The Multi-Band Inverted-V from Many Angles

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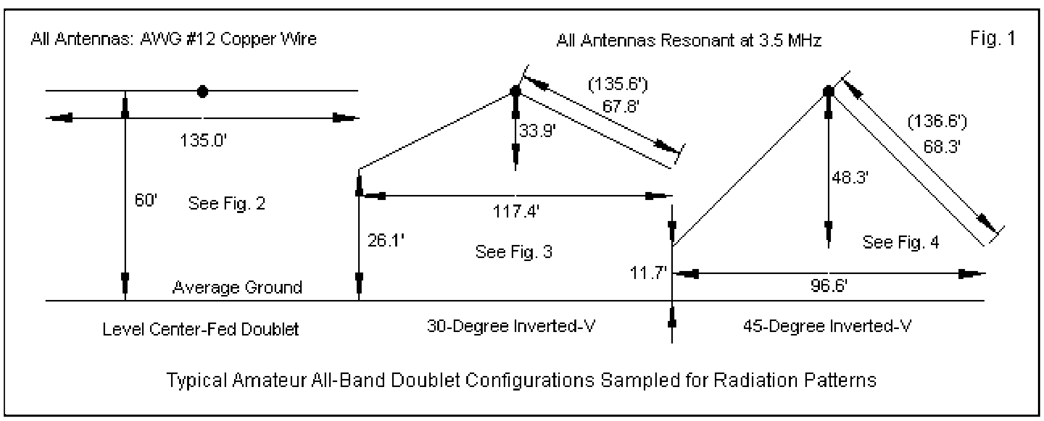
The smaller the backyard, the less room that we have to construct a full-size 135' level center-fed doublet as an all-band HF antenna. As a work-around, many amateurs try the inverted-V configuration. It requires only one very tall center support, with lower supports for the wire ends. Handbooks reassure us that the inverted-V will perform quite well, with only a small reduction in gain and a slight expansion of the radiation pattern off the ends of the wire. So we dutifully build the inverted-V and then wonder why neighboring hams are doing so much better at hearing stations. We rationalize that perhaps our antenna is broadside in the wrong direction. We may think that we have to grow taller trees to raise the feedpoint of the antenna even higher. Possibly, we need to buy a new rig. We never stop to think that the basic antenna may be at fault, especially on the upper bands. After all, the handbooks have reassured us that the all-band inverted-V is a good general purpose antenna.

Let's back up a step and make a plan to study the situation. The first step is to review what we can expect from a level doublet with the same feedpoint height as our inverted-V. We cannot possibly survey every feedpoint height in this exercise. So I shall set the feedpoint at 60' above average ground. That level is somewhat high for the average backyard, but I have reasons for picking it, and they will appear in a moment.

The second step is to replace the level doublet with an inverted-V, keeping the same feedpoint height. The immediate problem that we face is selecting an angle at which to slope the wires relative to the doublet. Again, we cannot possibly survey every sloping angle. However, we likely only need to look at two angles. One is a slope of 30 degrees down from the doublet. The other angle is 45 degrees down from the doublet. The difference is only 15 degrees, but--as we shall see--what a big difference those 15 degrees will make. **Fig. 1** sketches the 3 antennas that we shall include in our survey.



Typical Amateur All-Band Doublet Configurations Sampled for Radiation Patterns

If we start on the right in the figure, we can see why I chose the 60' feedpoint height. The wire ends are between 11' and 12' above ground. Letting inverted-V ends go any lower is an invitation for someone to receive an RF burn, since the wire ends will carry a high voltage when we transmit. Hence, safety dictates that we keep the inverted-V ends at least 10' above ground, and higher, if feasible.

The inverted-V sketches show the length of the legs, with the total wire length in parentheses. All three antennas are resonant at 3.5 MHz (using AWG #12 or 0.0808" diameter wire). As we slope the wires into the inverted-V configuration, we need slightly more wire to achieve resonance at the baseline frequency.

We can also see the important reason for using an inverted-V instead of a doublet. Every addition degree of slope reduces the required end-to-end span for the antenna. The 45-degree slope allows the antenna to fit a yard with a maximum dimension of 100'. For this exercise, then, I shall assume that the backyard has one mighty oak--or Douglas fir--or ancient magnolia--that is precisely positioned to let us construct an inverted-V to use on all of the HF bands.

The next question is simple: what can we expect from our antenna. To create a basic answer and set up some reasonable expectations, we should survey all of the HF amateur bands. Therefore, I shall sample each amateur band, jotting down some basic information and creating both elevation and azimuth patterns for the antennas. For each band, I shall use the lowest frequency in the band, since the patterns will not change much within a given band. The one exception is 75 meters, where I used 4.0 MHz to allow us to see how much the very wide 80/75-meter ham band changes antenna performance.

My procedures will be fairly simple, but there will be a twist or two along the way. I shall collect information on the gain level of the strongest lobe(s) in the pattern. In the azimuth patterns, I shall record the first maximum-gain lobe away from the broadside direction to the wire, unless the strongest lobe is exactly broadside to the wire. I shall also record the take-off (TO) angle, that is, the elevation angle of strongest radiation. Wherever the strongest lobe is not broadside to the wire, I shall make my elevation pattern using the direction of the strongest lobe. If the elevation angle of maximum radiation is above 45 degrees, I shall create the corresponding azimuth pattern at 45 degrees. Under these conditions, you must assume that the azimuth pattern has a maximum strength that is lower than the maximum possible gain, since that gain value is for another elevation angle.

For reference, I shall also record the modeled feedpoint impedance as a series resistance and reactance--rounding just a bit. This impedance will be at the antenna feedpoint. However, you will undoubtedly use a parallel transmission line--probably with an impedance between 300 and 600 Ohms--to connect your antenna to an antenna tuner in the shack. Since the transmission line impedance will rarely--if ever--match the antenna feedpoint impedance, the line will become an impedance transformer. The impedance that appears at the antenna tuner terminals will be a function of the antenna impedance, the line impedance, and the length of the line. Since I cannot cover every possible type of line and every possible line length, the antenna feedpoint impedances will have to do for our information collection.

For each antenna, we shall create two graphical documents. The first is a table of information gathered from the antenna model. The second is a page of elevation and azimuth patterns. My reason for creating both the tables and the patterns as graphics is simple. You may be keeping a notebook of what you learn about antennas. You can copy and save the graphics from these HTML notes as separate files. Then, you can import them into a word processing program, such as Word. The program's importation feature should size the galleries of patterns to fit the margins of your paper. Printing the gallery and its associated tables of data will let you store the information nearly in your notebook. That way, you can omit the commentary that I weave around the tables and the patterns.

The 135' Center-Fed Doublet

Although our main topic is the inverted-V, we need a point of reference in order to make sense of the data that we gather. The doublet is the root antenna, of which the inverted-V is one variation. Therefore, reviewing what happens to the patterns of a center-fed doublet is critical to our overall understanding. The doublet that we shall use is 135' long, just long enough to be a resonant dipole at 3.5 MHz, at least when we place the antenna 60' above ground and build it from AWG #12 copper wire. 60' is not very high if we measure the distance as a fraction of a wavelength. In fact, the height is less than 1/4-wavelength at the root frequency. If we lower the height of the antenna, then the 80-meter TO angle will be higher, whereas if we raise the antenna, the TO angle will be lower. To really obtain good DX results from a horizontal dipole or doublet, we should increase its height to 3/8-wavelength--and much more if possible. But 3/8-wavelength on 80 meters is close to 100', and so we may have to settle for mostly regional contacts on that band. Of course, as we raise the operating frequency, the antenna height increase as measured in wavelengths. By 40 meters, the antenna is getting close to 1/2-wavelength above ground. For all higher bands, 60' is not a significant problem for a general purpose antenna, even though the old saying that higher is better still applies to this or any other horizontal antenna (but not necessarily to HF vertical antennas).

Let's see what we derive from our 135' doublet on the amateur HF bands. **Table 1** provides the tabular data, while **Fig. 2** presents the gallery of patterns.

Table 1. Modeled Data for an AWG #12 Copper-Wire Level 135' Center-Fed Doublet 60' above Average Ground

Band Meters	Frequency MHz	Max. Gain dBi	Lobe Azimuth Angle degrees	TO Angle degrees	Impedance R+/-jX Ω
80	3.5	6.41	0	83	75 - j0
75	4.0	6.29	0	63	130 + j250
60	5.332	6.65	0	44	500 + j1070
40	7.0	8.41	0	32	5150 + j95
30	10.1	9.01	0	22	86 - j325
20	14.0	8.94	35	16	3580 + j790
17	18.068	9.82	59	12	125 - j5
15	21.0	9.96	47	11	2140 + j1270
12	24.89	9.79	66	9	125 - j195
10	28.0	10.99	54	8	1460 + j1240

Notes: 1. Frequencies are at the low end of each band except for 75 meters. 2. Maximum gain is for the strongest lobe at the TO or elevation angle of maximum strength. 3. Lobe azimuth angle is the bearing of the strongest lobe, where 0° is broadside to the wire and any other angle is a departure from broadside.

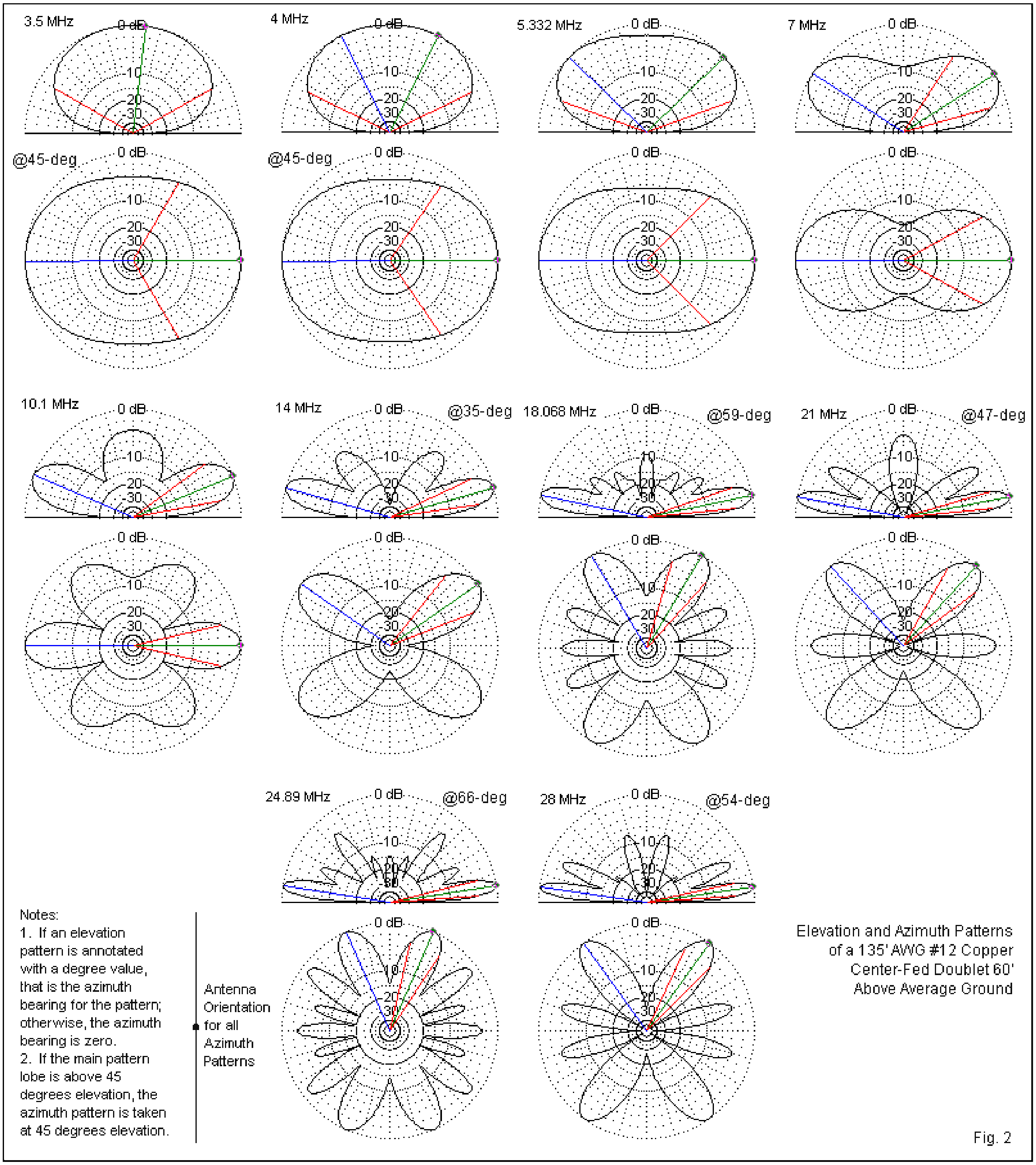


Fig. 2

We can begin with the table and immediately jump to the feedpoint-impedance column. The values seem to be all over the place, with some very high values and some fairly low values of resistance. The reactance also shows very wide swings. To make sense out of the column, we have to think about the antenna length. At 3.5 MHz, the antenna is 1/2-wavelength, and so we expect and receive a lower impedance with almost no reactance. At 7, 14, 21, and 28 MHz, the antenna is close to 1, 2, 3, and 4 wavelengths, respectively. At these lengths, we expect very high impedances--and get them. At 10.1, 18.068, and 24.89 MHz, the antenna is 3, 5, and 7 half-wavelengths, respectively--or thereabouts. Since these bands dov not have a direct harmonic relationship to 3.5 MHz, we cannot expect precision. But can can expect and obtain fairly low impedance values with relatively modest reactance values. So the impedance values in the table do make sense after all.

Note in both the table and the gallery that on 80 and 75 meters, the TO angle is higher than 45 degrees, and that requires azimuth patterns at 45 degrees. There is nothing magical in my selection of 45 degrees. It is too high for good DX work and too low for most NVIS work. Its one claim to fame is that it gives us a reasonably good picture of the azimuth pattern shape at that angle and below. Hence, we can clearly see the gradual narrowing of the beamwidth up through 40 meters, although the azimuth pattern remains broadside to the wire.

From 30 meters through 10 meters, we find that the pattern is breaking into many lobes. For a center-fed doublet, let's measure the antenna length in wavelengths. For lengths that are near an integral multiple of a wavelength (that is, 1-wavelength, 2-wavelengths, etc.), the number of lobes will be twice the antenna length in wavelengths. Hence, at 20 meters, the antenna is 2 wavelengths and we find 4 lobes. The situation changes for lengths that are odd multiples of 1/2-wavelength (that is, 3/2 wavelengths, 5/2 wavelengths, etc.). Now the number of lobes will be twice the number of half-wavelengths. So at 24.89 MHz, we have close to 7 half-wavelengths, and we find 14 lobes. Since lobes do not simply pop into and out of existence, we find on odd frequencies a mixture of lobes emerging or decaying. Note that when the antenna length is closer to an odd multiple of 1/2-wavelength, we not only see more lobes, but the strongest lobe is further away from a direction that is broadside to the wire and closer to the axis of the wire. Hence, the tabular data shows an up-and-down swing to the azimuth angle of the strongest lobe as we check out the bands from 20 through 10 meters.

The elevation angle of maximum radiation or TO angle of a doublet is almost wholly a function of the height of the antenna above ground. An antenna that is about 1/2 wavelength up will show a TO angle of about 25-26 degrees. When 1 wavelength up, the angle drops to about 14 degrees. If we physically raise or lower the entire antenna, we can change the elevation angle, but the lobe structure of the azimuth patterns will remain intact.

You can use the table and the gallery when planning an all-band doublet installation, assuming that you have some room to maneuver. Pick your favorite bands and see where the lobes go. Then align the antenna wire so that the lobes are in the direction of your choice communications targets. It is likely that you will have to compromise--not only in terms of lobe direction, but also in terms of the limitations of your yard. However, be careful of making to strict of a compromise, or your lobes may miss all of your targets.

If you shorten the antenna--perhaps making it resonant at 4 MHz instead of 3.5 MHz--then you will have to create your own gallery of patterns. You will not find much trouble on most bands, but the highest 2 or 3 bands may be a good bit away from the antenna lengths that produced these patterns. Hence, the exact directions of the lobes may differ enough to make a difference. I recommend that you obtain a rudimentary antenna modeling package and master it enough to plan an effective all-band doublet.

A 30-Degree 135.6' Inverted-V

The level doublet provides a touchstone for the results that we receive from any inverted-V antenna. We shall first look at a modest inverted-V, one with legs that slope downward 30 degrees from the horizontal. With a 60' feedpoint, the ends are about 26' above ground. 30-degree slopes on each side of the feedpoint mean that the angle between wires is 120 degrees (instead of the 180-degree value that applies to the level doublet). This version of the inverted-V is perhaps typical of amateur installations, although the exact top height may change from one location to another.

Without further ado, let's see what kind of performance we can expect from the 30-degree inverted-V. **Table 2** provides the tabular data, and **Fig. 3** gives us a gallery of patterns.

Table 2. Modeled Data for an AWG #12 Copper-Wire 135' Center-Fed 30° Inverted-V with a Feedpoint 60' above Average Ground

Band Meters	Frequency MHz	Max. Gain dBi	Lobe Azimuth Angle degrees	TO Angle degrees	Impedance R+/-jX Ω
80	3.5	5.40	0	88	60 - j0
75	4.0	5.46	0	85	105 + j255
60	5.332	5.42	0	57	460 + j1145
40	7.0	6.01	0	45	4805 - j580
30	10.1	7.31	0	50	125 - j580
20	14.0	6.45	39	20	3270 + j1495
17	18.068	5.17	62	13	130 - j25
15	21.0	7.43	53	13	1940 + j1955
12	24.89	5.98	71	9	160 - j165
10	28.0	7.11	61	10	1160 + j1550

Notes: 1. Frequencies are at the low end of each band except for 75 meters. 2. Maximum gain is for the strongest lobe at the TO or elevation angle of maximum strength. 3. Lobe azimuth angle is the bearing of the strongest lobe, where 0° is broadside to the wire and any other angle is a departure from broadside.

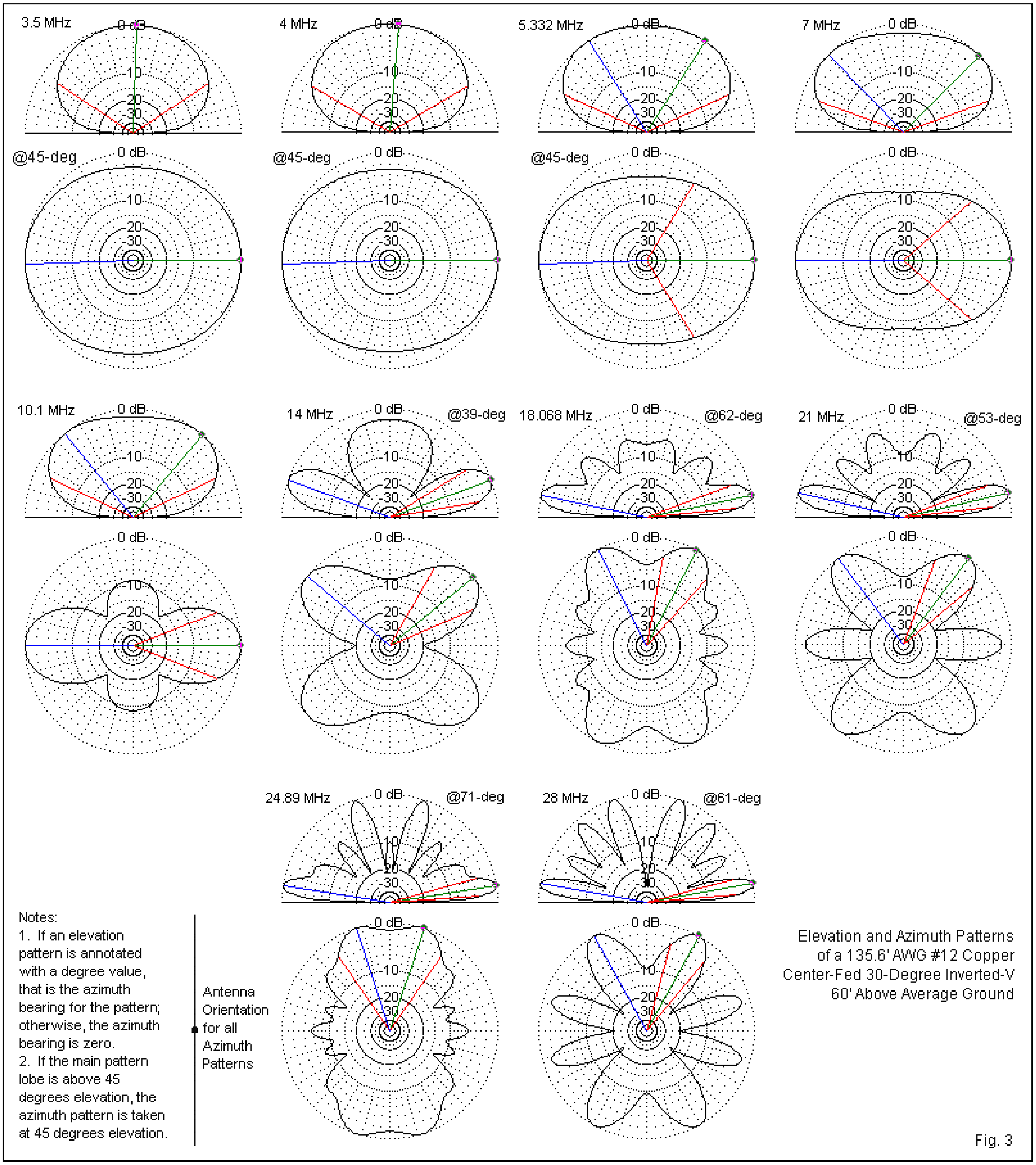


Fig. 3

We shall not find very significant changes in the impedance column. Since the antenna is resonant at 3.5 MHz, its electrical length is similar to the length of the doublet on every band. The sloping wires do interact a bit, and the wire ends are closer to the ground. But the changes to the feedpoint impedance are moderate to modest.

If we look at the column of TO angles, we find that they are typically higher than the TO angles for the doublet. In fact, the azimuth patterns for 80 through 30 meters require a default 45-degree elevation angle for the azimuth patterns due to the higher TO angles. (The doublet required this treatment only on 80 and 75 meters.) Even though the inverted-V has the same feedpoint height, it is lower at every other point along the wire. In general, the effective height of an inverted-V is about 2/3 of the way upward between the lowest point and the highest point along the wire. Hence, our inverted-V is effectively lower than the doublet at every operating frequency.

We can easily compare the two tables and see that the inverted-V yields a lower value for maximum gain than the doublet. The lower effective height is partially responsible. In addition, there is some radiation off the ends of the wires, since they now slope and have a vertical as well as a horizontal component. That energy has to come from somewhere, and a good part of it comes from a reduction of the gain of the main lobe or lobes. Nevertheless, the amount of reduction is not enough to disqualify the 30-degree inverted-V as a good general-purpose all-band HF antenna.

We should also compare with some care the gallery of patterns for both the doublet and the 30-degree inverted-V. From 80 through 40 meters, we notice seemingly small changes. For example, the inverted-V 40-meter pattern is an oval that has lost the "peanut" waist of the doublet. However, from 30 meters upward, the pattern changes are much more pronounced. For example, the doublet on 30 meters had 6 lobes, but we can only identify 4 in the inverted-V pattern for the same band. As we continue to increase the operating frequency, the sharply defined doublet azimuth lobes give way to less defined undulations, especially on 17 and 12 meters, two bands in which the patterns have many lobes.

Do not forget to review the two galleries with respect to the elevation patterns. On the highest bands, note the growth of the high-angle lobes relative to the much more modest development of the same lobes with the level doublet. Energy that goes almost straight upward is not available at the lower angles more favorable to making contacts. As a result, the maximum gain values of the inverted-V shows a greater high-band deficit relative to the doublet than the gain values for the lower bands. What is more important, perhaps, is that these high-angle lobes foreshadow what is to come with our next inverted-V.

A 45-Degree 136.6' Inverted-V

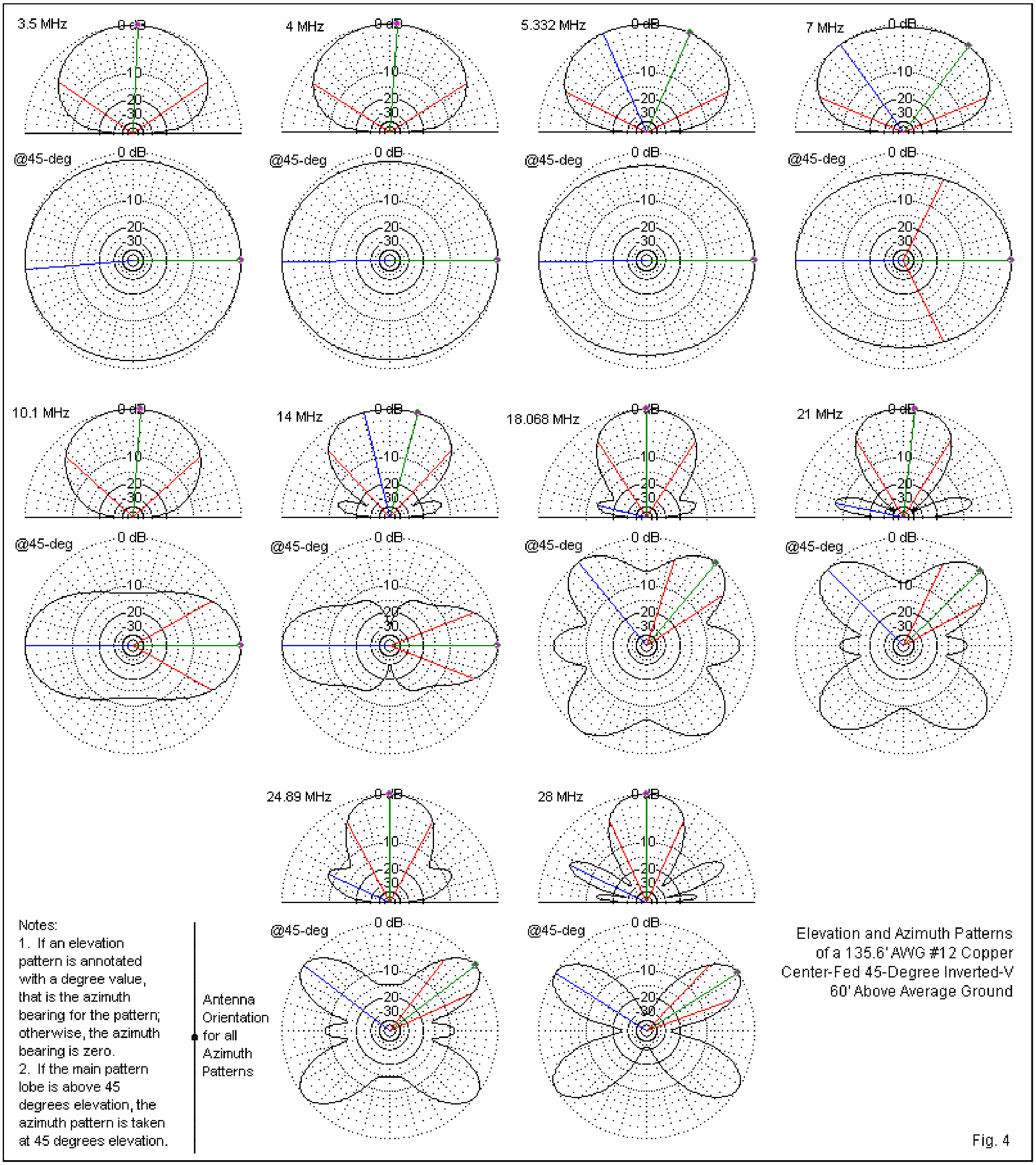
If we add only 15 degrees to the slope of each inverted-V leg, can anything harmful happen? The legs now slope downward by 45 degrees relative to the horizontal. The angle between the legs is 90 degrees. Since the antenna will fit inside my 100' lot, it is a tempting construction project.

To find the answer to our question, we need only examine the information. The changes in patterns and performance that we saw between the doublet and the 30-degree inverted-V suggest that we might see some further evolution in key properties. However, I wonder if we are prepared for some surprises. **Table 3** supplies the tabular data, while **Fig. 4** gives us the associated pattern gallery.

Table 3. Modeled Data for an AWG #12 Copper-Wire 135' Center-Fed 45° Inverted-V with a Feedpoint 60' above Average Ground

Band Meters	Frequency MHz	Max. Gain dBi	Lobe Azimuth Angle degrees	TO Angle degrees	Impedance R+/-jX Ω
80	3.5	4.08	0	87	50 - j0
75	4.0	4.19	0	86	85 + j260
60	5.332	3.99	0	66	410 + j1230
40	7.0	3.76	0	53	4480 - j1950
30	10.1	5.84	0	86	150 - j285
20	14.0	8.19	0	75	4400 + j815
17	18.068	8.29	0	90	180 + j45
15	21.0	9.32	0	84	2295 + j1760
12	24.89	8.38	0	90	175 - j95
10	28.0	8.66	0	90	1340 + j1550

Notes: 1. Frequencies are at the low end of each band except for 75 meters. 2. Maximum gain is for the strongest lobe at the TO or elevation angle of maximum strength. 3. Lobe azimuth angle is the bearing of the strongest lobe, where 0° is broadside to the wire and any other angle is a departure from broadside.



Notes:
1. If an elevation pattern is annotated with a degree value, that is the azimuth bearing for the pattern; otherwise, the azimuth bearing is zero.
2. If the main pattern lobe is above 45 degrees elevation, the azimuth pattern is taken at 45 degrees elevation.

Elevation and Azimuth Patterns of a 135.6' AWG #12 Copper Center-Fed 45-Degree Inverted-V 60' Above Average Ground

Fig. 4

Once more, the impedance column in the table gives us no clues to revolutionary changes, since the values show only a small evolution in the progressions of values that began with the doublet. As well, the gain column seems a bit odd, with lower values for the lower bands and higher values for the higher bands. The most meaningful changes occur in the two columns that list the azimuth angle of the strongest lobe and the TO angle. All TO angles are very high, indicating that on all bands, the predominant energy focus is straight upward or nearly so. The gain values shown are all for frying clouds and little else.

As a result of the very high TO angles, all azimuth patterns are at 45 degrees elevation. The azimuth patterns show some lobe development at this angle. However, the maximum number of lobes is 6. Up to 14 MHz, we find only 2 lobes. At 28 MHz, the old lobes that are broadside to the wire have finally disappeared, leaving only the 4 lobes that emerged around 18 MHz. In effect, the 45-degree inverted-V shows only half the number of lobes that we find in a doublet of the same overall wire length.

Moreover, these lower-angle lobes are considerably weaker than the very-high-angle main lobe. As the elevation patterns suggest, the 45-degree inverted-V provides relatively weak radiation at angles suitable for long-distance communications.

Although the 45-degree inverted-V might be useful for NVIS or regional communications through about 30 meters, it is not a desirable antenna for use above that band. In effect, the added 15 degrees of slope to each leg transformed the performance of the inverted-V. Given the normal desire for lower-angle radiation, the transformation has indeed been harmful. There is a limit to the slope of an inverted-V if we intend to use it for an all-band HF antenna. That limit is not much beyond a 30-degree slope.

Conclusion

By reviewing the properties of a 135' level doublet on all HF bands, we have been able to watch the evolution of inverted-V patterns as we increased the wire slope from 30 degrees to 45 degrees. While the 30-degree inverted-V gave useful general purpose performance, the 45-degree version of the antenna became generally useless on most bands for normal HF skip communications.

Had we begun with a set of antennas with a resonant 40-meter length, the results would not have ultimately changed. However, the complete degradation of patterns would not have occurred until about 20 MHz with a 45-degree inverted-V. If we had started with an antenna whose length was suitable for 160 meters, the patterns would have gone to pot at around 5 MHz. Indeed, the 45-degree inverted-V yields such poor performance that one might well do better by eliminating one leg and feeding the remaining leg at its center as a sloping doublet. Alternatively, an inverted-L--either base or center fed--might also yield better performance. The lesson is simple: if you must use an inverted-V as an all-band HF antenna, do not make the V too sharp.

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