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A Study of Tall Verticals

The author conducted a study of quarter wavelength vertical antennas used on bands higher in frequency than that for which they were designed. Here are the results of his analysis.

Some time ago my friend Joe Johnson, K3RR, asked me how his quarter wavelength 160 meter vertical would perform on 80 meters. We both knew that on 80 meters the antenna height would be about 0.5 λ, so we expected the gain to be higher, with the peak of the main radiation lobe occurring at a lower take-off angle. Neither of us had a good idea of what the exact numerical results might be, however.

With that in mind, this article was written in order to answer several questions: First, "How well does a vertical antenna that was designed for one band perform when it is operated on a higher frequency band?" The second (related) question: "Is it worth the effort to put up a ⅝ λ radiator?"

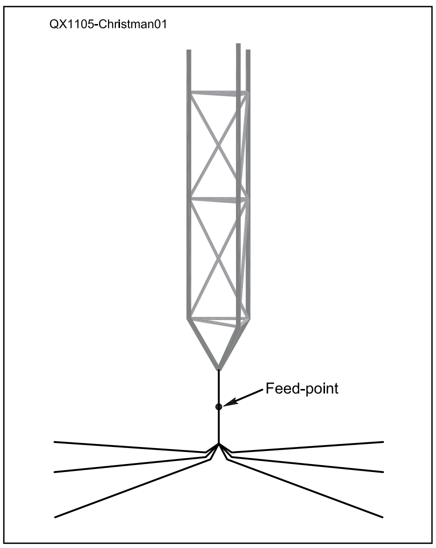

Figure 1 — Close-up of the base region of the full-size 160 meter vertical antenna system, showing how the three tower legs are tapered down to a single conductor at the lower end of the monopole. For clarity, only six of the 60 buried radials in the ground screen are shown.

Computer Simulations

Full-size 0.25 λ radiators on 160 meters are well over 100 feet tall, so it was decided to utilize a triangular tower as the basis for the top-band antenna model. A tower whose face width is 12 inches was employed, although the bottom end was "tapered" from three legs down to one single tubular conductor, to simplify the construction of the feed point (see Figure 1). The operating frequency was set to 1830 kHz, and a ground-screen consisting of sixty λ/4 no. 14 AWG radials (length = 134.4 feet) was installed. These radials were buried to a depth of 3 inches in "average" soil having a conductivity of 0.005 siemens per meter and a dielectric constant of 13.

I simulated all of the antennas described in this article using the *EZNEC* software package, which is available from Roy Lewallen, W7EL.[1] A real antenna system would probably be made from zinc-coated steel tower sections and copper radials. *EZNEC* allows the use of only a single type of conductor, so I selected aluminum since its conductivity is better than that of zinc, but inferior to copper.

Results for a Quarter Wavelength 160 Meter Vertical

Table 1 shows what happens when the full-size λ/4 top-band antenna is used on 160 meters and also on the 80 meter band. Initially, the length of the tower was

[1] *EZNEC* antenna-simulation software is available from Roy Lewallen, W7EL, PO Box 6658, Beaverton OR 97007.

Table 1

Performance of a full-size quarter-wavelength vertical monopole antenna designed for 160 meters, when used on that band and also on 80 meters. The monopole is built from triangular tower sections (12 inch face width), while the ground system is composed of 60 no. 14 AWG wire radials, whose length is 134.4 feet (0.25 λ at 1830 kHz). The vertical element is tuned to resonance at 1830 kHz, with a resulting antenna height of 125.418 feet. All conductors are aluminum, and the soil is "average" (conductivity = 0.005 siemens/meter and dielectric constant = 13).

	BAND	
	160 Meters	*80 Meters*
Operating Frequency (kHz)	1830	3650
Input Impedance (Ω)	36.0	706 – *j* 310
SWR (50 Ω ref.)	1.39	16.9
Peak Gain (dBi) and Take-off Angle (°)	1.20 at 22.9	1.14 at 18.7
Gain (dBi) at 5° Take-off Angle	–3.42	–3.45
Gain (dBi) at 10° Take-off Angle	–0.36	–0.13
Gain (dBi) at 15° Take-off Angle	0.75	0.95
Gain (dBi) at 20° Take-off Angle	1.15	1.12
Half Power Beamwidth (°)	43.7	31.6
Efficiency (%)	41.2	33.0

adjusted in order to resonate the entire system at a frequency of 1830 kHz. The input reactance fell to (approximately) zero when the overall tower height was "pruned" to just 125.418 feet. Key performance parameters — such as gain, take-off angle, input impedance, SWR, and efficiency — were then recorded from the *EZNEC* output.

Next, the operating frequency was changed to 3650 kHz, in the 80 meter band, and the computer analysis was repeated. An examination of Table 1 reveals that the peak gain of the tall monopole is similar on both bands, although the elevation angle is about four degrees higher on "Top Band." The SWR is quite high on 80 meters, so an impedance-matching network would be needed there. Figure 2 displays the accompanying elevation-plane radiation patterns. At take-off angles of 20° or less, the gain is very similar on both bands, but the signal strength at higher elevation angles is reduced on 80 meters, due to the greater electrical height of the tower on this band.

Notice that the system efficiency is significantly lower on 80 meters, as compared to 160 (33% versus 41.2%). This is probably because the region on the tower where maximum current occurs is more than 60 feet up in the air, and the corresponding displacement current strikes the earth on a portion of the ground screen where the radials are spread relatively far apart. To confirm this, the tower was shortened to a height of only 61.3 feet, which allowed the antenna system to resonate at 3650 kHz (with the groundscreen left unchanged). When using the λ/4 tower in combination with a λ/2 groundscreen, the efficiency on 80 meters rose to 40.7%

Results for Two Different Quarter Wavelength 80 Meter Verticals

The same kind of triangular tower sections (12 inch face width) were employed to construct an *EZNEC* model of a λ/4 monopole for the 80 meter band. The groundscreen was composed of sixty no. 14 AWG radials, each with a length of 67.368 feet, which is equal to λ/4 at a frequency of 3650 kHz. The vertical element was then adjusted to resonate the antenna system at this same frequency, which required an overall height of 61.163 feet. Recall from the previous discussion that the resonant height for a similar tower with a larger ground screen (134.4 foot radials) was 61.3 feet.

The outcome from the *EZNEC* simulation is posted in Table 2, not only for usage

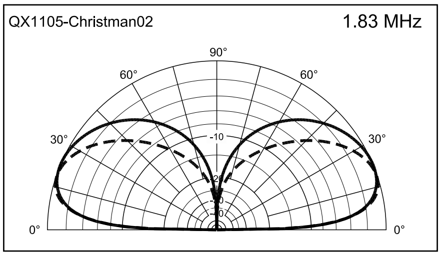

Figure 2 — Elevation-plane radiation patterns for a resonant ¼ λ 160 meter vertical antenna (made from tower sections) when used on both 160 and 80 meters.
Solid trace = operating on 160 meters (1830 kHz)
Peak gain = 1.20 dBi at 22.9° take-off angle
Dashed trace = Operating on 80 meters (3650 kHz)
Peak gain = 1.14 dBi at 18.7° take-off angle

Table 2

Performance of a full-size quarter-wavelength vertical monopole antenna designed for 80 meters, when used on that band and also on 60 and 40 meters. The monopole is built from triangular tower sections (12 inch face width), while the ground system is composed of 60 no. 14 AWG wire radials, whose length is 67.368 feet (0.25 λ at 3650 kHz). The vertical element is tuned to resonance at 3650 kHz, with a resulting antenna height of 61.163 feet. All conductors are aluminum, and the soil is "average" (conductivity = 0.005 siemens/meter and dielectric constant = 13).

	BAND		
	80 Meters	*60 Meters*	*40 Meters*
Operating Frequency (kHz)	3650	5367	7150
Input Impedance (Ω)	33.7	155 + *j*197	602 – *j*71.1
SWR (50 Ω ref.)	1.48	8.31	12.2
Peak Gain (dBi) and Take-off Angle (°)	0.53 at 25.1	0.75 at 23.7	1.05 at 20.9
Gain (dBi) at 5° Take-off Angle	–5.13	–4.98	–4.34
Gain (dBi) at 10° Take-off Angle	–1.61	–1.34	–0.70
Gain (dBi) at 15° Take-off Angle	–0.23	0.09	0.64
Gain (dBi) at 20° Take-off Angle	0.36	0.65	1.04
Half Power Beamwidth (°)	44.2	40.7	34.9
Efficiency (%)	35.1	35.3	34.5

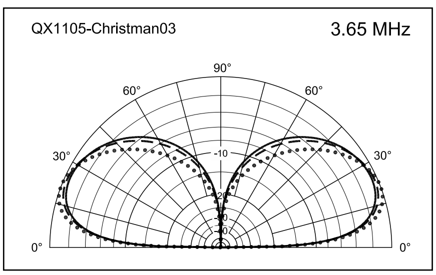

Figure 3 — Elevation-plane radiation patterns for a resonant ¼ λ 80 meter vertical antenna (made from tower sections) when used on 80, 60, and 40 meters.
Solid trace = operating on 80 meters (3650 kHz)
Peak gain = 0.53 dBi at 25.1° take-off angle
Dashed trace = operating on 60 meters (5367 kHz)
Peak gain = 0.75 dBi at 23.7° take-off angle
Dotted trace = operating on 40 meters (7150 kHz)
Peak gain = 1.05 dBi at 20.9° take-off angle

Table 3

Performance of a full-size quarter-wavelength vertical monopole antenna designed for 80 meters, when used on that band and also on both 60 and 40 meters. The monopole is built from lengths of tapered metal tubing (diameter varies from 3 inches to 0.75 inch), while the ground system is composed of 60 no. 14 AWG wire radials, whose length is 67.368 feet (0.25 λ at 3650 kHz). The vertical element is tuned to resonance at 3650 kHz, with a resulting antenna height of 67.482 feet. All conductors are aluminum, and the soil is "average" (conductivity = 0.005 siemens/meter and dielectric constant = 13).

	BAND		
	80 Meters	*60 Meters*	*40 Meters*
Operating Frequency (kHz)	3650	5367	7150
Input Impedance (Ω)	36.0	207 + *j*311	828 – *j*505
SWR (50 Ω ref.)	1.39	13.7	22.7
Peak Gain (dBi) and Take-off Angle (°)	0.77 at 24.7	0.79 at 22.9	1.07 at 19.6
Gain (dBi) at 5° Take-off Angle	–4.83	–4.83	–4.05
Gain (dBi) at 10° Take-off Angle	–1.33	–1.20	–0.46
Gain (dBi) at15° Take-off Angle	0.05	0.19	0.79
Gain (dBi) at 20° Take-off Angle	0.63	0.72	1.07
Half Power Beamwidth (°)	43.7	39.3	31.9
Efficiency (%)	37.0	34.9	32.7

on 80 meters, but also for both 60 and 40 meters. Notice that the peak gain and the input resistance rise continually as the operating frequency is increased, while the take-off angle falls by several degrees. The radiation-pattern plots (which are similar to one another) are given in Figure 3.

A second λ/4 80 meter vertical element was also designed, but this time the monopole was constructed from lengths of aluminum tubing, with the diameters of the various sections tapering down from 3 inches to a minimum of 0.75 inch. This vertical element was placed over the same ground screen as before (sixty no. 14 AWG aluminum radials, each 67.368 feet long), and immersed in the same type of "average" soil. Table 3 shows the key performance parameters calculated by *EZNEC*, on the three bands of interest (80, 60, and 40 meters). It can be seen that the values for gain and elevation angle are similar to those obtained earlier when the monopole was built from tower sections.

Results for a Quarter Wavelength 60 Meter Vertical

A full-size λ/4 monopole was then designed for operation on the 60 meter band, using lengths of tapered aluminum tubing. The diameter of the largest section is 3 inches, with subsequent portions gradually reduced in size, reaching 1.5 inches at the tip. The length of the 60 buried no. 14 AWG aluminum radials is 45.816 feet, or λ/4 at a frequency of 5367 kHz. The overall height of the vertical element was trimmed to 44.884 feet, which provided resonance at the center of the band (5367 kHz). This antenna can be utilized effectively on three bands (60, 40, and 30 meters), and the outcome from the computer modeling is summarized in Table 4. As before, we find that raising the frequency yields an increase in peak gain and feed-point resistance, along with a reduction in the take-off angle of the main radiation lobe.

Results for a Quarter Wavelength 40 Meter Vertical

Table 5 illustrates what happens when a λ/4 monopole constructed from aluminum tubing is employed on the 40 meter band. Here the diameter of the tapered sections of tubing ranges from 2 inches down to 0.75 inch, and the ground screen consists of sixty no. 14 AWG aluminum radials whose length is 34.39 feet, which is λ/4 at7150 kHz. The vertical element was adjusted to resonate the antenna system at this same frequency, leading to a final height of 33.736 feet.

The outcome from the computer analysis is displayed (Table 5) for applications on both 30 and 20 meters, along with the

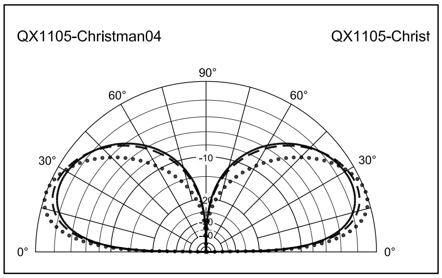

Figure 4 — Elevation-plane radiation patterns for a resonant ¼ λ 40 meter vertical antenna (made from tapered sections of tubing) when used on 40, 30, and 20 meters.
Solid trace = operating on 40 meters (7.15 MHz)
Peak gain = 0.29 dBi at 26.4° take-off angle
Dashed trace = operating on 30 meters (10.125 MHz)
Peak gain = 0.69 dBi at 24.7° take-off angle
Dotted trace = operating on 20 meters (14.175 MHz)
Peak gain = 1.28 dBi at 20.5° take-off angle

40 meter band. As was seen previously, the peak gain and the input resistance rise continually as the operating frequency is increased, while the elevation angle falls by several degrees. Figure 4 gives us the principal radiation patterns. The plots for 40 and 30 meters resemble each other, while that for 20 meters is clearly more compressed, peaking at a lower take-off angle.

Results for a Quarter Wavelength 30 Meter Vertical

A computer model of a full-size λ/4 monopole was then created for operation on the 30 meter band, again using lengths of tapered aluminum tubing. The diameter of the largest section is 1.5 inches, with subsequent pieces gradually reduced in size to a final value of 1 inch at the tip. The length of the 60 buried no. 14 AWG aluminum radials is 24.286 feet, or λ/4 at 10.125 MHz.

Table 4

Performance of a full-size quarter-wavelength vertical monopole antenna designed for 60 meters, when used on that band and also on both 40 and 30 meters. The monopole is built from lengths of tapered metal tubing (diameter varies from 3 inches to 1.5 inches), while the ground system is composed of 60 no. 14 AWG wire radials, whose length is 45.816 feet (0.25 λ at 5367 kHz). The vertical element is tuned to resonance at 5367 kHz, with a resulting antenna height of 44.884 feet. All conductors are aluminum, and the soil is "average" (conductivity = 0.005 siemens/meter and dielectric constant = 13).

	BAND		
	60 Meters	*40 Meters*	*30 Meters*
Operating Frequency (MHz)	5.367	7.15	10.125
Input Impedance (Ω)	37.2	112 + *j*182	898 – *j*68.1
SWR (50 Ω ref.)	1.34	8.48	18.1
Peak Gain (dBi) and Take-off Angle (°)	0.27 at 25.8	0.61 at 24.6	1.11 at 21.1
Gain (dBi) at 5° Take-off Angle	–5.80	–5.42	–4.43
Gain (dBi) at 10° Take-off Angle	–2.11	–1.68	–0.72
Gain (dBi) at 15° Take-off Angle	–0.61	–0.17	0.66
Gain (dBi) at 20° Take-off Angle	0.05	0.46	1.09
Half Power Beamwidth (°)	44.1	41.5	34.7
Efficiency (%)	32.9	34.5	34.8

Table 5

Performance of a full-size quarter-wavelength vertical monopole antenna designed for 40 meters, when used on that band and also on both 30 and 20 meters. The monopole is built from lengths of tapered metal tubing (diameter varies from 2 inches to 0.75 inch), while the ground system is composed of 60 no. 14 AWG wire radials, whose length is 34.39 feet (0.25 λ at 7150 kHz). The vertical element is tuned to resonance at 7150 kHz, with a resulting antenna height of 33.736 feet. All conductors are aluminum, and the soil is "average" (conductivity = 0.005 siemens/meter and dielectric constant = 13).

	BAND		
	40 Meters	*30 Meters*	*20 Meters*
Operating Frequency (MHz)	7.15	10.125	14.175
Input Impedance (Ω)	35.9	152 + *j*235	866 – *j*318
SWR (50 Ω ref.)	1.39	10.6	19.7
Peak Gain (dBi) and Take-off Angle (°)	0.29 at 26.4	0.69 at 24.7	1.28 at 20.5
Gain (dBi) at 5° Take-off Angle	–6.03	–5.49	–4.19
Gain (dBi) at 10° Take-off Angle	–2.25	–1.68	–0.48
Gain (dBi) at 15° Take-off Angle	–0.68	–0.13	0.89
Gain (dBi) at 20° Take-off Angle	0.03	0.53	1.28
Half Power Beamwidth (°)	44.2	41.3	33.0
Efficiency (%)	33.0	34.9	35.0

The over-all height of the vertical element was pruned to just 23.491 feet, providing resonance at mid-band. This antenna can be utilized effectively on five bands (30, 20, 17, 15, and 12 meters) and the outcome from the *EZNEC* simulations is posted in Table 6. We find (as expected) that raising the frequency yields a boost in the peak gain, accompanied by a lowering of the elevation angle of the main radiation lobe

Results for a Quarter Wavelength 20 Meter Vertical

Table 7 reveals what happens when a λ/4 monopole built from aluminum tubing is employed on the 20 meter band. Now the diameter of the tapered sections of aluminum tubing ranges from 1.0 inch to 0.75 inch, and the ground screen consists of sixty no. 14 AWG aluminum radials whose length is 17.347 feet (λ/4 at 14.175 MHz).The vertical element was adjusted to resonate the entire antenna system at this same frequency, leading to an overall height of 16.535 feet.

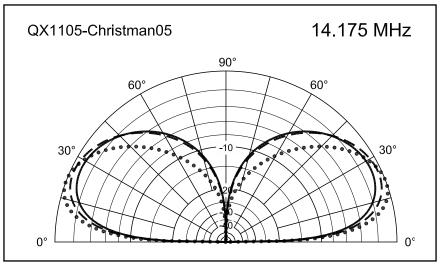

Figure 5 — Elevation-plane radiation patterns for a resonant ¼ λ 20 meter vertical antenna (made from tapered sections of tubing) when used on 20, 15, and 10 meters. Solid trace = operating on 20 meters (14.175 MHz) Peak gain = 0.56 dBi at 27.3° take-off angle Dashed trace = operating on 15 meters (21.225 MHz) Peak gain = 1.13 dBi at 25.2° take-off angle Dotted trace = operating on 10 meters (28.7 MHz) Peak gain = 1.48 dBi at 20.8° take-off angle

In Table 7, the outcome of the computer analysis is depicted for utilization on five amateur bands, from 20 through 10 meters. As was seen previously, the peak gain and the input resistance rise continually as the operating frequency is increased, while the take-off angle decreases by several degrees. Figure 5 summarizes the radiation-pattern plots for operation of the antenna on the 20, 15 and 10 meter bands. Notice that the lobe shapes are similar on 20 and 15 meters, but that for 10 meters is lower and more compressed.

Is a 5/8 Wavelength Antenna Really Superior?

In this part of the article, we will examine the electrical performance of vertical antennas as their height is varied from ¼ to ⅜ to ½ to ⅝ λ. Each antenna model is constructed from aluminum, using a single no. 10 AWG conductor for the monopole, along with 60 buried radials made from no. 14 AWG wire.

Table 6

Performance of a full-size quarter-wavelength vertical monopole antenna designed for 30 meters, when used on that band and also on 20, 17, 15 and 12 meters. The monopole is built from lengths of tapered metal tubing (diameter varies from 1.5 inches to 1.0 inch), while the ground system is composed of 60 no. 14 AWG wire radials, whose length is 24.286 feet (0.25 λ at 10.125 MHz). The vertical element is tuned to resonance at 10.125 MHz, with a resulting antenna height of 23.491 feet. All conductors are aluminum, and the soil is "average" (conductivity = 0.005 siemens/meter and dielectric constant = 13).

	BAND				
	30 Meters	*20 Meters*	*17 Meters*	*15 Meters*	*12 Meters*
Operating Frequency (MHz)	10.125	14.175	18.118	21.225	24.940
Input Impedance (Ω)	33.0	135 + *j*208	658 + *j*299	571 –*j*468	93.9 –*j*282
SWR (50 Ω ref.)	1.52	9.40	15.9	19.1	19.3
Peak Gain (dBi) and Take-Off Angle (°)	0.52 at 26.9	0.95 at 25.3	1.40 at 22.8	1.65 at 19.7	2.02 at 16.2
Gain(dBi) at 5° Take-off Angle	–6.02	–5.40	–4.54	–3.69	–2.42
Gain (dBi) at 10° Take-off Angle	–2.16	–1.54	–0.73	0.01	1.06
Gain (dBi) at 15° Take-off Angle	–0.54	0.05	0.77	1.34	2.00
Gain (dBi)at 20° Take-off Angle	0.22	0.75	1.33	1.64	1.75
Half Power Beamwidth (°)	44.5	42.0	37.6	30.9	24.3
Efficiency (%)	34.9	37.4	39.1	36.2	37.0

Table 7

Performance of a full-size quarter-wavelength vertical monopole antenna designed for 20 meters, when used on that band and also on 17, 15, 12 and 10 meters. The monopole is built from lengths of tapered metal tubing (diameter varies from 1 inch to 0.75 inch), while the ground system is composed of 60 no. 14 AWG wire radials, whose length is 17.347 feet (0.25 λ at 14.175 MHz). The vertical element is tuned to resonance at 14.175 MHz, with a resulting antenna height of 16.535 feet. All conductors are aluminum, and the soil is "average" (conductivity = 0.005 siemens/meter and dielectric constant = 13).

	BAND				
	20 Meters	*17 Meters*	*15 Meters*	*12 Meters*	*10 Meters*
Operating Frequency (MHz)	14.175	18.118	21.225	24.940	28.7
Input Impedance (Ω)	32.3	79.5 + *j*147	174 + *j*278	479 + *j*403	953 – *j*66
SWR (50 Ω ref.)	1.55	7.53	12.6	16.4	19.2
Peak Gain (dBi) and Take-Off Angle (°)	0.56 at 27.3	0.90 at 26.3	1.13 at 25.2	1.33 at 23.5	1.48 at 20.8
Gain (dBi)at 5° Take-off Angle	–6.12	–5.64	–5.25	–4.76	–4.12
Gain (dBi) at 10° Take-off Angle	–2.22	–1.75	–1.37	–0.92	–0.36
Gain (dBi) at 15° Take-off Angle	–0.57	–0.12	0.23	0.62	1.05
Gain (dBi) at 20° Take-off Angle	0.22	0.63	0.93	1.22	1.47
Half Power Beamwidth (°)	44.7	43.2	41.8	38.8	33.3
Efficiency (%)	35.2	37.4	38.9	39.1	36.7

Table 8

Performance comparison between vertical antenna systems of varying height, when operating on 80 meters at a frequency of 3650 kHz. The monopoles are made from no. 10 AWG wire, with a ground screen composed of 60 buried no. 14 AWG radials (radial length = monopole height). All conductors are aluminum, and the soil is "average" (conductivity = 0.005 siemens/meter and dielectric constant = 13).

	¼ λ System	*⅜λ System*	*½ λ System*	*⅝ λ System*
Monopole Height and Radial Length (ft)	67.368	101.05	134.74	168.42
Input Impedance (Ω)	41.4 + *j* 24.4	229 + *j* 605	2324 – *j* 1425	86.1 – *j* 479
SWR (50 Ω ref.)	1.75	36.8	64.0	55.5
Peak Gain (dBi) and Take-off Angle (°)	0.39 at 24.7	0.79 at 21.7	0.96 at 17.6	0.42 at 13.3
Gain (dBi) at 5° Take-off Angle	–5.21	–4.34	–3.42	–2.81
Gain (dBi) at 10° Take-off Angle	–1.70	–0.91	–0.14	0.06
Gain (dBi) at 15° Take-off Angle	–0.32	0.35	0.85	0.34
Gain (dBi) at 20o Take-off Angle	0.25	0.76	0.89	–0.63
Half Power Beamwidth (°)	43.7	38.0	29.0	20.3
Efficiency (%)	33.8	34.3	29.6	29.8

Table 9

Performance comparison between vertical antenna systems of varying height, when operating on 40 meters at a frequency of 7150 kHz. The monopoles are made from no. 10 AWG wire, with a ground screen composed of 60 buried no. 14 AWG radials (radial length = monopole height). All conductors are aluminum, and the soil is "average" (conductivity = 0.005 siemens/meter and dielectric constant = 13).

	¼ λ System	*⅜ λ System*	*½ λ System*	*⅝ λ System*
Monopole Height and Radial Length (ft)	34.391	51.586	68.781	85.976
Input Impedance (Ω)	39.9 + *j* 25.0	235 + *j* 570	1937 – *j* 1247	81.9 – *j* 436
SWR (50 Ω ref.)	1.81	32.5	54.8	48.7
Peak Gain (dBi) and Take-off Angle (°)	0.15 at 26.2	0.68 at 23.3	0.89 at 19.1	0.68 at 14.5
Gain (dBi) at 5° Take-off Angle	–6.15	–5.15	–4.13	–3.12
Gain (dBi) at 10° Take-off Angle	–2.38	–1.44	–0.56	0.08
Gain (dBi) at 15° Take-off Angle	–0.82	0.02	0.66	0.67
Gain (dBi) at 20° Take-off Angle	–0.11	0.59	0.88	0.04
Half Power Beamwidth (°)	44.1	39.3	30.7	22.3
Efficiency (%)	31.9	34.0	30.4	31.7

The length of these radials will always be adjusted so they are equal to the height of the vertical element.

80 Meters

The findings for 80 meter operation are revealed in Table 8. Peak gain climbs smoothly as the height of the monopole increases from ¼ to ⅜ to ½ λ, but actually diminishes somewhat for the ⅝ λ antenna. The elevation angle where maximum gain occurs, however, continually falls as the system is made taller. Figure 6 shows the principal radiation-pattern plots. Notice that the ⅝ λ element generates *slightly* more gain than the λ/2 vertical at the very lowest take-off angles. For general DX applications on this band, it seems that a monopole height in the vicinity of λ/2 may be the best choice, because of the large amount of high-angle radiation generated by the ⅝ λ element.

40 Meters

Table 9 lists the results for operation on the 40 meter band. As was true on 80, here the maximum-gain value rises continually as the height of the antenna increases from ¼ to ⅜ to ½ λ but once again we see a small reduction for the ⅝ λ system. Nevertheless, the elevation angle where maximum gain occurs constantly decreases as the element is made taller. Plots of the principal-plane radiation patterns are posted in Figure 7. Here, we can see that the ⅝ λ vertical is superior to the λ/2 monopole at *any* take-off angle up to 15°. According to *EZNEC*, at an elevation angle of 5° the ⅝ λ antenna performs better than the λ/2 version by a full decibel, so the taller system appears to be the best selection for DX work on this band.

20 Meters

The outcome for operation on 20 meters

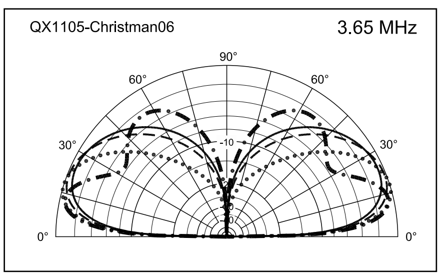

Figure 6 — Elevation-plane radiation patterns for vertical antennas of various heights, when operating on 80 meters (3.65 MHz). The monopoles are made from no. 10 AWG wire and the ground screens are composed of 60 buried no. 14 AWG radials (radial length = monopole height).
Solid trace = ¼ λ system
Peak gain = 0.39 dBi at 24.7° take-off angle
Dashed trace = ⅜ λ system
Peak gain = 0.79 dBi at 21.7° take-off angle
Dotted trace = ½ λ system
Peak gain = 0.96 dBi at 17.6° take-off angle
Dash-dotted trace = ⅝ λ system
Peak gain = 0.42 dBi at 13.3° take-off angle

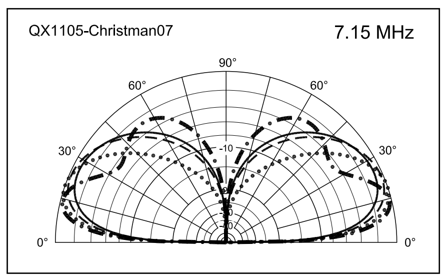

Figure 7 — Elevation-plane radiation patterns for vertical antennas of various heights, when operating on 40 meters (7.15 MHz). The monopoles are made from no. 10 AWG wire and the ground screens are composed of 60 buried no. 14 AWG radials (radial length = monopole height).
Solid trace = ¼ λ system
Peak gain = 0.15 dBi at 26.2° take-off angle
Dashed trace = ⅜ λ system
Peak gain = 0.68 dBi at 23.3° take-off angle
Dotted trace = ½ λ system
Peak gain = 0.89 dBi at 19.1° take-off angle
Dash-dotted trace = ⅝ λ system
Peak gain = 0.68 dBi at 14.5° take-off angle

Table 10

Performance comparison between vertical antenna systems of varying height, when operating on 20 meters at a frequency of 14.175 MHz. The monopoles are made from no. 10 AWG wire, with a ground screen composed of 60 buried no. 14 AWG radials (radial length = monopole height). All conductors are aluminum, and the soil is "average" (conductivity = 0.005 siemens/meter and dielectric constant = 13).

	¼ λ System	*⅜ λ System*	*½ λ System*	*⅝ λ System*
Monopole Height and Radial Length (ft)	17.347	26.020	34.694	43.367
Input Impedance (Ω)	39.0 + *j*28.4	247 + *j*536	1595 – *j*1070	77.4 – *j*392
SWR (50 Ω ref.)	1.97	28.3	46.3	41.8
Peak Gain (dBi) and Take-off Angle (°)	0.29 at 27.1	0.91 at 24.3	1.16 at 19.9	1.21 at 15.0
Gain (dBi) at 5° Take-off Angle	–6.35	–5.28	–4.18	–2.86
Gain (dBi) at 10° Take-off Angle	–2.46	–1.45	–0.49	0.48
Gain (dBi) at 15° Take-off Angle	–0.81	0.11	0.84	1.21
Gain (dBi) at 20° Take-off Angle	–0.04	0.76	1.16	0.70
Half Power Beamwidth (°)	44.4	40.4	31.5	22.8
Efficiency (%)	32.9	36.3	32.9	34.7

is given in Table 10. This time, the peak gain *always* rises whenever the system is made taller, accompanied by a simultaneous decrease in the take-off angle where maximum gain occurs. Figure 8 depicts the four elevation-plane radiation patterns, and an examination of these plots indicates that a ⅝ λ element yields the most desirable performance for 20 meter DX applications.

Losses

Notice that the input resistance for all of the resonant λ/4 elements is generally in the low-to-mid 30 Ω range, providing SWR values on the order of 1.5:1 in most cases. The SWR is much higher when using a taller monopole, however, so an impedance-matching network of some kind must be included as part of the antenna system. Such networks will dissipate a certain amount of power, mainly in the inductor(s), but this factor has been omitted from the present review. When this power loss is properly taken into account, the actual improvement in performance achieved by using a taller radiator will be less than what is shown in the tables.

I mentioned at the beginning of this article that all of the models were constructed using aluminum conductors. Table 11 illustrates what happens when either copper or zinc is substituted. *EZNEC* analysis indicates that copper works slightly better, while zinc is a bit worse. Variations in peak antenna gain amount to no more than 0.06 dB, and the efficiency changes by just 0.6% at most. The greatest impact takes place on 80 meters.

Table 11

Antenna performance as a function of the type of metal employed. In each case, the monopole height and radial length are fixed at 0.25 λ. The monopole is constructed of no. 10 AWG wire and the 60 buried radials are made from no. 14 AWG wire. The soil is "average" (conductivity = 0.005 siemens/meter and dielectric constant = 13).

	Aluminum	*Copper*	*Zinc*
80 Meters (3.65 MHz)			
Peak Gain (dBi) and Take-off Angle (°)	0.39 at 24.7	0.43 at 24.7	0.37 at 24.7
Efficiency (%)	33.8	34.2	33.6
40 Meters (7.15 MHz)			
Peak Gain (dBi) and Take-off Angle (°)	0.15 at 26.2	0.18 at 26.3	0.13 at 26.3
Efficiency (%)	31.9	32.1	31.8
20 Meters (14.175 MHz)			
Peak Gain (dBi) and Take-off Angle (°)	0.29 at 27.1	0.31 at 27.0	0.27 at 27.1
Efficiency (%)	32.9	33.1	32.8

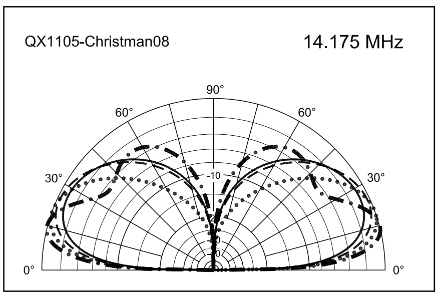

Figure 8 — Elevation-plane radiation patterns for vertical antennas of various heights, when operating on 20 meters (14 175 MHz). The monopoles are made from no. 10 AWG wire and the ground screens are composed of 60 buried no. 14 AWG radials (radial length = monopole height).
Solid trace = ¼ λ system
Peak gain = 0.29 dBi at 27.1° take-off angle
Dashed trace = ⅜ λ system
Peak gain = 0.91 dBi at 24.3° take-off angle
Dotted trace = ½ λ system
Peak gain = 1.16 dBi at 19.9° take-off angle
Dash-dotted trace = ⅝ λ system
Peak gain = 1.21 dBi at 15.0° take-off angle

Conclusions

This article has discussed the use of λ/4 vertical antennas on bands that are higher in frequency than the one for which they were primarily designed. Computer analysis reveals that an extended-length monopole can provide additional gain at a lower elevation angle, but the resulting input impedance is often far-removed from 50 Ω, so an impedance-matching network will be needed in order to present a low SWR to the transmitter. The losses that are generally present in such networks may partially negate the increase in gain generated by the taller monopole. Being able to use the same antenna structure on multiple bands, however, yields definite savings in terms of cost and real estate.

The ⅝ λ vertical has a reputation for generating a lot of extra gain at a much-lower take-off angle, when compared to a conventional λ/4 monopole. *EZNEC* studies suggest that a ⅝ λ antenna may be worthwhile on 40 and 20 meters (provided that ⅝ λ radials are also utilized in the ground screen), but the optimum monopole height on 80 meters may be closer to λ/2.

QEX