**2. Design Requirements/Constraints**

Intellitune is an automatic antenna tuning unit (ATU) for use in a ham radio setup where it fits between the radio transmitter and the antenna. Traditionally, a ham operator would manually tune the impedance of the network so that the transmitter could operate at maximum efficiency. The Intellitune aims to eliminate this time-consuming process by automatically tuning the network, allowing the user to operate the radio faster and with more ease. Once tuned, the transmitter will operate near its peak efficiency for the given setup, enabling the user to transmit a cleaner signal with less interference. To successfully implement this project, there are certain constraints to which the design must abide. Section 2.1 provides a description of five technical constraints, followed by section 2.2, which elaborates on five practical constraints. Finally, section 2.3 will detail the engineering standards which pertain to the Intellitune.

**2.1. Technical Design Constraints**

Table 2.1 describes the technical specifications that the Intellitune must meet upon completion.

Table 2.1. Technical Design Constraints

|  |  |
| --- | --- |
| **Name** | **Description** |
| Power Rating | The Intellitune must be capable of handling 1.5 kW of transmitting power. |
| Bandwidth | Tuning circuitry must pass through frequencies in the 1.5 MHz to 30 MHz band. |
| VSWR Sensing | The Intellitune must measure the forward and reflected power to determine the voltage standing wave ratio (VSWR) for up to a 32:1 mismatch. |
| Frequency Sampling | The microcontroller must sample the transmitting signal and determine the frequency up to the maximum 30 MHz limit. |
| Impedance Matching | The Intellitune must provide a tuning network that is capable of matching antenna impedances from 12-1600 ohms. |

**2.1.1. Power Rating**

The Intellitune must be capable of functioning at a transmitting power of 1.5 kW in single sideband (SSB) and continuous wave (CW) operating modes. This rating places the Intellitune in a strategic position among competitors, most of which are not capable of operating at such high power. The Intellitune will tie into the transmission line fed from the radio transmitter, after which it will connect to the variable inductor and variable capacitor. A single relay will be used to switch the capacitor onto each side of the inductor. Therefore, each part aforementioned shall be rated to a minimum of 1.5 kW. In addition, connections between each stepper motor and their respective reactive component, either the variable inductor or variable capacitor, must have proper insulation and protection to prevent transmission power from flowing through the control circuit.

**2.1.2. Bandwidth**

The Federal Communications Committee (FCC) allocates specific frequencies in the RF spectrum for varying applications. The spectrum allocated to amateur radio is described in 47 CFR 97.301 [1]. The Intellitune must be designed to operate in the 1.5 MHz - 30 MHz band, which encompasses most of the FCC allocated band.

**2.1.3. VSWR Sensing**

The Intellitune must sample the forward and reflected power on the RF feedline to determine the VSWR for up to a 32:1 mismatch. Past a 32:1 reading, it is difficult to extract useful information from the measurement. The tuning algorithm utilizes the VSWR reading for many of its calculations, so inaccurate or intermittent measurements will significantly impact performance. Therefore, the sensing circuit for VSWR must be sufficiently robust as to minimize any errors.

**2.1.4. Frequency Sampling**

The microcontroller must read the frequency of the transmitted RF wave for the tuning algorithm to function as desired. Frequency is a key component in determining the impedance of the antenna. Thus, the entire tuning process hinges on interpreting the frequency with a high level of confidence. Since the Intellitune is designed to operate at a maximum frequency of 30 MHz, the microcontroller must be capable of measuring frequency up to that limit. The sampling interval must be at a rate which allows for proper counting of RF signal peaks, while still providing enough computational resources for other critical measurements.

**2.1.5. Impedance Matching**

The Intellitune must provide a matching network capable of regulating the impedance observed by the signal source. It will be designed to match a 50 ohm output transmitter, transceiver, or amplifier to any antenna with an impedance ranging from 12 to 1600 ohms. Standard coaxial cables used for radio transmission typically have an intrinsic impedance of 50 ohms, so matching this amount minimizes the reflected radio frequency (RF) power in the system. If the antenna’s impedance is not matched, low power transfer and poor transmission quality will be observed at the transceiver. This will directly affect the radio operator’s experience, causing frustration and grief.

**2.2. Practical Design Constraints**

Table 2.2 describes the practical design constraints that must be followed for a successful execution of the final product.

Table 2.2. Practical Design Constraints

|  |  |  |
| --- | --- | --- |
| **Type** | **Name** | **Description** |
| Health and Safety | Physical Safety of the User | The product enclosure must be safe for human contact. |
| Manufacturability | Size | Size must be compact and within a two inch range of previous comparable antenna tuning units (13” x 7” x 15.72”). |
| Sustainability | Longevity | The device must support 100,000 tuning cycles before requiring maintenance. |
| Economic | Price | The cost must be comparable to currently available tuning units, therefore remaining near $700. |
| Environmental | Heat dissipation | The max allowable temperature of the outer case must be 45 degrees celsius (113 degrees fahrenheit). |

**2.2.1. Health and Safety**

Ensuring user safety is critical, so the auto tuner must not pose any potential risks to users during operation. The Intellitune may handle up to a 1.5 kW load, but this high load presents the risk of electrocution. The design must ensure that all potentially dangerous RF current is isolated from the enclosure surface. Therefore, the Intellitune must be placed in a durable yet lightweight enclosure that provides adequate grounding so surface charge does not accumulate.

**2.2.2. Manufacturability**

The size of the tuning unit must be suitable to fit in ham radio work stations. Ham radio users typically set up their radio equipment on a desk or workbench, so the Intellitune cannot be oversized such that it will not fit in a typical setup. The current and comparable MFJ-9982 model measures 13” x 7” x 15.72” [2]. The Intellitune employs similar components so the final product should remain within two inches of these dimensions, in each direction, to provide a compact automatic tuner.

**2.2.3. Sustainability**

The Intellitune must have a lifespan of 100,000 tuning cycles between maintenance intervals. A multitude of relays are used in the MFJ-998 model, which burn out and require service more frequently than other parts within the tuner [3]. Therefore, the Intellitune must feature a reduction of relays to increase the reliability of the product.

**2.2.4. Economic**

The Intellitune must be priced at $700 to remain competitive in the marketplace. One comparable model, the MFJ-998, is offered at $699.95. The Intellitune features a more reliable and higher rated design, while maintaining a similar cost [3]. In house manufacturing and the use of off-the-shelf components will reduce manufacturing costs.

**2.2.5. Environmental**

The Intellitune must be capable of dissipating the rated power without rapid heating. The enclosure must be safe to touch after operating at maximum power. According to a NASA study, the highest temperature that a human can safely come in contact with is 45°C (113°F) [4]. Additionally, if extreme heating were to occur, the risk of fire from contact with the ATU would reduce the safety of the unit. Furthermore, the enclosure must be robust enough to sustain minor bumps or collisions with other equipment when moved.

## **2.3. Appropriate Engineering Standards**

While satisfying the practical and technical constraints, the Intellitune must also abide by the specific engineering standards detailed in table 2.3.

Table 2.3. Appropriate Engineering Standards

|  |  |  |
| --- | --- | --- |
| **Specific Standard** | **Standard Document** | **Specification / application** |
| EIA-RS-225A | 50 Ohm EIA Standard Connectors | The coaxial RF connectors used in the Intellitune will adhere to the Electronics Industries Alliance (EIA) standard |
| C95.1 | IEEE Std C95.1-2005 | Maximum Permissible Exposure (MPE) |
| FCC e-CFR 97.301 | Electronic Code of Regulations | Authorized frequency bands |

**2.3.1 EIA-RS-225A**

Since Intellitune will be working as one part of a system comprised of the user’s other ham radio equipment, it is imperative that everything on the tuner is compatible with the system as a whole. The physical connections made between the RF cables must carefully be taken into consideration as not to cause any interference between equipment. For this reason, the design of the 50-ohm RF connectors must strictly adhere to the description found in EIA-RS-225A.

**2.3.2 C95.1**

The Intellitune is a RF device, so it follows that there is a potential for RF energy to escape the main transmission line and radiate elsewhere. C95.1 specifies the maximum allowable electromagnetic energy that may be radiated into free space, referenced as MPE. The MPE limit must be met to ensure user safety from RF radiation [5].

**2.3.3 FCC e-CFR 97.301**

Amateur radio has specific sets of frequency bands that operators must adhere to based on licensure. Intellitune must adhere to these standards, and it should not promote or permit violating the FCC regulations [1].

**References:**

[1] LII / Legal Information Institute. (2018). 47 CFR 97.301 - Authorized frequency bands. [Online] Available: <https://www.law.cornell.edu/cfr/text/47/97.301> . Accessed: 19 Sep. 2018.

[2] MFJ Enterprises, Inc., Starkville, MS, USA, “MFJ-9982,” Available: <https://www.mfjenterprises.com/Product.php?productid=MFJ-9982> . Accessed: 18 Sep. 2018.

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[4] Eugene Ungar and Kenneth Stroud, “A New Approach to Defining Human Touch Temperature Standards,” NASA/Johnson Space Center, Houston, TX, USA. [Online]. Available: <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20100020960.pdf> . Accessed: 19 Sep. 2018.

[5] IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz, in *IEEE Std C95.1-2005*, pp.1-238, 19 April 2006. [Online]. Available: [http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1626482&isnumber=34126 . Accessed: 19 Sep. 2018.](http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1626482&isnumber=34126)