2.4 GHz Phased Array System for Lunar Extravehicular Activity (EVA) Communications

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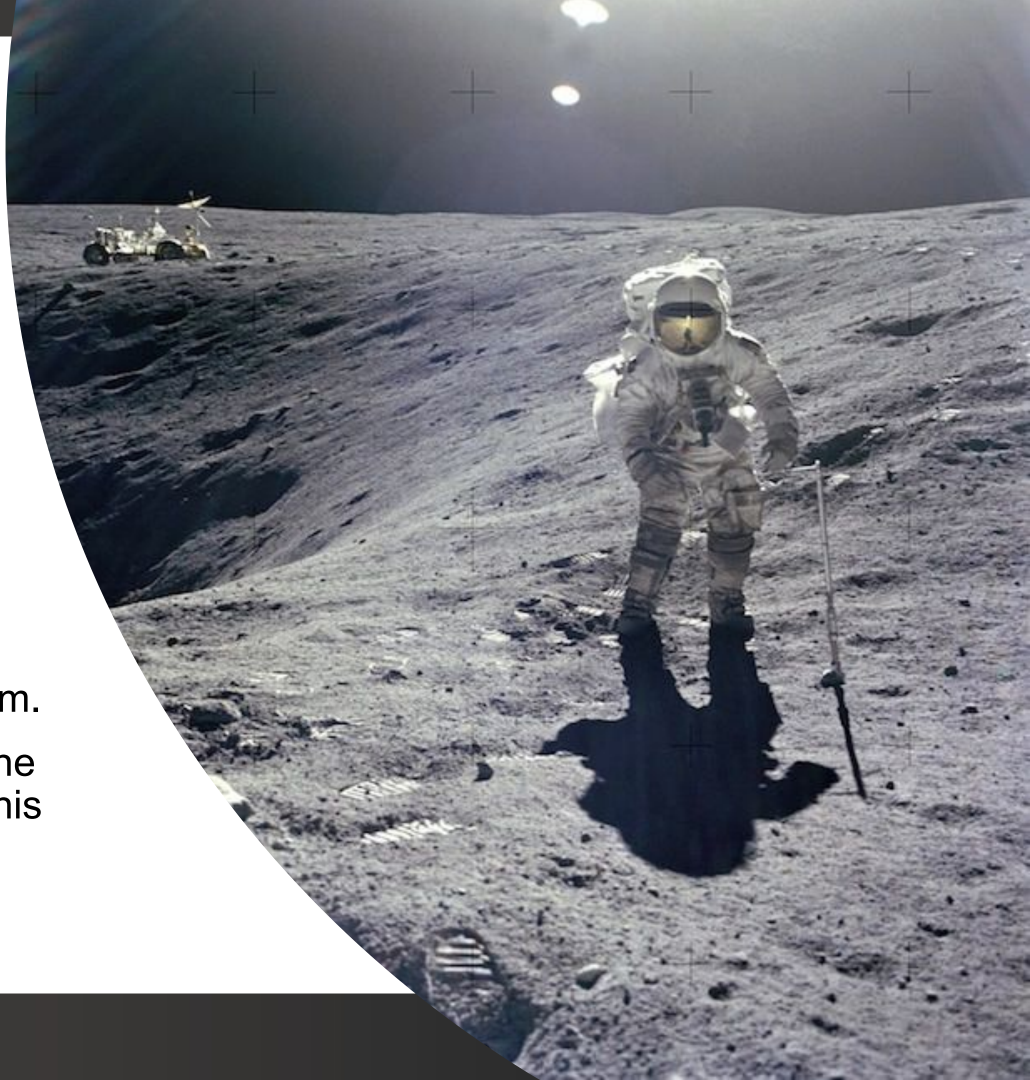
Motivation

- 2.4 GHz Wi-Fi links are used for EVA communications on the lunar surface.
- Compared to VHF links, 2.4 GHz links introduce 18 dB more path loss.
- This severely limits the range of communication devices on the lunar surface.
- Current NASA goal for EVA range is 0.5 km.
- A phased array can be used to increase the gain in the azimuthal plane and surpass this goal.

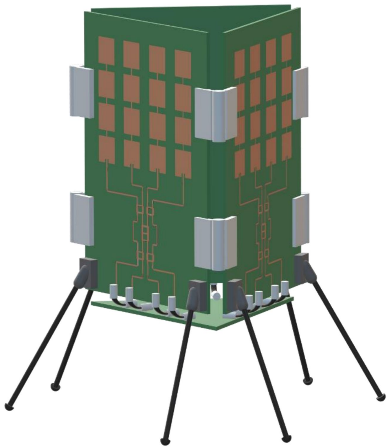


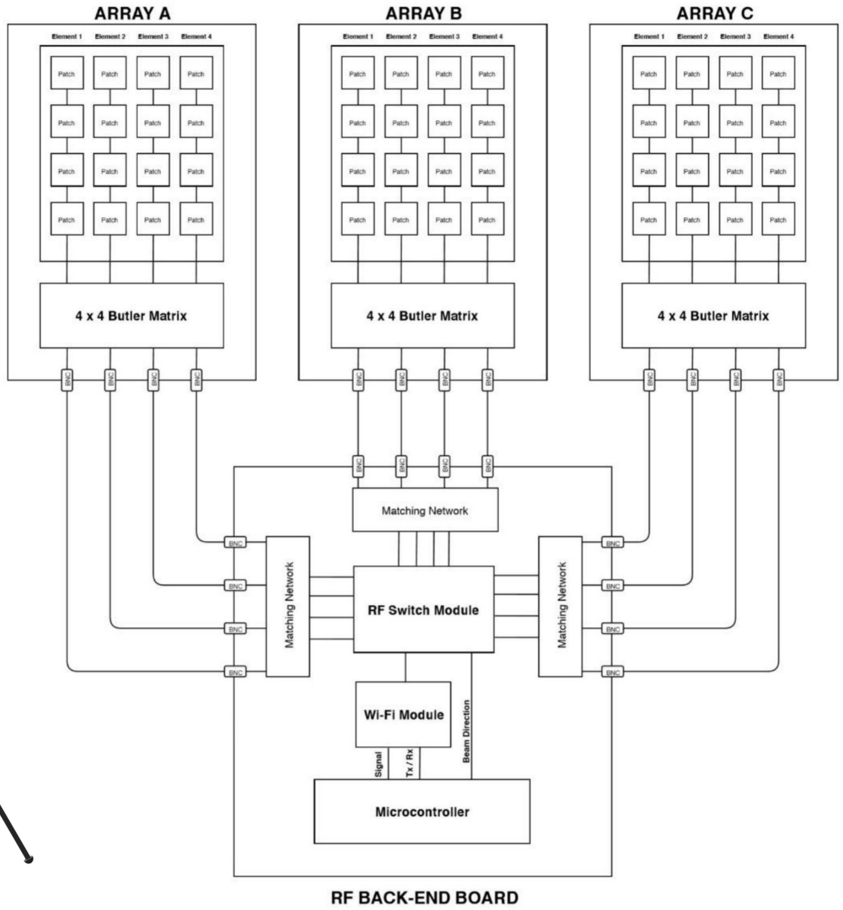
Technical Specifications

- 2.4 - 2.5 GHz (Wi-Fi band)
- 10 dB bandwidth ≥ 20 MHz (802.11b channel BW)
- Power delivered to 0.5 km ≥ -91 dBm
- 360° azimuthal coverage (resolution ≤ 30°)

System Design

- Front end:
  - Series-fed linear patch antennas
  - Butler matrices
- Back end:
  - RF switch module
  - Wi-Fi module
  - MCU
- Mechanical Fixture:
  - BNC connectors
  - Hinges
  - Mechanical supports

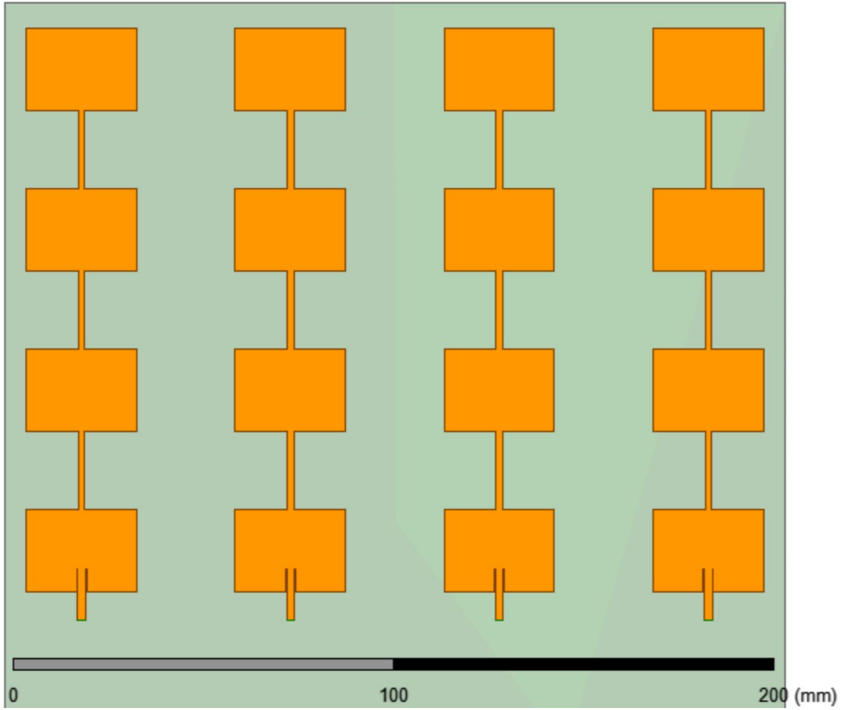




Antenna Array Design

- Series-fed patch elements
  - Designed to 2.45 GHz
  - Inset feed for 50 Ω match
- 4-element linear array
  - λ/2 element spacing
  - 0.060” Rogers 3006 ($\varepsilon_r = 6.15$)

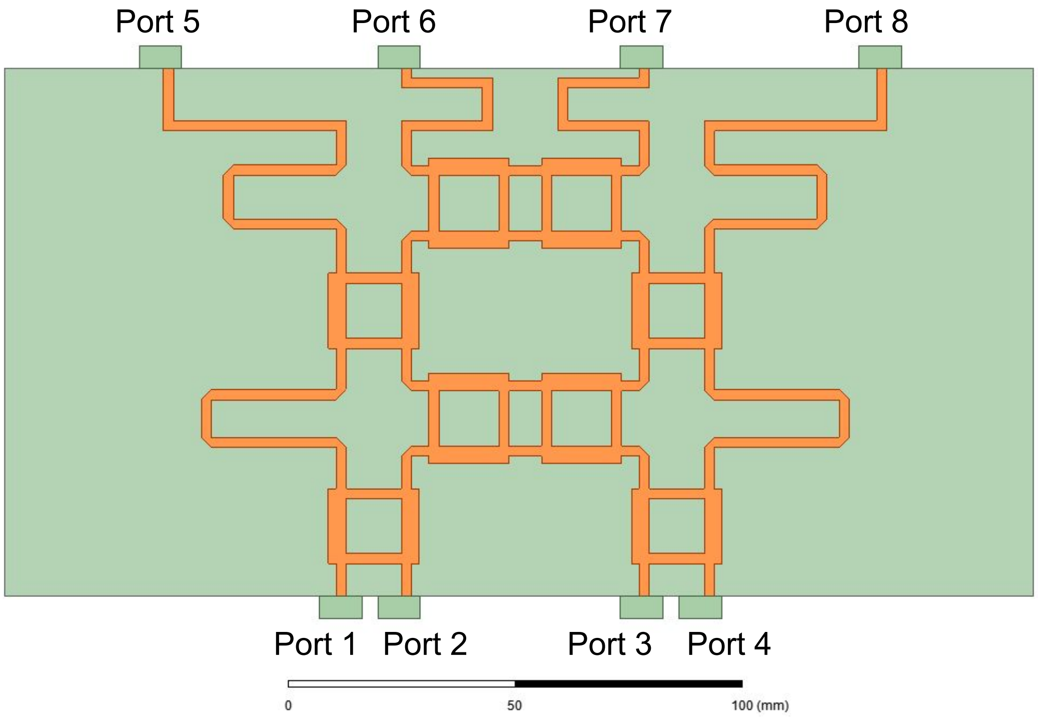
	Single Element	4-Element Linear Array
Gain	8.0 dBi	15.0 dBi (broadside)
Δf_{10dB}	28 MHz	24-28 MHz
HPBW	35.5°	25.4° (broadside)



Butler Matrix Design

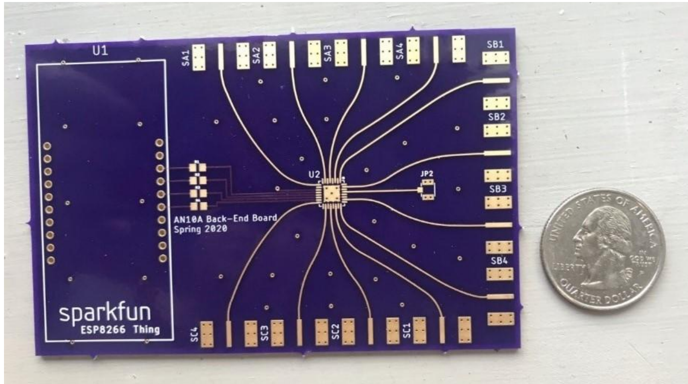
- 4×4 topology:
  - 4 90° hybrid couplers
  - 4 phase shifters
  - 2 crossover structures

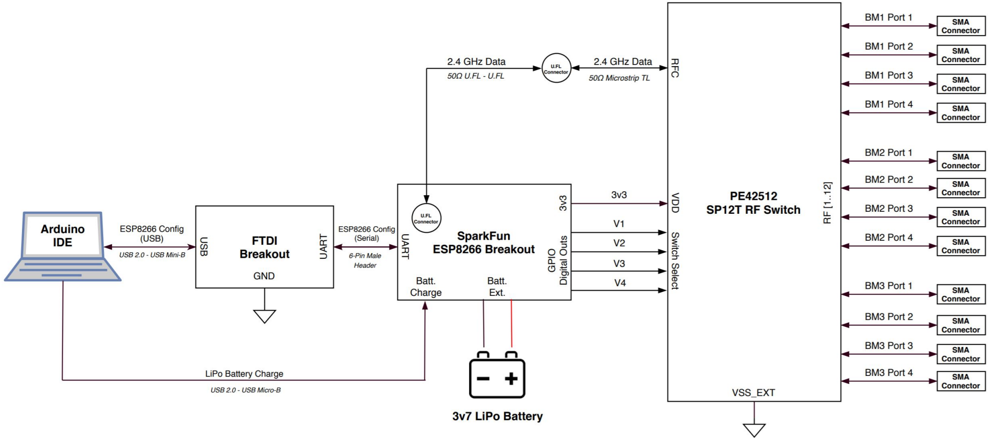
Distributions Unit: dB, degree	Port 1	Port 2	Port 3	Port 4
Port 5	-6.12∠-38.5°	-7.58∠-113°	-7.42∠-70.8°	-7.47∠-162°
Port 6	-6.58∠-62.0°	-7.65∠12.9°	-6.48∠137.9°	-8.80∠-95.3°
Port 7	-7.37∠-92.5°	-6.60∠139.0°	-7.74∠14.1°	-6.55∠-61.1°
Port 8	-7.64∠-162°	-7.36∠-71.0°	-7.64∠-112°	-5.50∠-36.8°
Steer Angle (from broadside)	15°	-45°	45°	-15°



Back-End Design

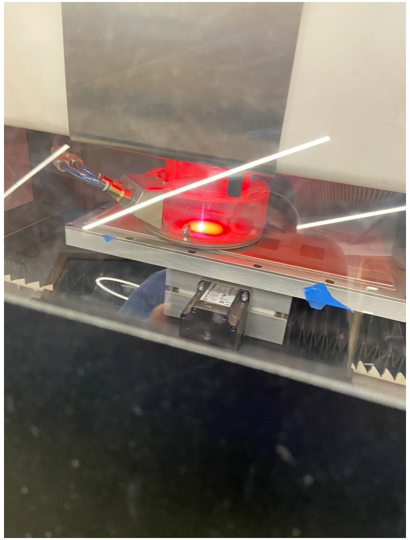
- **Wi-Fi module/MCU** (ESP8266 Thing)
  - Runs high-level C code
  - Built-in Wi-Fi APIs
  - 2.4 GHz signal output
- **Single pole, 12-throw switch** (PE42512)
  - Bidirectional
  - Connects Wi-Fi module to one of 12 ports
  - Switch (and thus beam direction) controlled by 4 input bits
- PCB layout (Osh Park)
  - 4-layer board
  - Signal layer: 0.17mm FR408 ($\varepsilon_r = 3.67$)
  - 50 Ω microstrip lines
  - SMA I/O ports to front-end



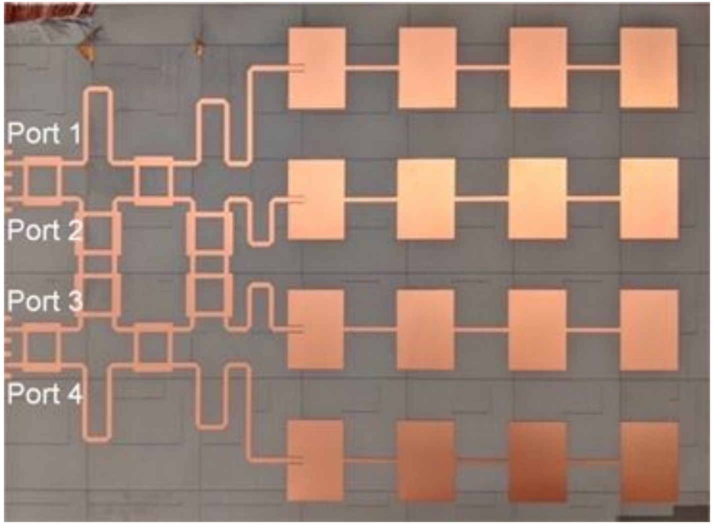


Front-End Fabrication

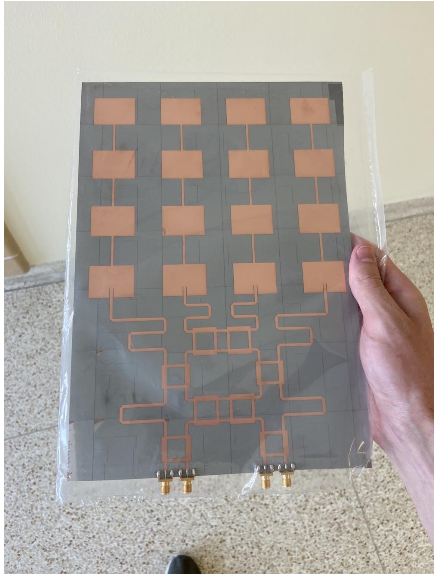
Utilized Georgia Tech's Interdisciplinary Design Commons to print the front end boards on Rogers 3006 substrate and solder connectors.



Printing



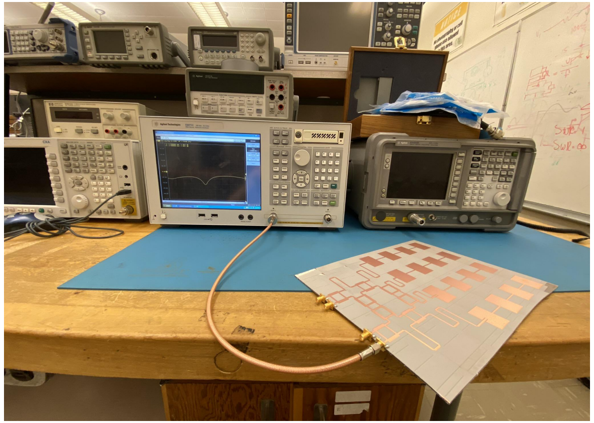
Fabricated Board



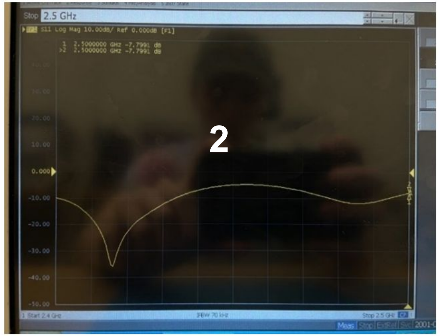
With hand to show scale

Front-End Measurements

Return loss as measured in VL365



VNA S11 Measurements		
Port	**f_c (GHz)**	**Δf_{10dB} (MHz)**
1	2.500	N/A
2	2.416	34
3	2.418	35
4	2.448	17



Project Demonstration

Range Demonstration

$$d = 10^{\frac{G_{TdB}+G_{RdB}+P_{TdB}-P_{RdB}+2(h_{TdB}+h_{RdB})-M}{40}}$$

$$d = 10^{\frac{(11.5)+(2)+(-15.22)-(-121)+2((7)+(3))-(20)}{40}}$$

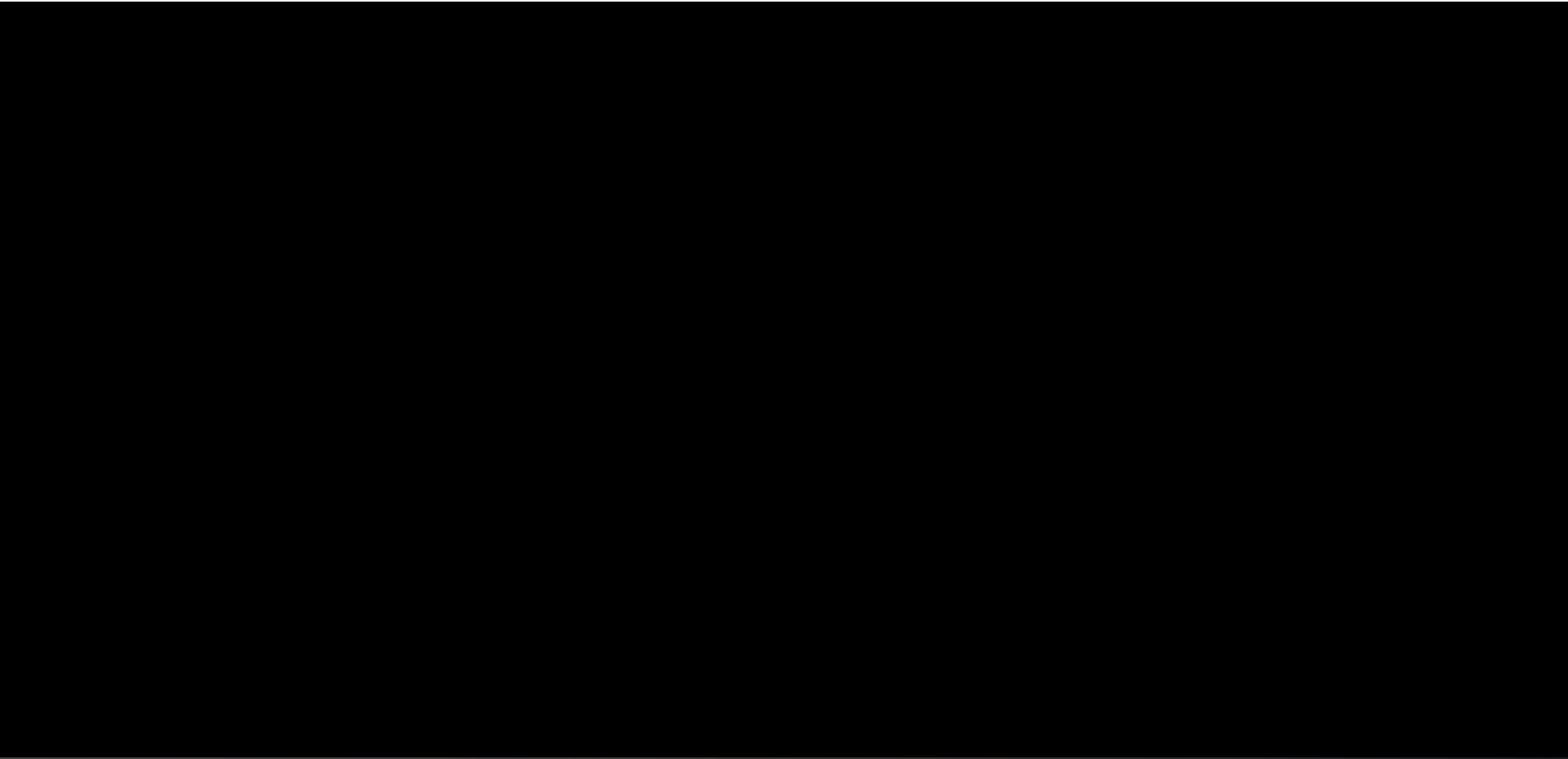
$$d = 0.95km$$

Source of Values

- G_T = Front End Design
- G_R = Assumed
- P_T = 100 mW - assumed 2dB internal loss at back end and 3 dB internal loss at Butler matrix
- P_R = ESP8266 minimum sensitivity using 802.11 b
- h_T = 5 meters
- h_R = 2 meters
- M = 20 dB, upper limit on lunar surface

https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20070025224.pdf

Coverage Demonstration



Acknowledgments

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Thank you for listening!