# Modeling a MEMS probe-based storage device


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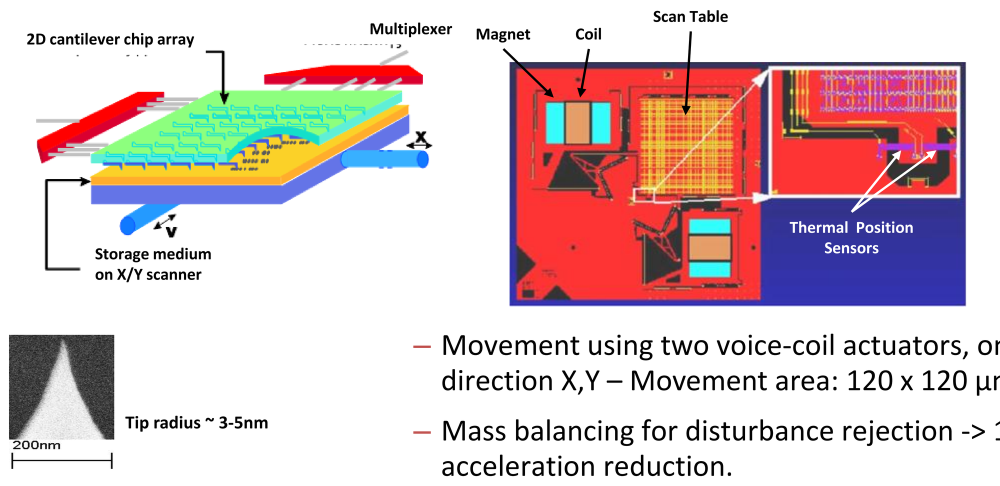
## Introduction

Atomic Force Microscopy (AFM) techniques use nanometer-sharp tips for imaging the surface of materials down to the nanometer scale. Such tips are exploited for creating storage devices capable of storing information with much higher density than conventional devices. This work presents a very accurate simulator of such a device and verifies its accuracy using experimental data of a prototype platform.

## Probe-based Storage Device

- Ultra-high density storage device based on AFM techniques (> 1Tbit/in$^2$) [1].
- Thermo-mechanical recording in thin polymer films.
- Parallel operation of multiple probes to compensate for low data rate of individual probes.
- The medium is moved underneath the probes on X/Y axes via an electromechanical microscanner.

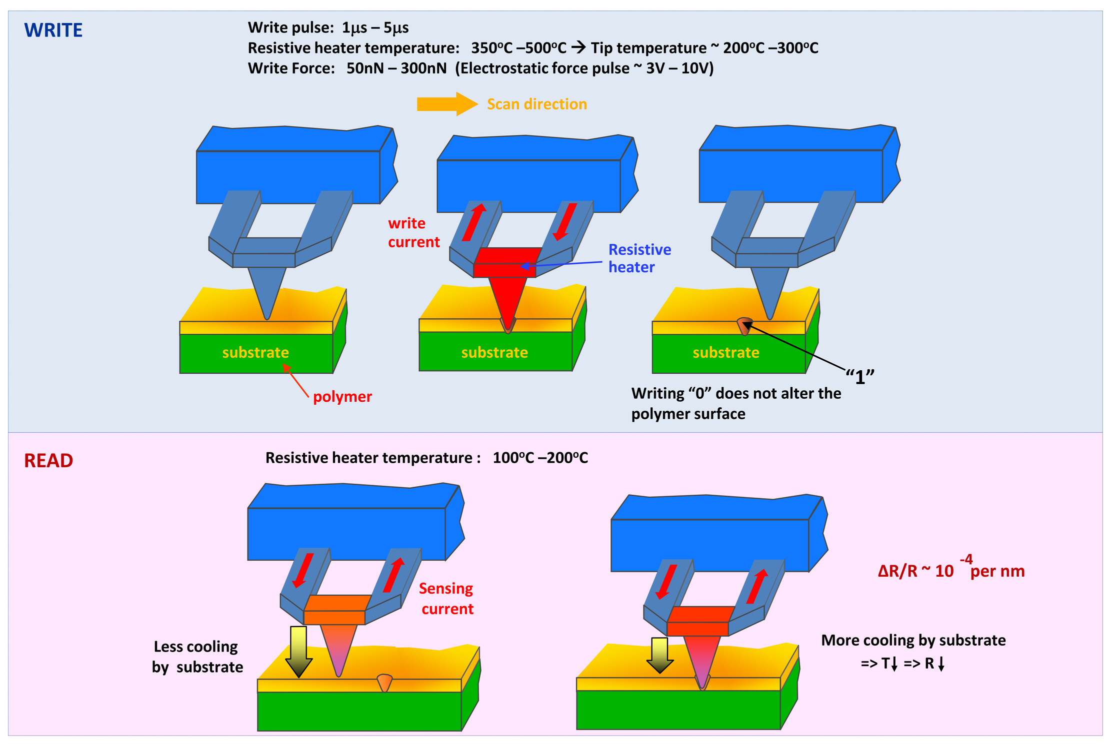



– Movement using two voice-coil actuators, one for each direction X,Y – Movement area: 120 x 120 μm$^2$

– Mass balancing for disturbance rejection -> 100 times acceleration reduction.

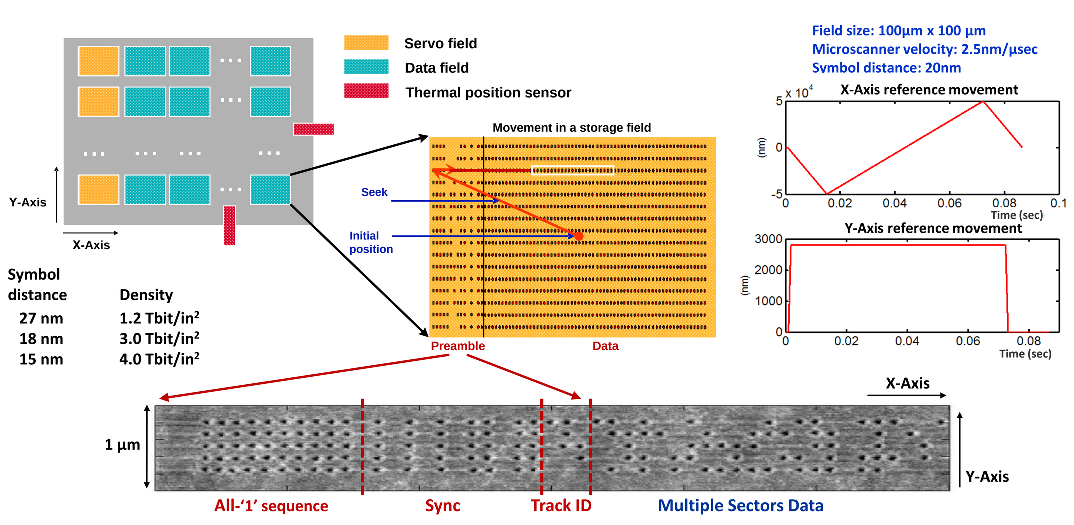
– Two pairs of thermal sensors provide X/Y position information of the microscanner to the servo controller – Sensitivity 1 - 2 nm

## Thermo-mechanical write/read



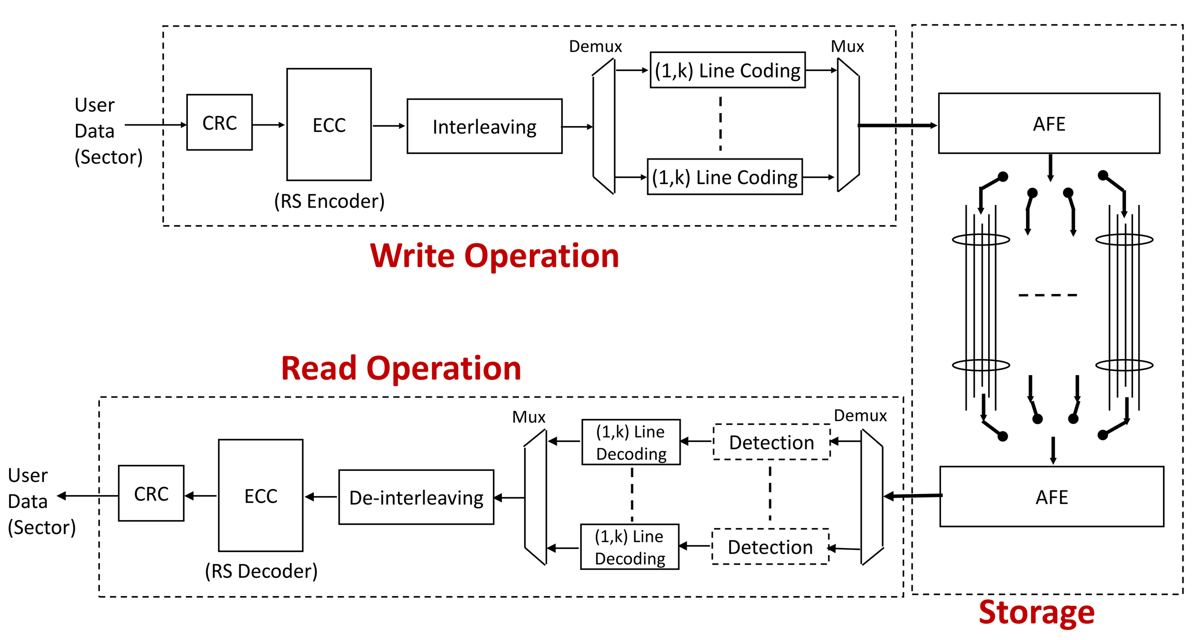

## Storage fields layout

- Each probe performs write/read/erase operations on a dedicated storage field ~ 100μm x 100μm.
- The data are stored on constant symbol distance on X-axis, forming sequences of indentations which are stored on constant line distance on Y-axis.



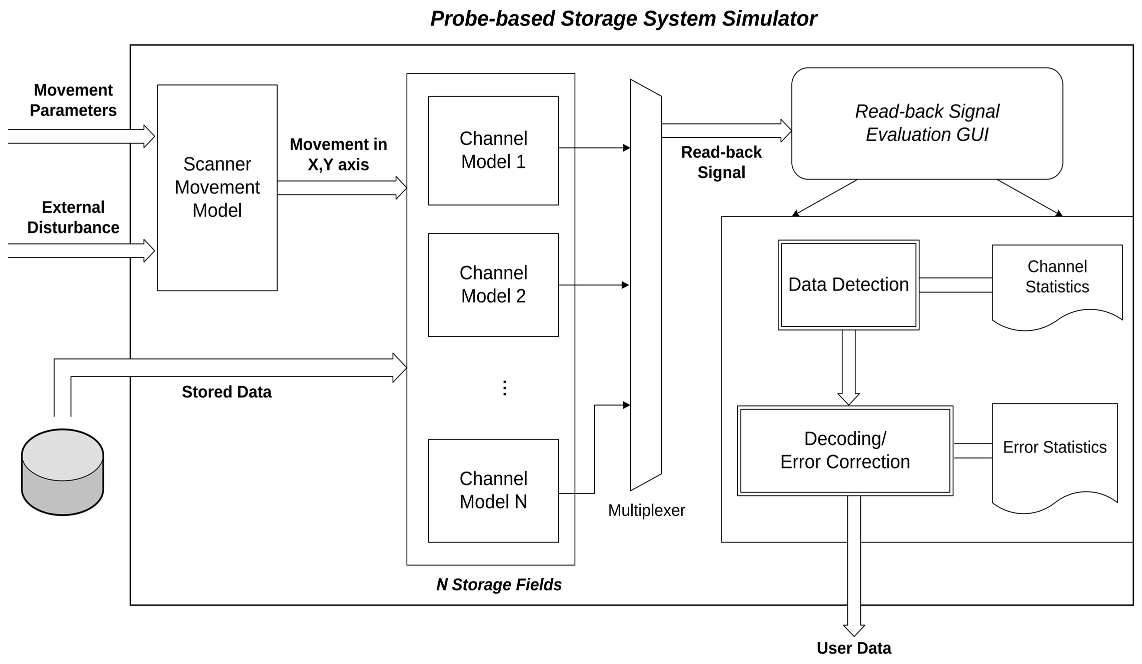

- A preamble is used at the beginning of each line for synchronization purposes.
- Dedicated servo fields with predefined indentations sequences are used for generating a medium-derived positioning error signal (PES).
- During write/read operation the microscanner is moved with a constant velocity.

## Data Controller Architecture

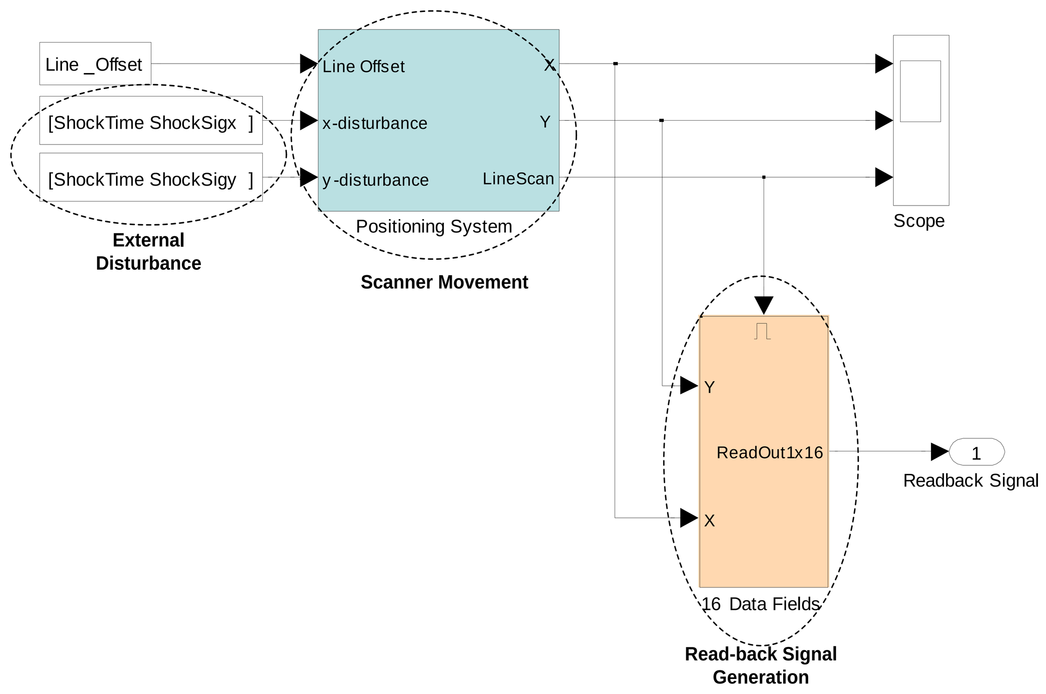



## System Simulator

- Exact simulator that enables the reliability study of a probe-based MEMS storage device even under extreme noise conditions and various kinds of external disturbances.




- The simulator incorporates all system functionalities, i.e. the microscanner movement and the sensing capabilities, the read-back signal of multiple storage fields and the complete data mapping and coding scheme.
- Based on Matlab/Simulink standard and custom functions/models.
- The reference movement signal is generated according to the line offset from the beginning of the storage field.
- External disturbances in the form of acceleration measurements over time can be applied as an input.

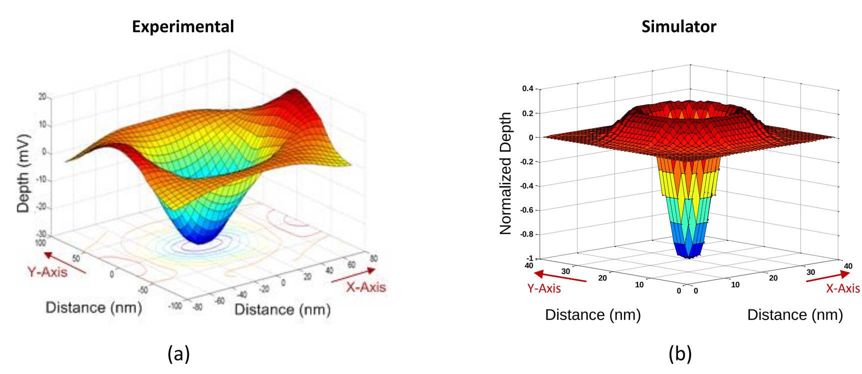



## Positioning system

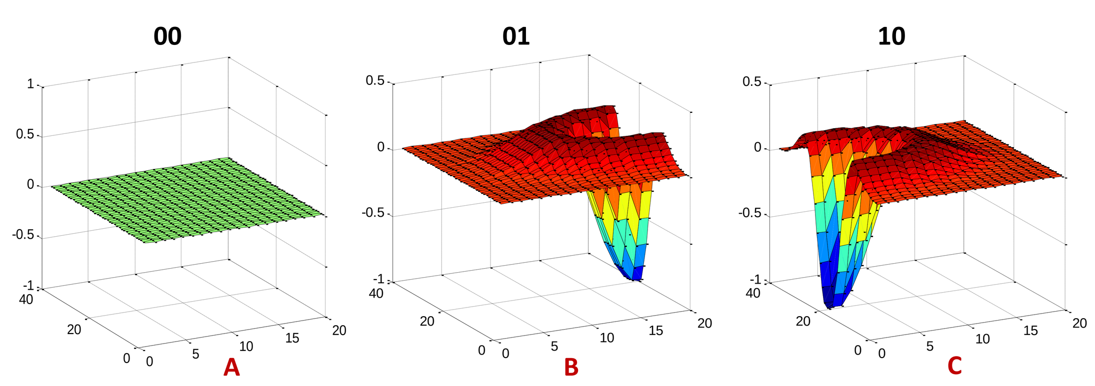
- Exact models of the microscanner and the thermal position sensors based on measurements on a actual prototype are included.
- The exact LQG algorithms that control the microscanner movement on both X,Y axes are implemented.
- The medium-derived PES that assists the control algorithms is generated.

## Storage field representation

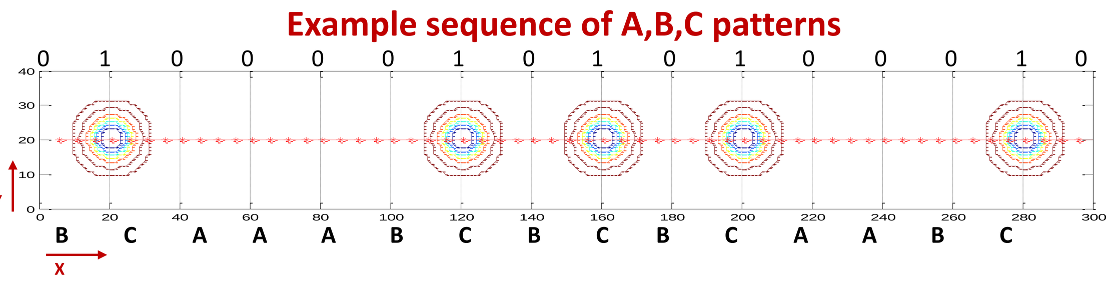
- Distinct models to generate the read-back signal from each storage field – Can be parameterized for any number of fields.
- A 3D indentation model (b) produced by experimental data regarding the actual indentation (a) is used.



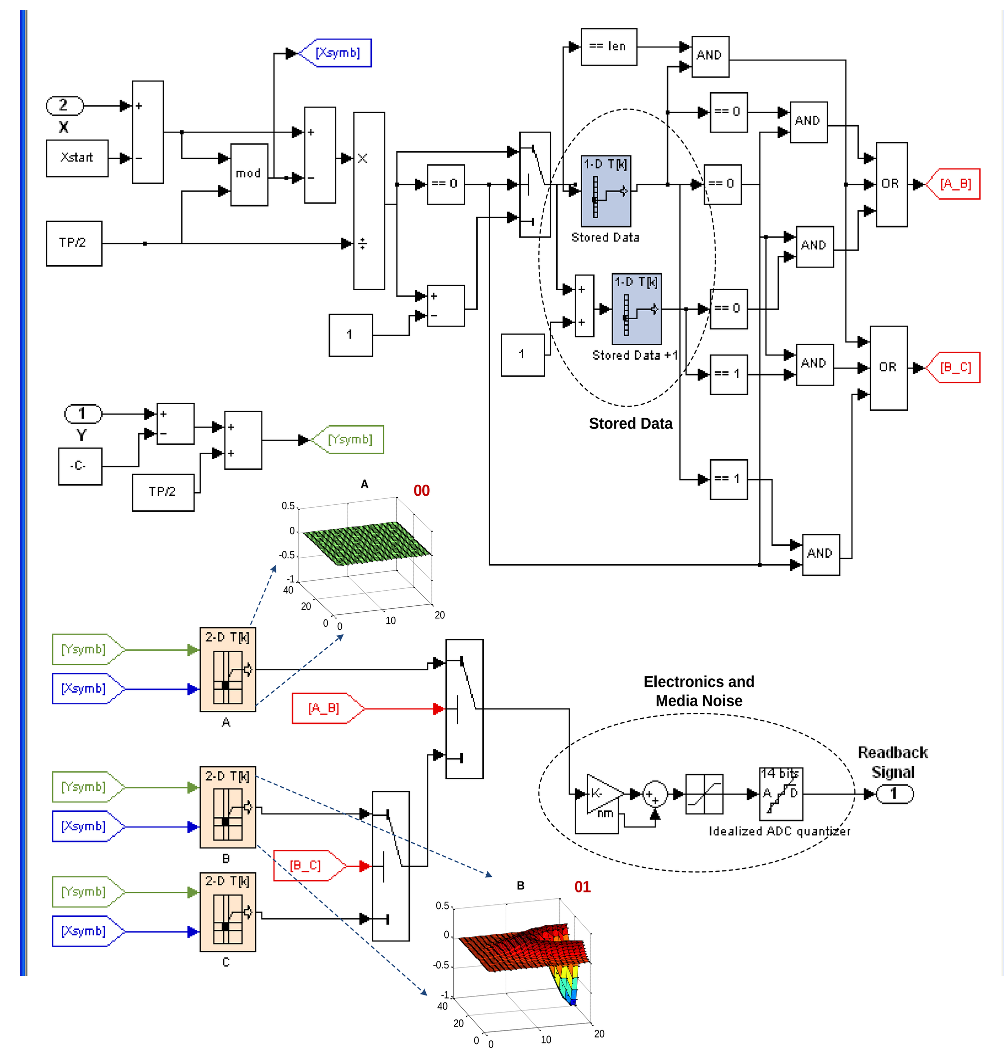

- Normally, 3D huge arrays with depth values at nanometer-level accuracy for all stored lines for every storage field would be necessary for the read-back signal generation.
- Due to the (1,k)-constrained code, there are only three allowable combinations of successive symbols -> (00) , (01), (10)
- Three 3D patterns (A,B,C) can be used along with the data sequences of '1' and '0' stored on the device.




Example sequence of A,B,C patterns




## Read-back signal generation system



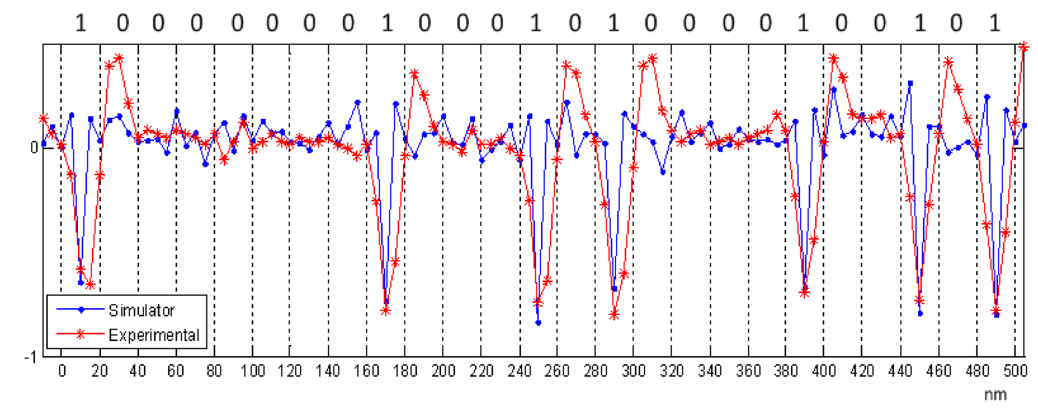

- For every (X,Y) value of the probe movement, the current line and the current symbol inside the line is calculated. Depending on the next stored symbol, the A,B,C pattern is decided. The (X,Y) depth value in the pattern gives the read-back sample.
- The model also includes the various noise sources that affect the read-back signal [2], such as the electronics noise and the media noise (due to the anomalies on the polymer surface), based on measurements on an actual prototype.

## Dataflow Graphical User Interface

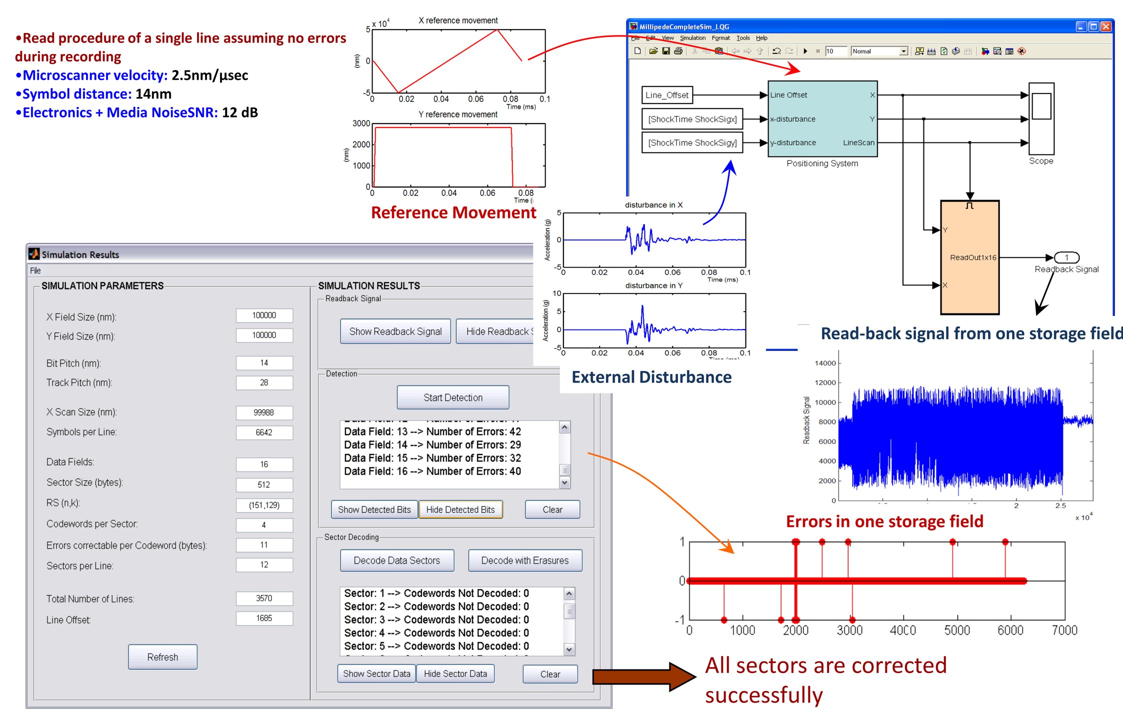
- Based on the read-back signals, the procedures of symbol detection, data decoding and error correction can be perfomed to recover the initial user data.
- Statistics regarding the bit errors that appear in each storage field, the symbol errors that affect the ECC codewords, the total number of codewords that cannot be decoded are produced.

## Simulation Results

### A) Simulated vs. Experimental read-back signal




### B) Complete read operation simulation when the system is affected by a specific external disturbance




## Conclusions and References

- The simulator is a flexible tool that can be used to determine the reliability of a probe-based storage device under various noise conditions, evaluate new microscanner technologies and control architectures, as well as other parameters that affect the device functionality and performance.
- Although it is based on the thermo-mechanical recording mechanism, it can be easily modified to simulate any probe-storage technology.


[1] A. Pantazi, A.Sebastian, *et al*, "Probe-based ultrahigh-density data storage technology," *IBM J. Res. and Dev.*, vol. 52, no. 4/5, pp. 493–511, 2008.

[2] A.Sebastian, A. Pantazi, H. Pozidis, and E. Eleftheriou, "Nanopositioning for Probe-Based Storage Device," *IEEE Control Systems Magazine*, pp. 26–35, August 2008.