Measurement of Susceptibility Using Colpitts Oscillator

Final project report

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Abstract

Using Labview, a program is built to remotely measure the susceptibility of a material using simple circuit design, a Colpitts oscillator. First, using PID algorithm, temperature controller is made and later it is used for temperature dependent measurement of resonant frequency. Due to thermal drift, the resonant frequency seemed to show fluctuating nature, however keeping the oscillator at a temperature above room temperature solved the issue at least in a part. Temperature dependent measurements of resonant frequency show some qualitative hints about the magnetic nature of material being used. The measurements on more materials and efforts to reduce the thermal drift are currently underway.

1. Introduction

Temperature dependent study of physical parameters such as magnetization, conductivity, to name a few, is essential to understand the material property and to make it suitable for practical application. In this project, we would like to design a setup to measure the susceptibility of a material with varying temperature. We use a Colpitts oscillator circuit for this purpose. As oscillators are best known for their ability to produce stable waveform at certain resonant frequency, which only depends upon the value of capacitor and inductor used in the tank circuit. The key idea of this project is to change the value of inductor by putting an magnetic material inside the inductor coil, which helps changing the inductance and hence a shift in resonant frequency can be expected. This shift in resonance frequency (Δf) can be related to the susceptibility (χ) of material by using following equation;

$$\frac{\Delta f}{f_{res}} = -\frac{1}{2}\frac{Vs}{Vc}4\pi\chi^{1} \quad \dots\dots\dots\dots\dots\dots..(1)$$

where *Vs* is sample volume and *Vc* is inductor coil volume.

From Curie law,

$$\chi \, \alpha \, \frac{1}{T} \quad \dots\dots\dots\dots\dots\dots\dots..(2)$$

From equation (1) and (2)

$$\Delta f \; \alpha \; \frac{1}{T} \qquad \qquad \text{………………(3)}$$

Thus, for a paramagnetic material, the shift in resonant frequency is inversely related to the temperature.

2. Procedure

To perform the actual measurement, we use LabView program to make interfacing of the instruments with the computer using GPIB connection. We then write subVIs and VIs so that we can perform measurement remotely. Below we have a brief explanation of the subVIs and VIs that were built and used for this project.

2.1 Temperature controller

As we are interested in temperature dependent measurement, hence at first we would like to build a program so that we can have excellent control over the temperature. A temperature controller can be made using basic PID algorithm.

2.1.1 Initialize power supply

It is necessary to initialize power supply before starting the measurement. To do that we have used already installed Agilent 66XX driver. Appropriate GPIB address is provided, which in present case is 30. Controls are selected so that the power supply operates in meter mode (Boolean F) and displays the value (Boolean T).

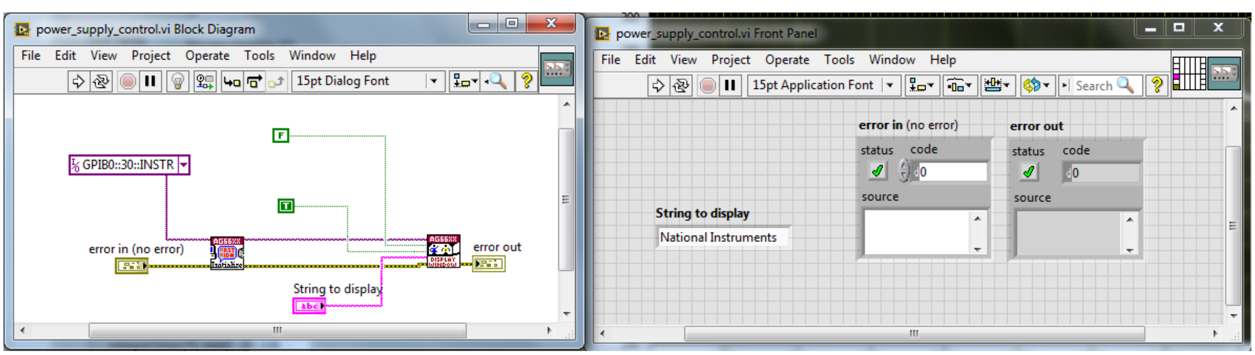


Fig 1: Power supply initialization block diagram and front panel.

2.1.2 Read temperature

The power supplied heats up the resistor and its temperature is measured with the help of k-type thermocouple. The value of thermocouple voltage is read through hp 3478A digital multimeter. A subVI is built to perform this task. For this VI, already installed driver is used. DC measurement function is selected, and appropriate ranges are defined.

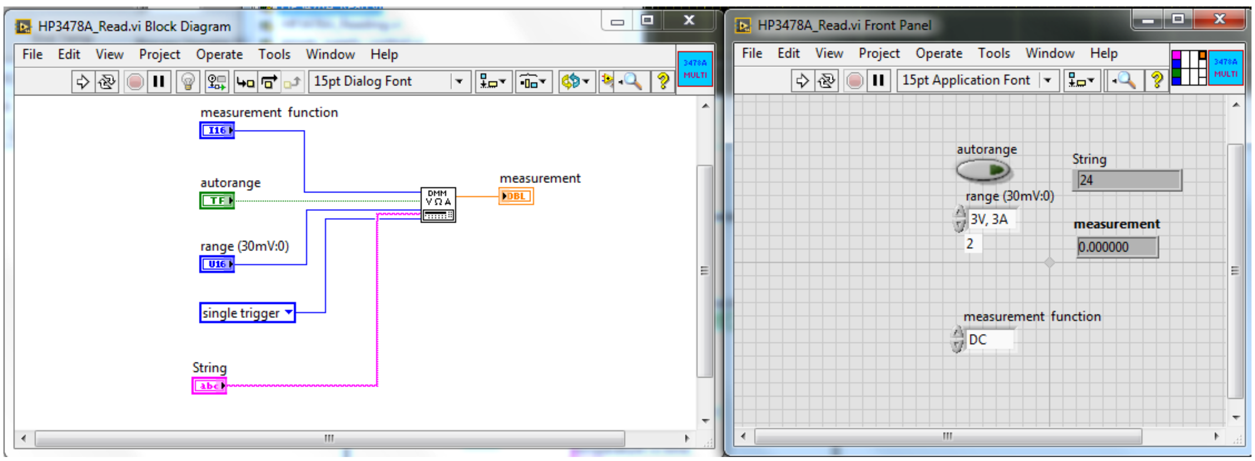


Fig 2: Digital multimeter block diagram and front panel.

2.1.3 Convert V to T

The voltage value read through the multimeter needs to be converted into temperature before sending it to PID VI. A subVI is build including arrays of temperature and corresponding thermocouple voltage value. This subVI converts the voltage from multimeter into temperature by doing interpolation.

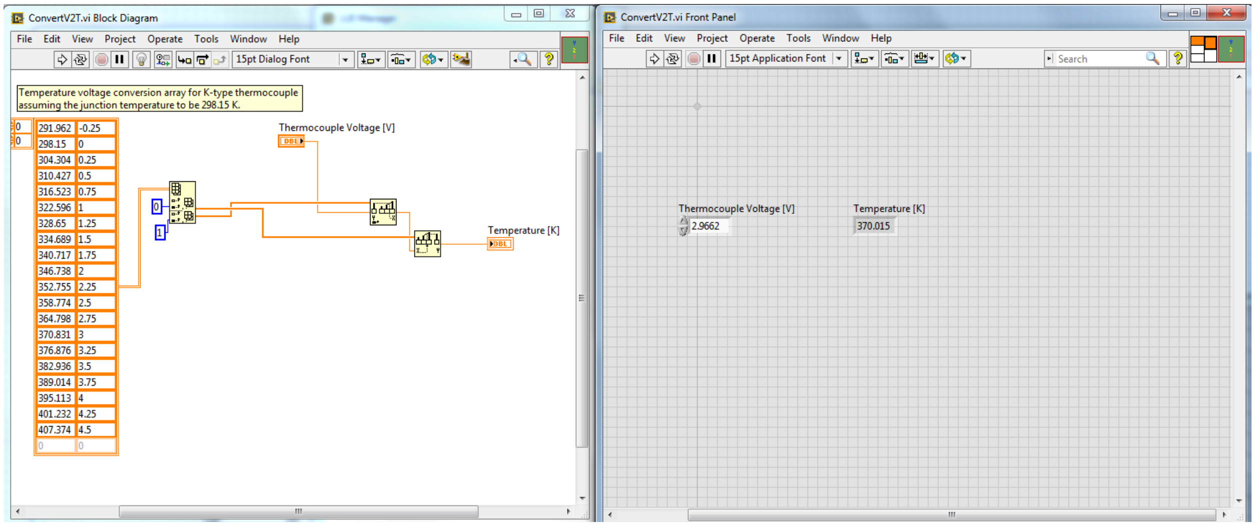


Fig 3: Voltage to temperature conversion subVI block diagram and front panel.

The converted temperature serves as a process variable and it is then sent to the built-in PID VI along with setpoint temperature. The PID VI performs proportional, integration and differentiation response correction and sends out an output. The output is then fed back into the power supply, which then heats up the power resistor to the desired temperature. This is how a closed loop is formed and this process goes on continuously.

2.1.4 Temperature controller main VI

Using all of the previously mentioned subVIs, main VI for temperature controller is made as shown figure 4. Here, we have used PID autotuning VI instead of basic PID VI. This allows additional features, such as automatic tuning of parameters, in addition to the basic PID algorithm. To determine whether the temperature has reached stable state, a statistical approach is used. In this approach, mean and standard deviation is calculated for 300 data points, which are then compared with a threshold value of 0.1. So that, whenever the measured values are less than this threshold value the state is determined as stable. The idea of finding stable state is very crucial for the temperature dependent frequency measurements, which will be explained shortly. The tuning parameters shown below were achieved by manual tuning.

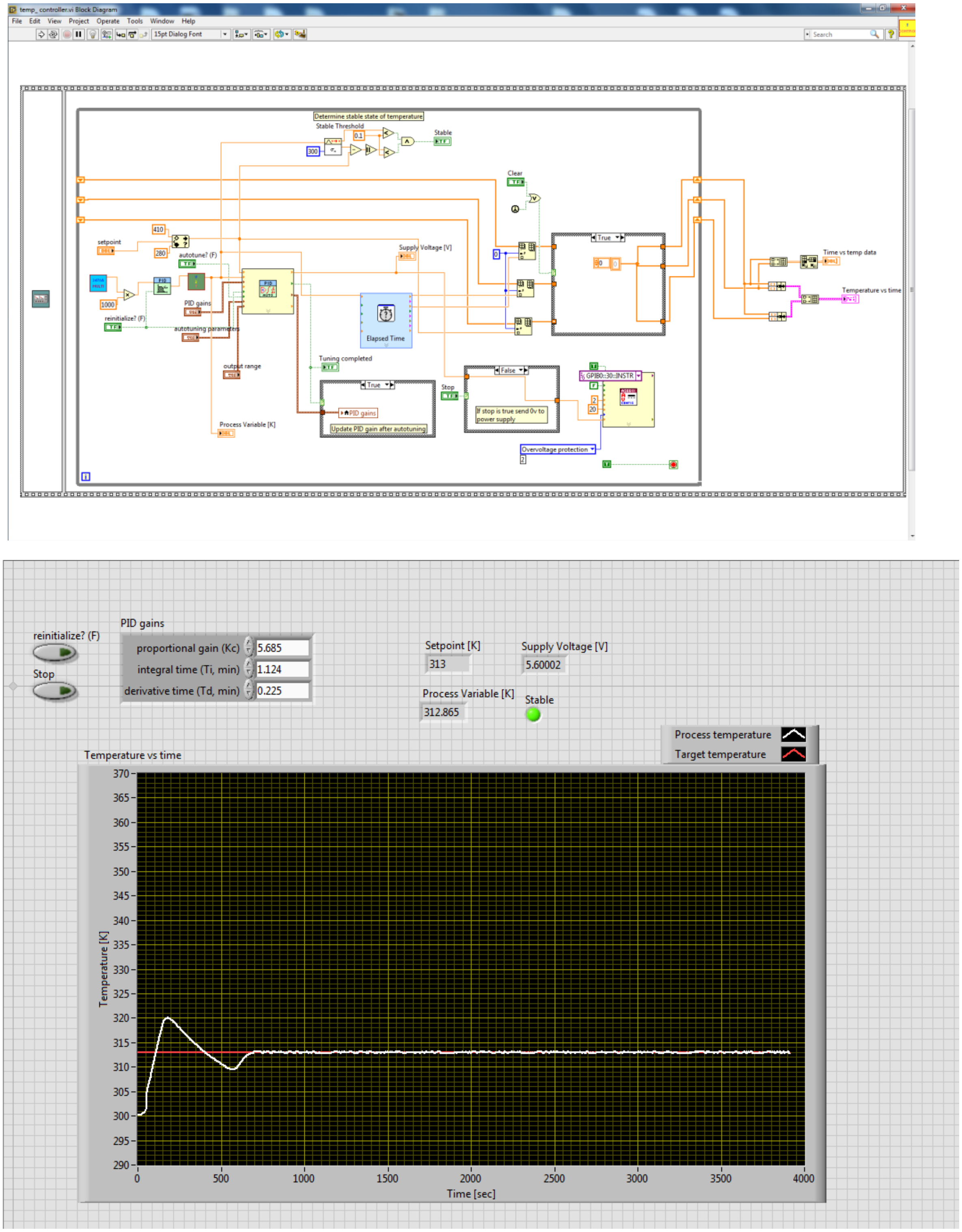


Fig 4: Temperature controller main VI block diagram and front panel.

2.2 Frequency measurement

After having workable temperature controller, our next step is to build VIs for the measurement of Frequency as a function of temperature.

2.2.1 Read Frequency counter

The measurement of frequency with varying temperature is the main goal of this project. For the frequency measurement, we use HP 5350A frequency counter, which supports GPIB connection. The subVI shown below uses VISA read function. This basically sets the counter to listen condition and continuously reads the counter frequency value. A wait time of 3 sec is given between each measurement so that we wouldn't get any timeout error.

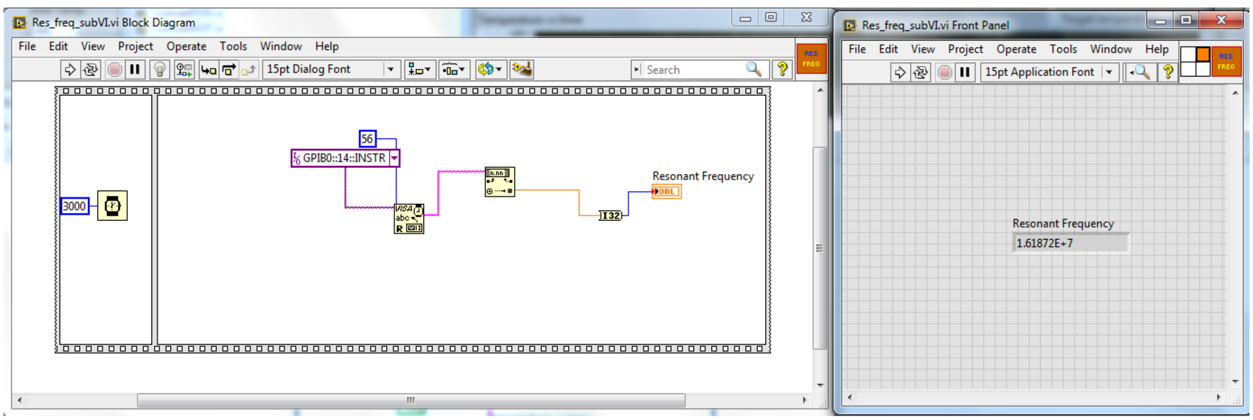


Fig 5: subVI to read resonant frequency block diagram and front panel.

2.2.2 Data Save

It necessary to save the data after each measurement for future analysis of it. The subVI shown in figure 6 allows user to select folder path and also the name of sample for data logging. This subVI saves data in .txt file, which can be open by any of the software (Origin, Excel, Matlab etc).

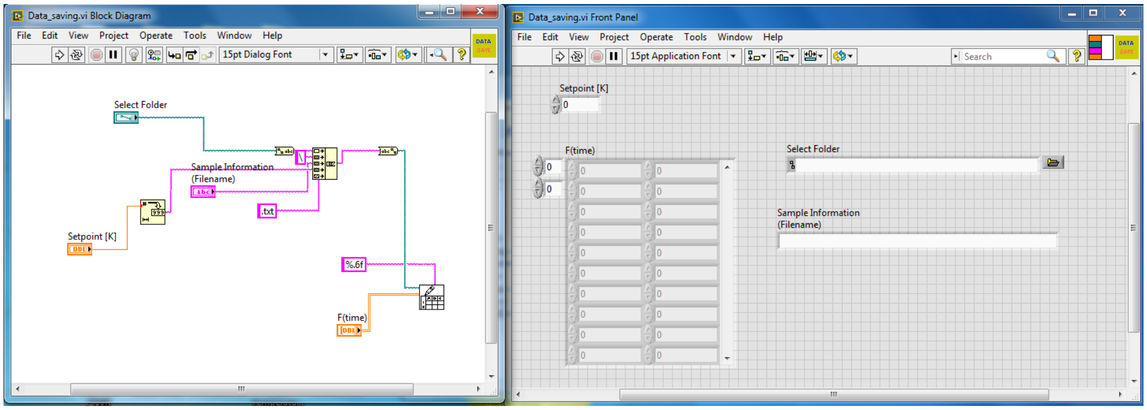


Fig 6: Data saving subVI block diagram and front panel.

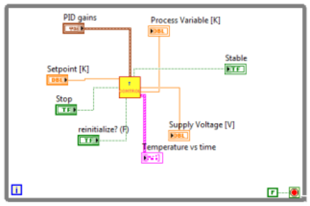
2.2.2 F vs T Measurement

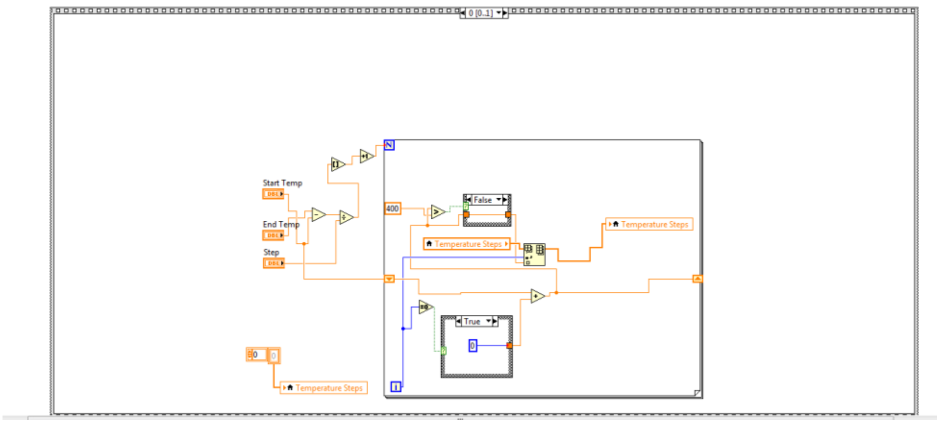
While doing F vs T measurement, we want temperature controller to run continuously throughout whole measurement. So, it is kept outside of stacked sequence in a while loop with its stop condition set as false. A temperature array with desired step size, within the start and end temperature values is created using for loop. The temperature steps array is defined as a local variable so that it can be used in other parts of VI without having to have a wire connection.

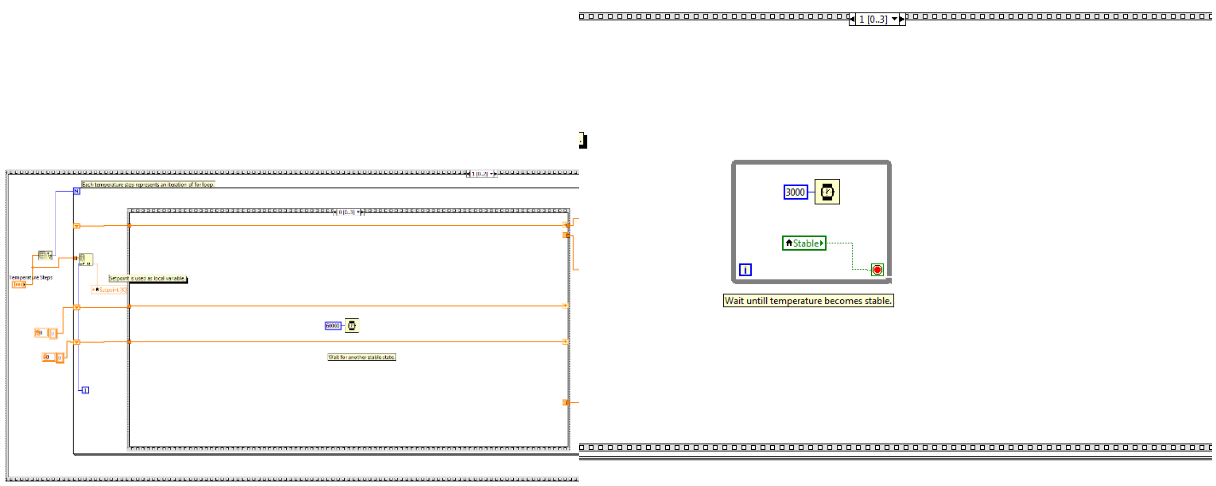
Within the stacked sequence, a for loop is used, for which the number of iterations is set equal to the size of temperature steps array. Each iteration of for loop sets the temperature setpoint for temperature controller. Another stacked sequence is used inside the for loop to allow different options, like to wait until the temperature reaches stable state. This is achieved by using a while loop and setting its stop condition as stable, a local variable.

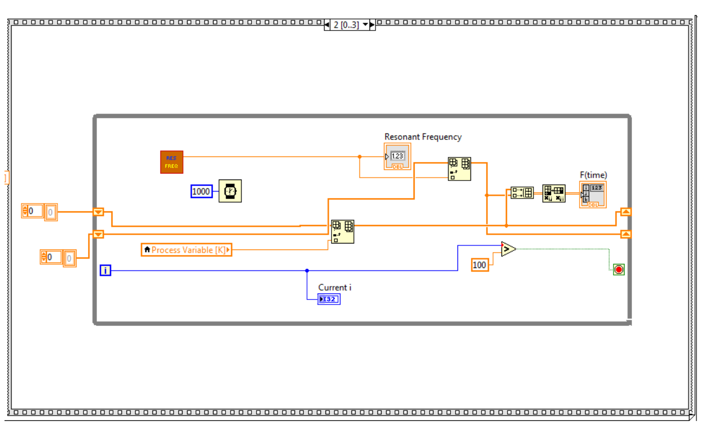
Once the temperature is stable, the measurement of frequency begins with one count per second. Total of 100 frequency counts is performed and the data is saved to appropriate folder with defined name.

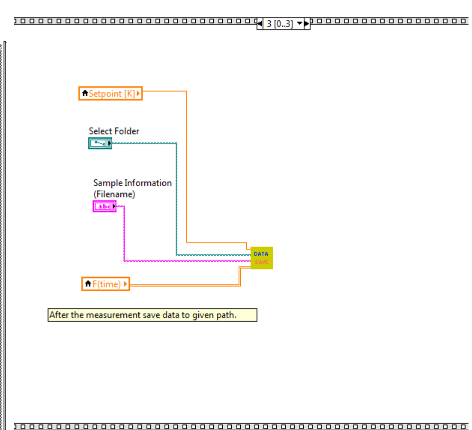
Once the measurement is done for each temperature step, the mean of 100 frequency counts is determined and is plotted against temperature and the mean value is also saved. After all the iteration steps, the temperature is set back to room temperature so that the user wouldn't have to worry about being physically present to turn off the set up, which also makes possible to let it run overnight. An example of a measurement is shown below.


PID gains
Process Variable [K]
Stable
Setpoint [K]
Stop
reinitialize? (F)
Supply Voltage [V]
Temperature vs time


0 [0..1]
Start Temp
End Temp
Step
400
False
True
Temperature Steps


1 [0..3]
3000
Stable
Wait untill temperature becomes stable.


2 [0..3]
Resonant Frequency
1000
F(time)
Process Variable [K]
100
Current i


3 [0..3]
Setpoint [K]
Select Folder
Sample Information
(Filename)
F(time)
After the measurement save data to given path.

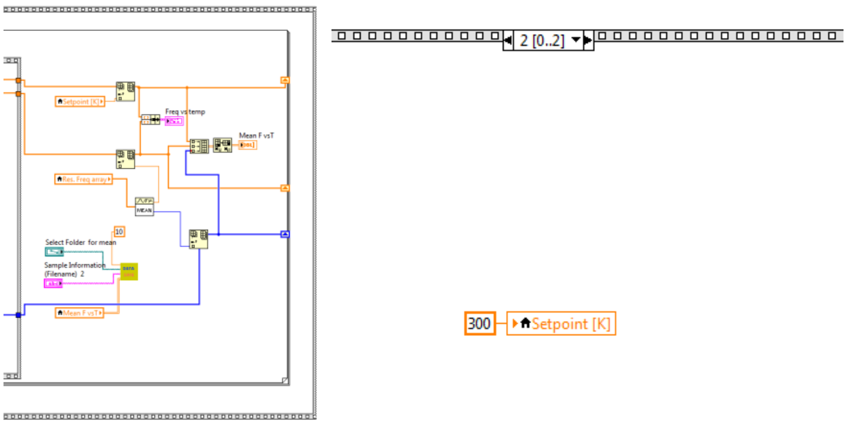
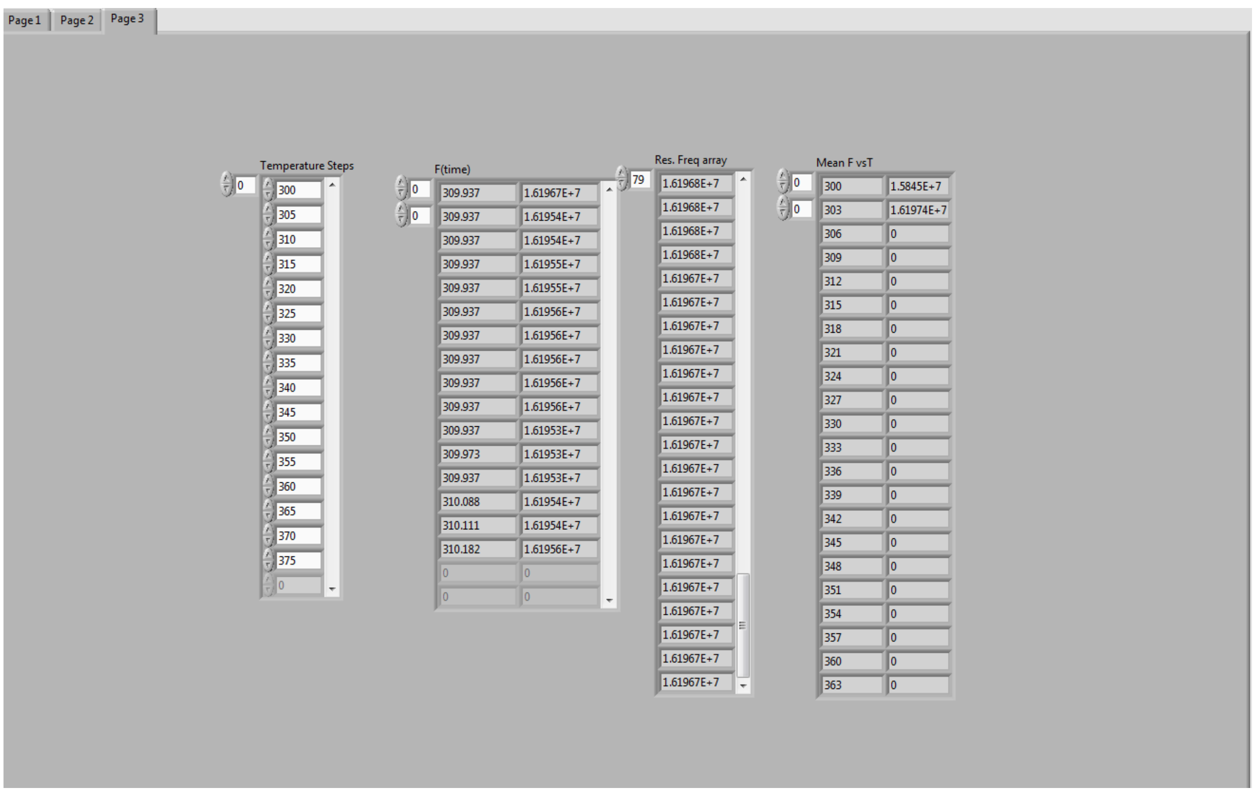


Fig 7: Block diagram of different sequence within the flat sequence.



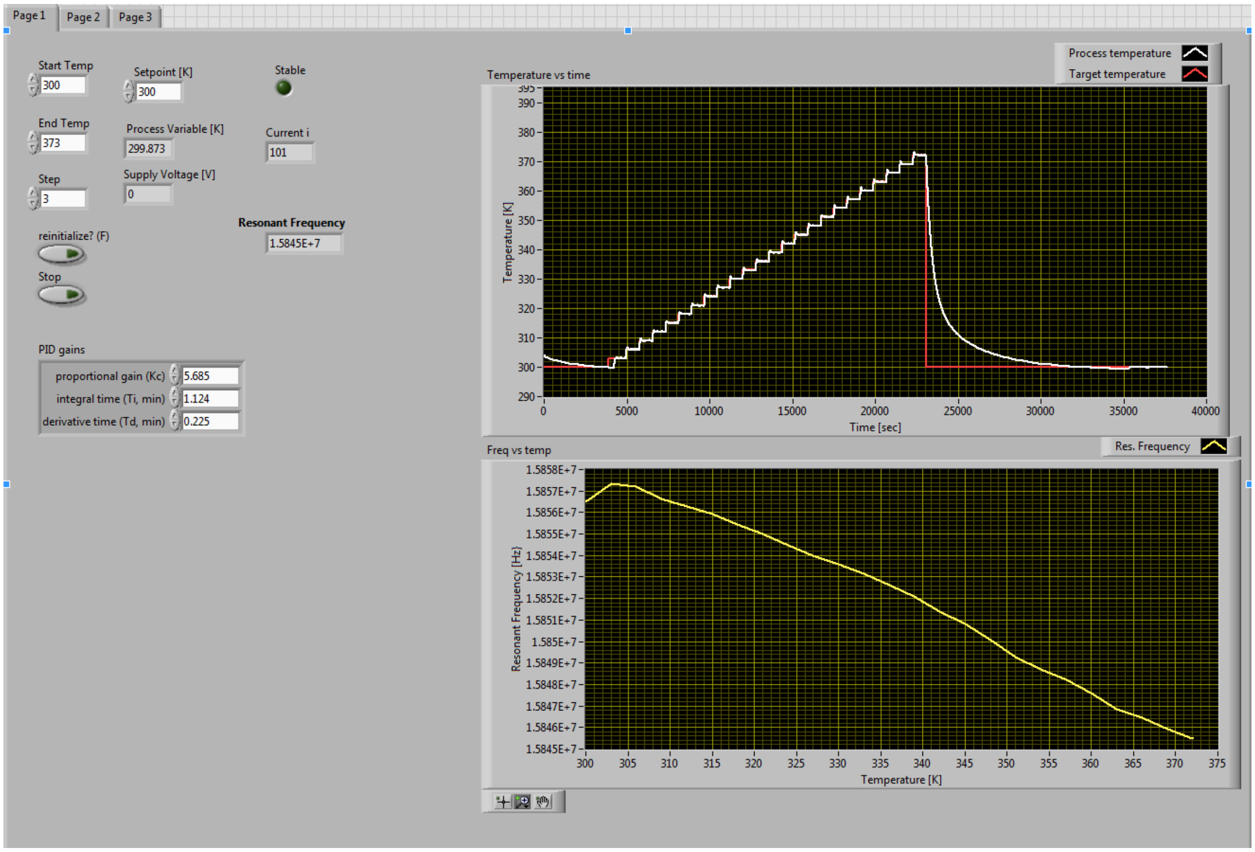


Fig 8: Front panel image of main VI for F (T) measurement.

3. Experimental Results

Though, a current source (LM134H) was used instead of simple resistor in Colpitts oscillator to theoretically remove the thermal drift issue, however, there will be always be some thermal effect. Hence, we wanted to check how the frequency is behaving in ambient situations due to thermal drift. As shown below, in normal condition the change in frequency is about 5 KHz. We then came up with an idea of keeping the oscillator at a temperature above room temperature, which was in fact quite helpful in reducing the thermal drift issue (a drift of 1.5 KHz was obtained in one hour, see figure 9). We then did temperature dependent measurement of resonant frequency for two different samples. One of them was ferromagnetic ($FeCo_{1.75}Ti_{0.25}Ge$) while the other was antiferromagnetic (Cr). The experimental measurement shows different behavior for the two samples, showing some qualitative hints about their susceptibility. However, due to temperature dependent variation of resonant frequency, we couldn't extract the exact quantitative results. The efforts to minimize the thermal fluctuations and measurements on more samples are currently underway.

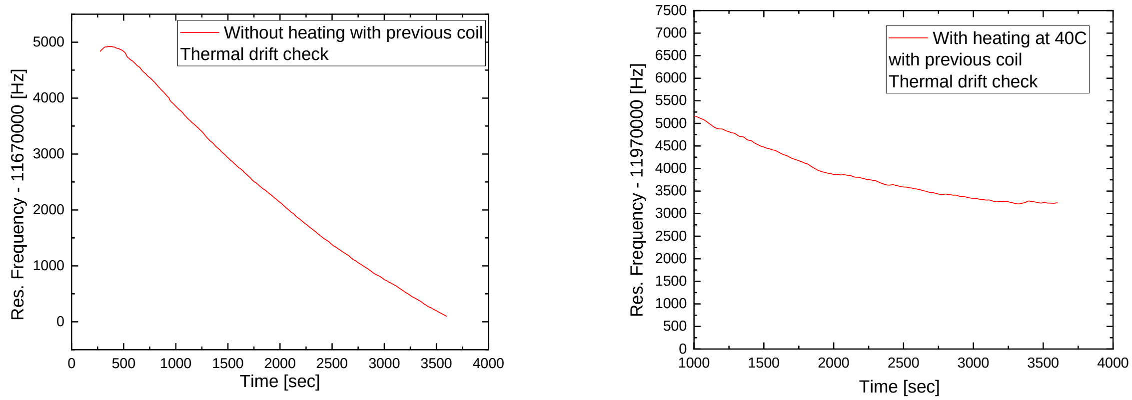


Fig 9: Thermal drift check.

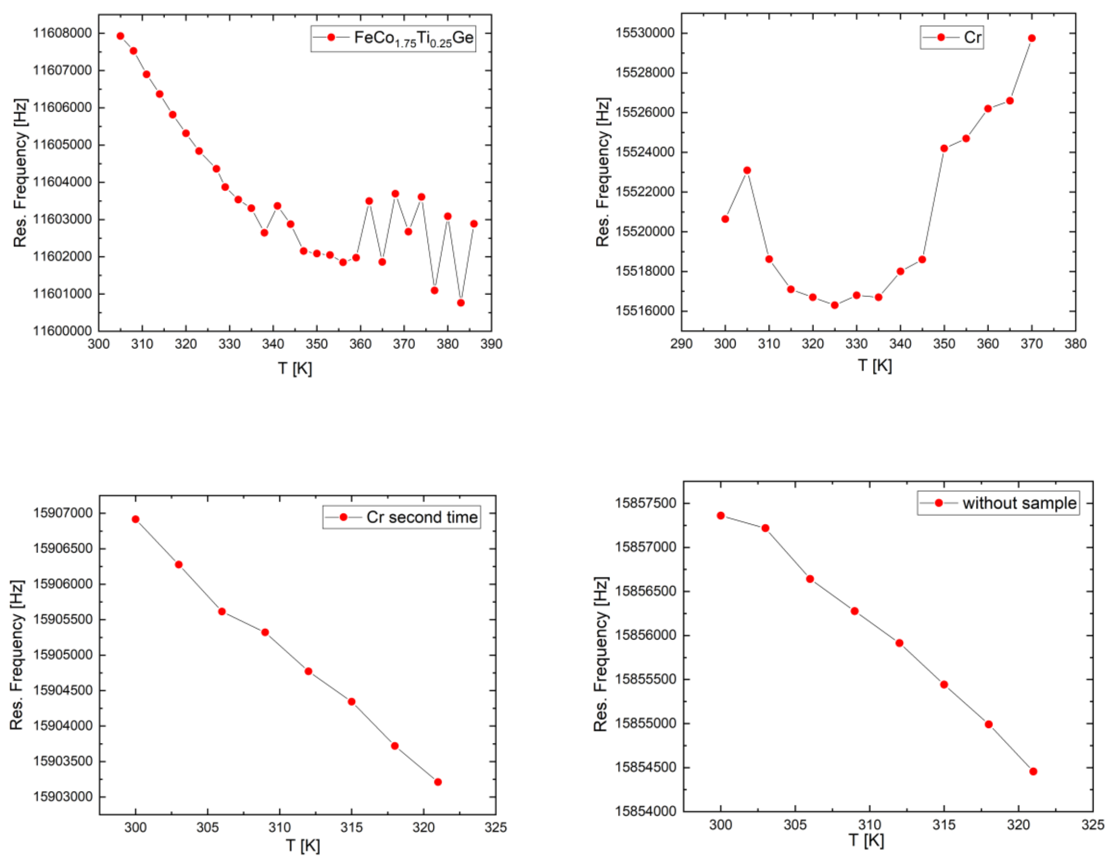


Fig 10: Temperature dependent measurement of frequencies.

4. Conclusions

We were able to build a temperature controller using PID algorithm and to tune the PID gain values to achieve stable setpoint temperature. The temperature controller was successfully used to measure the resonant frequency versus temperature. Initial measurement performed on some samples, showed qualitative behavior of their susceptibility at least in some form. However, due to fluctuating nature of resonant frequency with time and temperature, it was quite hard to extract the exact nature of their susceptibility.

5. Future applications of VIs

We were able to utilize our VIs for temperature dependent measurement of oscillator resonant frequency. Most of the measurements that we do in our lab (Dr. LeClair's lab) is somehow related to temperature. Hence, in future we are planning to use these programs to study the temperature variation of resistance and noise factor (K) of VO_2 thin films to explore the causes of its reversible transition from insulator to metallic phase. Also, it can be used to study high temperature FMR measurement. Particularly, one can use it for VO_2/Py multilayers thin films. As, it has been shown that an enhancement in spin pumping is achieved upon crossing the metal to insulator transition of VO_2 and VO_2 shows that transition at about 341 K. So, the program that we have built in this project will be very helpful for such measurement.

Acknowledgement

I would like to express my deep gratitude to Dr. Tim Mewes for teaching this course. For a rookie experimentalist like me, this course was helpful to learn and understand the techniques designing an experiment, especially by using LabView. It was made possible with his guidance and supervision, so I specially thank him for providing this opportunity. I would also like to acknowledge Mr. Anish Rai for his support throughout the labs. Finally, I would like to give special thanks to my supervisor, Dr. Patrick LeClair for giving me the idea of this project and also teaching me basic circuitry concepts.

References

1. Vannette, M. D., A. S. Sefat, S. Jia, S. A. Law, G. Lapertot, S. L. Bud'ko, P. C. Canfield, J. Schmalian and R. Prozorov (2008). "Precise measurements of radio-frequency magnetic susceptibility in ferromagnetic and antiferromagnetic materials." Journal of Magnetism and Magnetic Materials **320**(3-4): 354-363.