A Short Note on Tilted Vertical VHF Antennas

L. B. Cebik, W4RNL

Increasingly, innumerable towers surround us with antennas designed to provide cell and other wireless services. The antennas seem almost universally to tilt forward (except for the somewhat obvious tower-to-tower horns and parabolas). Somehow, the tilt must improve performance—at least such is the reasoning of the average amateur who operates in the VHF and UHF range. The basic thought is quite correct, although what sometimes follows is not. One common thought is that the tilt increases the field strength of point-to-point (line-of-sight) communications over a significant distance. Consider the free-space E-plane patterns in **Fig. 1**. To many, it seems initially plausible that the down-tilt of the patterns from tilted dipoles may overcome ground reflections.

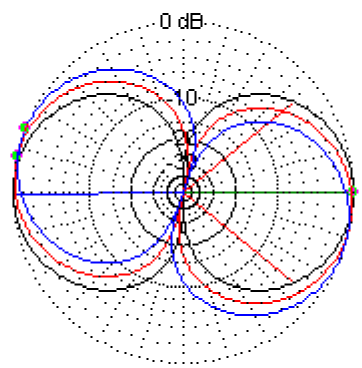


Fig. 1

The thought is semi-natural, since we see journal pages filled with far-field elevation patterns. All of the patterns show a minimum elevation angle for the lowest lobe in the pattern. Perhaps the tilt lowers the angle of that lobe to increase signal strength at even lower elevation angles. The problem with this thought is that far-field patterns are indicators of point-to-point performance levels, but they do not report that performance. To obtain a reliable model of point-to-point communications, we need to use a different output report from NEC, the RP1 ground-wave report. This report calculates the total set of field components between the antenna and a user-positioned observation point specified in terms of its distance from the antenna and its height above ground. Unfortunately, most implementations of NEC do not provide us with any useful graphical outputs for ground-wave reports. Therefore, we have to scan and interpret tabular data. However, we can import the data into a spreadsheet and create some useful, if unexciting, graphs to assist with the interpretation.

This note proceeds in two steps. First, we shall look at what happens to signal strength at a significant distance from the antenna as we both tilt the antenna toward the observer and as we raise the antenna above ground to very significant heights. Second, we shall look at the signal strength at close-in distances, those distances in which we might well have a clear view of the antenna overhead and its supporting tower.

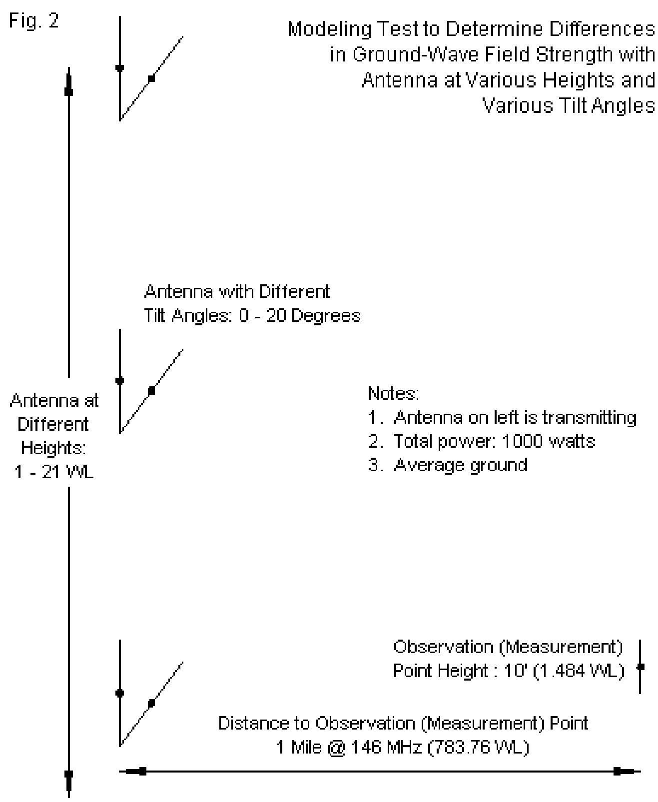
Tilted Vertical Antennas and Field Strength at a Significant Distance from the Antenna

The terms of a NEC ground-wave report differ from those of the normal far-field pattern. The report appears as a set of field-strength values. We shall use the EZNEC implementation, which provides tabular values as mV/m rms. The table provides phase angle values as well, but these will play no role in this note. There are three field-strength readings: vertical, horizontal, and radial. Since we shall use vertical antennas exclusively, we may focus solely on the vertical field-strength reading.

Now let's set up a modeling situation that we may systematically vary. Our antenna will be a vertical dipole for 146 MHz. We shall change the feedpoint height above average ground in regular steps. The initial exercise will vary the height in 2-wavelength increments from 1 λ to 21 λ. Although the upper heights are well above those an amateur might use, they are short of what we might find for antenna heights in the GHz range used by wireless services. Although the exact numbers might change, the general principles illustrated by the exercise apply at all VHF and UHF frequencies.

As well, we shall tilt the antenna, meaning that we shall tip the top of the antenna toward a defined observation point. We often see at the top of wireless towers several antennas pointing in directions that likely cover the entire horizon, one antenna at a time in a polling arrangement. A single tilted dipole tipped toward the observation point suffices to capture the principles of antenna tilting. Larger arrays may increase the basic gain, but they will not change the relative field strength differences that we encounter.

Our observation point is the position for which NEC will calculate the field strength values. For our exercise, we shall assign this point a position exactly 1 mile from the antenna and 10' above average ground. At 146 MHz, the height is 1.484 λ, while the distance is 783.76 λ from the antenna. One may replicate the exercise using any observation point that is many wavelengths from the antenna and select any desired height above ground. **Fig. 2** provides in general outline form the parameters of the exercise. To obtain clear numbers that permit easy comparisons, I set the radiated power level to 1000 Watts. Other power levels are equally usable.



The field-strength data for this modeled test set-up appear in **Table 1**. **Fig. 3** graphs the data for selected antenna heights above ground. For every antenna height, as we increase the tilt angle of the dipole and measure the field strength at significant distance from the antenna position, the field strength decreases. The percentage of decrease is not large—an important fact—but the phenomenon is invariable. Tilting an antenna does not improve point-to-point communications between stations at a significant distance from each other.

Ground-Wave (Point-to-Point) Field Strength 1 Mile from Antenna					
Antenna Power: 1000 Watts					Table 1
Tilt Angle	0	5	10	15	20
Height					
1	4.02	3.96	3.86	3.73	3.55
3	10.46	10.40	10.22	9.93	9.55
5	17.07	16.98	16.71	16.26	15.65
7	23.59	23.48	23.12	22.50	21.67
9	29.99	29.86	29.41	28.64	27.59
11	36.35	36.11	35.58	34.66	33.40
13	42.38	42.23	41.62	40.56	39.10
15	48.99	48.82	48.12	46.90	45.21
17	54.82	54.65	53.88	52.54	50.66
19	60.51	60.34	59.52	58.05	56.00
21	66.05	65.89	65.01	63.44	61.26
Notes:	Tilt angle in degrees, top tilted in observer direction				
	Height in wavelengths over average ground				
	Test frequency: 146 MHz				
	Values only for direction of observation point				

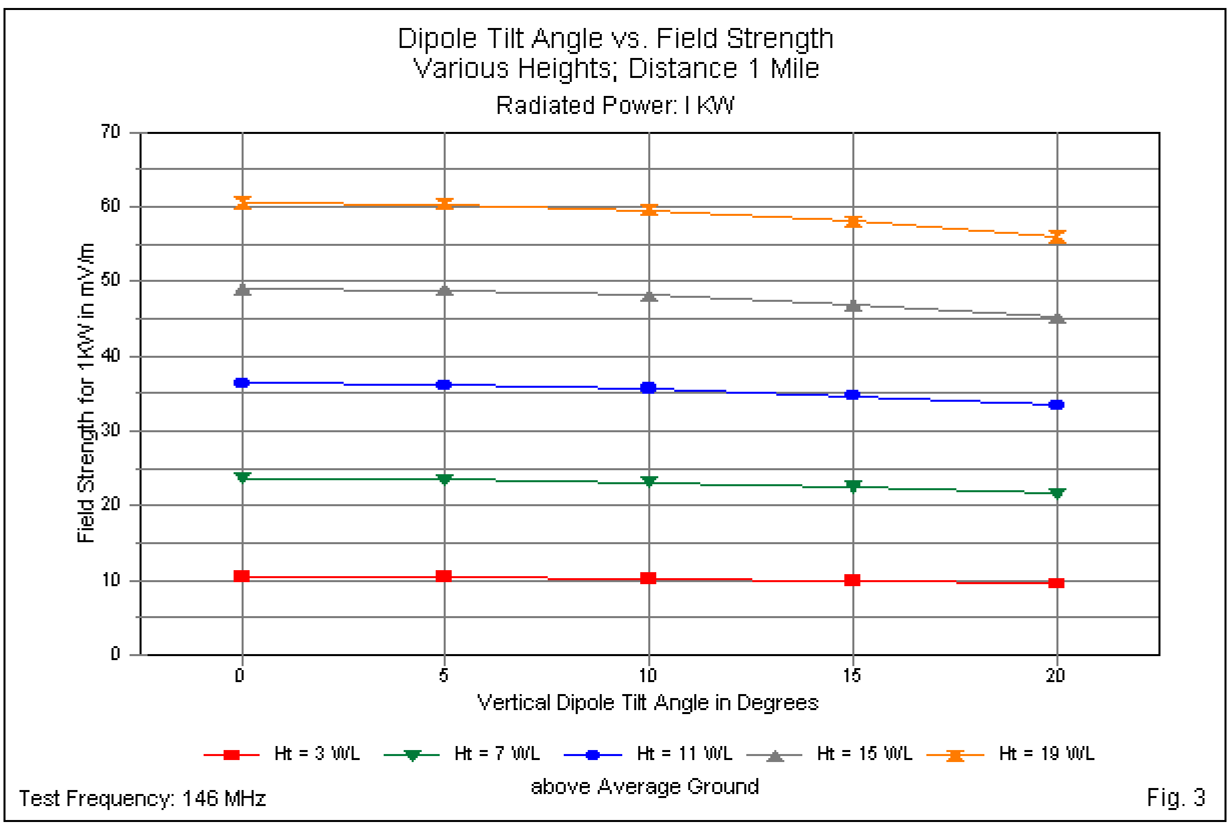


Fig. 3

Nevertheless, amateurs have sought out antennas that produce a natural down-tilt in their free-space patterns, such as the E-plane pattern for a base-fed collinear array shown in **Fig. 4**, sometimes in the belief that the down-tilt will produce better point-to-point signal strengths. However, no matter how many times one replicates the exercise, the same results emerge. When stations are significantly distant from each other but still within point-to-point communications range, a down-tilted free-space pattern—whether produced by tilting the antenna or other techniques—yields less field strength than an antenna with a level or untilted free-space pattern of the same maximum gain in free space.

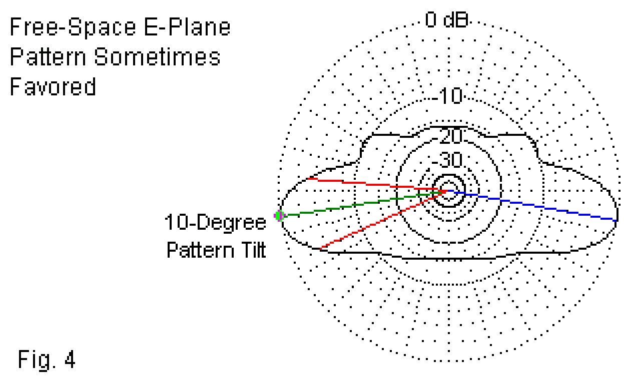


Fig. 4

Our sample does not prove, but only illustrates the principle that a down-tilted antenna or antenna pattern does not improve signal strength at a distance. In the present context, it is sufficient to lead us in another direction. Since the field strength reduction is relatively small, perhaps it represents a "sacrifice" an array designer is willing to make for a different advantage.

Tilted Vertical Antennas and Field Strength at Distances Close to the Antenna

The free-space pattern of an untilted dipole, as shown in **Fig. 1**, has the properties of any simple dipole: almost negligible radiation from the ends of the element. In theory, this condition leaves a hole in the antenna's coverage. Aeronautical beacons, range-finding stations, and air traffic control ground stations have long noted this problem. With a vertical dipole, the station and an aircraft nearly overhead often lose contact with each other. The ground stations have resorted to some interesting antenna designs to fill the gap while still maintaining omni-directional coverage. For our purposes, we need merely note the long history of our knowledge of the communications hole above a vertical antenna.

The advent of VHF business and governmental communications following World War II presented users with the opposite problem. As base-station antennas increased their height to improve overall coverage, the aeronautical "hole" reappeared upside down. In some cases, mobile stations positioned relatively close to the base-station location could not communicate with the base station. The locations fell into the weak signal strength area of vertical dipoles and derivative antennas below the antenna itself. As operating frequencies increased, the antennas grew higher as measured in wavelengths, even without changing the antenna's physical height. The development of cell and other wireless services that relayed near-ground signals among well-spaced antenna towers increased the problem of the communications hole. Economics and citizen reactions limited the number and location of such very tall towers. Allowing communications with a station (or cell phone) close to the tower called for a solution based on the antennas at each tower. Just here lies the foundation of the tilted vertical dipole antenna.

Fig. 5

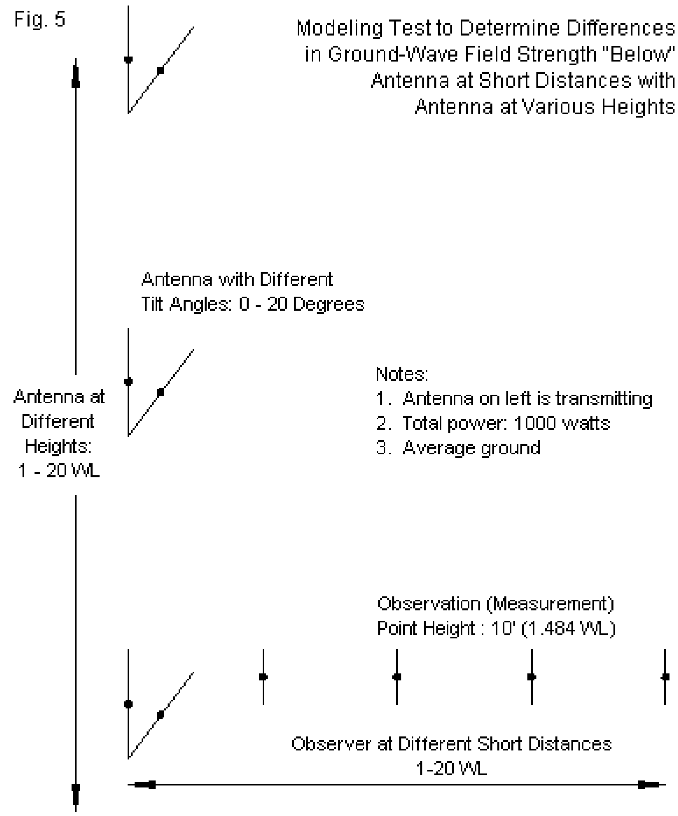


Fig. 5 sketches a revised modeling test to illustrate what happens when we tilt a vertical dipole at various heights above ground using new observation points. We shall retain the 146 MHz test frequency, the 1 KW power level, and the 10' observation height. However, we shall use distances of 1, 5, 10, 15, and 20 wavelengths from the antenna position as field-strength calculation points. We shall also try tilt angles from 0° to 20° in 5° increments. In all cases, we shall sample the field strength only in the direction of the antenna's tilt, which is toward the observation point.

As we examine the data, we should remember that the situation is simplified relative to reality. It contains enough detail to show the principle involved, but not sufficient detail to replicate an actual engineering challenge. The frequencies involved may be much higher than 146 MHz, resulting in much higher towers than the 20-λ limit in the sample. As well, the field-strength values (in mV/m) represent values based on a 1000-Watt power level in order to give us readily comparable numbers. Actual power levels may differ radically. As well, the sample does not define a minimum or threshold value for signal strength, a value toward which antenna engineers may design as they wrestle with their specific tilted antennas.

Still, the numbers in **Table 2** are revealing as we interpret their general trends rather than the individual values. For example, only an antenna height of 1 λ produces a reduction in signal strength as we increase the tilt angle of the antenna. Of course, this height gives us an antenna that is actually lower than the observation point. For all heights greater than the observation point height (1.484 λ), the close-in field strength values increase as we increase the tilt angle. **Fig. 6** graphs the values for an antenna 5 λ above ground. The graph may seem somewhat odd until we begin to read it aright.

Ground-Wave Field Strength at closer Distance to Antenna					
Antenna Power: 1000 Watts					Table 2
Distance	1 WL	5 WL	10 WL	15 WL	20 WL
Tilt Angle: 0 Degrees					
Height					
1 WL	65074	17705	9993	6202	4082
5 WL	4084	10784	7414	7460	5170
10 WL	702	1157	4986	3594	3480
15 WL	269	643	747	3247	3059
20 WL	141	275	659	973	2412
Tilt Angle: 5 Degrees					
Height					
1 WL	59627	17164	9892	6149	4045
5 WL	4973	11752	7686	7661	5252
10 WL	1055	1338	5479	3809	3640
15 WL	484	793	833	3579	3288
20 WL	295	362	762	1100	2661
Tilt Angle: 10 Degrees					
Height					
1 WL	53736	16438	9686	6030	3695
5 WL	5871	12646	7879	7780	5276
10 WL	1416	1517	5941	3990	3765
15 WL	707	944	916	3892	3493
20 WL	455	450	864	1223	2896
Tilt Angle: 15 Degrees					
Height					
1 WL	47488	15550	9381	5847	3844
5 WL	6770	13447	7989	7815	5242
10 WL	1783	1691	6364	4133	3852
15 WL	932	1093	995	4180	3668
20 WL	617	538	963	1340	3112
Tilt Angle: 20 Degrees					
Height					
1 WL	40972	14522	8986	5612	3685
5 WL	7662	14137	8012	7765	5151
10 WL	2152	1857	6736	4234	3897
15 WL	1159	1241	1068	4435	3809
20 WL	780	626	1059	1450	3305
Notes:	Tilt angle in degrees, top tilted in observer direction				
	Height in wavelengths over average ground				
	Test frequency: 146 MHz				
	Values only for direction of observation point				

Because the antenna does not have great height, the field strength values from a distance of 10 λ outward show only small differences with changes of the tilt angle. At a distance of 5 λ, the field strength readings spike, with lower readings just below the antenna at a distance of only 1 λ. The 1-λ distance readings fall into the weakest region of signal strength off the end of even a tilted dipole, while the high readings at 5 λ result from close-in reception of energy from the mail dipole lobe. More significant than these facts are the increments of increased field strength between tilt angles for both of the closest distances. The greater the tilt angle, the greater the improvement becomes in the signal strength. Of course, translated into wireless frequencies, a 5-λ antenna height is implausibly low.

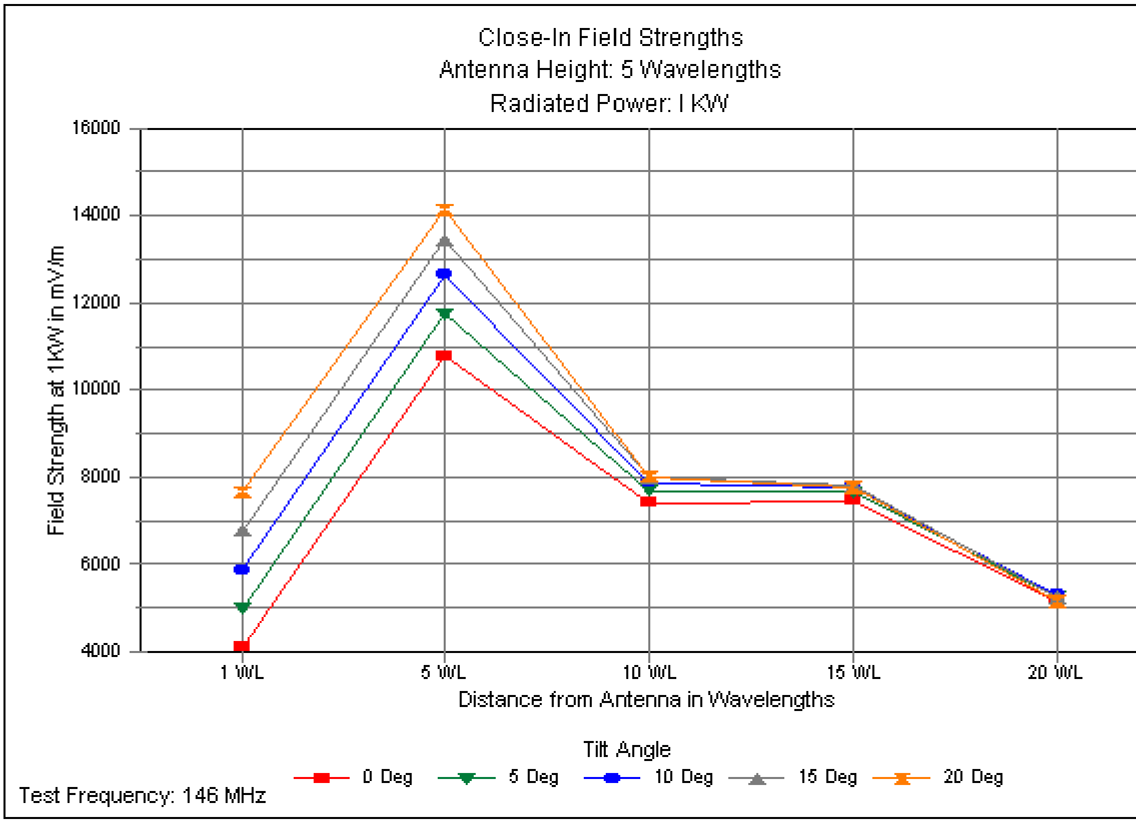

Close-In Field Strengths
Antenna Height: 5 Wavelengths
Radiated Power: I KW
Field Strength at 1KW in mV/m
16000
14000
12000
10000
8000
6000
4000
1 WL
5 WL
10 WL
15 WL
20 WL
Distance from Antenna in Wavelengths
Tilt Angle
0 Deg
5 Deg
10 Deg
15 Deg
20 Deg
Test Frequency: 146 MHz

Fig. 6

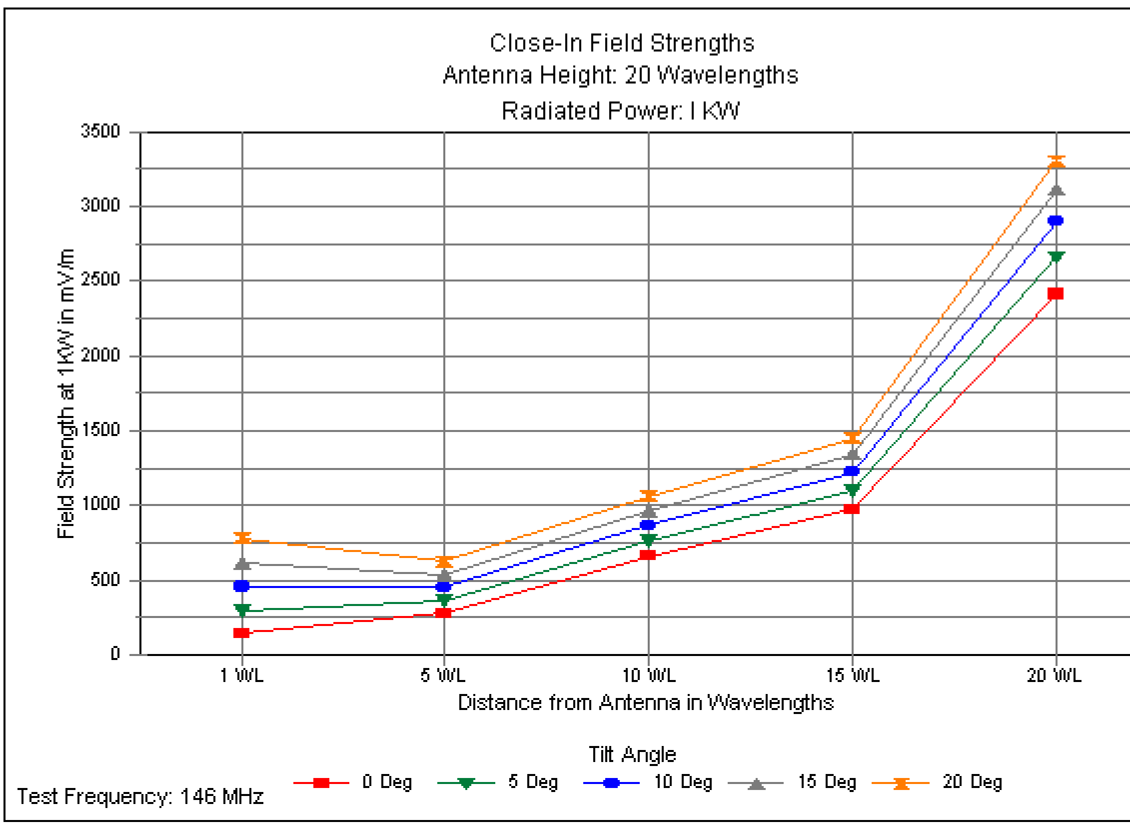

Close-In Field Strengths
Antenna Height: 20 Wavelengths
Radiated Power: I KW
Field Strength at 1KW in mV/m
3500
3000
2500
2000
1500
1000
500
0
1 WL
5 WL
10 WL
15 WL
20 WL
Distance from Antenna in Wavelengths
Tilt Angle
0 Deg
5 Deg
10 Deg
15 Deg
20 Deg
Test Frequency: 146 MHz

Fig. 7

Fig. 7 graphs what happens when we raise the antenna to a more plausible 20-λ height above average ground. The entire sampled range from 1 λ to 20 λ distant from the antenna benefits from the increased tilt angles. In the most critical region from 1-λ to 10-λ distance, the level of change with changing tilt angles may be difficult to read due to the total range of values on the graph's Y-axis. Therefore, let's confine the graph somewhat and reverse the procedure. **Fig. 8** presents the reduced scope of data, but arranges the X-axis to record tilt angles, with separate lines for the distances from the antenna position.

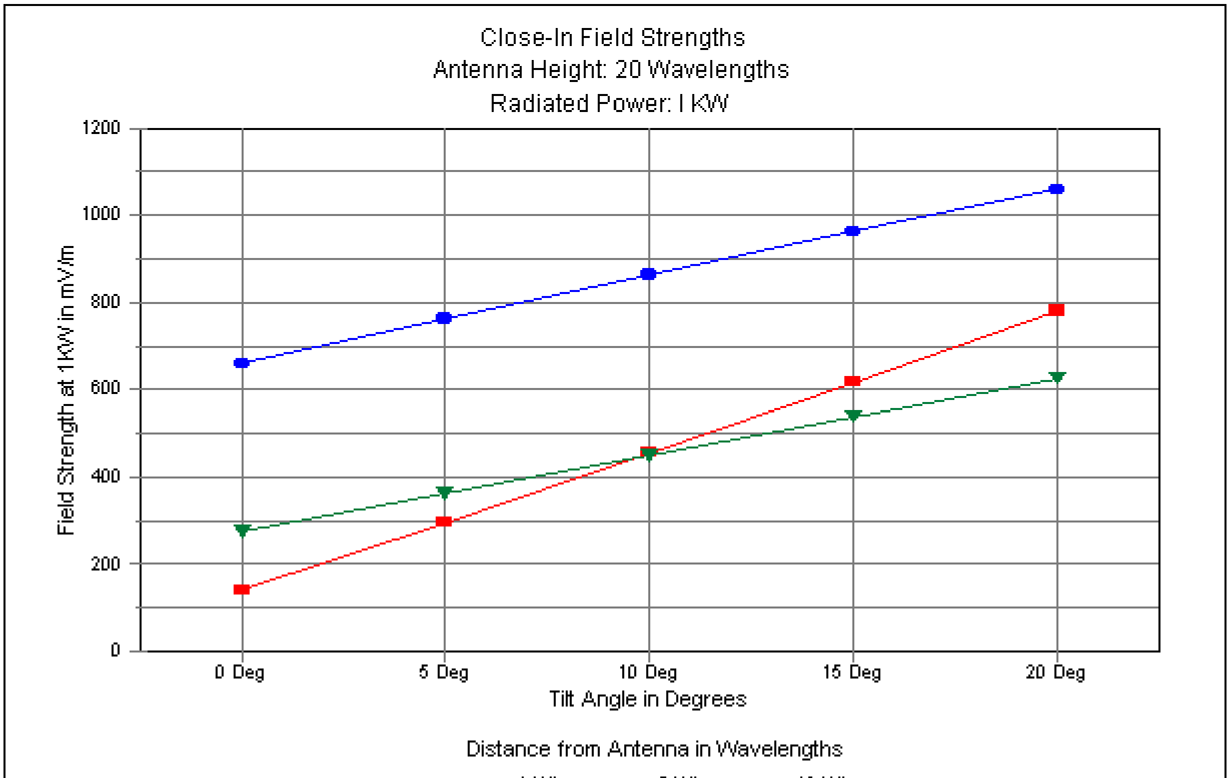


Fig. 8

Relative to the antenna's 20-λ height, the graph illustrates the degree of improvement that antenna tilt may yield for very close-in signal strength. Even at a distance of 10 λ from the antenna position, field strength increases by 160%. At a distance of 5 λ, the increase is nearly 230%, while almost immediately below the antenna, the increase is over 500%. Of course, in a real situation, there will be innumerable other factors that influence actual measurements. In general, if the system has a certain threshold of required field strength (and reception sensitivity) to permit reliable communication, then for weak signals in the area immediately in the vicinity of the antenna, antenna tilting may resolve the difficulty without significantly reducing the field strength at much larger distances from the antenna.

Conclusion

The goal of this brief note has been to demonstrate that vertical antenna tilting has no benefit for distant point-to-point communications. In fact, tilting reduces distant field strength—and conversely, reception sensitivity—but not by an amount that one would normally be unwilling to sacrifice for an alternative benefit. The added benefit is increased field strength in the close-in region below the antenna. With a correctly set tilt angle, the system can increase field strength by a considerable amount just below the antenna.

Actual antenna sites may employ a variety of techniques to achieve the close-in benefits. A high amateur repeater antenna might use a design with a natural pattern tilt, such as shown in **Fig. 5**, to fill a close-in void, especially if the repeater tower stands within an urban region. Wireless systems tend to use much higher towers with multiple high-gain antennas in polling arrangements. The required tilt angle for proper coverage both below the antenna and at a distance may require not only careful calculation and simulation, but as well, a long round of site adjustments to compensate for terrain factors.

Tilting a vertical antenna, then, is not for the benefit of our distant communications partners. Instead, it helps us stay in touch with our most immediate neighbors.