Squeezing the decibels out of a simple dipole

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As a **novice** antenna modeller, immediately after the purchase of EZNEC Pro/4, I started to browse through the wealth of antenna information available on the Internet. It was soon that I found Tom's (W8JI) awesome web site, www.w8ji.com. In the Antenna section of his site, Tom explained that a simple horizontal half-wave dipole has about 8.5 dB gain over an isotropic radiator. This was my inspiration to delve into modelling the simple dipole with EZNEC not to consciously waste the invaluable gain this antenna has to offer.

Lesson 1. The dipole typically has a 8 dBi gain or less over an isotropic radiator.

When a half-wave dipole is placed over the real earth, the dipole really has more gain that the theoretical 2.15 dB over an isotropic radiator. Tom says the dipole has about 8.5 dB gain over the isotropic, and if any EZNEC antenna model over earth shows such a gain, that particular model effectively has the same gain as a dipole. His claim is based on the calculations with EZNEC+; a claim which I was happy trying to confirm with EZNEC Pro/4 (incorporating a double-precision NEC-4 engine from the Lawrence Livermore National Laboratory) which is the most advanced version of EZNEC available for mortals like me, outside the U.S.

But soon I realized **the Pro/4 was slightly more conservative** in its calculations than the version Tom has used. The Pro/4 suggests that the dipole gain peaks at about 8.0 dBi with a cyclic nature, so I guess it would be safe to assume that its typical gain is just a little less than 8 dBi (using EZNEC's "average" ground), in contrast to the 8.5 dBi Tom's observations suggest.

What is important to note is, however, that **the dipole gain over the ground is dependent on many factors** such as

- the height over ground
- the ground characteristics
- the thickness of the wire
- and, in some degree, the frequency, in the eyes of EZNEC.

The ground characteristics are one of the most important factors that has a direct impact on the gain and radiation pattern of the antenna. In EZNEC, there are a dozen typical ground characteristics the user can choose from. Unfortunately, **what is labelled as an "average" ground in EZNEC, may not be that "average" in a specific country**. For instance, the "average" ground in EZNEC is better than the average ground in Finland. As a matter of fact, if we look at the conductivity map of Finland (see summary in Table 1), we soon realize that Finland's average ground is close to a "very poor" ground in EZNEC's terms.

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TABLE 1. TYPICAL GROUND CHARACTERISTICS IN FINLAND

Ground type                         Conductivity (S/m)      Dielectric constant

Very poor (Lapland):                0.0005                    3
Average:                            0.001                    13
Very good (Turku archipelago & OH0): 0.02                    40
Sea water (Gulf of Finland/Bothnia): 1                       80
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Lesson 2. The optimal minimum height is 0.6 wavelengths over the ground.

So, the gain of the half-wave dipole has a **regular variation as a function of height over the ground**. This leads effortlessly to my next question:

- At what height I should place my dipole in order to exploit all the available gain from this antenna?

The quick answer is: 0.6 wl (wavelengths) and all the heights that are multiples of 0.5 wl above 0.6 wl (i.e. 1.1, 1.6, 2.1, 2.6 wl, etc.).

Let's now take a brief glance at Figure 1 that shows how the gain (dBi) of the horizontal half-wave dipole develops from the height of 0.05 wl to 1.25 wl on 160M, 80M and 10M over the Finnish average ground.

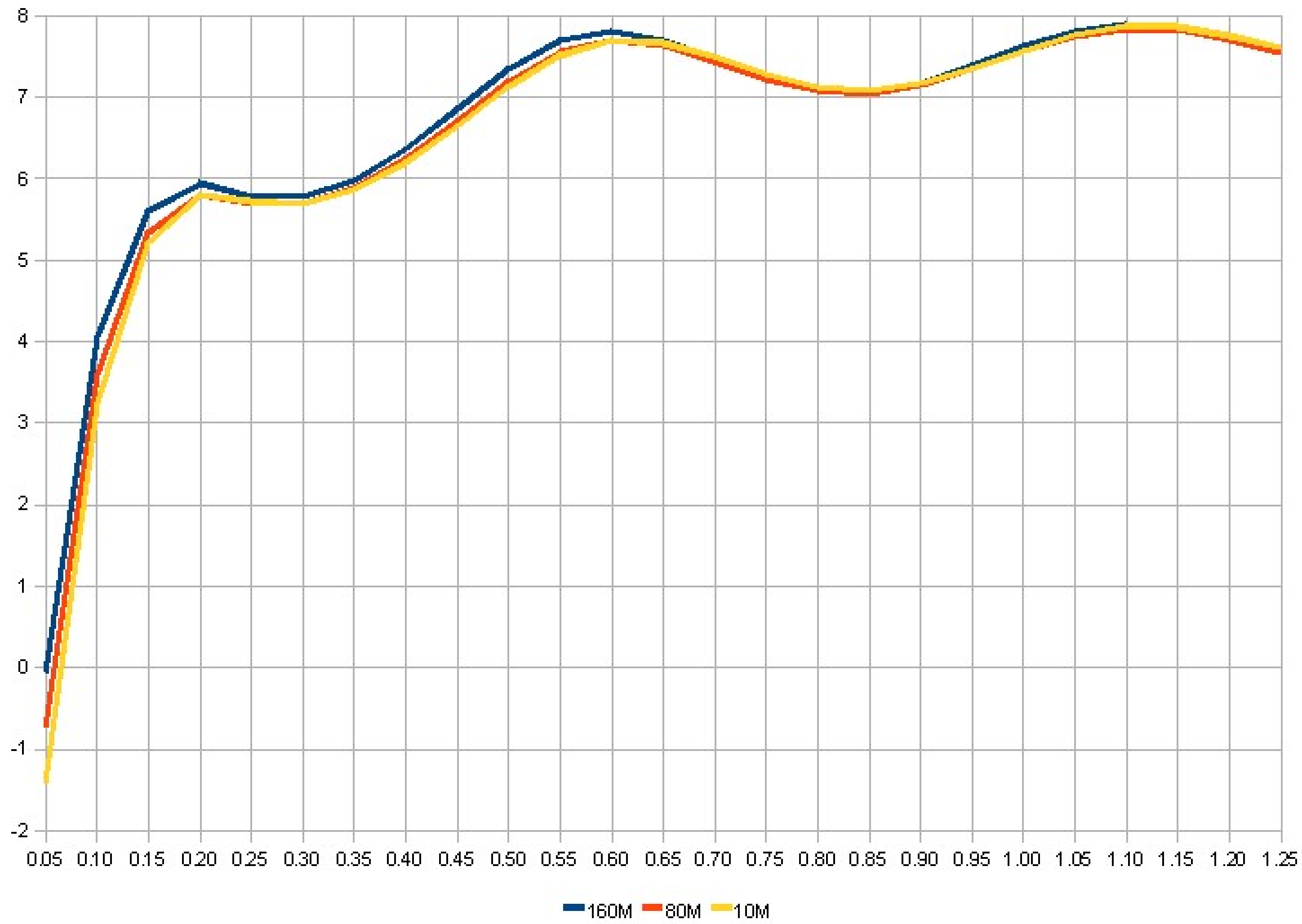

Figure 1. The dipole gain (in dBi) as a function of height (in wavelengths) over average ground. 160M (1.83 MHz), 80M (3.7 MHz) and 10M (28.1 MHz).

This simple figure also tells us that if we have to place our low-band antennas at a considerably low height, **the suggested absolutely minimum height in terms of gain would be in the range of 0.15 to 0.25 wl.** This is 25 to 41 meters (82 to 134 ft) above the ground on 160M, and 12 to 20 meters (39 to 65 ft) above the ground on 80M.

Now, let's see the variation of the gain and the lowest elevation angle as a function of height in more detail on 80M over the Finnish soil (Table 2).

Height over ground	Sea water		Very good ground		Average ground		Very poor ground		Average values, excl. Sea water	
	dBi	Elev	dBi	Elev	dBi	Elev	dBi	Elev	dBi	Elev
0.6 wl	8.98	24	8.60	24	7.70	23	6.85	21	7.72	22.7
1.1 wl	8.54	13	8.34	13	7.84	13	7.34	12	7.84	12.7
1.6 wl	8.38	9	8.25	9	7.90	9	7.51	8	7.89	8.7
2.1 wl	8.30	7	8.19	7	7.92	7	7.61	7	7.91	7.0
2.6 wl	8.17	6	8.09	5	7.89	5	7.69	5	7.89	5.0
3.1 wl	8.15	5	8.07	5	7.88	5	7.65	4	7.87	4.7
3.6 wl	8.20	4	8.14	4	7.98	4	7.81	4	7.98	4.0

Table 2. A 3.7-MHz dipole gain (in dBi) and the lowest elevation angle (deg) over four typical Finnish grounds. Modelled with a copper wire of 2 mm in diameter, taking into account the wire losses, using the high-accuracy NEC Sommerfeld ground simulation model in EZNEC.

Lesson 3. The best heights are 44 m (144 ft) and 47 m (154 ft) above the ground.

Now that I discovered that 0.6 wl and its 0.5-wl multiples are the best heights in terms of gain, my next question was:

- Is there a height or heights that would be optimal for multiband dipole gain (or for my Mosley 5-band TA-53-M Yagi, for that matter)?

I ran an extensive set of calculations with EZNEC's double-precision NEC-4 engine trying to find the heights where the dipole gain reached its peak dB values. The model used a 2-mm (diameter) copper wire with 51 segments on all frequencies, and was placed over a Finnish medium-type ground (conductivity 0.001 S/m; dielectric constant 13). Calculations were made with EZNEC's high-accuracy NEC Sommerfeld ground algorithm. Wire losses for the copper wire were taken into account. For detailed results, see Tables 3 and 4.

Table 3 shows the heights that optimally support our quest for squeezing out the maximum decibels from the dipole, or any horizontal antenna. **To cover all amateur radio bands from 80M to 10M, there is not one solution** but we will have to build two dipoles, one for lower-bands (from 80M to 30M) and second for higher bands (from 20M to 10M).

We would place our multiband dipole for the lower bands at about 47 meters/154 ft (or 47.5 m as the average of 48.6, 46.8 and 47.5 m) above the ground. For the higher bands, we would place our multiband dipole at about 44 meters/144 ft (approximately the average of 44.6, 43.1, 44.0, 43.3 and 43.7 m) above the ground.

How about the elevation angles? you may ask. If you take another look at Table 3, you will see that the elevation angle with the best gain for the lowest lobe remains the same across all frequencies at the given height in wavelengths. The angles shown in Table 3 have been calculated with EZNEC.

The angle of the lowest lobe for most horizontal antennas can also be estimated with this simple equation:

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angle = arc sin 1/(4h)
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where angle is the elevation angle in degrees and h is the height in wavelengths. Arc sin means the inverse of sine.

Example: arc sin 1/(4 x 0.6) = arc sin 1/2.4 = arc sin 0.4167 = **24.6 degrees** (EZNEC says 23 degrees).

HORIZONTAL 0.5-wl DIPOLE ANTENNA (2MM Cu, 51 seg) OVER FINNISH AVERAGE GROUND

wl/deg\MHz	1.83	3.7	7.05	10.1	14.1	18.1	21.1	24.9	28.1
0.6 wl/23	98.3	48.6	25.5	17.8	12.8	9.9	8.5	7.2	6.4
1.1 wl/13	180.2	89.1	46.8	32.7	23.4	18.2	15.6	13.2	11.7
1.6 wl/9	262.1	129.6	68.0	47.5	34.0	26.5	22.7	19.3	17.1
2.1 wl/7	344.0	170.2	89.3	62.3	44.6	34.8	29.8	25.3	22.4
2.6 wl/5	425.9	210.7	110.6	77.2	55.3	43.1	36.9	31.3	27.7
3.1 wl/5	507.8	251.2	131.8	92.0	65.9	51.3	44.0	37.3	33.1
3.6 wl/4	589.8	291.7	153.1	106.9	76.5	59.6	51.1	43.3	38.4
4.1 wl/3	671.7	332.2	174.3	121.7	87.2	67.9	58.3	49.4	43.7

Table 3. Optimum height (in meters) for maximum gain (dBi)

wl/deg\MHz	1.83	3.7	7.05	10.1	14.1	18.1	21.1	24.9	28.1
0.6 wl/23	7.81	7.70	7.68	7.68	7.68	7.69	7.69	7.69	7.70
1.1 wl/13	7.88	7.84	7.84	7.85	7.86	7.86	7.87	7.87	7.87
1.6 wl/9	7.92	7.90	7.91	7.92	7.92	7.93	7.93	7.94	7.94
2.1 wl/7	7.92	7.92	7.93	7.94	7.95	7.96	7.96	7.96	7.97
2.6 wl/5	7.89	7.89	7.90	7.91	7.92	7.93	7.93	7.93	7.94
3.1 wl/5	7.87	7.88	7.90	7.91	7.92	7.93	7.93	7.94	7.94
3.6 wl/4	7.97	7.98	8.00	8.01	8.02	8.03	8.03	8.03	8.04
4.1 wl/3	7.79	7.80	7.82	7.83	7.84	7.84	7.85	7.85	7.85

Table 4. Maximum gain (dBi) of the lowest elevation lobe (deg)

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1.83 MHz = 163.821 m, 537.471 ft
3.70 MHz = 81.0250 m, 265.830 ft
7.05 MHz = 42.5238 m, 139.514 ft
10.1 MHz = 29.6824 m, 97.3833 ft
14.1 MHz = 21.2619 m, 69.7568 ft
18.1 MHz = 16.5631 m, 54.3409 ft
21.1 MHz = 14.2082 m, 46.6147 ft
24.9 MHz = 12.0399 m, 39.5009 ft
28.1 MHz = 10.6688 m, 35.0025 ft
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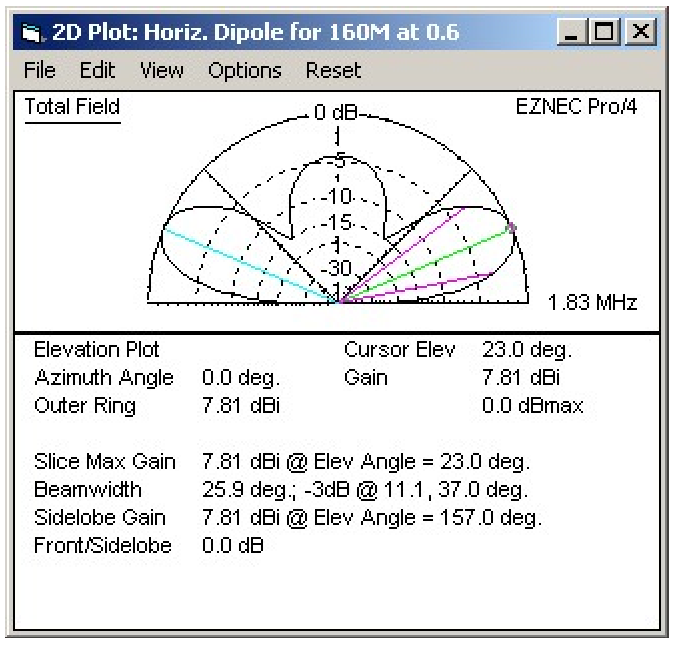
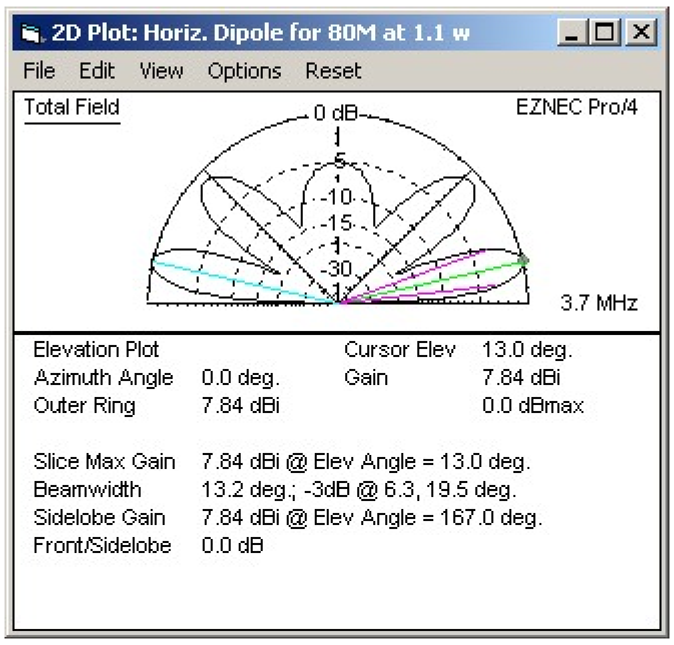
Table 5. Amateur-band frequencies in MHz and their corresponding wavelengths from EZNEC

If you wish to do calculations of your own, please visit http://www.voacap.com/antennas/ for the EZNEC and NEC input files. On the VOACAP site, there is also a collection of antenna files presented here that are suitable for running VOACAP propagation predictions.

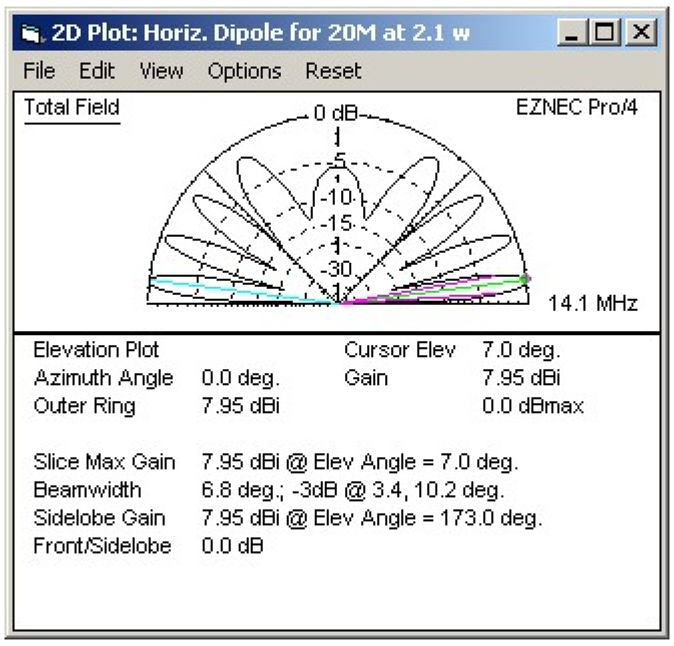
Elevations Plots



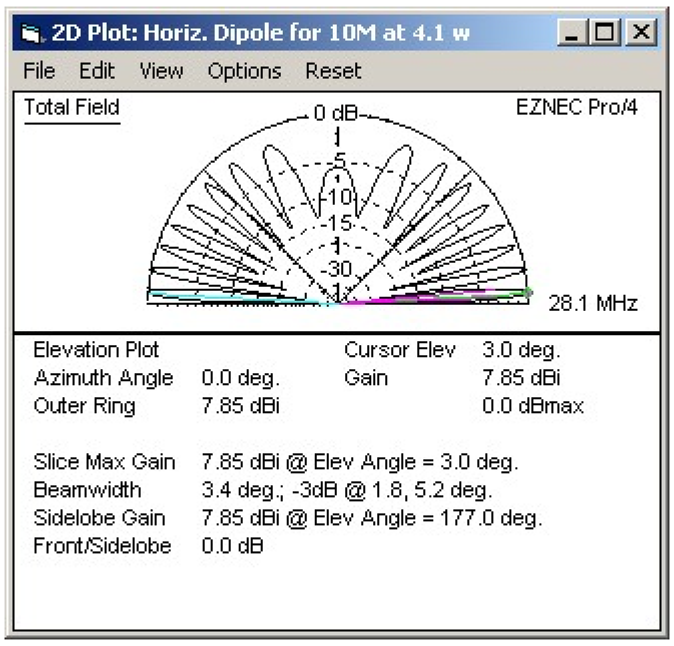
For all dipoles at 0.6 wl



For all dipoles at 1.1 wl



For all dipoles at 2.1 wl



For all dipoles at 4.1 wl

What next?

Although we now have a picture of

- how the dipole gain is dependent on the ground and the height, and
- how the elevation angles are directly related to the height of the antenna

we still need to have another study where we will see **which elevation angles are necessary for making the best QSOs** from Finland to all corners of the globe.

This will be discussed in our next article, and we will use the elevation angle data available on the ARRL Antenna Handbook CD-ROM as the basis of that study.

Resources

- Dipole antenna models from 160M to 10M as NEC files
- Dipole antenna models from 160M to 10M as EZNEC files