Frequency response measurement system for at-home laboratory work

DESIGN DOCUMENT

sdmay21-49
Client: Gary Tuttle
Advisers: Gary Tuttle
Team Members: David Gorzney, Rohan Gijare, Samuel Ferguson, George Youngwirth, Kathryn Blesi, Tabitha Kiiru
Team Email: sdmay21-49@iastate.edu

Revised: Oct 2nd, 2020

Executive Summary

Development Standards & Practices Used

- The development of the prototype will be guided by the IEEE standards for technical reliability and soundness.
  - IEEE 1149.8.1-2012 - IEEE Standard for Boundary-Scan-Based Stimulus of Interconnections to Passive and/or Active Components
  - IEEE 1522-2004 - IEEE Standard for Testability and Diagnosability Characteristics and Metrics
  - IEEE 1636-2009 - IEEE Standard for Software Interface for Maintenance Information Collection and Analysis (SIMICA.)
  - IEEE Standard for SystemVerilog--Unified Hardware Design, Specification, and Verification Language - Redline," in IEEE Std 1800-2009
- Solderless breadboards will be used as a construction base for the testing of all the components for the final product.

Summary of Requirements

Functional

- A low cost component system that creates, measures and records the frequency responses and can be purchased to be operated at-home.
- The final product should have the following components incorporated into it :
  - a sweepable AC source with frequency ranging from 1 Hz to 1 MHz
  - a chip to measure RMS voltages
  - a microcontroller to automate the sweep and measurement
  - a memory module for storing the measured results
  - an interface for that can be used with a computer to control measurements

Non-functional

- Entire design must be assembled with minimal soldering skills
- Should cost less than $25

Applicable Courses from Iowa State University Curriculum

EE 201

EE 224

EE 230

EE 333

New Skills/Knowledge acquired that was not taught in courses

Soldering

Microcontroller Programming

Microchip testing

Table of Contents

List of figures/tables/symbols/definitions (This should be the similar to the project plan)

Section to be completed when the figures are finalized.

1 Introduction

1.1 Acknowledgement

Great acknowledgements are given to Professor Gary Tuttle of the Iowa State University Electrical Engineering department for his insight and knowledge to the topics revolving around the project specifications

1.2 Problem and Project Statement

- This project is a take home frequency generator. Throughout the COVID19 pandemic, students were left without a lab bench while taking heavy lab classes. Iowa State University figured out how to send the students take home exploration boards. The problem though, was that these boards cost way too much money. On top of that the boards were sold out as many other programs attempted to buy the same boards. The take home frequency generator project has the goal of giving students the hardware to measure the frequency response of their circuits for a price that is reasonable.
- The project is to consist of a printed circuit board and other components that could be sold as a bag of parts to be soldered together.
- There are going to be two probes for measurement along with the frequency input wire and the ground.
- The assembly will have a way to store values either through external memory such as an SD card or through software directly into the computer.

1.3 Operational Environment

This product is designed to be worked on in an at home lab environment. The product is designed to be able to be put into a backpack and carried around so it will not be too fragile, though it is not rugged enough to be dropped or crushed. Being as it is a piece of electrical lab equipment, it is not designed to be wet or left out in the elements.

1.4 Requirements

- A frequency generator
    - Output range of 1Hz to 1MHz
    - At least 1 - 5mV variation of waveforms
- A way to measure frequency response
    - Stretch goal: A way to measure phase response
- A way to move, store, and view data
- An interface for inputting specifications
- Four wires total
    - Two probes, a frequency generator, and a ground
- The final product should be under $25

1.5 Intended Users and Uses

Our end product will be used by college students enrolled in EE201. EE230, and EE333 at Iowa State. It will be used as a way to complete laboratory assignments if a student is not able to physically be in the lab.

1.6 Assumptions and Limitations

Assumptions:

- Student will have access to a power source
- Student should be able to easily assemble final product from a bag of parts and assembly instructions

Limitations:

- Should be completed by the end of spring semester 2021
- The Frequency range of the function generator will be between 1 Hz to 1 MHz
- Manufacturing cost should be $100 or less

1.7 Expected End Product and Deliverables

The project is a frequency response module that will be used by students for at home lab work. End product will be a bag of parts, including:

- PCB
- Probes
- Various Computer chips
- LCD screen
- Potentiometer (for selection knobs)
- Instructions for assembly
- User manual

The bag of parts will be given to the client as the physical product. The purpose of these parts is to be soldered together following the instructions given in the "Instructions for assembly." The PCB will be used to connect all of the various parts and will have circuit logic used to hold the system together. The probes will be used to send out the generated frequency, for ground, and for reading the information for the frequency response. The LCD display will be used to know what the input is, which will be controlled by the POT that is the selection knob. Instructions will detail how to assemble the bag of parts using a soldering iron. Students using our end product will have access to a soldering iron through Iowa State. This should be done after the product is designed to ensure instructions are correct. The user manual details how to use the end product after it has been put together. This will be the last thing we make, once we know how the end product will work. This will be completed by April of 2021. This will be completed by April of 2021.

2 Project Plan

2.1 Task Decomposition

Our first task was to find and order components that can meet the requirements of the final product. The components included the following: two probes for frequency analysis for input and output, an integrated circuit for AC voltage reading, an integrated circuit for function generation.

Once the components are ordered, the next step is to design modules for the overall project. There will be three modules that will be designed, the RMS to DC module, the function generator module and the phase measurement module.

Our third task is to create a prototype of our design. In order to do this, we will need to first need to implement our integrated circuits according to their datasheets. For this task, we will try to stick with designs that utilize breadboards, but we are able to use breakout boards if necessary.

After successful construction of our prototype, we will need to run tests to ensure that it meets our expectations. The prototype will be put through different tests concerning individual requirements for our project. We will make note of the deficiencies observed during each test and work to correct them by adjusting our design and prototype.

We will design a PCB to bring our circuit to life in the physical form. This will involve component placement and routing to define electrical connectivity of our circuit on a circuit board. After all the testing of individual components and software , we will assemble the components together.

The last step in the project is to thoroughly test the final product to make sure it suffices every requirement for the project as well as note any deficiencies in the prototype. Once all the testing is completed and the product is ready for display, the user manual and datasheet will be updated to showcase all the changes made during the testing process.

2.2 Risks And Risk Management/Mitigation

For task 1, the primary objective is to find compatible components that will satisfy the requirements of the project without lots of design work by the group. However, some components can be overly expensive or come in hard to implement packages. To manage this, we will be listing multiple components that can satisfy the requirements of the project so that other options for components can be easily found and implemented.

Task 2, is the most time consuming portion of the project because it takes time to build an understanding of what each module of the project must accomplish and implement it.

The third task is where the most problems in the project can occur because the group will need to synthesize the designed modules into one cohesive prototype. To mitigate issues with the creating, the group will need to communicate consistently and concisely with the rest of the group about any issues they might be running into so issues can be addressed from multiple perspectives in the group.

Task 4, testing the prototype, has the least risk and should go faster than most tasks in the project. Task 5 will require the group to implement corrections to the original design to make up for the deficiencies. This could lead to some hard to solve deficiencies such as having a phase measurement system that does not work as expected. This could set the project back another week to redesign an entire module. To account for this, we will need to leave at least one week of room in our semester to solve issues in the design.

Task 5 includes designing the user manual. This can be spread over two weeks with the group working on it individually at their own pace so it is not to hinder the project.

The final task will be the final testing of the product. If there are still deficiencies that cannot be addressed in time, the final product will be released as is, but the user manual and datasheet will be updated according to its deficiencies.

2.3 Project Proposed Milestones, Metrics, and Evaluation Criteria

For task 1, the milestone for completing this task is to have a complete list of components needed for the project along with attached datasheets for electronics and product numbers with associated retailers. For task 2, the milestone for this task is to have a completed design for each module. The modules consist of a RMS to DC module that can read voltages from 0 to over 5Vrms, a function generation module that can generate square, triangle, and sine waveforms between 10Hz and 1Mhz, a phase measurement module with 90% accuracy, a power module, and a signal processing module with MCU. The milestone for task 3 will be to have a physical prototype with all the module designs combined into a single top-level design. The milestones for task 4 are to have a complete list of test cases and results. The milestones for task 5 are to have new module designs to account for deficiencies, have a complete PCB layout, and have a comprehensible user manual and datasheet for the project. The final milestones for task 6 are to have a working product with an up-to-date user manual and a final test of the product with a list of deficiencies or improvements (optional).

2.4 Project Timeline/Schedule

The project timeline will be split between four different sections for each semester. For the fall semester, the project will be split between planning, design, prototyping, and testing. For the spring semester, the project will be split between testing, final design, final testing, and finalization (documentation). Each section is split into specific subcomponents with time allocations for the period at which that subcomponent should be worked on and completed.

Figure 2.4.1: Fall 2020 Project Timeline

Figure 2.4.2: Spring 2020 Project Timeline

2.5 Project Tracking Procedures

As a team, we have come to the decision to use Google Drive to organize our resources and information. This allows our group to easily access and locate, view, and papers which we may be working on. It also proves to be accessible to everyone on our team and does not require us to learn how to use the site or tools. We will also be organizing our plans and tasks into an Excel sheet which will be stored in the Google Drive as well. This will grant us the ability to to post, edit, and view what tasks need to and which tasks have been completed. The group will also be using Github for data storage and logging. This will allow the group to work on code and designs collaboratively without having to worry about changes to legacy code and designs. This also creates accessibility for all the group members as most of them have experience with Github. Project management will be done using Trello. This application will help the group keep track of tasks and overall progress of the design work for the project to ensure we are on schedule and meeting deadlines.

2.6 Personnel Effort Requirements

Personal effort requirements are based on the amount of expected hours per component of the project. Each of the subcomponents will be split equally between each group member. Each group member will have the same amount of time allocated to working on the project regardless of the amount of subcomponents they must complete.

Tasks	Hours
Planning	4
Project Requirements	2
List of Components	1
Order Compoents	1
Design	70
Design RMS to DC Mod.	15
Design Func. Gen. Mod.	15
Design Power Mod.	15
Design Interface (Hardware)	15
Design Interface (Software)	10
Prototyping	11
Combin Mods.	10
Impliment Demonstration	1
Testing	30
Impliment Testing	15
Record and Report Results	15
Testing Cont.	15
Retest Prototype	10
Address deficiencies and come up with solutions.	5
Design Final Product	31
Design PCB	25
Redesign for deficiencies	5
Order new parts	1
Final Testing	7
Test for requirements	5
Redesign if needed	2
Finalize Product	20
Finalize User manual	10
Finalize Assembly Instructions	10

Figure 2.6.1: Time allocations for personal effort.

2.7 Other Resource Requirements

Apart from financial resources, we will require intellectual and human resources. Our intellectual resources will include the data obtained from our research on various parts and materials. It will also include our own understanding of how the products work and how they will interact with each other. Human resources will include all of the members of our team working to complete this project as well as our project coordinator and contact. We all will be working on and putting time and effort into this project over the course of this and next semester.

2.8 Financial Requirements

To complete our project, we have decided on purchasing the following two components: a frequency synthesizer/stabilizer and an RMS voltage measurer. The frequency stabilizer we will procur is the AD9833 with a price of $4.10. The RMS measurement device will be the AD8436 which will cost $6.00.

3 Design

3.1 Previous Work And Literature

In the market currently there is a board called the DAD (Digilent Analog Discovery) board. This board has many different features that we are looking for. It has frequency response, phase response, and much more. The difference between this product and the product we are trying to create is that the DAD board has many more bells and whistles which cause it to be significantly more expensive than the $25 price tag we are searching for.

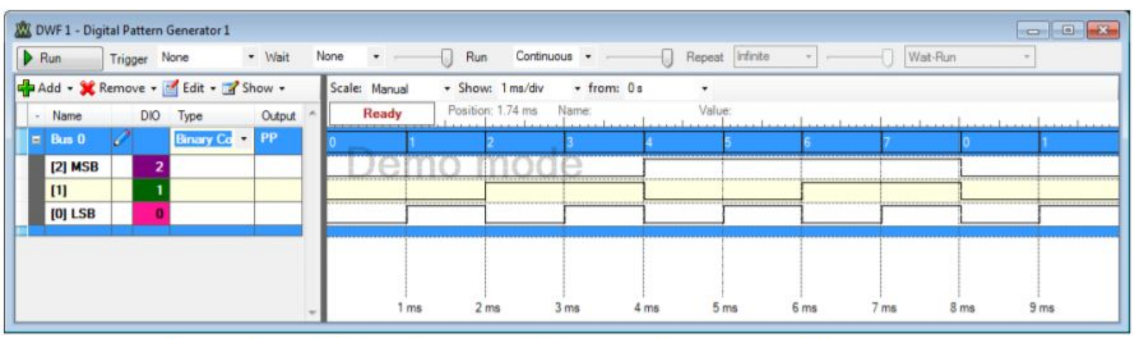

Figure 3.1.1: Digital Pattern Generator. A feature of the DAD that goes beyond the scope of our project.

3.2 Design Thinking

Researching: This step will consist of finding correct specifications, deciding performance standards, price, and size.

Testing: This step will consist of testing our components individually, at a component level.

Hardware choosing/finalizing/prototyping: This step will consist of picking out the parts that passed our testing, and putting them all together.

Testing 2: This step will consist of testing the prototype to ensure that the parts work together well.

Software production/testing: This step will consist of putting together the software for the user interface, data collection, and the code for the MCU.

Final Testing: This step will consist of ensuring that the software and the hardware all work together in a way that will allow the prototype to be turned into the final product.

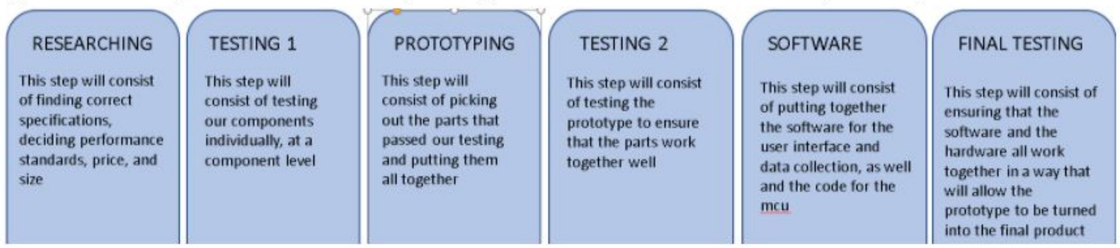

Figure 3.2.1: Design thinking flow design.

3.3 Proposed Design

The team has settled on a basic design on what a completed project containing the IC chips and the microcontroller would appear to be. There would be three main components that would be used to measure the frequency response of the required components decided by the user. The Microcontroller unit would be used to control the frequency generator chip as well as power and receive measurement data from the RMS voltage measurement chip.

In order to combine the IC chips with the MCU, it was necessary to test each component separately to detect the uncertainty in the measurement data received as well as limitations of the frequency generator chip.

The two components being tested were selected based on their technical limitations and capabilities that fulfil the functional requirements of the desired project. In terms of the non-functional requirements, the most important requirement was that the whole project be inexpensive and under $25. Currently the two chips we purchased cost approximately $10 total. The option for MCU being considered is under $5. This makes it so that the total cost of the prototype to be approximately $15. This allows us to comfortably be under the $25 limit and fulfill the non-functional requirement.

The circuit diagram on the next page shows how the components would be connected to build the prototype to get the frequency response of the test circuit components.

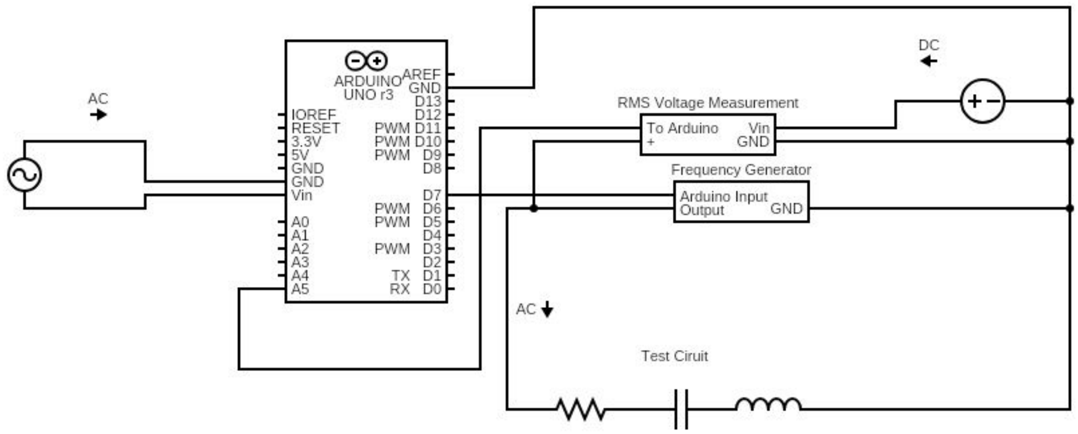

Figure 3.3.1: Top-Level schematic diagram of device.

3.4 Technology Considerations

As of currently, the components are still being tested for any weakness that may be a liability in the prototype, however, one possible liability observed was that the RMS voltage measurement chip and frequency generator are small in size and need careful soldering on the breakout boards. These might need to be soldered on the breakout boards before being provided to the client due to high risk of soldering errors which might damage the ICs. The strength of this design of the prototype would be the processing power of the MCU used as it is powerful enough to control the chips, receive data as well as do some calculations on board on the data to provide results that are easier to interpret and store on an external storage device.

The design of the prototype has been consistently the same for the most part since the beginning of the project. It did undergo some fine tuning based on the challenges faced as well as decisions made to fulfil the project requirements. The design would most likely be fine tuned even more as the team progresses onto the later stages of the project. However, it is certain that the base design of the prototype would remain the same.

3.5 Design Analysis

As of right now, we have our RMS voltage measurement chip and our frequency generator chip. We have started the testing process by conducting research about the chips we have, in order to determine how they work. Once we understand how our chips work, we will be able to determine the best way to go about testing them.

We have been successful in this research and have determined how to test our chips. We have time scheduled in the lab in order to do this.

Looking ahead, there are a few potential obstacles that we may encounter. One of these problems may be coding issues. When writing code, it is imperative that everything works correctly, but it is very common that bugs occur and the code does not run as desired. Another problem may be in the construction of our circuit. Similar to the coding, it is important that things are set up correctly or we may end up shorting our devices or receive incorrect readings. To overcome these problems, efficient planning beforehand and additional research will allow us to be more prepared when designing each part.

3.6 Development Process

The development process we will be using for this project is the Waterfall method. For this method. each step must be completed before moving onto the next. The first step of the waterfall method is "Requirements". We implemented this into our project by talking with our contact about what they wanted the end product to look like. Using this information, along with the info given in our project summary, we were able to create a list of requirements that our end product should have. The second step of the waterfall method is "High level design". Using the requirements we determined from the first step, we were able to create a general design of what we want our end product to look like. The next step of this method is "Detailed design". Once we had a general design, we were able to go in and add more details with the help of our contact/advisor. After creating our detailed design, we were able to move on to "Coding/building". For this step, we will be building it and writing any code needed for the different aspects of our end product. The next step of this process is "Unit Testing". This is testing done on one portion of the final project. We will start by testing each component individually in order to determine that they work. After this step, we can move onto "Integration Testing". This is testing of multiple units together. Once we know that each of our components work individually, we will start testing multiple components together to make sure they work together without interference. Finally, the last step of this method is "System Testing". This is testing of the system as a whole. Once we have everything tested individually, and in small groups, we will test the entire thing as a whole thing and make sure it meets all of the requirements we have previously made.

3.7 Design Plan

One of the design constraints we have to consider is a device that is affordable to students, and can be used by students with a home lab setting. Another constraint is to have a user assemble the parts with minimal soldering skills. Since some of the components for our design are too small to be carried around, our design plan includes having these parts be soldered on a transmission board and ready for use.

Our frequency measurement device is limited to the hardware capabilities of the Arduino microcontroller as well as the performance of the rms-to-dc converter. During this process, we expect our design to change as we adjust our components to meet specifications to requirements.

4 Testing

4.1 Unit Testing

The full design will contain three separate modules that will work in unison along with a software interface. For the first module, the RMS to DC module will be fed a sinusoidal that is frequency swept from 10Hz to 1MHz to ensure it works as expected with all the frequencies in the range and then it will be voltage swept between the minimum and maximum voltages (0Vrms to 5Vrms) per the datasheet. The second module will be the function generator module. This will be swept from 10Hz to 1Mhz with a triangle wave, sine wave, and a square wave to ensure all the frequencies and functions work as expected. The final module is the power module. To test this module, the current will need to be measured and recorded for performance to ensure the power draw of the device is compatible with the power rating of the power module. The final unit test will be with the software interface. The software interface will receive multiple user inputs that will be entered randomly to check for input issues and will also be used within the operating range of the system to ensure the device is getting the proper inputs per the user's input.

4.2 Interface Testing

The interface will be a software interface that will contain all the different functions of the function generator, a live readout of the Vrms value and the phase of the signal. The test will include using a function generator from the lab and an oscilloscope to test the input and output values that are being probed. If a sinusoidal with an amplitude of 1V is output by the generator, the oscilloscope should output the exact same value and frequency and the interface will need to show the same values as the oscilloscope on the input and output probes on the user interface within a range of error of approximately 10% due to errors within the function generator and oscilloscope and the device itself. The interface will also be tested for the correct inputs and outputs based on the function generation module. The output will be verified by an oscilloscope on the output to compare the interface value with the actual output value. For testing and range finding, there will also be a hard wired potentiometer that can control the frequency of the function generator module. This will be simply swept between the minimum and maximum frequencies of the function generator to ensure that the input values are within operating range.

4.3 Acceptance Testing

To demonstrate that the design requirements are being met, we will compare the results obtained from testing to the expected and desired results. Component schematics exist that contain unit figures and variables for the parts that we are using. Comparing our numbers to those provided will give a clear picture of whether our design meets the requirements or not.

Another way is to run the same tests but use a different device. Our product is meant to carry out specific operations and tasks, so using a device that performs the same operations will allow us to differentiate the success and failures of our own device. Our client would be provided the results of the testing to ensure they are aware of the accuracy of our device and that no errors are present. This way, they will get firsthand knowledge of our devices capabilities and performance details.

4.4 Results

At this present time, we have just begun the testing phase of our project. The first few testing attempts did not bear much fruit as we are still familiarizing ourselves with the equipment and parts, but we did learn about the pins on the devices and that we will be able to control the registers using spi interface. As we continue with the tests, we will undoubtedly learn more about the devices we are using. Once we have tested everything to the fullest, we will be able to determine whether they meet our expectations as we move forward, or if they do not and we use a different part.

5 Implementation

1. Work out the issues with the SPI interface by the end of February 2021.
2. Solder all the components together for the final testing phase of the prototype.
3. Work out any of the kinks in the system and get it ready for demo by mid-April 2021.

6 Closing Material

6.1 Conclusion

We are currently working on testing individual parts and making sure that the components work well with each other. We are making progress on this aspect and are on track to finish it early next semester. Once this is done, the parts would then be connected to each other and then we would test the prototype system as a whole to detect any issues before getting it ready for the demo.

6.2 References

List technical references and related work / market survey references. Do professional citation style (ex. IEEE).

Schwartz, Eric M. "Digilent Analog Discovery (DAD) Tutorial." *University of Florida*, 2015, mil.ufl.edu/3701/DAD/DAD_tutorial.pdf.

6.3 Appendices

Additional Information for the components used in the project:

ATmega328P Microcontroller Unit Data Sheet -

https://ww1.microchip.com/downloads/en/DeviceDoc/Atmel-7810-Automotive-Microcontrollers-ATmega328P_Datasheet.pdf

AD9833 Frequency Generator IC Data Sheet -

https://www.analog.com/media/en/technical-documentation/data-sheets/AD9833.pdf

AD8436 RMS Voltage Measurement IC Data Sheet -

https://www.analog.com/media/en/technical-documentation/data-sheets/AD8436.pdf