Half-Length 80-Meter Vertical Monopoles: the Best Method of Loading

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4. Top (Element-Extension) Loading: Linear, Zig-Zag, and Helical Loading

Models used:

35LH1030 35LH1530 35LH2030
35VT1010 35VT1510 35VT2010
35VT1020 35VT1520 35VT2020
35VT1030 35VT1530 35VT2030
35VZ1025 35VZ1525 35VZ2025
35VH1525

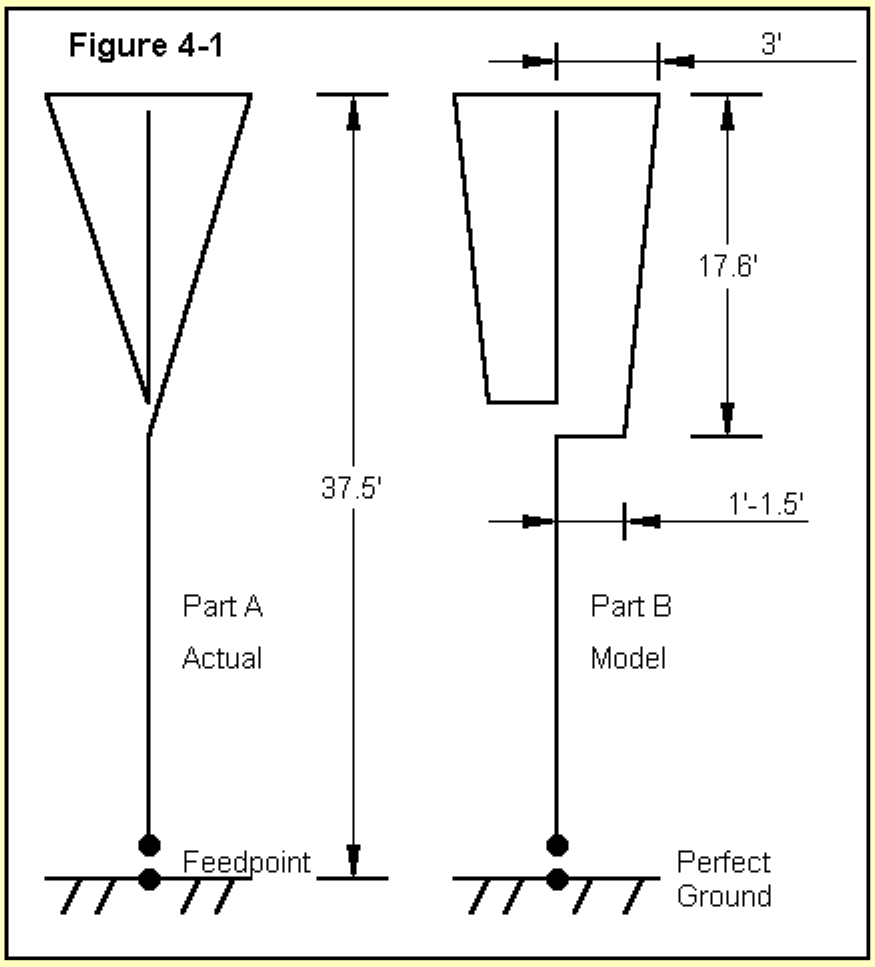
Virtually all forms of top-loading are forms of element extension loading, that is, means of extending the element length electrically without adding physical height to a given monopole. So-called capacity hats form a special case in which two or more extensions are symmetrically arranged to minimize radiation from the assembly. This measure is considered desirable whenever the designer wishes to preserve an essentially vertically polarized field from the monopole. With this in mind, we may overlook the inverted-L configuration, since the horizontal extension of the monopole element provides substantial horizontally polarized radiation to the overall pattern, thus disrupting the essentially circular, low angle pattern of a true vertical radiator.

However, there are a number of techniques of element extension loading that are not true hats and which do not add significant horizontally polarized radiation to the pattern. The pattern remains circular, low angle, and the horizontal component is at least 30 to 35 dB below the level of the overall radiation pattern.

A. Top Linear Loading

A top linear load represents a fold-back of the antenna element and a refold forward. The resulting assembly is visually similar to the base linear load. However, because it does not occur in the high current portion of the antenna element, it cannot be treated as a transmission line stub with inductive reactance. Indeed, inductive reactance grows progressively less influential on antenna performance the farther outward it is placed along the element. The top linear load should be treated as a simple fold-back whose overall length will be somewhat longer than the linear extension of the element to resonance. The lengthening is due to interaction with the nearby "lower" portion of the antenna it parallels, with consequential current cancellation. Since the current along the element is sinusoidal rather than linear, cancellations do not yield an easily calculable remainder apart from method-of-moments techniques.

One common form of top linear loading is the addition of a Tee element across but insulated from the top of the antenna. Supplementary wires from the ends of the conductive Tee connect to either side of an insulated break in the main element. Figure 4-1 illustrates the general principle.



Modeling the linear top load as in part A. of the figure would require a very tight acute angle, a difficulty for all method-of-moments software. To evaluate the general principle of top loading, an alternative model was developed with angles more closely approaching right angles, as shown in part B of the figure. A top bar at the 37.5' mark extends 3.0' either side of the main element. Supplementary wires (#12 AWG) drop to the 19.9' mark and to a mark 0.05' lower, connecting to horizontal extension rods from each side of the split main element. Interestingly, it was only necessary to extend or contract the length of this lower bar to adjust the configuration for main element diameters of 1 to 2 inches. The figure in the table is the length of the lower bar on one side of the antenna, with the other lower bar being of equal length.

Antenna Filename	Diameter in inches	Lower Bar length (feet)	Gain in dBi	Feedpoint Impedance in R ï¿½ jX ohms
35LH1030	**1.0"**	**1.5'**	**4.911**	**16.71 - 0.46**
35LH1530	**1.5"**	**1.25'**	**4.913**	**16.84 - 0.26**
35LH2030	**2.0"**	**1.0'**	**4.913**	**16.94 - 0.38**

The decreasing length of the lower bar indicates that less supplementary wire length was needed as the main element increased in diameter. Gain exceeds either form of base loading and approaches the gain of a capacity-hat monopole. Horizontally polarized radiation is down by at least 40 dB, and the vertical characterization of the field is thus undisturbed. The feedpoint impedance is considerably higher than that of base-loaded models, but still significantly lower than the capacity-hat models.

Antenna	Feed	3.5 MHz	3.55 MHz	3.6 MHz	3.65 MHz	3.7 MHz
35LH1030	**SWR**	**4.7**	**2.3**	**1.0**	**2.1**	**4.2**
	Z	**15.1-26.9**	**15.9-13.8**	**16.7-0.5**	**17.6+13.2**	**18.6+27.3**
35LH1530	**SWR**	**4.6**	**2.3**	**1.0**	**2.1**	**4.3**
	Z	**15.1-26.9**	**16.0-13.7**	**16.8-O.3**	**17.8+13.5**	**18.8+28.3**
35LH2030	**SWR**	**4.7**	**2.3**	**1.0**	**2.1**	**4.3**
	Z	**15.2-27.1**	**16.0-14.0**	**16.9-0.4**	**17.9+13.6**	**19.0+28.4**

The operating bandwidth of the top linear loaded monopole is slightly under 100 kHz with the lossless wire used in these models. With aluminum and copper materials, the bandwidth is likely to expand slightly to reach the 100 kHz mark.

B. Zig-Zag Top Loading

One alternative to using a single linear load element extension that eliminates some of the current cancellation as below the 20' mark of the main element is to use multiple folds. These folds, of uniform length, would surround the main element symmetrically in a 2-down-2-up pattern, resulting in four wires. A simple insulated cross at the antenna top and at the lower extremity of the element extension assembly could provide proper spacing. Figure 4-2 illustrates the general principle behind this zig-zag element extension.

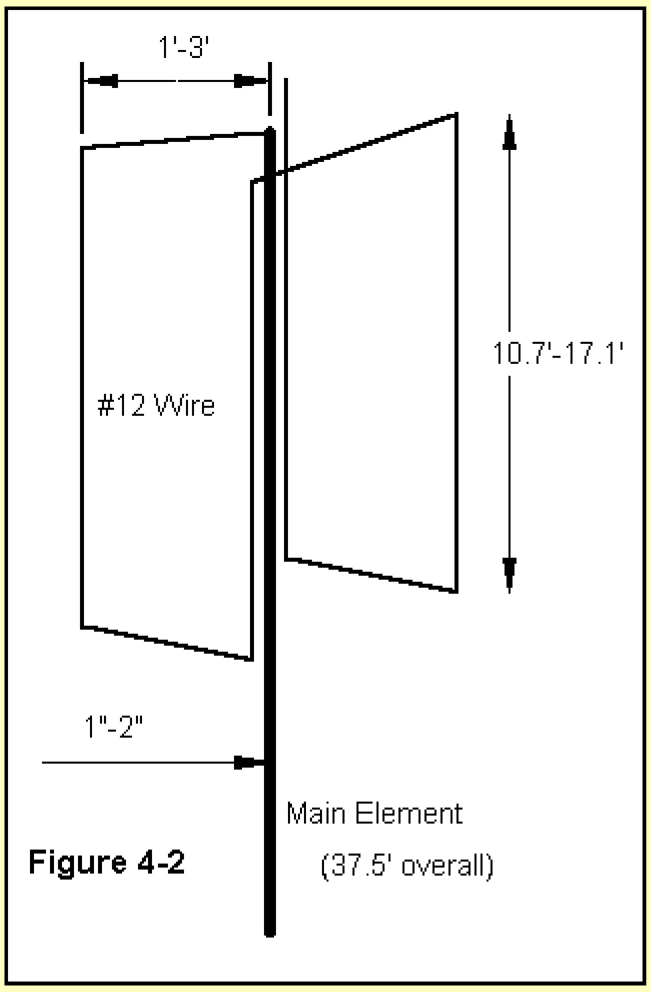


Figure 4-2

In principle, the zigzag assembly should result in a shorter overlap than the single linear top load. As a result, the antenna should exhibit additional gain, although this figure might well be marginal from an operational perspective.

A fairly large number of models were constructed, using different main element diameters and differing spacings from the main element of the supplemental wires (#12 AWG). In each table, the Zig-Zag length entry represent the length in feet of the wire assembly as measured from the top downward.

1. 1' center-to-center spacing from main element to zigzag assembly wires

Antenna Filename	Diameter in inches	Zig-Zag length (feet)	Gain in dBi	Feedpoint Impedance in R ï¿½ jX ohms
35VT1010	**1.0"**	**16.55'**	**4.914**	**16.55 + 0.24**
35VT1510	**1.5"**	**16.9'**	**4.913**	**16.47 - 0.10**
35VT2010	**2.0"**	**17.1'**	**4.913**	**16.42 - 0.70**

2. 2' center-to-center spacing from main element to zigzag assembly wires

Antenna Filename	Diameter in inches	Zig-Zag length (feet)	Gain in dBi	Feedpoint Impedance in R ï¿½ jX ohms
35VT1020	**1.0"**	**13.25'**	**4.924**	**17.78 + 0.41**
35VT1520	**1.5"**	**13.75'**	**4.923**	**17.66 + 0.13**
35VT2020	**2.0"**	**14.1'**	**4.923**	**17.57 + 0.32**

3. 3' center-to-center spacing from main element to zig-zag assembly wires

Antenna Filename	Diameter in inches	Zig-Zag length (feet)	Gain in dBi	Feedpoint Impedance in R ï¿½ jX ohms
35VT1030	**1.0"**	**10.7'**	**4.933**	**18.71 + 0.32**
35VT1530	**1.5"**	**11.26'**	**4.932**	**18.56 + 0.38**
35VT2030	**2.0"**	**11.62'**	**4.932**	**18.43 - 0.45**

The series of models exhibits several important traits. First, as the separation of the zigzag assembly grows larger, so too does the gain and the feedpoint impedance, while the required zigzag assembly length decreases. Second, within each group of models, increasing the main element diameter decreases gain and feedpoint impedance, while lengthening the required zigzag assembly. Figure 4-3 compares the required zigzag assembly length for each level of spacing and main-element diameter. The progressions are regular, but not precisely linear. Increasing the main element diameter actually decreases slightly the spacing of the assembly from the radiating surface of that element. Within each group, best performances comes from the smallest diameter main element, which may not be consistent with mechanical requirements for such antennas.

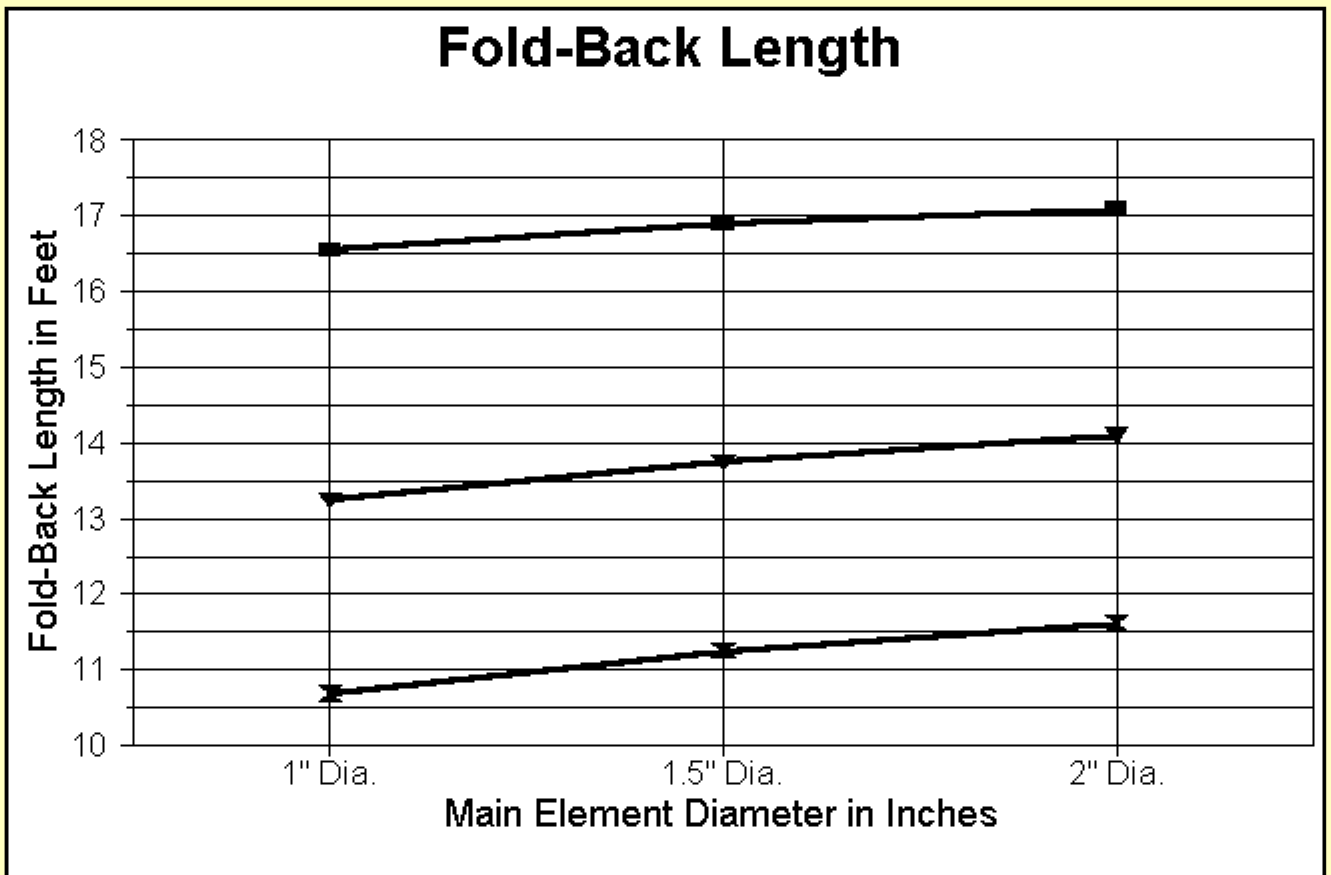


Figure 4-3

The overall length of the 4-wire zigzag assemblies may be compared with the length of the single top linear load: 17.6' from the antenna top downward at a top spacing of 3' from the main element. With equivalent 3' spacing from the element, the 4-wire zigzag assembly length is approximately two-thirds that of the 2-wire fold-back. The models using 1' spacing result in an assembly almost as long as the top linear load. However, had the top linear load been more closely spaced than 3' from the main element, it would have extended several feet farther down the element. In mechanical terms, the 1' spacing of the 4-wire zigzag assembly may be more mechanically sound than the 2-wire assembly spaced at 3' for very similar performance.

Although the gain increase of the zigzag loading method is operationally marginal, garnering the highest feedpoint impedance possible is of operational importance. Moreover, the assemblies spaced 3' from the main element exhibit another advantage over more closely spaced zigzags and linear top-loads: a wider operating bandwidth.

1. 1' center-to-center spacing from main element to zigzag assembly wires

Antenna	Feed	3.5 MHz	3.55 MHz	3.6 MHz	3.65 MHz	3.7 MHz
35VT1010	**SWR**	**6.4**	**2.7**	**1.0**	**2.8**	**6.5**
	Z	**14.7-33.2**	**15.6-17.0**	**16.5+0.2**	**17.6+18.5**	**18.8+37.9**
35VT1510	**SWR**	**7.1**	**3.0**	**1.0**	**3.0**	**7.4**
	Z	**14.5-35.3**	**15.4-18.4**	**16.5-O.1**	**17.6+19.6**	**19.0+41.4**
35VT2010	**SWR**	**7.9**	**3.3**	**1.0**	**3.2**	**8.2**
	Z	**14.3-37.5**	**15.3-19.9**	**16.4-0.7**	**17.7+20.7**	**19.2+44.6**

2. 2' center-to-center spacing from main element to zigzag assembly wires

Antenna	Feed	3.5 MHz	3.55 MHz	3.6 MHz	3.65 MHz	3.7 MHz
35VT1020	**SWR**	**4.1**	**2.1**	**1.0**	**2.1**	**4.1**
	Z	**16.0-25.9**	**16.9-13.0**	**17.8-0.4**	**18.8+14.2**	**19.8+28.5**
35VT1520	**SWR**	**4.3**	**2.2**	**1.0**	**2.2**	**4.2**
	Z	**15.8-26.6**	**16.7-13.5**	**17.7+O.1**	**18.7+14.4**	**19.8+29.4**
35VT2020	**SWR**	**4.4**	**2.2**	**1.0**	**2.2**	**4.5**
	Z	**15.6-27.0**	**16.6-13.6**	**17.6+0.3**	**18.7+15.0**	**19.9+30.7**

3. 3' center-to-center spacing from main element to zigzag assembly wires

Antenna	Feed	3.5 MHz	3.55 MHz	3.6 MHz	3.65 MHz	3.7 MHz
35VT1030	**SWR**	**3.4**	**1.9**	**1.0**	**1.9**	**3.3**
	Z	**16.9-23.3**	**17.8-11.7**	**18.7+0.3**	**19.7+12.5**	**20.7+24.9**
35VT1530	**SWR**	**3.5**	**1.9**	**1.0**	**1.9**	**3.4**

	Z	16.7-23.2	17.6-11.6	18.6+O.4	19.6+12.7	20.7+25.5
35VT2030	SWR	3.6	2.0	1.0	1.9	3.4
	Z	16.5-24.1	17.5-12.4	18.4-0.5	19.5+12.0	20.6+25.0

The trends in the general performance figures are replicated in the SWR and impedance sweeps. Within each group, the large the main element diameter, the narrower the operating band width. The greater the spacing of the zigzag assembly from the main element, the greater the operating bandwidth. A spacing of 1' does not achieve 100 kHz between 2:1 SWR figures. Figure 4-4 compares SWR curves for the 2" diameter main element models at the three spacings.

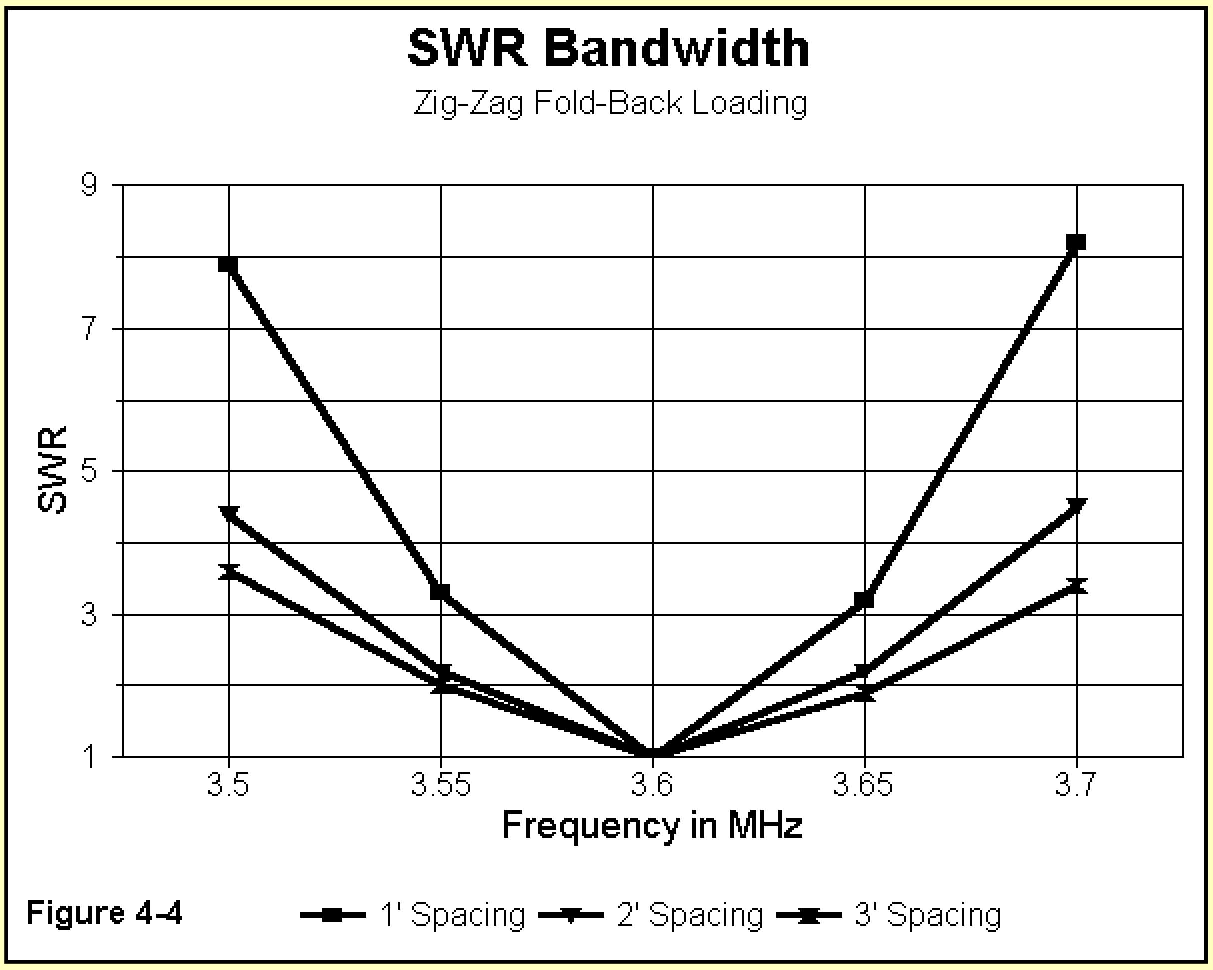


Figure 4-4

Although the 2' spaced assemblies exhibit a bandwidth similar to that of the 3' spaced top linear load, the 3' spaced zigzag assemblies show a clearly superior operating bandwidth. Added to the higher feedpoint impedance, this structure may be worth considering, despite its greater mechanical difficulties.

For all these models, horizontal components to the total field were greater than 35 dB down from the total pattern and virtually without effect on pattern strength and shape.

C. Helical Loading

An alternative to either the linear of zigzag top loading arrangements is the use of a helical loading extension. Such an arrangement is most effective when spaced some distance from the main element: a standardized 3' spacing was adopted for these models. Additionally, for efficiency and in anticipation of mechanical requirements for such a system, a coil-wire diameter of 0.25" was selected for the test loading elements.

When placed on an antenna far from the feedpoint, a loading helix shows little inductive reactance effect. Rather, the wire forms a coiled element extension to provide a current path sufficient for resonance. The inductive effect of the coil appears mostly in the fact that the total length of wire required for resonance is greater that for linear systems. On the other hand, the assembly can be quite compact. In the test models, the assembly was about 2' long. This figure may be best appreciated when compared to the 11' assemblies required for zigzag structures spaced 3' from the main element. Figure 4-5 illustrates the principle.

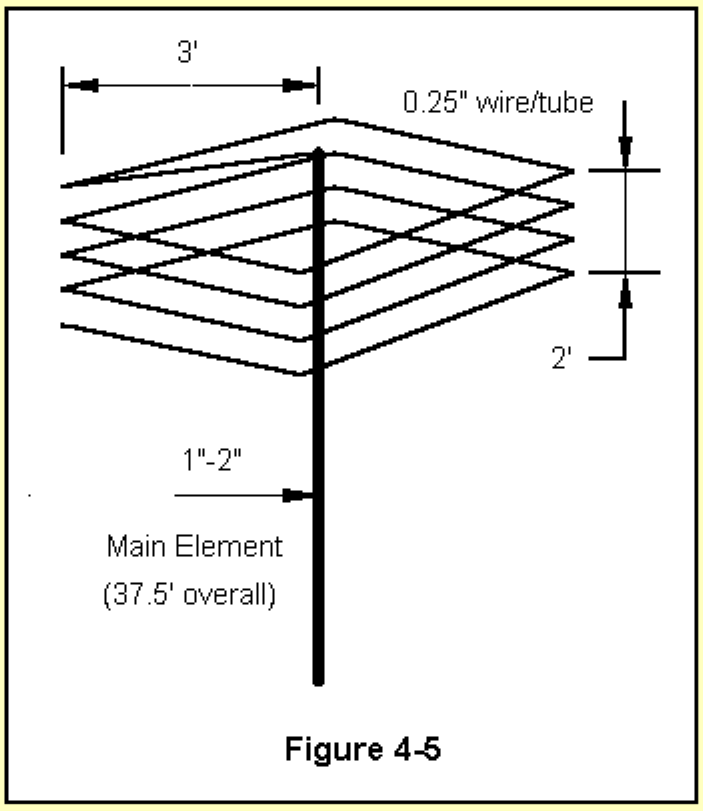


Figure 4-5

For test purposes, models were constructed using a square helix form, with each turn held at the same level and only the last of the 4 wires in the turn dropped to the next lower level. turns were spaced 0.5' apart. In the model table, the length of the coil is indicated by the number of turns and can be converted into feet by dividing by 2. Since spacing is a standard 3' from the coil, the last pair of numbers in the file name indicates the wire diameter. One constraint on the model due to the use of a square model coil is that part of each quarter turn passes as close as a little over 2' from the main element. A truly circular coil will require fewer turns for the same effect.

Antenna Filename	Diameter in inches	Number of turns	Gain in dBi	Feedpoint Impedance in R ï¿½ jX ohms
35VZ1025	1.0"	3.98	4.954	22.10 + 0.10
35VZ1525	1.5"	4.05	4.953	22.07 - 0.80
35VZ2025	2.0"	4.13	4.953	22.08 - 0.94

Shortening the length of the top-loading assembly has two beneficial effects. First, it reduces the amount of interaction between the assembly and portions of the main element carrying higher currents, with a consequential increase in antenna gain. Indeed, lossless wire gain figures are higher even than those for a capacity hat vertical (4.940 dBi vs. 4.953 dBi), although marginally so. The horizontal component of the total radiation field of the helical loading system is greater than 35 dB below the total field value.

Second, the same decrease in interaction raises the resonant feedpoint impedance to the 22-ohm range. This figure is second only to the capacity hat verticals (22.75 ohms) among the shortened monopole models and several ohms greater than corresponding zigzag and top linear loaded models (about 18.5 ohms). However, a relatively high resonant feedpoint impedance does not guarantee the widest operating bandwidth.

Antenna	Feed	3.5 MHz	3.55 MHz	3.6 MHz	3.65 MHz	3.7 MHz
35VZ1025	SWR	4.0	2.1	1.0	2.1	4.1
	Z	19.5-31.5	20.7-16.2	22.1+0.1	23.6+17.3	25.3+36.0
35VZ1525	SWR	4.4	2.2	1.0	2.1	4.3
	Z	19.3-33.1	20.6-16.0	22.1-O.8	23.7+17.3	25.7+37.3
35VZ2025	SWR	4.5	2.3	1.0	2.2	4.2
	Z	19.1-34.0	20.5-18.1	22.1-0.9	23.9+18.0	26.0+39.3

The 2:1 SWR operating bandwidth is less than 100 kHz (in these lossless wire models). The higher sweep limit SWRs are due to higher reactance components than in corresponding models of top loading using linear of zigzag assemblies.

Because the models used flat turns, the results were checked against several alternative models. Reversing the direction of the helix produced identical output figures. Bending the last turn in the helix toward the main element and using a vertical wire closely spaced to the main element as a means of resonance adjustment also had no effect upon the gain, the feedpoint impedance, or the SWR curve, although this arrangement may have significant mechanical implications. Finally, a model was created using a 0.125' per quarter turn descent rate. A model corresponding to the 1.5" flat turn model is presented for comparison:

Antenna Filename	Diameter in inches	Number of turns	Gain in dBi	Feedpoint Impedance in R ï¿½ jX ohms
35VH1525	1.0"	4.14	4.952	21.95 - 0.09

Antenna	Feed	3.5 MHz	3.55 MHz	3.6 MHz	3.65 MHz	3.7 MHz
35VH1525	SWR	4.3	2.2	1.0	2.2	4.5
	Z	19.2-32.7	20.5-17.1	22.0-0.1	23.6+18.3	25.5+38.6

These figures are virtually indistinguishable from those for the corresponding flat turn model, so further modeling of constant rate descent helical top loads and other similar configurations was judged unnecessary at this stage of the investigation.

Among the top-loading methods examined here, the wide-spaced helical method offers the highest gain and highest feedpoint impedance. The wide- spaced zig-zag assembly offers the greatest operating bandwidth. Figure 4- 6 compares the SWR curves of a sample (using 1.5" diameter main elements) of each top-loading method with the same main element diameter. Whether either is equally or more mechanically feasible than top linear loading is a judgment beyond the scope of this modeling study.

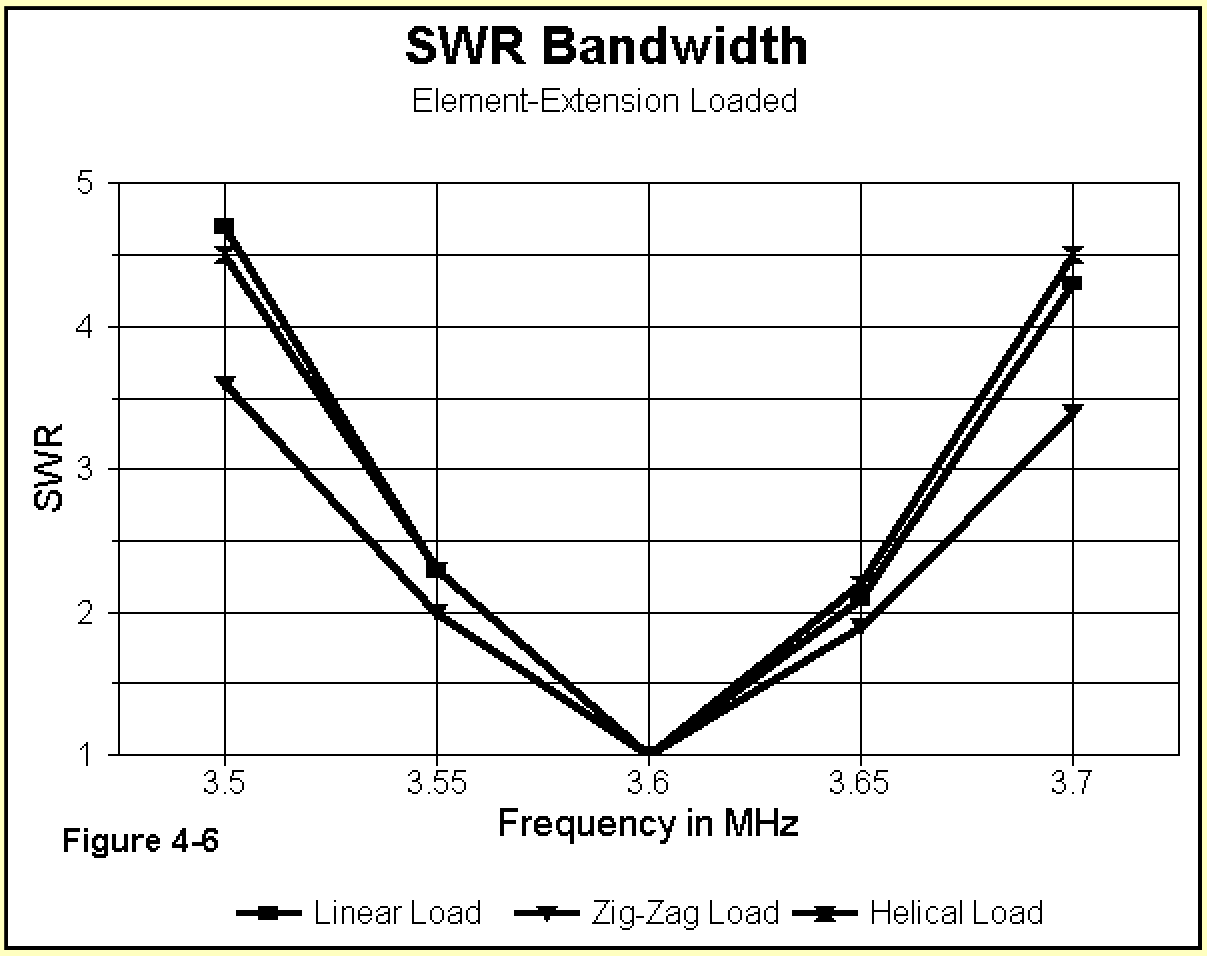


Figure 4-6

Using lossless wire against perfect ground permits a detailed comparison of the theoretical possibilities of element extension top loading. However, it is also fair to ask to what degree the use of real materials will moderate the promise shown by some of these models. The answer to this question is complicated by the fact that a real structure of any of these sorts is likely to be a composite of copper and aluminum in differing proportions, according to the load type. However, some indication may be given by looking at models of samples of each type of antenna. For an initial comparison with models using lossless wire, models were constructed of both all-copper and all-aluminum antennas using 1" diameter main elements. Given are the gain in dBi and the resonant feedpoint impedance.

File Name	Antenna Description	Gain dBi	Feedpoint Impedance Z = R ï¿½ jX in ohms	
1. Linear top-loaded model				
35LH1030	17.6x1.5' load, 1" mast	4.91	16.71 + 0.46	Lossless
		4.72	17.51 + 0.47	Copper
		4.62	17.92 + 0.45	Aluminum
2. Zig-Zag top-loaded models				
35VT1010	16.55' load, 1" mast	4.91	16.55 + 0.24	Lossless
	1' spacing	4.61	17.76 + 0.19	Copper
		4.45	18.40 + 0.17	Aluminum
35VT1020	13.25' load, 1" mast	4.92	17.78 + 0.49	Lossless
	2' spacing	4.76	18.47 + 0.46	Copper
		4.68	18.83 + 0.45	Aluminum
35VT1030	10.7' load, 1" mast	4.93	18.71 + 0.24	Lossless
	3' spacing	4.82	19.22 + 0.22	Copper
		4.76	19.49 + 0.20	Aluminum
3. Helically top-loaded model				
35VZ1025	3.98 turn load, 1" mast	4.95	22.10 + 014	Lossless
	3' spacing	4.89	22.41 + 0.13	Copper
		4.86	22.57 + 0.11	Aluminum

For further comparison, aluminum antennas falling into the full-size and capacity hat categories do not decrease gain or significantly change feedpoint impedance relative to lossless wire models. Gain reductions are of the order of 0.01 to 0.02 dB and impedance factor changes are less than 0.1 ohm.

Of the selected models, the 1' spaced zigzag model shows the greatest change of gain when modeled in aluminum. This occurs because the length of #12 wire is so long and the interaction with the main element extends farthest down the antenna. By way of contrast, the helical model, with only 2' of interactive length and 0.25" wire shows the least change of gain and feedpoint impedance of all the element extension top-loaded models.

Wide-spacing of the element extension load along with minimal load length appear to offer the most promise among models of this type for the best balance of gain, feedpoint impedance, and operating bandwidth. None of the top-loaded element extension models showed any type of resonance in or near the 20-meter band.

Go to Index