DOODLE LABS

Long-Range Radio Performance (L and S Bands)

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1. Introduction

This paper presents the findings from a long-range radio validation test conducted by Doodle Labs, focusing on throughput, latency, and signal stability under real-world, long-range conditions. The goal of this test was to validate the establishment of an RF link and to transfer at least 2mbps of data while observing latency.

The test consisted of two radios at fixed locations, one on a mountaintop, the other in the desert at a calculated distance of 47km. The location was selected to provide for a difference in elevation along with line of sight (LOS).

On both sides of the link, testing occurred with multiple antennas, including a dual-dish tracking system (Optimum Solution), blade antennas (Optimum Solution & Freedom Atlantic), and a Hascall-Denke patch antenna.

It was found that Doodle Labs' radios consistently maintained reliable connectivity and data transfer rates at 47km. We were able to transmit a 2 Mbps UDP video stream from the Mountain Station to the Desert station. The radios accurately responded to changes in antenna polarization and orientation, underscoring their versatility and suitability for UAV and drone applications.

2. Objectives

- Validate range and throughput performance on L and S bands.
- Assess the effectiveness of different antenna configurations, including directional and omnidirectional setups with varying polarization and orientations.
- Evaluate signal integrity and environmental resilience over a 47 km test distance.
- Transfer reliability and latency while passing 2mbps of data.
- Determine maximum throughput and latency performance.

3. Tests Conducted

S-Band

- Maximum TCP & UDP iperf3 Throughput | Bidirectional | Multiple Channel Bandwidths
  - iperf3 commands
    - `iperf3 -c 10.223.116.83 -u -t 20 -b 100M`
    - `iperf3 -c 10.223.116.83 -t 20 -b 100M`
    - `iperf3 -c 10.223.116.83 -u -t 20 -b 100M -R`
    - `iperf3 -c 10.223.116.83 -t 20 -b 100M -R`
- Constant ping was run simultaneously for latency
- 2mbps Video Stream Sent from Mountain Station to Desert Station

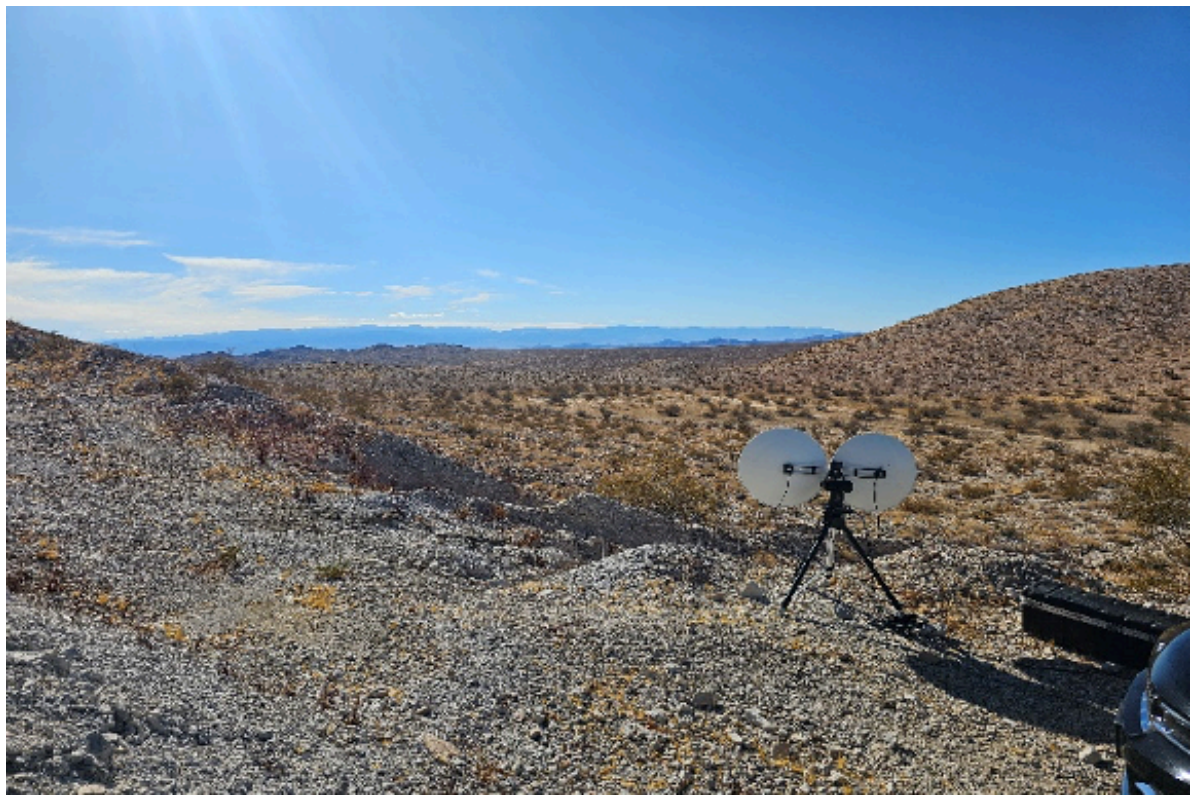
L-Band

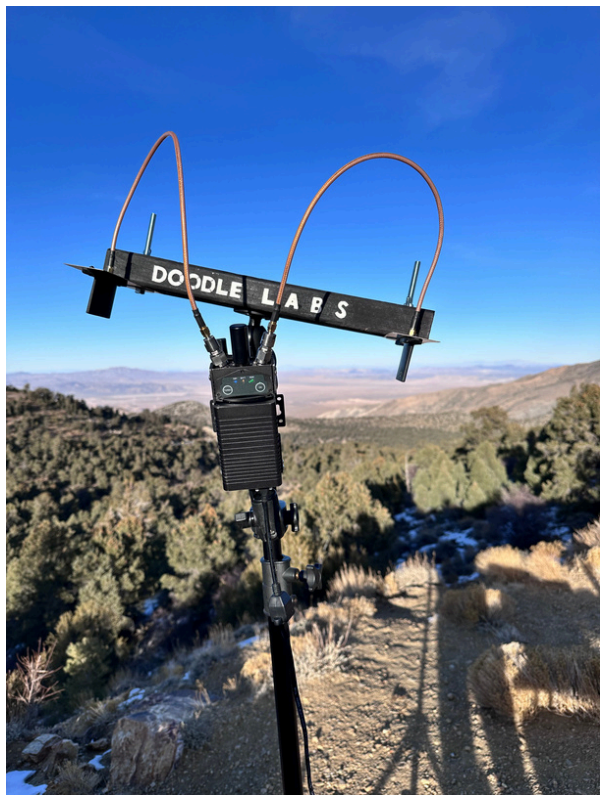
- UDP iperf3 Validation set for 2Mbps | Bidirectional | Multiple Channel Bandwidths | Various Orientations on Mountain Station
  - Iperf3 commands
    - `iperf3 -c 10.223.116.83 -u -t 20 -b 2M`
    - `iperf3 -c 10.223.116.83 -t 20 -b 2M`
    - `iperf3 -c 10.223.116.83 -u -t 20 -b 2M -R`
    - `iperf3 -c 10.223.116.83 -t 20 -b 2M -R`
- Constant ping was run simultaneously for latency
- 2mbps Video Stream Sent from Mountain Station to Desert Station

4. Test Details & Methodology

4.1. Test Locations and Configuration

- **Desert Station (Left):** Positioned in the desert, LOS to Mountain Station (1275 meters elevation)
- **Mountain Station (Right):** Positioned on a mountain with LOS to the Desert Station (1900 meters elevation)





4.2. Test Configuration

Environmental Conditions:

- Clear skies
- Moderate wind
- Temperature
  - 32°F / 0°C (Mountain Station)
  - 58°F / 14°C (Desert Station)

4.3. Radio Configuration

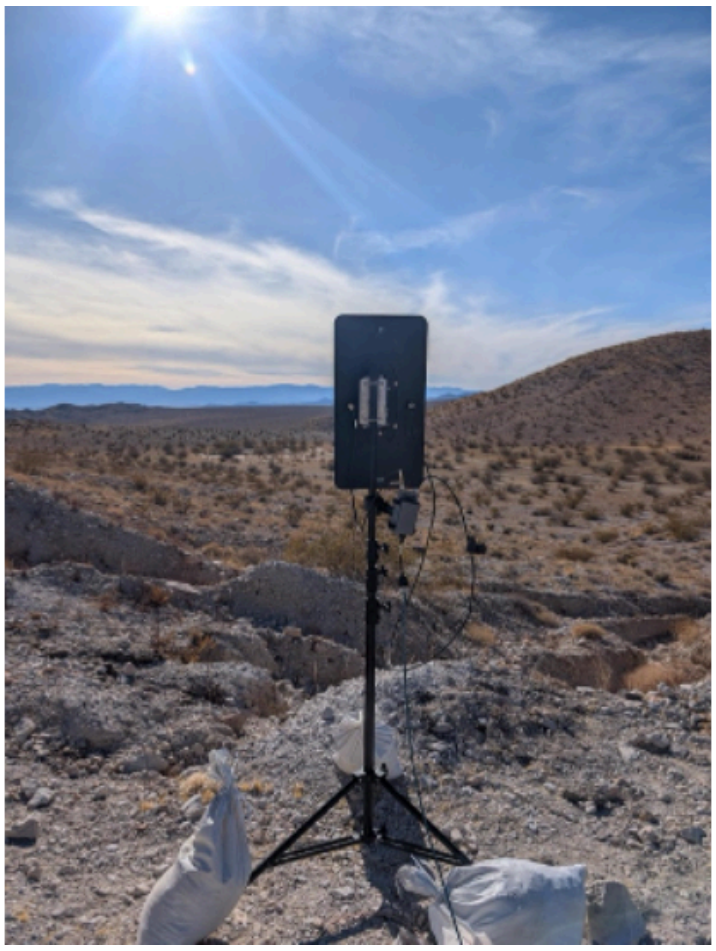
- **Models Used:** RM-2025-62W3 & RM-2100-42W3
- **S-Band Center Frequency:** 2220 MHz (Day 1)
- **L-Band Center Frequency:** 1370 MHz (Day 2)
- **Channel Bandwidth:** 5MHz, 10MHz, & 20MHz
- **Firmware Version:** 10.1
- **Max Distance Setting:** 100,000 Meters
- **Transmit Power Control & Aggressive Transmit Power Control:** OFF
- **Operating Mode:** Mesh
- **All Other Settings:** Firmware Defaults

4.4. Test Procedures

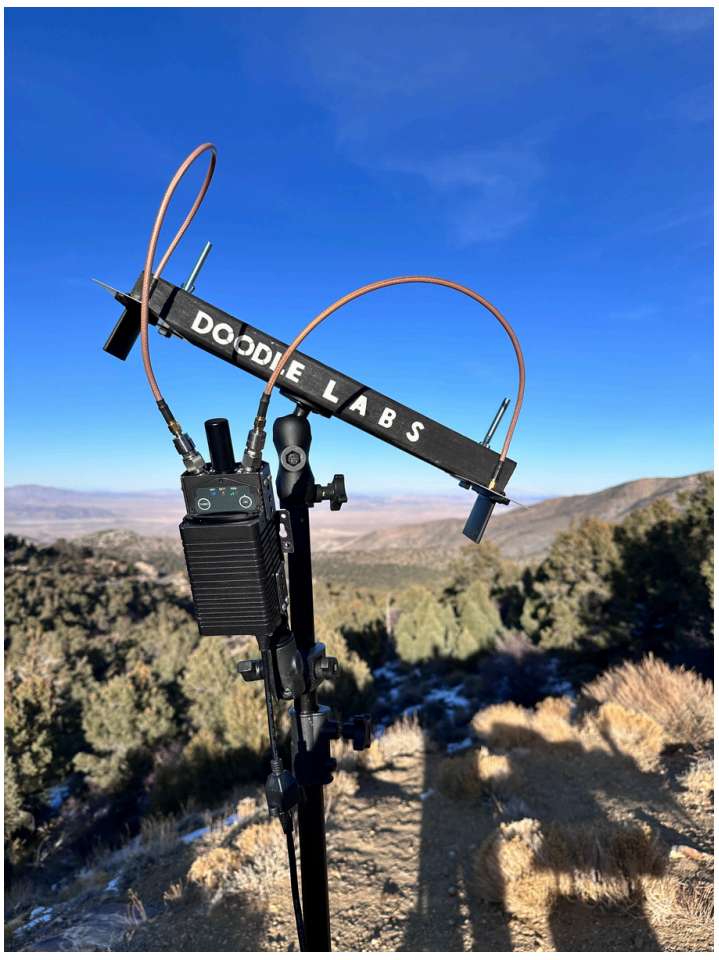
1. Antenna Setup:

- **Optimum Tracking System (Desert Side)**
  - **Deployment:** The tracking system was affixed to the provided tripod. Stakes and sandbags were used to ensure the system was secured to the ground. Alignment and calibration were performed using a compass.
  - **Positioning:** Automated positioning of the system was enabled by manually inputting the coordinates of the Mountain Station to the Optimum Solution's software via a virtual serial port using Python.
  - **Power:** Power was provided to the system through a LiFePO4 Battery with an inverter attached.
  - **Polarity & Cabling:** Each dish feed offered two RF ports, corresponding with vertical or horizontal polarization. Various configurations such as Horizontal & Vertical, Vertical & Vertical, and Horizontal & Vertical were tested throughout the session. SMA to TNC cables were used.

- **Hascall-Denke (Desert Side)**
  - **Deployment:** The antenna was mounted on a tripod using the included mounting hardware.
  - **Positioning:** The antenna was raised 3 meters from the ground and manually positioned in the direction of the Mountain Station.
  - **Polarity & Cabling:** The antenna has one horizontal and one vertical N-type plug. Type N to TNC adapters were used to connect the antenna to each channel of the Wearable unit with coax.



- **PIDSO, Optimum Solution, & Freedom Atlantic Blade Antennas (Mountain Station)**
  - **Deployment:** Antennas were mounted to copper clad PCB boards which serve to function as a ground plane. The copper clad antenna boards were attached to a wooden board. This assembly was outfitted with an adjustable RAM mount and attached on top of a tripod at 3 meters in height.
  - **Positioning:** The RAM mount offered the ability to easily manipulate the mount into many orientations. The antennas were tilted 45 degrees and rotated at various angles to simulate what would normally occur when mounted on a UAV as it navigates airspace.
  - **Cabling:** TNC to SMA adapters were used to attach coax to the Wearable.



2. Testing Script & Data Collection

- Channel bandwidth was manually configured via UCI ssh commands.
- A Python script was executed, which performed the following functions:
  - Started Link Status Log
  - Latency test using ping
  - Timed TCP (Forward & Reverse) throughput tests using iperf3
    - (Varied time and maximum throughput)
  - Timed UDP (Forward & Reverse) Throughput tests using iperf3
    - (Varied time and maximum throughput)
- All link metrics and test command results were captured and stored for analysis.

5. Results and Analysis

5.1. Performance on S-Band (2220 MHz)

- **Max UDP throughput at 3 MHz bandwidth:** 4.30 Mbps
- **Max UDP throughput at 5 MHz bandwidth:** 6.48 Mbps
- **Max UDP throughput at 10 MHz bandwidth:** 12 Mbps
- **Max UDP throughput at 20 MHz bandwidth:** 13.2 Mbps
- **Signal Strength (RSSI):** -78 to -81 dBm
- **Noise Floor:** -92 to -94 dBm
- **Latency:** 2–7ms
- **Packet loss:** <3%

5.2. Performance on L-Band (1370 MHz)

- **Max UDP throughput at 5 MHz bandwidth:** 1.9–4.9 Mbps
- **Signal Strength (RSSI):** -78 and -81 dBm
- **Noise Floor:** -95 dBm
- **Latency:** up to 12ms

5.3. Comparison and Observations

- **Throughput:** S-Band achieved higher bandwidth scalability and better data rates.
- **Stability:** L-Band provided more consistent link stability with longer distance potential.
- **Antenna Performance:**
  - Optimum Solution Tracking System & Hascall-Denke Patch Antenna excelled in directional LOS scenarios.
  - All Omni Blade antennas demonstrated strong performance, even in different physical orientations.

6. Conclusion

The Doodle Labs' radios exhibited reliable connectivity and data transfer rates at 47km. These impressive results were achieved through adaptive dynamic modulation rate adjustments that typically selected MCS 4 in most tests.

In our tests, the radios effectively demonstrated their ability to operate with different antenna polarizations by accurately responding to changes in the Mountain Station's orientation. We conducted various combinations of polarization tests with both the Desert Station and the Mountain Station antennas, including Vertical + Horizontal, Vertical + Vertical, and Horizontal + Horizontal. The Mountain Station antenna mount was rotated through a full 360 degrees on the azimuth and tilted up to 45 degrees, simulating the shifts that would occur during flight.

No significant performance differences were observed among the varying polarization configurations, reinforcing the notion that Doodle Labs' radios, along with this antenna selection, are suitable for UAV applications. It should be noted, however, that these results could potentially change under dynamic conditions or during extreme aerial maneuvers.

During this test, the S-Band provided higher throughput than the L-Band. At the same time, L-Band proved more suitable for longer distances while retaining stable connectivity.

The results show that with just a 1W radio, we were able to achieve a ~50km link on a 10MHz channel bandwidth. This suggests that with a 5MHz bandwidth, further ranges can be achieved with the same antennas.

In summary, the Doodle Labs' radios have demonstrated impressive performance capabilities in both S-Band and L-Band communication, making them suitable options for applications such as long-distance drone operation.

7. Future Testing

- Dynamic environmental effects on link performance.
- Adjust MCS Rate for Static & Adaptive modulation techniques.
- Throughput and latency performance when integrated into UAV and mobile platforms. (Real-time deployment scenarios with active motion).

8. Appendices

Full Antenna and Radio Equipment List:

Hascall-Denke Patch Antenna: https://hascall-denke.com/project/1y42900-fxsp1-35-2-7-14-d-rev-a/
PIDSO´s SDI.016-00A
RM-2100-42W3: https://techlibrary.doodlelabs.com/multiband-wearable-mesh-rider-radio-1370-mhz-and-22002510-mhz-l-s-1
RM-2025-62W3: https://techlibrary.doodlelabs.com/multiband-wearable-mesh-rider-radio-16252500-mhz-m1-m6-hex-bands
Optimum Solution Tracking System: https://optimumsolution.com/index.php/gps-automatic-tracking-pedestals/
Freedom Atlantic Blade Antennas: https://freedom-atlantic.com/apollo-antenna/

[1] Link Status Log is a service on the radio to collect link metrics, system debug information, and configuration settings. More information available on Doodle Labs' Technical Library: