DF
DEPARTAMENTO
DE FÍSICA
TÉCNICO LISBOA

Nanotechnologies and Nanoelectronics

2021-semestre 1-P2

Homework #3

The work should be sent to: susana.freitas@tecnico.ulisboa.pt

Deadline: 21 January 2022 @ 23:59[1].

Please send the work in one single file[2] (e.g., pdf, jpeg, word)
identified as: **NN2021_YourName_HW3**

[1] The documents received up to 5 days after the deadline will have a penalty of 1 point (out of 20) per day. No documents will be accepted after the 6th day.

[2] In case you need to have pictures of hand-written work, or multiple format digital formats for your solutions, please merge them into one single document.

Support bibliography:

Book "Theory of Magnetic Recording" by H.Neal Bertram, Cambridge University Press [in Fenix]

Chapters 4 (to answer questions 1-4) and Chapter 8 (to answer question 5)

Magnetic data storage and positioning systems relies on highly sensitive and reliable transducers to measure encoded patterns in magnetic media. A magnetized recording media is characterized by a finite magnetized thickness ***t*** and a bit length ***B*** while its track width (***w***) along the *y* axis is much wider than the other dimensions of interest. Consequently, the medium magnetization $\vec{\boldsymbol{M}}$ lies in the *x0z* plane (2D approach) and the normal H_n and longitudinal H_l magnetic field components produced at each bit surface arise by virtue of a linear charge density $\vec{n}'.\vec{M}$, where $\vec{n}'$ is the unit vector normal to the outward surface.

$$\vec{H} = H_n\vec{n} + H_l\vec{l}$$

$$\begin{cases} H_n = -\dfrac{\vec{n}'.\vec{M}}{2\pi}\Delta\theta \\ H_l = -\dfrac{\vec{n}'.\vec{M}}{2\pi}\ln\dfrac{r_1}{r_2} \end{cases}$$

Figure 1 shows the schematic of an in-plane recorded magnetic medium with a uniform magnetization along the $+x$ axis comprising $N = 2$ bits and assuming a 2D approximation. The magnetic medium is a hard-ferromagnetic material that in the absence of an external magnetic field exhibits a uniform magnetization $M_r = 580\,\mathrm{kA/m}$ along a thickness of $t = 100\,\mathrm{nm}$ and bit length of B. Consequently, the signal is measured at the position $(x, z = t + h = \mathrm{constant})$, where h is equivalent to half of the bit length $(B/2)$.

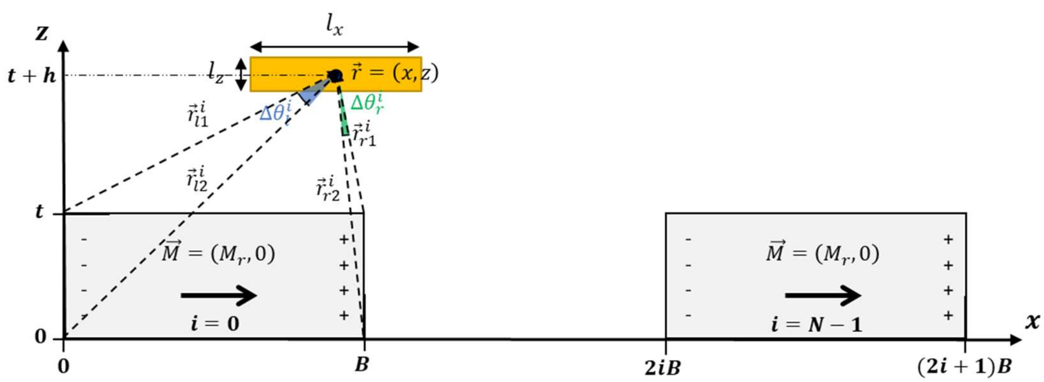

Figure 1: Schematic of an in-plane recorded magnetic medium with a uniform magnetization along the $+x$ axis comprising $N = 2$ bits and assuming a 2D approximation.

The magnetic signal is detected by a magnetoresistive sensor at $z = t + h$ while it is moving along the x axis. The sensor has a length of $l_x = 20\ \mu\text{m}$ and $l_z = 2\ \mu\text{m}$ along the x and the z axis, respectively. Furthermore, it is characterized by a magnetoresistance of MR = 200 %, a minimum resistance of $\text{R}_{\text{min}} = 1\ \text{k}\Omega$, and a linear range between $\pm\text{H}_{\text{keff}} = 2\ \text{kA/m}$. Assuming a bias current of $\text{I} = 0.1\ \text{mA}$ and the average magnetic field over the sensor area $\langle \text{H} \rangle$, the sensor output ΔV is given by:

$$\Delta V\ (H) = MR.\frac{R_{min} I}{2 H_{keff}} \langle H \rangle$$

Questions

NOTE: *Explain and comment all answers, and present the proofs of all computer calculations*

1. Based in the geometric parameters described in Figure 1 write the expressions for the longitudinal and the normal magnetic field components for a single bit and for N bits magnetized along the $+x$ axis assuming a linear superposition of bits.

2. Plot the longitudinal magnetic field component ($H_l = H_z$) as a function of the position *x* generated by a single bit and 10 bits for a bit length of 10 µm, 100 µm and 1mm.

3. Plot the sensor output voltage produced by the longitudinal magnetic field component as a function of the *x* position taking into account the sensor area for a bit length of 10 µm, 100 µm and 1mm ($l_x = 20\ \mu\text{m}$ and $l_z = 2\ \mu\text{m}$).

4. Plot the maximum sensor output produced by the longitudinal magnetic field component as a function of l_x ($l_z = 2\ \mu\text{m}$) for a bit length of 100 µm. Which is the maximum l_x to neglect the sensor dimension? Please consider the maximum sensor output around the middle of the pattern under study with enough bits (N >> 1) to neglect the border effects.

5. Indicate (no need to calculate) how the equations would change to include:

    a. An inhomogeneous magnetization profile along the media thickness
    b. An irregular bit transition, with width δ (δ ~ 10% of the bit size)

6. [Optional] Check examples of product technical details from manufacturers of similar magnetic readout systems for linear encoders:
    a. Sensitec (Germany)
    b. Renishaw (USA)