

Design and construction of an experimental setup to study ferromagnetic resonance

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Abstract: In this “Treball de Fi de Grau”, I have designed and built an experimental device that allow us to study ferromagnetic resonance. The objective of this device is to be implemented as a didactic laboratory experiment in the laboratory of Modern Physics of the Physics Degree at U.B.

I. INTRODUCTION

When we place a ferromagnetic sample inside a magnetic field, the magnetic moments of the ferromagnet tend to line up parallel to the field, precessing around that direction. If while we fix the precession of the magnetic moments of the ferromagnet with a magnetic field, we also send an oscillating magnetic field perpendicularly to the first one, and the frequency of this one equals the precessional frequency, known as Larmor precession frequency, the resonance condition is fulfilled and the sample absorbs its energy, leading to a change of its angle. In ferromagnets the Larmor frequency is typically 1-35 GHz, and the electromagnetic waves of this spectrum are known as microwaves.

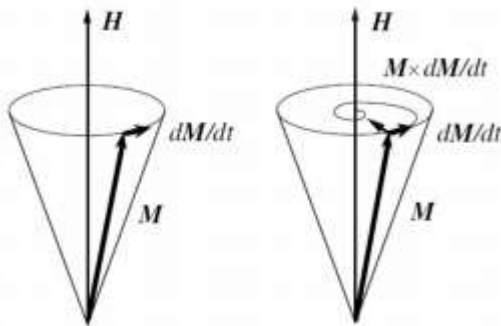


Figure 1: Precession of the magnetization \vec{M} of a material in a static magnetic field \vec{H} , and the magnetic force moment, proportional to $\vec{M} \times \frac{d\vec{M}}{dt}$.

II. DESIGN AND CONSTRUCTION

To build the experimental setup capable of carrying a study on ferromagnetic resonance, we

need the following components: an electromagnet, a Hall probe, a microwave generator VCO, a coplanar waveguide, a microwave detector, a protoboard, coaxial cables, two power supplies, the ferromagnetic sample, an Arduino m0 board and a computer to interact with the Arduino board and collect the data we receive.

The whole experimental setup is either directly fed by the Arduino board or controlled by it, but the board has certain characteristics that limit its options, and it is necessary to have a protoboard with electrical components soldered in it in order to build some electronics to amplify, filter and treat the signals coming in and out of the Arduino board.

The Voltage Controlled Oscillator (VCO) is an electronic oscillator, that allow us to send microwaves of different frequency to the sample. The oscillation frequency of the VCO is determined by a voltage input, that in our case is controlled by the Arduino board. We selected the VCO ZX95-3800A+. This VCO allows us to generate microwaves in a range from 1,7 GHz to 4 GHz, controlled by an input voltage from 0 V to 21 V, it is important to never overpower the VCO because it may get damaged. It also needs to have a constant feeding of 6 V to work, again it is important to not overpower it. We use one power supply to feed the VCO, fixing the power supply to 21 V and connecting it to the electronic components soldered in the protoboard, a voltage regulator with an output of 6 V that provides the constant voltage that needs the VCO to work and also connected with the operational amplifier that will control the input voltage that selects the operating microwave frequency.

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We use Pin 2 of the Arduino board, this pin provides from 0 V to 3,3 V in the form of a pulse width modulation, we take this signal and make it pass through two low-pass filters that will clear the noise caused from being a PWM signal, and it also goes through the operational amplifier mentioned before that multiplies the 0-3,3 V to 0-21 V.

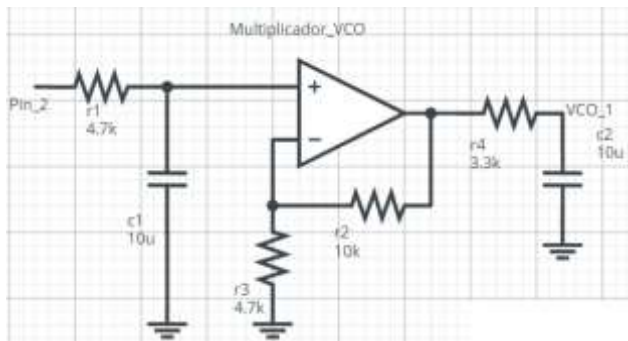


Figure 2: Schematic of the multiplier and filters used.

Once the microwave leaves the VCO, we use a coaxial cable to transport the signal to the coplanar waveguide that will contain the sample.

The coplanar waveguide allows us to carry the signal onto the sample without energy loss. This consist of a conducting track printed onto a dielectric substrate, in our case fiberglass, together with a pair of return conductors, one on each side of the central track, and separated from it by a small gap. The electromagnetic wave exists partly in the dielectric substrate, and partly in the air above it, so if we place the sample onto the central track the microwave will interact with it.



Figure 3: Design of the coplanar waveguide printed on the fiberglass board.

Since we use coaxial cables to carry the signal to the coplanar waveguide and from it to the detector, it is important that the source and load impedance match to ensure maximum power transfer and minimum standing wave ratio, so the characteristic impedance of the coplanar waveguide must be the same as the cables, which is of 50 Ω . The characteristic impedance of the coplanar waveguide depends on the width of the central conductor track, the width of the gap between the central track and the return conductors, the substrate thickness, and the relative dielectric constant of the substrate.

Substrate Thickness (mm)	0,850	$\pm 5\%$
Gap Width (mm)	0,300	$\pm 5\%$
Conductor Width (mm)	1,100	$\pm 5\%$
Relative Dielectric Constant	4,700	$\pm 5\%$
Impedance (Ω)	50,025	
Effective Dielectric Constant	3,097	

Table 1: Values used in the coplanar waveguide and the resulting impedance.

Right after the coplanar waveguide we place a detector, in our case we used the Agilent Technologies 8471E detector. This is a Planar Doped Barrier (PDB) diode detector with an effective performance on frequencies from 10 MHz to 12 GHz, and a Low Level Sensitivity of about 0.5mV/ μ W. The detector gives us a signal in the units of Volts, and we process this response through the protoboard and programing the Arduino to clear and amplify the signal. The procedure to accomplish this is as follows: the first few measures we make, are used as a guide on the signal we receive, and use this information to make an offset on the following measures which result will be amplified by 20, in order to be able to see even the slightest variations on the signal. The value used in the offset is send through the Pin 3 of the Arduino board, this sends a PWM signal, so we make it go through a filter to clear the noise.

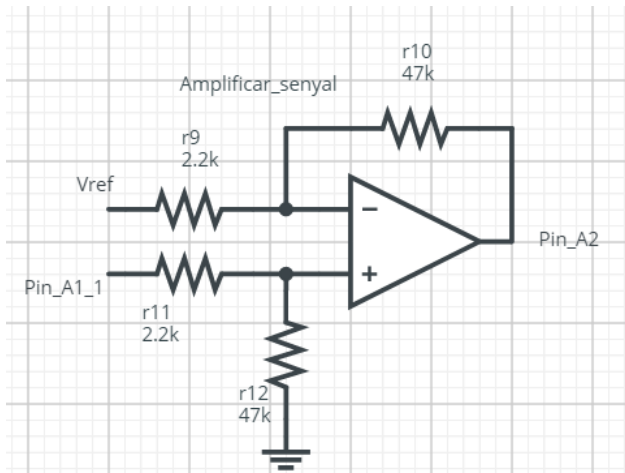


Figure 4: Schematic of the amplifier used.

The coplanar waveguide is placed in the centre of the electromagnet, which will generate the static magnetic field \vec{H} that orients the magnetic moments of the sample. The electromagnet is fed by an external power source, which is controlled by the Arduino board, sending voltage from the pin A0. This pin sends a true analog voltage value, so we don't need to put a filter to clear the noise, and we chose this pin to control the electromagnet because it is important to be as accurate as possible with the magnetic field applied, since small uncontrolled differences would severely affect the results. This signal goes through a voltage divider, since due the characteristics of the power source used and the electromagnet it is important to not overcome 1 A in the output of the power supply.

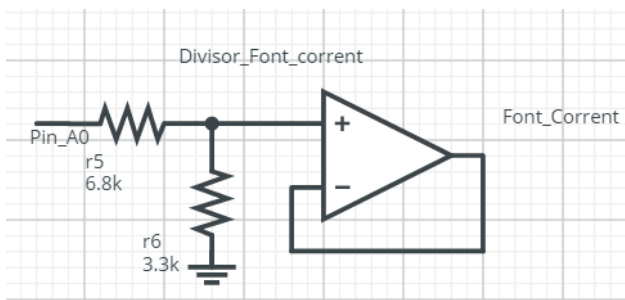


Figure 5: Schematic of the voltage divider used.

We will apply values of magnetic field from 0 mT to 100 mT, and in order to be sure of the magnetic field applied we place the Hall probe inside it, and read the values with the Arduino board.

The detection and generation of analog signals (with the ADCs and DACs) with the Arduino

board is performed with 12 bit resolution, which offers us a range of reading and writing values from 0 to 1023.

The experimental procedure planned is: we place the ferromagnetic sample on the coplanar waveguide inside the magnetic field generated by the electromagnet, then we fix a value of the magnetic field and with the VCO we send microwaves in all the frequencies that it can. The computer collects the data regarding the frequency, the value of the magnetic field and the intensity of the microwave after crossing the sample, and then amplify this signal. Once this process is done, the magnetic field changes and the operation is repeated.

III. RESULTS

As mentioned before, we use a resolution with the Arduino board of 12 bites, but we must be sure of the correlation between the digital levels we write and read and the actual values we are providing and reading in terms of physical measures. To accomplish that we need to calibrate our instruments according to these values.

First, we calibrate the VCO to establish a correlation between the level we write in the Arduino board and the output frequency that the VCO generates. We connect the VCO with the Arduino, and generate signals that we read with an Agilent Spectrum Analyzer.

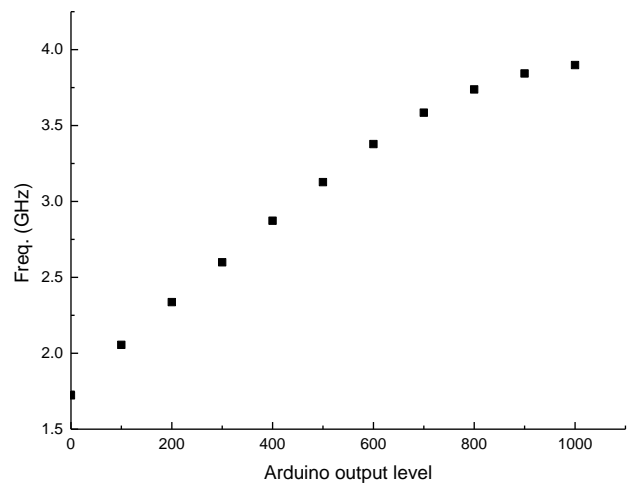


Figure 6: VCO frequency output according to the number the Arduino board writes.

Another correlation we need to know is the equivalence between the magnetic field we are generating, that is read by the Hall probe, and the value that the Arduino reads.

To test this, we generate magnetic field through the Arduino board with the electromagnet and read the value of the Hall probe with the Pin A3 of the board. Notice that we only consider the reading value, and not the one we are writing, because the magnetic field we generate depends also on the variable gap of the electromagnet we put the sample in, and that may not be constant from one measure to another.

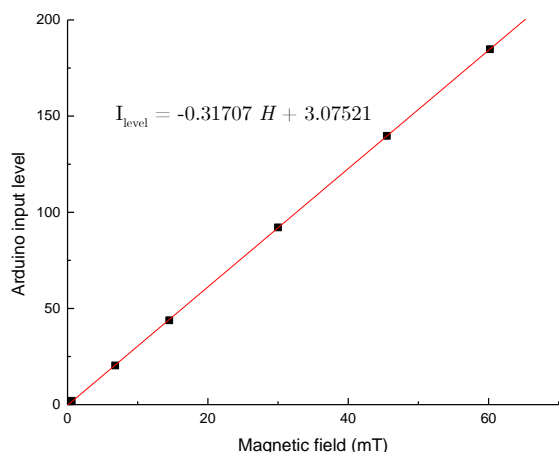


Figure 7: Dependence of the Arduino input level we read on the magnetic field generated.

Even though the experimental setup described in this article has been tested and proved to work properly, the VCO used was damaged and stopped to work before we could get viable results to present in this paper, and the substitute will not arrive in time to replace it and run the tests before the presentation date, so we present the results obtained using the experimental setup described, but instead of using the VCO to send microwaves we used an Agilent RF signal generator. Also, instead of fixing the magnetic field and make a sweep of all the possible frequencies, we fixed one frequency and made a sweep of the magnetic field. This procedure is then iterated for the different operating frequencies.

The results exposed are for samples of Permalloy (Py) with thickness of 250 nm and 150 nm. Permalloy is a nickel-iron alloy which is normally composed by 80 % nickel and 20 % iron. We chose this material because in a ferromagnetic resonance experiment like the one we designed the absorption pick of the microwave energy produced

is deep enough to be seen without any doubt and it is also wide enough to be noticed without taking excessive number of point to measure, which accelerates the process. But the experimental setup works for any ferromagnetic material.

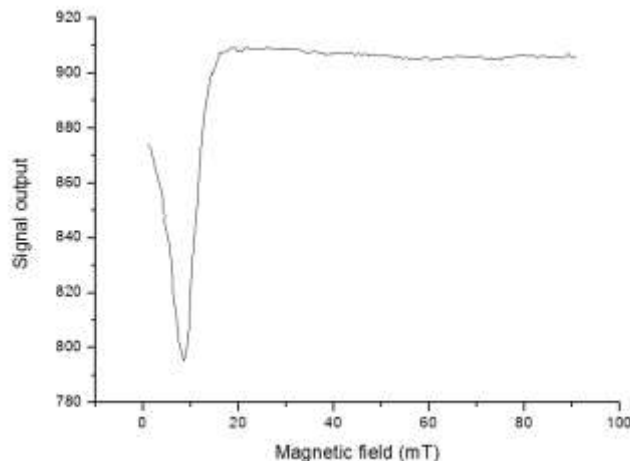


Figure 8: Intensity vs magnetic field for a sample of permalloy of 150 nm, at a frequency of 2GHz and 5 dBm.

The Y axis is the signal after processing the initial signal of the detector. Since we want to see that given a frequency the ferromagnetic sample presents an absorption of energy that depends on the external magnetic field, the units of this axis can be considered arbitrary.

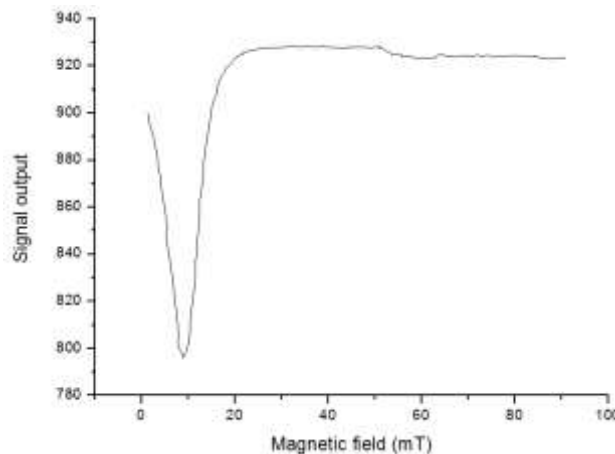


Figure 9: Intensity vs magnetic field for a sample of permalloy of 250 nm, at a frequency of 2GHz and 5 dBm.

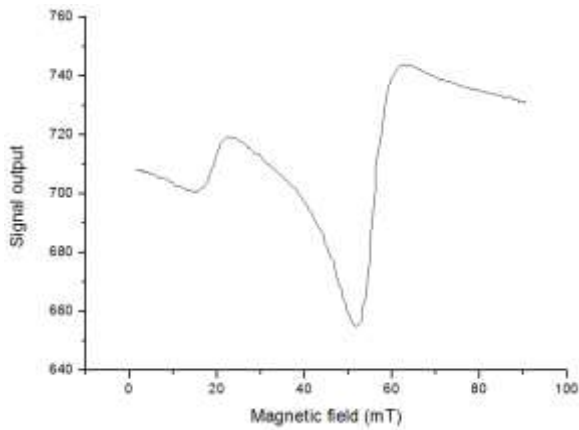


Figure 10: Intensity vs magnetic field for a sample of permalloy of 150 nm, at a frequency of 4GHz and 5 dBm.

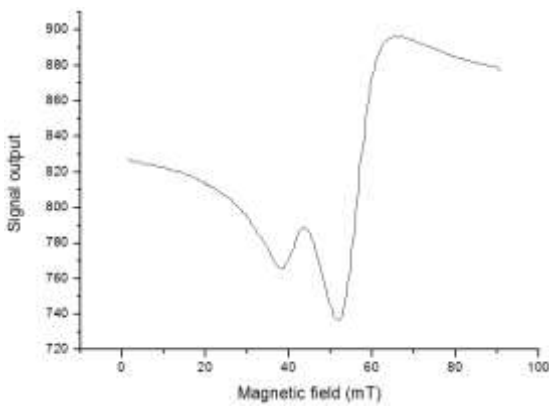


Figure 11: Intensity vs magnetic field for a sample of permalloy of 250 nm, at a frequency of 4GHz and 5 dBm.

At 4 GHz we can see a second absorption peak; this is due to spin waves modes in the sample. The effect of these spin waves modes depends on the thickness of the sample, as we can see the differences between the sample of 150 nm and the 250 nm.

IV. CONCLUSIONS

With the results obtained we can affirm that the experimental setup designed and built is appropriate to carry on experiments of ferromagnetic resonance, and we can also see that in case of a malfunction of a component it is easy to replace it or find a suitable substitute. It is also remarkable the low cost of the whole setup, an order of magnitude cheaper than a similar setup you can find in the market.

Acknowledgments

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