Half-Length Dipoles (for 40 Meters)
Part 3: Element Loading to Achieve Dipole Resonance

L. B. Cebik, W4RNL

We have set the half-length 40-meter dipole (using AWG #12 copper wire) at 33.33' (400"), which is within 1% of the modeled free-space length for such and antenna. We discovered that the precise length of a half-size dipole will actually vary with the height of the element above ground. So our arbitrary limit is useful in giving us a ready reference throughout these notes.

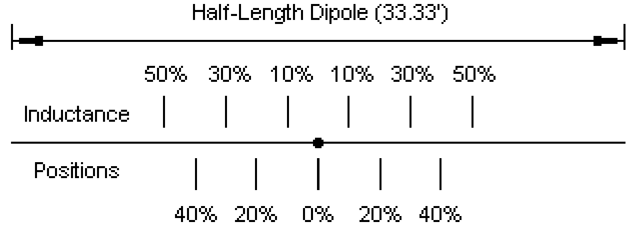
The first set of attempts to deal with this length involved reshaping a full-length dipole to fit this linear dimension. Of the distorted dipoles, the U shape proved most promising, since it provided usable gain and a feedpoint impedance value close to 50 Ω. However, the zigzag and the square interrupted loop versions may also have applications if we apply appropriate impedance matching techniques. However, only the U (in either an inverted vertical position or a horizontal orientation) held promise of covering the entire 40-meter band with less than a 2:1 SWR value.

In this episode, we shall examine the linear half-length element as a one-dimensional object, that is, one having only length without vertical or horizontal width. The challenge is to deal with the low feedpoint resistance (less than 13 Ω) and the high capacitive reactance (more than 900 Ω). The two operations are normally separate. We have noted—and shall note again—methods of transforming the feedpoint resistance to a usable (normally 50-Ω) value. First, we must compensate for the high reactance. The common expression for the techniques used reduce the reactance to zero and to thereby achieve resonance at the design frequency (7.15 MHz in this exercise) is element loading. If we introduce into the element a reactance of the same effective value, but of the opposite type, as the problematical reactance we measure at the feedpoint, the net effect will be a purely resistive feedpoint impedance, at least at the design frequency. We shall survey some of the variables associated with loading elements. In fact, before we close, we shall look at an additional method that also bears the name of loading, but which is in principle an entirely different technique altogether.

Inductive Loading

As we shorten the length of a dipole, the feedpoint reactance increases, slowly at first, but at an increasing rate with each additional increment of length reduction. Our half-length dipole intercepts this curve at a challenging point, just where the rate of reactance change begins to increase very rapidly with only small length changes. For reasons that will become very apparent, for most amateur installations, half-length is about the limit of shortening.

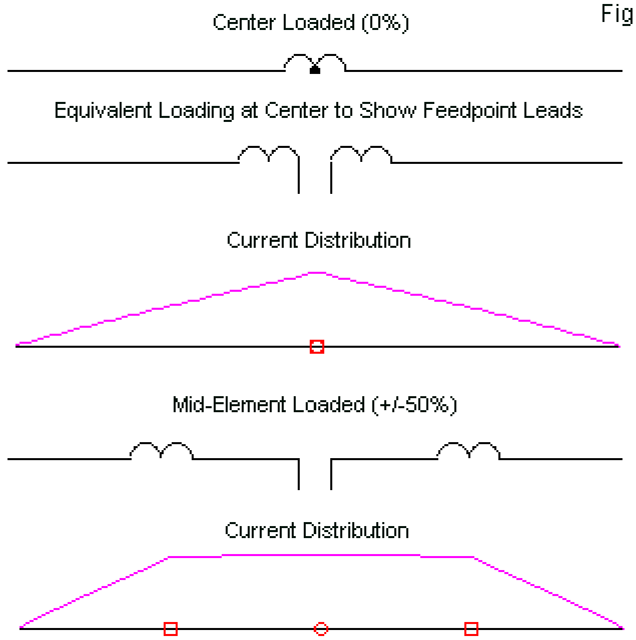
Fig. 1



Potential Load Positions along
Half-Length Dipole Element

Fig. 1 gives us a bit of important information. We may place the opposite type of reactance (inductive) at the element center, or we may place it in the form of two equal inductances away from the element center. For tubular elements, the center position is often mechanically convenient, but outer positions or mid-element loading is often used. If we think of the center inductance as actually two solenoid inductors (coils) in series with the feedpoint at their junction, then we discover that mid-element loading is simply an extension of center loading. **Fig. 2** provides a glimpse into the process.

Fig. 2



Effect of Load Position on Current Distribution along Half-Length Dipole Element

With a center-loading coil, the current is at peak value only at the very center of the element. A full-length dipole would show a broad region of high current before the current tapers to the element-end value of zero. A center loading coil substitutes for the part of the antenna that is normally at high current. Since the coil has almost no radiation, we lose much of the radiation that the high current would yield, with a resulting gain reduction. In contrast, if we place the coils further away from the feedpoint, we retain part of the element with the high current level. The lower part of the figure shows the current distribution with the loading coils at the middle or 50% point of each half element on either side of the feedpoint.

Unfortunately, we do not gain as much as the current distribution curve might suggest. Let's install loading coils at various points along the dipole in 10% increments, where 10% means a distance away from the feedpoint toward the element end. Initially, we shall treat the coils as pure inductances with no resistive losses. The results of our small experiment in modeling appear in **Table 1**. In the table, we treat the center-loading coil as a series combination of two coils so that the progression of required inductance values is clear. The farther outward from the center that we place the loading coils, the higher must be the individual inductance values. At the 50% mark, each individual coil has an inductance that is almost double the series center coil. The rate of inductance increase rises steadily as we move away from the center position. For this reason, the 50% mark represents a practical limit to loading inductor placement.

Half-Length Dipole with Inductive Loading				Table 1	
Load Position and Required Reactance and Inductance					
Pos: %	Ld React	Ld Induct	Gain dBi	Resist	React
0	464.85	10.35	1.71	12.7	-0.03
10	513	11.42	1.71	15.32	-0.46
20	570	12.69	1.72	17.81	-0.67
30	645	14.36	1.72	20.31	-0.75
40	748	16.65	1.73	22.86	0.11
50	894	19.9	1.74	25.44	-0.27
Notes:	Pos. %: Position measured from element center to				
		element end as a percentage of distance			
	Ld React: Load reactance in Ohms required to				
		resonate element			
	Ld Induct: Inductance in uH required to yield Ld React				
	Gain dBi: Free-space gain in dBi				
	Resist: Feedpoint resistance in Ohms				
	React: Feedpoint reactance in Ohms				
	Center (0%) load treated as 2 inductances in series				

Fig. 3 graphs the progression of required inductive reactance and inductance values that apply to the loads in the table. The chart allows us to sense more vividly the rate of increase in values with increasing distance between the loading component and the feedpoint.

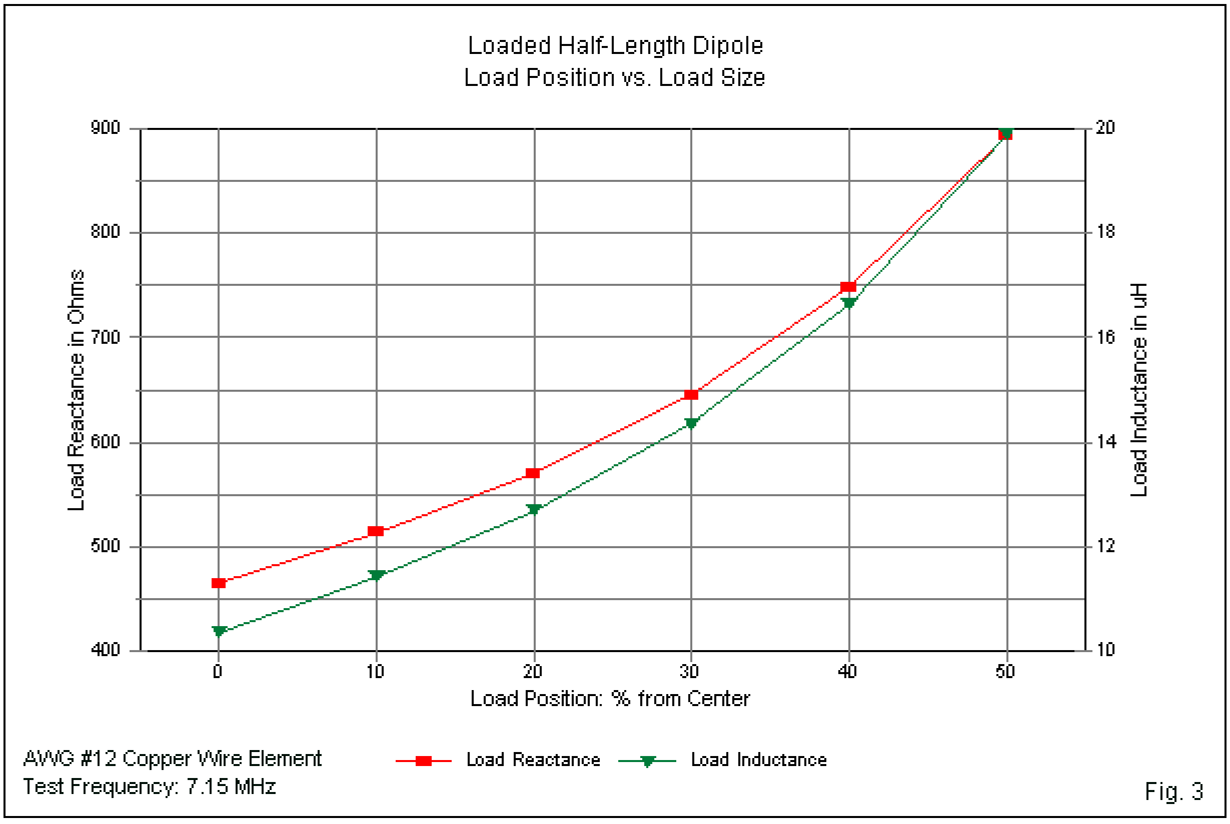


Fig. 3

Surprisingly, the element gain does not increase significantly as we move the loading coils outward from the center position (0%). (Mobile vertical monopole antennas have special circumstances that may call for loading-coil placement away from the feedpoint, but our horizontal dipole—here in free space—does not share in those circumstances.) The net difference in gain between center loading and 50% mid-element loading is only 0.03 dB, far short of a difference that we could detect in operation.

The table does reveal a different reason why some antenna builders prefer mid-element loading over center loading. As we move the coil outward, the resonant impedance rises. The center loading value of under 13 Ω calls for some form of impedance transformer at the feedpoint if we use a 50-Ω cable. In the previous set of notes, we noted some limitations of 1:4 transmission-line transformers. Before such transformers became readily available, antenna builders would employ second coil so that the turns-ratio of the two closely coupled coils created a 1:4 impedance transformer. The 50% mid-element coil placement yields a resonant impedance of about 25 Ω. We examined in the earlier notes a single series transformer composed of transmission line sections for converting this impedance to 50 Ω.

Regardless of the coil placement, inductive loading has one very negative consequence: very limited SWR bandwidth. **Fig. 4** provides curves for a center-loading coil and for a pair of mid-element loading coils. Coils at all other positions would yield curves that fit between these two limiting cases. The 2:1 SWR bandwidth of the inductively loaded is less than 1/5 of the entire band. (Longer elements with less loading would show wider SWR bandwidth values.)

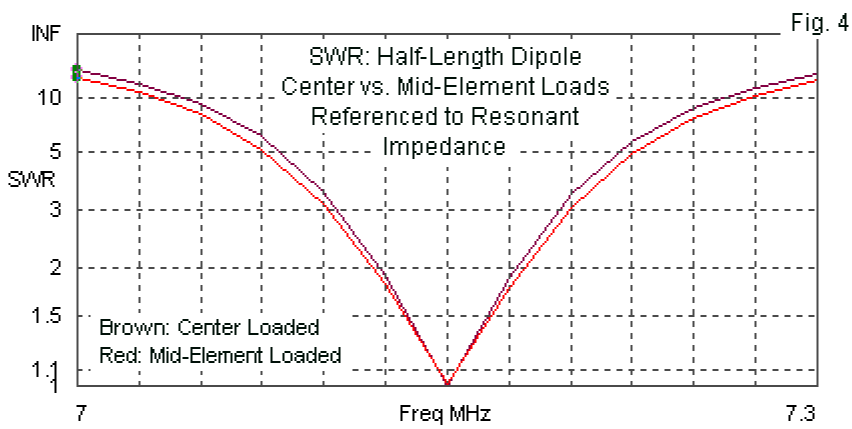
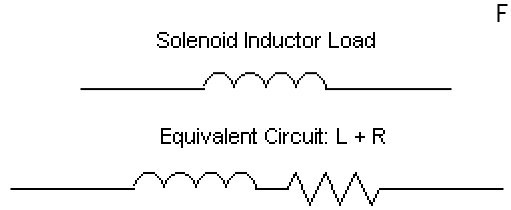


Fig. 4

In our examination of the basic properties of inductive loading with solenoid coils, we have purposely set aside an important aspect of loading: coil Q. The Q of a solenoid coil is simply the coil's inductive reactance divided by the series resistance, as shown by the equivalent circuit in **Fig. 5**. Since coil wire is subject to skin effect, the RF resistance of a coil is higher than the simple DC resistance of the wire. As well, the value of Q and the resulting resistive losses depend on the coil shape.

Fig. 5



Equivalent Circuit for an Inductive Load

Let's begin with the center-loading coil, which has a total inductance of over 20 µH to obtain a reactance of over 900 Ω. Practical values of Q may range from a low of 100 to perhaps 600 for a coil with a high ratio of diameter to length. Most practical coils tend to fall in the range of 250 to 350. **Table 2** shows the consequences for performance for Q values between 600 and 100 in steps of 100.

Center-Loaded Half-Length Dipole: Q				Table 2
Reactance: 929.7 Ohms			Inductance: 20.69 uH	
Q	Ind Res	Gain dBi	Resist	React
Infinity	0	1.71	12.7	-0.03
600	1.55	1.21	14.3	-0.03
500	1.86	1.12	14.6	-0.03
400	2.32	0.98	15	-0.03
300	3.1	0.76	15.8	-0.03
200	4.65	0.36	17.4	-0.03
100	9.3	-0.67	22	-0.03
Notes:	Q: Loading coil Q			
	Ind Res: Loading coil series resistance			
	Gain dBi: Free-space gain in dBi			
	Resist: Feedpoint resistance in Ohms			
	React: Feedpoint reactance in Ohms			
	Values for a single solenoid inductor			

As we lower the value of Q and thereby increase the resistive losses, we discover a further reduction in dipole gain. The values are still usable, if we remember that the free-space gain of a full-length AWG #12 copper wire dipole is only about 2.05 dBi. However, for low values of Q, the difference is operationally noticeable. In the process of lowering the gain due to resistive losses in the loading coil, we rediscover the resistance in the feedpoint impedance, which is now the sum of the radiation resistance and the loss resistance. By itself, the impedance with a Q of 100 seems promising until we remember that nearly half of it represents lost energy.

Mid-Element-Loaded Half-Length Dipole: Q				Table 3
Reactance: 894 Ohms			Inductance: 19.90 uH	
Q	Ind Res	Gain dBi	Resist	React
Infinity	0	1.74	25.4	-0.27
600	1.49	1.29	28.3	-0.31
500	1.79	1.2	28.8	-0.32
400	2.24	1.07	29.7	-0.34
300	2.98	0.88	31.1	-0.37
200	4.47	0.5	33.9	-0.43
100	8.94	-0.46	42.3	-0.67
Notes:	Q: Loading coil Q			
	Ind Res: Loading coil series resistance			
	Gain dBi: Free-space gain in dBi			
	Resist: Feedpoint resistance in Ohms			
	React: Feedpoint reactance in Ohms			
	Values for each of two solenoid inductors			

We can repeat the exercise with loading coils placed at the mid-element (50%) position. When separated from the feedpoint, neither the coil inductance nor its impedance impact the feedpoint resistance directly. Therefore, we find a small variation in the feedpoint reactance column that was absent from the center-load table. However, the trends are identical. The lower the value of coil Q, the lower will be the overall antenna gain, but with a rise in feedpoint resistance that reflects the increased losses in the coils. The gain values may seem to be higher for the mid-element loading case than for the center loading situation, but **Fig. 6** shows just how little that difference is. Moreover, the curves almost exactly parallel each other across the sampled span of Q values.

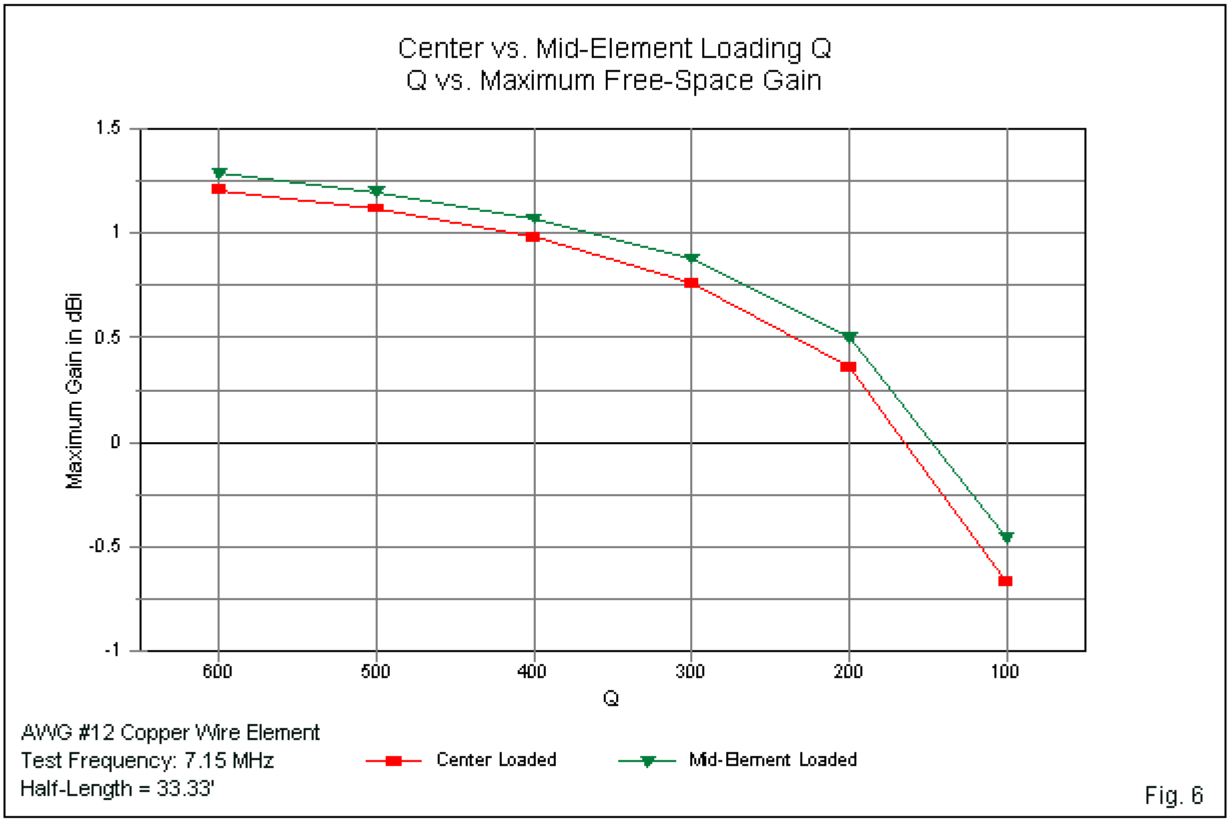


Fig. 6

The trends for the resonant feedpoint resistance show a comparable set of parallel curves, even though the initial values for the curves are more widely separated. **Fig. 7** shows the two data sets. A high-Q loading coil set for mid-element loading provides a matchable situation relative a 50-Ω transmission line. The low-Q situation may in fact allow a direct match to the cable, although at the cost of considerable gain from the antenna element.

Of course, the mid-element loading coils, with their high inductive values, also present special support problems not fully shared by the center-loading coil. Each mid-element coil is nearly the same weight (given a fixed construction method for a fixed level of Q) as the single center-loading coil. For a wire element, such as our copper wire half-length dipole, the coils can create significant sag. In antennas using tubular aluminum as the desired material, a center-loading coil is in line with the normal single support for the element. In contrast, mid-element loading coils place the weight away from the supporting mast, increasing gravity's stress on the element and also increasing the element's wind load. The use of mid-element loading coils for a 33' aluminum element (about the length of a 20-meter full-length dipole) may call for increased tubing sizes, with some sections doubled, to support the coils effectively for the same all-weather, all-season survivability as a single center-loading coil. The knowledgeable antenna builder will take these factors into consideration long before actual antenna construction begins.

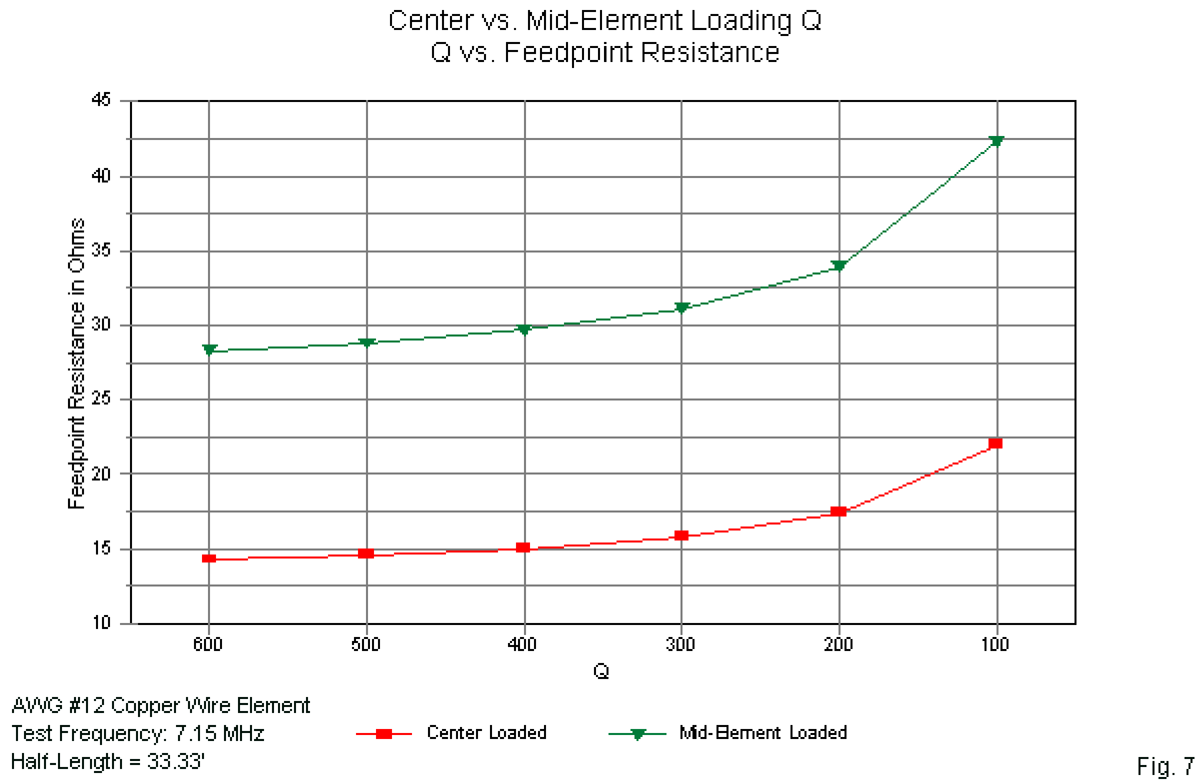
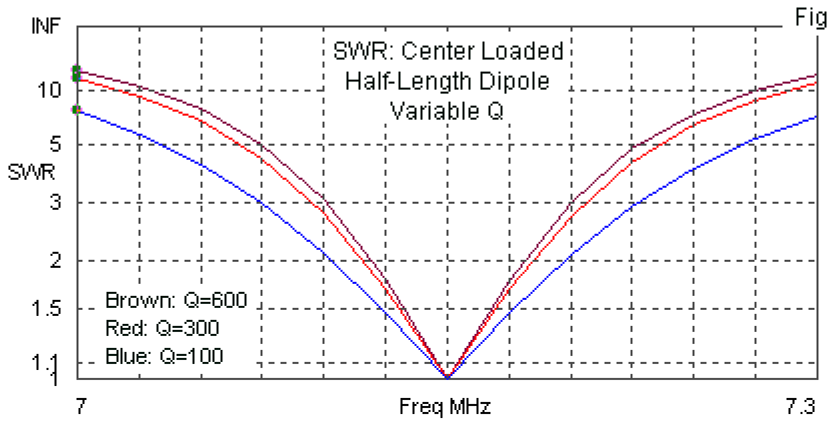


Fig. 7

Loading coil Q has an affect upon the SWR bandwidth of a half-length dipole. However, the broadening of the bandwidth does not become significant until the Q drops below about 300. **Fig. 8** shows the SWR bandwidth (referenced to the resonant impedance of each sample) of a center-loaded dipole for Q values of 600, 300, and 100. Only in the last case do we find a bandwidth that approaches 100 kHz, at the cost of appreciable gain, of course. For the two higher values of Q, we find bandwidths ranging from a little under 50 kHz to a little over 50 kHz.

Fig. 8



Moving the loading coils outward to the mid-element (50%) position does not improve the bandwidth beyond the very slight advantage shown by the initial lossless coils, as revealed by the SWR curves in **Fig. 9**. High values of Q yield a bandwidth of about 70 kHz, while a Q of 100 yields a 100-kHz bandwidth. One of the severe limitations of inductive loading is always the limited coverage of an amateur band as wide as 40 meters compared to a full-length dipole, however, we may implement the required element loading.

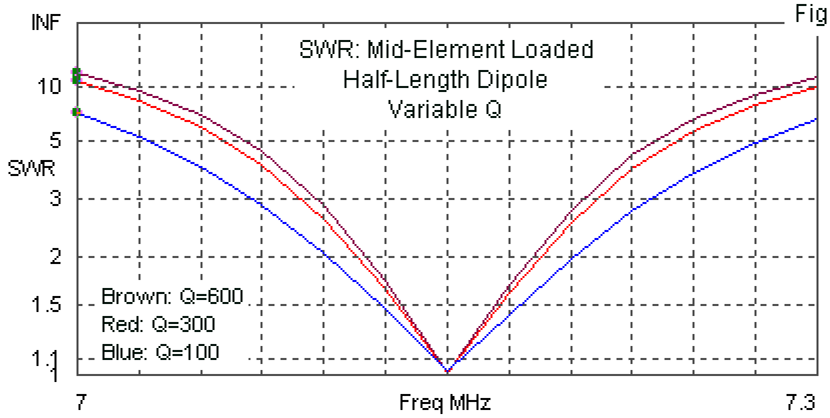


Fig. 9

Linear Loading

In the history of amateur radio's experimentation with loaded elements, beyond the range of direct recall, an alternative system of loading emerged. Called "linear loading" by its early users (and some present-day users), the scheme used lengths of wire, usually paralleling the main element, to effect the required loading. Because the scheme did not use inductors with known loss sources, early proponents claimed that linear loading was lossless. Once we began to understand exactly what was going on—besides adding a set of wires to an element—the claim of no losses began to disappear. As shown in **Fig. 10**, the wires actually form shorted transmission line stubs that replace solenoid inductors as the source of loading reactance for an element. Unfortunately, shorted transmission line stubs do exhibit losses.

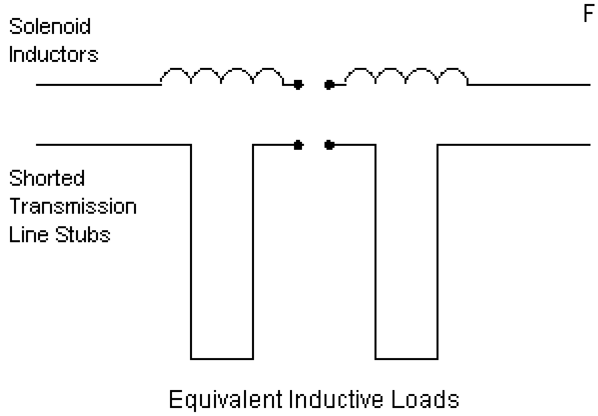
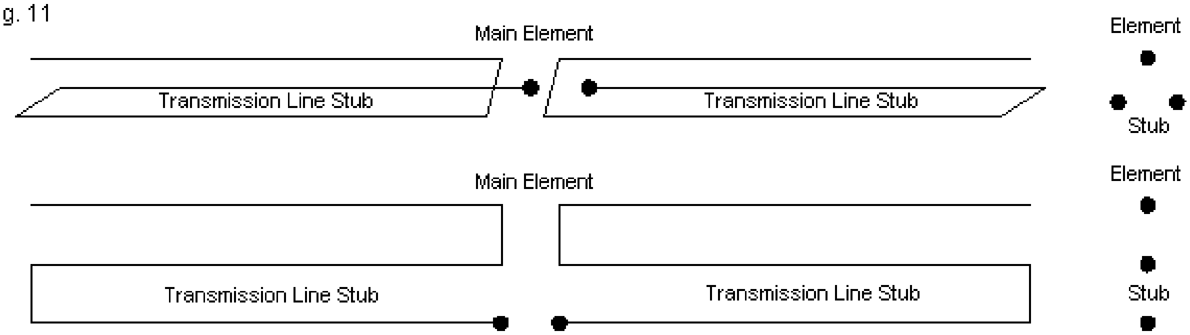


Fig. 10

The calculation of stub length requires a two-step process. First, we can calculate the likely characteristic impedance (Zo) of the stubs by knowing the wire diameter and the spacing (center-to-center) between wires, using any of several utility programs or a calculator. Then the inductive reactance of a shorted stub that is less than ¼ λ long is simply the product of the Zo times the tangent of the electrical length of the stub in degrees (or radians). If we know the desired reactance, we can always back out the electrical length in degrees and then the physical length as a fraction of a wavelength, and finally, the physical length in inches or feet.

There are two general implementations of linear loads for an element, both of which are applicable to our 40-meter half-length dipole. **Fig. 11** provides an outline of both forms. First, in both cases, the linear load or transmission-line stubs do not hang at right angles to the element, although the hanging configuration is possible, however impractical. Instead, we parallel the stubs, one on each side of the feedpoint, to the main element. In the first case, the shorted stub lines are equidistant from the element and form a triangle when taken together with the main element. Under these conditions, the lines act most like a pure transmission-line stub, since coupling with the main element is equal on both lines.

Fig. 11



Common Forms of Linear Loading with Transmission Line Stubs

The second case that places the stubs in a linear row beneath the main element is more common to home built wire antennas than to commercial implementations of linear loading. In this scheme, the differential coupling between the two wires and the main element creates a small imbalance in the currents in the load lines. The system will still work perfectly well, but usually requires a longer stub length on each side of the feedpoint.

Unfortunately, if we restrict ourselves to a main element with a total length of 400", the stub lengths will slightly exceed the element length. The antenna will still work, but for the sake of aesthetics, I set each type of linear load so that the load lengths and the element length were all the same. All AWG #12 wires in each scheme are two inches apart. **Table 4** shows the differences in the free-space models. The table also includes a special entry that uses NEC transmission lines with the same total length as the element. I assigned the lines a typical ladder-line loss factor of 0.06 dB/100' at 10 MHz to sample potential line losses.

Table 4. Linear loading using shorted transmission line stubs

Model Type	Half Length Inches	Max. Gain dBi	Feedpoint Z R +/- jX Ω
NEC Xmsn Lines	204.2	0.86	16.8 – j0.0
Triangular Wires	205.0	0.49	17.1 + j0.9
Linear Wires	210.4	0.77	17.0 – j0.1

Notes: Transmission-line stubs and main elements are the same length.
Total dipole length is twice the length shown.
Each of two shorted stubs is the length shown.
All wire assemblies use AWG #12 copper wire.
Wire Spacing: 2".
Model environment: free space.

The first notable item in the table is the similarity of antenna lengths when using non-interactive NEC transmission lines and when constructing the lines from copper wires in a triangular formation allowing equal interaction of the main element with each stub wire. The gain suggests an overly optimistic assignment of losses to the NEC lines. The triangular version of the wire loads shows increased gain if we move both stub wires farther from the main element. At a distance of 4", the level of the lowest wire in the linear system, the gain rises to about 0.7 dBi. The gain is similar to the value that we obtain from the linear system, which requires about 5" of additional length at both ends of the element-stub combination.

The gain values are consistent with a center-loading system with a Q of about 300. Since the loads are electrically about 1% to 2% off center, the feedpoint impedance values are also consistent for Q values of about 300. We may note in passing that all three impedance values are sufficiently alike to confirm the equality of the three schemes shown.

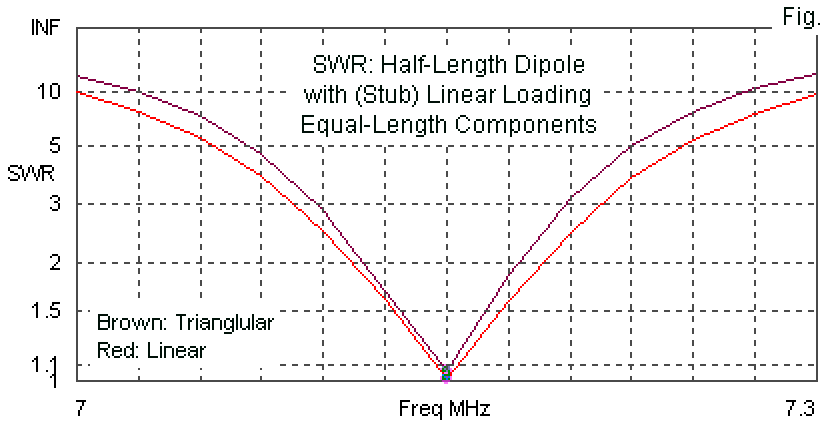
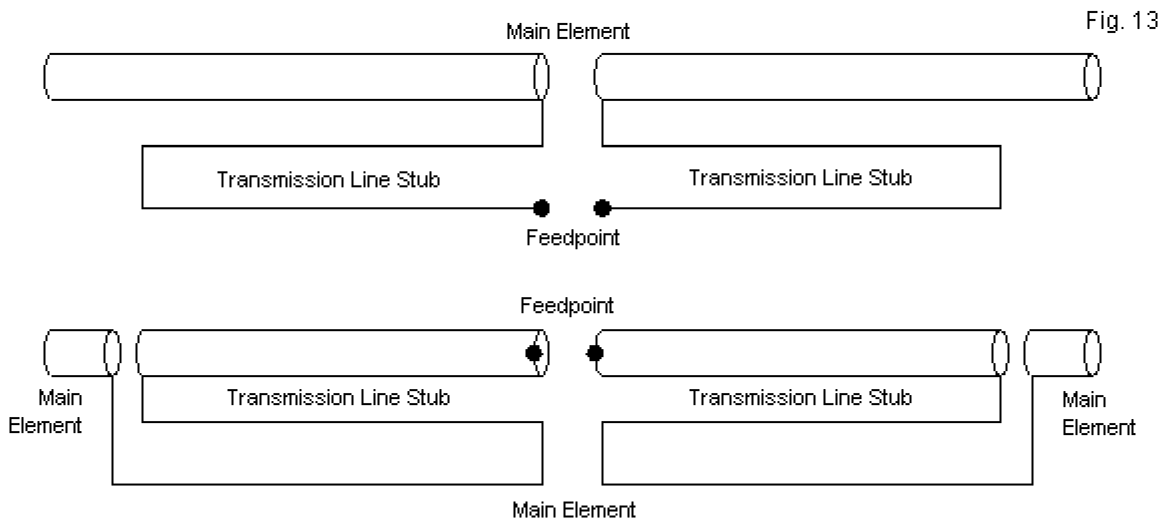


Fig. 12

As shown in **Fig. 12**, the SWR bandwidth of a linear loaded system is only marginally broader than the curves for the center-loaded dipole with a Q or 300. The linear system is slightly broader than the triangular system, but again in the margins of significant improvement. The curves also establish the limited Q-equivalence of linear loading, since a very high Q or very low loss value for the linear loads would yield a narrower SWR operating bandwidth.

Perhaps the chief reason for using linear loading has little to do with the performance of the element. Rather, by distributing the weight of the loading element along the entire length of the antenna, we generally remove many of the support problems that accompany the use of coils in a wire antenna that we intend to support only at the ends. Linear loads in some circumstances offer a mechanical advantage in antenna construction.

One perennial matter of perspective sometimes clouds the eyes of less experienced antenna builders. Suppose that we intend to use a tubular main element, with wires or rods for the linear loading elements. We might end up with an assembly like the upper half of **Fig. 13**, shown in linear form for pictorial clarity. The feedpoint clearly goes to the pair of transmission-line stubs. However, numerous commercial linear-loaded elements (usually for 20 meters and higher) bring the feedpoint to the tubular element and use a set of wires or rods that seem to begin at a point further outward on the element. It appears that the antenna is using a form of linear loading that is a version of mid-element loading. For whatever reason, the antenna builder has bent the linear loading stubs back toward the center of the element. Unfortunately, this view of the lower element sketch can deceive us.



Alternative Implementations of Linear-Loading Transmission Line Stubs

The lower sketch is electrically identical to the upper sketch. In this case, the loading element is composed of two wires with different diameters, a situation that slightly complicates the calculation of the stub characteristic impedance. The main element employs one of the thinner lines as part of its structure until that line intersects with the tubular material beyond the end of the stub. (There are cases in which one may employ mid-element loading with a transmission-line stub, but they require elements longer than the half-length dipole that we have set as our project limit. With element lengths about 70% of full size, one may install a mid-element stub and bend it outward toward the element end—or let it hang in the wind.)

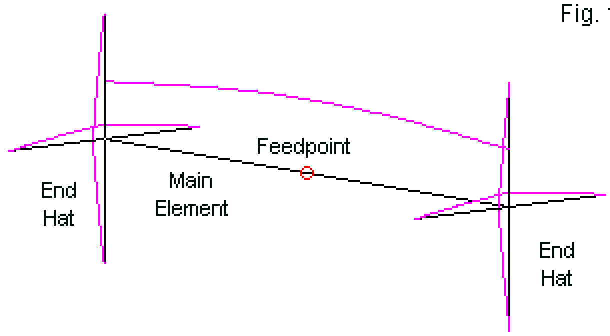
Linear-loading, then, is simply a form of inductive loading that makes use of shorted transmission-line stubs to create the necessary inductive reactance to bring an element to resonance. The stubs are substitutes for the solenoid inductors that we most commonly think of when the subject of loading arises.

End-Hat Loading

For many decades, an alternative form of bringing a shortened element to resonance has gone under a misleading label: end capacity-hat loading. The name derives from an early method of approximating the hat size on low and medium frequencies. The calculation scheme breaks down in the HF region into a complex of factors that include the relative sizes of the wires making up the hat and the main element, and capacity has little if anything to do with the method of resonating a short element. The "hat" portion of the name has some visual validity, since the system requires the installation of a symmetrical set of wires on and at right angles to the ends of the shortened main element. It is dubious whether the system of resonating a short element even deserves the name "loading."

Fig. 14 shows the outline of a simple short dipole. On each end, we find a set of four equal length wires symmetrically arranged. Under these conditions—using the correct lengths for the spokes in the hat wheels—we can obtain resonance and the current distribution pattern shown in the sketch. Up to the point at which the hats begin, the shortened dipole shows a current distribution curve that is virtually identical to one that would occur over the same central length of a full-length dipole.

Fig. 14

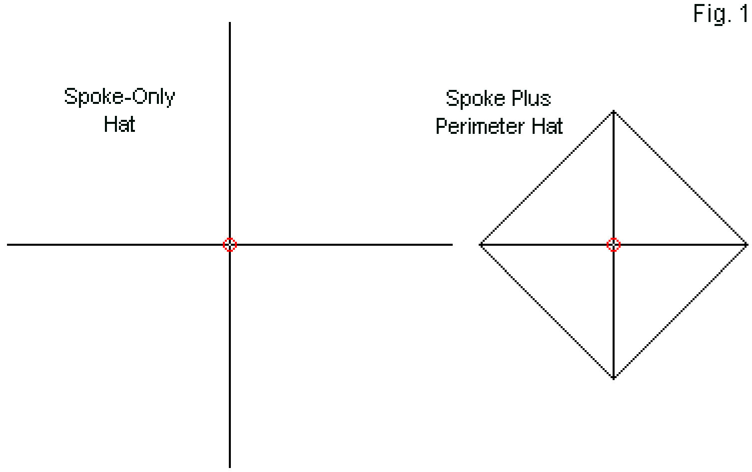


The Basic Concept of "End Loading"

At the junction of the main element and the hat wires or spokes, the current divides equally into four branches. It continues to decrease toward the spoke tips, just as it would in a full size dipole. However, any radiation from a given spoke is offset by the radiation from the other spokes so that there is virtually no far-field radiation from the spoke assembly. Hence, the central section of the dipole controls the far-field pattern with respect to both the pattern shape and strength.

There are two general forms of constructing end hats that provide resonance in a shortened dipole of some specific central length. One system uses only radial spokes. The other system uses spokes plus a perimeter wire. **Fig. 15** shows the relative sizes of such assemblies with 4 spokes and applied to the half-length (33.33') dipole with which we have been working. With a perimeter wires, we can reduce the spoke length significantly (by 40% or more). In the spoke+perimeter wire system, we can think of the spoke length as consisting of the spoke itself plus half the length of the perimeter wire that connects one tip to the next.

Fig. 15



Relative Hat Sizes: Spoke-Only vs. Spoke + Perimeter

The two systems are electrically equivalent. Adding intermediate wires circling the spokes generally adds almost nothing electrically to the hat, although such wires might be useful in large hats to help brace the spokes. For our 400" AWG #12 copper wire dipole with hats composed of the same material in alternative spoke-only and spoke+perimeter wire configurations, we can sample the free-space performance in **Table 5**.

Table 5. Performance of half-length dipole with two types of end hats

Hat Type	Spoke Length Inches	Max. Gain dBi	Feedpoint Z R +/- jX Ω
Spokes only	81.5	1.79	38.9 – j0.1
Spokes plus perimeter wire	46.5	1.80	39.0 + j0.8

Notes: Element length 400" (33.33').
Element and hat wires: AWG #12 copper wire.
Samples use 4 spokes per end hat.

The table establishes the electrical identity of the two systems. We can further shorten the length of the spokes in either system by adding more spokes. **Fig. 16** provides a sample of modeled systems using 4 through 32 spokes and records the relative spoke length using the shortest spoke as the base line. As we increase the number of spokes, the two curves gradually converge. Somewhere in the vicinity of 60 spokes or more, the two lines come together as the assembly effectively simulates a solid or a wire-mesh surface.

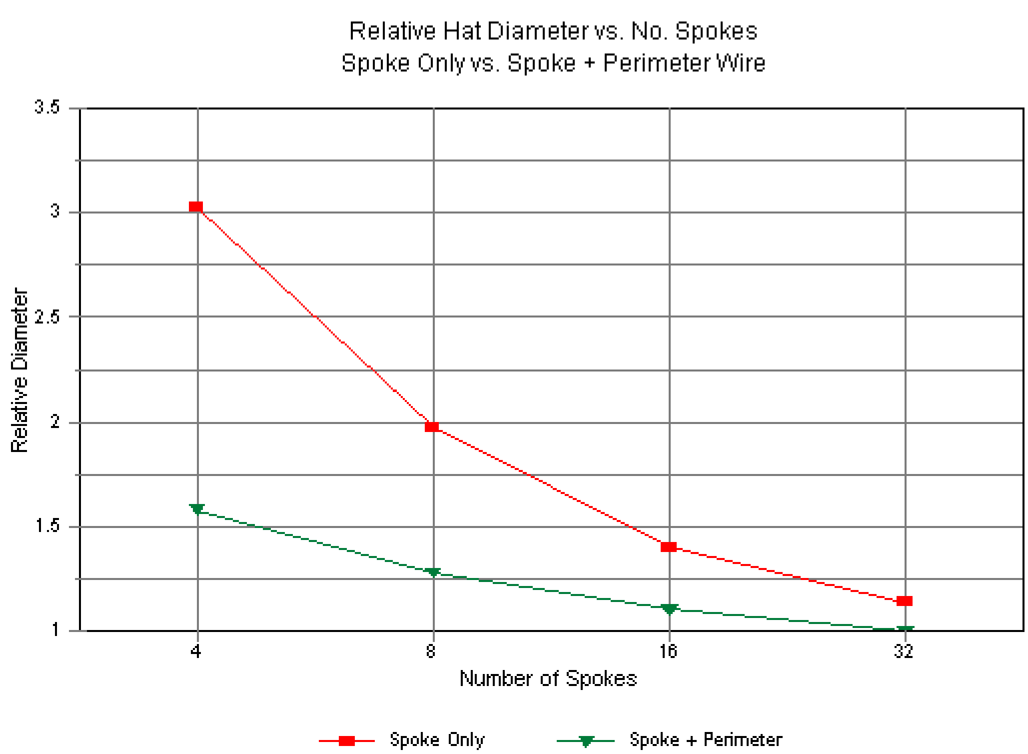
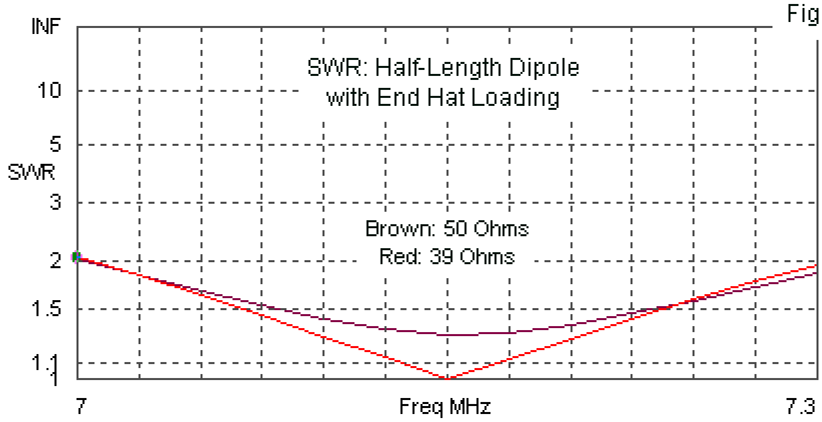


Fig. 16

We should not pass over the data in **Table 5** only noticing the similarity of the numerical entries. The gain of the hatted half-length dipole does not show the decrease that marked all forms of inductive loading, since the primary radiating portion of the element has no loss other than the resistivity of its copper wire. In fact, the gain values are up (by less than 0.1 dB) because the hat structure does narrow the dipole beamwidth by about 2°. Despite its mechanical inconvenience, a hatted short dipole delivers all of the gain possible from an element of the given length.

In addition, the hatted dipole shows the highest resonant impedance of any of the versions of the half-length dipole where the impedance is not artificially raised by loss resistance. The test frequency value of 39 Ω would increase to a value closer to 50 Ω without much further lengthening of the main element (along with accompanying shorter spoke lengths in the hat).

Fig. 17



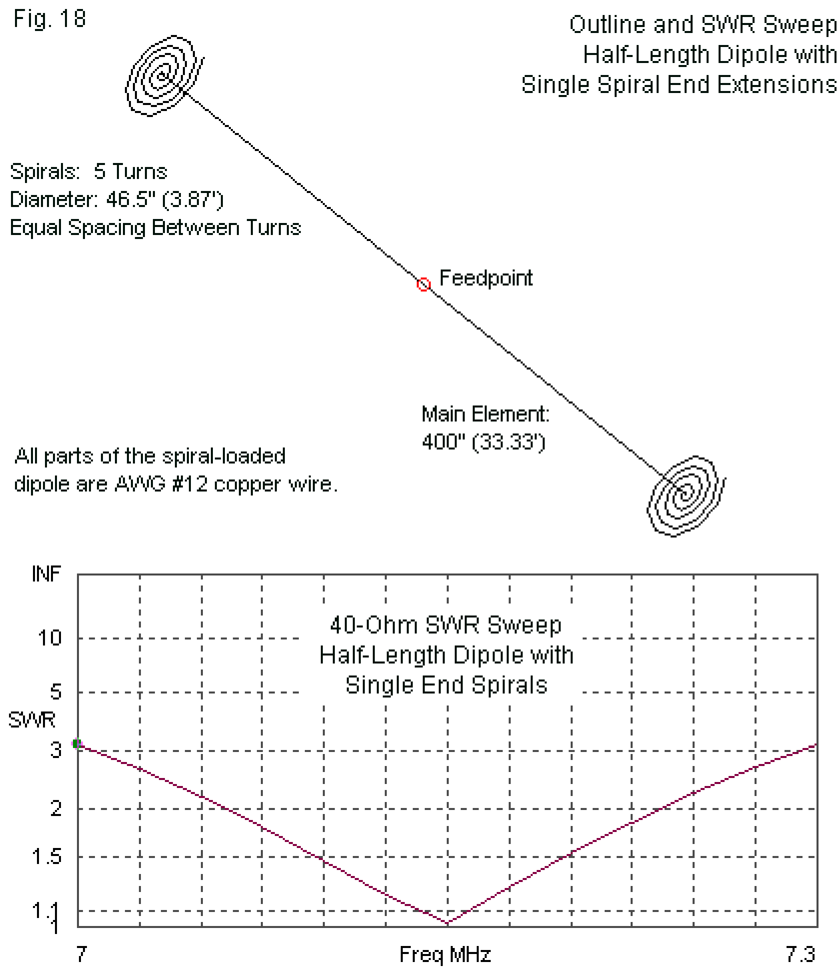
The feedpoint impedance shows a further advantage of hat loading: the SWR curve is virtually as broad as the curve for a full-length dipole. The sample antenna offers full-band coverage with less than a 2:1 50-Ω SWR even though the test-frequency impedance is a bit lower than optimal. Despite all of these advantages, the physical difficulty of implementing end hats on shortened elements tends to discourage the use of this technique, especially in the lower HF region.

There are many variations on the hat theme. Among true (symmetrical) hats, perhaps the most promising is the double concentric spiral that can include a considerable quantity of wire in a smaller space than even the spoke+perimeter wire system. A tight single spiral works well, but due it its asymmetry, the SWR bandwidth tends to be smaller.

Fig. 18 provides a sample of a half-length dipole equipped with end extensions composed of single spirals. All parts of the assembly are AWG #12 copper wire. Like the hat-loaded dipole, the main element is 400” (33.33’). The spirals consist of 5 equally spaced turns of wire with an outer or limiting diameter of 46.46” (3.87’). This value is virtually identical to the spoke length required for the hats that used a perimeter wire. Hence, the spiral would require about half the space of the 4-spoke hat, although we might shrink the hat by adding more spokes.

The single spiral, however, is not a true hat with virtually complete cancellation of radiation from the end assembly. There is a small component of radiation at right angles to the main element. The free-space gain is 1.73 dBi, a small amount below the level of the hatted assembly (about 0.07 dB). This difference is operationally insignificant. The feedpoint impedance at the test frequency (7.15MHz) is 40.0 + j0.9 Ω, almost identical to the value derived from the hatted half-length dipoles.

The shortcoming of the single-spiral end extension shows up in the 40-Ω SWR sweep in the lower portion of **Fig. 18**. The true end hat allowed full band coverage with an SWR of 2:1 or less. In contrast, the single spiral provides the same level of SWR performance over only about 60% of the band, for the sample, from about 7.06 to 7.23 MHz. In addition, the support requirements for the spiral may prove to be more complex than those needed by the hat.



Nevertheless, for some applications, the single spiral may be an attractive alternative to a true hat. As a further alternative, one may create a double opposed spiral on each end of the dipole and achieve the symmetry required for true hat performance.

Conclusion and Preface

In one sense, we have completed our task of examining the half-length dipole and the main ways of utilizing the antenna. Among reshaped full-length dipoles, the U form proved most promising. Turning to loaded elements, the hat system preserved the greatest performance and operating bandwidth of the full-size element. These conclusions do not overrule the use of other techniques as circumstances dictate.

Perhaps we should consider one more episode before we close the book on the half-length dipole. There are many antenna arrays based on the dipole, most notably the parasitic array that we call the Yagi-Uda (or Yagi for short). We might find something interesting in exploring that antenna—and variants—using our half-length copper wire 40-meter element.