Some of you might want to file this away under "I" for ideal, but it just might provide some interesting things to consider.

Notes on the Angle of Radiation

BY AL P. LAPLACA*, W2WW

In April 1948 *CQ* magazine published an article by its then assistant editor, Oliver P. Ferrell, on the subject of antenna take-off angles. The article was called "Notes on the Angle of Radiation," and I found it to be most intriguing, to the extent that it left a lasting impression on me. To this day the study of that subject greatly interests me.

It has long been appreciated in amateur radio that antenna height plays a very important role in a station's ability to put substantial signal levels into DX locations. As a general rule, "the higher, the better." But not always. There are certain conditions under which a low antenna will outperform a much higher one. I'm sure you've noticed it. Have you ever wondered why that is? Read on.

**Box 233, Centereach, NY 11720-0233*

The mechanics of HF radio wave propagation and the interaction with the ionosphere are covered in substantial detail elsewhere[1,2] and will not be repeated here. However, an understanding of these fundamentals is necessary before proceeding further, and the reader is urged to "come up to speed" on the subject before reading the remainder of this article.

Every antenna radiation pattern has lobes. These vary in number, size, shape, magnitude, and the angle of their axes with respect to the horizon. It is the latter quality with which this article deals. For any given height above ground, an antenna's major lobe will have a specific angle between its axis and ground. This angle is called by various names, usually either "vertical angle of radiation," "wave-angle," or "takeoff angle." In general, there is a specific *range* of these angles which is *optimal* for any given amateur HF band. Fortunately, the average amateur antenna at low heights has such broad lobes that variations of ionospheric height, tilt, and density are easily accommodated during the short term (the duration of a contact, or a series of contacts over a short period of time) so that antenna height adjustments to maintain communications are not necessary.

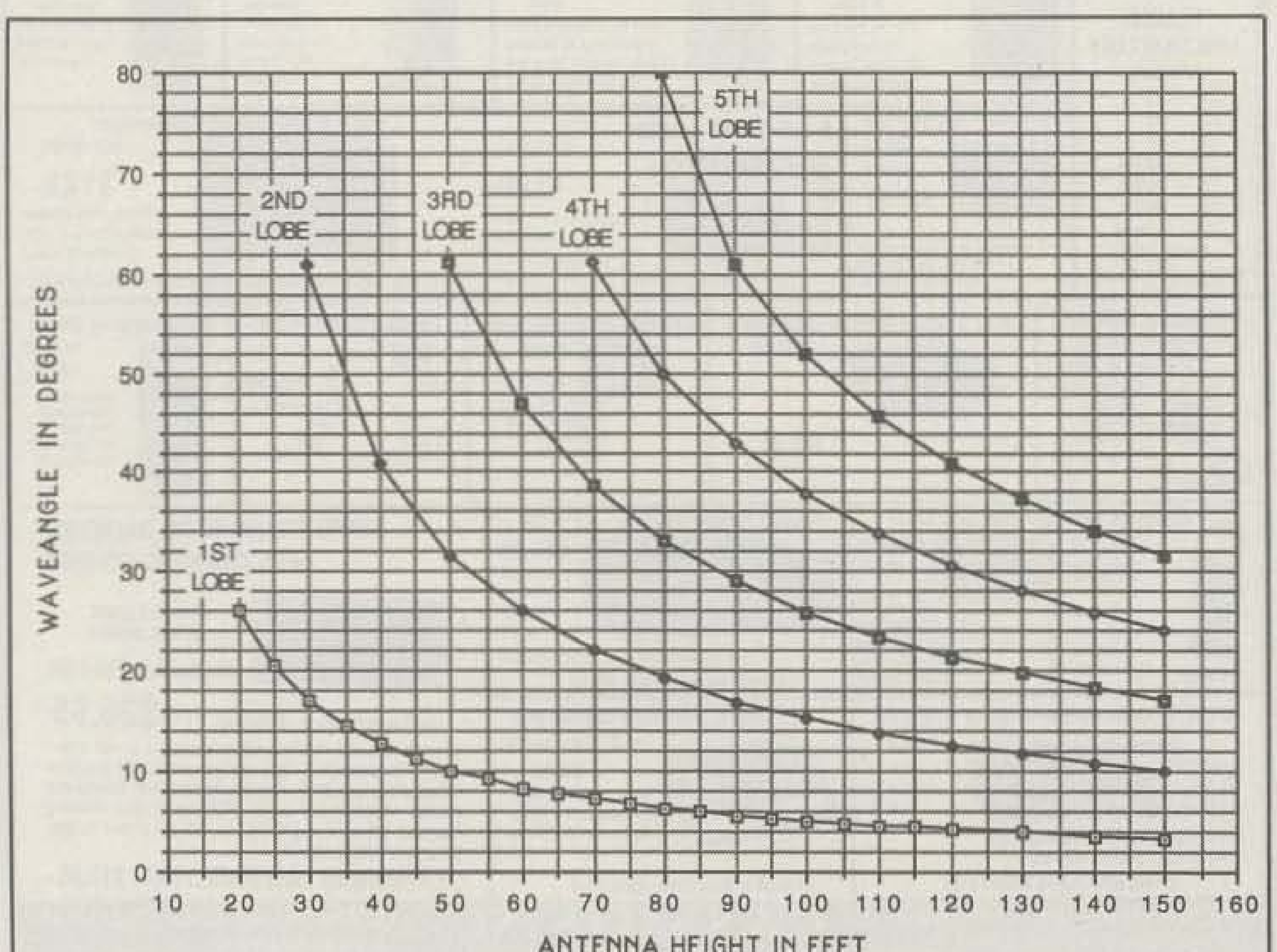

Fig. 1 – Comparisons for a 10 meter horizontal antenna.

Amateur and commercial radio communications experience on HF over a long period has concluded that the optimum wave-angles for the major DX and contest amateur bands are shown in Table I.[3]

40 meters	10–35 degrees
30 meters	8–26 degrees
20 meters	6–17 degrees
17 meters	5–12 degrees
15 meters	4–11 degrees
12 meters	3–10 degrees
10 meters	3–9 degrees

Table I – Optimum wave-angle ranges for HF amateur bands

Knowing what these angles are is merely academic. However, applying that knowledge to your benefit is a very worthwhile exercise. But where do you begin? What do you do with this information? How does it apply to your station? These are questions you might well ask. Otherwise this information will remain forever arcane and useless.

The antenna's lowest wave-angle can easily be calculated by the formula[4]

wave-angle = wavelength/4 × height
where:
wave-angle is in radians (radians × 57.3 = degrees)
wavelength is in meters (299.793077/MHz = wavelength)
height is antenna height in meters (feet × 0.3048 = meters).

If, for example, we were to calculate the required minimum height (corresponding to the *highest* useful angle of radiation as indicated above) for each of the bands, antenna heights would be as shown in Table II.

40 meters	60.5 feet
30 meters	55.5 feet
20 meters	60.0 feet
17 meters	65.0 feet
15 meters	61.0 feet
12 meters	57.0 feet
10 meters	55.0 feet

Table II– Antenna height for highest optimum wave-angle.

This is not to say that lower antenna heights will not work. Of course they will; it just means you'll spend more time in the pileups, you won't be the first to hear the DX when the band is just opening, and you won't be the last to hear the DX when the band is closing. But take heart. You'll still work plenty of DX. It will just take longer. If, just for laughs, we were to calculate the *maximum* height required (corresponding to the *lowest* useful angle of radiation as indicated above) for each of the bands, antenna heights would be as shown in Table III.

40 meters	199.5 feet
30 meters	175.0 feet
20 meters	167.0 feet
17 meters	155.5 feet
15 meters	167.0 feet
12 meters	188.5 feet
10 meters	164.5 feet

Table III– Antenna height for lowest optimum wave-angle.

Somewhere between these minimum and maximum antenna heights lies the most useful heights for each of the amateur bands, and contrary to popular belief, heights closer to the minimums (except on 40 meters) are probably more desirable than heights up near the maximums. This is true for a number of reasons. To begin with, the late Jim Lawson, W2PV, after much experimentation regarding antenna heights, concluded in his book[5] that the optimum antenna height for all-around usefulness is probably 1.5 wavelengths. This corresponds to the heights shown in Table IV for each band.

40 meters	208.0 feet
30 meters	146.0 feet
20 meters	105.0 feet
17 meters	81.5 feet
15 meters	70.0 feet
12 meters	59.3 feet
10 meters	51.8 feet

Table IV– Antenna heights of 1.5 wavelengths for amateur HF bands.

Note that on 10 meters the 1.5 wavelength height is lower than that required for the minimum height to meet the highest useful angle. Fortunately, the −3 dB beamwidth of most antennas, especially in the H-plane, is broad enough so that the difference is of no real concern.

The other reasons for favoring lower heights (as long as they are above the minimum) are that less tower height and coax are required (big dollar savings there), there should be less hassle with the neighbors, and there is less likelihood of wind damage to the antenna. Last, as an antenna is placed higher above ground, it exhibits additional lobes at higher angles than the major (lowest angle) lobe. All lobes become narrower. The ERP is constant for a given power output, so if there are more lobes, then the energy is split among them and each lobe is narrower. Now the lowest lobe is less forgiving—less able to "fill in" at nearby (lower) takeoff angles, and height is very much more critical. And these higher angle lobes make for stronger reception of closer-distance signals (read that as unwanted QRM).

The greatest height, in terms of wave-

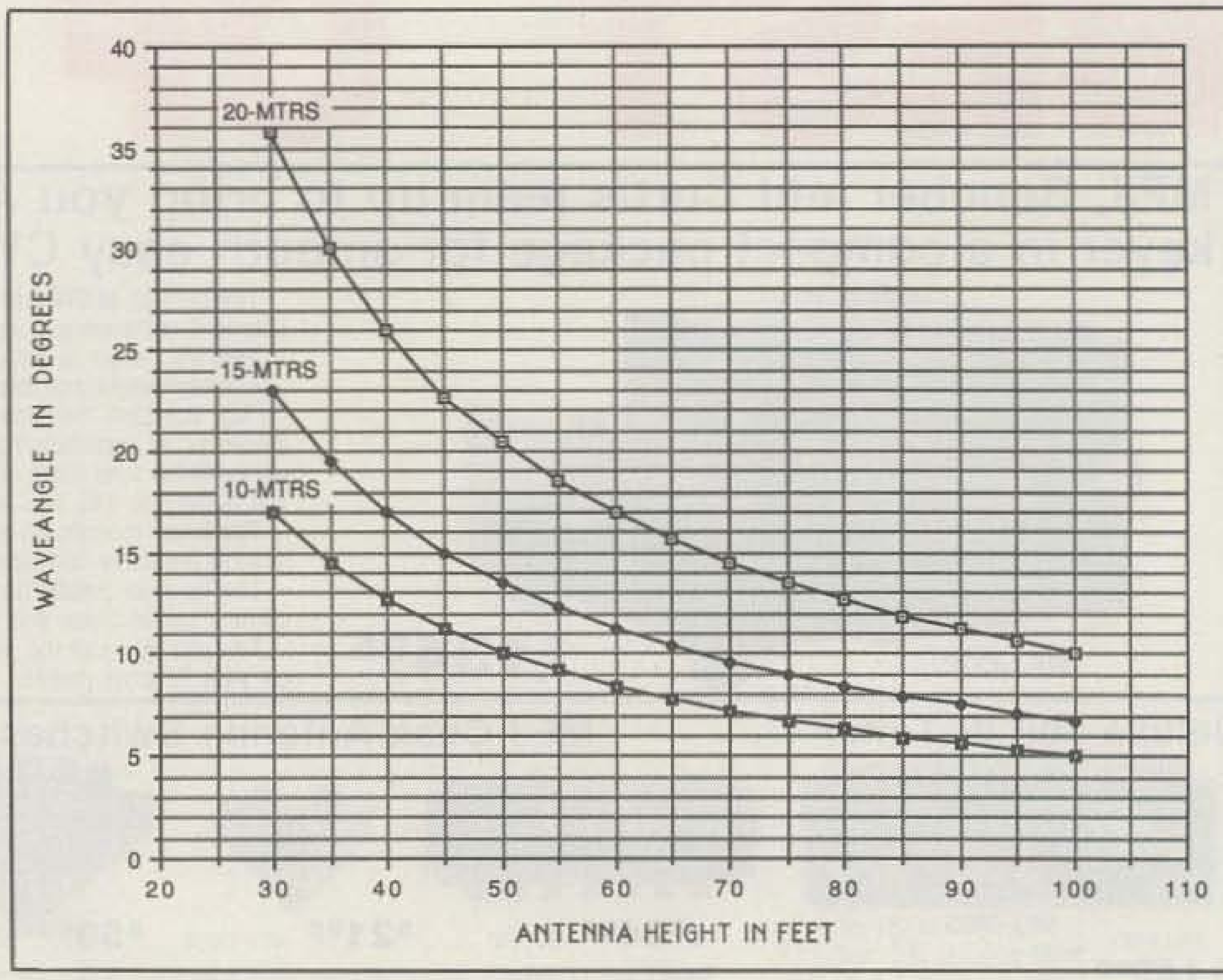

Fig. 2– Figures for a typical 10–15–20 meter triband antenna.

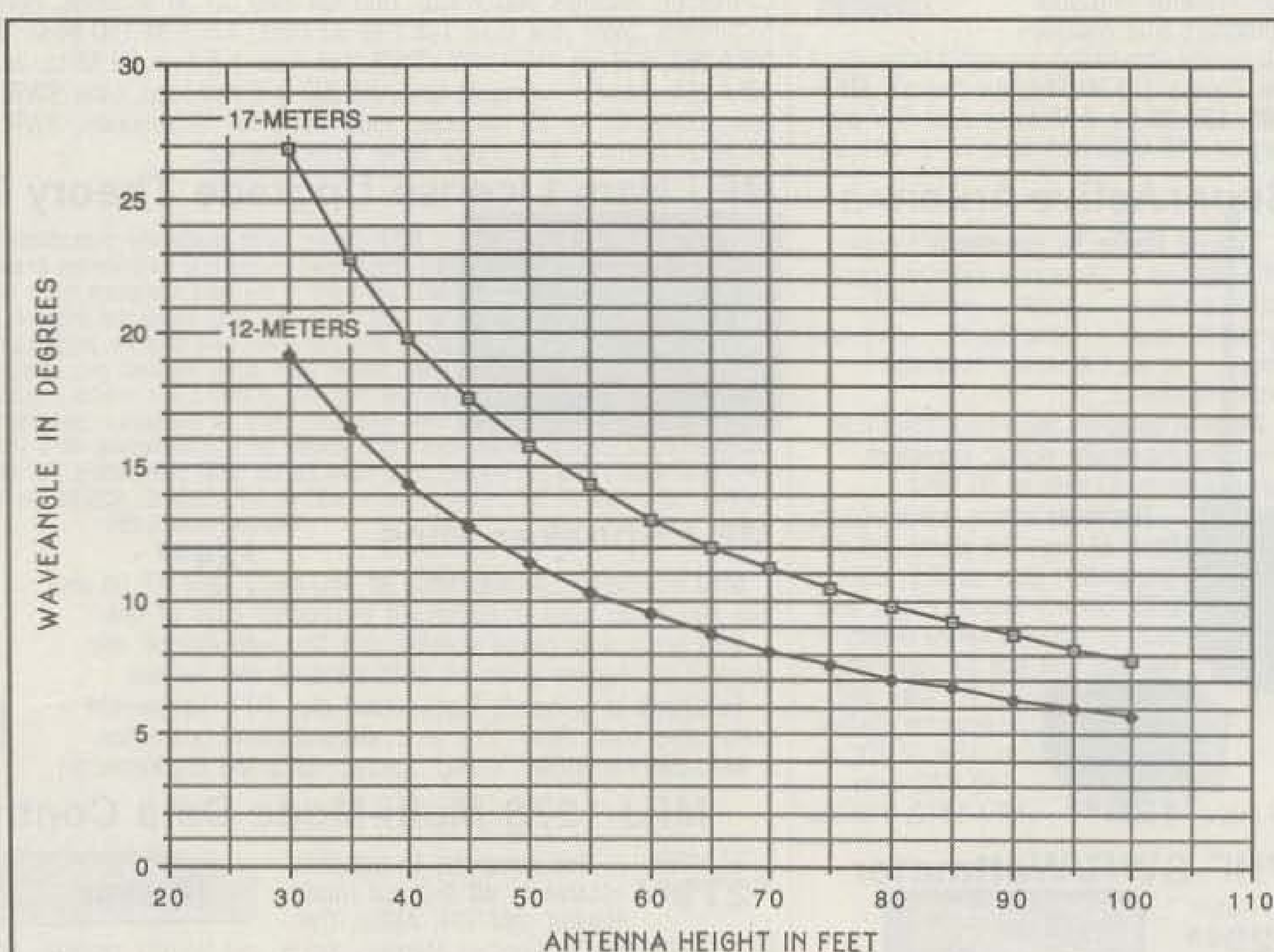

Fig. 3– The data for a 12 and 17 meter duoband antenna.

length, at which an antenna produces only one major radiation lobe (other than straight up, at 90 degrees) is 0.75 wavelength high. Above that, a second lobe appears. Table V shows a listing of *minimum* heights at which further lobes appear.

3rd lobe	1.275 wavelength
4th lobe	1.758 wavelength
5th lobe	2.267 wavelength

Table V–Minimum heights at which lobes appear for horizontal antennas.

There are times when the condition of the ionosphere is such that higher angles are refracted better than lower ones. Higher antennas, then, with their array of lobes at various angles, could be competition for the lower antennas the takeoff angles of which are normally higher to begin with. Fig. 1 depicts the first five lobes of a 10 meter horizontal antenna. Note that the higher-order lobes are not present at the lower heights above ground. Also, for a given angle, if the antenna is high enough, there may be more than one lobe.

By this time it should have become apparent that a motorized tower capable of varying antenna heights from a low of 50 feet to a high of approximately 200 feet is very desirable—not too practical or affordable, but certainly desirable!

Okay. Let's get real. Most of us have antenna supports ranging from 30 feet to 100 feet. If a Gaussian distribution of all amateur radio antenna heights worldwide were plotted, I'm sure that the highest percentile would be in that range (skewed slightly to the high side thanks to the OHs and W6s).

Probably the most common antenna in use by the DX and contest crowd these days is the triband beam. This puts one antenna for 10, 15, and 20 meters at a fixed height. Presumably at best it will be optimum on only one band. If that band is 15 meters, it will be a good compromise. Is that true, though? Fig. 2 shows the takeoff angles for each of the three bands of a tribander as a function of height above ground over the range of heights at which most of us have our antennas. It can be seen that a tribander at 60 feet will do the job. But one at 80 feet will lower the 10 meter angle by 1.25 degrees, the 15 meter angle by 2.6 degrees, and the 20 meter angle by a whopping 4.2 degrees!

Now take a look at the 100 foot level and compare the wave-angles with those in Table I. At 100 feet the wave-angles for each band are precisely those of the geometric mean[6] for the range of angles indicated for each band in Table I. Given the normal H-plane −3 dB beamwidth of the average 3-element Yagi (even several wavelengths above ground), the entire range is covered quite nicely by the main lobe. Food for thought there.

The 12 and 17 meter bands are beginning to get noticed by the antenna manufacturers, and at least two of them, Cushcraft and Mosley, put out duoband 3-element Yagis for these WARC bands. Fig. 3 shows the takeoff angle versus height plot for such an antenna. Again, compare the wave-angles at a height of 100 feet to those listed in Table I. Interesting, that.

Calculations for the tables and graphs in this article have been taken from the author's Excel 2.2[7]-based spreadsheet running on an Apple Macintosh II. The spreadsheet contains wave-angle information for all non-90° lobes and nulls up to and including the 10th, for antennas from 5 to 250 feet above ground. Copies of this 482k file, along with instructions for its use, are available at nominal cost from the author. If interested, please send an SASE for details.

Footnotes

1. *The ARRL Handbook*, ARRL, Newington, CT, any edition.

2. *The ARRL Antenna Book*, ARRL, Newington, CT, 1988, p. 23-1.

3. *The ARRL Antenna Book*, ARRL, Newington, CT, 1988, p. 23-17.

4. Oliver P. Ferrell, *CQ* magazine, Radio Magazines, Inc., April 1948, p. 43.

5. *Yagi Antenna Design*, Lawson, ARRL, Newington, CT, 1968, pp. 5–12.

6. The *n*th root of the product of *n* numbers (the square root of *x* times *y*, for example) which yields more accurate mean for non-linear sequence.

7. Microsoft® Corporation, One Microsoft Way, Redmond, WA 98052-6399.