Horizontal High Frequency System Design

Advisors: Dr. Chuck Bunting, Dr. Pavithrakrishnan Radhakrishnan
Stakeholders: Naval Surface Warfare Center Dahlgren Division (Marshall Sowell)

Juliette Reeder, Jack Hicks, Forrest Tuschhoff

Team Introduction

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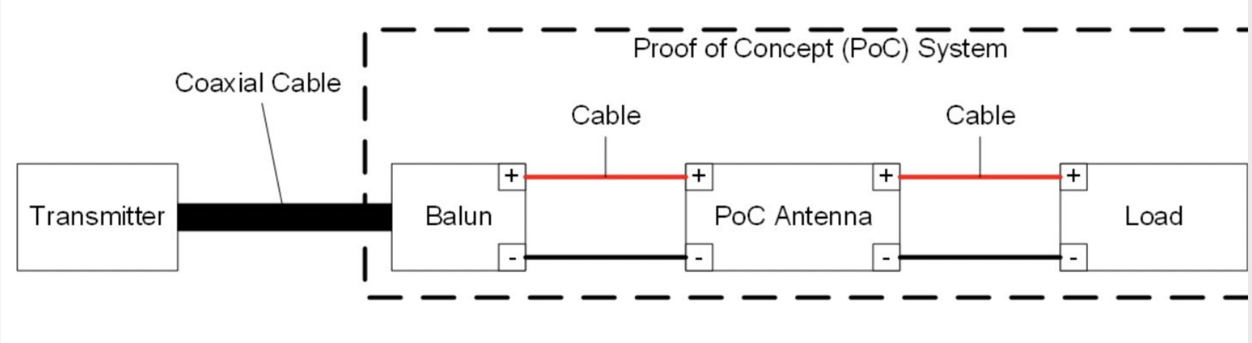
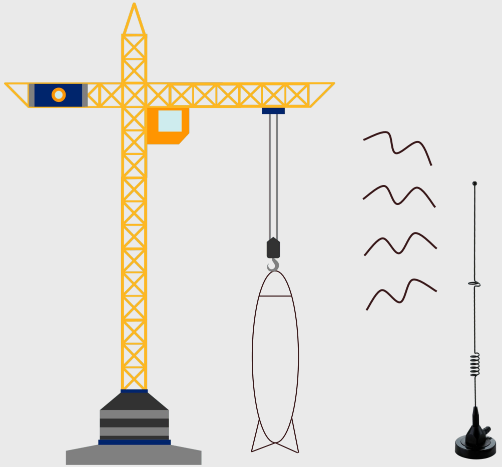
Project Description



Test Frequencies (MHz)	
4.040	13.530
4.803	16.060
5.385	17.048
6.400	18.036
6.970	19.270
7.595	20.510
7.990	21.460
9.050	23.180
9.803	24.450
11.064	26.875
12.045	

Focus on 13-26 MHz



Problem:

Naval shipboard electronics must withstand HF communication fields.

Naval Surface Warfare Center Dahlgren Division tests how these electronic systems respond to EM fields before deployment.

Standard tests use a **vertical** whip/telescoping antenna with the missile suspended vertically.

Large missiles cannot be lifted with available cranes.

Need for a **horizontal** broadband HF antenna system to test missiles on non-metallic carts.

Project Constraints

- Transmit/receive on 5–10 frequencies between 13-26MHz, or show coverage.
- Include balun or 50Ω impedance match for 10 kW HF transmitter.
- Generate sufficiently uniform horizontal 3dB EM field over 40′ x 6′ x 6′ volume for HF HERO and EMV testing purposes.
- Demonstrate scalability for 10 kW transmit power.
- No size constraint, but within reason.

Focus on 13-26 MHz

Test Frequencies (MHz)	
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12.045	

Considerations

Environmental and sustainability considerations:

- Waste during fabrication.
- ROHS Compliance - minimize toxic materials.
- Electricity use during high-power testing.

Health and safety considerations:

- Consider ICNIRP guidelines → 27.7 V/m is the 5 minute occupational limit.
- A 1kW HF antenna can reach this field strength at more than 30 feet away.[1]

Cultural and global considerations:

- How will more efficient electromagnetic compatibility (EMC) testing reduce costs?
- How might operating on the allocated frequencies affect bandwidth and communication interference?
- What happens in the case a missile does not detonate when intended?

Ethical considerations:

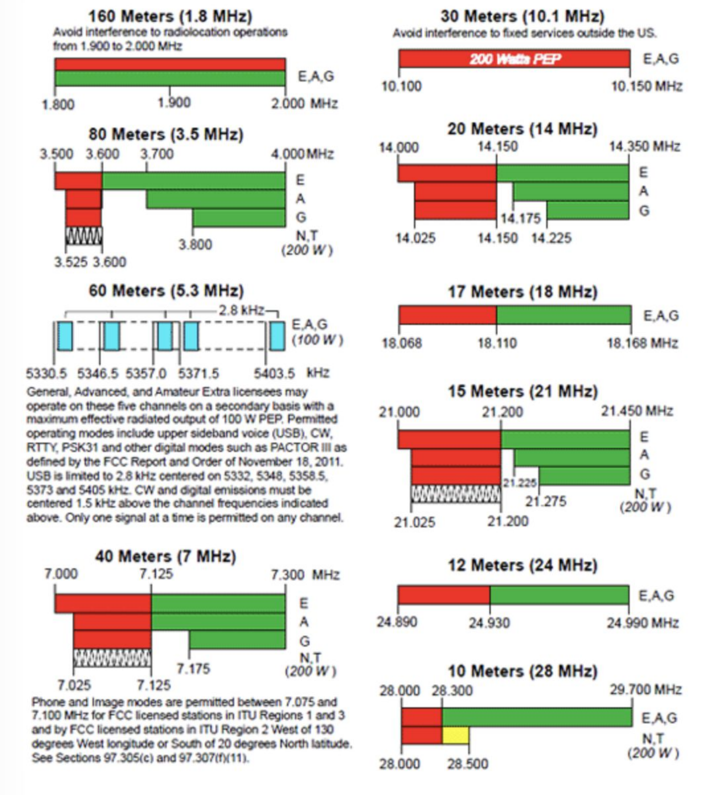
- Ramifications of a false positive test
  - Accidental detonation in the field or damage to equipment.
- FCC Violations

Professional considerations:

- Properly testing the design and presenting a working product.
- Being honest about limitations so that the testing system is not overly relied upon.

Engineering codes, standards, and guidelines.

- **FCC Part 97** - general license required to transmit in HF band
- **FAA 14 CFR Part 77** - maximum height of antennas and distance from airports
- **IEEE/ANSI C63 Series** - standards on EMC
- **IEEE Std 149** - standards on testing antenna power and field strength
- **IEEE Std 291** - standards on spurious emissions
- **MIL-STD-461** - standards on EMC
- **MIL-STD-464** - standards on Electromagnetic Environments (EMEs)
- **MIL-HDBK-240** - standards on testing under ordnance



HF Bands available to Amateur Radio operators with General License
Source: K5IJB

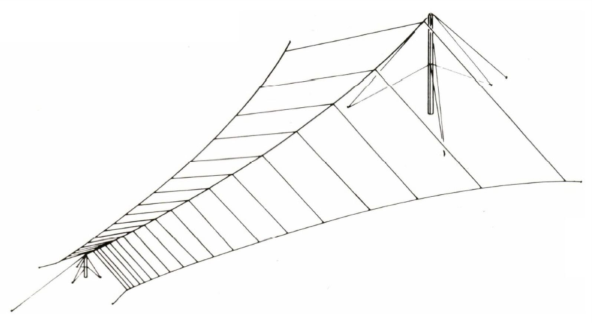
Background Information

Technical terms:

- Antenna element: Individual conductive part of an antenna that radiates or receives EM waves
- dB: Logarithmic representation of power gain/loss → +/- 3dB is about twice/half power, respectively
- dBm: Logarithmic power gain/loss relative to a power of 1 mW (milliwatt)
- VSWR: How efficiently power is transmitted into an antenna; lower values are better → less reflections and mismatch
- Azimuth: An antenna’s horizontal angle (measured clockwise)
- EZNEC: Software used to simulate antennas – gain, radiation pattern, etc

Design: Log-Periodic Dipole Antenna

Antenna:
- Log-Periodic Dipole Antenna (LPDA)
- Consists of many half-wavelength dipole elements along a central boom support
- Elements spaced following a logarithmic function
- Length of the elements gradually increases
- Unidirectional with wide bandwidth

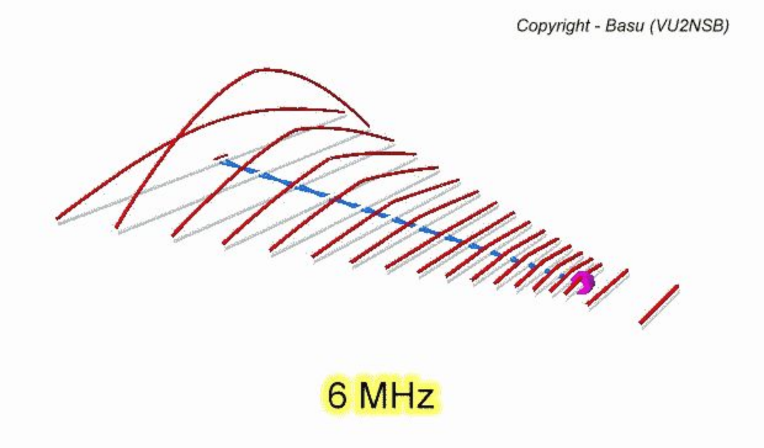


Balun:
- 4:1 broadband balun
- LDG Electronics RBA-4:1: 100-watt 1.8–30 MHz – $29.99

Design: Log-Periodic Dipole Antenna

Desired parameters:

- **Bandwidth**: 13.530 - 26.875 MHz
- **VSWR**: <2:1 (10% returned power)
- **Current**: see VU2NSB's graphic
- **Radiation Pattern (Azimuth) 3dB Beamwidth**: 40′ x 6′



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Design: Log-Periodic Dipole Antenna

Determining LPDA element lengths and spacing:

- Each element is resonant at a wavelength that is twice its length
    - Driven element changes depending on operating frequency
- Choose longest and shortest dipole elements to be half of the longest and shortest wavelengths
- Choose τ and σ based on desired cost, size, performance (VSWR, gain ripple), and bandwidth. Greater τ and smaller σ → more elements, so better performance but greater size and cost.
    - Common choices: $0.84 < \tau < 0.92$ and $0.05 < \sigma < 0.12$
- Calculate # elements: $N = 1 + \mathrm{ceil}[\ \ln(f_{max}/f_{min}) / \ln(1/\tau)\ ]$
- Find element lengths: $L_n = L_1 * \tau^{n-1}$
- Find element spacings: $S_n = 2 * \sigma * L_n$

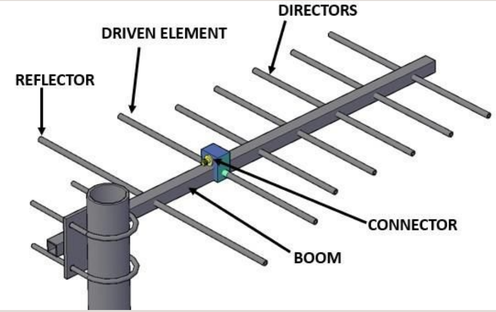
Design: Log-Periodic Dipole Antenna

Design specs:

$\tau = 0.93$, $\sigma = 0.05$

Frequency range from 13 MHz to 26 MHz:

Element	Length(ft)	Position(ft)	Frequency
1	37.8	0	13
2	35.2	3.5	13.978
3	32.7	6.8	15.031
4	30.4	9.8	16.162
5	28.3	12.7	17.378
6	26.3	15.3	18.687
7	24.5	17.7	20.093
8	22.8	20	21.605
9	21.2	22.1	23.232
10	19.7	24.1	24.98
11	18.3	25.9	26.86
12	17	27.6	28.882
13	15.8	29.2	31.056
14	14.7	30.7	33.394



Source: Martin Lema, “Yagi Antenna Theory, Math Free”

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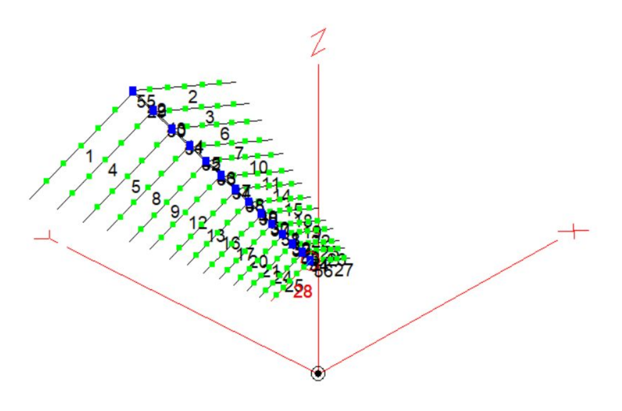


Design: Log-Periodic Dipole Antenna **MATLAB**

```
%Find wavelength
lambda = c./(f.*1e6.*sqrt(e_a));
lambda_f = (lambda.*100)./(12.*2.54);

alpha = 30; %angle of boom in degree
beta = 20; %angle of wires in degrees

%z positions
z_start = P_f.*sind(beta)+10;
z_end = z_start - ((L_f./2).*sind(alpha));

%y positions
y_start = P_f.*cosd(beta);
y_end = y_start;

%x posistions
x_end = (L_f./2).*cosd(alpha);

%print statements for wire coordinates
n=1;
while n <= elements
    if (mod(n,2)==0)
        fprintf("Start wire %1.0f: 0, %0.2f, %0.2f\n",n, y_start(n), z_start(n)-0.2);
        fprintf("Start wire %1.0f: %0.2f, %0.2f, %0.2f\n",n, x_end(n), y_end(n), z_end(n)-0.2);
        fprintf("End wire %1.0f: 0, %0.2f, %0.2f\n",n, y_start(n), z_start(n));
        fprintf("End wire %1.0f: -%0.2f, %0.2f, %0.2f\n",n, x_end(n), y_end(n), z_end(n));
    else
        fprintf("Start wire %1.0f: 0, %0.2f, %0.2f\n",n, y_start(n), z_start(n)-0.2);
        fprintf("Start wire %1.0f: -%0.2f, %0.2f, %0.2f\n",n, x_end(n), y_end(n), z_end(n)-0.2);
        fprintf("End wire %1.0f: 0, %0.2f, %0.2f\n",n, y_start(n), z_start(n));
        fprintf("End wire %1.0f: %0.2f, %0.2f, %0.2f\n",n, x_end(n), y_end(n), z_end(n));
    end
    n = n + 1;
end
```

```
clc; clear all; close all;

f_max = 35e6;
f_min = 13e6;
T = 0.93;
s = 0.05;
c = 299792458;

%find number of elements
N = 1 + ceil(log(f_max/f_min)/log(1/T));
fprintf("Number of elements --> %d\n",N);

L(1:N) = 0;
S(1:N) = 0;

L(1) = c/(2*f_min)*100/2.54/12;
%calculate lengths
for n=2:N
    L(n) = (L(1)*T^(n-1));
    S(n) = (2*s*L(n))+S(n-1);
end

fprintf("Element length:");
disp(L(1:N));
fprintf("Element spacing:");
disp(S(1:N));

%calculate frequencies of elements
f(1:N)=0;
for n=1:N
    f(n) = c/(2*(L(n)/100*2.54*12));
end
fprintf("Element frequencies:");
disp(f(1:N));
```

EZNEC Wires

Wires

Wire Create Edit Other

Coord Entry Mode Preserve Connections Show Wire Insulation Show Loss

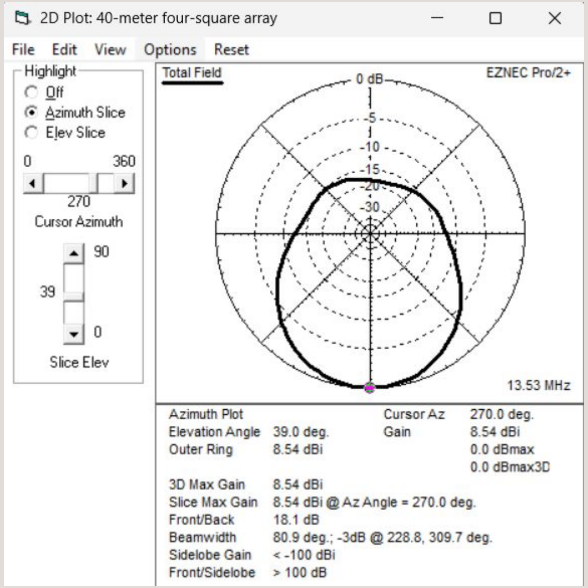
Wires

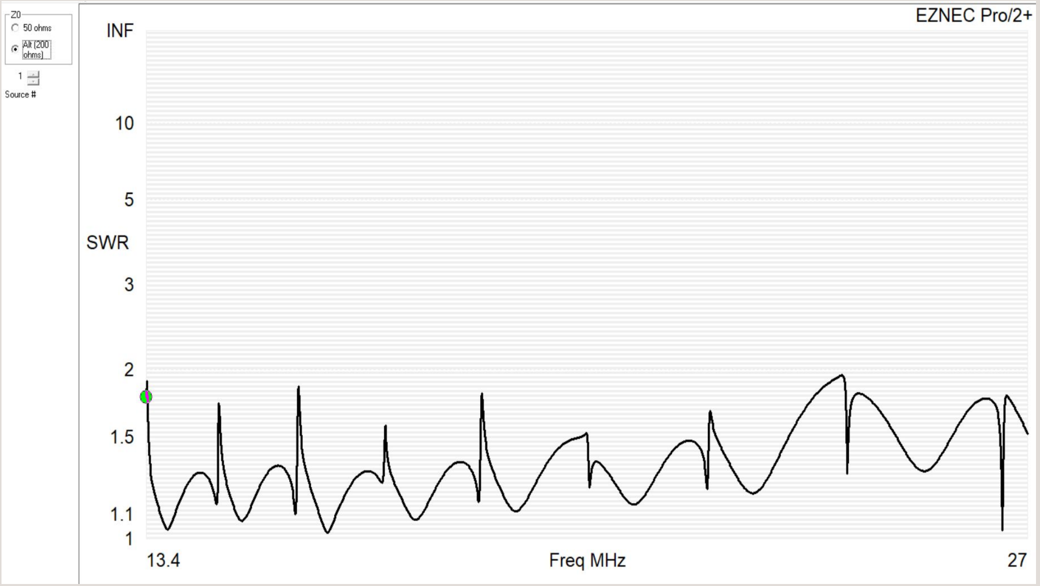
No.	End 1				End 2				Diameter	Segs	Insulation			Wire Loss		
	X (ft)	Y (ft)	Z (ft)	Conn	X (ft)	Y (ft)	Z (ft)	Conn	(in)		Diel C	Thk (in)	Loss Tan	R (ohm-m)	Perm	Type
1	0	30.13	24.8	W29E1	-17.77	30.13	18.33		0.162	6	1	0	0	1.74E-08	1	Copper
2	0	30.13	25	W42E1	17.77	30.13	18.53		0.162	6	1	0	0	1.74E-08	1	Copper
3	0	26.82	23.59	W29E2	16.53	26.82	17.58		0.162	6	1	0	0	1.74E-08	1	Copper
4	0	26.82	23.79	W42E2	-16.53	26.82	17.78		0.162	6	1	0	0	1.74E-08	1	Copper
5	0	23.75	22.47	W30E2	-15.37	23.75	16.88		0.162	6	1	0	0	1.74E-08	1	Copper
6	0	23.75	22.67	W43E2	15.37	23.75	17.08		0.162	6	1	0	0	1.74E-08	1	Copper
7	0	20.89	21.43	W31E2	14.3	20.89	16.23		0.162	6	1	0	0	1.74E-08	1	Copper
8	0	20.89	21.63	W44E2	-14.3	20.89	16.43		0.162	6	1	0	0	1.74E-08	1	Copper
9	0	18.23	20.47	W32E2	-13.3	18.23	15.63		0.162	6	1	0	0	1.74E-08	1	Copper
10	0	18.23	20.67	W45E2	13.3	18.23	15.83		0.162	6	1	0	0	1.74E-08	1	Copper
11	0	15.76	19.57	W33E2	12.37	15.76	15.06		0.162	6	1	0	0	1.74E-08	1	Copper
12	0	15.76	19.77	W46E2	-12.37	15.76	15.26		0.162	6	1	0	0	1.74E-08	1	Copper
13	0	13.46	18.73	W34E2	-11.5	13.46	14.54		0.162	6	1	0	0	1.74E-08	1	Copper
14	0	13.46	18.93	W47E2	11.5	13.46	14.74		0.162	6	1	0	0	1.74E-08	1	Copper
15	0	11.32	17.95	W35E2	10.69	11.32	14.06		0.162	6	1	0	0	1.74E-08	1	Copper

Design: Log-Periodic Dipole Antenna

EZNEC Simulations

Frequency range from 13 MHz to 26 MHz:





Design: Log-Periodic Dipole Antenna

EZNEC Simulations

Test Frequency Max Gain (dBi) and SWR:

Frequency (MHz)	Max Gain (dBi)	SWR
13.53	8.54	1.19
16.06	9.09	1.11
17.05	10.66	1.26
18.04	9.4	1.31
19.27	9.38	1.17
20.51	9.18	1.31
21.46	9.53	1.39
23.18	9.49	1.4
24.45	9.22	1.79
26.88	9.4	1.63

Test Frequencies (MHz)	
4.040	13.530
4.803	16.060
5.385	17.048
6.400	18.036
6.970	19.270
7.595	20.510
7.990	21.460
9.050	23.180
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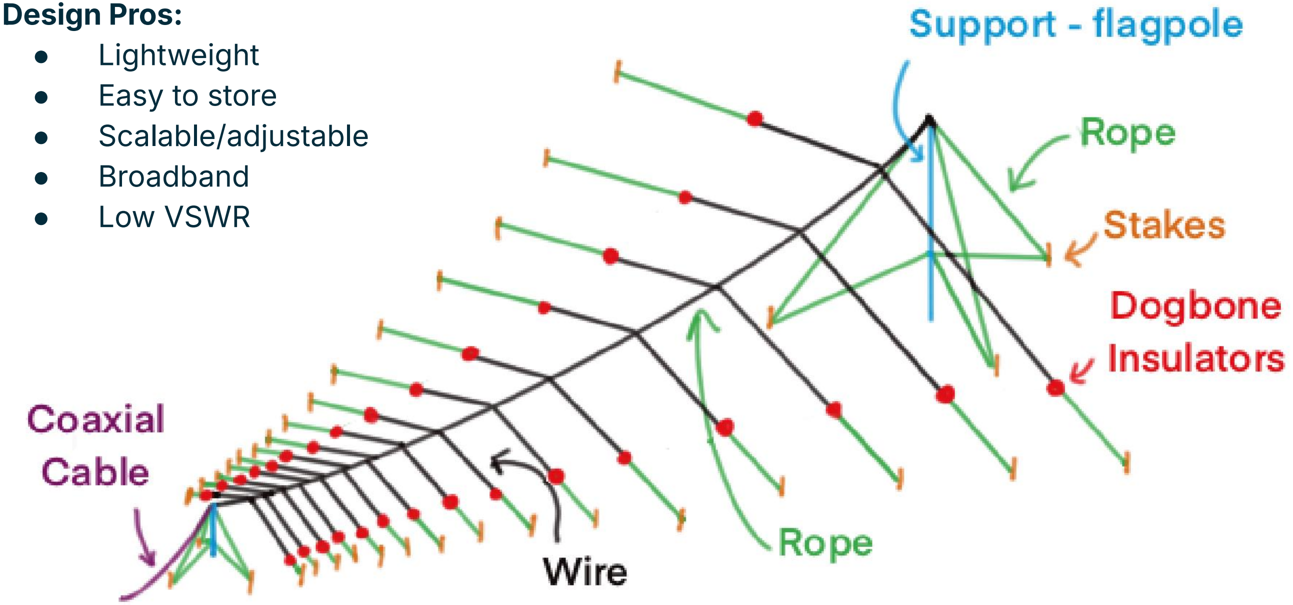
12.045	

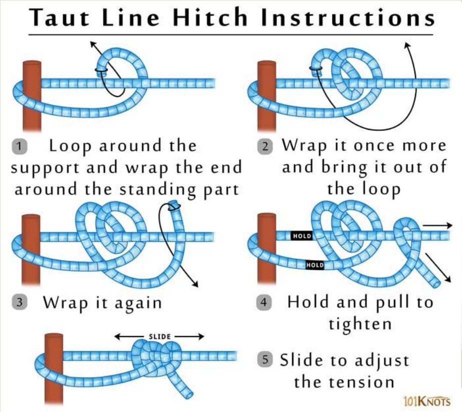
Design: Log-Periodic Dipole Antenna

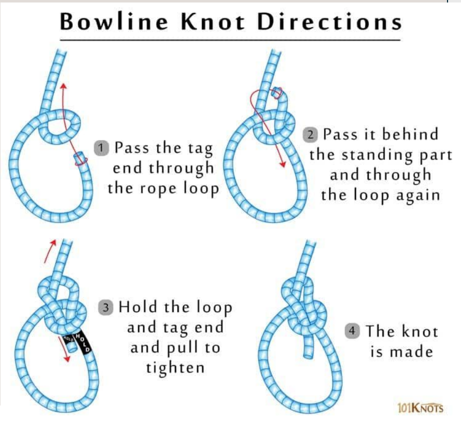
Design Pros:

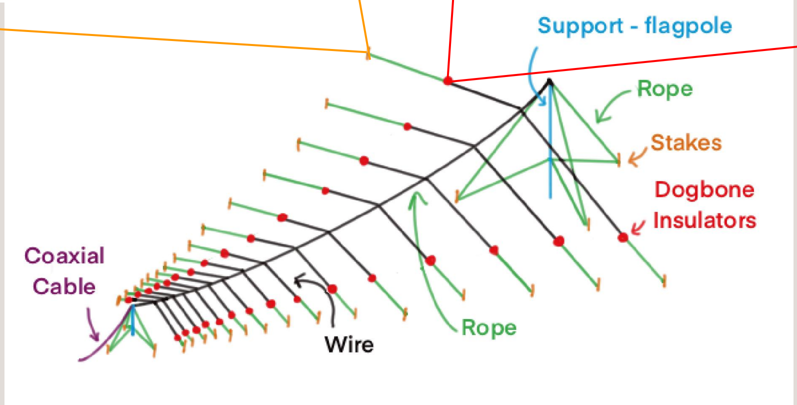
- Lightweight
- Easy to store
- Scalable/adjustable
- Broadband
- Low VSWR



Design: Log-Periodic Dipole Antenna **Knot Details**







Taut line hitch for stakes

- Can be untied after being under tension
- Adjustable

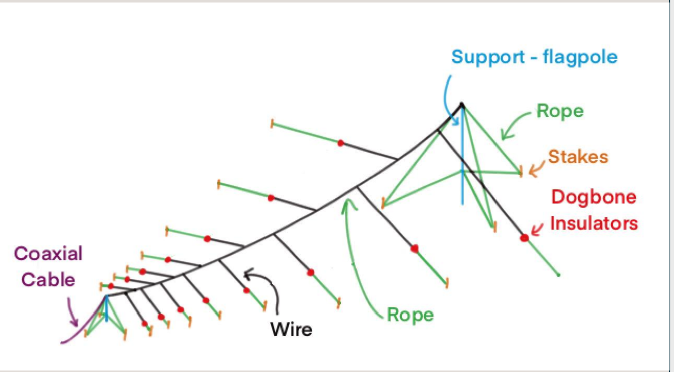
Bowline knot for dogbone insulators

- Can be untied after being under tension
- Not adjustable

Design: Log-Periodic Dipole Antenna

Materials:

- **Rope:** 500 ft. Fluorescent Yellow Braided Nylon Mason's Line
    - boom support, 23ft
    - tension cables, ~100ft
- **Wire:** 250 ft. 18-Gauge Stranded SD Bare Copper Grounding Wire
- **Stakes:** 0.31 in. x 16 in. Rebar Stakes J Hook Extra Heavy-Duty, Garden Stake Steel Stakes Tent Stakes (48-Pack)
- **Coaxial Cable:** LMR-400 coax cable, 50ft
    - Balun: LDG Electronics RBA-4:1: 100-watt 1.8–30 MHz
    - Various connectors
- **Insulators:** 30+ Dogbone Insulators (3D printed)
- **Support:** flagpole (13′ pole from Moonbounce)
- **Cable Spools:** 3D printed, as necessary



Costs - LPDA

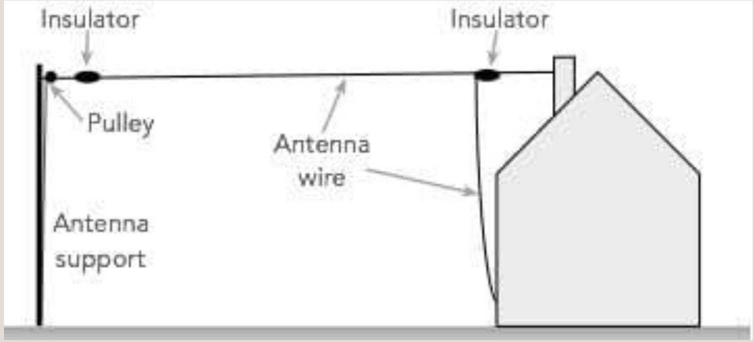
Antenna	500 ft. Nylon Rope: 250 ft. 18-Gauge Wire: Stakes (48): 50 ft coax cable: ~$1.50/ft → Fasteners/hardware and connectors: Miscellaneous:	**$10.97** (Home Depot) **$17.98** (Home Depot) **$74.34** (Home Depot) **$75** (Digikey) **~$50** **~$50**	**$278.29**
Balun	LDG Electronics RBA-4:1: 100-watt 1.8–30 MHz	**$29.99** (DX Engineering)	**$29.99**
Total			**$308.28**
Contingency			**$462.42**

Design **Backup** Option: End Fed Long (Random) Wire Antenna

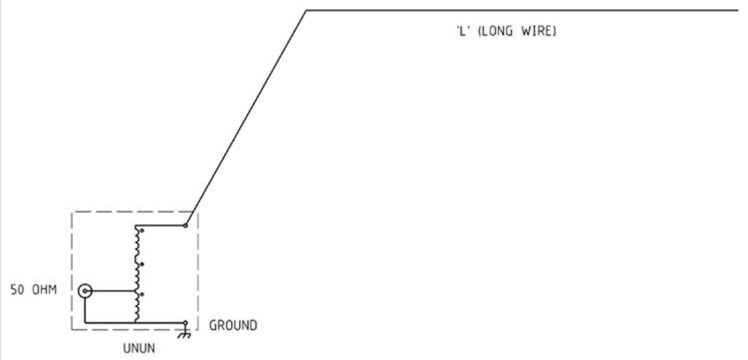
Antenna:
- End Fed Long Wire / Random Wire Antenna.
- Equally bad SWR for all required frequencies.
- Consists of a long wire.
- Requires a balun and tuner.

Balun:
- 9:1 unun; wind nine turns of a trifilar winding around a toroid core.

Tuner:
- Automatic tuner
- Source of most power scalability considerations
  - Increase C value for high power



Example of EFLW Antenna System Setup
Source: electronicsnotes



Typical 9:1 voltage unun and long wire antenna configuration
Source: VK6YSF

Costs - **Backup** Design (EFLW)

Antenna	50m 14 AWG Copper Wire (PVC Insulated)	**$138.18** (Digikey)
Balun	LDG Electronics RU-9:1 Unun RU-9-1	**$29.99** (DX Engineering)
Tuner	4.7 kΩ Resistor Compression trimmer capacitor (x6, different capacitances)	**$3.29** (Digikey) **$47.70** (CCI)
Total		**$219.16**
Contingency		**$328.74**

Testing and Experimentation

None of the required frequencies are legal for amateur radio operators to transmit on.

Anechoic chamber:

- May be difficult to detect EM field at lower frequencies.
    - **Requested EM probe from Dahlgren.**
- Antenna will likely be too large.
    - Create a dummy load with RLC circuit to test in anechoic chamber.

Other options:

- Surrogate frequencies that are legal for amateur radio general license holders.
- VNA simulation.

Navy Freq	HAM Freq
4.040	3.885
4.803	
5.385	5.373
6.400	6.2205
6.970	7.000
7.595	7.300
7.990	
9.050	
9.803	10.100
11.064	
12.045	
13.530	14.000
16.060	
17.048	
18.036	18.068
19.270	
20.510	
21.460	21.450
23.180	
24.450	24.890
26.875	28.000

Testing and Experimentation - Small LPDA Details

SAS-510-2 Log Periodic Antenna

Frequency Range: ------------------- 290 MHz - 2000 MHz
Antenna Factor: ---------------------- 14 to 32 dB/m
Average Gain: ------------------------ 6.5 dBi
Maximum Continuous Power: --- 1000 Watts
Max Radiated Field: ---------------- 200 V/m
Pattern Type: ------------------------- directional
3dB Beamwidth (E-Field): -------- 45°
3dB Beamwidth (H-Field): -------- 100°
Impedance: --------------------------- 50 Ω
VSWR: --------------------------------- 1.45:1 typ. (2.2:1 max)
Connector: ---------------------------- N-Type, female
Mounting Base: ---------------------- ¼ - 20 thread, female

Physical Dimensions:

Length: -------------------------------- 24.7 in. (62.7 cm)
Width: --------------------------------- 20.1 in. (51.1 cm)
Weight: -------------------------------- 1.4 lb.'s (0.64 kg)

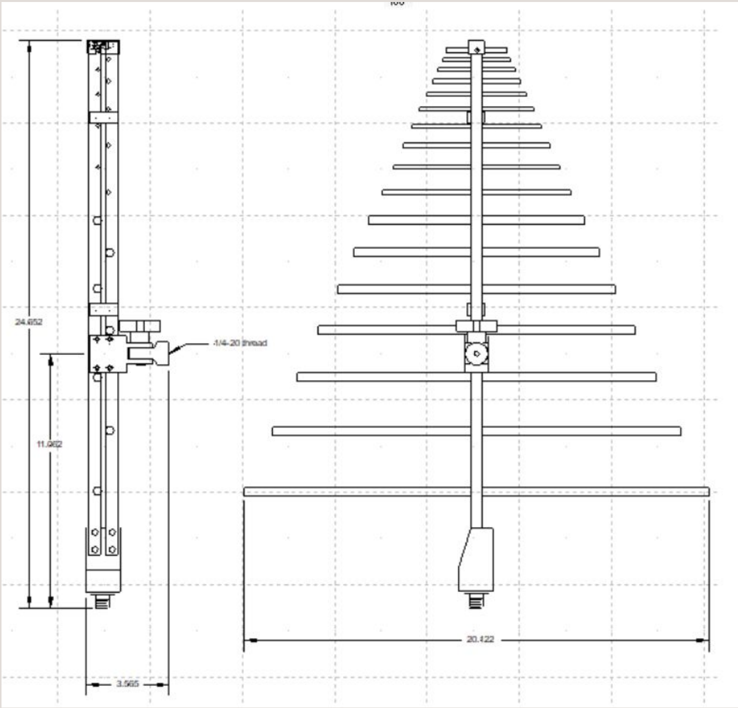
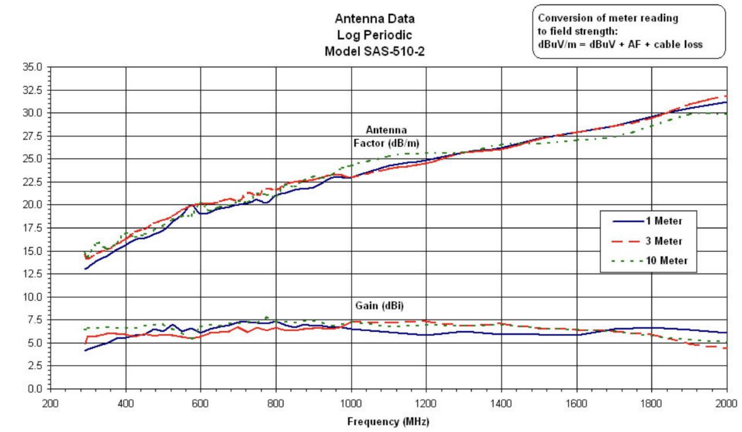
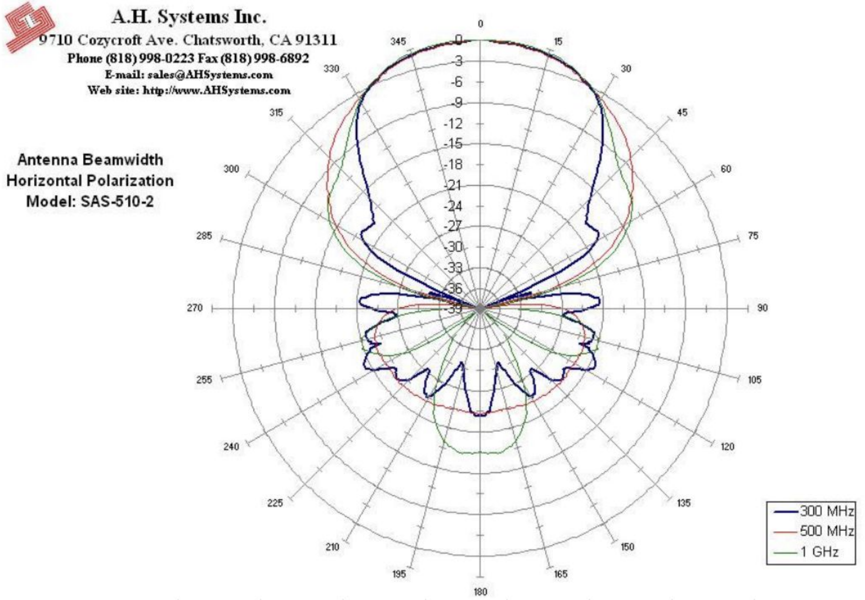
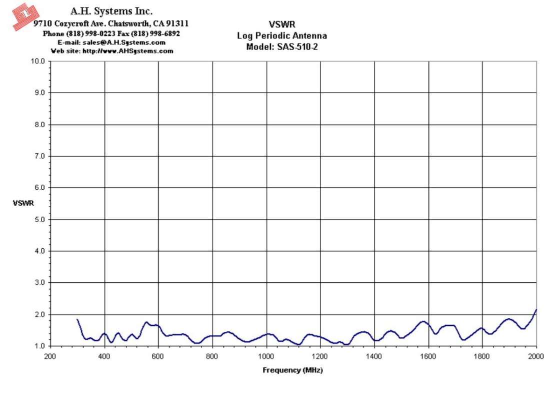


Diagram of antenna from datasheet.
A.H. Systems, Inc.

Testing and Experimentation - Small LPDA Details







▲Antenna factor and gain from datasheet.
A.H. Systems, Inc.

▲Antenna 3dB beamwidth azimuth plot from datasheet.
A.H. Systems, Inc.

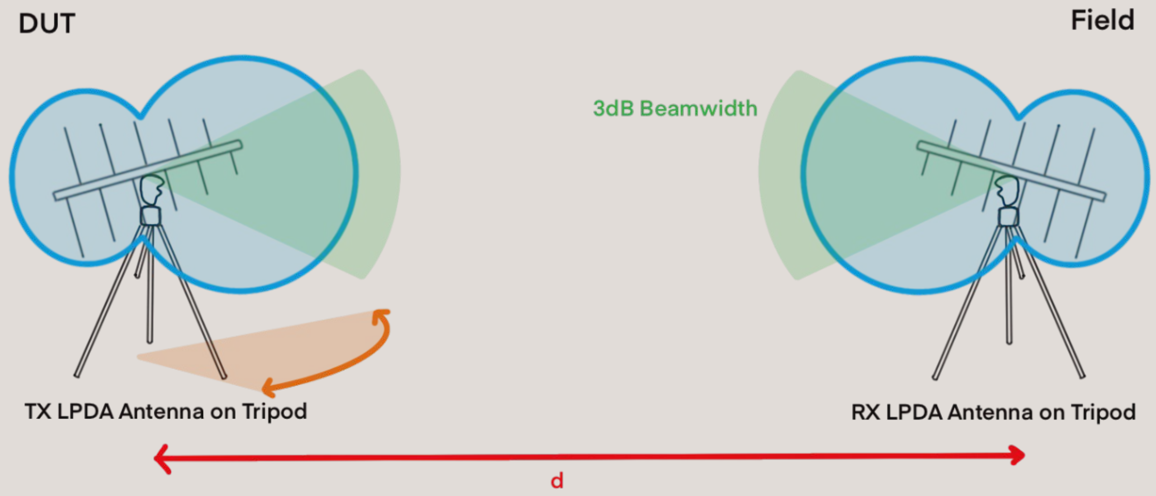
▸Image of antenna from datasheet.
A.H. Systems, Inc.

◂VSWR from datasheet.
A.H. Systems, Inc.

Testing and Experimentation - Traditional 3dB Modeling

Test to determine 3dB bandwidth of UHF LPDA antenna:

- Two matching LPDA antennas (290 MHz to 2 GHz)
- Field antenna moved further from DUT (increasing d)
- DUT rotated with pivot point based on phase with field antenna at fixed distance

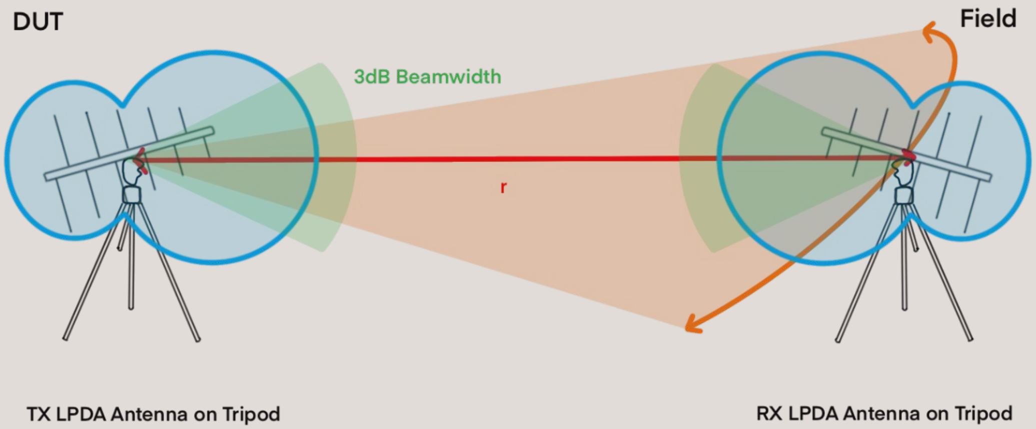


Note: These graphics are not true or accurate representations of azimuth plots, nor are the antennas oriented like this. This is a graphic purely for easy visual reference.

Testing and Experimentation - Adapted 3dB Modeling

Modified test to determine 3dB bandwidth of UHF LPDA antenna:

- Two matching LPDA antennas (290 MHz to 2 GHz)
- DUT kept fixed
- Field LPDA moved along radius r

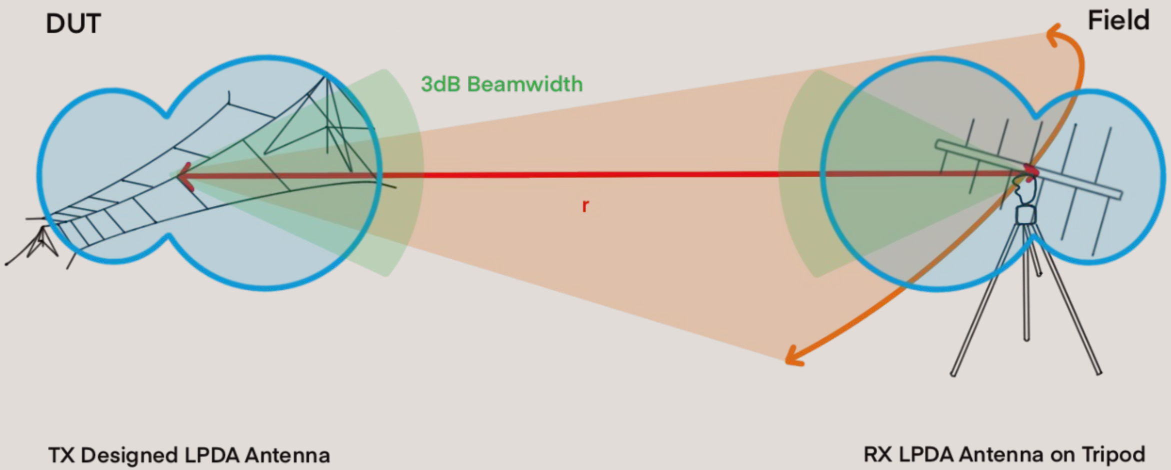


Note: These graphics are not true or accurate representations of azimuth plots, nor are the antennas oriented like this. This is a graphic purely for easy visual reference.

Testing and Experimentation - Adapted 3dB Modeling

Modified test to determine 3dB bandwidth and distance of designed HF LPDA antenna:

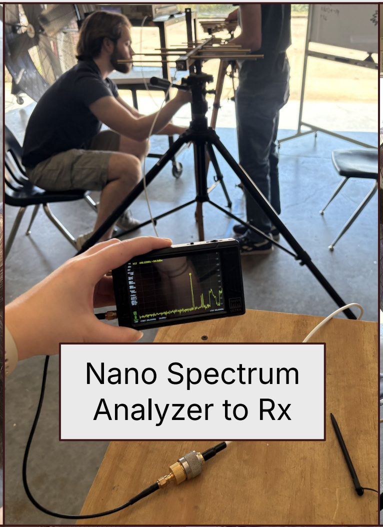
- Small antenna from previous test as field antenna
- DUT kept fixed
- Field LPDA moved along radius r



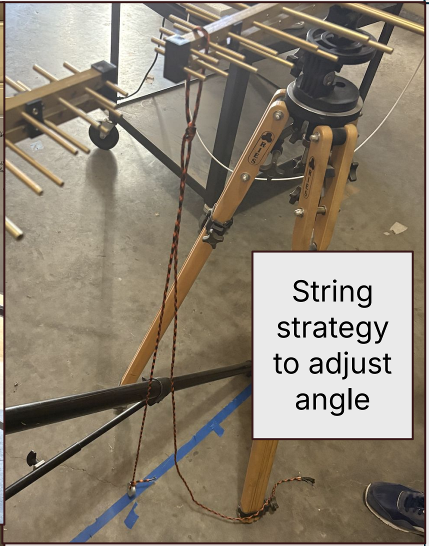
Note: These graphics are not true or accurate representations of azimuth plots, nor are the antennas oriented like this. This is a graphic purely for easy visual reference.

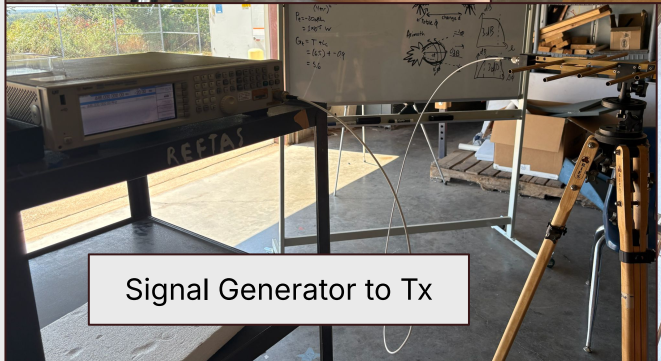
Testing and Experimentation


Adjusting angle

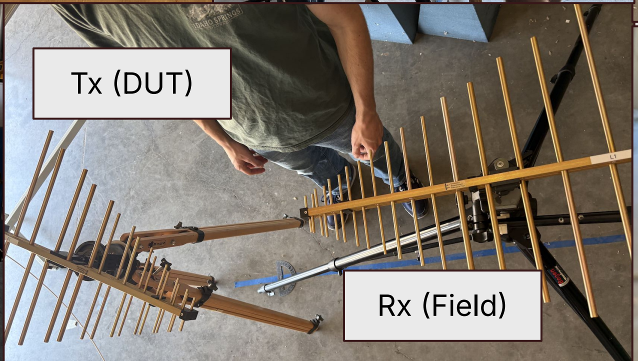

Nano Spectrum Analyzer to Rx

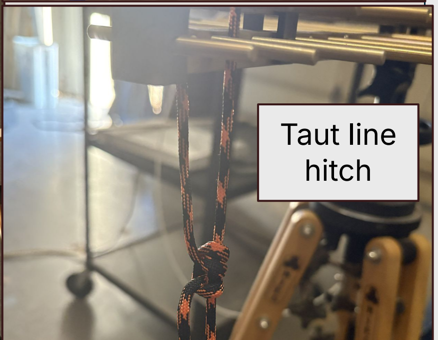

Adjusting distance between excited dipoles


String strategy to adjust angle



Signal Generator to Tx

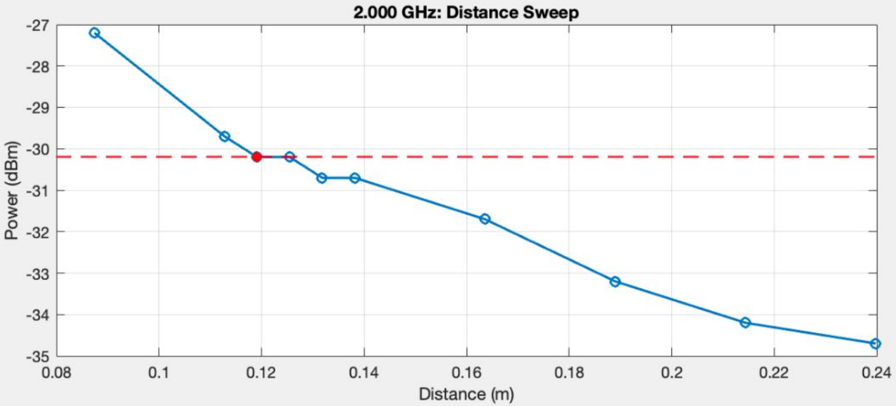

Tx (DUT)
Rx (Field)

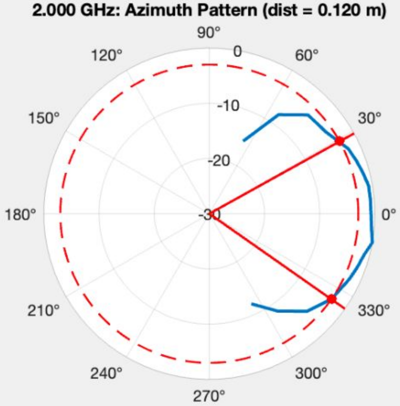

Taut line hitch

Testing and Experimentation

Results from **free space traditional testing** of smaller LPDA at Richmond Hills:

2.000GHz:



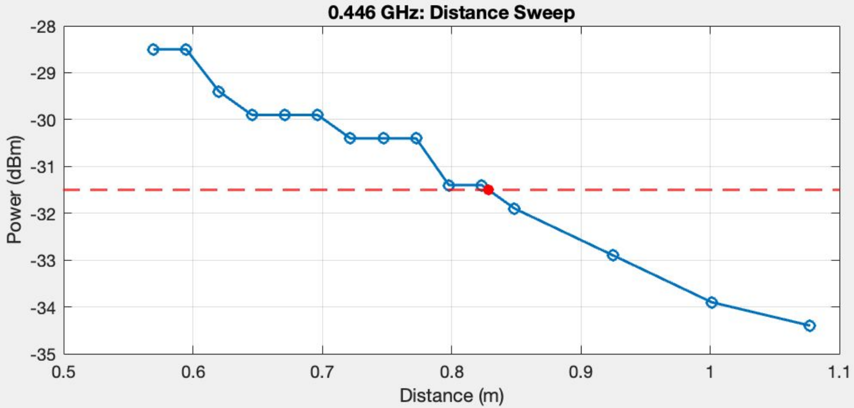


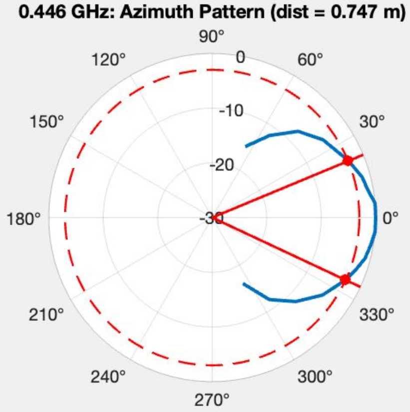

```
2.000 GHz distance sweep −3 dB crossing at distances (m): 0.11915
2.000 GHz azimuth pattern −3 dB crossing at angles (deg): −35        29
```

Testing and Experimentation

Results from **free space traditional testing** of smaller LPDA at Richmond Hills:

0.446GHz:



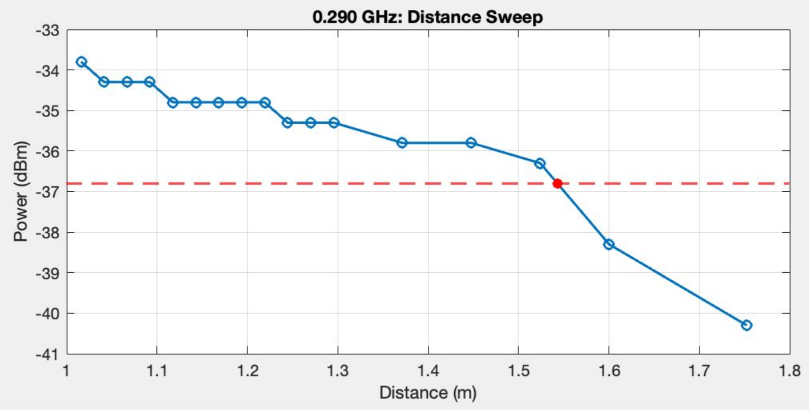


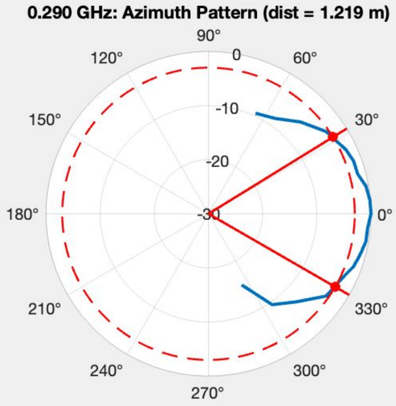

```
0.446 GHz distance sweep −3 dB crossing at distances (m): 0.82848
0.446 GHz azimuth pattern −3 dB crossing at angles (deg): −25        22.5
```

Testing and Experimentation

Results from **free space traditional testing** of smaller LPDA at Richmond Hills:

0.290GHz:






```
0.290 GHz distance sweep −3 dB crossing at distances (m): 1.5431
0.290 GHz azimuth pattern −3 dB crossing at angles (deg): −30      31.6667
```

Project Plan Overview

Phase 1

Research and Planning

The first few weeks will include project planning and research. Preliminary design will be conducted and reviewed in this phase.

Phase 2

Design and Establishing Testing Strategy

Design will be fine-tuned in this phase and testing strategy verified.

Phase 3

Procurement and Fabrication

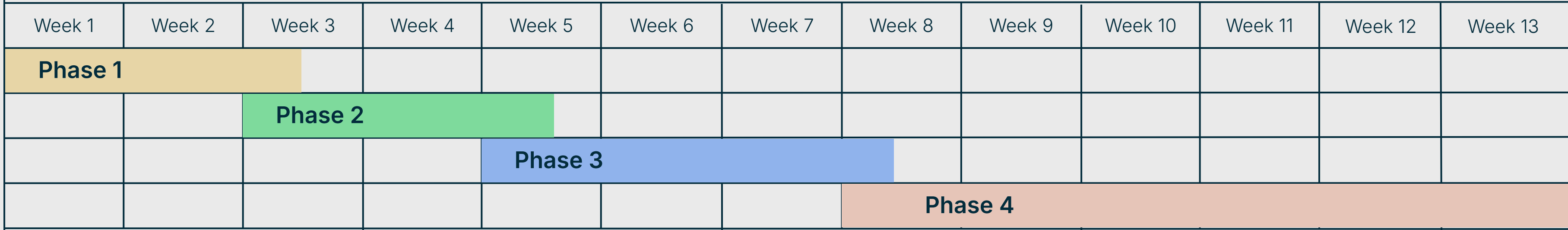
Design will be fabricated during this phase. Some VNA testing will be conducted during this phase to ensure design is decent.

Phase 4

Testing and Validation

Design will be tested and satisfactory operation verified. Plenty of time will be allowed for adjustments to the design.

Project Plan Overview



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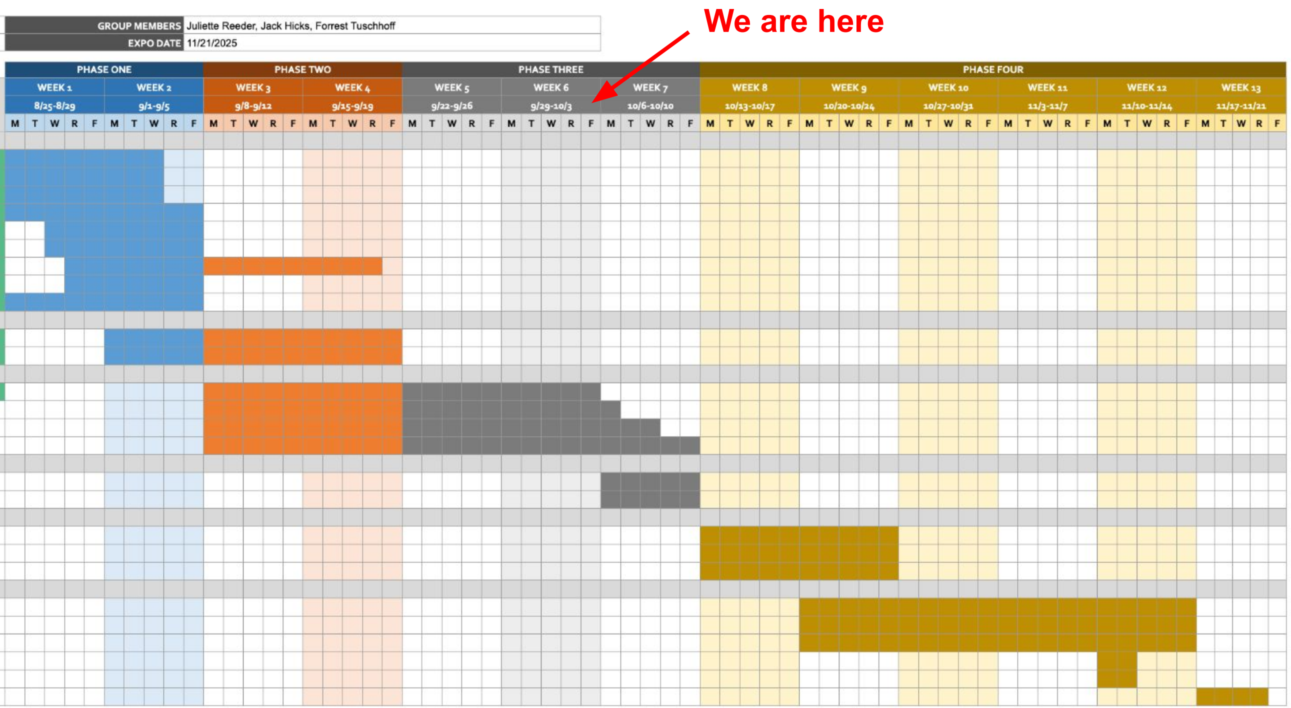
Gantt Chart

GANTT CHART

PROJECT TITLE	Horizontal HF	GROUP MEMBERS	Juliette Reeder, Jack Hicks, Forrest Tuschhoff
PROJECT MANAGER	Juliette Reeder	EXPO DATE	11/21/2025

TASK TITLE	TASK OWNER	START DATE	DUE DATE	DURATION	PCT OF TASK COMPLETE
Research and Planning					
Whip antenna design research	Jack	8/25/25	9/5/25	10	100%
Random wire antenna design research	Juliette	8/25/25	9/5/25	10	100%
Log-periodic antenna design research	Forrest	8/25/25	9/5/25	10	100%
Guidelines and considerations research	Full Team	8/25/25	9/5/25	10	100%
Testing and validation methods research	Full Team	8/25/25	9/5/25	10	100%
Risk management and hazard analysis	Full Team	8/25/25	9/5/25	10	100%
Amateur radio license	Juliette	8/25/25	9/18/25	23	100%
Costs plan	Full Team	8/25/25	9/5/25	10	100%
Project planning	Full Team	8/25/25	9/5/25	10	100%
Design					
Antenna design details	Full Team	9/1/25	9/19/25	18	100%
Balun design details	Full Team	9/1/25	9/19/25	18	100%
Testing Strategy Validation					
Free space traditional test	Full Team	9/1/25	10/10/25	39	100%
Anechoic chamber traditional test	Full Team	9/1/25	10/10/25	39	0%
Free space modified test	Full Team	9/1/25	10/10/25	39	0%
Anechoic chamber modified test	Full Team	9/1/25	10/10/25	39	0%
Procurement					
BOM	Jack	9/8/25	9/19/25	11	0%
Parts ordering	Jack	9/10/25	9/22/25	12	0%
Fabrication					
Antenna fabrication	Full Team	9/22/25	10/3/25	11	0%
Balun fabrication	Full Team	9/22/25	10/3/25	11	0%
VNA simulation	Full Team	9/30/25	10/17/25	17	0%
Testing and Validation					
VNA simulation	Full Team	10/13/25	11/14/25	31	0%
Anechoic chamber measurements	Full Team	10/13/25	11/14/25	31	0%
Surrogate frequency testing	Juliette	10/13/25	11/14/25	31	0%
Video filming	Full Team	11/10/25	11/11/25	1	0%
Video editing	Full Team	11/10/25	11/11/25	1	0%
Exposition prep	Full Team	11/17/25	11/20/25	3	0%



Gantt Chart

GANTT CHART

PROJECT TITLE	Horizontal HF	GROUP MEMBERS	Juliette Reeder, Jack Hicks, Forrest Tuschhoff
PROJECT MANAGER	Juliette Reeder	EXPO DATE	11/21/2025

PHASE ONE: WEEK 1 (8/25-8/29), WEEK 2 (9/1-9/5) · PHASE TWO: WEEK 3 (9/8-9/12), WEEK 4 (9/15-9/19) · PHASE THREE: WEEK 5 (9/22-9/26), WEEK 6 (9/29-10/3), WEEK 7 (10/6-10/10) · PHASE FOUR: WEEK 8 (10/13-10/17), WEEK 9 (10/20-10/24), WEEK 10 (10/27-10/31), WEEK 11 (11/3-11/7), WEEK 12 (11/10-11/14), WEEK 13 (11/17-11/21) — each week M T W R F

TASK TITLE	TASK OWNER	START DATE	DUE DATE	DURATION	PCT OF TASK COMPLETE
Research and Planning					
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Project planning	Full Team	8/25/25	9/5/25	10	100%
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Antenna design details	Full Team	9/1/25	9/19/25	18	100%
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Testing Strategy Validation					
Free space traditional test	Full Team	9/1/25	10/10/25	39	100%
Anechoic chamber traditional test	Full Team	9/1/25	10/10/25	39	0%
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BOM	Jack	9/8/25	9/19/25	11	0%
Parts ordering	Jack	9/10/25	9/22/25	12	0%
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Antenna fabrication	Full Team	9/22/25	10/3/25	11	0%
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VNA simulation	Full Team	9/30/25	10/17/25	17	0%
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Video filming	Full Team	11/10/25	11/11/25	1	0%
Video editing	Full Team	11/10/25	11/11/25	1	0%
Exposition prep	Full Team	11/17/25	11/20/25	3	0%

Risk Management

Risk Matrix		Severity		
		Minor	Moderate	Severe
Likelihood	Likely	Scheduling Conflicts	Test Equipment Delay	Scope Underestimate
	Unlikely	Faulty Wiring	Parts Delay	Test Equipment Malfunction
	Rare	Accidental Transmission	Over Budget	Injury

Risk Mitigation:

- Ask Dahlgren about obtaining test equipment early
- Check equipment before testing
- Order parts earlier than needed
- Have faculty review designs multiple times to ensure no components are missing

Work Breakdown Overview

Juliette Reeder	Jack Hicks	Forrest Tuschhoff
• Title • Table of Contents • Introduction • Project Description • Constraints • Testing and Experimentation • Data Analysis • Costs • Project Plan	• Introduction • Considerations • Engineering Codes, Guidelines, and Standards • Design • EZNEC Simulation • Project Plan	• Introduction • Considerations • Background Information • Design • Costs • Project Plan • Data Analysis • Risk Management

Citations

General Links:

1. https://www.icnirp.org/cms/upload/publications/ICNIRPrfgdl2020.pdf
2. https://www.ecfr.gov/current/title-47/chapter-I/subchapter-D/part-97
3. https://www.dau.edu/sites/default/files/Migrated/CopDocuments/MIL-STD-464D.pdf
4. https://www.arrl.org/frequency-allocations
5. https://standards.ieee.org/ieee/C95.1/4940/

End Fed Long (Random) Wire Antenna:

1. https://webclass.org/k5ijb/antennas/End-fed-multiband-antenna-BalunDesigns.htm
2. https://www.electronics-notes.com/articles/antennas-propagation/end-fed-wire-antenna/end-fed-long-wire-antenna-basics.php
3. https://www.hamuniverse.com/randomwireantennalengths.html
4. https://www.kb6nu.com/playing-end-fed-wire-antennas-91-ununs/
5. https://udel.edu/~mm/ham/randomWire/
6. https://vk6ysf.com/unun_9-1.htm
7. https://www.aa5tb.com/efha.html

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Log-Periodic Dipole Antenna:

1. http://montoya.sdsmt.edu/ee483_583/notes/LPDA2.pdf
2. chatgpt.com - Matlab code and tables generation
3. https://www.tennadyne.com/lpda-systems/
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5. https://issuu.com/martin_lema/docs/antenas_yagi_libres_de_matematica_jul_22_eng
6. https://www.ahsystems.com/catalog/SAS-510-2.php - Small 0.29-2GHz LPDA Datasheet

Insulators:

1. https://www.thingiverse.com/thing:4077607

Knots:

1. https://www.101knots.com/taut-line-hitch.html
2. https://www.101knots.com/bowline-knot.html

People Consulted:

1. Dr. Chuck Bunting
2. Dr. Pavithrakrishnan Radhakrishnan
3. Marshall Sowell

Thank you

Questions?

If you have any further questions, contact:
juliette.reeder@okstate.edu

Appendix:

2.00 GHz	-20 dBm transmit	d=0.12 m		0.446 GHz	-20 dBm transmit	d = 0.7472 m		0.29 GHz	-20 dBm transmit	d=1.2192m		
Distance (m)	**Power (dBm)**	**Angle (deg)**	**Power (dBm)**	**Distance (m)**	**Power (dBm)**	**Angle (deg)**	**Power (dBm)**	**Distance (m)**	**Power (dBm)**	**Angle (deg)**	**Power (dBm)**	**Distance between antennas (in)**
0.0874	-27.2	-65	-41.8	0.5694	-28.5	-65	-47.1	1.016	-33.8	-65	-49.9	1
0.1128	-29.7	-55	-38.3	0.5948	-28.5	-55	-42.1	1.0414	-34.3	-55	-43.9	1.5
0.11915	-30.2	-45	-34.8	0.6202	-29.4	-45	-38.7	1.0668	-34.3	-45	-41.4	2
0.1255	-30.2	-35	-32.8	0.6456	-29.9	-35	-35.7	1.0922	-34.3	-35	-37.9	2.5
0.13185	-30.7	-25	-31.8	0.671	-29.9	-25	-33.4	1.1176	-34.8	-25	-36.9	3
0.1382	-30.7	-20	-31.3	0.6964	-29.9	-20	-32.4	1.143	-34.8	-20	-35.9	3.5
0.1636	-31.7	-15	-30.8	0.7218	-30.4	-15	-31.4	1.1684	-34.8	-15	-35.4	4
0.189	-33.2	-10	-29.8	0.7472	-30.4	-10	-30.9	1.1938	-34.8	-10	-34.9	4.5
0.2144	-34.2	-5	-30.3	0.7726	-30.4	-5	-30.4	1.2192	-34.8	-5	-34.9	5
0.2398	-34.7	0	-30.5	0.798	-31.4	0	-30.4	1.2446	-35.3	0	-34.4	5.5
		5	-30.5	0.8234	-31.4	5	-30.4	1.27	-35.3	5	-34.5	6
		10	-30.5	0.8488	-31.9	10	-31.4	1.2954	-35.3	10	-34.9	6.5
		15	-31	0.925	-32.9	15	-31.9	1.3716	-35.8	15	-35.9	7
		20	-31.5	1.0012	-33.9	20	-32.9	1.4478	-35.8	20	-35.9	7.5
		25	-32	1.0774	-34.4	25	-33.9	1.524	-36.3	25	-36.4	8
		35	-34			35	-35.6	1.6002	-38.3	35	-37.9	8.5
		45	-34.5			45	-38.1	1.7526	-40.3	45	-40.4	9
		55	-37.9			55	-42.1			55	-42.9	9.5
		65	-45.3			65	-46.1			65	-43.9	10