Smart Enclosure Design For Resilient Measurement Systems

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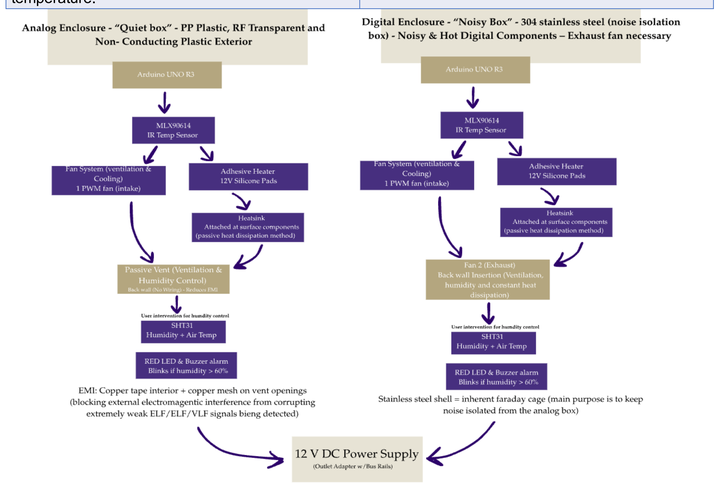
Quiet and Durable Box

Problem Statement

- **A durable, environmentally controlled housing – sealed enclosure for consistent and reliable signal analysis of ULF/ELF/VLF** signals naturally occurring from ionospheric disturbances (e.g., lighting, natural disasters).
- The equipment used for **ULF/ELF/VLF** signal analysis is extremely sensitive to environmental variables including **temperature, humidity and physical shock.**
- Any variations in these factors may affect **signal integrity** which will result in **poor data collection** and analysis.
- Previous use of copper foil in enclosed spaces was helpful in **shielding electromagnetic interference (EMI),** but resulted in increased **heat buildup**, even at night when cooling would take place.
- The solution implied should be **modular and reusable**, supporting multiple facets of future measurement systems beyond ionospheric sensing.

EMI Protection and Weather Feature

Thermal & Environmental Requirements	EMI Requirements
Temperature: Industry standard controlled interior –30°C to +80°C; early mitigation-controlled interior +10°C to +50°C.	**EMI/RF:** Measurable VLF/ULF shielding (3 Hz – 30kHz band), analog channels individually isolated, Arduino placed outside the copper shell; single fan only in analog enclosure.
Humidity: Operating range 0-80% RH; alert LED/Buzzer triggers at 60% RH.	**Outer polypropylene shell:** RF-transparent antenna signals pass through unimpeded.
Environmental/Mechanical: IP54 min. Weatherproofing (IP65 : Weather/dust proof); – 30°C to +80°C material rating; robust internal mounting rails.	**Inner Copper Sheet:** forms the primary Faraday cage with single-point grounding.
Peak Power Budget (Per Enclosure – 10 Adhesive Heaters) : 12V DC, ~120W / 10A (Cold-start) **Steady State Power Budget (Per Enclosure – 10 Adhesive Heaters) :** ~1-3A depending on ambient temperature.	**Two copper-mesh sub-cages:** One per analog channel (surge protector → LNA → LPF) : Prevent inter-channel crosstalk.



Implementation

Dual-Enclosure Architecture

- **Analog "Quiet Box"** - Polypropylene (non-conductive, RF- transparent) shell; inner copper sheet/mesh Faraday cage; 1xPWM fan (Noctua NF-F12) + passive vent; Arduino placed outside the EMI shell; houses LNA, analog filters, surge protectors.
- **Digital "Noisy Box"** - VEVOR NEMA 4x stainless steel (304 SS, inherent Faraday effect); 2x PWM fans (intake + exhaust); houses PC, hard drives, DAQ hardware.

Control Logic for both enclosures:

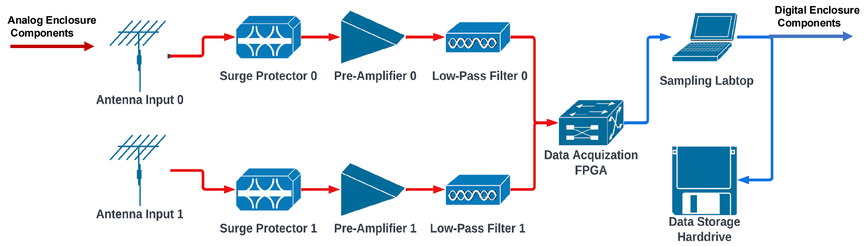
Dual Enclosure - Thermal Management Control Logic

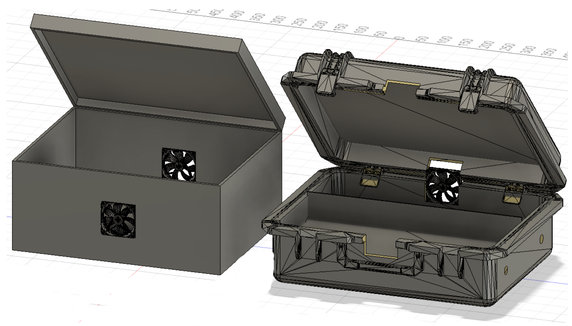
Temperature (MLX90614 Sensor)	Fan Speed	Heater
Obi Temp > 50°C (Critical heat)	100%	OFF
Obi Temp 35-50°C (High)	70%	OFF
Obj_Temp 20-35°C (Normal)	40%	OFF
Obi Temp < 10°C (Cold)	20%	ON – Arduino Digital Pin

- This system uses active convection cooling by integrated **control fan + heat sink** in both enclosures. Implement careful selection of physical threshold to manage dew point.

EMI Strategy:

- Copper mesh/foil Faraday cage with single-point grounding; separate channel sub-cages per analog channel; no switching electronics inside the analog shell.
- Two copper-mesh sub-cages — one per analog channel (surge protector → LNA → LPF) — prevent inter-channel crosstalk..
- Microcontroller isolate outside of the component box to minimize EM interference.





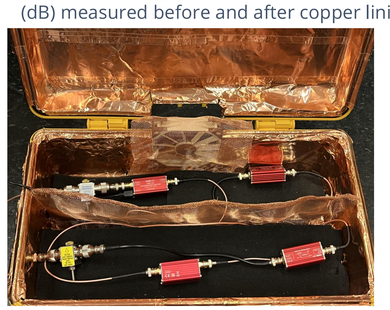
Result

Results

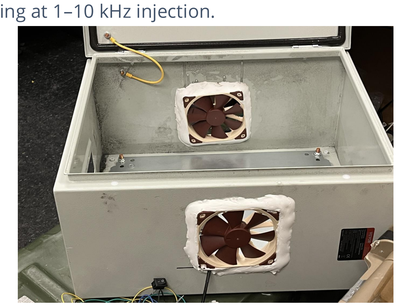
- A dual-enclosure architecture was successfully designed to **isolate sensitive analog** components from noise-generating digital systems, improving signal integrity for **ULF/ELF/VLF** measurements.
- Core subsystems, including **thermal control, humidity monitoring, and control logic** were prototyped and validated, demonstrating feasibility of stable environmental regulation.
- The design directly addresses key failure modes observed in prior systems, including **overheating, condensation, and EMI interference**.

Conclusion

- This work establishes a scalable and reusable enclosure framework for protecting sensitive measurement systems in harsh outdoor environments.
- Temperature regulation , humidity response confirmed: EMI attenuation: noise floor (dB) measured before and after copper lining at 1–10 kHz injection.



Analog Box with EMI shielding and weather module



Digital box with strong weather module

Discussion/Future Work

- **High-bandwidth real-time climate monitoring** — interrupt-driven logging for finer temporal resolution of thermal gradients inside the enclosure.
- **Higher-resolution internal thermal imaging** — map the physical temperature gradient across the enclosure volume during operation.

References and Acknowledgments

[1] M. Mamishev and Z. Liu, "Nimbusort: Advanced Detection of Ionospheric Disturbances Using EM Signatures," 2025 IEEE, 2025, doi: 979-8-3315-5937-3/25
[2] A. Mamishev and S. Makhsous, Embedded antenna system and weak signals instrumentation," University of Washington, Seattle.

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SPONSOR: UW Sensors, Energy and Automation Laboratory