Shortened HF Meander Dipole Antenna: A Modern Implementation of a Classic Design

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Abstract

This article presents a modern implementation of a shortened HF dipole antenna using meander loading, based on designs dating back to 1958. We combine historical research, MATLAB-based electromagnetic modeling, and practical construction to validate this space-efficient antenna design. Our prototype demonstrates comparable performance to a full-size vertical on 15 meters while occupying significantly less space, making it suitable for restricted environments such as apartments and temporary installations.

Introduction

Amateur radio operators frequently face space constraints that make full-size HF antennas impractical. Whether due to HOA restrictions, apartment living, or portable operations, the need for compact yet effective antennas remains a constant. This project revisits a classic solution, the meander dipole, which achieves physical shortening through linear loading rather than lumped elements.

The Antenna Design Triangle

The Iron Triangle of Project Management is a framework of three interconnected constraints. Scope, time, and cost. Management theory tells us that these constraints must be balanced to ensure project success and quality. Any change to one constraint, such as adding more project features (scope), will necessitate a trade-off in one or both of the others, requiring more time or a higher budget. Project managers use this model to understand and manage these trade-offs, which ideally allows everyone to make informed decisions to keep projects on track.

The fundamental challenge in antenna miniaturization is what we call the "Antenna Triangle". We have size, efficiency, and bandwidth. If we pick any one or two, then it's highly likely we have to compromise on the remaining constraints. Size is the physical dimension of the antenna. Efficiency is radiation performance. Bandwidth is the frequency range of the antenna. Bandwidth and gain are related, with gain being the directivity and received signal strength.

As Roger F. Harrington stated in his 1960 NBS paper: *"The maximum gain obtainable from a broad-band antenna is approximately equal to that of the uniformly illuminated aperture. If higher gain is desired, the antenna must necessarily be a narrow-band device. In fact, the input impedance becomes frequency sensitive so rapidly that, for large antennas, no significant increase in gain over that of the uniformly illuminated aperture is possible."*

This fundamental trade-off governs all antenna design. When we reduce size, we must accept compromises in efficiency, gain, and bandwidth. Understanding and managing these trade-offs is essential for practical shortened antenna design. Improving one parameter typically degrades another. Our goal with the meander dipole is to optimize this balance for space-constrained HF operation. We want the benefits of the smaller size to not cost us too much in terms of performance.

Historical Context

The meander dipole concept was documented as early as 1958 in the Radio Society of Great Britain newsletter by M.J. Heavyside, G2QM. Heavyside's key insight was to manipulate radiation resistance distribution along a dipole by folding the low-radiation-resistance end sections back upon themselves.

More recently, Monty Northrup, N5ES, designed and built a portable version specifically for hotel room operation. His practical implementation provided the foundation for our modern reproduction and analysis.

Theoretical Foundation

Radiation Resistance Distribution

A conventional half-wave dipole exhibits non-uniform current distribution, with maximum current at the center and zero current at the ends. This distribution directly affects radiation resistance, which quantifies how effectively different sections of the antenna convert RF energy into electromagnetic radiation.

The 1958 Heavyside paper illustrated this concept using a $\sin^2(x)$ curve to represent radiated power as a function of electrical distance from the antenna ends (Fig. 1 in the RSGB Bulletin article). The area under this curve represents radiation resistance for each section. The key insight made in this article is that the center 57 feet of a 256-foot aerial contributes nearly as much radiation as the 120 feet measured from the end. Each section uses the same length of wire, but one provides significantly more radiation resistance than the other.

Linear Loading vs. Lumped Loading

Traditional antenna shortening often employs lumped elements. We often see loading coils or capacitive hats in practical antenna designs. These approaches work but they do introduce losses and they narrow the bandwidth. Meander loading offers an alternative: we physically fold the low-efficiency end sections back upon themselves in a non-inductive winding pattern. These folds are not coils, which would be inductive.

As described by M0PZT: *"The method of 'linear-loading' is a fancy way of saying 'fold the wire back on itself.' Linear loading reduces the overall length of an antenna without using loading coils."*

Why Does Folding Work? A D&D Analogy

Think of your antenna as a party of adventurers, and radiation as the damage they deal to the Ice Dragon they are confronting in a dungeon cavern.

A full-size dipole is like having your entire party spread out in a line. The fighters in the middle (high current region) are dealing massive damage with their Radiant Swords. They are rolling natural 20s on the game dice consistently. But your rogues, henchmen, porters, and hirelings at the ends of the line, which is like the low current region in a dipole? They're barely participating, rolling 1s and 2s.

When you meander the antenna, you're essentially telling everyone at the ends of the line "Look, you're not contributing much to the fight anyway. So instead of taking up valuable dungeon floor space, fold back on yourselves and stay out of the way, But, keep your weapons ready because you're still technically in the party and we couldn't get down here to fight the Ice Dragon without you doing all of the chores."

The end sections contribute so little to radiation resistance (they're in the low-current region) that folding them back on themselves doesn't hurt performance much. Meanwhile, your center "fighters" maintain their high damage output because they're still fully extended along the main battle line.

The Football/Soccer Analogy

Imagine a soccer pitch or football field where only the center third of the players contribute towards scoring points. Players in that zone rack up goals, while players near the sidelines barely contribute.

A full-size dipole uses the entire field or pitch, but most players near the sidelines aren't helping your score. The meander approach says: "Keep the center third at full width (that's where the action is), but fold the sideline thirds back behind the main playing area. Your sideline players are still technically on the field and can contribute a little, but now the whole setup fits in a much smaller stadium."

You're sacrificing some of the sideline players' minimal contribution in exchange for fitting everything in a space-constrained venue. The center third, where most of the scoring happens, remains fully functional and continues scoring goals.

The Technical Translation

Both analogies capture the same principle: In a dipole, current distribution follows a sin(x) curve with maximum at the center and zero at the ends. The radiation resistance contribution follows $\sin^2(x)$. By folding the low-contribution ends (where $\sin^2(x)$ is small), we reduce overall physical footprint, maintain the high-efficiency center section at full extension, keep all the wire electrically connected (no lossy loading coils), and accept a small efficiency penalty from the folded sections.

Unlike our heroes in the dungeon, the meander isn't fantasy magic. It’s strategic resource allocation based on understanding where your antenna's "damage" actually comes from.

Folding reduces overall antenna length, maintains wire continuity (no lossy components), preserves much of the radiation resistance of an unfolded dipole, and creates what Heavyside termed "non-inductive end loading”.

The folded sections are not coils in the traditional sense. In a coil, wires adjacent to each other are all “running” in the same direction, like water spiraling down a drain. When we look at two wires in a meander next to each other, they have reversed direction. A meander is like a folded line at an amusement park ride, or a line at airport security. Adjacent lines are going in the opposite direction, not in the same direction. A coil is like following a bunch of people down a spiral staircase. If you look above and below you, then you would see people traveling in the same direction that you are. These two different structures. When these structures are implemented in a circuit, then they result in two different things.

Meanders provide linear loading by effectively relocating current distribution rather than adding inductive reactance. As documented by Warnagiris and Minardo (1998), the radiation resistance of a 15-foot wire at 1.8 MHz can be increased by a factor of 14 using this technique, while a 66-foot wire sees a 4x improvement.

Meander Antenna Size Reduction Theory

The Size Reduction Factor β

Warnagiris and Minardo's 1998 IEEE work established quantitative relationships for meander antenna performance. They defined the size reduction factor Beta as:

Beta = phys/Lref

where phys is the physical length of the meandered antenna and Lref is the length of a conventional monopole with the same resonant frequency.

The size reduction factor depends primarily on the number of meander elements (N) per wavelength. For line-spacing to line-diameter ratios >20, Beta remains relatively constant. A meander antenna with Beta = 0.6 uses 60% of the physical space while maintaining comparable radiation resistance. For Beta < 0.5 (greater than 50% size reduction), careful attention to element spacing becomes critical.

Their nomographs (Figs. 8-9 in the IEEE paper) show that with 3 meander elements. Beta ≈ 0.5. With 6 elements: Beta ≈ 0.3. With 10+ elements: Beta ≈ 0.15.

However, diminishing returns set in beyond 6-8 meanders. Each additional fold contributes less frequency reduction than the previous one, as demonstrated by Olaode et al. (2012) in their systematic study of 0 to 8 meanders.

Experimental Process Overview

Our work at ORI followed a systematic three-phase approach. Phase 1 was Simulation. Initial simulations using MMANA software by the Washington DC team showed promising results, validating the basic concept. This led to development of a comprehensive MATLAB model for detailed analysis and automated design. Phase 2 was Construction. An antenna was constructed using dimensions from N5ES's documentation, applying the concepts established in earlier papers. We built both the copper-tape portable version and a PVC-based outdoor prototype. Phase 3 was Testing. The prototype antenna was tested and performance matched simulation predictions. Field testing confirmed multi-band operation with appropriate tuning.

All materials are publicly available in our GitHub repository organized into three main sections.

- MATLAB_model_and_results/ - Complete simulation code and field testing data
- Washington_DC_efforts/ - MMANA software simulations and photographs from the East Coast team (lead by Samudra Haque)
- papers/ - Technical articles and historical references

Repository: https://github.com/OpenResearchInstitute/dumbbell/

We first replicated the theoretical model from the 1958 paper using a 256-foot aerial. This established baseline understanding of radiation resistance distribution and verified our interpretation of the original work.

Rather than using fixed dimensions, we parameterized the entire design starting from frequency. N5ES's explanation guided our approach:

"There is a method by which the portion acting as an aerial can be made to act as the center portion. This method causes the current, after reflection at the insulator, to build up to maximum in the aerial by putting the required length of wire between the aerial proper and the insulator. This special length of wire must be wound non-inductively and spaced at least 1 inch and of a length equal to a quarter wavelength for the band in use, minus one half the length of the aerial top."

N5ES's 12-foot 7-band "doublet" design uses:

- 11.5 feet in each loading coil (meander section)
- 5 feet of radiator on each side
- Total: 33 feet (11.5 + 11.5 + 5 + 5)

We started with frequency and calculated dimensions:

```
frequency = 14.2e6;  % Target 20m band
c = 299792458;       % Speed of light
wavelength = c/frequency;
radiatorLength = wavelength/6;  % One-third of half-wave dipole
```

This calculation yields the length of wire we need to fold into each meander section. For 14.2 MHz, radiatorLength ≈ 3.5 meters (11.5 feet) per side. This matched N5ES's design.

We consistently saw "at least 1 inch gap between meanders” mentioned in papers without explanation. We parameterized this as NotchLength = 0.0254 m (exactly 1 inch) and made it a variable for future experimentation. This spacing requirement remains on our list for systematic testing.

For the outdoor "birdcage" configuration, we converted the flat rectangular meander into a cylindrical form by calculating spacer disc diameter based on number of folds, accounting for chord vs. arc length (wire follows chord, not circumference), and generating spacer geometry for 3D printing in OpenSCAD.

Using MATLAB's Antenna Toolbox, we created a meander dipole object with calculated dimensions, converted to wire-stack representation for proper feed point modeling, simulated impedance, radiation pattern, efficiency, and current distribution, added coaxial transmission line model as load, and generated VSWR curves and Smith charts.

Mathematical Models for Resonant Frequency

Two complementary methods exist for calculating the resonant frequency of a meander line dipole antenna. We get useful wisdom from these calculations. First, we go through the two methods. Then, we explain the repercussions.

Method 1: T. Endo's Transmission Line Model (2000)

Endo decomposed the meander dipole into short-ended transmission line sections, modeling each with lumped elements. The inductance of each meander section LM is:

$$LM = (\mu_0 w/\pi) \times \log(l/r) \times \{1 + (1/3)(\beta w)^2\}$$

where:

- w = vertical segment height
- l = horizontal segment spacing
- r = wire radius
- $\beta = 2\pi/\lambda$ (wave number)

For M meander sections, total inductance becomes $LT = LS + M \times LM$, where LS is the self-inductance of the straight radiating portions.

Method 2: Mutual Inductance Model (Rahman & Sarkar, 2017)

This alternative approach calculates inductance based on mutual coupling between parallel wires.

For the straight portions: $LS = (\mu_0 H/2\pi) \times (\log(2H/r) - 1)$
For each meander fold (two parallel wires with opposite current): $LM = 2L_1 - 2m$
where m is the mutual inductance: $m = (\mu_0 w/2\pi) \times (\log(2w/l) - 1)$
Simplifying: $LM = (\mu_0/\pi) \times w \times \log(l/r)$

Comparison of Methods

Rahman and Sarkar demonstrated that their mutual inductance method provides approximately 90% agreement with electromagnetic simulation, compared to 75-80% for Endo's method. For an 8-meander antenna we see that:

- Endo method: $f_0 = 1.16$ GHz
- Mutual inductance method: $f_0 = 1.01$ GHz

- FEKO simulation: $f_0 = 1.05$ GHz

The improvement comes from properly accounting for current distribution in the parallel wire sections.

Capacitance Calculation

Once inductance L is known, the overall antenna capacitance C can be calculated from:

$C = 1/(4\pi^2 f_0^2 L)$

The capacitance per unit length between parallel wires depends on spacing:

$C_1 = \pi\varepsilon/(\cosh^{-1}(l/2r))$

This shows that both L and C are functions of the antenna's geometry. They are not constants!

In many simplified antenna models (especially textbook examples), inductance and capacitance are treated as fixed values that you look up in a table or calculate once. You might see something like "a dipole has a capacitance of X picofarads" as if that's a universal constant. But that's actually wrong. For some designs, they're good to use as approximations. But, L and C actually change based on multiple factors.

- Wire radius (thicker wire = different L and C)
- Spacing between parallel sections (closer spacing = higher C, lower L)
- Number of meanders (more folds = more total L)
- Physical length vs. electrical length

Why does this matter for a meander dipole?

Design iteration becomes possible. Because we know L and C depend on geometry, we can tweak the geometry to hit a target frequency. Do we want to lower resonant frequency? Increase wire spacing or add more meanders.

The "1-inch rule" now might make sense. That empirically-derived spacing isn't arbitrary. The spacing is balancing the mutual inductance and capacitance between parallel wires. Change the spacing, we change L and C, and then we change the resonance.

MATLAB automation can now work better. Our quadratic equation solution works because L and C are functions of geometry. We can calculate how many humps you need for a given frequency target with confidence, not just because we ventured into the math and gave it a try.

If we treated L and C as constants (like older models might), then we might think "This antenna has inductance X, so it resonates at frequency Y, end of story."

But because L and C are geometry-dependent, we can say "I can adjust the spacing, meander count, and wire radius to tune this antenna to any frequency I want, while keeping the same overall physical size."

This geometry-dependence is critical for this antenna design. Unlike lumped-element circuits where we might select a 10μH inductor and a 100pF capacitor from a parts bin, antenna inductance and capacitance emerge from the physical structure itself. This means we can achieve different resonant frequencies by adjusting geometry rather than adding components. This is the foundation of the meander approach.

ORI MATLAB Implementation

Validating the 1958 Heavyside Theory

Our first step was to recreate Heavyside's fundamental insight from the 1958 paper. We plotted the $\sin^2(\theta)$ radiation resistance distribution over a 256-foot aerial:

```
aerial_length = 256;
x = 0:pi/18:pi;
y = sin(x).*sin(x);
```

This visualization clearly shows why the meander approach works: the cyan-colored end sections (A-B and E-F) contribute far less radiation resistance than the green center section (C-D), despite using equal lengths of wire. By folding the end sections into non-inductive meanders, we effectively make them "act like the center portion."

Parameterized Design Calculations

Rather than using fixed dimensions, we parameterized the entire design starting from frequency.

```
frequency = 14.2e6;  % Target 20m band
c = 299792458;       % Speed of light
wavelength = c/frequency;
radiatorLength = wavelength/6;  % One-third of half-wave dipole
```

For a 14.2 MHz design, this yields approximately 7 meters per radiating section, leaving 14 meters of wire to fold into the meander sections.

Solving for Meander Geometry

The key innovation in our approach was automatically calculating the optimal meander geometry. Given the following:

- Total wire length to fold: radiatorLength
- Desired spacing: NotchLength = 1 inch (0.0254 m)
- Goal: Square or near-square meander sections

We need to determine how many "humps" (folds) to use. Each hump consists of:

- 2 × NotchWidth (vertical travel up and down)
- 2 × NotchLength (horizontal travel)

Setting NotchWidth = NotchRun = numHumps × 2 × NotchLength (for a square), we get:

radiatorLength = 4 × NotchLength × numHumps² + 2 × NotchLength × numHumps

This is a quadratic equation we solve for numHumps:

```
A = 4*NotchLength;
B = 2*NotchLength;
C = -radiatorLength;
numHumps = ((-B) + sqrt(B^2 - 4*A*C))/(2*A);
integerNumHumps = floor(numHumps);
```

For our 14.2 MHz design, this yields 5 complete humps per side. We then recalculate the exact NotchWidth to use all available wire:

```
finalNotchWidth = (radiatorLength -
2*integerNumHumps*NotchLength)/
                  (integerNumHumps*2);
```

Birdcage Cylinder Design

For outdoor installations, we designed a "birdcage" structure using toothed disc spacers. We have a rectangular section of zig-zag wire. We wrap this rectangle around to make a cylinder in order to achieve a more practical and potentially more durable physical prototype. Whether the meanders are in a flat plane or wrapped around a cylinder to make a birdcage does not change the electrical characteristics of the antenna.

Starting with NotchRun (total horizontal span):

```
cowlingDiameter = NotchRun/pi;
```

But we need to optimize for chord length.

```
arc_length = (cowlingDiameter*pi) * (2*pi/(2*integerNumHumps))/
(2*pi);
chord_length = 2*(cowlingDiameter/2) * sin((2*pi/
(2*integerNumHumps))/2);
optimized_cowlingDiameter = arc_length/sin((2*pi/
```

```
(2*integerNumHumps))/2);
```

This correction ensures the wire spacing remains constant at 1 inch around the entire cylinder. For our design, this yielded discs approximately 4.5 inches in diameter.

Full Electromagnetic Analysis

Using MATLAB's Antenna Toolbox, we performed a comprehensive analysis.

First, a strip to wire conversion.

```
wireAntennaObject = wireStack(antennaObject);
```

This converts the PCB-trace model to a wire model with proper feed point characteristics.

Second, an impedance analysis. We swept from 7-28 MHz to characterize multi-band behavior. The antenna showed multiple resonances, with the primary resonance at approximately 23.65 MHz . And, this is where we observed best SWR in practice.

Third, a radiation pattern. Pattern analysis at the test frequency confirmed the expected dipole-like characteristics, with nulls off the ends and maximum radiation broadside to the antenna.

Fourth, efficiency analysis. MATLAB reported suspiciously high efficiency (approaching 100%), consistent with results noted by other researchers. This suggests the simulation doesn't fully account for all loss mechanisms in tightly-folded structures.

Fifth, current and charge distribution. This is a visualization of current distribution and shows maximum current at the feed point and in the radiating sections, with reduced but non-zero current in the meander sections. This confirms that they contribute to radiation.

Transmission Line Analysis

We modeled the effect of our actual LMR-400 feedline (23.8 meters):

```
coax_cable = rfckt.coaxial;
coax_cable.OuterRadius = 0.0813/2;  % 8.13mm overall braid
diameter
coax_cable.InnerRadius = 0.0274/2;  % 2.74mm inner conductor
coax_cable.EpsilonR = 1.38;         % Dielectric constant
coax_cable.LineLength = 23.8;       % meters
```

We constructed the first antenna with coax because we didn't have twin-lead in stock initially. By modeling the antenna impedance as the load, we calculated input VSWR across the frequency range. The VSWR plot showed the antenna could be matched on multiple bands with an appropriate tuner. This is exactly what we observed in practice.

Electric Field Animation

Following the philosophy that "if a picture is worth 1000 words, then an animation is worth 1000 pictures," we created an electric field animation using helper functions from the MATLAB community. The animation shows the time-varying E-field distribution around the antenna structure, visualizing how energy propagates away from the meander sections and radiating elements.

All animation code is available in the repository. Credit to the MATLAB File Exchange community for the visualization framework.

MATLAB Visualization Results

Impedance Analysis

The impedance plot shows the complex impedance trajectory across 7-28 MHz. Two key observations were that resistance (blue trace) remains relatively flat around 50Ω across most of the band, and reactance (red trace) shows the characteristic inductive rise, with a zero crossing around 23-24 MHz indicating resonance.

A detailed view around the resonance point reveals the impedance crossing near 50+j0Ω at approximately 23.65 MHz This became our "frequency under test" (fut) for detailed pattern analysis.

Radiation Pattern

The 3D radiation pattern at 14.2 MHz shows the expected dipole characteristics.

- Maximum directivity: 1.8 dBi
- Nulls off the ends (along the wire axis)
- Maximum radiation broadside to the antenna
- Pattern closely resembles a half-wave dipole despite the meandering

The visualization clearly shows the classic "donut" or toroidal pattern with the antenna wire passing through the center of the donut hole.

Efficiency Analysis gives an Unreasonable Result

MATLAB's Antenna Toolbox reported efficiency of 1.0 (100%) across the entire frequency range. This is clearly unreasonable for a shortened antenna with tightly-folded sections. As noted in the code comments: *"Not reasonable. What are you doing, MATLAB?"*

This issue has been observed by other researchers and suggests the simulation doesn't properly account for the following.

- Proximity losses in closely-spaced parallel wires
- Additional resistive losses from current redistribution
- Potential dielectric losses if using supports

This remains an open investigation topic. Real-world measurements will be needed to characterize actual efficiency.

Charge and Current Distribution

The charge density visualization reveals the following.

- Maximum charge concentration at the feed point
- High charge density at the far ends of the wire
- Reduced but non-zero charge in the meander sections

Current distribution shows the following.

- Maximum current at feed point and in the radiating sections
- Significant current in the meander sections (confirming they contribute to radiation)
- Current maxima alternate along the meander folds
- The visualization uses a color scale from deep blue (minimum) through green/yellow to red (maximum)

These visualizations confirm that the meander sections aren't merely "invisible" loading coils—they actively participate in radiation.

Smith Chart Analysis

At the request of Paul Williamson (KB5MU), we generated Smith chart plots. As digital signal processing engineers rather than RF specialists, this was a learning experience! The S11 plot at 50Ω reference impedance over 23-28 MHz shows multiple loops, confirming multi-band resonant behavior.

```
s_50 = sparameters(wireAntennaObject, freqRange, 50);
hg = smithplot(s_50,[1,1]);
hg.LegendLabels = {"S11 at 50Ω"};
```

The MATLAB Analysis has a parameterized approach. This allows rapid design iteration for any target frequency. The quadratic solution ensures efficient use of available wire in an optimized way. Accounting for chord vs. arc length corrects for the cylinder construction technique and ensures uniform spacing. Multiple resonances were confirmed across the HF spectrum. Predicted resonance at 23.65 MHz matched measured performance, giving a practical validation.

All MATLAB code, results, and generated figures are available in the project repository under MATLAB_model_and_results/.

Construction

N5ES Copper Tape Method

Monty Northrup (N5ES) pioneered an ingenious portable construction technique using adhesive-backed copper tape on transparency film. The entire antenna fit into a three-ring binder. This was perfect for hotel room operation, which was his motivating use case. This method deserves special attention for its elegance and practicality, and is reproduced in this paper.

Materials (N5ES Method)

- 2× transparency sheets, 8.5"×11" (letter size)
- 4× adhesive laminating sheets, 9"×12"
- 2× brass eyelets, 1/4" I.D.
- 12 yards copper foil tape, 1/4" wide, 1.25 mil thick (hobby stores)
- 11 feet AWG 16-18 stranded wire

- 15 feet 300-ohm twin-lead
- Small amount of AWG 22-24 wire for pigtails
- 10 feet 1/16" braided nylon cord
- Center insulator (binding post or plastic)

N5ES Assembly Process

1. Template Creation: Print the meander pattern template at 180 DPI with zero margins. The zig-zag pattern should provide 1" spacing between parallel runs.
2. Copper Tape Application:
   - Place transparency sheet over template (landscape orientation)
   - Mark eyelet location 1/2" from upper right corner
   - Begin laying copper tape at eyelet location, following template
   - Leave 1" pigtail extending beyond edge
   - Create 90° turns at ends without breaking tape
   - Total tape length per side: 138 inches (11.5 feet)
   - Avoid eyelet and 3-ring binder hole locations
3. Double-Sided Construction:
   - Flip transparency over
   - Apply second tape layer in exact parallel to first
   - Both pigtails now meet at eyelet location
   - Press firmly to ensure good adhesion
4. Electrical Connection:
   - Solder 2" length of AWG 22-24 wire to both pigtails
   - Solder close to transparency but not so close as to melt it
   - This forms the electrical connection point
5. Encapsulation:
   - Cover both sides with self-adhesive laminate sheets
   - Seal everything except the 2" wire pigtail
   - This protects the copper and provides mechanical strength
6. Mechanical Reinforcement:

- Install 1/4" eyelet 1/2" from corner near pigtail
- Punch holes for 3-ring binder
- Repeat entire process for second antenna arm

7 Final Assembly:

- Cut two 5.5-foot lengths of AWG 16-18 wire
- Strip 4" on each end
- Attach twin-lead and wires at center insulator
- Thread antenna wire through eyelet with loose loop
- Connect copper tape pigtail to antenna wire (solder)
- Thread nylon support cord through eyelet loop
- Run nylon cord through 3-ring binder holes for support

The key advantages of the N5ES method are that the entire antenna fits in 1" three-ring binder, the setup time is 5-10 minutes, the teardown time is 2-3 minutes, it is TSA-friendly for air travel, no metal detector issues, a professional appearance, and reproducible construction.

Operational Notes from N5ES, in using 5W on 15m from a first-floor bedroom in central Texas, USA show a successful implementation. First QSO was VE3ADX in Ontario (549 report, 8-minute QSO). Second QSO was KC4ZPB in Tennessee (559 report, 30-minute QSO). Signals approximately 1.5-2 S-units down vs. outdoor dipole. An increased susceptibility to power line noise (indoor proximity effect) was observed. Antenna was used to successfully work HF from multiple hotel rooms across several states.

Materials cost remained under 100 USD for ORI's outdoor "dumbbell" version using PVC and 3D-printed spaces. Most components were available from hardware stores. Components included PVC pipe for support structure, hardware store fittings, 3D-printed spacers (1/2" thick, designed in OpenSCAD), copper wire, patio umbrella stand (mast support), and twin-lead feedline.

Spacer Design and Construction

OpenSCAD Design Process

We designed 3D-printable spacer discs using OpenSCAD, exporting STL files for fabrication. Thanks to Mark Whittington for 3D printing the prototype cowlings! The design went through several iterations. Version X1 was an initial design with gear teeth for wire routing. Dimensions calculated from MATLAB cowling diameter equations. Teeth spaced to maintain 1-inch wire separation resulted in a spacer that was 12.85 inches in diameter.

Early sketches on graph paper helped visualize the mechanical assembly before CAD work began. We explored multiple mounting approaches including a vertical mast configuration, a horizontal boom with end-loading sections perpendicular, and various truss designs to prevent boom droop. For the San Diego prototype, we went with a truss and boom design, with the spacers drilled out in the center, slipped on to the boom, and secured with stiff wire pins.

Fabrication Details:

The "dumbbell" name comes from the visual appearance—two end-loaded meander sections (the weights) connected by a straight radiating section (the bar).

Assembly process consisted of drilling holes in 3D-printed spacers for PVC mounting, building a PVC mast and boom with truss support, mounting spacers on PVC with friction fit and straight pins, lacing the copper wire through spacer teeth in meandering pattern, and securing wire ends through spacer holes with nut-bolt fasteners.

The honeycomb interior of 3D-printed parts can be fragile at the surface. While suitable for prototyping and short-term deployment, more robust spacer construction is recommended for permanent installations.

Performance Testing

Test configuration began with our primary test band of 15 meters (21 MHz). A comparison antenna was a 40-foot vertical at same location. The radio was a FlexRadio 6000. The tuner, a vintage Hallicrafters. Feedline was initially RG-8X coax that was replaced with 300-ohm twin-lead.

Results

VSWR Performance

The antenna exhibited good VSWR characteristics when properly tuned, though requiring an external tuner for multiband operation. The tuner allowed operation across multiple HF bands beyond the design frequency.

Comparative Reception

Side-by-side comparisons with a full-size 40-foot vertical showed comparable signal strengths on 15 meters. The meander dipole successfully demonstrated that a significantly shortened antenna can match the performance of a full-size installation when properly designed.

Frequency Response

Using a NanoVNA, we confirmed the impedance characteristics matched MATLAB predictions. The resonance curve aligned with simulation results.

Practical Considerations

Advantages of this design are a significantly reduced physical size (approximately 1/3 of full-size dipole), no lossy loading coils, multi-band capability with external tuner, hotel-room friendly if using the N5ES construction, and low cost and accessible materials.

There are limitations. The design requires an external tuner for optimal multi-band performance. There are some reports of increased susceptibility to certain types of noise. It has a narrower instantaneous bandwidth than full-size dipole. The pattern remains dipole-like, and not omnidirectional.

Environmental Sensitivity

As with all antennas, surrounding structures significantly affect performance. Indoor operation in steel-framed buildings or near electrical interference sources will degrade performance. For hotel room use, distance from ice machines, elevator motors, and other noise sources improves results.

Future Work

Several areas warrant further investigation:

Scaling this design to 160 meters presents the most significant size-reduction benefits. Several ORI team members are developing prototypes targeting the "top band."

Optimization studies include confirmation of optimal wire spacing. It is currently fixed at 1 inch. Maximum achievable shortening ratio. Resolution of MATLAB efficiency calculation discrepancy. Mechanical Improvements include enhanced spacer design using through-holes rather than teeth, spacer rotation locking features so that the meanders do not become twisted over time. Weather-resistant materials for permanent outdoor installation. Preliminary investigation suggests interesting possibilities for phased arrays or Yagi-style director/reflector elements using meander-shortened elements. Systematic testing at various power levels to establish safe operating limits and identify any tendency toward arcing in tightly-folded sections.

Reproducibility was a Requirement

All design files, MATLAB code, 3D models, and documentation are available in our public GitHub repository. This includes complete MATLAB simulation scripts, OpenSCAD spacer source files, STL files for 3D printing, collected historical papers and references, field test results and photographs.

We encourage replication, modification, and improvement of this design by the amateur radio community.

Conclusions

This project successfully validates a 65-year-old antenna design using modern modeling tools and construction techniques. The meander dipole offers a practical solution for space-constrained HF operation, achieving performance comparable to full-size antennas while occupying a fraction of the space.

The combination of historical research, computational modeling, and hands-on experimentation exemplifies the ongoing vitality of amateur radio's experimental tradition. Designs from the 1950s remain relevant today, and modern tools allow us to better understand and optimize them. There are undoubtedly many other amateur radio newsletter articles are out there waiting for amateur experimenters to pick up and move forward with modern tools and techniques.

For operators facing HOA restrictions, apartment living, or portable operation requirements, the meander dipole deserves consideration as a compact yet effective antenna solution.

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