Adjusting Near-Perfect Broadband Antennas for 80-75 Meters

L. B. Cebik, W4RNL (SK)

In "Notes on Ribbons, Cages, Parasites, and Lines: Broadband Coverage of the 80-75-Meter Band with AWG #12 Copper Wire" in a past issue of *antenneX*, I explored some of the methods for obtaining full coverage across the 3.5 to 4.0 MHz span with a single antenna. I re-examined some further options in a *QEX* column ("Antenna Options") that opened some additional possibilities offered by combining broadbanding techniques. Some of the methods of matching via combinations of transmission line proved robust enough to allow the use of ribbon or cage constructs with relative small proportions, instead of the very large dimensions required for direct full coverage by the antenna alone. In fact, we were able to obtain 50-Ω SWR curves with values less the 1.5:1, thus meeting the most rigorous requirements of amateur amplifiers having the most sensitive fold-back circuits.

Near the end of the *QEX* piece, I cautioned that the dimensions shown in the samples applied only to antennas in the 70' to 100' height range over average ground. Outside that range, the antenna builder will have to make a considerable number of experimental adjustments to assure performance, and at some heights, the arrangement may not work at all. Because most amateurs under-appreciate the effects of height on the resonant frequency and feedpoint impedance of dipoles less than 1 λ above ground, we might well re-visit the question. Along the way, we shall discover why certain matching schemes have application only at certain heights for 80-75-meter antennas. As well, we can investigate how we might tailor the dipole length and the lengths of cables forming the matching system to optimize performance at heights within the usable range.

Some Fundamentals

The restrictions and the goals for our project remain unchanged relative to earlier investigations. The antenna material is AWG #12 copper wire. I use the following transmission lines to model the matching system with the dipole at 90' above average ground: 50 Ω: RG-213, VF 0.66, loss 0.6 dB/100' @ 10 MHz; 75 Ω: RG-216, VF 0.66, loss 0.7 dB/100' @ 10 MHz. These lines easily handle amateur power limits on 80 and 75 meters. The goal is to achieve with reasonable efficiency a 50-Ω SWR curve from 3.5 to 4.0 MHz with no SWR value exceeding 1.5:1.

Fig. 1 reviews the most common options for obtain wide-band performance directly from the antenna structure. A single wire that is 16" in diameter will just cover the band with a 72-Ω SWR of 2:1 or less. Such a wire is impractical in amateur (or any other) service, so we tend to create simulations composed of several wires (AWG #12 by our specification). One popular choice is a ribbon element composed of 2 or more wires in a common plane. An alternative is the 4-wire or 6-wire cage of wires.

Models of these structures use end structures similar to those shown in the sketches rather than creating junctions of wires forming a point. At the center feedpoint, the models use linear wires and create a parallel feedpoint by running near-zero length transmission lines from the designated source wire to the center segment of each other wire. These measures result in uniformly ideal average gain test values that facilitate comparisons. In these notes, we shall be interested almost solely in matters relating to the feedpoint impedance and the SWR curves across the 3.5-4.0-MHz band.

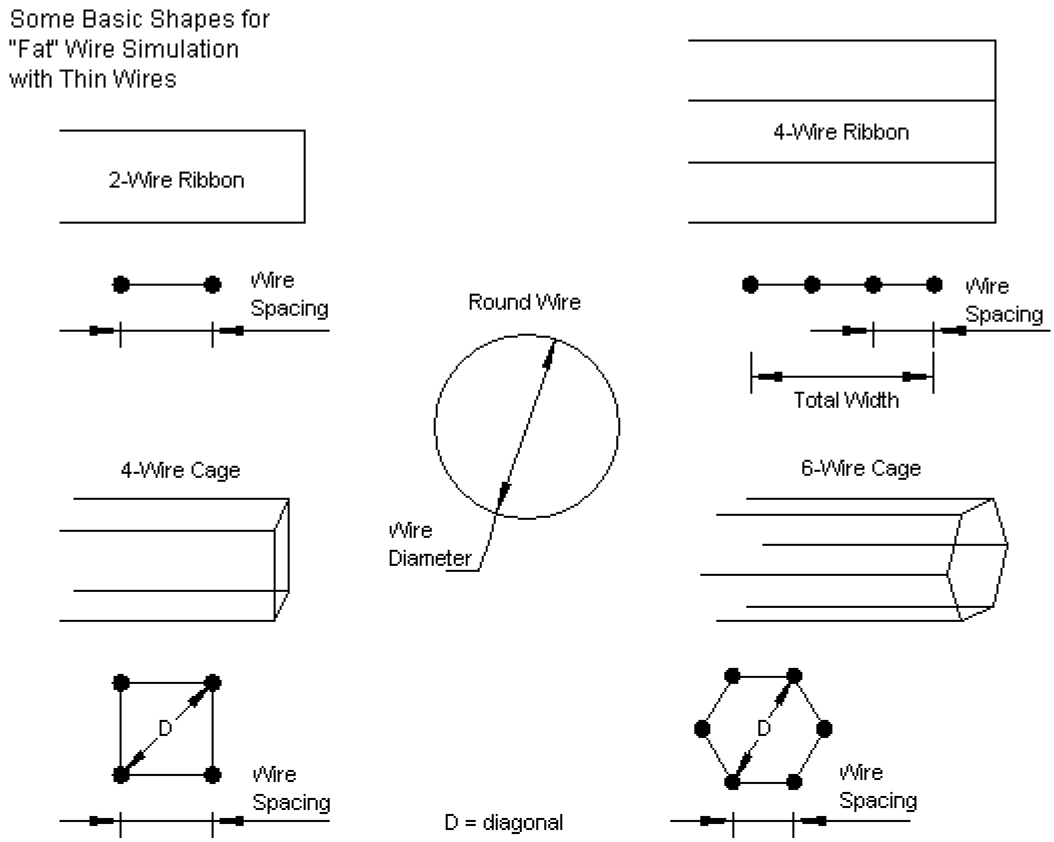


Fig. 1

Table 1 provides the required dimensions for full-size dipoles using each type of structure displayed in **Fig. 1**. The 2-wire ribbon antenna is missing because there is no practical size that will cover the entire band.

Table 1. Dimensions of dipoles with virtually identical full-band coverage of 80-75 meters with less than a 2:1 72-Ω SWR value

Antenna	Length	Res. Frequency	Impedance
Single wire 16" diameter	123.6'	3.72 MHz	71.6 – j0.4 Ω (free space) 89.1 – j4.8 Ω (90')
4-wire ribbon Wire spacing 2' Total width 6'	123.4'	3.72 MHz	72.4 + j0.4 Ω (free space) 89.3 – j4.1 Ω (90')
4-wire cage Wire spacing 3' Diagonal 4.24'	121.8'	3.71 MHz	72.1 – j0.5 Ω (free space) 88.3 – j6.0 Ω (90')
6-wire cage Wire spacing 1.5' Diagonal 3'	122.2'	3.73 MHz	72.1 – j0.7 Ω (free space) 88.6 – j5.9 Ω (90')

Since our goal is to combine the simulated fat dipole with a second broadbanding technique, we do not need to achieve full band coverage. Instead, we may opt for more reasonable cross-section dimensions for the multi-wire dipoles. **Table 2** provides very usable dimensions of dipoles having virtually identical properties. Note that the band-edge 72-Ω SWR values are just about the same in each case. The cross section dimensions fall within the shop capabilities of most serious 80-75-meter antenna users. Despite the smaller dimensions, the ribbons and cages achieve a fair amount on initial broadbanding when compared to the reference single AWG #12 wire dipole at the bottom of the list.

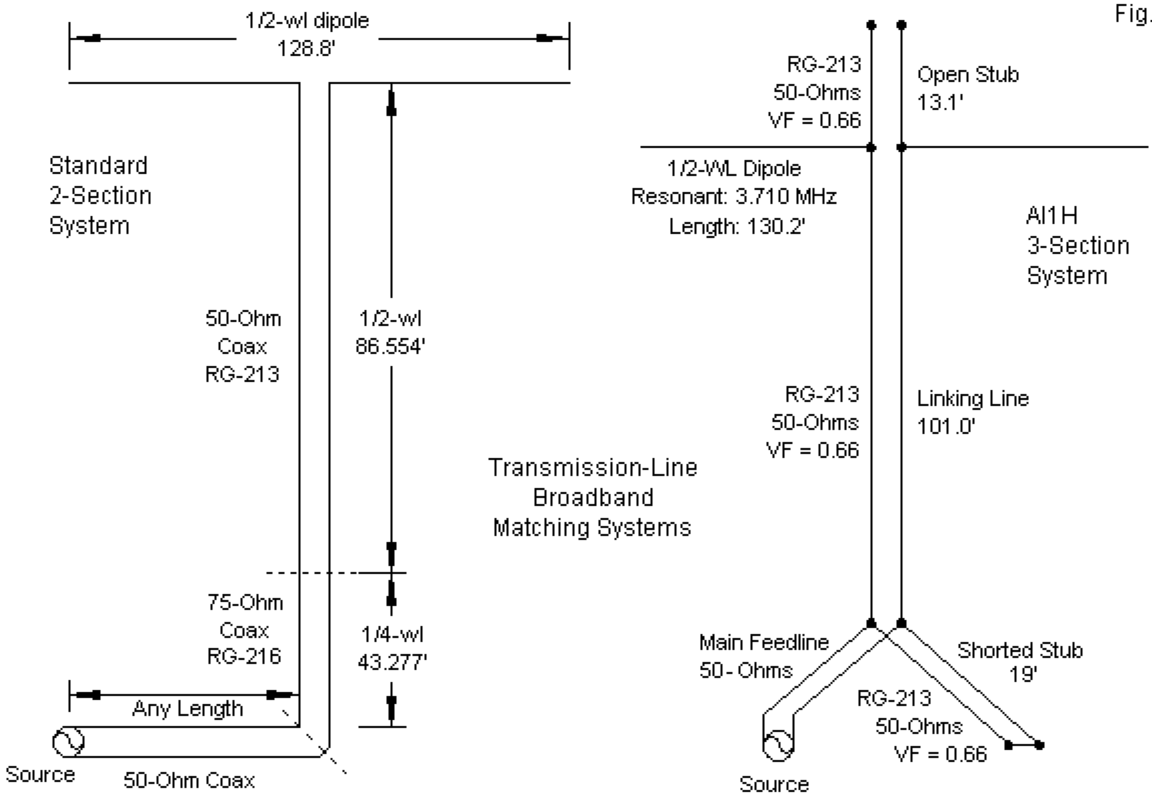
Table 2. Dimensions of dipoles at 90' above average ground with virtually identical coverage of 80-75 meters

		72-Ω SWR at	
Antenna	Length	3.5 MHz	4.0 MHz
2-wire ribbon Wire spacing 5' (60")	122.4'	2.42	2.17
4-wire ribbon Wire spacing 0.3' (3.6") Total width 0.9' (10.8")	125.3'	2.41	2.15
4-wire cage Wire spacing 0.4' (4.8") Diagonal 0.57' (6.79")	125.2'	2.41	2.16
6-wire cage Wire spacing 0.2' (2.4") Diagonal 0.4' (4.8")	125.4'	2.39	2.16
Single #12 wire (reference)	128.8'	3.54	3.78

We do not need to use a 2:1 limiting value of SWR because the transmission-line matching systems we shall employ are capable of achieving that value with a single AWG #12 wire dipole. Instead, we need sufficient broadbanding from the antenna structure alone so that when we apply the transmission-line matching schemes, the maximum 50-Ω SWR value will be less than 1.5:1.

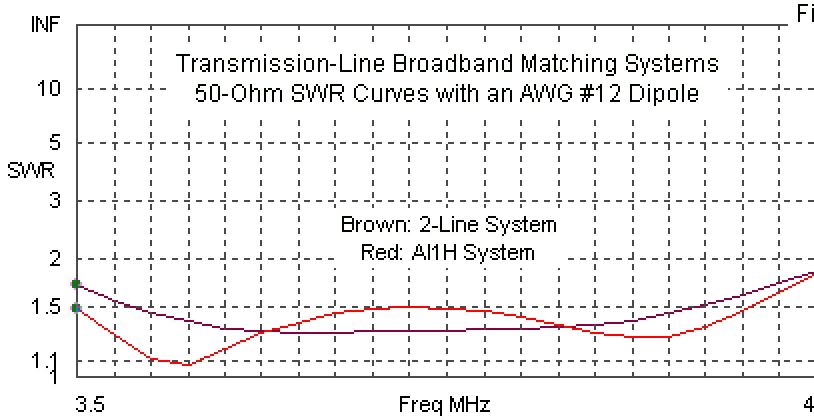
There are two general matching methods in use, and both appear in **Fig. 2**. The two-line system uses a ½-λ section of 50-Ω cable followed by a ¼-λ section of 75-Ω cable. At 90', the dipole impedance is close to 90 Ω at resonance. If we cut the ½-λ section of 50-Ω cable for the geometric mean frequency of the passband (about 3.742 MHz), the feedpoint impedance will repeat itself at that frequency. On either side of this frequency, the cable length will no longer be precisely ½-λ. Hence, the impedance at the source end will be a transformed value. When we pass the range of transformed impedance values through a ¼-λ 75-Ω matching section, the new impedance values will be very close to 50 Ω across the entire band. Adjusting the cables for the 0.66 velocity factor that applies to both lines, we obtain a combination of 86.55' and 43.28' for a total length close to 130'. For an antenna that is 90' above ground and offset from the operating position, the line length is reasonable as a minimum needed to reach from the equipment to the antenna. Any additional cable length would use 50-Ω cable.

Fig. 2



The right side of **Fig. 2** shows the three-line system developed by Frank Witt, AI1H, in 1995. One can view the system equally as a single line with the antenna tapped down from the open top and the main 50-Ω feedline tapped upward from the shorted bottom. For full-band coverage with a simple AWG #12 dipole, Witt discovered that the SWR bandwidth improved if he moved the self-resonant dipole frequency downward from the geometric mean frequency to the indicated value of 3.710 MHz. Since we shall make comparisons and since the line length of this all-50-Ω system between the antenna and the main feedline does not quite equal 130', I added 30' of RG-213 between the shorted-stub junction and the model source.

Fig. 3



As the 50-Ω SWR sweeps in **Fig. 3** show, both matching systems are capable of matching a single-wire AWG #12 copper dipole to values less than 2:1 across the entire 80-75-meter band. In the test model, the total transmission-line length is 130'. Moreover, the antenna is at a fixed 90' height above average ground. Our requirement is more severe: 50-Ω SWR values of less than 1.5:1 across the band. In pursuit of that goal, we shall have to adopt a dipole with an initial SWR bandwidth that is wider than the value we may obtain from a single #12 wire. Moreover, we may wish to vary the antenna height and the soil quality. Each of these variations from the original problem confronts us with limitations of the matching systems.

Both matching systems rely on the fact that at about 90' the dipole impedance at resonance is approximately 90 Ω. An impedance value in this vicinity provides the correct conditions for the main 50-Ω line in either system to transform off-resonance impedance values within the passband to values that, when further transformed by the ¼-λ series section or compensated for by the open and shorted stubs, provide near-50-Ω impedance values across the band. At other heights, the dipole resonant impedance may not be optimal.

To sample what happens to a dipole with changes in antenna height, let's select one of the semi-fat multi-wire constructs. Since they all have the same resonance impedance and SWR bandwidth, any of the constructs will do the job. Therefore, I selected the 4-wire cage as our representative from the group in **Table 2**. I then surveyed the results of varying the height in 10' increments from 30' to 150'. **Table 3** provides data from this series.

Table 3. The effects of antenna height above average ground on the impedance properties of a semi-fat 4-wire cage dipole 0.4' (4.8") per cross-section side dimension

Height		Impedance (Ω)	72-Ω SWR		Resonant
Feet	λ	at 3.745 MHz	3.5 MHz	4.0 MHz	Frequency MHz
30	0.114	51.1 + j14.6	2.68	3.81	3.675
40	0.152	61.2 + j17.6	2.27	3.54	3.650
50	0.190	71.9 + j16.4	2.05	3.21	3.650
60	0.228	80.8 + j11.3	2.00	2.90	3.675
70	0.266	86.5 + j3.8	2.07	2.61	3.700
80	0.304	88.4 – j4.7	2.22	2.36	3.725
90	0.342	86.9 – j12.5	2.41	2.16	3.750
100	0.380	82.6 – j18.4	2.62	2.03	3.775
110	0.418	76.8 – j21.7	2.83	1.99	3.800
120	0.457	70.6 – j22.3	3.03	2.07	3.800
130	0.496	65.2 – j20.3	3.18	2.24	3.775
140	0.533	61.3 – j16.5	3.26	2.45	3.775
150	0.571	59.6 – j11.6	3.25	2.64	3.750
(Free Space		72.4 + j0.6	2.73	2.41	3.745)

Notes: 1. Dipole length: 125.2'. 2. Height in λ at 3.745 MHz. 3. Resonant frequency to nearest 0.025-MHz increment.

The table reveals that the impedance at the geometric mean frequency of the 80-75-meter band varies both the resistive and reactive components, but the cycles are offset from each other. There are two significant consequences of the variation. First, the impedance value is only optimal for broadband transformation in a fairly narrow range of heights above ground, perhaps in the 70' to 110' range for the low maximum value of permitted 50-Ω SWR. Second, the shifting reactive component strongly suggests that the dipole length itself may become one of the variables as we attempt to optimize the matching system for different heights above ground.

Adjusting the 2-Line Matching System with a 4-Wire Cage Dipole

As shown in **Fig. 2** on the left, the 2-line matching system consists of a ½-λ 50-Ω line that functions to pre-transform dipole feedpoint impedance values in preparation for the final transformation in the ¼-λ 75-λ line section. The initial system used lines calculated for a height of 90' above average ground and for the geometric mean frequency in the passband. The SWR curve in **Fig. 4** shows that the result meets the initial specifications. The character of the curve differs somewhat from the curve for the same matching system applied to the single-wire dipole. Rather than having SWR peak values only at the band edges, we also find a mid-band peak value. We shall use this peak value in conjunction with the band edge values as we characterize the performance of the system at various heights above ground.

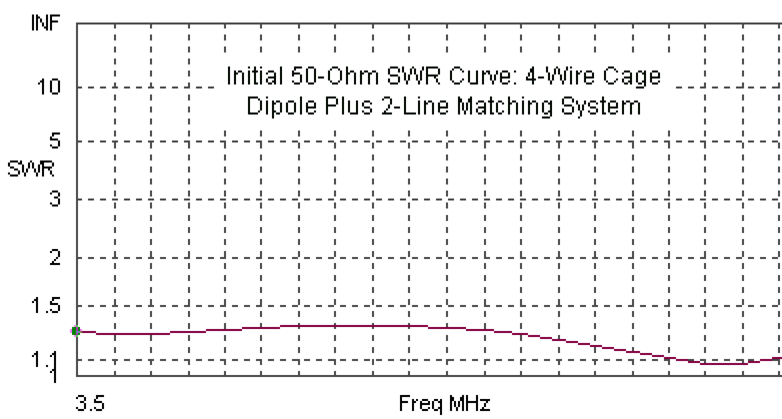


Fig. 4

Table 4. The effects of antenna height above average ground on the impedance properties of a semi-fat 4-wire cage dipole plus a 2-line matching section

Height		Impedance (Ω)		50-Ω SWR		Resonant
Feet	λ	at 3.745 MHz	3.5 MHz	Mid-Band	4.0 MHz	Frequency MHz
30	0.114	88.0 – j39.1	1.94	2.27	1.86	3.650
40	0.152	76.2 – j31.9	1.70	1.97	1.74	3.650
50	0.190	69.5 – j23.9	1.48	1.72	1.61	3.625
60	0.228	66.0 – j16.6	1.33	1.52	1.49	3.650
70	*0.266*	*64.6 – j10.3*	*1.24*	*1.40*	*1.38*	*3.650*
80	*0.304*	*64.7 – j4.6*	*1.24*	*1.33*	*1.28*	*3.700*
90	*0.342*	*66.1 + j0.4*	*1.29*	*1.33*	*1.18*	*3.745*
100	*0.380*	*68.7 + j4.8*	*1.37*	*1.40*	*1.10*	*3.775*
110	*0.418*	*72.6 + j8.2*	*1.47*	*1.50*	*1.09*	*3.800*
120	0.457	77.7 + j10.1	1.56	1.61	1.16	3.800
130	0.496	84.1 + j9.5	1.65	1.72	1.26	3.775
140	0.533	89.6 + j5.7	1.72	1.81	1.34	3.750
150	0.571	92.1 – j0.8	1.75	1.87	1.40	3.750

Notes: 1. Dipole length: 125.2'. 2. Height in λ at 3.745 MHz. 3. Resonant frequency to nearest 0.025-MHz increment.

Table 4 provides data on what happens as we change the antenna height with the standard matching system. The italicized entries show the range of acceptable SWR curves to meet the stringent 1.5:1 50-Ω SWR limit. As the changing difference in the band-edge SWR values with different heights suggests, the mid-band peak value may vary its frequency. In most instances, the mid-band peak SWR value is the limiting factor in meeting specifications. Still, we may note that for all heights except the lowest, the semi-fat cage plus the matching system meets the usual 2:1 SWR limit that may apply to less critical systems.

There are no rules against adjusting the dipole and the transmission line lengths to better optimize the system. The standard calculation of the ½-λ 50-Ω line section yields a length of 86.5', while the 75-Ω transformer section is half that length—when we adjust the lengths for the velocity factor of 0.66. The standard calculation uses the geometric mean frequency of about 3.742 MHz. We may alter any one or more of the three variables to seek a better curve. We may define a better curve as one in which all peak SWR values are the lowest possible with relatively equal values for all three peaks (band-edge and mid-band). We shall eventually modify this definition slightly.

As samples of what the adjustment process may yield by way of different lengths for the dipole and the two transmission lines, let's arbitrarily select dipole heights of 70', 90', and 110'. In this way, we can compare the results with the initial table that used standard calculated length for the transmission lines. In general, changing the dipole length has no significant effect on the mid-band peak. However, it does allow one to equalize as best possible the band-edge peak values of SWR. Changing the line length affects the impedance transformations and may raise or lower all three peaks. **Table 5** provides the key dimensions and SWR results from optimizing the system for each of the three heights.

Table 5. Optimized dimension and 50-Ω SWR results for 70', 90', and 110' high 4-wire cages dipoles with a 2-line matching system

Dipole	Dipole	½-λ Line	¼-λ Line		50-Ω SWR	
Height	Length	Length	Length	3.5 MHz	Mid-band	4.0 MHz
70'	124.4'	85.5'	43.75'	1.23	1.39	1.30
90'	125.2'	86.0'	41.25'	1.22	1.32	1.19
110'	126.0'	85.5'	42.25'	1.33	1.44	1.24

The changes in line lengths for a 90' dipole height are largely cosmetic, compared to using the standard calculations. However, at both 70' and 110', the changes in all three variables yield superior SWR curves compared to making no changes at all. The required dipole length increases with height. However, for both new heights, the ½-λ 50-Ω line is slightly shorter than for 90'. In contrast, in both cases, the ¼-λ 75-Ω transformer section is longer. The precise changes are functions of the fact that as we change the antenna height, the resistive and reactive components of the impedance does not change in step with each other.

Although we have altered the dimensions to improve the SWR curves over average soil at the three test heights, we have yet to see how the curves change as we change the soil quality. To test this aspect of the broadbanding question, I created SWR curves for each variation of the original system for three soil types: very good (cond. 0.0303 S/m, perm. 20), average (cond. 0.005 S/m, perm. 13), and very poor (cond. 0.001 S/m, perm. 5). **Fig. 5**, **6**, and **7** show the family of curves for each antenna height. The results may provide us with clues as to further refinements we might make to the adjustments.

Fig. 5

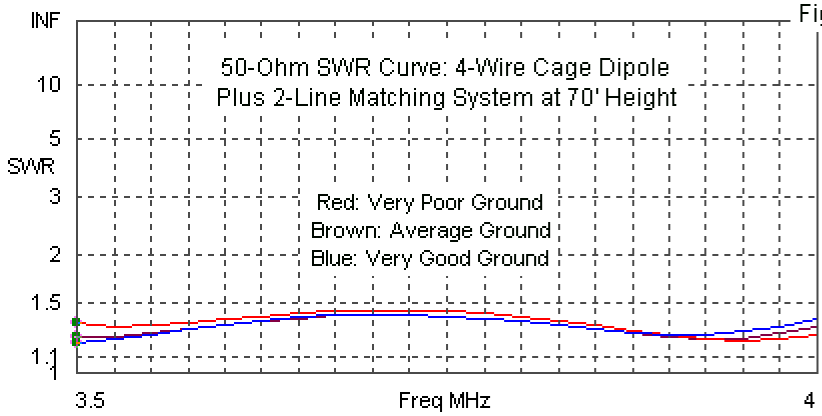


Fig. 6

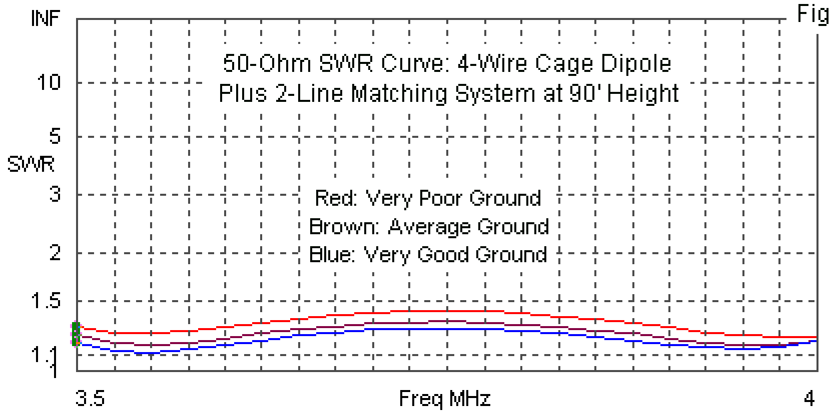
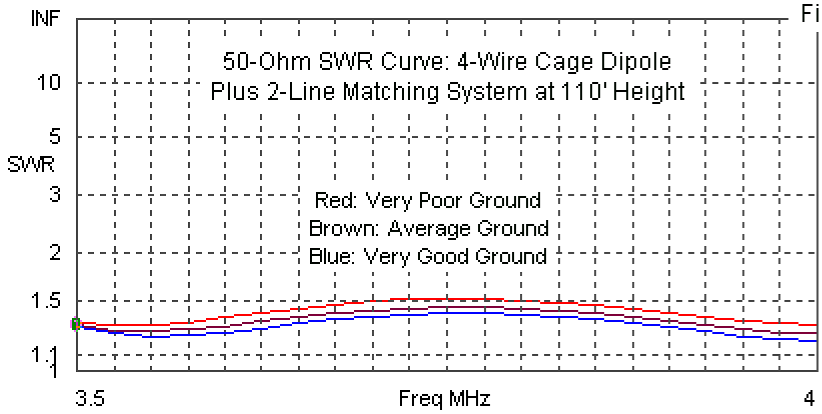


Fig. 7



In conjunction with the data in **Table 5**, the three SWR plot collections tell us a bit of a story. Over average ground, the dipole at 90' provides the best SWR pattern across the passband. We must note that soil improvement also yields SWR improvement—however small it might be—while soil degradation provides a less optimal plot. As we reduce the antenna height, with a resulting change in the dipole length to keep the curve centered, we find slightly lesser values over average ground than we found at 90', but the three curves for different soil types are more tightly grouped with far less difference related to soil quality. In contrast, the family of patterns at 110' results in patterns with a higher set of mid-band peak values. In fact, the SWR curve for very poor soil yields a mid-band peak value just slightly above our 1.5:1 limit. The variations that we see inform us of a basic system limitation.

The 2-line matching system limits the degree of variation that we can put into the antenna and feedlines in terms of adjusting the impedances that the lines transform. As a result, the basic curves for heights that depart from the most optimal value (90' in this example) are less optimal (although quite acceptable). A superior matching system would be one that would allow us to match at 70' and at 110' the basic curves displayed at 90'. Such a system would not necessarily be able to fully compensate for the antenna impedance changes for all mounting heights, especially when the impedance approaches 50 Ω. However, it would allow us to carry the compensation for height changes a good bit further.

Adjusting the AI1H Matching System with a 4-Wire Cage Dipole

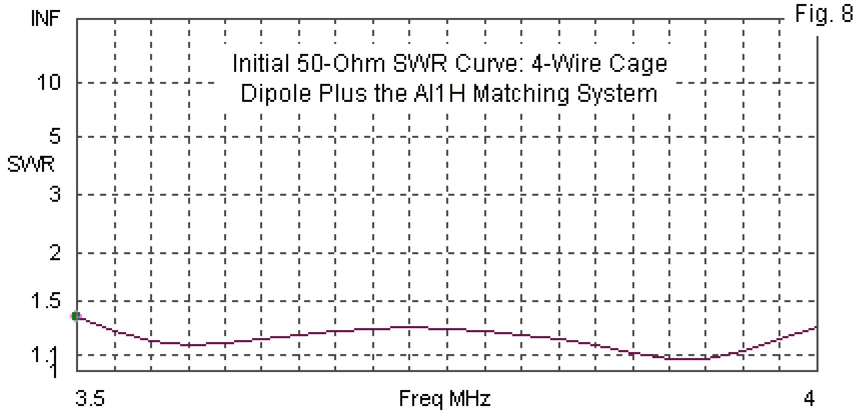
If we use the same 4-wire cage construction for our dipole and then employ the AI1H matching system, as outlined on the right in **Fig. 2**, we add a fourth variable to the adjustment list. We may change the length of the dipole itself, which will be longer than the dipole for the 2-line system. In addition, we can change the lengths of the main linking line, the open stub at the dipole end, and the shorted stub at the junction with the main feedline. Before we explore these changes, let's create a set of data on the changes created by simple height changes with the standard set-up relatively optimized for a height of 90'. **Table 6** provides the necessary information.

Table 6. The effects of antenna height above average ground on the impedance properties of a semi-fat 4-wire cage dipole plus the AI1H matching system

Height		Impedance (Ω)		50-Ω SWR		Resonant
Feet	λ	at 3.745 MHz	3.5 MHz	Mid-Band	4.0 MHz	Frequencies MHz
30	0.114	103.4 – j27.4	1.28	2.26	1.79	3.650, 4.000
40	0.152	87.8 – j28.7	1.22	2.02	1.72	3.625, 4.000
50	0.190	76.5 – j25.0	1.21	1.79	1.64	3.525, 3.975
60	0.228	70.1 – j20.1	1.24	1.60	1.55	3.550, 3.950
70	*0.266*	*65.9 – j15.0*	*1.28*	*1.46*	*1.47*	*3.575, 3.950*
80	*0.304*	*63.6 – j10.1*	*1.32*	*1.34*	*1.38*	*3.600, 3.925*
90	*0.342*	*62.6 – j5.4*	*1.36*	*1.28*	*1.29*	*3.650, 3.925*
100	*0.380*	*62.9 – j0.9*	*1.38*	*1.28*	*1.20*	*3.625, 3.950*
110	*0.418*	*64.4 + j3.4*	*1.40*	*1.35*	*1.12*	*3.600, 3.975*
120	*0.457*	*67.4 + j7.0*	*1.39*	*1.45*	*1.11*	*3.575, 4.000*
130	0.496	71.9 + j9.4	1.38	1.56	1.18	3.550, 4.000
140	0.533	77.4 + j9.5	1.34	1.65	1.27	3.525, 4.000
150	0.571	82.6 + j6.6	1.29	1.72	1.35	3.525, 4.000

Notes: 1. Dipole length: 125.2'. 2. Height in λ at 3.745 MHz. 3. Resonant frequency to nearest 0.025-MHz increment.

For reference, **Fig. 8** shows the 50-Ω SWR sweep for the initial system at 90' above average ground. The curve is similar to the one for the 2-line system (in **Fig. 4**) in having not only band-edge peak values, but also a distinct mid-band peak SWR value. Essentially, when we place an antenna analyzer at the junction of the main feedline and the matching system, we shall find two near-resonant frequencies, as reflected in the tabular data. We may note in passing that the two frequencies are closest together at the height at which we obtain the most optimal results. As we move away from that height, either upward or downward, the two frequencies grow father apart.



The height range for basically acceptable results extends from about 70' to 120' over average ground, using the unmodified matching system. In fact, performance tilts toward higher elevations using a 2:1 standard, with usable values all of the way to 150' and beyond. However, at lower height (30' and 40'), the curves exceed even a 2:1 50-Ω SWR limit.

Adjusting all four of the variables to optimize the curves for various heights requires patience, and even so, there are other combinations that can produce virtually the same results. **Table 7** shows the results of optimizing the 50-Ω SWR curves for 70', 90', and 110' above average ground. Once more, the dipole length increases as we increase the antenna height over the span of the samples. However, the other length values do not appear to follow a clearly regular pattern because the antenna feedpoint impedance value changes with both the height above ground and the length of the dipole. Since the resonant points are widely separated, resonating the dipole at a particular frequency does not provide ready guidance.

Table 7. Optimized dimension and 50-Ω SWR results for 70', 90', and 110' high 4-wire cages dipoles with a 2-line matching system

Dipole	Dipole	Open St.	Shorted St.	Link Line		50-Ω SWR	
Height	Length	Length	Length	Length	3.5 MHz	Mid-band	4.0 MHz
70'	124.4'	13.5'	21.5'	99.0'	1.33	1.25	1.35
90'	127.0'	13.5'	21.0'	99.0'	1.33	1.25	1.33
110'	127.8'	13.1'	22.0'	99.5'	1.28	1.27	1.28

The goal of the optimizing exercise was to produce roughly equal band-edge SWR values accompanied by the lowest possible mid-band peak SWR value. The process does yield curves for each height that are very close to coincident, unlike our results with the 2-line system. In none of the curves does the SWR value exceed 1.35:1.

As we did for the 2-line system, we shall compare the SWR curves with the optimized settings for very good, average, and very poor soil. **Fig. 9**, **10**, and **11** provide the visual comparisons among the soil types for each of the 3 heights. Because the availability of 4 variables allows the basic curves at each height to reach similarly low levels, none of the soil variations pushes any curve close to the 1.5:1 50-Ω limit.

Fig. 9

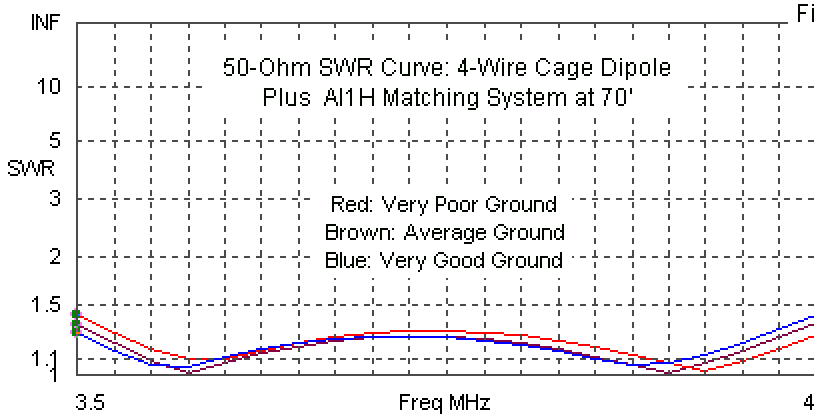


Fig. 10

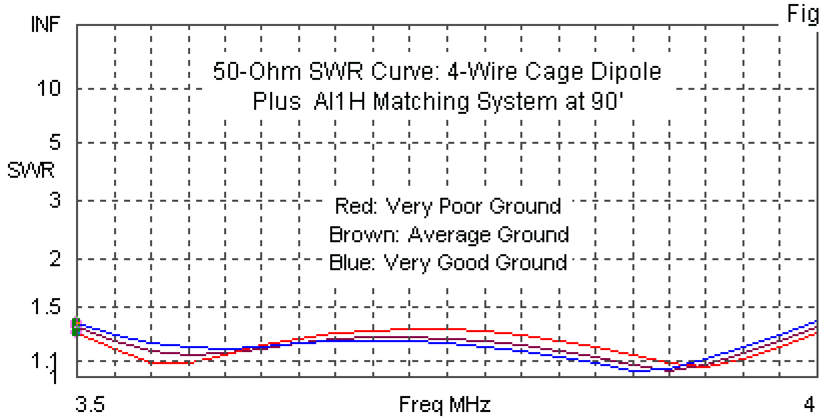
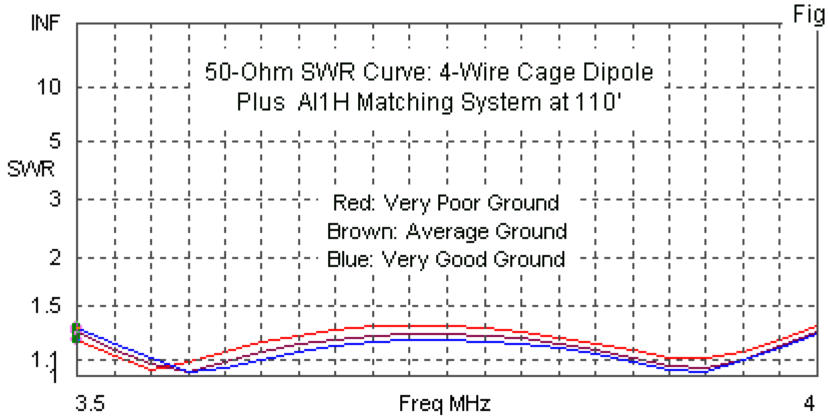


Fig.11



The curves share a common trait: as the soil quality increases, the frequency differential between resonant points decreases. In fact, the frequency spacing between SWR minimum points follows the same pattern with the 2-line matching system, but those curves are too shallow to detect it easily. The poorest soil yields the highest mid-band SWR peak values, regardless of antenna height (within the sampling range), but the spread of the SWR minimum points often accompanies these peaks with lower band-edge SWR values. In the end, construction and installation site variables would likely obscure the fine shades of difference in the plots.

Nevertheless, the similarity in SWR plot families is a function of adjusting the variables in the antenna and its matching system, and the differences show up as measureable differences in the dimensions used. Whatever the matching system, modeling and optimizing the system in advance of installation yields two beneficial results, even in the presence of unmodeled site objects. First, it normally leads to first tests that are closer to final adjustments. Second, the modeling process gives some insight into what adjustments are necessary to move the system's SWR curves in the desired direction.

Conclusion

Of the two transmission-line matching system, the AI1H version offers more flexibility in bringing SWR curves under the most stringent control over a greater range of dipole heights, if we presume the use of a semi-fat wire simulation, such as the 4-wire cage used in these exercise. Similar results would accrue to the other equivalent dipoles in ribbon or cage form. The variability of a dipole's impedance with height changes in the region below 1 λ limits any matching system, but for covering the full 80-75-meter band with a single antenna that requires no tuning and that is at heights normal to serious amateur operation, The AI1H matching system has a few distinct advantages compared to the simpler two line system

The more complex matching system also has one disadvantage: a slight deficiency in efficiency relative to the 2-line system. **Table 8** compares the maximum gain of each system to a 4-wire cage dipole fed directly at its source (with no transmission line at all). The difference is small and perhaps not operationally noticeable. But it exists and is worth noting.

Table 8. Comparative performance of the composite solutions to broadbanding antennas for 80-75-meters using 4-wire cage dipoles at 90' above average ground plus a transmission-line matching system

	Gain at		
System	3.5 MHz	3.75 MHz	4.0 MHz
4-wire cage fed at feedpoint	6.16	6.29	6.48
With 2-line system	5.41	5.75	5.78
(Gain loss)	(0.75)	(0.54)	(0.70)
With AI1H system	5.18	5.56	5.52
(Gain loss)	(0.98)	(0.73)	(0.96)

Whichever system one uses, the combination of a semi-fat dipole and a transmission-line match, assuming that the antenna height is within the range of the matching system, does allow a degree of adjustment that is worth exploration if the goal is to produce the lowest 50-Ω SWR over the widest possible 80-75-meter bandwidth.