and the distances G and G_b are functions of the angle T between the local horizon and the direction to the wave source point at height h_i in the ionosphere. Figure 1 shows the spherical earth reflection geometry and identifies all of the parameters.

The angle T is also called the "take off angle" and the "local elevation angle." See the ARRL website files update to *The ARRL Antenna Book.*[3] The direct wave arrives along path D_{ir}, and the reflected path includes distance R_i from the ionosphere to the earth reflection point and R_b from the reflection point to the receiving location. The reflection occurs at the arc distance G_b from the base of the antenna tower, and as the direct wave arrival angle T deceases, then the arc distance to the reflection point increases. Our chief concern is with the difference in the path lengths,

$$\Delta R = (R_b + R_i - D_{ir}) \qquad \text{[Eq 2]}$$

and with the surface reflection coefficient at the reflection point because these determine the nature of the field variation versus height, h_{ant}.

Reflection Coefficients and Combined Waves

The plane wave reflection coefficients Γ_H for horizontal and Γ_V for vertical polarization are used to find the reflection from land or sea on a spherical earth. (See Chapter 6 of *Radiowave Propagation and Antennas for Personal Communications.*[4]) The reflection coefficient is modified by the divergence factor D and surface roughness S_r factor. The wave divergence factor is:

$$D = \left[1 + \frac{2G_bG_i}{a_eG\sin\psi} \right]^{-1/2} \qquad \text{[Eq 3]}$$

where ψ is the angle of incidence on the earth's surface. The surface roughness factor is:

$$S_r = \exp(-r)\mathrm{I}_0(r); \quad r = 2\left(kh_{sd}\sin(\psi)\right)^2 \qquad \text{[Eq 4]}$$

where:
I_0 is the modified Bessel function
$k = 2\pi f / c$ is the wave number
f is the signal frequency in Hz
c is the speed of light in m/s.

The roughness factor for the reflected wave is based on a roughness factor originally derived for a ratio of rough-sea to smooth-sea reflection, and is applied here generally to an earth reflection. The surface roughness parameter h_{sd} is the standard deviation of the surface height distribution in the reflection region. The complete reflection coefficients are thus $\Gamma_H S_r D$ and $\Gamma_V S_r D$ for a rough spherical earth. The reflected term fields are also multiplied by $d = D_{ir} / (R_b + R_i)$ to account for the difference in free space loss due to the differential distance between the direct and reflected waves.

For this study we will assume that horizontally polarized power is added to vertically polarized power in a ratio, P_{HV}. For substantially horizontally polarized waves, P_{HV} is chosen here to be between 10 and 20, and for substantially vertically polarized waves, P_{HV} is between 0.005 and 0.01. The polarization impurity primarily results in a slight reduction of the depths of nulls in the vertical standing wave patterns. The two polarization components are added as power because the polarization is decomposed by the ionosphere into elliptical polarization, (see *Ionospheric Radio Propagation*[5]) and reflections from a rough surface are generally random and time-variable. The expression for the signal power, P normalized to the free space value, of the combined waves at the receiving height, h_{ant} is:

$$P = \frac{P_{HV}\left[1 + \exp(-jk\Delta R)\Gamma_H S_r Dd\right]^2 + \left[1 + \exp(-jk\Delta R)\Gamma_V S_r Dd\right]^2}{1 + P_{HV}} \qquad \text{[Eq 5]}$$

The unity terms in each of the brackets represent the direct wave amplitude, and the remaining terms are the reflected wave, each in ratio to the free space value. The phase difference, $k\Delta R$, along with the phase of the reflection coefficients conspire to produce the vertical standing wave pattern of the field strength at the receiving location. *This is before any antenna is placed at the receiving location.* Since the earth's radius is large compared with the height of the ionosphere, angles T and ψ are nearly the same value, despite the exaggerated view in Figure 1. Since antenna free space elevation patterns for a level antenna are essentially symmetrical in elevation about the local horizontal plane, the direct wave entering the antenna from angle T above the horizontal plane is weighted by the same antenna pattern gain value as the reflected wave entering the antenna from angle ψ below the horizontal plane. Note also that the earth's horizon is *slightly below* the elevated antenna horizontal plane.

Expected Angles of Arrival

We will be optimizing our solution over a desired range of arrival angles. Expected arrival angles T for waves from the ionosphere for HF Propagation are available in *The ARRL Antenna Book* product notes files on the ARRL website for HF (see Note 3). For example, the combined 80 m to 10 m arrival angle statistics between Florida (FL) or Massachusetts (MA) and all regions of the World are shown in Figure 2.

Those statistics show that half the arrival angles are less than 6°, and that 90% of the arrival angles are smaller than 16°. So for HF cases, we will confine our interest to arrival angles between 2 to 16°. Viewed in transmit mode, this is the *range* of "take-off" angles that must be accommodated. Similar curves may be derived for 6 m band sporadic-*E* propagation. Notably, in the July and August 2009 "World Above 50 MHz" *QST* column, Gene Zimmerman, W3ZZ, comments on the work of Joe Kraft, CT1HZE, suggesting that arrival angle probabilities for 6 m band sporadic-*E* are bimodal, with one peak at ~5° and another at ~10° with very little below 3° or 4° or above ~13° or 14°.[6,7] Thus, arrival angles of 3° to 14° emerge as a range of interest for 6 m sporadic-E operations. Also see my article, "Optimum Height for an Elevated Communications Antenna," in *DUBUS* magazine.[8] While different from HF in the specifics, the angle ranges of interest are similar, and justify the range between 2° and 16°.

Location of the Reflection Point

The distance G_b to the reflection point on the earth's surface is solved by Equation 1 as a function of receiving point height. There is only a very

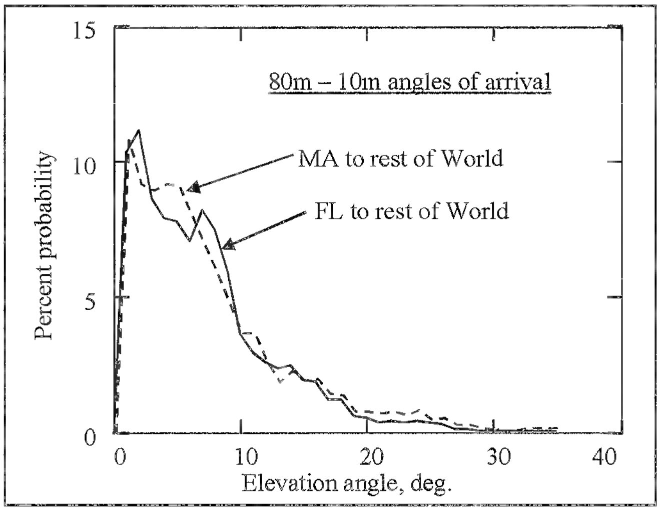

Figure 2 — Composite probability of arrival angles.

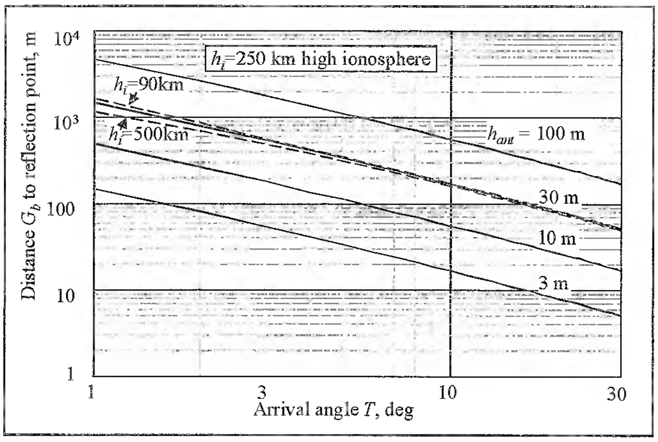

Figure 3 — Distance to the reflection point is tens to thousands of meters.

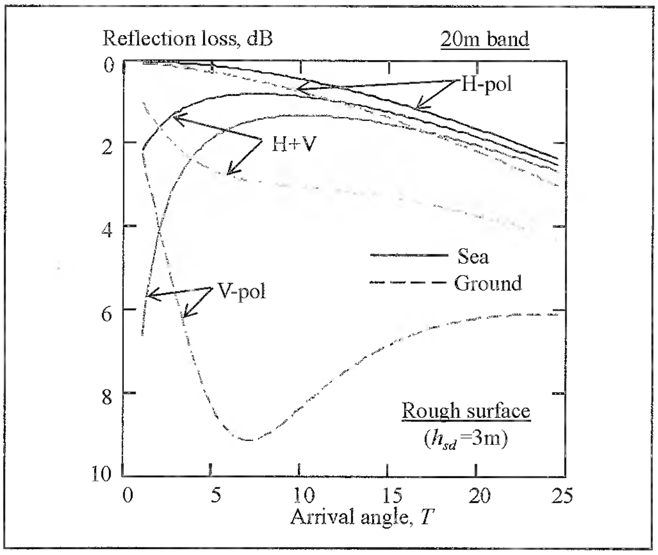

Figure 4 — Reflection coefficient with surface roughness, 20 m band.

weak dependency on the height of the ionosphere; heights from 90 km to as much as 500 km, the range of heights for the E, E_S, and F layers of the ionosphere, give very nearly the same geometrical result. There is, however, a strong dependency on the receiving height location. Figure 3 shows the distance to the reflection point versus the arrival angle for several receiving heights between 3 and 100 m with a 250 km high ionosphere. The 30 m high antenna distances are also shown (dashed lines) for 90 km and 500 km high ionosphere. *Since the reflection point is typically from a few kilometers to tens of meters away the ground immediately below the antenna does not affect elevated antenna performance*. A very good approximation to the reflection point distance is:

$$G_b = \frac{55h_{ant}}{T} \qquad \text{[Eq 6]}$$

where:
h_{ant} is the antenna height in meters
T is the arrival angle in degrees.

The reflection point given by Equation 6 is the same as for the transmit case; please see "The Effect of Ground in the Far Field" in Chapter 3 of *The ARRL Antenna Book* (see Note 1). It should be noted that transmit patterns computed in the presence of the ground often quoting a "take off angle," *implicitly assume that, the ground is flat to beyond the distance given by Equation 6*. Here, in contrast, recall that we have allowed for a ground roughness factor.

Earth Reflection Loss

The ground or sea reflection loss, L_{earth} in dB for *multiple hop paths* can be found by setting the direct wave "1" terms to zero in Equation 5 and expressing the result in decibels. Figure 4 shows the loss in the 20 m band for horizontal, vertical and a 50% mix of the polarization, for reflection from the sea and from a medium earth (ε = 12) versus the angle T. The reflection includes a surface roughness factor of 3 m. For $2 \leq T \leq 16°$ this reflection loss can amount to more than 1 dB for horizontal polarization, but as much as 9 dB for vertical polarization reflected from earth ground.

Optimum Antenna Height

We can now solve Equation 5 at various frequencies, polarizations, ground constants and as a function of the height of an antenna. The specific antenna pattern — that is, the free space pattern — is not important as long as the elevation plane beamwidth is sufficient

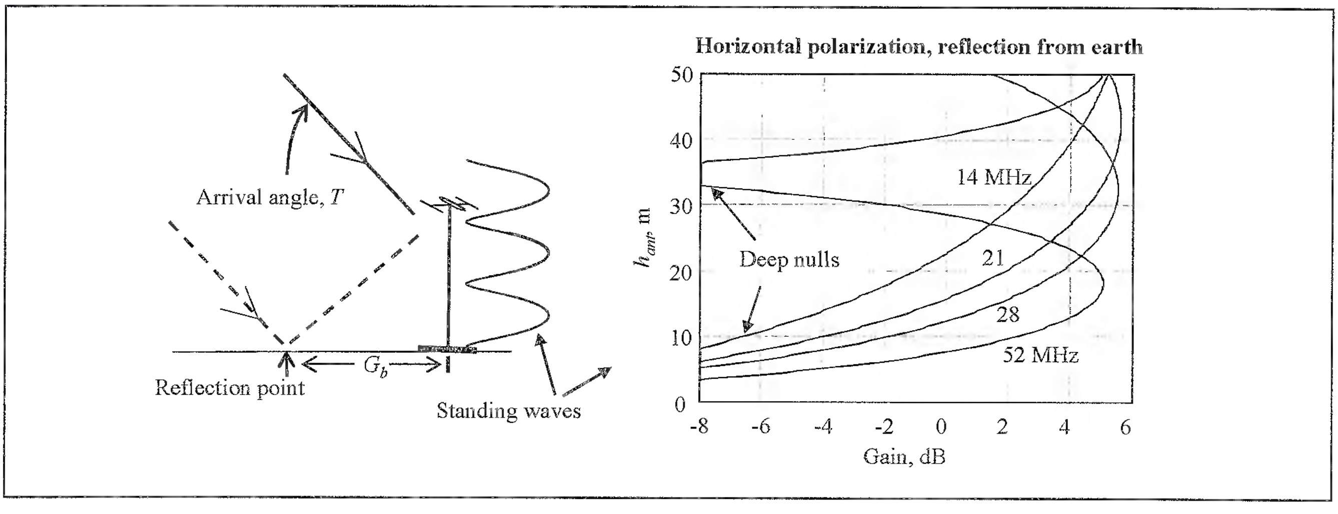

Figure 5 — Horizontal polarization (P_{HV} = 20), earth ground, T = 5°, roughness is 3 m.

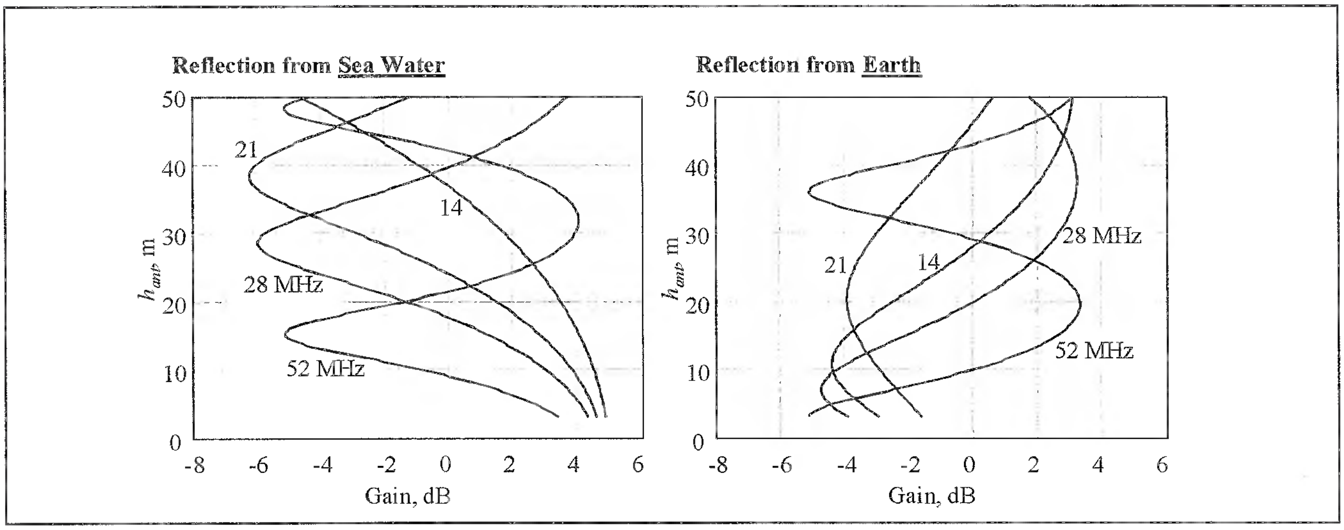

Figure 6 — Vertical polarization (P_{HV} = 0.05), T = 5°, roughness is 3 m, reflections from (left) sea water and from (right) earth ground.

to include the important angles of arrival, both above and below the local horizontal plane. We do note, however, that as the angle T increases, the waves arrive in pairs above and below the main beam peak, so that the full antenna gain for directive antennas cannot be always be realized — especially for very high gain (narrow elevation plane beamwidth) antennas.

Figure 5 shows the geometry and the calculated vertical standing wave patterns produced by the interaction of the direct and earth reflected waves for earth ground parameters $\varepsilon = 5$ and $\sigma = 0.005$ S/m. The standing wave peaks and nulls depend on frequency and on arrival angle, here 5°. This suggests placing the antenna at the signal peak, which is one definition of the optimum antenna height.

Results for horizontally polarized waves reflected from the sea differ primarily in the depth of nulls compared with earth ground reflected results of Figure 5. There are transmitter mode equivalents to the receive mode standing wave patterns shown in Figure 5. The transmit mode patterns are computed in the presence of a ground, and usually a peak "take-off angle" is identified; see for example Figure 3 in the companion article in the June 2011 issue of *QST*.[9] Clearly the transmit mode patterns do not make it easy to identify the best height for the antenna.

Figure 6 shows the vertical polarization performance for reflection from sea water $\varepsilon = 70.6$ and $\sigma = 4.54$ S/m, on the left and from ground with $\varepsilon = 5$ and $\sigma = 0.005$ S/m on the right. The saline water model is from *Radiowave Propagation and Antennas for Personal Communications* (see Note 4). The sea-reflected, vertically polarized case has an optimum at sea level. This is why vertically polarized antennas on the beach are so effective on some DXpeditions such as during the VP6DX operation. Note that the optimum heights per frequency for vertically polarized antennas with the reflection from earth ground are not the same as for horizontal polarization. Ground mounted vertical antennas with a reflection from earth ground will have negative height gains of –1 to –5 dB. The gains shown in Figures 5, 6 and 7 are in addition to any free space directive gain provided by the antenna system. Results in Figures 5 and 6 are exactly analogous to the results that have been predicted and measured to within a decibel at open air test sites in the 30 to 932 MHz range. See Section 6.3 in *Radiowave Propagation and Antennas for Personal Communications* (see Note 4).

Concentrating now on the 20 m band, Figure 7 shows field-strength signal levels relative to the free space value for reflections from the ground. *These are not antenna patterns but rather signal field strength levels that are then sampled by an antenna.* The axes have been flipped compared with the previous figures. The upper dashed asymptote is the *maximum constructive interference* for the continuum of all arrival angles between 2 and 16°. Specific results for 2°, 5°, 10° and 15° are shown by the embedded curves. The lower dashed asymptote is defined by the *destructive interference* for the continuum of arrival angles. The lower asymptote intersects the 2° arrival angle curve at a cusp, which defines an optimum antenna height for that frequency. At that elevation, the height gain, g_w has the smallest variation versus the range of arrival angles, and its minimum gain value is the highest. When an antenna is placed there, the actual free space antenna gain, at the pattern elevation angle, T, adds to this field strength height gain. Antennas that are higher than the optimum height will encounter degraded performance at the higher angles of arrival because the nulls defining the lower asymptote to the right of the cusp are likely to be a factor. This is why in some cases a lower antenna can significantly outperform a higher antenna. If we had chosen a higher minimum required arrival angle, the optimum height would decrease. Similar curves can be drawn for other HF bands or combinations of bands, and optimum heights can be found.

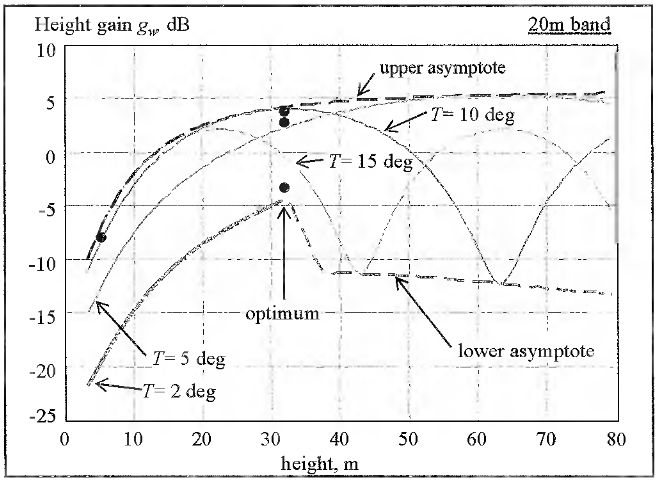

Figure 7 — Height gain for horizontal polarization in the 20 m band.

Multiband Considerations

Since the geometry of the reflection point, including divergence and surface roughness, are fixed in physical dimensions, the vertical interference patterns don't quite scale with wavelength. Thus, the optimum height does not scale exactly with frequency. Some multiband Yagi beams can cover the 40 m to 6 m bands in a single structure. Raising and lowering such an antenna is not usually desirable, so knowing an overall optimum height could be very useful. A family of curves like the 20 m band curves in Figure 7 can be calculated for any frequency band or any combination of frequency bands.

One effective strategy for finding an overall optimum over multiple bands is to choose the best height for the highest frequency band of interest. That somewhat sacrifices the performance for the lowest arrival angles at the lower frequency bands, but more gently than the destructive interference loss of height gain for higher arrival angles if a higher antenna were chosen.

The optimum heights for various frequency bands between 7 and 54 MHz are shown in Figure 8. The three curves are for three different minimum angles, the upper curve shows optima for a 1° to 16° arrival angle range, the middle curve for 2° to 16°, and the lower curve for 3° to 16°. The middle curve slopes from about 1.5 to 1.6 wavelengths between 7 and 29 MHz.

If operation anywhere in the 10 m to 40 m bands is of equal interest, the "best" height works out to about 19.9 m. That height is suitable for arrival angles as low as 1° in the 10 m band, and is also suitable for angles above about 4° in the 20 m band. In the 40 m and 30 m bands the results are "best effort," but as will be shown in the next section, paths at higher arrival angles may exist, but with an increased number of earth-ionosphere hops. If the 20 m band is to be optimized, then the best height is about 32 m. If 6 m band operation is important then the optimum height is about 15.3 m. The heights between about 15 m and 32 m (50 to 105 ft) emerge as a good range of compromise choices for multiband HF and 6 m band operations.

This analysis also provides some insight into the physical basis for the operation of phased Yagi antennas mounted at different heights on a tower. By combining the signals from the two or more Yagis using phase shifters, it is possible to enhance gain in the direct-wave path while minimizing the destructive interference from the earth reflection. Possibly significant performance improvement might be realized.

Path Link Considerations

Many details are important in calculating a path link at HF, but for illustration here we examine a simplified path where both ends of the link are located on relatively flat (but not smooth) terrain, and the ionosphere and earth are suitable for the needed reflections along the path. Path link margin depends on the height of the ionosphere, h_i as well as on the arrival angle, T. Figure 9 shows the hop distances for several ionospheric heights as a function of the arrival angle over a spherical earth. For our example we will assume that the ionospheric refraction and reflection occurs at an effective height of 250 km. So a 10,000 km path might be traversed with 3, 4 or 5 hops, each 3,333 km or 2,500 km or 2,000 km respectively. Other paths are possible as well, as Davies described in *Ionospheric Radio Propagation* (see Note 5). The three different hops are marked by the shaded circle in Figure 9, with corresponding marks in Figure 7. Different hop distances mean different arrival angles, which affects the total path loss.

The wave interference gain, or height gain, g_w in dB shown in Figure 7 applies to each end of the link. Ionospheric reflection/refraction loss is L_{ion} in dB and can be as little as 2 to 5 dB.[10] In this simplified example, we will use 3 dB to account for polarization decomposition, as described by Davies (see Note 5). The free space loss is $27.6 + 20 \log(2\ D_{tr} \times f)$ dB for one hop, where the frequency,

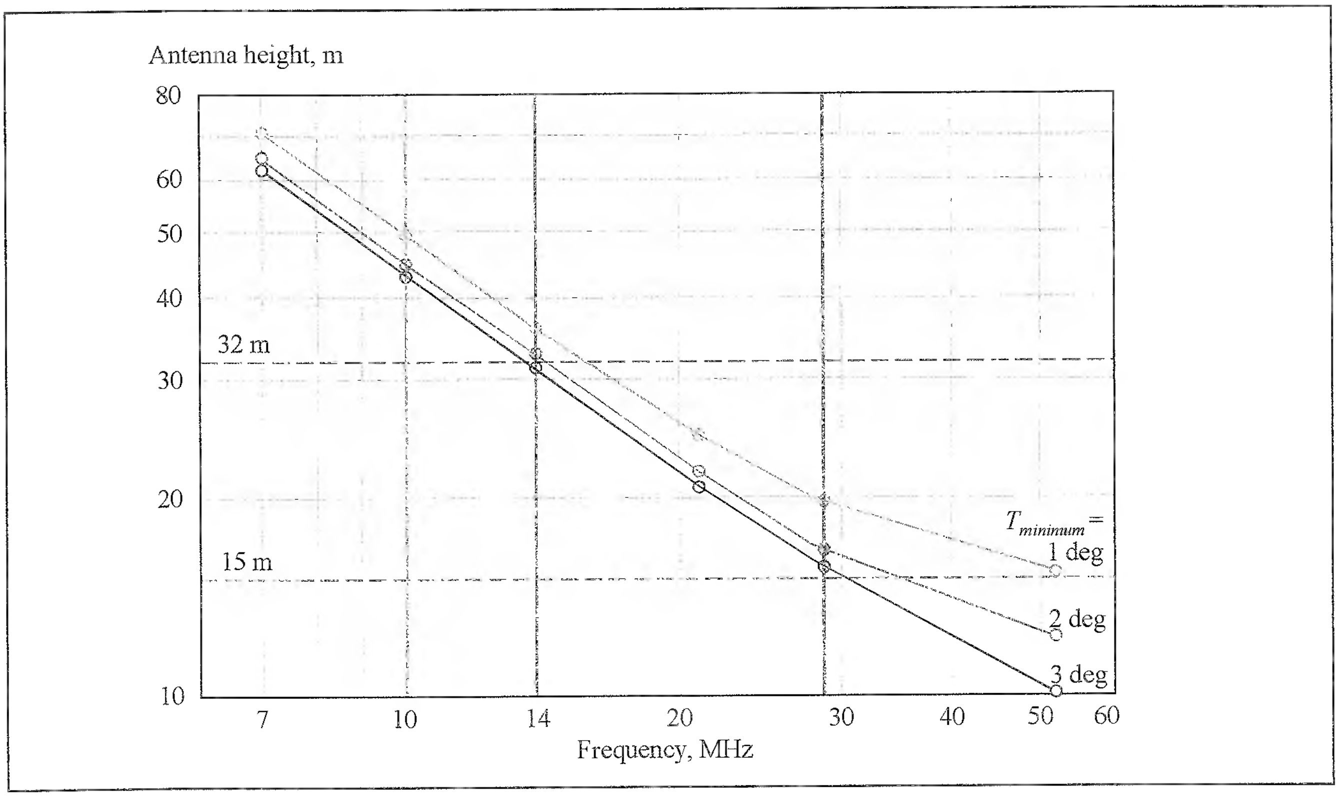

Figure 8 — Optimum antenna heights over even terrain for various frequencies.

Table 1

Path Losses in a 10,000 km Path for Different Numbers of Hops.

Hops	*T (deg)*	*First hop loss (dB)*	*Height gain (dB)*	*Rest of hops loss (dB)*	*PL (dB)*	*S-units*
3	2.8	[126.1 + 3]	–[–4 – 4]	{ 9.6 + 7.1}	153.8	3.6
4	6.9	[123.7 + 3]	–[+3 + 3]	{10.6 + 8.1 + 7.1}	146.4	4.8
5	10.4	[121.8 + 3]	–[+4 + 4]	{11.7 + 9.2 + 8.2 + 7.6}	157.8	2.9

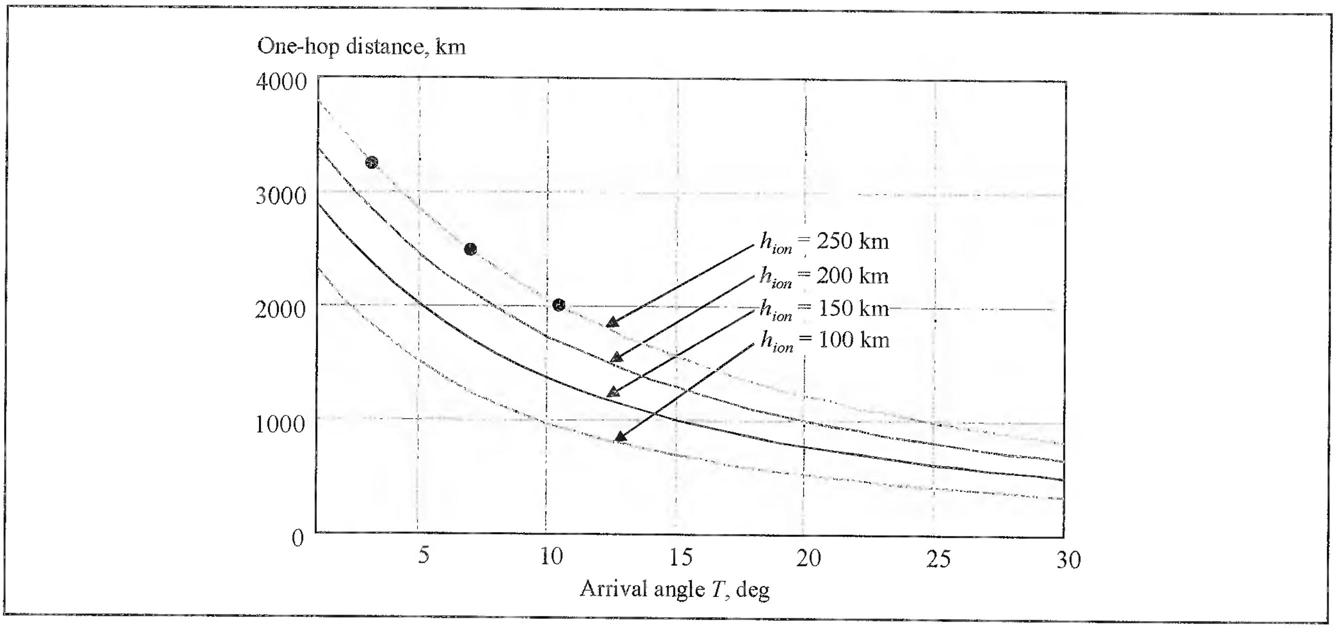

Figure 9 — Hop distances, with the 3, 4, and 5 hop points marked for a 10,000 km path.

f, is in MHz and the distance, D_{tr} is in meters. Each additional j^{th} hop adds an incremental free space loss, an earth reflection loss, $L_{earth,j}$ (from Figure 4), and another ionospheric reflection loss, $L_{ion,j}$. The path loss for n hops is written in Equation 7 so that the bracketed terms are for a single hop or first hop, including wave interference at the link ends A and B. The braces contain additional losses for hops 2 through n if present.

$$L_{path} = \left[27.6 + 20\log(2D_{tr}f_{MHz}) + L_{ion} - g_{w,A} - g_{w,B}\right] + \cdots$$
$$+\left\{\sum_{j=2}^{n}\left(20\log\left(\frac{j}{j-1}\right) + L_{ion,\ j} + L_{earth,\ j}\right)\right\} \qquad \text{[Eq 7]}$$

Our example path in the 20 m band with a 250 km effective ionospheric height might require 3 to 5 or more hops to traverse a 10,000 km path. The various gains and losses for this idealized example are listed in Table 1. In general, several of these as well as other possible paths will exist, causing fading and signal variations as the ionosphere changes. Table 1 shows the path losses and estimated received S-units for 50 W transmitted power (approximately 100 W PEP for CW or processed SSB) and with 32 m high dipoles at each end. Gain antennas will improve signals in proportion to the antenna gains. The bracketed and braced terms in Table 1 correspond to the same terms in Equation 7.

Notice that the four-hop path has a stronger signal by over an S-unit more than the example three-hop path because the increased height gains g_w of a combined 8 dB at the higher arrival angle (the difference between the top and bottom solid circles at the optimum height in Figure 7) at both ends of the link more than compensate for the additional reflection losses of an additional hop. The height gain is the intersection of the arrival angle, T, with the antenna height in Figure 7. The four-hop 6.9° arrival angle results in less destructive interference by 7 dB at each end of the link than the three-hop 2.8° arrival angle. *The lowest arrival angle path is not always the best!* Agonizing over a lower "take-off angle" is futile. This effect justifies a compromise lower limit for the angle of arrival at lower frequencies when choosing a compromise height for a multiband antenna. The five-hop path suffers additional earth and ionospheric reflection losses, but still results in a respectable S = 2.9 signal.

Suppose that the antenna at one end of the link is lowered to 5m. The height gain, g_w becomes –17 dB for the 2.8° three-hop path, so that path is not viable. The gain is –8 dB for the four-hop path, however, which is 12 dB lower than at the optimum height, resulting in an S = 1 reading. That is still a –115 dBm signal, which is suitable for CW as well as SSB. This result helps to explain the occasional spectacular DX results possible from low and indoor attic antennas.[11] If the arrival angle is, say >5°, the low antenna captures signals that are not dramatically worse than from a high antenna. Indeed, KE4PT has earned WAS-TPA and DXCC, now with 200 confirmed entities as well as a 6 meter VUCC from southern Florida, using just an indoor antenna.

Uncertainties in the ionospheric reflection/refraction loss increase as the number of hops increases, and Equation 7 represents a best case value. Link reliability can be estimated by attaching variances to the several propagation loss components and by using the method of Hagn described in Section 8.4 of *Radiowave Propagation and Antennas for Personal Communications* (see Note 4).

Summary and Conclusions

Constructive and destructive wave interference from a direct path and an earth reflected path causes a vertical standing wave at the antenna location. The standing wave pattern details depend on the wave angle of arrival, polarization, on whether the reflection point was ground or sea water, and on the terrain profile (not considered here). Optimum antenna heights are largely governed by the lowest arrival angle deemed important at the highest desired frequency. Antennas that are placed too high can suffer from significant wave destructive interference at desired higher arrival angles. The earth reflection point is typically several kilometers away for low arrival angles, but can be tens of meters for very high arrival angles, so the condition of the ground immediately below an elevated antenna is of little importance. Because height gain can be significantly greater for higher arrival angles, the lowest arrival angle path (fewest hops) does not always result in the best link margin for paths that can be closed with different numbers of earth-ionosphere hops. Optimum height is 1.5 to 1.6 wavelengths for any one band, or a compromise height can be found for a multiband antenna operating over several bands by using the optimum for the highest frequency. Keeping in mind that this analysis was limited to rough, but not locally mountainous earth, nor a dense urban region, antenna heights in the range of 15 m to 32 m (50 to 105 ft) are found to be reasonable compromise choices for multiband antennas operating from a fixed height.

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Notes

[1] R. Dean Straw, N6BV, Ed., *The ARRL Antenna Book*, 21st Edition, 2007.

[2] M. I. Skolnik, *Radar Handbook*, Second Edition, McGraw-Hill Professional, 1990.

[3] See the *Antenna Book* tab at **www.arrl.org/product-notes**, updated statistical elevation-angle files, accessed 29 December 2010.

[4] K. Siwiak, Y. Bahreini, *Radiowave Propagation and Antennas for Personal Communications*, Third Edition, Artech House, Norwood MA, 2007.

[5] K. Davies, *Ionospheric Radio Propagation*, National Bureau of Standards Monograph 80, Washington DC, 1965.

[6] Eugene Zimmerman, W3ZZ, "Long Distance E_s Propagation on 50 MHz at Solar Cycle Minimum — Part 1," The World Above 50 MHz, *QST*, July 2009, p 88.

[7] Eugene Zimmerman, W3ZZ, "Long Distance E_s Propagation on 50 MHz at Solar Cycle Minimum — Part 2," The World Above 50 MHz, *QST*, August 2009, p 86.

[8] K. Siwiak, "Optimum Height for an Elevated Communications Antenna," *DUBUS Magazine*, Vol. 39, 3rd Quarter 2010, pp 86-99.

[9] K. Siwiak, "What's the Optimum Height for an HF Antenna?," *QST* June 2011.

[10] Recommendation ITU-R P.534-4.

[11] K. Siwiak, KE4PT, "You Can Enjoy DXing with a Modest Station," *CQ Amateur Radio*, November 2010, pp 46-48.

Antenna Height and Communications Effectiveness

Second Edition

A Guide for City Planners and Amateur Radio Operators

By R. Dean Straw, N6BV, and Gerald L. Hall, K1TD
Senior Assistant Technical Editor and Retired Associate Technical Editor

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Executive Summary

Amateur radio operators, or "hams" as they are called, communicate with stations located all over the world. Some contacts may be local in nature, while others may be literally halfway around the world. Hams use a variety of internationally allocated frequencies to accomplish their communications.

Except for local contacts, which are primarily made on Very High and Ultra High Frequencies (VHF and UHF), communicating between any two points on the earth rely primarily on high-frequency (HF) signals propagating through the ionosphere. The earth's ionosphere acts much like a mirror at heights of about 150 miles. The vertical angle of radiation of a signal launched from an antenna is one of the key factors determining effective communication distances. The ability to communicate over long distances generally requires a low radiation angle, meaning that an antenna must be placed high above the ground in terms of the wavelength of the radio wave being transmitted.

A beam type of antenna at a height of 70 feet or more will provide greatly superior performance over the same antenna at 35 feet, all other factors being equal. A height of 120 feet or even higher will provide even more advantages for long-distance communications. To a distant receiving station, a transmitting antenna at 120 feet will provide the effect of approximately 8 to 10 times more transmitting power than the same antenna at 35 feet. Depending on the level of noise and interference, this performance disparity is often enough to mean the difference between making distant radio contact with fairly reliable signals, and being unable to make distant contact at all.

Radio Amateurs have a well-deserved reputation for providing vital communications in emergency situations, such as in the aftermath of a severe icestorm, a hurricane or an earthquake. Short-range communications at VHF or UHF frequencies also require sufficient antenna heights above the local terrain to ensure that the antenna has a clear horizon.

In terms of safety and aesthetic considerations, it might seem intuitively reasonable for a planning board to want to restrict antenna installations to low heights. However, such height restrictions often prove very counterproductive and frustrating to all parties involved. If an amateur is restricted to low antenna heights, say 35 feet, he will suffer from poor transmission of his own signals as well as poor reception of distant signals. In an attempt to compensate on the transmitting side (he can't do anything about the poor reception problem), he might boost his transmitted power, say from 150 watts to 1,500 watts, the maximum legal limit. This ten-fold increase in power will very significantly increase the *potential* for interference to telephones, televisions, VCRs and audio equipment in his neighborhood.

Instead, if the antenna can be moved farther away from neighboring electronic devices—putting it higher, in other words—this will greatly reduce the likelihood of interference, which decreases at the inverse square of the distance. For example, doubling the distance reduces the potential for interference by 75%. As a further benefit, a large antenna doesn't look anywhere near as large at 120 feet as it does close-up at 35 feet.

As a not-so-inconsequential side benefit, moving an antenna higher will also greatly reduce the potential of exposure to electromagnetic fields for neighboring human and animals. Interference and RF exposure standards have been thoroughly covered in recently enacted Federal Regulations.

Antenna Height and Communications Effectiveness

By R. Dean Straw, N6BV, and Gerald L. Hall, K1TD
Senior Assistant Technical Editor and Retired Associate Technical Editor

The purpose of this paper is to provide general information about communications effectiveness as related to the physical height of antennas. The intended audience is amateur radio operators and the city and town Planning Boards before which a radio amateur must sometimes appear to obtain building permits for radio towers and antennas.

The performance of horizontally polarized antennas at heights of 35, 70 and 120 feet is examined in detail. Vertically polarized arrays are not considered here because at short-wave frequencies, over average terrain and at low radiation angles, they are usually less effective than horizontal antennas.

Ionospheric Propagation

Frequencies between 3 and 30 megahertz (abbreviated MHz) are often called the "short-wave" bands. In engineering terms this range of frequencies is defined as the *high-frequency* or *HF* portion of the radio spectrum. HF radio communications between two points that are separated by more than about 15 to 25 miles depend almost solely on propagation of radio signals through the *ionosphere*. The ionosphere is a region of the Earth's upper atmosphere that is ionized primarily by ultraviolet rays from the Sun.

The Earth's ionosphere has the property that it will refract or bend radio waves passing through it. The ionosphere is not a single "blanket" of ionization. Instead, for a number of complex reasons, a few discrete layers are formed at different heights above the earth. From the standpoint of radio propagation, each ionized layer has distinctive characteristics, related primarily to different amounts of ionization in the various layers. The ionized layer that is most useful for HF radio communication is called the *F layer*.

The F layer exists at heights varying from approximately 130 to 260 miles above the earth's surface. Both the layer height and the amount of ionization depend on the latitude from the equator, the time of day, the season of the year, and on the level of sunspot activity. Sunspot activity varies generally in cycles that are approximately 11 years in duration, although short-term bursts of activity may create changes in propagation conditions that last anywhere from a few minutes to several days. The ionosphere is not homogeneous, and is undergoing continual change. In fact, the exact state of the ionosphere at any one time is so variable that is best described in statistical terms.

The F layer disappears at night in periods of low and medium solar activity, as the ultraviolet energy required to sustain ionization is no longer received from the Sun. The amount that a passing radio wave will bend in an ionospheric layer is directly related to the intensity of ionization in that layer, and to the frequency of the radio wave.

A triangle may be used to portray the cross-sectional path of ionospheric radio-wave travel, as shown in **Fig 1**, a highly simplified picture of what happens in propagation of radio waves. The base of the triangle is the surface of the Earth between two distant points, and the apex of the triangle is the point representing refraction in the ionosphere. If all the necessary conditions are met, the radio wave will travel from the first point on the Earth's surface to the ionosphere, where it will be bent (*refracted*) sufficiently to travel to the second point on the earth, many hundreds of miles away.

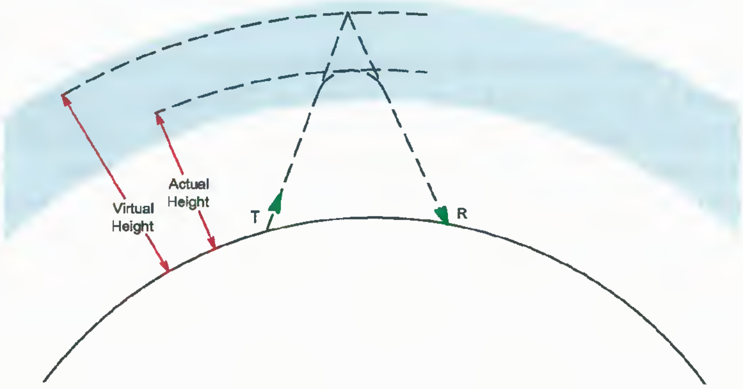

Fig 1—A simplified cross-sectional representation of ionospheric propagation. The simple triangle goes from the Transmitter T up to the virtual height and then back down to the Receiver R. Typically the F layer exists at a height of 150 miles above the Earth at mid-latitudes. The distance between T and R may range from a few miles to 2500 miles under normal propagation conditions.

Of course the Earth's surface is not a flat plane, but instead is curved. High-frequency radio waves behave in essentially the same manner as light waves—they tend to travel in straight lines, but with a slight amount of downward bending caused by refraction in the air. For this reason it is not possible to communicate by a direct path over distances greater than about 15 to 25 miles in this frequency range, slightly farther than the optical horizon. The curvature of the earth causes the surface to "fall away" from the path of the radio wave with greater distances. Therefore, it is the ionosphere that permits HF radio communications to be made between points separated by hundreds or even thousands of miles. The range of frequencies from 3 to 30 MHz is unique in this respect, as ionospheric propagation is not consistently supported for any frequencies outside this range.

One of the necessary conditions for ionospheric communications is that the radio wave must encounter the ionosphere at the correct angle. This is illustrated in **Fig 2**, another very simplified drawing of the geometry involved. Radio waves leaving the earth at high elevation angles above the horizon may receive only very slight bending due to refraction, and are then lost to outer space. For the same fixed frequency of operation, as the elevation angle is lowered toward the horizon, a point is reached where the bending of the wave is sufficient to return the wave to the Earth. At successively lower angles, the wave returns to the Earth at increasing distances.

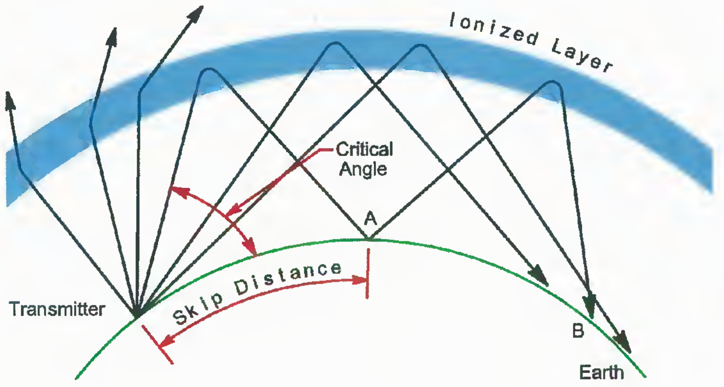

Fig 2—Behavior of radio waves encountering the ionosphere. Rays entering the ionized region at angles above the critical angle are not bent enough to return to Earth and are lost to space. Waves entering at angles below the critical angle reach the Earth at increasingly greater distances as the angle approaches the horizontal. The maximum distance that may normally be covered in a single hop is 2500 miles. Greater distances may be covered with multiple hops.

If the radio wave leaves the earth at an *elevation angle* of zero degrees, just toward the horizon (or just tangent to the earth's surface), the maximum distance that may be reached under usual ionospheric conditions is approximately 2,500 miles (4,000 kilometers). However, the Earth itself also acts as a reflector of radio waves coming down from the ionosphere. Quite often a radio signal will be reflected from the reception point on the Earth back into the ionosphere again, reaching the Earth a second time at a still more distant point.

As in the case of light waves, the angle of reflection is the same as the angle of incidence, so a wave striking the surface of the Earth at an angle of, say, 15° is reflected upward from the surface at the same angle. Thus, the distance to the second point of reception will be approximately twice the distance of the first. This effect is also illustrated in Fig 2, where the signal travels from the transmitter at the left of the drawing via the ionosphere to Point A, in the center of the drawing. From Point A the signal travels via the ionosphere again to Point B, at the right. A signal traveling from the Earth through the ionosphere and back to the Earth is called a *hop*. Under some conditions it is possible for as many as four or five signal hops to occur over a radio path, but no more than two or three hops is the norm. In this way, HF communications can be conducted over thousands of miles.

With regard to signal hopping, two important points should be recognized. First, a significant loss of signal occurs with each hop. Lower layers of the ionosphere absorb energy from the signals as they pass through, and the ionosphere tends to scatter the radio energy in various directions, rather than confining it to a tight bundle. The earth also scatters the energy at a reflection point. Thus, only a small fraction of the transmitted energy actually reaches a distant receiving point.

Again refer to Fig 2. Two radio paths are shown from the transmitter to Point B, a one-hop path and a two-hop path. Measurements indicate that although there can be great variation in the ratio of the two signal strengths in a situation such as this, the signal power received at Point B will generally be from five to ten times greater for the one-hop wave than for the two-hop wave. (The terrain at the mid-path reflection point for the two-hop wave, the angle at which the wave is reflected from the earth, and the condition of the ionosphere in the vicinity of all the refraction points are the primary factors in determining the signal-strength ratio.) Signal levels are generally compared in decibels, abbreviated dB. The decibel is a logarithmic unit. Three decibels difference in signal strengths is equivalent to a power ratio of 2:1; a difference of 10 dB equates to a power ratio of 10:1. Thus the signal loss for an additional hop is about 7 to 10 dB.

The additional loss per hop becomes significant at greater distances. For a simplified example, a distance of 4,000 miles can be covered in two hops of 2,000 miles each or in four hops of 1,000 miles each. For illustration, assume the loss for additional hops is 10 dB, or a 1/10 power ratio. Under such conditions, the four-hop signal will be received with only 1/100 the power or 20 dB below that received in two hops. The reason for this is that only 1/10 of the two-hop signal is received for the first additional (3rd) hop, and only 1/10 of that 1/10 for the second additional (4th) hop. It is for this reason that no more than four or five propagation hops are useful; the received signal eventually becomes too weak to be heard.

The second important point to be recognized in multihop propagation is that the geometry of the first hop establishes the geometry for all succeeding hops. And it is the elevation angle at the transmitter that sets up the geometry for the first hop.

It should be obvious from the preceding discussion that one needs a detailed knowledge of the range of elevation angles for effective communication in order to do a scientific evaluation of a possible communications circuit. The range of angles should be statistically valid over the full 11-year solar sunspot cycle, since the behavior of the Sun determines the changes in the nature of the Earth's ionosphere. ARRL did a very detailed computer study in the early 1990s to determine the angles needed for propagation throughout the world. The results of this study will be examined later, after we introduce the relationship between antenna height and the elevation pattern for an antenna.

Horizontal Antennas Over Flat Ground

A simple antenna that is commonly used for HF communications is the horizontal half-wave *dipole*. The dipole is a straight length of wire (or tubing) into which radio-frequency energy is fed at the center. Because of its simplicity, the dipole may be easily subjected to theoretical performance analyses. Further, the results of proper analyses are well borne out in practice. For these reasons, the half-wave dipole is a convenient performance standard against which other antenna systems can be compared.

Because the earth acts as a reflector for HF radio waves, the directive properties of any antenna are modified considerably by the ground underneath it. If a dipole antenna is placed horizontally above the ground, most of the energy radiated downward from the dipole is reflected upward. The reflected waves combine with the direct waves (those radiated at angles above the horizontal) in various ways, depending on the height of the antenna, the frequency, and the electrical characteristics of the ground under and around the antenna.

At some vertical angles above the horizon, the direct and reflected waves may be exactly in phase—that is, the maximum signal or field strengths of both waves are reached at the same instant at some distant point. In this case the resultant field strength is equal to the sum of the two components. At other vertical angles the two waves may be completely out of phase at some distant point—that is, the fields are maximum at the same instant but the phase directions are opposite. The resultant field strength in this case is the difference between the two. At still other angles the resultant field will have intermediate values. Thus, the effect of the ground is to increase the intensity of radiation at some vertical angles and to decrease it at others. The elevation angles at which the maxima and minima occur depend primarily on the antenna height above ground. (The electrical characteristics of the ground have some slight effect too.)

For simplicity here, we consider the ground to be a perfectly conducting, perfectly flat reflector, so that straightforward trigonometric calculations can be made to determine the relative amount of radiation intensity at any vertical angle for any dipole height. Graphs from such calculations are often plotted on rectangular axes to show best resolution over particularly useful ranges of elevation angles, although they are also shown on polar plots so that both the front and back of the response can be examined easily. **Fig 3** shows an overlay of the polar elevation-pattern responses of two dipoles at different heights over perfectly conducting flat ground. The lower dipole is located a half wavelength above ground, while the higher dipole is located one wavelength above ground. The pattern of the lower antenna peaks at an elevation angle of about 30°, while the higher antenna has two main lobes, one peaking at 15° and the other at about 50° elevation angle.

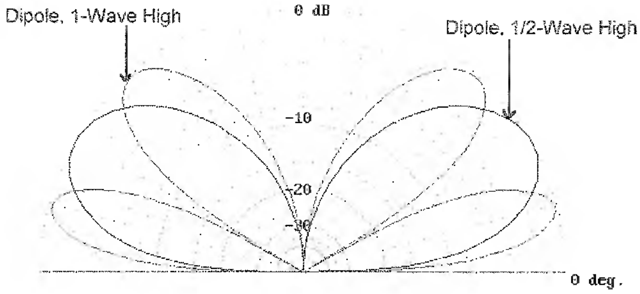

Fig 3–Comparison of elevation responses for two dipoles: one ½-wavelength high, and the other 1-wavelength high.

In the plots shown in Fig 3, the elevation angle above the horizon is represented in the same fashion that angles are measured on a protractor. The concentric circles are calibrated to represent ratios of field strengths, referenced to the strength represented by the outer circle. The circles are calibrated in decibels. Diminishing strengths are plotted toward the center.

You may have noted that antenna heights are often discussed in terms of *wavelengths*. The reason for this is that the length of a radio wave is inversely proportional to its frequency. Therefore a fixed physical height will represent different electrical heights at different radio frequencies. For example, a height of 70 feet represents one wavelength at a frequency of 14 MHz. But the same 70-foot height represents a half wavelength for a frequency of 7 MHz and only a quarter wavelength at 3.5 MHz. On the other hand, 70 feet is 2 wavelengths high at 28 MHz.

The lobes and nulls of the patterns shown in Fig 3 illustrate what was described earlier, that the effect of the ground beneath an antenna is to increase the intensity of radiation at some vertical elevation angles and to decrease it at others. At a height of a half wavelength, the radiated energy is strongest at a rather high elevation angle of 30°. This would represent the situation for a 14-MHz dipole 35 feet off the ground.

As the horizontal antenna is raised to greater heights, additional lobes are formed, and the lower ones move closer to the horizon. The maximum amplitude of each of the lobes is roughly equal. As may be seen in Fig 3, for an antenna height of one wavelength, the energy in the lowest lobe is strongest at 15°. This would represent the situation for a 14-MHz dipole 70 feet high.

The elevation angle of the lowest lobe for a horizontal antenna above perfectly conducting ground may be determined mathematically:

$$\theta = \sin^{-1}\left(\frac{0.25}{h}\right)$$

Where

θ = the wave or elevation angle
h = the antenna height above ground in wavelengths

In short, the higher the horizontal antenna, the lower is the lowest lobe of the pattern. As a very general rule of thumb, the higher an HF antenna can be placed above ground, the farther it will provide effective communications because of the resulting lower radiation angle. This is true for any horizontal antenna over real as well as theoretically perfect ground.

You should note that the *nulls* in the elevation pattern can play an important role in communications—or lack of communication. If a signal arrives at an angle where the antenna system exhibits a deep null, communication effectiveness will be greatly reduced. It is thus quite possible that an antenna can be *too high* for good communications efficiency on a particular frequency. Although this rarely arises as a significant problem on the amateur bands below 14 MHz, we'll discuss the subject of optimal height in more detail later.

Actual earth does not reflect all the radio-frequency energy striking it; some absorption takes place. Over real earth, therefore, the patterns will be slightly different than those shown in Fig 3, however the differences between theoretical and perfect earth ground are not significant for the range of elevation angles necessary for good HF communication. Modern computer programs can do accurate evaluations, taking all the significant ground-related factors into account.

Beam Antennas

For point-to-point communications, it is beneficial to concentrate the radiated energy into a beam that can be aimed toward a distant point. An analogy can be made by comparing the light from a bare electric bulb to that from an automobile headlight, which incorporates a built-in focusing lens. For illuminating a distant point, the headlight is far more effective.

Antennas designed to concentrate the radiated energy into a beam are called, naturally enough, *beam antennas*. For a fixed amount of transmitter power fed to the transmitting antenna, beam antennas provide increased signal strength at a distant receiver. In radio communications, the use of a beam antenna is also beneficial during reception, because the antenna pattern for transmission is the same for reception. A beam antenna helps to reject signals from unwanted directions, and in effect boosts the strength of signals received from the desired direction.

The increase in signal or field strength a beam antenna offers is frequently referenced to a dipole antenna in free space (or to another theoretical antenna in free space called an *isotropic antenna*) by a term called *gain*. Gain is commonly expressed in decibels. The isotropic antenna is defined as being one that radiates equally well in all directions, much like the way a bare lightbulb radiates essentially equally in all directions.

One particularly well known type of beam antenna is called a *Yagi*, named after one of its Japanese inventors. Different varieties of Yagi antennas exist, each having somewhat different characteristics. Many television antennas are forms of multi-element Yagi beam antennas. In the next section of this paper, we will refer to a four-element Yagi, with a gain of 8.5 dBi in free space, exclusive of any influence due to ground.

This antenna has 8.5 dB more gain than an isotropic antenna in free space and it achieves that gain by squeezing the pattern in certain desired directions. Think of a normally round balloon and imagine squeezing that balloon to elongate it in one direction. The increased length in one direction comes at the expense of length in other directions. This is analogous to how an antenna achieves more signal strength in one direction, at the expense of signal strength in other directions.

The elevation pattern for a Yagi over flat ground will vary with the electrical height over ground in exactly the same manner as for a simpler dipole antenna. The Yagi is one of the most common antennas employed by radio amateurs, second in popularity only to the dipole.

Putting the Pieces Together

In **Fig 4**, the elevation angles necessary for communication from a particular transmitting site, in Boston, Massachusetts, to the continent of Europe using the 14-MHz amateur band are shown in the form of a bargraph. For each elevation angle from 1° to 30°, Fig 4 shows the percentage of time when the 14-MHz band is open at each elevation angle. For example, 5° is the elevation angle that occurs just over 12% of the time when the band is available for communication, while 11° occurs about 10% of the time when the band is open. The useful range of elevation angles that must accommodated by an amateur station wishing to talk to Europe from Boston is from 1° to 28°.

In addition to the bar-graph elevation-angle statistics shown in Fig 4, the elevation pattern responses for three Yagi antennas, located at three different heights above flat ground, are overlaid on the same graph. You can easily see that the 120-foot antenna is the best antenna to cover the most likely angles for this particular frequency, although it suffers at the higher elevation angles on this particular propagation path, beyond about 12°. If, however, you can accept somewhat lower gain at the lowest angles, the 70-foot antenna would arguably be the best overall choice to cover all the elevation angles.

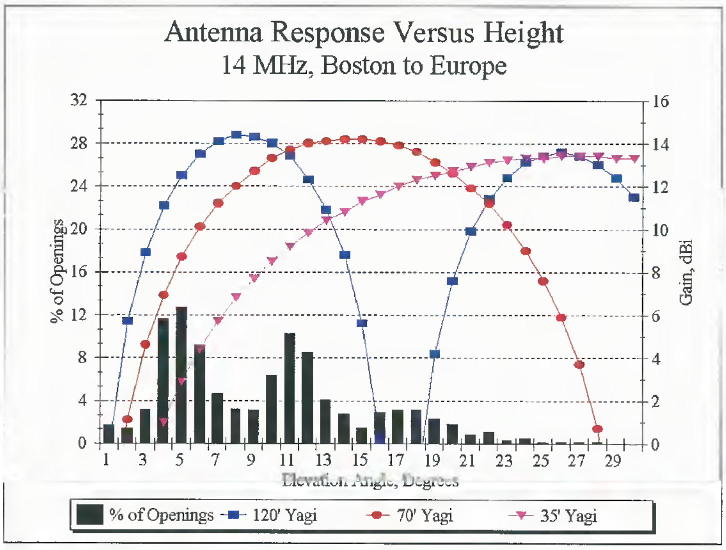

Fig 4—Elevation response patterns of three Yagis at 120, 70 and 35 feet, at 14 MHz over flat ground. The patterns are overlaid with the statistical elevation-angles for the path from Boston to continental Europe over the entire 11-year solar sunspot cycle. Clearly, the 120-foot antenna is the best choice to cover the low angles needed, but it suffers some at higher angles.

Other graphs are needed to show other target receiving areas around the world. For comparison, **Fig 5** is also for the 14-MHz band, but this time from Boston to Sydney, Australia. The peak angle for this very long path is about 2°, occurring 19% of the time when the band is actually open for communication. Here, even the 120-foot high antenna is not ideal. Nonetheless, at a moderate 5° elevation angle, the 120-foot antenna is still 10 dB better than the one at 35 feet.

Fig 4 and Fig 5 have portrayed the situation for the 14-MHz amateur band, the most popular and heavily utilized HF band used by radio amateurs. During medium to high levels of solar sunspot activity, the 21 and 28-MHz amateur bands are open during the daytime for long-distance communication. **Fig 6** illustrates the 28-MHz elevation-angle statistics, compared to the elevation patterns for the same three antenna heights shown in Fig 5. Clearly, the elevation response for the 120-foot antenna has a severe (and undesirable) null at 8°. The 120-foot antenna is almost 3.4 wavelengths high on 28 MHz (whereas it is 1.7 wavelengths high on 14 MHz.) For many launch angles, the 120-foot high Yagi on 28 MHz would simply be too high.

The radio amateur who must operate on a variety of frequencies might require two or more towers at different heights to maintain essential elevation coverage on all the authorized bands. Antennas can sometimes be mounted at different heights on a single supporting tower, although it is more difficult to rotate antennas that are "vertically stacked" around the tower to point in all the needed directions. Further, closely spaced antennas tuned to different frequencies usually interact electrically with each other, often causing severe performance degradation.

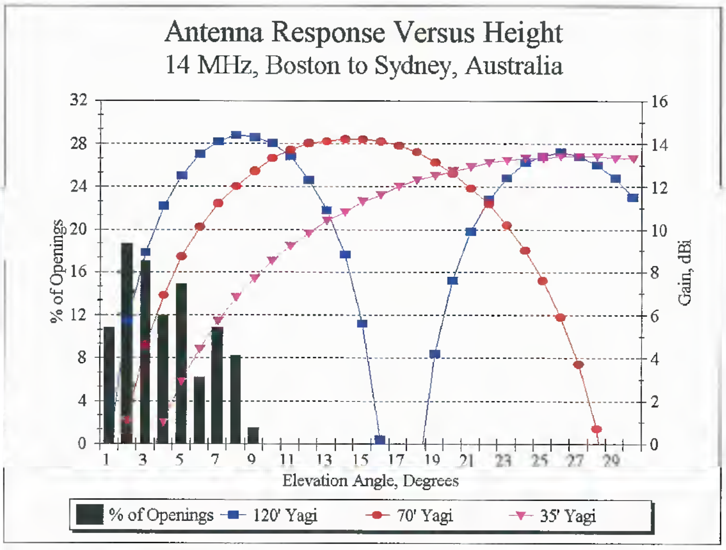

Fig 5—Elevation responses for same antennas as Fig 4, but for a longer-range path from Boston to Sydney, Australia. Note that the prevailing elevation angles are very low.

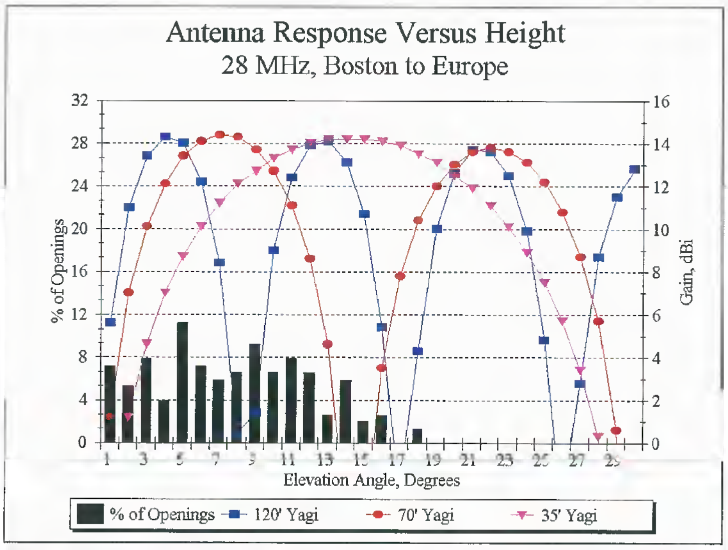

Fig 6—Elevation angles compared to antenna responses for 28-MHz path from Boston to Europe. The 70-foot antenna is probably the best overall choice on this path.

During periods of low to moderate sunspot activity (about 50% of the 11-year solar cycle), the 14-MHz band closes down for propagation in the early evening. A radio amateur wishing to continue communication must shift to a lower frequency band. The next most highly used band below the 14-MHz band is the 7-MHz amateur band. **Fig 7** portrays a 7-MHz case for another transmitting site, this time from San Francisco, California, to the European continent. Now, the range of necessary elevation angles is from about 1° to 16°, with a peak statistical likelihood of about 16% occurring at an elevation of 3°. At this low elevation angle, a 7-MHz antenna must be *very* high in the air to be effective. Even the 120-foot antenna is hardly optimal for the peak angle of 3°. The 200-foot antenna shown would be far better than a 120-foot antenna. Further, the 35-foot high antenna is *greatly* inferior to the other antennas on this path and would provide far less capabilities, on both receiving and transmitting.

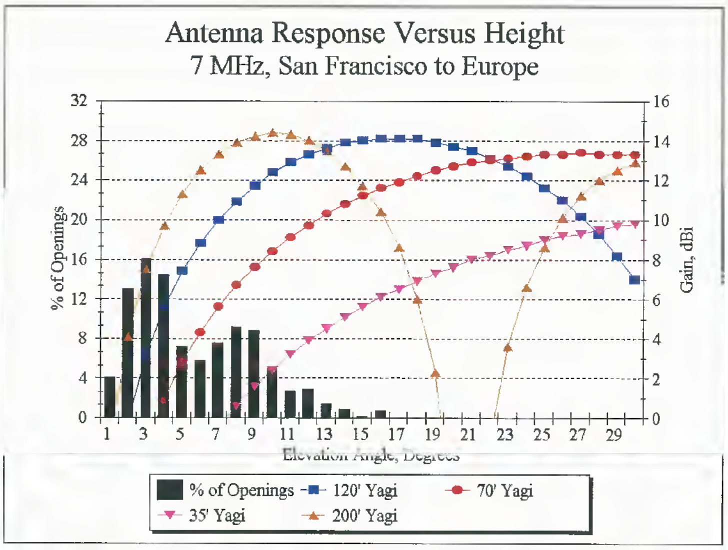

Fig 7—Comparison of antenna responses for another propagation path: from San Francisco to Europe on 7 MHz. Here, even a 120-foot high antenna is hardly optimal for the very low elevation angles required on this very long path. In fact, the 200-foot high antenna is far better suited for this path.

What If the Ground Isn't Flat?

In the preceding discussion, antenna radiation patterns were computed for antennas located over *flat ground*. Things get much more complicated when the exact local terrain surrounding a tower and antenna are taken into account. In the last few years, sophisticated ray-tracing computer models have become available that can calculate the effect that local terrain has on the elevation patterns for real-world HF installations—and *each* real-world situation is indeed different.

For simplicity, first consider an antenna on the top of a hill with a constant slope downward. The general effect is to lower the effective elevation angle by an amount equal to the downslope of the hill. For example, if the downslope is –3° for a long distance away from the tower and the flat-ground peak elevation angle is 10° (due to the height of the antenna), then the net result will be 10° – 3° = 7° peak angle. However, if the local terrain is rough, with many bumps and valleys in the desired direction, the response can be modified considerably. **Fig 8** shows the fairly complicated terrain profile for Jan Carman, K5MA, in the direction of Japan. Jan is located on one of the tallest hills in West Falmouth, Massachusetts. Within 500 feet of his tower is a small hill with a water tower on the top, and then the ground quickly falls away, so that at a distance of about 3000 feet from the tower base, the elevation has fallen to sea level, at 0 feet.

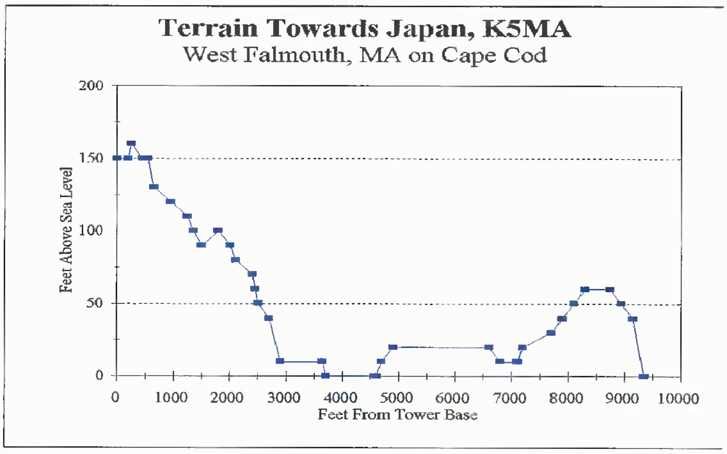

Fig 8—Terrain profile from location of K5MA, Jan Carman, in West Falmouth, MA, towards Japan. This is a moderately complicated real-world terrain on one of the highest hills on Cape Cod.

The computed responses toward Japan from this location, using a 120- and a 70-foot high Yagi, are shown in **Fig 9**, overlaid for comparison with the response for a 120-foot Yagi over flat ground. Over this particular terrain, the elevation pattern for the 70-foot antenna is actually better than that of the 120-foot antenna for angles below about 3°, but not for medium angles! The responses for each height oscillate around the pattern for flat ground — all due to the complex reflections and diffractions occurring off the terrain.

At an elevation angle of 5°, the situation reverses itself and the gain is now higher for the 120-foot-high antenna than for the 70-foot antenna. A pair of antennas on one tower would be required to cover all the angles properly. To avoid any electrical interactions between similar antennas on one tower, two towers would be much better. Compared to the flat-ground situation, the responses of real-world antenna can be very complicated due to the interactions with the local terrain.

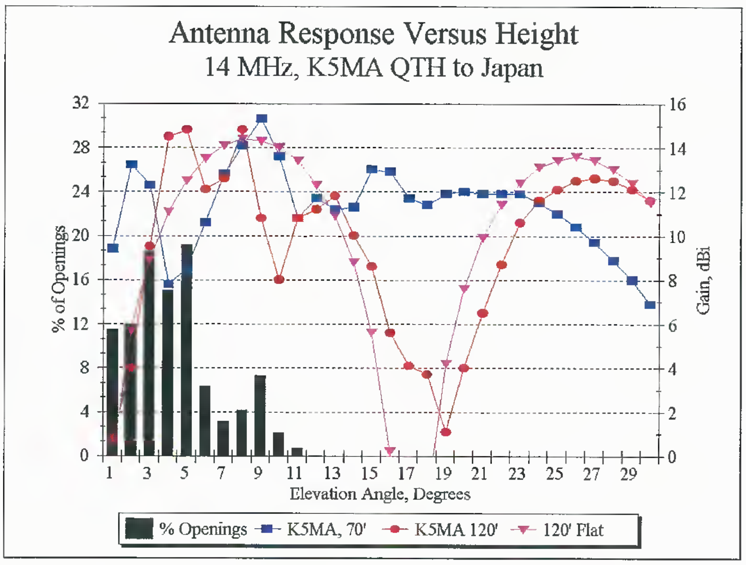

Fig 9—Computed elevation responses of 120- and 70-foot high Yagis, at the K5MA location on Cape Cod, in the direction of Japan and over flat ground, for comparison. The elevation response of the real-world antenna has been significantly modified by the local terrain.

Fig 10 shows the situation for the same Cape Cod location, but now for 7 MHz. Again, it is clear that the 120-foot high Yagi is superior by at least 3 dB (equivalent to twice the power) to the 70-foot high antenna at the statistical elevation angle of 6°. However, the response of the real-world 120-foot high antenna is still up some 2 dB from the response for an identical antenna over flat ground at this angle. On this frequency, the local terrain has helped boost the gain at the medium angles more than a similar antenna 120 feet over flat ground. The gain is even greater at lower angles, say at 1° elevation, where most signals take off, statistically speaking. Putting the antenna up higher, say 150 feet, will help the situation at this location, as would adding an additional Yagi at the 70-foot level and feeding both antennas in phase as a vertical stack.

Although the preceding discussion has been in terms of the transmitting antenna, the same principles apply when the antenna is used for reception. A high antenna will receive low-angle signals more effectively than will a low antenna. Indeed, amateur operators know very well that "If you can't hear them, you can't talk to them." Stations with tall towers can usually hear far better than their counterparts with low installations.

The situation becomes even more difficult for the next lowest amateur band at 3.5 MHz, where optimal antenna heights for effective long-range communication become truly heroic! Towers that exceed 120 feet are commonplace among amateurs wishing to do serious 3.5-MHz long-distance work.

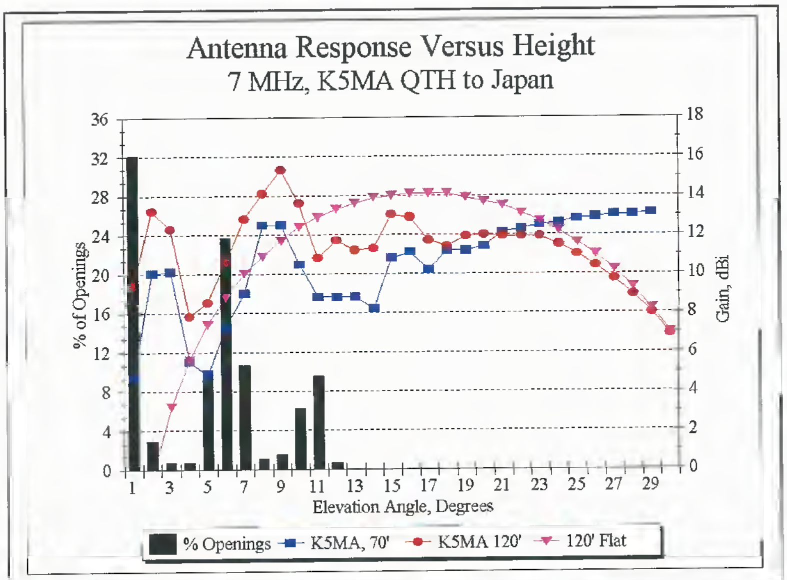

Fig 10—Elevation response on 7 MHz from K5MA location towards Japan on 7 MHz. The 120-foot high Yagi is definitely superior to the one only 70-feet high.

The 3.5 and 7-MHz amateur bands are, however, not always used strictly for long-range work. Both bands are crucial for providing communications throughout a local area, such as might be necessary in times of a local emergency. For example, earthquakes, tornadoes and hurricanes have often disrupted local communications—because telephone and power lines are down and because local police and fire-department VHF/UHF repeaters are thus knocked out of action. Radio amateurs often will use the 3.5 and 7-MHz bands to provide communications out beyond the local area affected by the disaster, perhaps into the next county or the next metropolitan area. For example, an earthquake in San Francisco might see amateurs using emergency power providing communications through amateurs in Oakland across the San Francisco Bay, or even as far away as Los Angeles or Sacramento. These places are where commercial power and telephone lines are still intact, while most power and telephones might be down in San Francisco itself. Similarly, a hurricane that selectively destroys certain towns on Cape Cod might find amateurs in these towns using 3.5 or 7.0 MHz to contact their counterparts in Boston or New York.

However, in order to get the emergency messages through, amateurs must have effective antennas. Most such relatively local emergency situations require towers of moderate height, less than about 100 feet tall typically.

Antenna Height and Interference

Extensive Federal Regulations cover the subject of interference to home electronic devices. It is an unfortunate fact of life, however, that many home electronic devices (such as stereos, TVs, telephones and VCRs) do not meet the Federal standards. They are simply inadequately designed to be resistant to RF energy in their vicinity. Thus, a perfectly legal amateur-radio transmitter may cause interference to a neighbor's VCR or TV because cost-saving shortcuts were taken in the design and manufacture of these home entertainment devices. Unfortunately, it is difficult to explain to an irate neighbor why his brand-new $1000 stereo is receiving the perfectly legitimate transmissions by a nearby radio operator.

The potential for interference to any receiving device is a function of the transmitter power, transmitter frequency, receiver frequency, and most important of all, the proximity of the transmitter to the potential receiver. The transmitted field intensity decreases as the inverse square of the distance. This means that doubling the height of an antenna from 35 to 70 feet will reduce the potential for interference by 75%. Doubling the height again to 140 feet high would reduce the potential another 75%. Higher is better to prevent interference in the first place!

Recently enacted Federal Regulations address the potential for harm to humans because of exposure to electromagnetic fields. Amateur-radio stations rarely have problems in this area, because they use relatively low transmitting power levels and intermittent duty cycles compared to commercial operations, such as TV or FM broadcast stations. Nevertheless, the potential for RF exposure is again directly related to the distance separating the transmitting antenna and the human beings around it. Again, doubling the height will reduce potential exposure by 75%. The higher the antenna, the less there will any potential for significant RF exposure.

THE WORLD IS A VERY COMPLICATED PLACE

It should be pretty clear by now that designing scientifically valid communication systems is an enormously complex subject. The main complications come from the vagaries of the medium itself, the Earth's ionosphere. However, local terrain can considerably complicate the analysis also.

The main points of this paper may be summarized briefly:

> **The radiation elevation angle is the key factor determining effective communication distances beyond line-of-sight. Antenna height is the primary variable under control of the station builder, since antenna height affects the angle of radiation.**
>
> **In general, placing an amateur antenna system higher in the air enhances communication capabilities and also reduces chances for electromagnetic interference with neighbors.**

Submission on Plan Change 26 - Minor Amendments to the Marlborough Sounds Resource Management Plan

MARLBOROUGH DISTRICT COUNCIL

RECEIVED
21 DEC 2012
MARLBOROUGH DISTRICT COUNCIL

Submissions close 5.00 pm Friday, 21 December 2012

1. Submitter Details

Full Name: RICHARD WARWICK EVANS

Organisation (*if applicable*):

Contact Person (*if applicable*):

Postal Address: 40 Percy St
Blenheim

Post Code:

Email:

Telephone *Business*:   *Home*:

Fax: *Mobile*: 021 648783

Address for Service (*if different from above*): 40 Percy St
Blenheim

Post Code:

Signature (*of submitter or person authorised to sign on behalf of submitter*):

Date: 21-12-2012

2. Trade Competition

Could you gain an advantage in trade competition in making this submission? ☐ Yes ☐ No

If you answered yes, pelase note that there are restrictions on your ability to make a submission. Refer to Clause 6(4) of the First schedule of the RMA for further information.

3. Council Hearing

Do you wish to be heard in support of your submission? ☑ Yes ☐ No

If you answered 'Yes to being heard, would you be prepared to consider presenting a joint joint case with others who have made a similar submission? ☑ Yes ☐ No

4. Return Submission to:

Attention Planning Technician
Marlborough District Council
PO Box 443
Blenheim 7240

Fax: 520 7496

Email: pc61@marlborough.govt.nz

For Office Use
Submission No: 12

5. The specific parts of the proposed plan change the submission relates to are as follows:

(1) family flat definition – size limit

(B) Set back from water bodies –

(4.2) Inclusion of Yard Setbacks & easements

(4.3) Access Standards – widths

(7) Limit Home Occupation to 1 person (additional)

(8) Drainage Channels to include 'artificial or other' channels

Continue on a separate sheet if necessary

6. My submission is: *(state the nature of your submission whether you support or oppose (in full or in part) specific provisions)*

(1) Size limit is arbitrarily defined, personal choice is excluded
(2) read with (8) this will significantly restrict owners development choices
(4.2) will restrict subdivision & infill, ~~ebt~~ and reduce choice of development
(4.3) Standards are not representative of real life development & will restrict development.
(7) Single person limit is restrictive & will limit start up businesses
(8) This will massively restrict development throughout the area & will result in significant costs to Marlborough.

Continue on a separate sheet if necessary

7. The decision I seek from Council is: *(where amendments are sought, provide details of what changes you would like to see)*

(1) remove size limit
(2) exclude riparian management from all but large rivers & streams.
(4.2) exclude yard setbacks from rule
(4.3) reduce requirements to realistic widths consistent with NZ standards
(7) remove additional single person limit – match with homestay no 5
(8) remove 'artificial or other' – redefine to only include flowing streams or rivers

Continue on a separate sheet if necessary

Submission on Plan Change 26 - Minor Amendments to the Marlborough Sounds Resource Management Plan

MARLBOROUGH DISTRICT COUNCIL

Submissions close 5.00 pm Friday, 21 December 2012

1. Submitter Details

Full Name: David Muir Mclaren

Organisation *(if applicable)*: McLaren Family Trust

Contact Person *(if applicable)*: David McLaren

Postal Address:
4 Cambria Gardens,
The Wood
Nelson
Post Code: 7 , 0 1
7610

Email: mclaren@ts.co.nz

Telephone *Business*: 35,484,943 *Home*: 35,484,943

Fax: *Mobile*: 210,343,861

Address for Service *(if different from above)*:

Post Code:

Signature *(of submitter or person authorised to sign on behalf of submitter)*: D Mc Laren Date: 21-12-12

2. Trade Competition

Could you gain an advantage in trade competition in making this submission? ☐ Yes ☑ No

If you answered yes, pelase note that there are restrictions on your ability to make a submission. Refer to Clause 6(4) of the First schedule of the RMA for further information.

3. Council Hearing

Do you wish to be heard in support of your submission? ☐ Yes ☑ No

If you answered 'Yes to being heard, would you be prepared to consider presenting a joint joint case with others who have made a similar submission? ☐ Yes ☐ No

4. Return Submission to:

Attention Planning Technician
Marlborough District Council
PO Box 443
Blenheim 7240

Fax: 520 7496

Email: pc61@marlborough.govt.nz

For Office Use
Submission No: 13

5. The specific parts of the proposed plan change the submission relates to are as follows:

Proposed plan change 26
It would appear that with the introduction of s68A of the RMA1991 a change has to be made.
As an owner of marine farms and a harvesting entity also we would have concerns as to how the rule change would apply to discharges and how to quantify such discharges given that pumps vary and the amounts harvested vary from site to site.
The proposed change may just add another grey area to grapple with.
We also have farms with additions and the consents vary so a problem will arise from one part of the site to the next when harvesting and applying for a variation to harvest.

Continue on a separate sheet if necessary

6. My submission is: *(state the nature of your submission whether you support or oppose (in full or in part) specific provisions)*

We oppose any change to the status quo but accept that council has to accommodate the vagaries of the law makers.
All we can ask that council come up with a clear guideline that covers all marine farms and all the individual variations to the farm consents and licences that does not impose another grey area and another layer of paper to deal with.

Continue on a separate sheet if necessary

7. The decision I seek from Council is: *(where amendments are sought, provide details of what changes you would like to see)*

WE would ask that council limit the need to seek any type of consent to harvest the product from marine farms.
Should any change be necessary we would ask that it be a controlled activity with an industry code of conduct in place.

Continue on a separate sheet if necessary

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- 3 JAN 2013
MARLBOROUGH
DISTRICT COUNCIL

Submission on Plan Change 26 - Minor Amendments to the Marlborough Sounds Resource Management Plan

MARLBOROUGH
DISTRICT COUNCIL

Submissions close 5.00 pm Friday, 21 December 2012

1. Submitter Details

Full Name

Organisation (*if applicable*) Guernsey Road Residents Association Incorporated

Contact Person (*if applicable*)

Postal Address C/- M Leigh-Lancaster
93 Guernsey Road R D 1
BLENHEIM 7271 Post Code

Email teddimontaldo@hotmail.com

Telephone *Business* *Home*

Fax *Mobile*

Address for Service
(if different from above)
Post Code

Signature *(of submitter or person authorised to sign on behalf of submitter)* [illegible] [illegible] and [illegible] authorised agent Date 21/12/12

2. Trade Competition

Could you gain an advantage in trade competition in making this submission? ☐ Yes ☑ No

If you answered yes, pelase note that there are restrictions on your ability to make a submission. Refer to Clause 6(4) of the First schedule of the RMA for further information.

3. Council Hearing

Do you wish to be heard in support of your submission? ☑ Yes ☐ No

If you answered 'Yes to being heard, would you be prepared to consider presenting a joint joint case with others who have made a similar submission? ☑ Yes ☐ No

4. Return Submission to:

Attention Planning Technician
Marlborough District Council
PO Box 443
Blenheim 7240

Fax: 520 7496

Email: pc61@marlborough.govt.nz

For Office Use
Submission No: 14

5. The specific parts of the proposed plan change the submission relates to are as follows:

Item 6 - Deletion of the definition of "Wineries" and replacement of the definition with the term Winery and a new definition for Winery.

Continue on a separate sheet if necessary

6. My submission is: ***(state the nature of your submission whether you support or oppose (in full or in part) specific provisions)***

We are opposed to the change to the definition of winery.
The definition of wineries should not be amended as proposed without comprehensive consideration of the wider effects of industrial activities located or established in the Rural Zone and in the rural environment. Furthermore the appropriate location for industrial activities is the Industrial Zone.

That any amendments have proper regard to the implications of industrial activities including water use, waste and other discharges, traffic, noise, lighting and the other effects from those activities which are incompatible with the Rural Zones and the rural environment.

The Section 32 evaluation is incorrect when it refers to an evaluation of the proposed in particular it refers to wineries as a "permitted activity". It does not address the obvious option of waiting for the pending Plan review and gives a proper justification for implementing an ad hoc change now in the absence of a comprehensive review.

The definition as proposed does not make sense in particular the phrase "or juice from the subsequent production of wine".

Continue on a separate sheet if necessary

7. The decision I seek from Council is: ***(where amendments are sought, provide details of what changes you would like to see)***

-Decline to make the proposed deletion of the definition of wineries and replace it with the new definition of "Winery" as proposed.
-Alternatively consider amendment of the definition of wineries and for a new definition to limit the size and scale of facilities to ensure that conflict in the rural environment between industrial facilities and those activities that occur in the Rural Zone are minimised.
- Require the location of industrial activities into the industrial zone where appropriate services including water and effluent disposal services can be provided.
- Limit the size and scale of such facilities to a scale of activity consistent with the receiving rural environment and ensure that adverse effects are avoided. Such adverse effects include significant effects on rural amenity and character, productive soils from inappropriately located industrial facilities contracted to process wine.
-Exclude bottling and consequential activities from the definition of processing.
-Exclude the processing of juice previously crushed or processed off site from the definition.

Continue on a separate sheet if necessary

Marlborough District Council
Marlborough Sounds Resource Management Plan Change No 26
&
Wairau/Awatere Resource Management Plan Change No 61

By

Royal Forest and Bird Protection Society NZ (Inc), Central Office
(incorporating Marlborough branch)

Contact Person:	Debs Martin
Address:	PO Box 266, Nelson 7040
Phone:	03-989-3355
Email:	d.martin@forestandbird.org.nz

The Royal Forest and Bird Protection Society Incorporated ("Forest and Bird") has campaigned for nearly 90 years for the protection of New Zealand's native species and the habitats on which they depend. Around 80,000 members and supporters nation wide support the Society's objectives of secure protection for native species, ecosystems, and landforms.

The constitutional purpose of Forest and Bird is to:

> *"To take all reasonable steps within the power of the Society for the preservation and protection of the indigenous flora and fauna and natural features of New Zealand, for the benefit of the public including future generations."*

General Comments:

We note these changes are considered minor amendments for consistency. We restrict our submissions therefore to minimal comments and only with respect to issues that are of primary importance to our Society.

1. The specific parts of this Plan that our submission relates to are:	**2. Our submission is that:**	**3. We seek the following decisions:**
Marlborough Sounds RMP Plan Change 26 Item 2 Setback from water bodies	We support the proposed changes for the reasons outlined in the report.	Retain proposed change.
Item 8 Include drainage channels in the rules requiring discharge setbacks from water bodies	We support the proposed changes for the reasons outlined in the report.	Retain proposed change.
Wairau/Awatere RMP Plan Change 61 Item 1 Policy on term of water permits to take and use water	We support the proposed changes for the reasons outlined in the report.	Retain proposed change.
Item 3 Setback from water bodies for reasons other than avoiding flood hazard	We support the proposed changes for the reasons outlined in the report.	Retain proposed change.
Item 8 Include rules for the damming of water	We are neutral on this issue, but see that it is a logical step to include the damming of water as an effect of constructing the dam. However, Council would need to ensure that the consequences of constructing a dam then considered the effects of damming water behind it.	Neutral on proposal for change. If it is changed, ensure factors are present in the plan to consider the effects of damming the water, e.g. inundation effects, riparian, etc.
Item 9 Subdivisions in the Conservation Zone	Support proposed change for reasons outlined.	Retain proposed change.
Item 12 Include drainage channels in the rules requiring discharge setbacks from water bodies	Support proposed change for reasons outlined.	Retain proposed change.

We wish to be heard in support of our submission. Please note that I am on annual leave between 21 December 2012 and 11 February 2013.

Signed: Debs Martin, Regional Field Officer Date: 21 December 2012