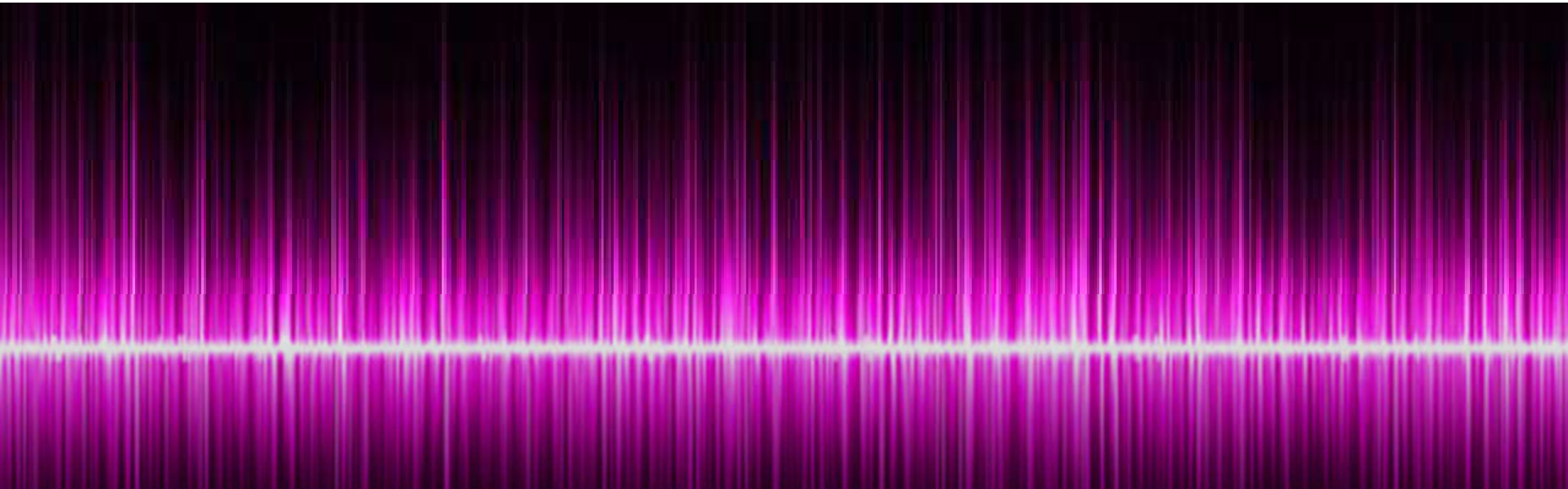


# Characterizing Noise in Magnetic Tunnel Junctions

- Jay Motka

Image from: health.cleavelandclinic.org

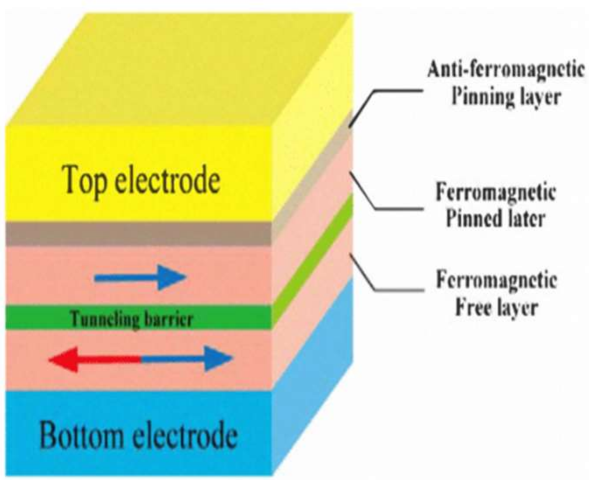
# Outline

- Introduction to MTJ
- Theory of MTJ & 1/f Noise in MTJ
- Experimental Details
- Data Analysis & Results
- Errors & Limitations
- Concluding Thoughts
- Acknowledgment

# Introduction to MTJ

- Due to their high sensitivity and small sizes, MTJ are very useful across various industries.
- Especially, useful in development of Magnetocardiography (MCG) and Magnetoencephalography (MEG).
- These magnetic signals from the heart and the brain are in the range of pico-Tesla (pT).
- So, it is necessary to characterize noise at those smaller range of magnetic field.

# How does MTJ work?




From Lei et. al. (2010)

- As shown in the diagram, one FM layer has a "pinned" magnetization by an AFM layer attached to it.
- Assuming the spin of electrons remains constant during tunneling, according to Fermi's golden rule, spin-up electrons from one electrode would fill spin-up states in the second electrode.
- FMs with different magnetization have different numbers of spin-up electrons/states.
- So, when both FM have parallel magnetization, there would be more current.
- But during antiparallel magnetization, there would be less current because there are lesser no. of spin up states for the spin-up electrons to fulfill.
- So, there is discrepancy in resistance of these two – parallel and – antiparallel state, and it is measured by TMR ratio,

$$TMR = \frac{R_{AP} - R_P}{R_P}$$

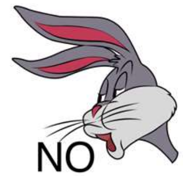
# 1/f Noise in MTJ

- There are many different types of noise in MTJ sensors: Thermal, shot, 1/f, RTN, etc.
- However, 1/f noise is dominant in low frequency regime.
- So, we focused on 1/f noise in this project.
- The voltage power spectra of 1/f noise can be characterized by,

$$S_V = \frac{\alpha V^2}{Af}.$$

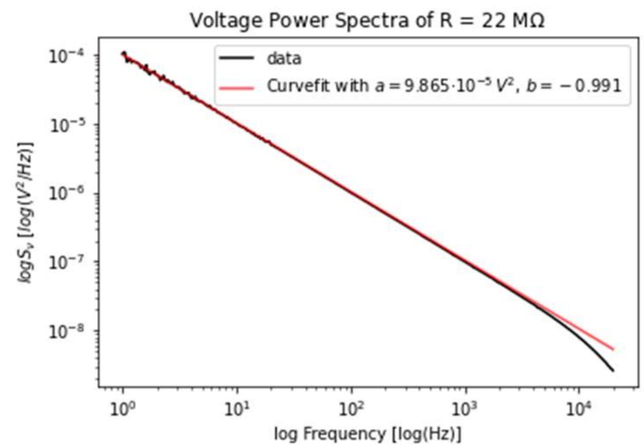
- So, the 1/f noise can be identified by fitting a function of the type,

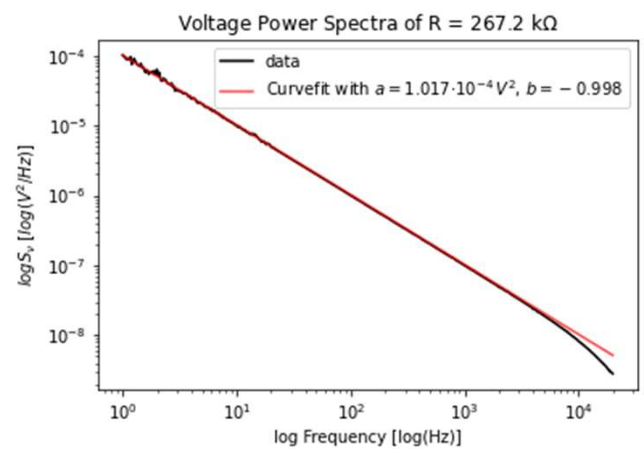
$$S_V = af^b$$




# Failure from the get-go!

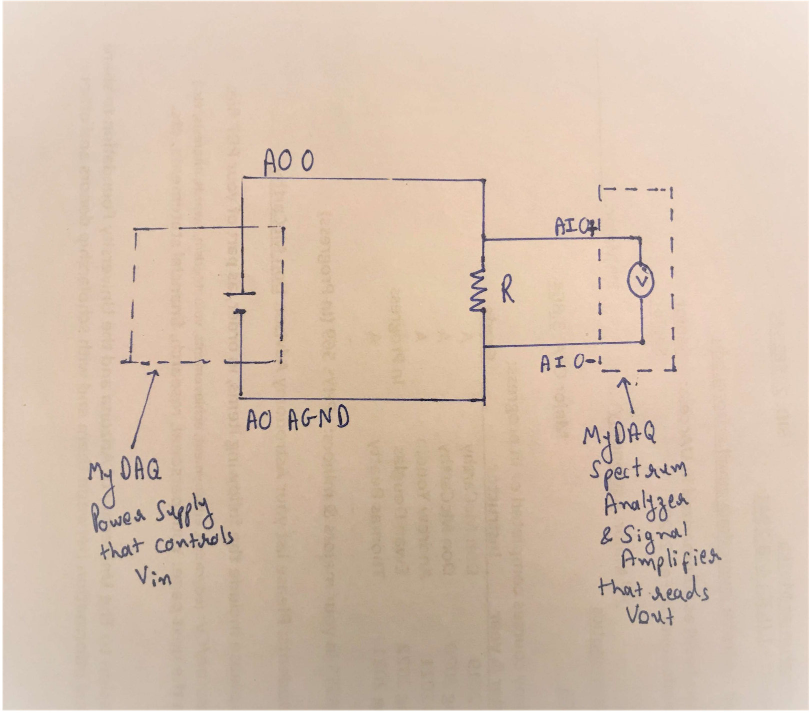
- We were unable to connect the spectrum analyzer to the GPIB interface.
- So, we decided to use the MyDAQ device and NI ELVISmx software to obtain the voltage power spectra.
- We started by obtaining voltage power spectra of resistors: R = 22 MΩ and R = 267.2 kΩ.
- By least-squares curve fitting, we find $b \approx -1$. However, the values of parameter a is extremely similar for both resistors.
- This means the noise that is identified is 1/f, but the noise from the MyDAQ device is dominating the noise from the resistors.



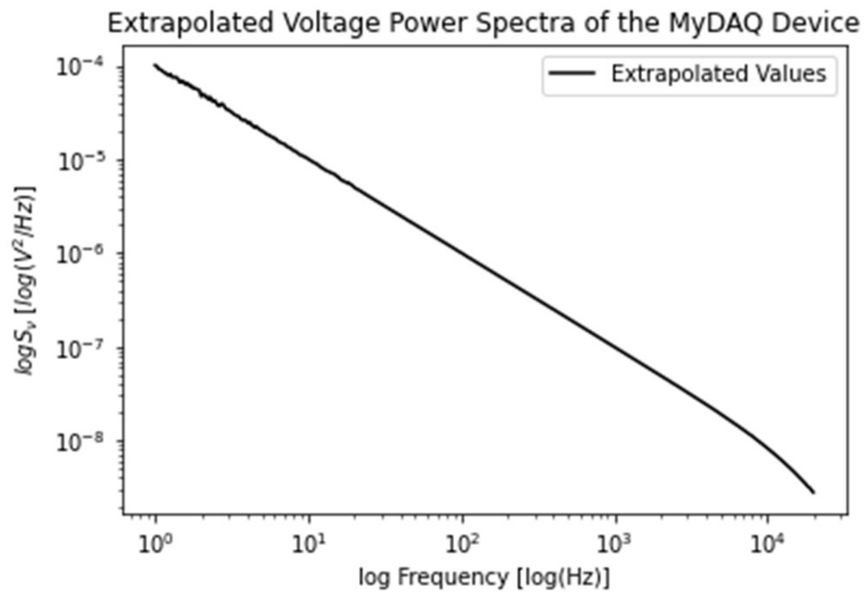



# Nice Save!

- It was necessary to distinguish the power spectrum of the MyDAQ device, so that we can calibrate.
- So, we decided to approach this problem with a new method.
- We found power spectra from various resistors from 1 kΩ to 22 MΩ using the circuit shown.
- We fitted a surface function of power spectra through this data, i.e., $S_v(R, f)$.
- Now, we can extrapolate $S_v(R=0, f)$, which is the MyDAQ device's voltage power spectrum.
- We used machine learning for this - in particular, scikit-learn's RandomForestRegression() method.



# Extrapolated Voltage Power Spectrum of the MyDAQ Device



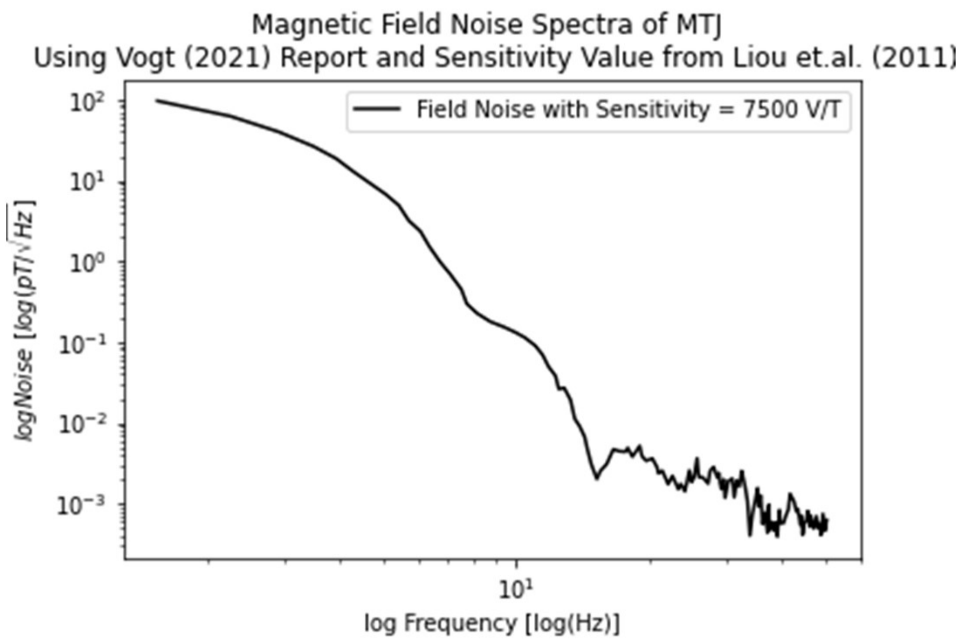
# Finding the Noise in MTJ

- Given the time constraint, we analyzed the MTJ voltage power spectrum data given in Vogt (2021) report.
- The voltage noise can be found by taking the square root of the voltage power spectrum.
- The relationship between the magnetic field noise and the voltage noise is given by,

$$Noise_B = \frac{Noise_V}{Sensitivity}$$

- Sensitivity is the slope of output voltage vs. applied magnetic field graph for an MTJ.
- From Liou et. al. (2011), we found the sensitivity of an MTJ to be 7500 V/T.
- Assuming this to be the standard scale of sensitivity, we obtained a graph of magnetic field noise for the MTJ used in Vogt (2021).

# Magnetic Field Noise of an MTJ

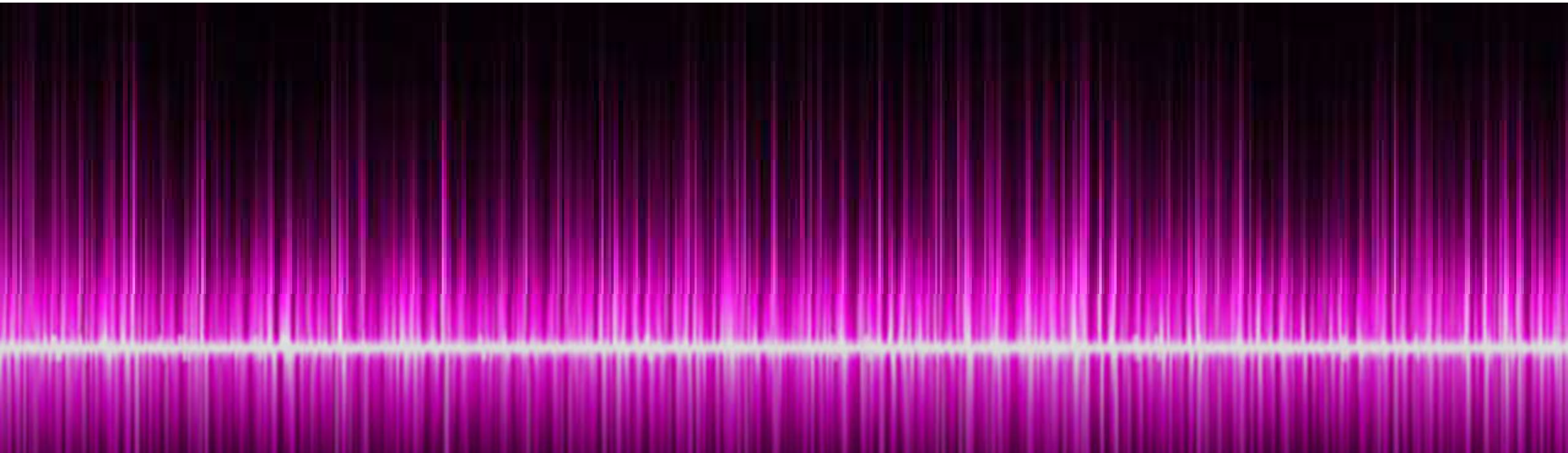


# Errors and Limitations of the Experiment

- Assumptions in extracting the voltage power spectra of the device:
  1. The voltage power spectrum of the MyDAQ device is constant for all measurements.
  2. There is a linear correlation between the voltage power spectrum of the device with the voltage power spectra of resistors that we found.
- Not the most robust assumptions but given the limitation of available equipment this was the best way to calibrate.
- The data from Vogt (2021) was digitized from a photo of spectrum analyzer screen – not having the right tilt while taking the photo may have induced some errors in data.
- The value of the sensitivity may be different for the given MTJ, which may also be a source of error.
- Contribution of other types of noise sources: thermal noise, shot noise, RTN noise, etc.

# Concluding Thoughts

- To be sure of the extrapolated voltage power spectrum of the MyDAQ device, the correlation can be tested by calculating Pearson's product-moment correlation coefficient.
- Other more powerful calibration technique might be useful.
- Using four-probe circuit instead might give us more sensitive results.
- More sensitive device such as a spectrum analyzer would make things much easier.
- However, given the limitation of equipment, we extracted a very powerful result that, if further tested and proven to be correct, can be used to characterize noise in MTJ using the MyDAQ device in the future experiments.
- Furthermore, we found that the magnetic field noise in MTJ was found to be in the range of $10^2 \frac{pT}{\sqrt{Hz}}$ to $10^{-3} \frac{pT}{\sqrt{Hz}}$. Thus, it can be safely concluded that MTJ can be utilized to measure magnetic fields of the brain and the heart.



# Thank you!

Special thanks to both Tas, Gavin Vogt, and Prof. Wang.

- Jay Motka

Image from: health.cleavelandclinic.org