Project Proposal: Senior Engineering Capstone Design Project

Title: Design and Build of a Radio Telescope System for 1 GHz to 2 GHz Operation

1. Project Objectives

The goal of this project is to design, build, and test a working prototype of a radio telescope system for operation in the 1 GHz to 2 GHz frequency range. The system will be used for amateur radio astronomy and include key components such as:

- A Low Noise Amplifier (LNA)
- A 3-meter parabolic dish antenna with 1/4 wave-in-horn waveguide feed
- A Software Defined Radio (SDR)
- FPGA-based signal processing and interfacing with a laptop PC running amateur radio astronomy software.

This system will meet stringent design specifications for performance, robustness, and cost while demonstrating the ability to detect weak celestial signals, such as those at 1.42 GHz (Hydrogen Line).

2. Customer Specifications

2.1 Low Noise Amplifier (LNA):

- **Gain:** ≥ 30 dB across 1 GHz – 2 GHz
- **Noise Figure:** ≤ 0.7 dB
- **Power Supply:** 12 V DC
- **Power Consumption:** ≤ 600 W over 12 hours continuous use
- **Temperature Stability:** -25°C to +60°C (passive heat sink if required)

2.2 Parabolic Dish Antenna:

- **Diameter:** 3 meters

- **Surface Deviation:** Root Mean Square deviation ≤ wavelength/10 as fabricated and assembled
- **Material:** Aluminum mesh surface with structural tube frame
- **Mounting:** Manual adjustment ±180° azimuth, ±60° altitude without >3% parabola deformation from gravity load
- **Wind Load Resistance:** Withstand up to 90 mph winds without >3% parabola deformation
- **Feed Design:** 1/4 wave ground plane vertical for each: 1 GHz, 1.42 GHz, and 2 GHz operating frequencies, within a horn and waveguide optimized for an **f/D ratio = 0.45**
  - **Aperture Efficiency:** > 55%
  - **VSWR:** ≤ 1.5
- **Antenna Temperature:** < 100K at 30 degree elevation

2.3 Software Defined Radio (SDR):

- Compatible with Society of Amateur Radio Astronomy (SARA) standards
- Open-source software preferred; licenses ≤ $150 acceptable
- Integration with laptop PC via shielded USB

2.4 Signal Processing and Interface:

- FPGA-based processing to achieve:
  - **Signal Resolution:** 0.01 mW
  - **Signal-to-Noise Ratio (SNR):** ≥ 3:1 under system noise conditions
- Shielded coaxial connections for all critical signal paths

2.5 Operational Constraints:

- System budget: **≤ $1000 (BOM only)**
- Prototype fabrication, assembly, and testing within 5 calendar months

3. Estimated Cost and Timeline

3.1 Bill of Materials (BOM) (Preliminary, to be defined by student project plan and design):

Component	Estimated Cost (USD)
Parabolic Dish Antenna (Aluminum Mesh, Frame, Hardware)	$400
Low Noise Amplifier (COTS components)	$150
Dipole Feed with Horn and Waveguide	$100
Software Defined Radio (SDR)	$200
FPGA Development Board	$100
Shielded Coaxial Cables and Connectors	$50

Total Estimated BOM Cost: $1000

3.2 Project Timeline (5 Months):

Phase	Duration	Key Deliverables
1. Literature Review & Research	Weeks 1–2	Background analysis and requirements doc
2. Conceptual Design	Weeks 3–4	Two designs with trade-off analysis
3. Simulation & Design Refinement	Weeks 5–6	Performance simulation and selection
4. Component Sourcing	Weeks 7–8	Procurement of components
5. Prototype Assembly	Weeks 9–11	Fully assembled system
6. System Testing	Weeks 12–14	University lab validation
7. Field Testing & Delivery	Week 15	Deployment to customer dark-sky site

4. Design Options and Analysis

- **LNA Options:** Trade-off between custom design and Commercial Off-The-Shelf (COTS) options to ensure performance and cost balance.
- **Antenna Options:** Evaluate aluminum mesh construction versus solid dish for weight and cost efficiency.
- **Waveguide Design:** Horn design will be simulated and optimized for minimal signal loss and best f/D ratio.
- **Signal Processing:** FPGA platforms like Xilinx or Intel Cyclone evaluated for cost-effectiveness and compatibility.

5. Risks and Limitations

5.1 Technical Risks:

- Ensuring the LNA noise figure is maintained at ≤ 0.7 dB.
- Achieving sufficient parabolic surface accuracy under environmental loads.
- FPGA signal processing complexity and debugging time.

5.2 Budget Constraints:

- Components such as the parabolic dish and SDR must be sourced cost-effectively to stay within the $1000 BOM limit.

5.3 Environmental Constraints:

- Wind and temperature stability of the dish system, ensuring robustness in the field.

6. Skills Required for the Project Team

- **Radio Frequency Engineering:** For LNA design and waveguide feed analysis.
- **Antenna Design and Simulation:** Experience with CST Microwave Studio or similar software.
- **FPGA Development:** Proficiency in VHDL/Verilog and signal processing implementation.
- **Software Integration:** Experience with SDR hardware and amateur radio astronomy software.
- **Mechanical Design:** Structural design for the dish antenna and environmental stability.

7. Reporting and Milestones

- **Weekly Progress Reports:** Delivered to project advisor summarizing accomplishments, issues, and corrective actions.
- **Key Milestones:**
  - Completion of conceptual design and simulation (Week 6).
  - Assembly of the working prototype (Week 11).
  - Validation testing in lab conditions (Week 14).
  - Final deployment and field testing (Week 15).

8. Conclusion

This project proposal outlines a clear, cost-conscious, and performance-oriented plan to design, build, and test a functional radio telescope prototype. The system will meet the operational needs of amateur radio astronomy while adhering to the defined technical and financial constraints. Successful completion will demonstrate mastery of RF design, FPGA signal processing, and mechanical system development, making it an ideal capstone project for senior engineering students.

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