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A New Look at Verticals

Electrifying results measuring take-off angles over flat ground, sloping ground, and salt water.

Take-off angles. Why are they important? Those who operate HF, and especially those who chase DX, know that their signals get to distant point B using multi-hop propagation, as compared to line-of-sight paths for VHF/UHF. An HF antenna over ground (i.e., not in free space) will launch its energy at some angle to the Earth. Presuming the ionosphere is favorable, the signal will then be refracted by the ionosphere at some point and head back to Earth, where it will again be launched upward. The distance between these Earth launch points is determined by the take-off angle. As one would expect, the shallower/lower the take-off (launch) angle, the farther the signal travels before returning to Earth. Arriving at point B with fewer hops is desirable, because each hop reduces the signal strength by 6-10 dB, and that's a ton. If the signal can arrive in two fewer hops, that's 12 – 20 dB, which is unattainable to achieve by making the antenna larger at HF. In fact, it is an order of magnitude to physically increase an antenna system gain 6 – 10 dB; therefore, when design and/or location can lower the take-off angle, it is highly beneficial for long-range propagation.

What Works?

Over the years, I have used just about every kind of antenna imaginable, from light bulbs (see "Everything Works," July 2000 *QST*) to massive TCI-611 curtain antennas (21 dBi) on Saipan, which re-calibrated my mind[1]. It wasn't until using verticals on the beach with Team Vertical that I discovered an antenna that equaled Saipan: The 2 × 2 "flame thrower" vertical array. The success of Team Vertical having set more than 20 world records plus long-term testing and observations pushed me to research why some verticals work better than others — and not all were "verticals on the beach," such as my portable 160-meter vertical that set the CQ World Wide DX CW 160-meter QRP World Record in 2007.

A Shortcoming of *NEC2*-Based Software

Figure 1 offers an example of the measurements for an asymmetrical vertical antenna with tubing counterpoise on 12° sloping ground. Energy was measured at and below the visual horizon all the way down the slope. There is also only one lobe, meaning no nulls in the elevation pattern. If we are depending on *NEC2*-based software such as *AO* or *EZNEC*, we will be unable to confirm this data, but it's possible using newer software such as *H.O.B.B.I.E.S.*[2], *WiPL-D*, or *FEKO*.

A shortcoming of *NEC2*-based software is that it presumes ground is flat, homogeneous, and extends to infinity. These basic parameters are *not* the real world and create errors in the take-off angle calculations for vertical antennas. Earth is not flat, it is not homogeneous, and it does not extend to infinity. Our far field must end somewhere well before infinity.

Empirical Testing

These are the high points of empirical testing for take-off angles since 2014. The term "resonant vertical antenna" means one that is above ground using elevated radials/counterpoise of some type and "vertical antenna" implies ground-mounted with radials.

- Real-time pattern measurements for *horizontal* dipole antennas track the computer model on flat ground as well as *HFTA* on sloping ground.
- The measured take-off angle of vertical antennas is lowered when moving from poor to good ground and to salt water.
- Resonant vertical antennas located above the surface of salt water, or adjacent to the ocean within certain distances from the salt water boundary, will have energy down close to 0°.
- Resonant vertical antennas on or immediately adjacent to ground that slopes 8 – 12° have the lobe lowered significantly in the direction of the slope (lowered greater than 1° per degree of slope), to the extent of having energy at and below the horizon; the energy follows the sloping ground.
- Resonant vertical antennas on sloping ground exhibit lobe compression when looking up the slope.

The first tests were conducted using a fiberglass pole over flat ground, with the oscillator vertically polarized and passing from about 2 – 20 feet in altitude. Watching a digital S-meter, Evan Mason, N6BXL, could see the signal source passing through the lobe at a distance of 1.5 λ. The *NEC2*-based model showed the compact,

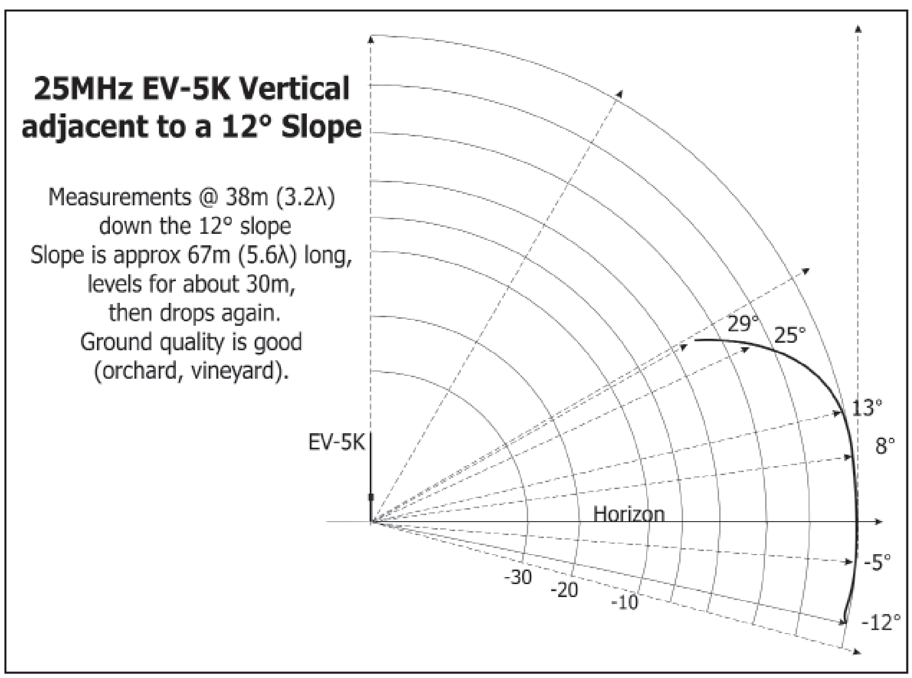

Figure 1 — An example of the measurements for an asymmetric vertical antenna with tubing counterpoise on 12° sloping ground.

Figure 2 — The author with a helium-filled large-diameter balloon used for measuring take-off angle radiation patterns in vertical arrays.

Figure 3 — Evan Mason, N6BXL, measures signal strengths during antenna testing.

42-inch tall vertical dipole having maximum energy at 25° over good ground (20, 30), but the actual location was an asphalt parking lot, so we weren't sure what to expect. To our surprise, our peak-reading test showed the maximum signal was much lower than the model, calculating out at 13°. We had not compensated for the possible influence of the moving signal source antenna, but this was still worth more investigation, as we were using relative measurements.

Test Series 1

Several large (3-foot diameter) balloons were acquired (see Figure 2), along with a tank of commercial-grade helium. A 50-foot long, high-visibility line was attached to the balloon and calibrated in 5-foot increments. Our test antenna was a 75% full-size asymmetric vertical dipole. Over good ground, the *NEC2*-based computer model showed the angle should be 20°. Measurements were made at 1 λ and 2 λ from the antenna, placing our test distances out of the near field. The ground was average/good (vineyard soil), and our measurements identified the peak at 8 – 11°. The procedures were consistent with those over the asphalt and showed that improved ground conditions lowered the take-off angle. We went next to sloping ground.

The slope was calculated at 12° and extended down range over 200 feet (5 λ at 12 meters). The antenna was set up and leveled toward the top of the slope. Our previous on-air and long-term observations had led us to theorize that the measurement would show the take-off angle was lowered due to the slope. The oscillator attached to the balloon was walked down the hill to the measurement positions (see Figure 3)

We expected to see the lobe slowly decreasing in strength as Evan walked down the hill, presumably with our signal source floating along beneath the lobe. What we saw, however, was that the height above ground of maximum signal was approximately the same down the slope as it was over flat ground. We thought we had made a mistake, so we repeated it several times, including having Evan go all the way down the hill. He also went up the hill, above where the antenna was placed. In general, the measurements indicated the maximum signal was following the slope down the hill, meaning it was below the visual horizon. At a distance of 200 feet (5 l) down the hill, we measured the same signal level at the same height as on flat ground. Measuring up hill, the lobe also followed the slope, but the height of the lobe was compressed. This was fascinating. We kept looking for some procedural error but did not find anything obvious.

The basic theory was that the slope lowered the lobe from a resonant vertical antenna, thereby making it a more effective antenna for long-range propagation. So far, the altitude of maximum signal strength

Figure 4 — IRIS+ quadcopter equipped with a receiving array to measure signal strength at various take-off angles.

remained the same as Evan traversed the hill; raising the balloon to its 50-foot full height offered insufficient altitude to find any noticeable change in the readings. It was obvious that we needed to go much higher, but calm days for balloon flights were few and far between. We needed a skyhook that gave telemetry for height above ground and below ground, as the drone would fly down the slope below the launch point. An IRIS+ quadcopter could do this (see Figure 4). It could also carry our oscillator payload and was stable in winds up to 20 – 25 MPH.

The measurement transceiver was modified to provide more accurate signal strength readings. The S-meter voltage was available via an accessory connector, and Ron Patterson, W6FM, calibrated the voltage readings in 5-dB increments at 25 MHz (12 meters). An equipment platform was constructed to fit into the bed of my truck.

The first location for the new equipment setup was at a friend's ranch ("Longhorn"), where we shared the field with longhorn cattle. The ground quality was anything but rich, with the only moisture in the ground coming from what the cattle had provided earlier that day. It is flat as a pancake, barren for several hundred yards, and completely in the clear. The IRIS+ performed perfectly on its maiden voyage.

Test Series 2

The next series was performed in two sessions at Ron's (W6FM) QTH. The ground is flat, in the clear and very good quality with 6 feet of topsoil. One would anticipate the take-off angles to be lower with very good ground compared to the Longhorn location, and such was the case.

We next set up a full-size tubing dipole at 0.5 λ above flat ground with the oscillator slung horizontally. The objective was to obtain a reference and possibly validate computer modeling of horizontal antennas. As the drone passed vertically through the field at the 1.0 λ marker, the signal was steady and we read repeatable data at both 1 and 2 λ distances.

The take-off angle for the dipole was measured at an elevation of 7 meters (23 feet) at the 1 λ marker and 14 meters (46 feet) at the 2 λ marker. This gave us 0.568 for the tangent of the angle, translating almost exactly to 30°, the same as the *NEC2*-based model predicted. This confirmed that our real-time testing matched the computer model for a horizontal dipole at 0.5 λ high. Confidence in models for horizontal antennas was looking good (see Table 1).

We then measured various verticals including the pink flamingo yard art (very asymmetrical) at distances of both 1 λ and 2 λ (see Table 2). All were tuned to the 12-meter test frequency. Our procedure was made more extensive, with a minimum four passes for each test — two passes going up, two descending, and using the average.

The take-off angles between poor ground (Longhorn) and good ground (W6FM) confirmed again that the better the ground, the lower the take-off angle for vertical antennas. Although our measured take-off angles were always lower than the *NEC2*-based model, the measurements between the various vertical tests were relative and useful.

Testing over sloping ground was delayed one series due to advantageous tides in our intended location for salt water testing (see Figure 5). High tide was for early morning, meaning minimal spectators (important when flying a drone). This is a calm, salt water bay with good access and a small boardwalk. The 1-meter tether from the drone to the XG-3 oscillator was increased to 2 meters, so I would have more leeway lowering the oscillator antenna to the water without much concern for drone prop wash, or possible operator glitch. Dropping the drone in the drink would not make for a fun day at the beach.

Back Bay Café and Back Bay Inn turned out to be a perfect location. Not only was the café open early enough while we were catching the high tide of the morning, it has great coffee and breakfasts. The high tide for this day was at 8:16 AM, and we backed the truck into the closest space along the beach. The antennas under test were placed on the beach within 0.25 λ (10 feet) from the water's edge, which varied, depending on how far the little wind-driven ripples pushed the water and foam on to the sand.

Back Bay is a salt water bay and is completely clear for over a mile. The drone was flown out from the beach, and our testing distances were the same as over ground out to 2 λ over the salt water, which is not for the faint of heart. We ran four vertical passes at each distance for each antenna, and the XG-3 antenna was lowered right down to within a ripple-height of the water surface, which we defined as 0°. It was then raised ever so slowly, watching the mirrored analog meter for the exact peak. We then aligned the trace on the oscilloscope and continued to raise the XG-3 through the pattern until the receiver output voltage dropped by 0.2 V, equating to –5 dB. The altitude was noted, along with the altitude of the peak. In this case, our data was tracking the model set for salt water, perhaps because the ocean resembles the flat, homogeneous, infinite plane of *NEC2* (see Figure 6).

The measurement method was coming along, and we went back to the 12° slope. We flew missions through the horizontal dipole and the vertical, both located on the sloping ground. The results were tabulated and pretty much as expected. Our measurements on the horizontal dipole tracked the computer model, including using *HFTA* (thanks to K2KW's work and N6BV's great software). Our measured nulls were where *HFTA* had predicted.

The vertical antenna pattern tracked our prior findings, with energy following down the 12° slope (Figure 7). Making a real-time comparison between the 75% full-size asymmetric vertical dipole and the full tubing size dipole 0.5 λ high showed the dipole ahead by about 1.4 dB. This is the most difference observed to date and is a long way from the anticipated ground reflection gain of up to 6 dB and became an unplanned discovery.

Testing in the Desert

Countless books continue to sing the refrain that a horizontally polarized antenna (i.e., a dipole) has "ground reflection gain" that can amount to +6 dB and the vertically polarized antenna does not. Many of these same texts, therefore, paint vertical antenna as beginning in a 6 dB hole, so to speak. The texts often give a polite nod to

Table 1 — NEC2 model vs empirical testing.

Antenna	Computer Model		Measured	
	Good Ground	Average Ground	W6FM Good Ground	"Longhorn" Poor Ground
Compact ZZ-5 (42" tall)	24°	28°	13°	17°
¼ λ with (4) ¼ λ radials	24°	28°	8°	17°
CushCraft R-7 @ 6'	N/A	N/A	6°	N/A
Evolution Vertical 5K	20°	23°	8°	13°

Table 2 — NEC2 model vs empirical testing.

W6FM Location Antenna	Model	1λ Measured	2λ Measured
	Good Ground	Good Ground	Good Ground
Full Size Horizontal Dipole ½ λ above flat ground	30°	30°	30°
Evolution Vertical 5K	20°	8°	9°
Pink Flamingo	N/A	9°	10°

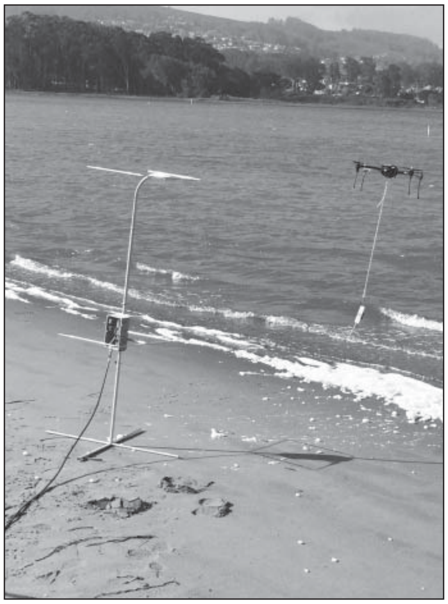

Figure 5 — Antenna set up for testing take-off angles over salt water.

the vertical, because it has a low take-off angle and might arrive at the target in fewer hops, thereby making up at least part of this deficit. Since the original testing on the 12° slope, dipole-to-vertical comparisons have been run many times, looking for that 6 dB of ground reflection gain in favor of the horizontal dipole. Although the airborne antenna is uncompensated in all cases (vertically and horizontally polarized), the most difference remains the 1.4 dB we noted on the 12° slope comparison (see Figure 8). Recent testing over the desert in Arizona using a full size Generation 7 vertical (balanced current, physically asymmetric vertical dipole) to the full-size horizontal dipole on 21 MHz tracks them as being equal within our margin for error. There is an excellent write-up by ON4KHG[3] on ground reflection gain for those desiring to know more.

We moved to Arizona in 2016 to a place with 7 acres of fairly flat, desert land right next to several hundred acres of state-owned land. The terrain is a gentle slope of about 1 – 2° to the eastern quadrants for more than 30 miles, with a view of the western rim of the Grand Canyon. We added a second drone (Yuneec Typhoon H, six rotor), portable spectrum analyzer, FPV, monitors, cameras and a FlexRadio 6700, all of which have enhanced our data collection.

One of the issues relating to the above empirical data, as noted earlier, is that patterns of verticals on sloping ground cannot be modeled using typical modeling software, such as *NEC2*, *AO*, and *EZNEC*. Other available software *is* capable of modeling a vertical antenna adjacent to sloping ground. Steve Stearns, K6OIK, set up a model of a full-size 15-meter vertical dipole antenna on sloping ground of 16.7°. One of the plots is shown and demonstrates the capabilities of *H.O.B.B.I.E.S.*, which validates our empirical data that the lobe from the vertical antenna is, indeed, lowered in the direction of the sloping ground. An estimate is that sloping ground can lower the peak take-off angle by more than 1° per degree of slope. In the example plot, the peak take-off angle is below 3° on the 16.7° slope (see Figure 9). On flat ground, it was calculated at 21.8°, giving a lowering of about 19° due to the sloping ground, a bit more than 1° per degree of slope.

Energy in the lowest angles from a vertical antenna over ground (assuming flat terrain) will be depleted by the ground as the energy extends from the antenna for a particular distance. If this distance is not limited, the *NEC2* model calculates

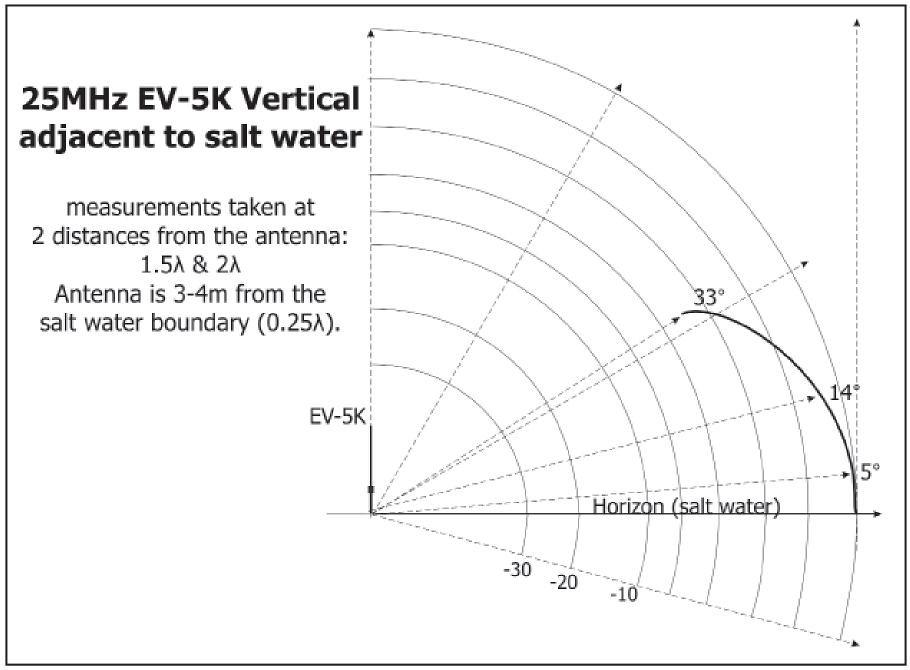

Figure 6 — Impact of salt water on take-off angles of vertical antennas.

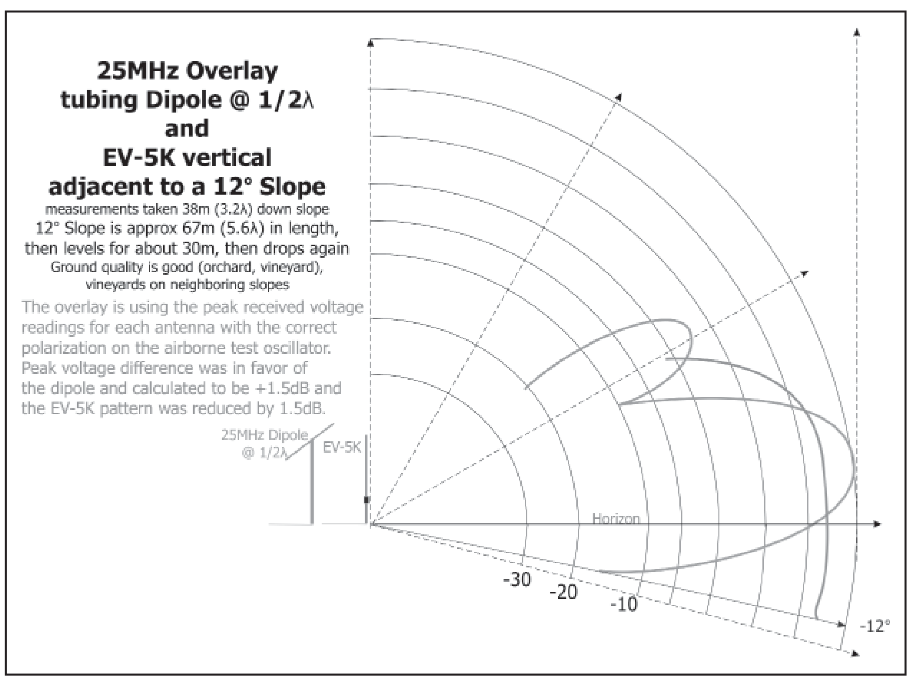

Figure 7 — Antenna testing over a 12° degree down-sloping takeoff.

the resulting take-off angle at an infinite distance. Earth's surface, of course, is not infinite, so the energy will be depleted over a distance that's much less than infinity. What might a realistic boundary be for the limit of this energy depletion? A suggestion during conversations on this subject led to considering that it might be when the surface wave (ground wave) ends. In our empirical testing, we have seen this wave over basically flat ground and noted it on drawings as "the spike." On one occasion, we were able to measure at a distance far enough that we did not see the spike.

We utilized our CanAm Commander to reach a 1,000 feet (21 λ) at a 21 MHz test location on the eastern slope of the desert adjacent to our Arizona location. We flew the drone up to the FAA limit of 400 feet to see what the pattern looked like on the 15-meter resonant vertical. We did not see the surface wave (spike) as we had many times at shorter distances, so it had dissipated. The take-off angle measured by some 2° higher at 21 λ than at 2 λ and was tapering back before the drone reached the 400 feet altitude. Taking into account that the measurement point at 21 λ was on a 1 – 2° slope, the probable difference was that the take-off angle was raised by 2 – 3°. Some lower-angle energy had been depleted at this distance, thereby raising the take-off angle.

Steeper sloping ground has similar results. The ground dissipates the energy as it moves outward from the antenna, following the sloping ground. Energy is depleted along the slope, which, depending on the slope, is some angle below the visual horizon (as shown in the *H.O.B.B.I.E.S.* plot). The result is that energy at and above the visual horizon might not be depleted when the vertical is located on steeper sloping ground, making an incredible low-angle antenna.

The above narrative contributes to explaining why some verticals perform much better than others. If you would like an accurate computer model of vertical antennas over various types of terrain and ground, then set aside *NEC2*-based software and move to newer software such as *H.O.B.B.I.E.S.*

Acknowledgements

My heartfelt thanks to Evan, N6BXL; Mary, W6ROX; Vicki, N6KLS; Steve, K6OIK; Ron, W6FM; Kenny, K2KW; Dean, N6BV; Fred, KE7X, and all the members of Team Vertical for their time and energy in our endeavors.

Licensed in 1959, Tom Schiller, N6BT, is an ARRL Life Member and Founder of Next Generation Antennas and Force 12 Antennas and Towers. He's the author of Array of Light, now in its 3rd edition (available in hard copy and also on Kindle). He is one of the three founders of NCJ.

Notes

[1] Schiller, Tom, N6BT, *Array of Light* (3rd ed.) 2010.

[2] *H.O.B.B.I.E.S.* Higher Order Basis Based Integral Equation Solver; John Wiley & Sons Inc, ©2012; ISBN: 978-1-118-14065-9.

[3] ON4KHG ground gain: (1) **http://on4khg.be/Ground%20Gain%20Measurement%20Procedure%20v2-0.pdf** (2) **http://on4khg.be/wordpress/wp-content/uploads/2015/02/Ground-Gain-Sun-Set-02042011.pdf**.

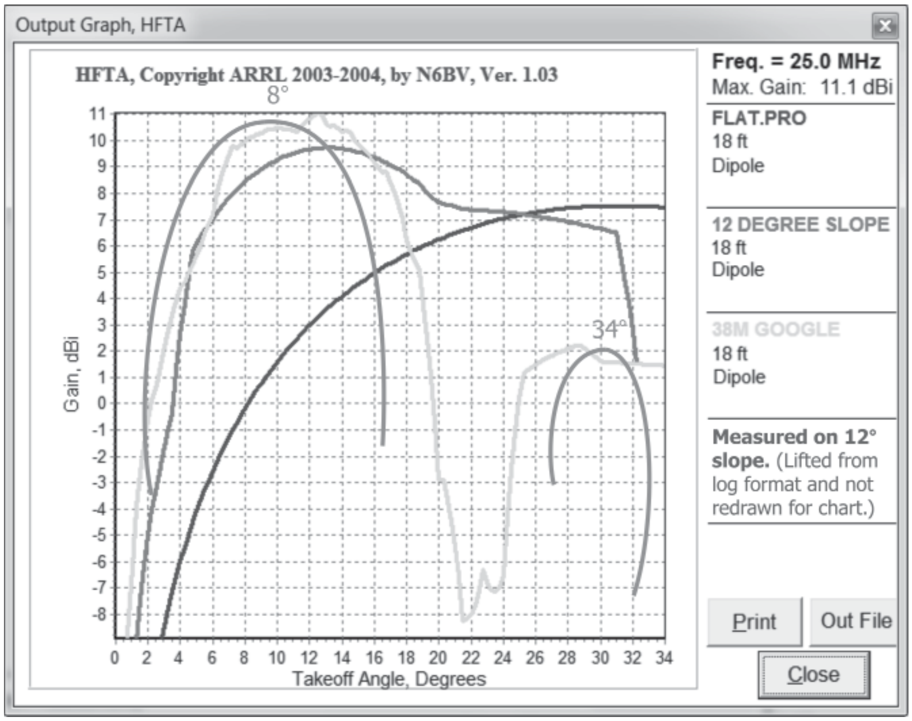

Figure 8 — *HFTA* analysis of flat ground vs 12° down-sloping take-off angle gain patterns.

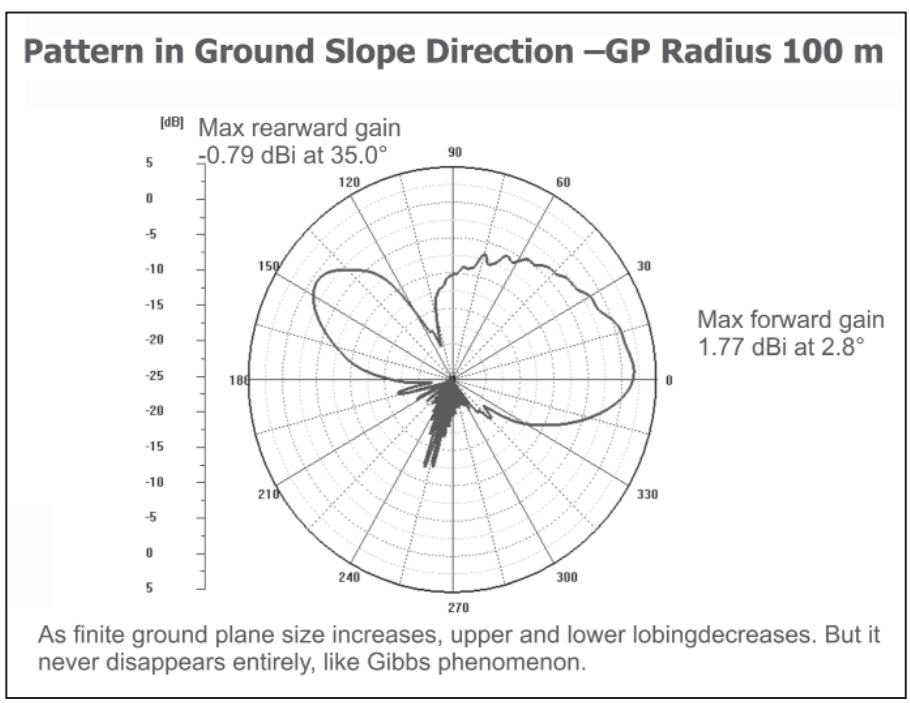

Figure 9 — *H.O.B.B.I.E.S.* validation of the impact of sloping ground on vertical take-off lobes.