Designing an Amateur Radio Antenna Installation using a Tailored Commercial System Engineering Process

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When I moved into my current home twenty years ago in a community with a homeowner association (HOA), I knew that setting up an effective antenna system that would not arouse the ire of the architecture review board would be a challenge. I operated mobile on VHF and HF for many years and operated a low "inverted vee" in the backyard for a while, but convenience and performance were lacking. I primarily wanted to operate HF DX contests from home and make reasonable numbers of contacts.

In my job as a professional system engineer and systems architect with the Raytheon Company (now retired), I was periodically called upon to help envision and design complex systems to meet challenging customer requirements. My company has developed and comprehensively applies a thorough systems engineering process defined by an *Integrated Product Development System* - a collection of business processes and tools that Raytheon uses throughout the product lifecycle. This system is applied to the complex task of satisfying customer needs with optimized system designs.

Faced with the need for a custom antenna system for my home amateur station, I decided to leverage my professional systems engineering background and apply some of the engineering analysis and design techniques I have used at work to design an antenna system that would be reasonably low profile yet provide adequate performance. Although this antenna design may provide the basis for others to build similar antenna systems through replication or adaptation, the primary thrust of this article is to present a simplified system engineering approach and the problem solving techniques I used so the reader can understand the overall thought process and then apply similar methods to solve their own amateur radio system design problems. It should be noted that I am not a professional RF engineer, so I approach this job with the RF technical skills of a typical technically-oriented amateur operator.

Although this antenna system is much simpler than most of the systems I design, many of the systems engineering activities needed to analyze and design a large complex system are applied in simplified form, i.e. the processes are *tailored*.

At the highest level, when designing, building, and maintaining a complex system we may perform the following system engineering activities:

1) Develop an understanding of what the user is trying to accomplish with the system; what is the user's **operational mission** and how will he / she operate the system to help them accomplish it?
2) Define the **requirements** that the system is to meet (e.g., functional, performance, safety requirements). These requirements primarily define <u>what</u> the system must do.
3) Define, analyze, and trade-off the **system quality attributes** (e.g., attributes such as low visibility, reliability, adaptability, or cost) that are important to the *stakeholders* – all those who "have a stake" in the system. Attributes frequently conflict (e.g., low visibility and performance) or have high levels of attainment that are expensive or impossible to achieve.
4) Analyze the (abstract or logical) **functions** that the system provides to satisfy the requirements – before proceeding to a specific physical implementation.
5) Define any required **technical standards** (e.g., 50 ohm feed point impedance or RF exposure field strength limits).
6) Conduct a **site survey** – how will the antenna installation relate to the surroundings – in this case the house and the large tree in the middle of the yard?
7) Identify several **design alternatives** (i.e., the *trade space*) that satisfy the system requirements and quality attributes.
8) Define **evaluation criteria** and assign them a priority

9) Analyze and **evaluate the design alternatives** in the trade space based on the prioritized evaluation criteria
10) Consider **risks** and factor them into the design approach
11) Consider **reuse** opportunities that can lower the cost – in amateur parlance, "what's in the junk-box?"
12) Consider commercially available antennas or components (i.e., commercial-off-the-shelf, commonly abbreviated as COTS.)
13) Select one or more designs for **detailed evaluation**
14) **Trace requirements** to the design(s) to verify they are met
15) Evaluate how well the designs **satisfy the quality attributes**
16) Simulate, model, or prototype to **validate the designs**
17) **Estimate the system costs (development, production, and operational)**
18) **Select** a design
19) **Add design details**
20) **Build** the system components and integrate them
21) **Write** design documentation, operations manuals, and maintenance instructions.
22) **Install** the system
23) **Test** the system
24) **Deliver** the system
25) **Operate** the system
26) **Maintain** the system
27) **Update** / refresh the system
28) Potentially **Move** and **re-install** the system?

29) **Retire** and dispose of the system

The order these steps are listed implies that they are performed sequentially, which would correspond to an older system development process commonly called the *waterfall model*. In practice, performing these steps may require earlier steps to be revisited or performed multiple times.

User Mission

In this project the author is the user so has the authority to define the user mission. The mission is to operate my amateur station to work high frequency (HF) DX from my suburban HOA-regulated home. So the antenna has to have a low profile – preferably be invisible from the street. I want to use the antenna to operate DX contests on all relevant HF bands on both SSB and CW (at a reasonable level of performance) and occasionally to contact other DX stations for casual operating or DX chasing. I have already decided that I want this antenna to be a vertical. This limits the space of possible alternatives.

System Requirements

Here is the set of requirements that I wrote as the user. The requirements are categorized as "must-have" or **threshold requirements** (**T**) and "nice-to-have" or **objective requirements** (**O**).

1. Have strictly limited visibility from the street during daytime (T).
2. Have limited visibility from the street at night (T).

3. Require no guy wires (O).
4. Operate the CW and Phone segments on the following ham bands: 160m, 80m, 40m, 20m, 15m, 10m (T).
5. Operate on all HF ham bands (O)
6. Support band switching in 5 minutes or less (T).
7. Support band switching in 1 second or less (O).
8. Support band switching without leaving the operating position (O).
9. Must be tunable to a SWR of 2:1 or less using my existing antenna tuner in the station (T).
10. Provide low angle radiation on all bands. (T)
11. Have “reasonable” efficiency on all bands. (T)
12. Operate at the 1500 watt CW level (T)
13. Survive a direct lightning strike with little or no damage to antenna or other equipment (T)
14. Support easy maintenance. (T)
15. Support 360 degree operations (O)
16. Provide support at the top for other antennas (T)
17. Be portable for vacation operations (O)
18. Be “relatively inexpensive”, and use as much of the junk box as possible (O).
19. Create no safety hazards (T).

A formal requirements exercise would eliminate the ambiguities, reword the requirements to be more testable, derive additional requirements and add formal “shall statements” to drive formal system acceptance testing and "sell-off". This is beyond the scope of this article and was not needed for this project.

Site Survey

- Sharply sloping ground to walk-out basement in back yard
- Small suburban lot
- HOA Common-ground on one side
- Friendly neighbor on other side
- A different HOA-controlled development in the back
- Friendly neighbors in the back.
- Ham shack in a rear basement room
- Fairly large tree in center of back yard

Performance Requirements

Some of the requirements will relate to the functional performance of the antenna system. These can be derived from the user mission or gleaned from the overall list of user requirements.

- 360 degree radiation pattern (in azimuth) plus or minus "to-be-defined" TBD dB.
- System gain within TBD dB of a reference antenna (e.g., resonant ¼ wave vertical) at TBD elevations of interest.
- Impedance at input to "in-shack" antenna tuner of less than TBD: 1.

- Ability to handle a power level of 15OOW CW.
- Band switching time of TBD Seconds.
- Instantaneous Bandwidth of TBD % of operating frequency.

These “to-be-defined” (TBD) will be replaced with actual numbers as we refine and evaluate design alternatives. Specifying these numbers unnecessarily or too early could lead to infeasible or difficult to satisfy requirements that would eliminate useful design alternatives.

Safety Requirements

Installation, operation, and retirement of the antenna system should not result in hazards to the operator, family members, or uninvited visitors. Some example requirements might include:

- Not require the operator to stand on ladders for band switching.
- Not expose the operator to shock from overhead electric wires during installation or operation.
- Counterpoise wires do not pose a trip hazard.
- No hazardous voltages used to operate antenna.
- Provide protection from lightning strikes.
- Antenna can withstand winds of TBD MPH without falling on house.
- Antenna will not fall on neighbor’s property.

System Quality Attributes

Quality attributes are used to capture, evaluate, and tradeoff the important features (to the stakeholders) of the antenna system that may not be captured by functional requirements. Each of these attributes may have a desired value or characteristic based on this analysis. Some of the stakeholders might include the operator, XYL, neighbors, and even the other stations I am communicating with. Each stakeholder generally has different priorities for these quality attributes.

The quality attributes defined for this system are summarized in Table 1.

Attribute	**Stakeholder Priorities**			
	Operator	**HOA**	**Neighbors**	**XYL**
DX Performance	High			
Low Visibility	High	Very High	High	Moderate
Ease of Use	Medium			
Multi-band Ability	High			
Incremental build-up	Medium			
Simplicity	Low - Medium			
Reliability	High			
Maintainability	Medium			
Adaptability	Medium			
Low Cost	Medium			Medium
Safety	High	High	High	Very High

Table 1 - Quality Attributes and Stakeholder Priorities

These attributes often conflict with each other and must be “traded off”. For example: low visibility and DX performance will almost certainly conflict. We need to find an acceptable balance for these and the other quality attributes. There is frequently a point where the cost of increasing a quality attribute “skyrockets” so we want to understand how much of the attribute to provide (i.e., find the “knee” of the cost vs. performance curve).

For example to achieve four different levels of the *low visibility* attribute:

Low Visibility Level	**Approach**	**Technical Difficulty**	**Cost**
A) Difficult to see from street	1) shield behind house	Very low	None
	paint unobtrusive color	Very low	Very low
	use thin wire counterpoises	Low	Low
B) Impossible to see from street	1) shield behind house	Very low	Very low
	limit conductor diameter	Low - Moderate	Very Low - moderate
	paint unobtrusive color	Very low	Very low
	use no counterpoises	Low	None
	no ancillary antenna	None	None
C) Difficult to see from backyard	1) hide radiator and other components among deck supports	Low	Low
	limit conductor diameter	Very Low	Very low
	limit radiator length	Low	Very low
D) Nearly impossible to see from up close	1) Embed in deck supports	Medium	Medium
	2) Full size antenna using “Star Trek cloaking technology”	Beyond state of the art	Exceeds U.S. GNP

Table 2 - Quality Attribute Example – low visibility attribute vs. cost

What we don't see in Table 2 is the tradeoff between *low visibility* and the other quality attributes, such as *performance*. This could be documented in additional tables. For example, the two technical approaches at level "D" might have very different levels of performance.

Table 3 shows an example of a quality attribute interaction matrix. This tool can be used to analyze how these quality attributes affect or conflict with each other. If desired, the type or severity of interaction could be described in the table, along with any decisions made relative to the two attributes. In any case, each of these interactions may need to be considered to balance the design.

As an example, low visibility conflicts with DX performance and the chosen balance point is to achieve "reasonable" levels of performance with "strictly limited" visibility from the street. In a commercial application, additional work would be necessary to quantify what "reasonable" and "strictly limited" mean.

Attribute											
	DX Performance	**Low Visibility**	**Ease of Use**	**Multi-band**	**Incremental**	**Simplicity**	**Reliability**	**Maintainability**	**Adaptability**	**Low Cost**	**Safety**
DX Performance	x										
Low Visibility	interaction	x									
Ease of Use	interaction		x								
Multi-band Ability	interaction		interaction	x							
Incremental build-up					x						
Simplicity			interaction	interaction	interaction	x					
Reliability			interaction	interaction		interaction	x				
Maintainability				interaction		interaction	interaction	x			
Adaptability			interaction	interaction	interaction	interaction	interaction	interaction	x		
Low Cost	interaction	interaction	interaction	interaction	interaction	interaction	interaction	interaction	interaction	x	
Safety		interaction	interaction				interaction	interaction			x

Table 3 - Quality Attribute Interaction Matrix

There may be some overlap between the quality attributes and system requirements, although functional requirements should describe what the system does, and quality attributes focus more on inherent properties of the system. The Software Engineering Institute (SEI) has developed an approach for working with quality attributes called the Architecture Tradeoff Analysis Method.

Antenna System Functions

It is frequently desirable to first analyze a system abstractly instead of immediately tackling the physical system solution. We can thus address important implementation-independent issues without being distracted by design details. We may think about the logical functions that the system provides or abstract "pieces" of the system that could be realized in multiple ways. For example, we could talk about the *radiation* function or the abstract concept of *structure*.   For my purpose here, I thought mostly about abstract descriptions of the major antenna subsystems / components as shown in Figure 1.

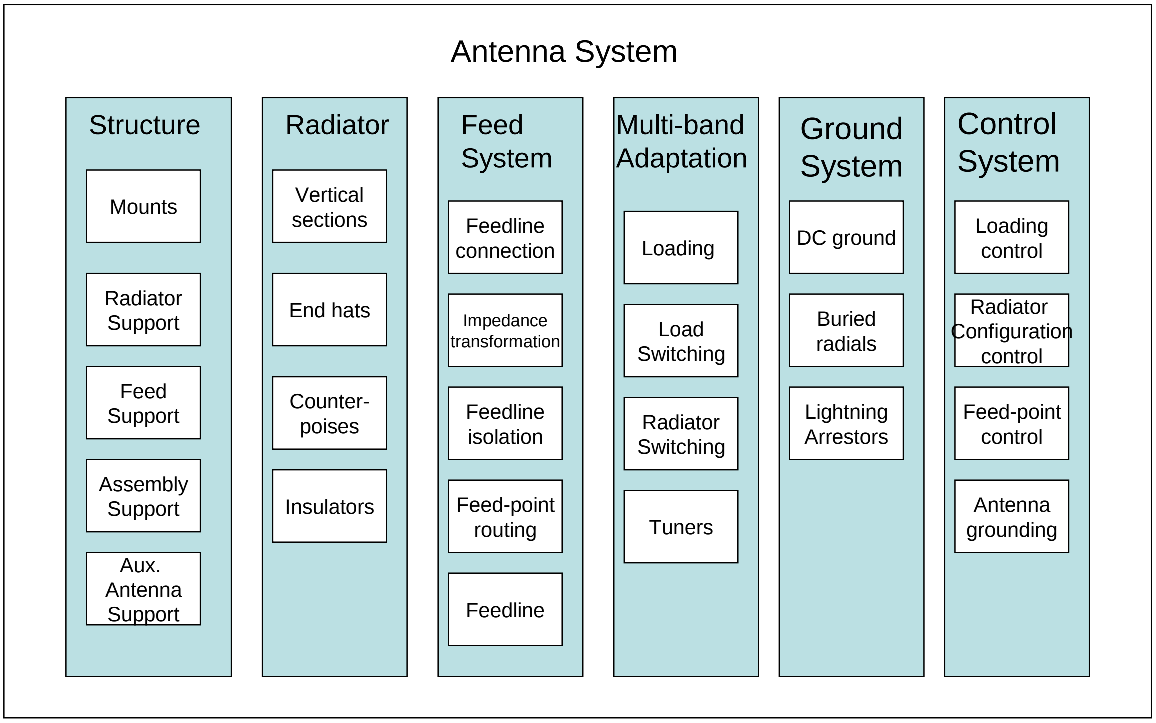


Figure 1 - Abstract Antenna System Components

The sections that immediately follow provide a description of these abstract subsystems and components.

Structure

The structure supports (or is) the radiator, provides separation from ground and other objects in the environment and supports the optional auxiliary antenna.

The author obtained some surplus aluminum tubing (purchased by the pound) at a junk dealer several years ago that could be used as the radiator (reuse opportunity). I have a two-story deck in the back-yard that might provide some good mounting points and minimize visibility. One of the 4” x 4” deck uprights could be a good choice for the mount. I could attach an insulated bracket to the mast about 15’ up to stabilize the antenna and eliminate the need for guy wires. A piece of solid Delrin 18” long was eventually purchased on EBay™ from a plastics dealer to serve as a center insulator.

An alternative structural approach would be to run a wire up the deck supports and then up and over the tree in the back yard. In a comprehensive analysis, this alternative would have been given more serious consideration, but was informally eliminated because it would not readily support the auxiliary antennas (threshold requirement), would be more difficult to switch loading in the center or at the top, and might suffer losses through close coupling to the tree.

End-hat(s) reduce the height requirement since they are an efficient means of electrically loading the antenna. Several alternatives were considered, including: 1) T-bar, multi-spoked, multi-spoked with perimeter wire, or longer wires. The late L.B. Cebik, W4RNL, did a great job of describing and analyzing various end loading structures in informal articles posted to his web page (see www.cebik.com), and this informed my design work.

Multi-band Adaptation

The mission statement requires the antenna to operate on most of the HF bands between 160 and 10 meters. A number of multi-band approaches are possible such as using trap loading, switched loading coils, or placing an antenna tuner at the base of the antenna, which currently seems to be a simple and popular commercial approach. I was unable to locate an automatic antenna tuner that would operate at the 1500W level externally and remotely at reasonable cost. I was concerned about the losses that traps might introduce and already had some surplus high power relays (another reuse opportunity), so I had a preference "going in" for the switched relay approach. The relays would be used to switch in the antenna loading and can also be used to electrically shorten the antenna for some degree of radiation elevation angle control at the higher frequencies.

Feed System

There are several alternatives for feed location. I looked at: 1) base feed – ground mounted monopole, 2) base feed of an elevated monopole, 3) center feed of a vertical dipole

The feed line alternatives considered were coaxial cable and 300 ohm transmitting twin lead. Larger 450 ohm open wire feeders were not considered due to the higher visibility. Low-loss coax seemed to be the best choice since it could be easily routed under the ground-level deck from the operating position, reducing visibility.

Impedance transformation – the author has already constructing a number of homebrew high power baluns and ununs ala Jerry Sevick[1][2]– another reuse opportunity - so this is a potential impedance matching approach.

Low Visibility (Attribute)

The antenna should be as low profile as possible, to be traded against the performance requirements. The antenna can use the house and ground slope to hide the antenna from the street. The antenna can also use the existing deck structure and tree to limit visibility. The antenna should not be tall enough to be visible above the roofline of the house from the street, particularly during daylight. Low visibility height extensions that could be conveniently raised at night may be considered.

Ground System

It appears necessary to operate the vertical as a monopole on the lower frequencies, so a ground system or counterpoise is required. Since buried radials are inherently low visibility, this is a likely alternative. Because the house location and size of the back yard limits the length and azimuth coverage of the buried radials, this ground system may be bettered by tuned counterpoises.

Auxiliary Antenna Support

[1] Sevick, Jerry, *Understanding, Building, and Using Baluns and Ununs, CQ Communications, 2003.*
[2] Sevick, Jerry, *Transmission Line Transformers, Noble Publishing Corp., 2001.*

The author values the option to suspend wire or other small antennas from the top of the vertical. The structure should be capable of supporting an inverted-vee antenna or small self-supporting dipole at or near the top.

Identifying Design Alternatives

Creating a good design for a system of this sort requires identifying a number of key design decisions and evaluating how they would effect satisfaction of the requirements or quality attributes. Because the number of design alternatives is large (even for this simple system), and the decisions interact, this is a non-trivial problem.

Some of the design alternatives identified were:

1. Vertical **antenna topology**: ground mounted monopole, elevated monopole with ground plane, vertical dipole – see Figure 2.

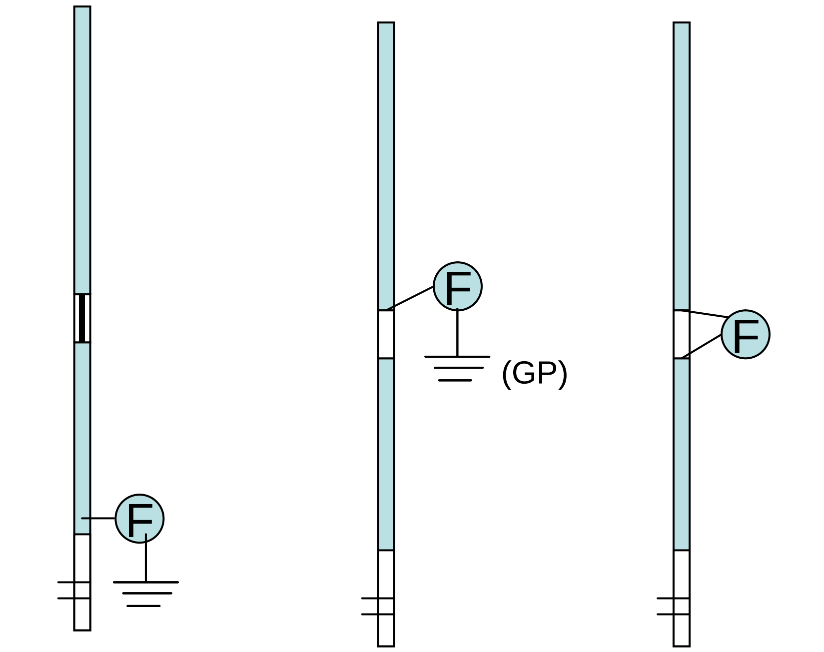


Figure 2 Antenna Topology Alternatives

2. Physical **height** (fixed, variable, maximum height)
3. **Feed point** (base, center, off-center, top)
4. **Band switching approach** (traps, switched loading elements, switched antenna topology, broadband, parallel radiators, variable electrical length (e.g., SteppIR$_{TM}$, none)
5. **Loading point(s)** (base, center, off-center, top)
6. **Loading type** (top-hat, end-hats, coils, linear loading, helical loading, auxiliary antenna). See Figure 3 and Figure 4.

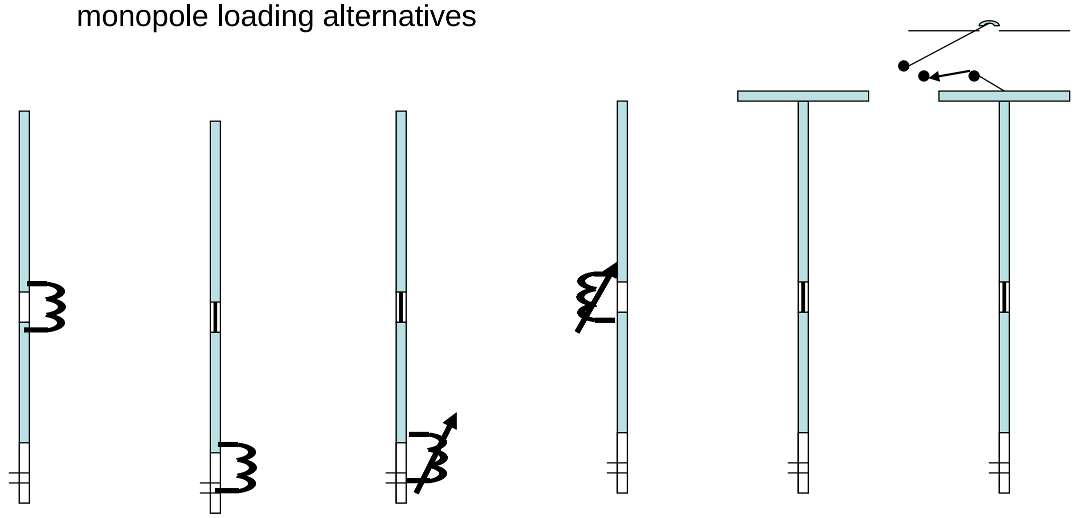


Figure 3 – Monopole Loading Alternatives

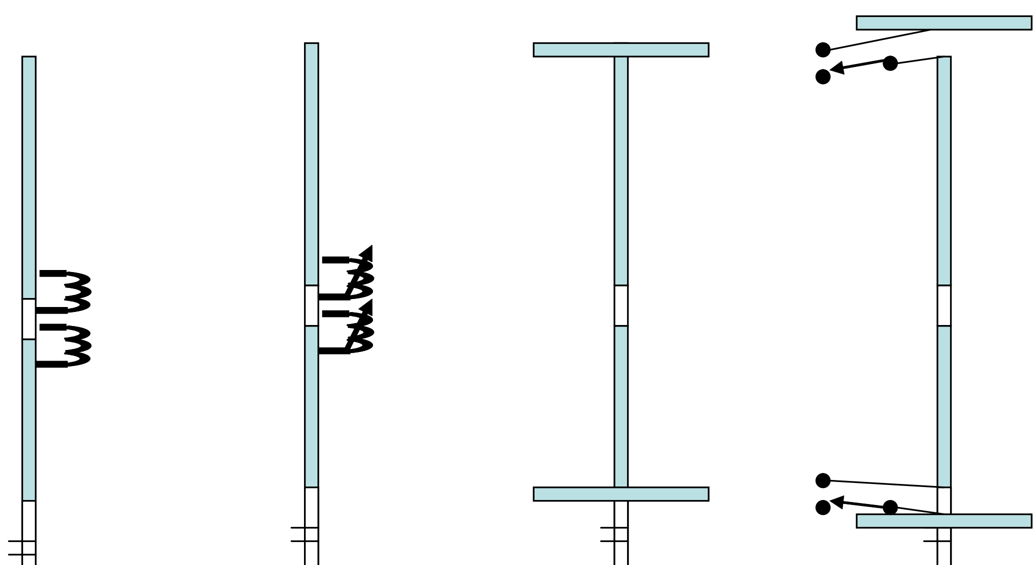


Figure 4 - Dipole Loading Alternatives

7. **Mount type** (fixed, fold-over, side, top)
8. Impedance matching approach (baluns, ununs, gamma match, delta match, etc.)
9. **Radiator type** (wire, aluminum tubing, stainless steel whips)
10. **Ground system type** (buried radials, counterpoise-bottom, counterpoise-middle, both). See Figure 5.

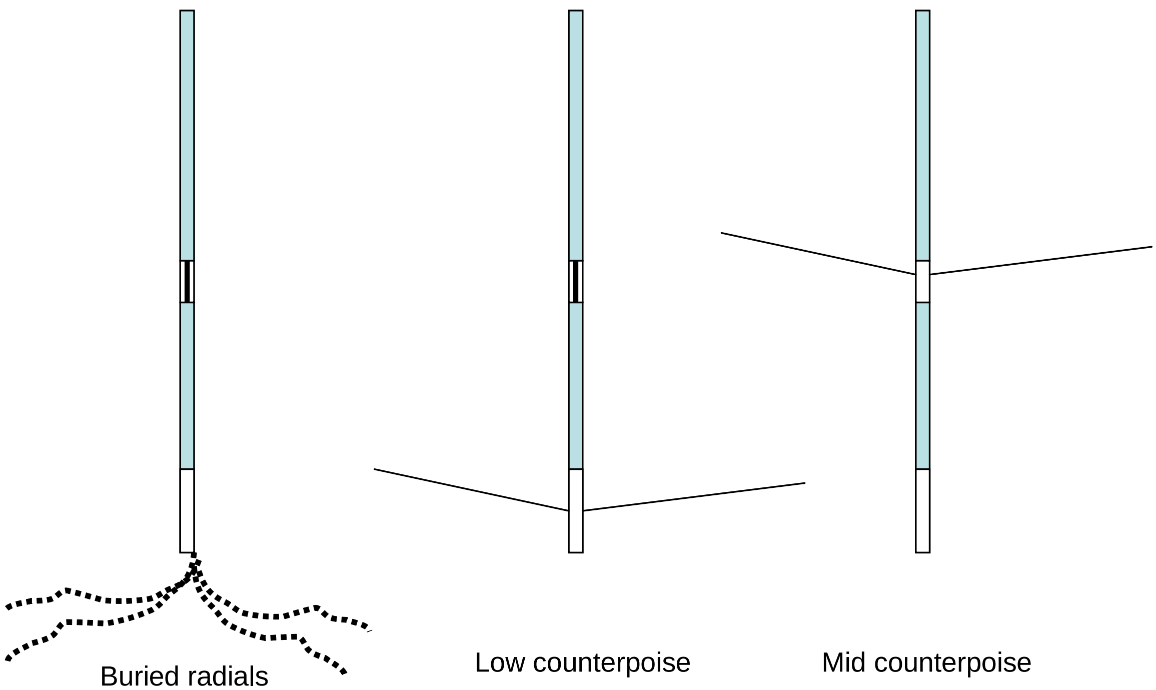


Figure 5 - Ground System Alternatives

11. **Length / Number of buried radials**
12. **Feed line type** (coax, balanced line)

Design Synthesis

This step requires substantial creativity. It is frequently useful to pull out the back of the napkin or the whiteboard and brainstorm multiple approaches. Here the experienced designer applies the general knowledge and rules of thumb that he or she has developed over the years. Previous successful and unsuccessful designs are reconsidered for their "lessons learned". For radio amateurs, the contents of the junk box may be a key factor. The result of this brainstorming activity was the collection of design alternatives shown in Table 4.

The possible designs are evaluated either informally or using formal approaches against their ability to satisfy the requirements, system quality attributes, and other defined evaluation factors.

Design Attribute	**Selected Alternatives (in bold)**					
Topology	**Monopole**	**Dipole**				
Physical height	**Fixed**	Variable				
Feedpoint	**Base**	**Center**				
Band Switching Approach	Traps	**Switched loading**	**Switched topology**	**Manual switching**	Parallel radiato rs	Variable electrical length
Loading Point	Base	**Center**	**Near-center**	Top		
Loading Type	**Top-hat, Top-wires**	**End-hats**	**coils**	Linear loading	Helical loading	Aux. antenna
Impedance matching	**Baluns**	**Ununs**	Delta match	Gamma match		
Ground system type	**Buried radials**	**Low counterpoise**	**High counterpoise**	**Parallel Counter-poise**	**Switch ed counte r-poise**	
Feed Line	**Coax**	Twin lead	Open wire			
Lightning protection	**Lightning arrestors**	**Antenna grounding (manual)**	**Antenna grounding (remote)**	**Antenna grounding (automatic)**		

Table 4 – System Design Alternatives

At the risk of becoming an overly complex “Swiss Army knife” of backyard antennas the selected approach supports a variety of topologies, feed points, and loading approaches to satisfy the requirements. Where multiple alternatives are highlighted in a table row, the interpretation is that all of the **bold** alternatives will be supported. This table can be used to generate a large number of system configurations by combining the alternatives in various ways. To make the potential instantiations of the design more concrete, notional examples are identified for specific bands in the following sections. These are not intended to be exhaustive and may not even be the “best” for each band. But they will show how multiple concrete designs can be generated from this abstract “reference architecture” and discuss some informal motivations for each band’s configuration. Each of these examples require additional design, to define accurate electrical lengths, impedance matching techniques, and detailed physical realizations.

160m and 80m Example Configurations

On 160 and 80 meters the primary considerations are achieving the highest possible radiation resistance (since the antenna height is electrically short) and the lowest possible ground losses since the efficiency of the antenna is driven by these factors. Bandwidth is also a concern. Here both examples use a large top hat consisting of two loading wires that can be electrically switched to the top of the radiator. The auxiliary antenna was considered for this role, but this conflicted with the ability to easily raise this antenna. Both examples use center loading coils since these have previously shown to be more efficient than base loading. The second shows a variable inductor which could be used to fine tune the resonant frequency. The first example uses a buried ground radial system; the second uses a tuned counterpoise. Incidentally, the tuned counterpoise is too large for the author's back yard on 160m and very nearly so on 80m. The buried radial system is also quite small and inefficient on these bands.

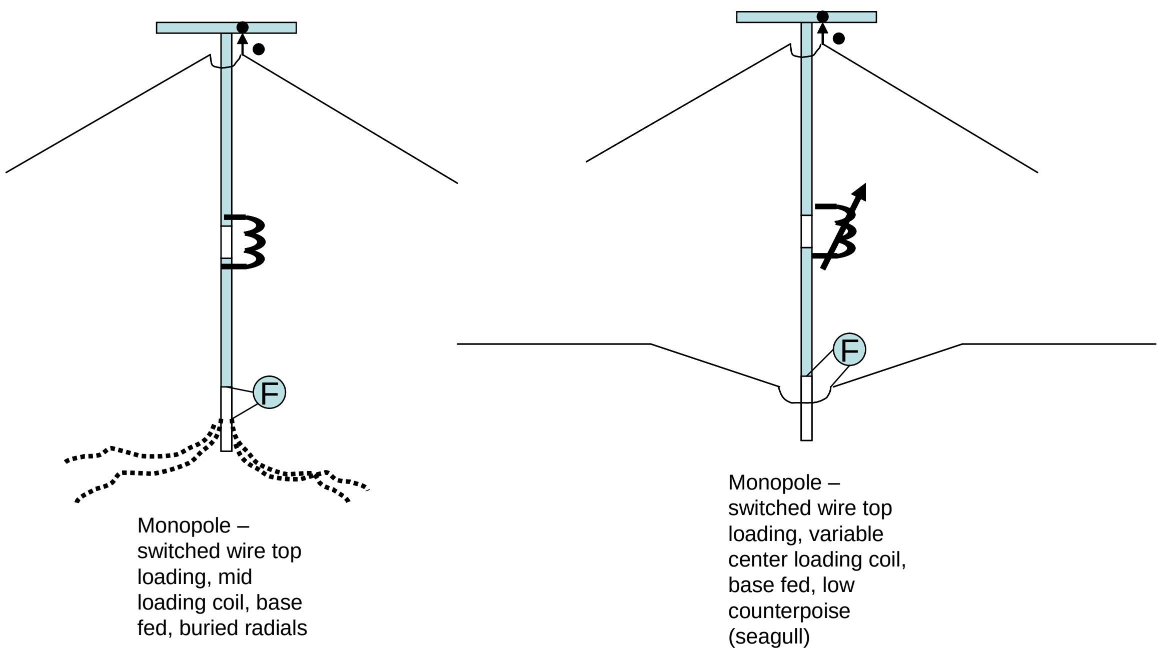


Figure 6 - Potential 160m and 80m configurations.

40m Example Configurations

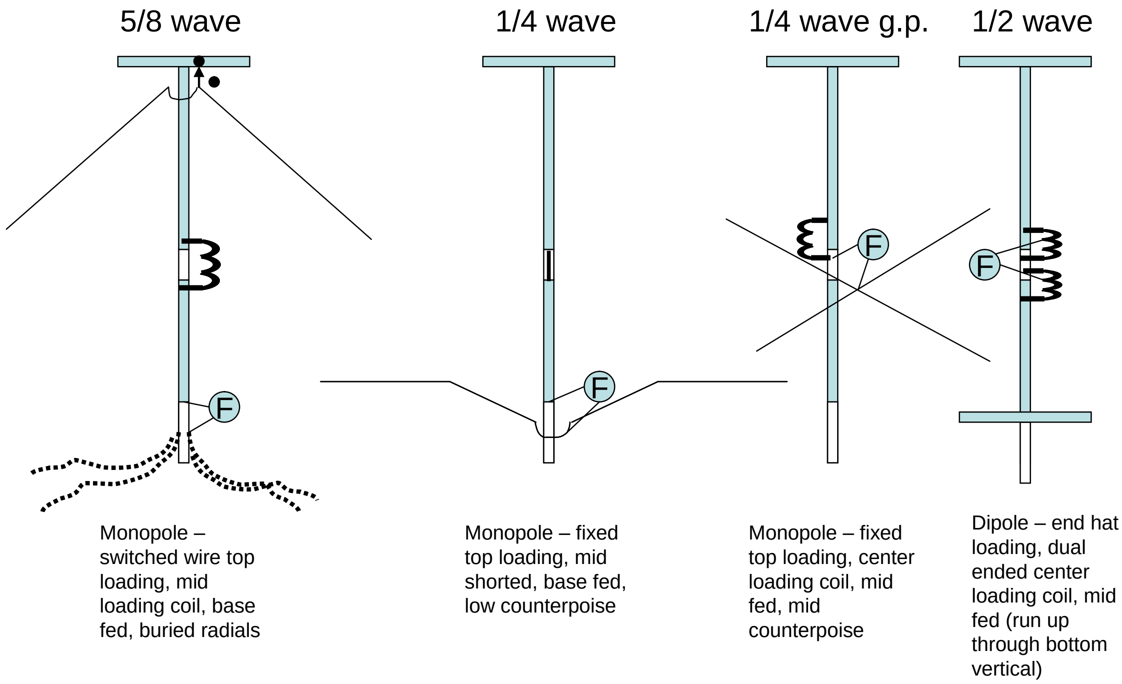


Figure 7 - Potential 40m configurations

On 40 meters, the length of the antenna and a fixed top hat yield a resonant frequency near the bottom of the band, so the radiation resistance is higher than on the lower bands. Here a number of alternatives can be generated including a 5/8 wave monopole with top loading, a ¼ wave ground mounted monopole with tuned counterpoise, a ¼ wave ground plane with elevated base loading, or a loaded ½ wave vertical dipole. The amateur literature contains much analysis of these alternatives, which is well-covered in the ARRL Antenna Handbook[3]. On this particular antenna site with the strongly sloping ground, the preferred alternative could vary depending on the desired azimuth.

20m / 15m Example Configurations

[3] American Radio Relay League, *The ARRL Antenna Book: The Ultimate Reference for Amateur Radio Antennas, Transmission Lines And Propagation, 21st edition, 2007.*

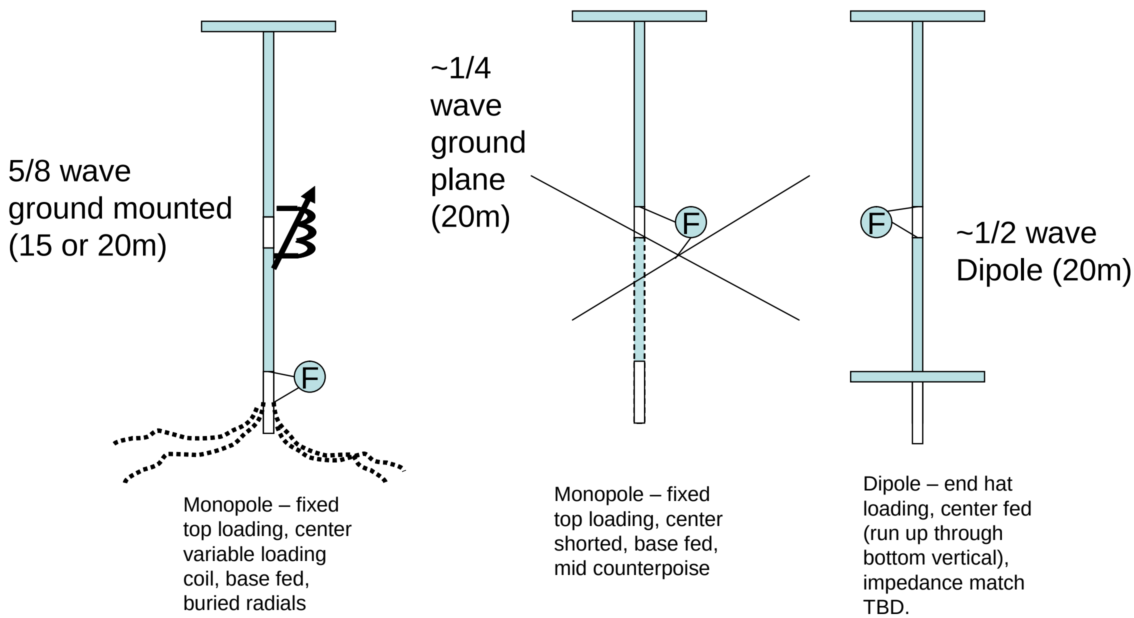


Figure 8 - Potential 20m / 15m configurations

Since the antenna with fixed top hat is approximately ¼ wave on 40 meters, it is roughly ½ wave on 20 meters and ¾ wave on 15 meters, so with impedance matching it could be used as a base fed monopole on these bands with some gain. The upper vertical could also be fed against a ground plane, or the antenna could be fed as a vertical dipole of approximately ½ waves on 20 meters or ¾ waves on 15m. Based on experience with the prototype ground mounted vertical on these bands, raising the current maximum is critical for making contacts to the South due to the sloping ground.

10m Example Configurations

Here a 5/8 wave ground plane is shown as one example; the second shows a 1 wavelength vertical dipole.

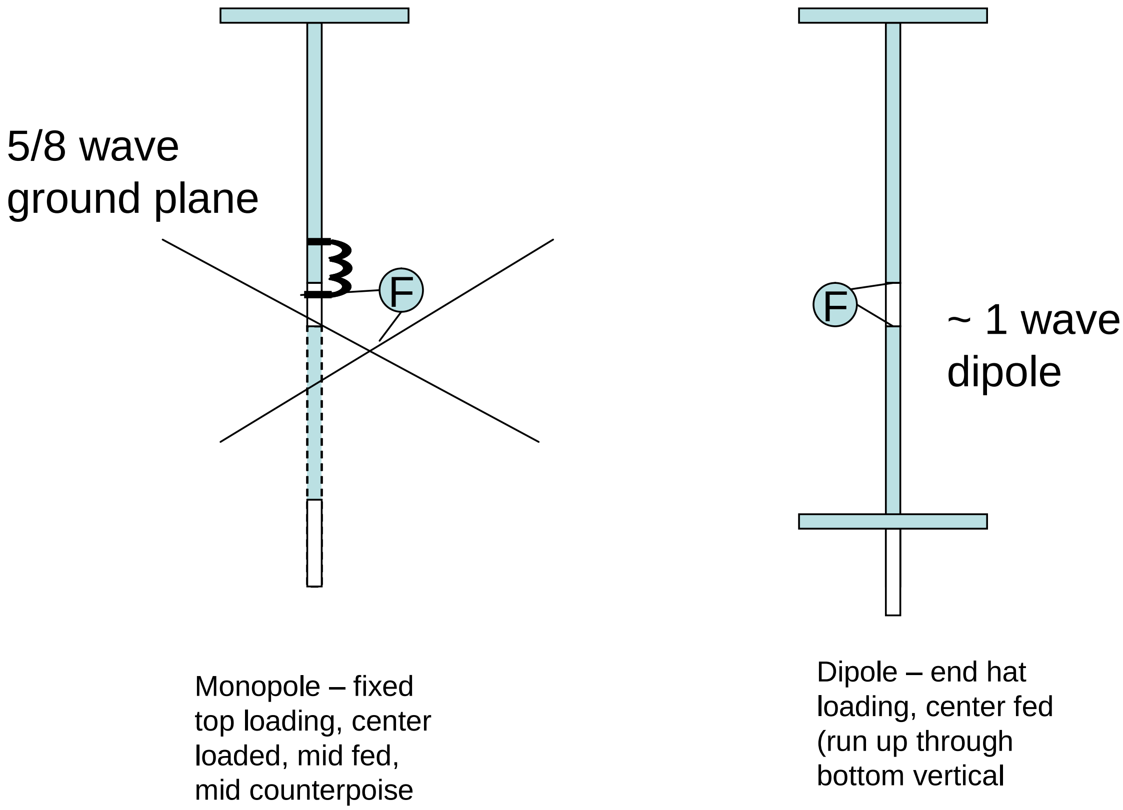


Figure 9 - Potential 10m configurations

The Selected Approach

In commercial practice, multiple system designs would be generated and evaluated. Due to cost and junk box limitations, I was able to narrow quickly to a single incrementally implemented approach with several minor variants. Figure 10 shows the top-level antenna architecture / design. The antenna system consists of the following physical design elements, listed from antenna top to bottom.

1. top-hat
2. upper assembly
3. upper vertical
4. center insulator
5. midpoint assembly
6. midpoint counterpoise
7. lower vertical
8. base assembly
9. low counterpoise
10. earth ground

Several of these components are complex. The top assembly, midpoint assembly, and base assembly are further analyzed. For each of these subsystem designs, the logical functions are identified, a functional block diagram is shown, and any required switching functions are documented. This supports the following physical design steps, which would include selection of specific components (e.g., in Figure 11, which lightning protector to use), and the detailed electrical and mechanical design. A single high-level design alternative was identified for each of the base and midpoint assemblies. Three alternatives were defined for the upper assembly.

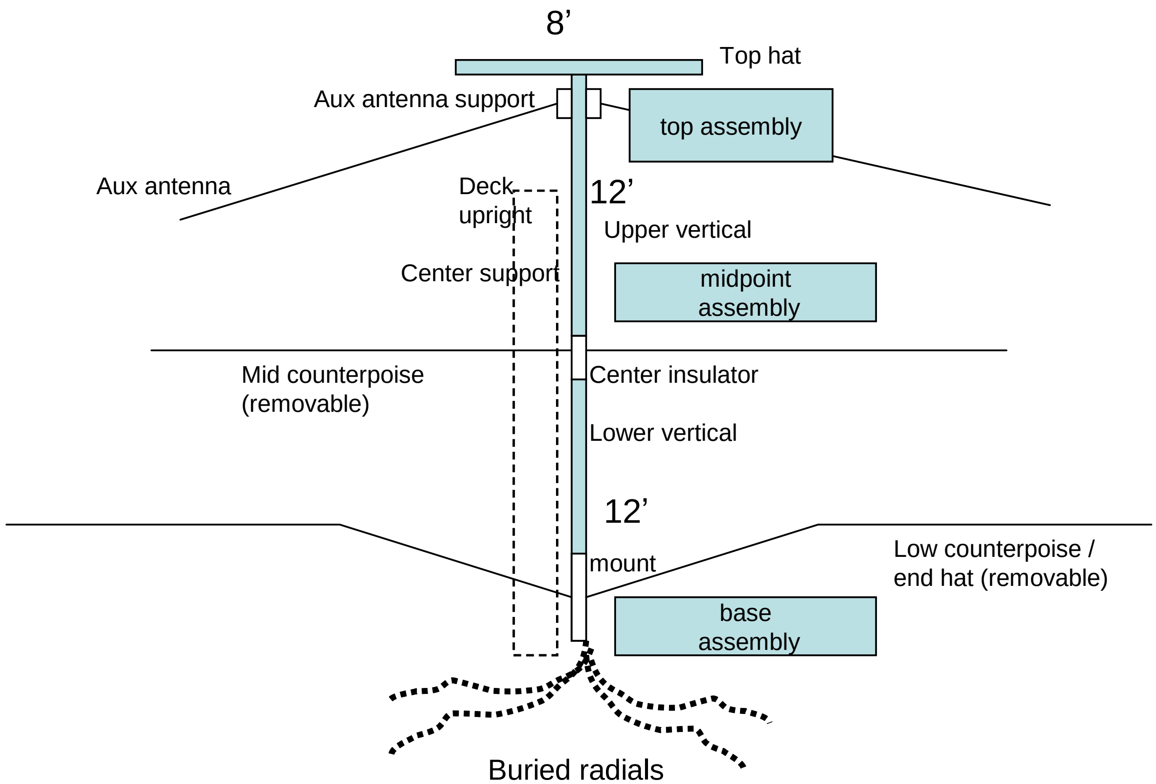
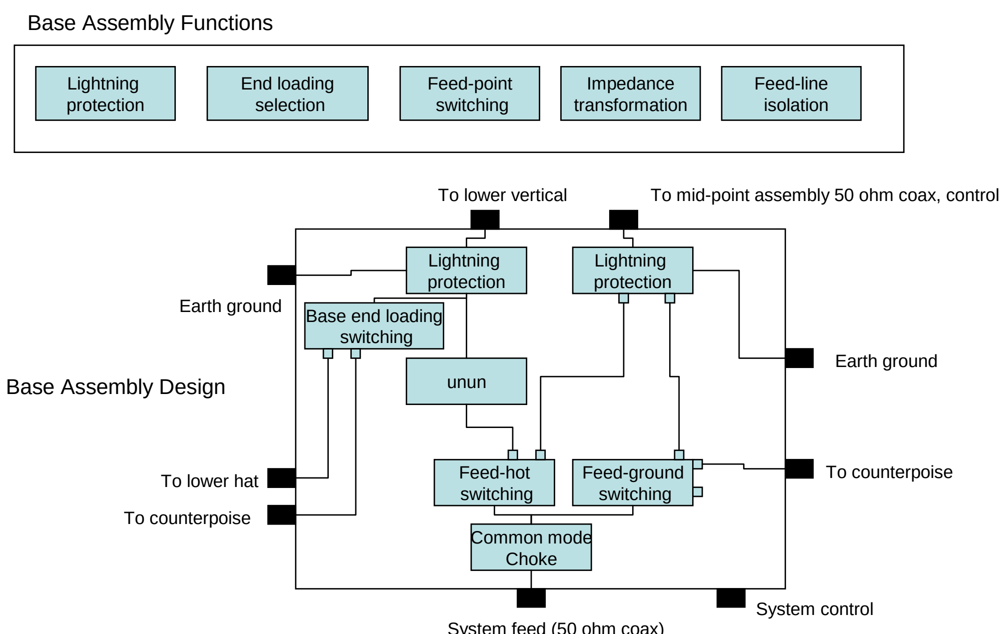


Figure 10 - Antenna System Architecture

Base Assembly Design

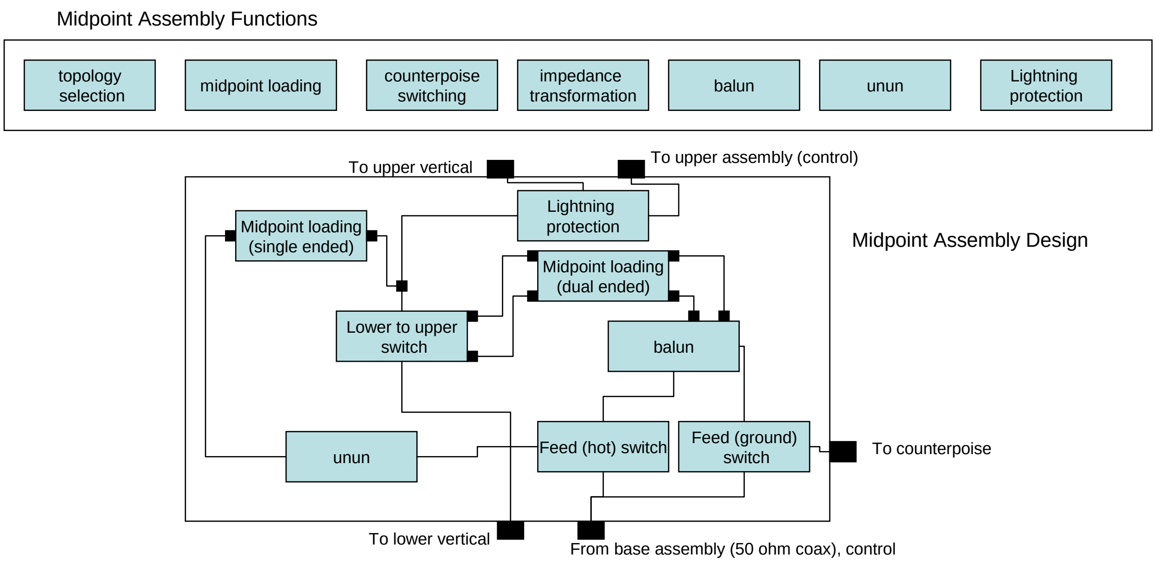


Base Assembly Switching Matrix

Antenna Topology Select	Feed (Hot) Switching	Feed Ground Switching	End Loading Selection
Monopole (buried radials)	To base of vertical	Connected to earth ground	Not connected.
Monopole (low counterpoise)	To base of vertical	Connected to low counterpoise	Not connected.
Monopole (Ground Plane)	To mid point assembly	To mid point assembly	Not connected.
Dipole	To mid point assembly	To mid point assembly.	Connected to lower hat, counterpoise, or both

Figure 11 - Base Assembly Design

Figure 11 shows the logical functions to be provided by the assembly, a design that realizes these functions by mapping the logical functions to design elements and identifies interfaces, and a table that was used to analyze the required switching functions. Although not shown here, the logical functions can map to multiple physical implementations, which could require trade studies to be performed at this design level. For example, here *the impedance transformation* function was realized by a unun, but could have been implemented by any of several impedance transformation methods. To avoid cluttering the diagram not all the control lines are shown. Since the control system approach is a significant design issue, the control system should be analyzed and documented in another *viewpoint* on the design. Similar definitions of the midpoint and top assemblies are provided in Figures 12 through 15. Table 5 documents a trade study performed to analyze the three top assembly alternatives.

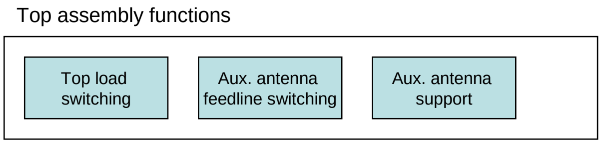


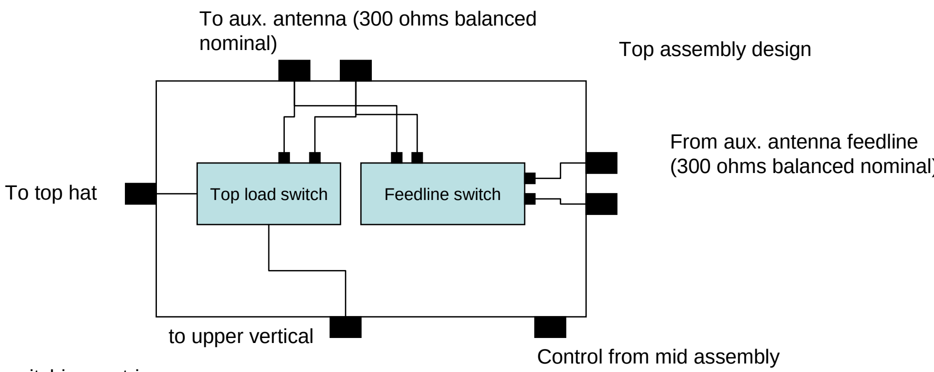
Midpoint Assembly Switching Matrix

Antenna Topology Select	**Lower – Upper Connection**	**Midpoint Feed Hot Switching**	**Midpoint Feed Ground Switching**	**Midpoint loading**
Monopole (buried radials)	Shorted or Open	Not connected	Not connected	Select 0..n or value (single ended)
Monopole (low counterpoise)	Shorted or Open	Not connected	Not connected	Select 0..n or value (single ended)
Monopole (Ground Plane)	Open	To upper vertical	To counterpoise	Select 0..n or value (single ended)
Dipole	Open	To balun	To balun	Select 0..n or value (dual ended)

Figure 12 - Midpoint Assembly Design

Top Assembly Alternative #1

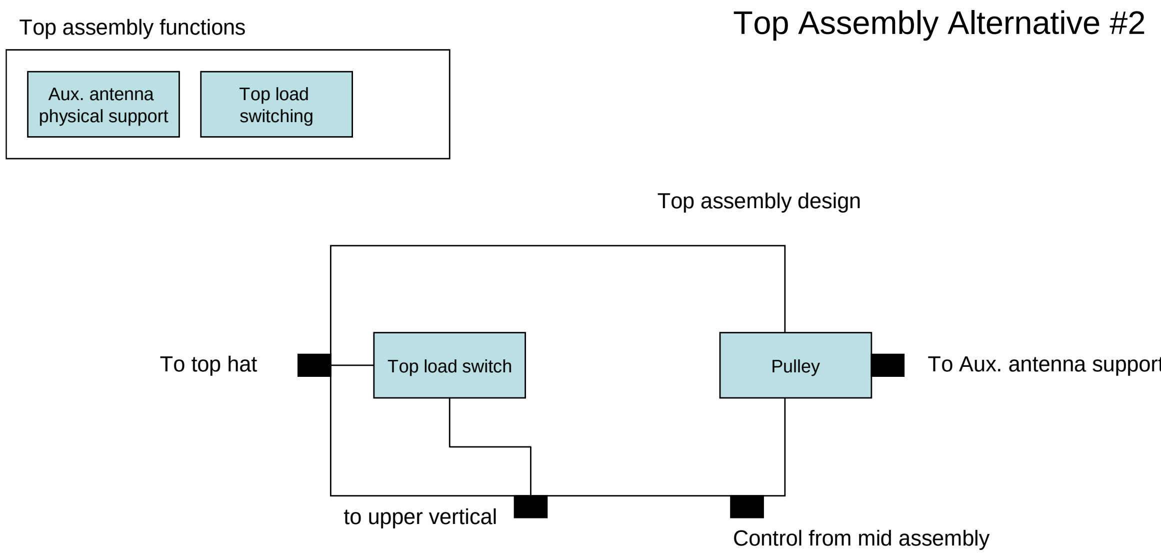




Top assembly switching matrix

Top Load Selection	Top Load Switch	Feedline Switch
None	No connect	Connected to aux. antenna
Hat	Hat	Connected to aux. antenna
Aux. antenna	Aux. antenna (legs shorted)	Not connected.
Both	Hat and both legs aux. antenna (legs shorted)	Not connected.

Figure 13 - Upper Assembly Alternate #1



Top assembly switching matrix

Top Load Selection	Top Load Switch
None	Open
Hat	Closed

Figure 14 - Upper Assembly Alternate #2

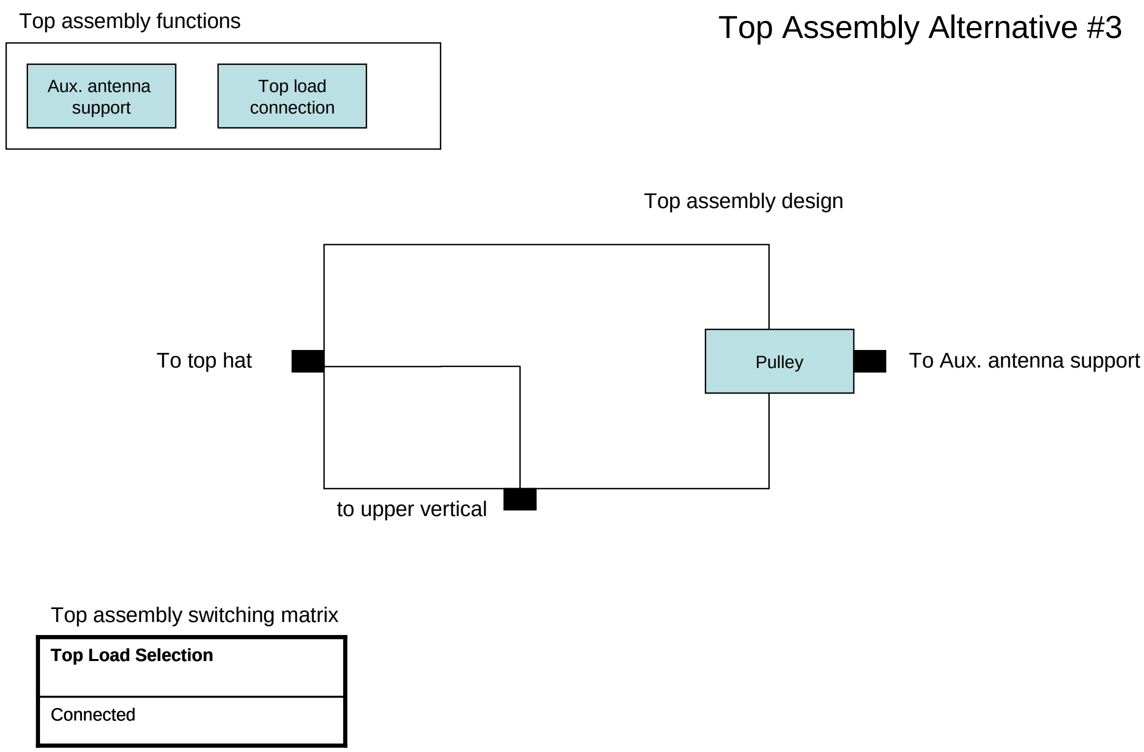


Figure 15 - Upper Assembly Alternative #3

Trading the Top Assembly Alternatives

Top Assembly Alternative	Support for raising aux. antenna	Variable Top Loading	Simplicity
Alt #1	None	Excellent	Poor
Alt #2	Yes	Fair	Fair
Alt #3	Yes	None	Excellent

Table 5 - Top Assembly Alternatives

Rating the three alternatives clarifies the importance of the pulley arrangement for raising the auxiliary antenna and how this capability conflicts with the capability to use the auxiliary antenna as an end load. In this application, alternative two or three would be preferred depending on how the utility of the limited variable end loading capability is traded against the increased complexity of the assembly due to the required switching.

Risk Analysis

During risk analysis, risks are forecast in terms of their probability of occurrence and the impact if they do occur.

The key risks identified for this project were:

Risk Event	**Probability of Occurrence**	**Impact**	**Mitigation Strategy**
homeowners association requires that antenna be removed	moderate	catastrophic	Limit visibility, preemptively request permission
lightning strikes	low	catastrophic	Use lightning arrestors and ground antenna
RF exposure exceeds limits	moderate	reduce power	conduct RF exposure analysis, produce plan
high winds	moderate	failure of structure	Build structure to withstand
ice storms	moderate	Failure of structure	Build structure to withstand

Table 6 - Risk Analysis

Risk management strategies were then defined to lessen the probability of the risk event occurring and to mitigate the impact if it does occur. The system design should be updated as a result of the risk analysis.

Reuse Opportunities

Reuse opportunities are considered, at least informally, starting with the inception of every design. This has both positive and negative aspects. Properly applied, reuse can substantially reduce system cost. Improperly applied, it can result in a suboptimal system, or in amateur terms, an ugly “junk box special”. A number of reuse opportunities were identified during the design process using materials that were in the author’s junk box.

- surplus aluminum tubing (2”, 1 ½”, ½”, 3/8”)
- surplus heavy duty DPST 24V relays
- 4” PVC pipe sections
- 50 ohm coaxial feedline
- Ununs and baluns built from Jerry Sevick’s book.

Incremental Build Approach

It is desirable to provide the capability to start simple and expand the design later. For example, much of the switching capability was deferred to a later version with manual band changing provided initially.

Increment 1:

- Vertical monopole with center insulator
- Manually switched center loading coils (ground mounted monopole mode)
- Top-hat loading (fixed)
- Base feed
- Coax feed
- Ununs, current chokes
- Buried ground radials
- Aux. antenna loading (parasitic) – this was unplanned
- Lightning arrestor
- Manual antenna grounding
- Manual tuner in shack

Increment 2:

- Low counterpoise (removable, manually selected)
- Dipole mode
- Center feed (dipole mode)
- Second End hat
- Manually switched center loading coils (dipole mode)

- Manual feed point selection
- Automatic tuner at base of antenna (150W)

Increment 3:

- Switched top hat
- Center feed (ground plane monopole mode)
- Mid-counterpoise
- Manually switched center loading coils (ground plane monopole mode)

Increment 4:

- Remote feed-point switching
- Remote topology switching
- Remote counterpoise switching
- Remote aux. antenna loading coil select
- Remote antenna grounding
- Automatic tuner in shack

Increment 5:

- Computer assisted control

- Automated band switching
- Automated antenna grounding
- Automatic tuner at base of antenna (1500W)

The flowing table shows how the Incremental builds satisfy the threshold and objective requirements. Requirements satisfaction is informally scored:

- (G) Green – good
- (Y) Yellow – fair
- (R) Red – unacceptable

Note that in some cases, the design approaches satisfy requirements for portability and cost in early increments, but increasing the complexity and sophistication of the designs eventually sacrifices both. This may require either the requirements or design to be re-evaluated.

Requirement	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Have strictly limited visibility from the street during daytime (T)	G (note 1)	G	Y	Y	Y
Have limited visibility from the street at night (T)	G	G	G	G	G
Require no guy wires in the fixed installation (T)	G	G	G	G	G
Operate CW and Phone on the following ham bands: 160, 80, 40, 20, 15, 10 (T)	G	G	G	G	G
Operate on all HF ham bands (O)	R	G	G	G	G
Support band switching in 5 minutes or less (T).	G	G	G	B	B
Support band switching in 1 second or less (O).	R	R	R	G	B
Support band switching without leaving the operating position (O).	R	R	R	G	G
Must be tunable to a SWR of 2:1 or less using my existing antenna tuner in the shack.	G	G	G	G	G
Provide low angle radiation on all bands (T)	Y	G	G	G	G
Have “reasonable” efficiency on all bands. (T)	Y	G	G	G	G
Operate at the 1500 watt CW level (T)	G	G	G	G	G
Survive a lightning strike with little or no damage to antenna or other equipment (T)	G	G	G	G	G
Support easy maintenance of all antenna components (T)	G	G	Y	R	R
Support 360 degree operations (O)	R	R	Y	Y	Y
Provide support at the top for other wire antennas (O)	G	G	G	G	G
Be portable for vacation operations (O)	Y	Y	Y	R	R
Be “relatively inexpensive”, and use as much of the junk box as possible (O).	G	G	G	Y	R
Create no safety hazards (T).	G	Y	Y	Y	Y

Table 7 - Phased Requirements Satisfaction

(Note 1) – The auxiliary antenna is slightly visible from the street (100’ long inverted vee).

Current Status and Performance

The antenna system has been implemented (through Phase 1) and has been used to operate several DX contests making significant numbers of contacts. A photograph of the system is provided in Figure 16. Here the antenna is being used as a center support for a 100' long open-wire-fed inverted Vee. The Vee does load the vertical and lowers the resonant frequency a bit when it is installed. Figure 17 shows the Phase 1 midpoint assembly with homemade 160 meter loading coil constructed from Teflon ™ insulated wire and a form made from PVC pipe.

Figure 16 - Installed Phase 1 System

Figure 17 - Phase 1 Midpoint Assembly

The antenna operates well to the Northern Hemisphere and Caribbean, but due to the sloping ground, performance to South America is very poor. An auxiliary antenna (inverted vee with apex at about 27 feet) was used to provide (very) limited coverage of South America. After raising the auxiliary antenna it was found that parasitic coupling of this antenna to the vertical lowered the resonant frequency of the vertical (by about 150 KHz on 40 meters). This should have been expected, but was not. The antenna tuner was able to deal with the SWR mismatch that resulted.

The author expects that Phase 2 will improve performance to the South by raising the current maximum approximately 12-14 feet, clearing front yard ground level. Incidentally, the sloping ground and aluminum sided house seems to act as an effective reflector on 160m (I received exceptionally strong reports from Pennsylvania during a recent 160m contest).

So far, no one has asked about the antenna, except a friendly neighbor who lives directly to the back of the house. The said they could barely see the antenna, but wondered what it was.

Although it would have been overkill to apply all of the “industrial strength” system engineering practices to the design of this antenna that I apply in my “day job”, it was very helpful to apply a tailored version of these to define the requirements and design for this antenna system. I believe this resulted in a better design. Although I make no claims that this is a superior antenna system or anything fundamentally new, it meets my needs and was an interesting project. Other radio amateurs can apply some of these same methods and thought processes to design their stations to efficiently meet their individual operating needs.