Project Title: MFJ ContinuousCarrierTM Intellituner

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Enter Project Keywords (IEEE keywords): amateur radio, antenna impedance matching

1. High-level project description (problem solved by design and functionality).

Amateur radio operators must currently manually tune their antennas. The project we have been tasked to complete is an autotuner for amateur radio that uses a Voltage Standing Wave Ratio (VSWR) meter along with variable capacitor and inductor to match the impedance of the load (antenna) as the frequency changes. The VSWR is a measure of impedance matching of a load to the characteristic impedance of the transmission line carrying the signal, and it is important because it determines how much power we can output from the antenna. Currently, MFJ Enterprises offers a manual tuner which employs the variable capacitor and inductor and an autotuner which makes use of a relay network with varying discrete capacitors and inductors. The advantage of the variable capacitor and inductor methodology is that the circuit lasts much longer. The lifetime of the product is short due to relay failures on their current autotuner. Our design would use stepper motors to control the variable components. In addition, the Intellituner would store the stepper motor locations for various frequencies so that it can quickly return to the same configuration when it encounters those conditions again, in turn improving the user experience.

2. A brief discussion of relevant technical background material on which the project is based (identify at least 3 published references).

Microcontrollers: From Assembly Language to C using the PIC24 Family will be the primary reference used when tasked with any problems involving the programming of the pic 24 microprocessor chip.
Jones, Bryan A and Reese, Robert and Bruce, J W. *Microcontrollers: From Assembly Language to C using the PIC24 Family*. 2nd ed. Boston, New Jersey. Cengage Learning, 2015.

Although our antenna has a two-part tuning process, “An RF electronically controlled impedance tuning network design and its application to an antenna input impedance automatic matching system" will be helpful when posed with problems related to the impedance tuning aspect of our antenna. https://ieeexplore.ieee.org/document/1266873/?part=1; "An RF electronically controlled impedance tuning network design and its application to an antenna input impedance automatic matching system" by J. de Mingo, A. Valdovinos, A. Crespo, D. Navarro, P. Garcia.

"Ham Radio and Engineering Education" explains the basics of ham radio operations and provides background information and many different uses for the product. https://peer.asee.org/14097.pdf; "Ham Radio and Engineering Education" by Michael Batchelder, Keith Whites, Susan Gasper.

3. Projects are evaluated, in part, on the inclusion of a number of the following "real-world" concerns. Provide preliminary comments on how these issues relate to your design.

- **Economic:** The price of the autotuner will be comparable to that of the manual tuner MFJ currently offers, but the product will provide consumers with greater efficiency and productivity. Variable components in the autotuner will be an efficient improvement from the relay network and will not experience burnouts. The microcontroller's saved stepper motor locations would eliminate searches for previously used frequencies and boost productivity.
- **Environmental:** Not applicable.
- **Sustainability:** Over time the variable capacitor, variable inductor, and stepper motors may require maintenance to ensure their proper function. These parts can also be replaced easily, if needed. However, the expected lifetime of this tuner will be much longer than current autotuners due to the absence of relay failures.
- **Manufacturability:** The design implements off-the-shelf parts, making manufacturing a simple and low-cost process.
- **Ethical:** Not applicable.
- **Health and Safety:** The tuner will be rated to allow up to 2500W of output power, which is certainly a safety concern. Therefore, we must develop a thorough test plan and do our due diligence to ensure the safety of everyone involved is paramount. For user safety, the tuner will be enclosed in a metal box to reduce the risk of harm.
- **Social:** According to the National Association for Amateur Radio, (http://www.arrl.org/what-is-ham-radio) "Amateur Radio (ham radio) is a popular hobby and service that brings people, electronics and communication

together. People use ham radio to talk across town, around the world, or even into space, all without the Internet or cell phones. It's fun, social, educational, and can be a lifeline during times of need." Our project will aim to improve the current design of the radio allowing for easier use, therefore leaving more time for the social application of the radio.

- **Political:** Amateur radio is regulated by the federal government, and a complete list of rules and regulations can be found on the FCC website (https://www.fcc.gov/general/amateur-radio-services-and-public-safety-communications).

4. More detailed description of hardware and software design components (both hardware and software design are required for CPE students and both are strongly encouraged for EE students).

Currently, MFJ offers the MFJ-9982 ContinuousCarrierTM antenna tuner. Below is a short description of this product taken from their website (https://www.mfjenterprises.com/Product.php?productid=MFJ-9982):

> *"The MFJ-9982 ContinuousCarrierTM antenna tuner handles 2500 Watts continuous carrier output on all modes and all HF bands into most unbalanced antennas -- even on 160 Meters where even the best antenna tuners fail! The MFJ-9982 gives you every feature youll ever want in a high power tuner -- wide matching range, 1.8 to 30 MHz coverage, 6-position antenna switch, 4-core balun, dummy load, true peak/average lighted SWR/Wattmeter, 6:1 reduction drives with detailed logging scales, 3-digit turns counter, extra large knobs."*

The goal of our project is to closely match the performance of this tuner, while automating the tuning process. Therefore, many of the hardware components needed for our design will be the same as those that appear in the MFJ-9982. The primary focus of our hardware design will be the implementation of a control circuit which will utilize a microprocessor that takes the VSWR reading and makes the proper calculation to turn stepper motors that will adjust the impedance and capacitance. The control circuit will have the following responsibilities:

1. Regulating power and providing isolation for the microcontroller.
2. Managing the needs of the stepper motors used for controlling the variable reactive components. This will include supplying the required power to the motors and a control signal route from the microcontroller to each motor.
3. Calculate the SWR from two DC voltages representing forward and reflected power from an SWR sensor. The two voltages go into an analog-to-digital converter in the PIC microcontroller. The ratio of these two voltages gives the reflection coefficient which is converted to SWR. The tuning algorithm

drives the stepper motors to vary the inductor and capacitor values and determines the tuner configuration until the SWR is minimized to less than 1:1.5. This algorithm has already been implemented in the previously mentioned MFJ auto tuner, so we will need to drive both stepper motors based on the output of the algorithm.

At an output power of 2500W, a nominal amount of EMI may be radiated from our circuit, which could affect our control circuit. Special considerations must be given to this issue in the design of our prototype.

Another product in the MFJ lineup is the MFJ-998: (https://www.mfjenterprises.com/Product.php?productid=MFJ-998)
This is another antenna tuning unit with a few notable differences to the previous. This tuner utilizes discrete reactive components instead of the variable reactive components present in the previous model. These discrete components are set up in the circuit such that a network of relays is capable of controlling the total output impedance, thus tuning the antenna. The second notable difference is the use of a microcontroller to switch the relays and tune the network automatically, with help from the VSWR meter. In addition, the microcontroller is capable of saving the relay configuration for a certain frequency, thus allowing for much faster tuning the next time that frequency is used. One more notable difference is the lower output rating at 1.5kW. This can in part be attributed to the stress applied to the relays at high power. These relays are often the first to fail in the tuner and are arguably the weakest link.

Our project will capitalize on the reliability of the variable reactive components and the versatility of the microcontroller. We will use a microcontroller similar to that used in the MFJ-998 and modify the code to control the stepper motors instead of a relay network. We will incorporate the ability to save stepper locations for frequencies read from an incorporated frequency counter similar to the relay design as well. The tuner will have a radio interface used to communicate between radio and tuner.

5. Vision for participation in project by team members.

The tasks will be divided as follows but are subject to change as the semester progresses. Each team member will have a particular task on which to focus but will not be limited to contributing on that task alone. Team work will be vital to ensure all pieces converge with ease. Duties are as follows:

Research: ALL. All members will be performing research throughout the development process. The topics we are researching will be subject to our individual tasks.

Team Webpage: Preston. The webpage will be maintained and updated as needed.

Documentation: ALL. Many of the deliverables will be a joint effort to document the progress made on each part of the project.

Control circuit design: Jonah, Haley. Both will work on circuit design together, doubling the amount of eyes in hopes of catching errors before fabrication. Haley will head up running simulations on the schematic capture. Jonah will work on the layout of the components on the PCB.

PCB design & manufacture: Jonah, Haley, Noah. Jonah will head up the soldering efforts of the PCB. Haley and Noah will test the completed board and ensure it performs as designed. Noah will also determine the physical dimensions of the board from inspecting the enclosure and relay them to Jonah in the PCB layout process.

Microcontroller programming: Preston, Noah. Preston will head up the structure of microprocessor code and identify the processes needed for the project to run as intended. From there, both Preston and Noah will work to develop the processes identified and integrate into the runtime behavior. Throughout the process, code reviews will be held to review and refactor code as necessary. Noah will test the code and identify bugs that need to be addressed.

Integration & debugging: ALL. Team members will work together when integrating each sub-task. Problems that arise throughout the project may require the help of all team members.

6. Preliminary schedule of what you are planning to do and discussion of feasibility.

We first plan to meet with MFJ at the start of the semester to evaluate our design, discuss the development schedule, and establish safety procedures. In this meeting, we will validate the design constraints to ensure all desired functionality will be present in the final device. From there, our team members will focus on their assigned roles and routinely communicate with other team members to maintain a consistent design in an effort to ease the integration process later in the semester. Once all required hardware and software have been completed and assembled, we will develop a test plan to verify the operating characteristics of our tuner. Allowing for an ample testing window will be in the best interest of everyone, primarily from a safety perspective. Following this mindset, it would be highly desirable to have a working prototype by Thanksgiving.