results not presented here have shown robustness to temperature and spindle variations. An example of the insensitivity to offtrack is shown in Figure 10. In this case, a long write was done with 4T-8T data and then 6T edits were done at various offtrack conditions. The data was then read with the lens on track and the jitter measured. The experiment schematic is shown in the left half of Figure 10. The jitter results are shown in the right half of the figure. Note that there is no increase in the data jitter as the edit moves off track. A single measurement of this offtrack condition is shown in Figure 11. Note that although the edit done with the actuator offtrack by 30 nanometers has produced a slight phase shift in the data clock at the edit point, this is not significant and does not result in any bit errors. Likewise the jitter plots in Figure 12 show robustness to defocus, decenter (beam walk), radial tilt, and tangential tilt.

5. CONCLUSIONS

Results such as this have been reliably repeated for a variety of edits and a variety of disturbance conditions. They indicate that the scheme has good robustness to radial and tangential tilt, offtrack, defocus, and modulation of the wobble for addressing.

The resulting write clock enables bit accurate editing. The results depicted here enable a rewritable format that is closer to the DVD-ROM specification than any these authors have seen. Furthermore, it is is the only demonstration to date that enables random rewritability in a DVD-ROM compatible format. Results such as these have been used in the creation of the 4.7GB DVD+RW format. Linkless editing forms a key property of this format.

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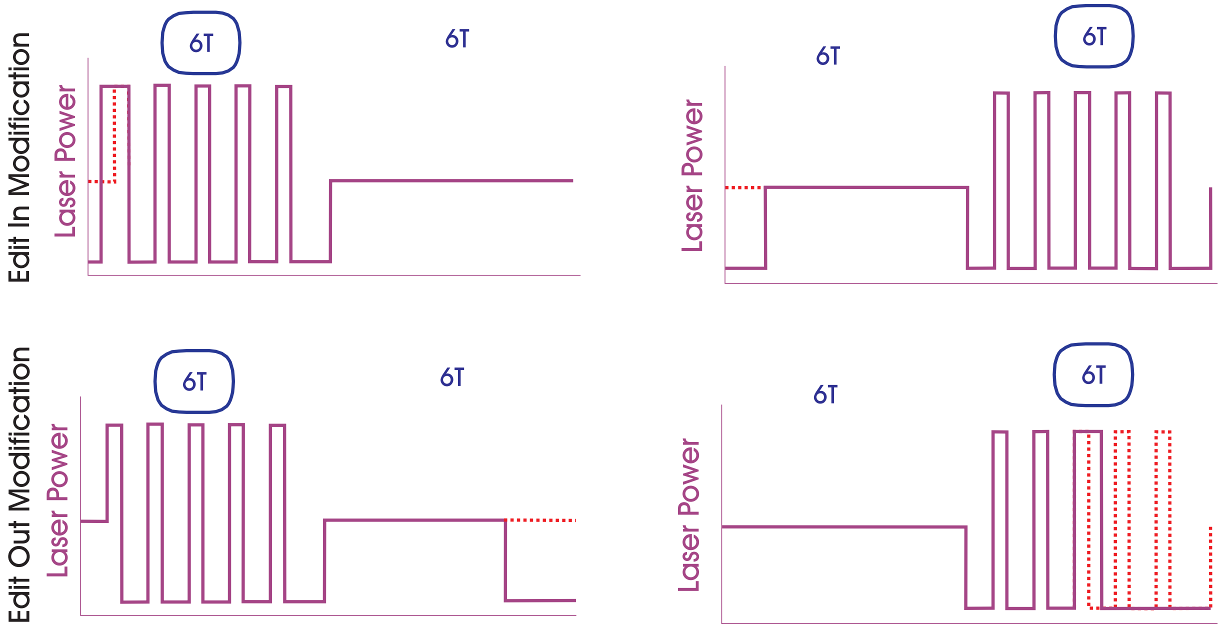

Figure 6. Adjustments to write strategy in edit in and edit out: adjust length of start and stop pulses to compensate. These lines show modifications to the write strategy. The dashed lines show the original write strategy, while the solid lines show the modified strategy. The top two drawings are for edit in: the first pulse of a leading mark is started slightly early, while the first pulse of a leading space is started slightly late. The lower two drawings are for edit out: both the pulses for a trailing space and a trailing mark are truncated early so as not to overwrite the preexisting data.

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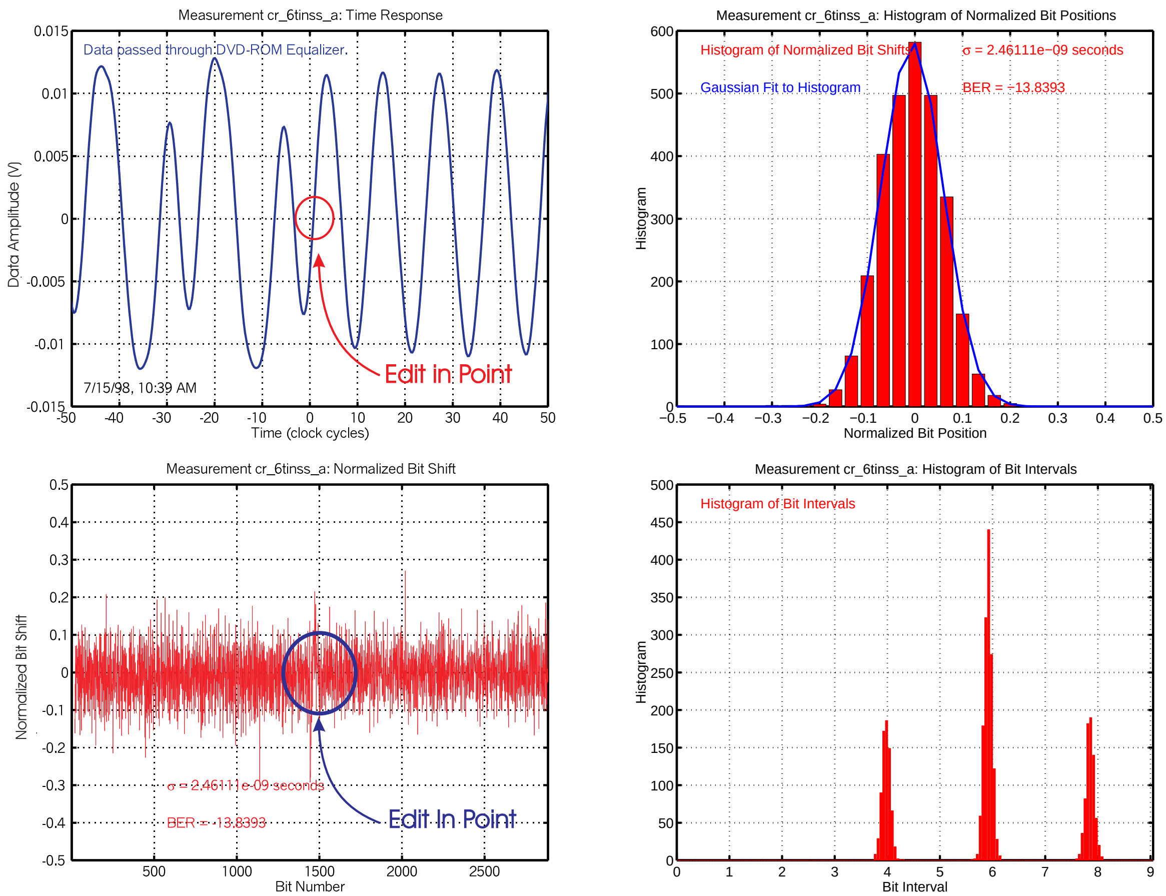

Figure 7. A 6T pattern spliced into a 4T-8T pattern. The upper left plot represents the time response at the edit-in point. The lower left represents the phase error for a data clock generated from the data. (Note the absence of any phase jumps.) The upper right plot is a histogram of the normalized bit positions from which a bit error rate can be computed. The lower right is a set of histograms of the bit intervals. The absence of any 5T or 7T bits is an indication that no bit errors have occurred.

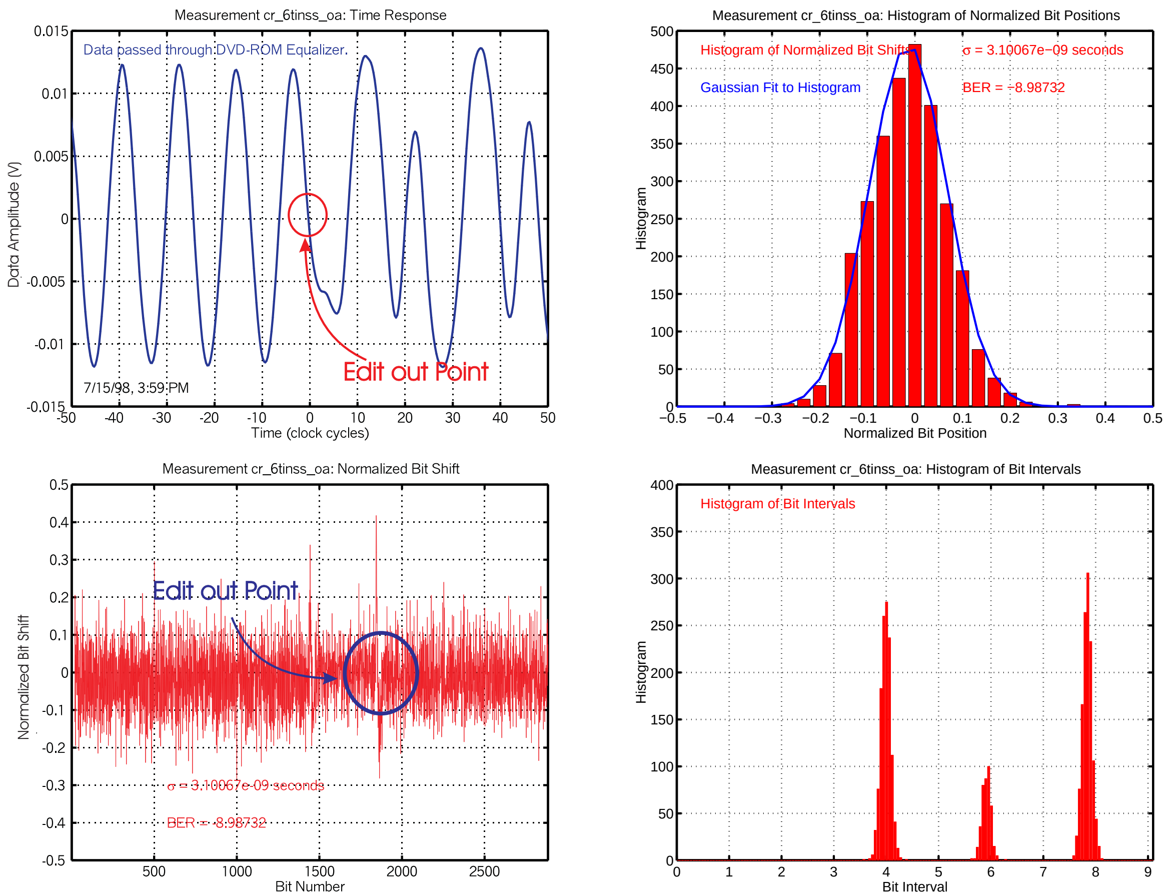

Figure 8. A 6T pattern spliced into a 4T-8T pattern. The upper left plot represents the time response at the edit-out point. The lower left represents the phase error for a data clock generated from the data. (Note the absence of any phase jumps.) The upper right plot is a histogram of the normalized bit positions from which a bit error rate can be computed. The lower right is a set of histograms of the bit intervals. The absence of any 5T or 7T bits is an indication that no bit errors have occurred.

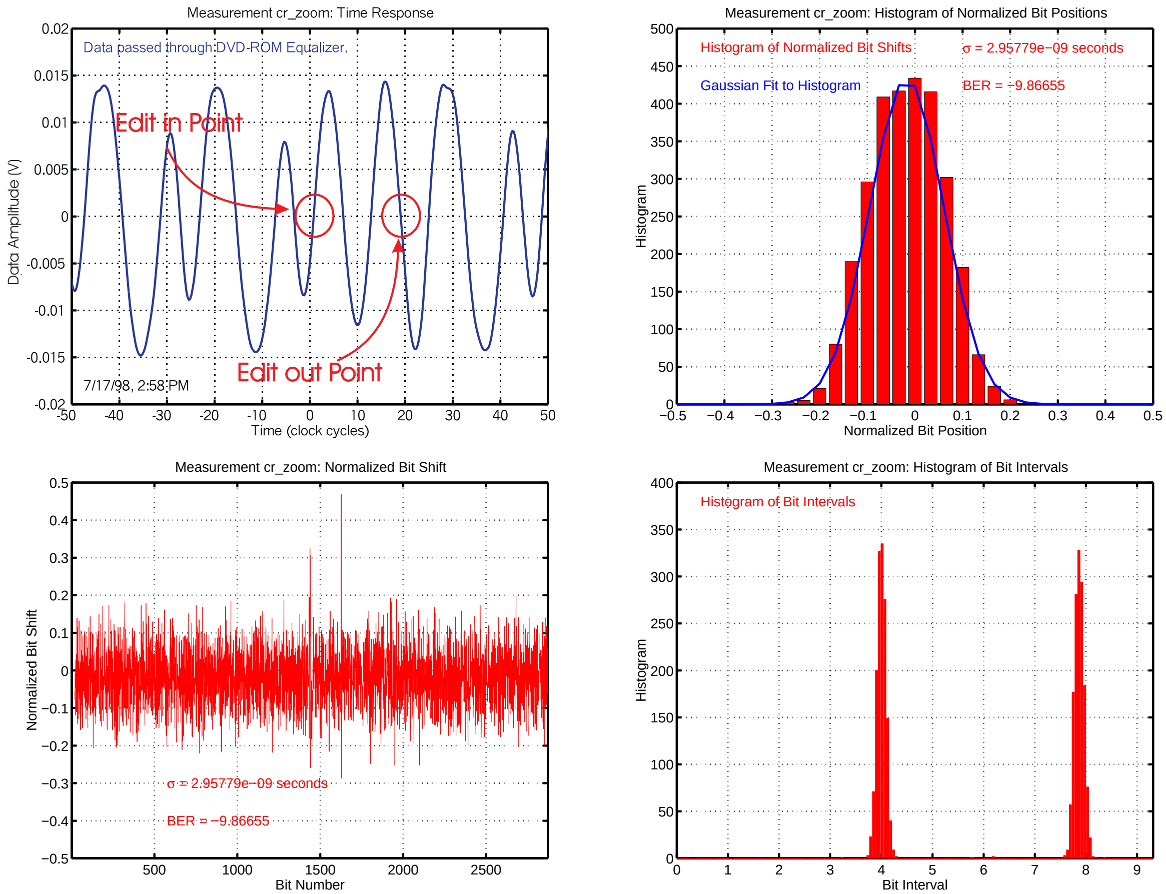

Figure 9. A 2 bit 6T pattern spliced into a 4T-8T pattern. The upper left plot represents the time response at the edit-in and edit-out point. The lower left represents the phase error for a data clock generated from the data. (Note the absence of any phase jumps.) The upper right plot is a histogram of the normalized bit positions from which a bit error rate can be computed. The lower right is a set of histograms of the bit intervals. The absence of any 5T or 7T bits is an indication that no bit errors have occurred.

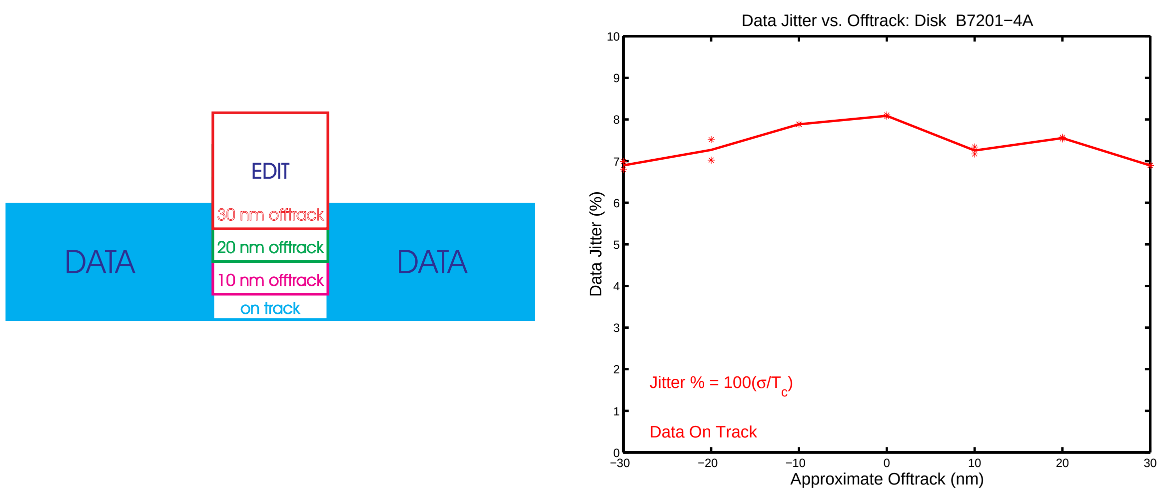

Figure 10. Data jitter versus offtrack insert on 30 nm wobble disk. A long write was done with a 4T-8T pattern. Then edit inserts were made with 6T pattern at various offtrack conditions. Finally, the data jitter was calculated with lens on track using the data channel model.

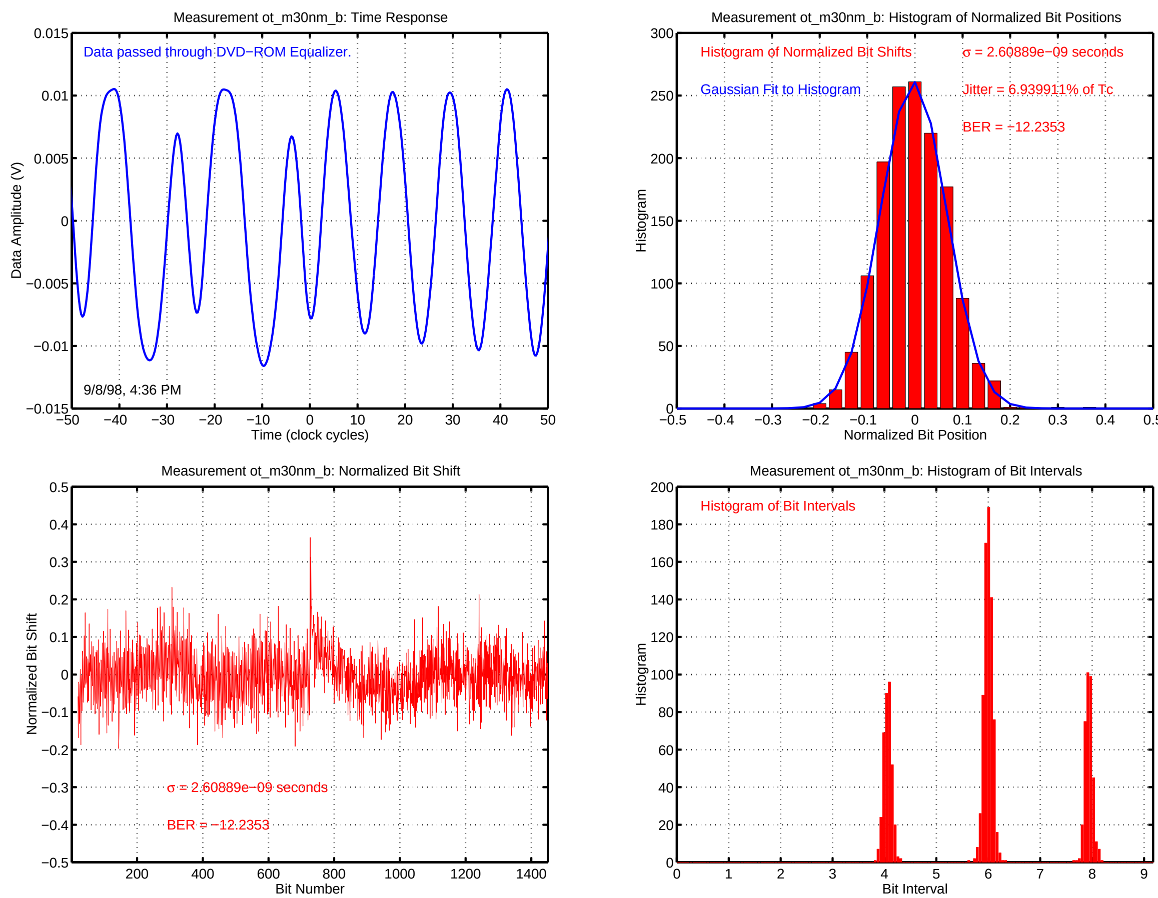

Figure 11. Offtrack measurement on 30 nm wobble disk. This case is offtrack by -30 nm. Note the absence of errors. Offtrack ranges in ±30 nm produce no bit errors.

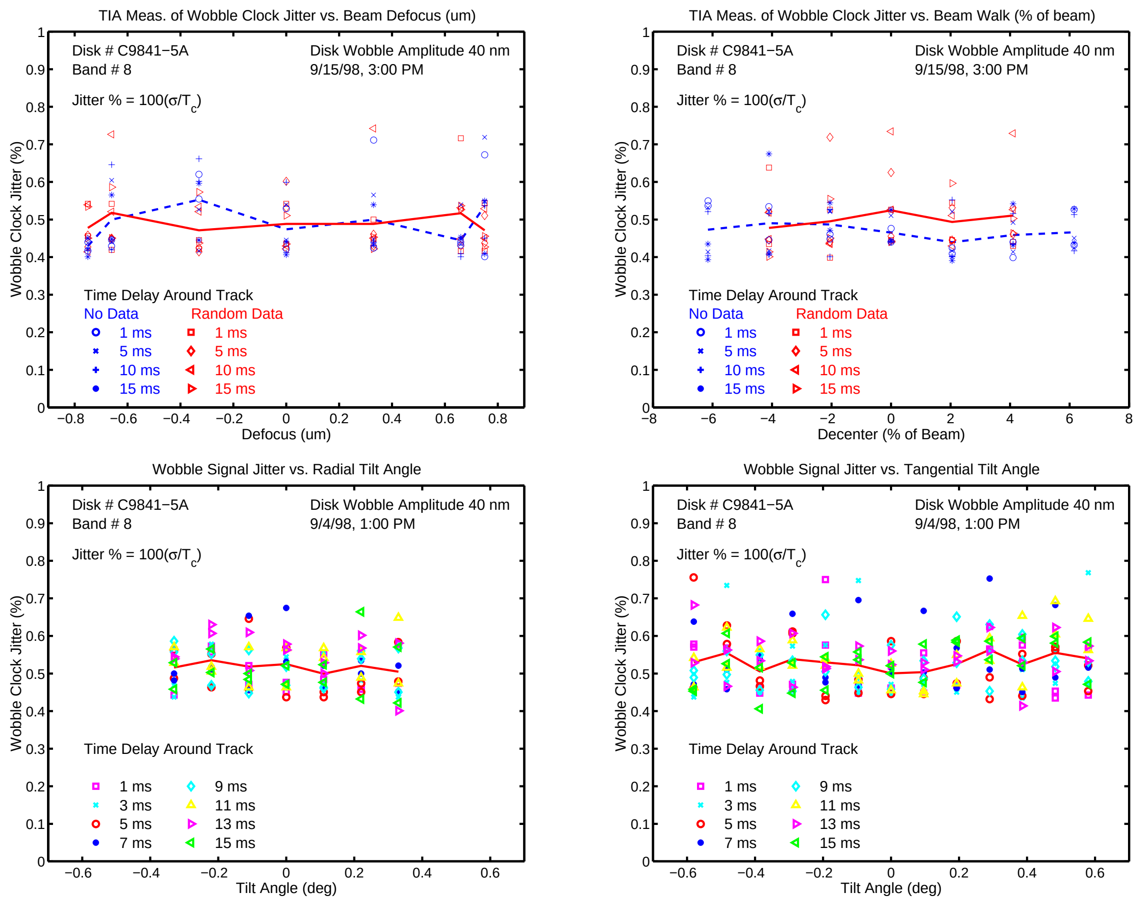

Figure 12. Wobble clock jitter measurements from a Time Interval Analyzer (TIA). Jitter was measured from 2000 leading edges per revolution for 50 revolutions. Measurements were done at different down the track positions by delaying the counting of the first edge by an adjustable number of milliseconds. The upper left plot is a measurement of jitter versus defocus. The upper right plot is a measurement of jitter versus decenter. Measurements were made both with random data on the track and without data on the track. The lower left plot is a measurement of jitter versus radial tilt. The lower right plot is a measurement of jitter versus tangential tilt. In both of these, there was random data both on the track being measured and on the two adjacent tracks. Line plots denote averages of the multiple down the track measurements for a given x-axis condition. Solid line plots are averages of measurements with data on the track. The dashed lines in the top two plots denote averages of measurements with no data on the track. Finally, every condition was measured twice at the same down the track position, and is represented by the same symbol. The variation on a given plot between any two similar symbols that share a common down x-ordinate gives an estimate as to the accuracy of the measurement process itself.