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Washoe County District Attorney
Attn: Nathan Edwards, Esq. nedwards@da.washoecounty.us
P. O. Box 1130
Reno, NV 89520

In re Appeal Case Number WBLD17-101171 (Richard Stone),
4675 Giles Way, Washoe Valley, NV 89704

Dear Atty. Edwards:

I am informed that you are the attorney consulted by the County's Planning and Development Office, as well as the Board of Adjustment, in matters such as the one that causes me to write to you today. If I am misinformed, please forward this letter to the appropriate lawyer, and please let me know with whom I should correspond.

I write to you about an Appeal of an Administrative Decision for a Building Permit. The Board of Adjustment Staff Report on this matter, prepared by Trevor Lloyd, Senior Planner, 775.328.3620, tlloyd@washoecounty.us, is attached.

To avoid questions on the matter, I am not admitted to practice law in Nevada and I participate here as a lawyer "representing a client, on an occasional basis and not as part of a regular or repetitive course of practice in this jurisdiction, in [an area] governed primarily by federal law." Nevada Rules of Professional Conduct, Rule 5.5(b)(6). The relevant federal law is 47 CFR § 97.15(b), referenced in NRS 278.02085 at ¶ 1.

Background

The applicant, Mr. Stone, my client, proposes to erect an amateur radio antenna system at his home on 1.55 acres in the LDS (Low Density Suburban) zone, based on an antenna support structure with a retractable to a total height, including antennas, of 43 feet. The bordering property to the West is 2,930 acres of undeveloped, unoccupied, wetlands owned by the State of Nevada. In other directions, to the South, the property is 10 acres of unimproved, unoccupied, sagebrush and lake, and to the East, 1.5 acres of undeveloped land owned by Bianca Daykin, from whom a letter of support is attached as Exhibit B1. To the North, there is an unimproved lot of 1.71 acres, with a half-acre pond. The proposed use is not a commercial use.

The Staff Report states:

> Staff interprets [Washoe County Code (WCC) Section 110.3234.20] to read that any time a private communication antenna exceeds 45 feet tall in the LDS regulatory zone, the owner or applicant is required to obtain approval of an administrative permit prior to the issuance of a building permit, regardless of whether the antenna is retractable or not.
>
> It is possible that Washoe County may have approved retractable antennas that extend beyond 45 feet tall without an administrative permit in the past; however, staff was unable to find any such recent permits.

WCC § 110.3234.20 reads:

> **Section 110.324.20 Private Communication Antennas: General.** Private communication antennas, including antenna support structures, are allowed as accessory uses in all regulatory zones pursuant to the provisions of this article. (a) Height. The retractable height of a private communication antenna is limited to the height limitation of a main structure allowed in the regulatory zone in which the antenna is erected with a bonus of up to ten (10) feet.

Stone's Positions

Mr. Stone wishes to call to your attention several things about the Staff's position that an Administrative Permit will be required.

The Division's interpretation is novel. While staff was unable to find permits granted under the interpretation Mr. Stone puts forward, we wish to call your attention to the following permits, all issued under the interpretation urged here:

1. Craig M. Sande, MD, 4284 Ross Drive, Reno 89519; Permit # 04-1828
2. Richard P. Hallman, 10275 Pathfinder Drive, Reno 89508; Permit # 04-3872
3. Ira Stoller, 1700 Taos Lane, for APN: 142-260-18, Reno 89519; Permit # 15-0512

Please note that each of these permits was issued AFTER the effective date of § 110.324.20, which was 7/23/2004.

The Division's interpretation defies standard statutory interpretation. Essentially, the ordinance reads: "The retractable height of a private communication antenna is limited to [45 feet.]" This sentence is not in question.

What is in question is staff's interpretation that 45 feet is the maximum, **"regardless of whether the antenna is retractable or not."** Staff Report at 3. (Emphasis added.) In other words, the Staff's position is that the word retractable is superfluous.

Mr. Stone's position is that staff is not allowed to disregard the plain wording of the ordinance. If he presents a proposal for a private communication antenna where the retractable height . . . is limited to [45 feet], he is entitled to a building permit, as a matter if law – which is why I write to you.

Nevada law does not allow Staff to disregard wording, in essence declaring that the word "retractable" is nugatory, not present, has no meaning, and may be ignored. This violates the basic rule of statutory interpretation that holds that statutes "must be construed as a whole and not be read in a way that would render words or phrases superfluous or make a provision nugatory." *Butler v. State*, 120 Nev. 879, 892-93, 102 P.3d 71, 81 (2004) (internal quotations omitted). "

Nevada "avoids statutory interpretation that renders language meaningless or superfluous." *Karcher Firestopping v. Meadow Valley Contr.*, 125 Nev. 111, 113, 204 P.3d 1262, 1263 (2009).

Why is Mr. Stone so concerned?

The Staff's position is that the applicant need merely file to obtain an Administrative Permit pursuant to Article 808. However, it is important to understand that amateur radio is a radio service without pecuniary interest, § 47 CFR § 97.113[1], and this is just a backyard antenna. It is an ordinary accessory use. Yet Article 808 sets forth material additional burdens to an Applicant's process:

---

[1] Sec. 97.113 Prohibited transmissions.

(a) No amateur station shall transmit:
(1) Communications specifically prohibited elsewhere in this part;
(2) Communications for hire or for material compensation, direct or indirect, paid or promised, except as otherwise provided in these rules;
(3) Communications in which the station licensee or control operator has a pecuniary interest, including communications on behalf of an employer. Amateur operators may, however, notify other amateur operators of the availability for sale or trade of apparatus normally used in an amateur station, provided that such activity is not conducted on a regular basis;
(4) Music using a phone emission except as specifically provided elsewhere in this section; communications intended to facilitate a criminal act; messages in codes or ciphers intended to obscure the meaning thereof, except as otherwise provided herein; obscene or indecent words or language; or false or deceptive messages, signals or identification;
(5) Communications, on a regular basis, which could reasonably be furnished alternatively through other radio services.
(b) An amateur station shall not engage in any form of broadcasting,
nor may an amateur station transmit one-way communications except as specifically provided in these rules; nor shall an amateur station engage in any activity related to program production or

- It will require a determination that the project is not of regional significance.
- It will require a showing that the proposed use is consistent with the Master Plan.
- It will require a showing that there are adequate utilities, roadway improvements, sanitation, water supply, drainage, and other necessary facilities.
- It will require a showing that the project is properly related to existing and proposed roadways.
- It will require that the Applicant secure a determination that there are adequate public facilities in accordance with Division Seven.
- It will require a showing that the site is physically suitable for a ham radio antenna structure.
- It will require a showing that the amateur radio antenna structure will not be significantly detrimental to the public health, safety or welfare; injurious to the property or improvements of adjacent properties; or detrimental to the character of the surrounding area.
- And it will require a public hearing, requiring notice to at least 30 property owners, and any relevant advisory boards,

These burdens, when put together, fail the requirement of NRS 278.02085 that an ordinance must constitute "the minimum level of regulation practicable." *None of these things was required when the three previous building permits (since the 2004 ordinance) were granted.*

Cost. I am informed that the filing fee for an Administrative Permit pursuant to Article 808 is $1,000. With regard to this fee, the FCC has written:

> an amateur operator may apprise a zoning authority that a permit fee is too high, and therefore unreasonable, or that a condition is more than minimum regulation, and, therefore, impracticable to comply with.

FCC ORDER ON RECONSIDERATION, RM 8763 (Adopted 11/13/2000) http://wireless.fcc.gov/services/index.htm?job=prb-1&id=amateur&page=3, at ¶7 (*emphasis added*).

In addition to the cost, the additional burdens of Article 808 fail to meet the requirements of NRS 278.02085(2)(b), and 47 CFR § 97.15(b), each of which

news gathering for broadcasting purposes, except that communications directly related to the immediate safety of human life or the protection of property may be provided by amateur stations to broadcasters for dissemination to the public where no other means of communication is reasonably available before or at the time of the event.

requires that the County's regulation **must** "constitute minimum level of regulation practicable to carry out the legitimate purpose of the governing body."

The Nevada statute further continues at ¶ 4, "Any ordinance, regulation or plan adopted by or other action taken by a governing body in violation of the provisions of this section is void."

The impact of NRS 278.02085, and its federal counterpart, 47 CFR ¶ 97.15(b), including its implementing FCC Reports and Orders, is that Article 808 is **not** the minimum level of regulation practicable (and we have three example proofs of previous permits where, one may suppose, it was practicable), and is void, resulting in no height limit.

Summary. The difference between the grant of a building permit under § 110.324.20, and an administrative permit under Article 808, is that a proper application under § 110.324.20 should be granted as of right. In contrast, an administrative permit under Article 808 is discretionary, costly, subject to notice to at least 30 property owners, requires a public hearing, and findings that are more than "minimum regulation," well beyond the reasonable scope of regulation for a homeowner seeking a permit for a backyard accessory amateur radio station antenna structure.

Assurance. I do not know why staff has changed its approach to a § 110.324.20 application in this case, and invented a new interpretation that defies the wording of the ordinance. But I do know that the applicant, Mr. Stone, would be pleased to provide submissions that respond to the Department's concerns (seen in § 110.324.30) that:

(1) The height of the private communication antenna support structure is necessary to receive or transmit a signal that meets the applicant's needs; and

(2) The height of the private communication antenna support structure shall be in compliance with all Federal Communications Commission (FCC) and Federal Aviation Administration (FAA) regulations.

Request. Attached as Exhibits to this letter is the documentation to show that the height of the antenna support structure is necessary, and that the height shall be in compliance with all FCC and FAA regulations. I ask that you provide guidance to the Planning and Development Office on the questions of law mentioned above - that the word retractable may not be regarded as superfluous, and that an Article 808 administrative permit is not the minimum practicable regulation, so that Staff may issue a building permit. The hearing now scheduled for October 5, 2017 should not go forward because, as a matter of law, not discretion, Mr. Stone is entitled to a building permit under WCC § 110.3234.20.

I look forward to your response.

Sincerely,

Fred Hopengarten, Esq.

C:

Washoe County District Attorney
Attn: Paul Liparelli, Esq. — Phone: 773.328.3200
Mills B. Lane Justice Center — pliparellii@da.washoecounty.us
1 South Sierra Street
Reno, NV 89501

Board of Adjustment — Phone: 775.815.8247
Attn: Kim Toulouse, Chairman — ktoulouse@washoecounty.us

Planning and Development
Attn: Mojra Hauenstein, — mhauenstein@washoecounty.us
Division Director
1001 East Ninth St.
Reno NV 89520

Planning and Development
Attn: Trevor Lloyd, Senior Planner — Phone: 775.328.3620
Washoe County Community Services Department
Planning and Building Division — tlloyd@washoecounty.us

Richard Stone, KD6BQ — KD6BQ@att.com
4765 Giles Way
Washoe Valley, NV 89704

Exhibits

A. Board of Adjustment Staff Report, dated July 11, 2017
B. Letters of Support for the amateur radio station antenna structure. From:
   -- 4755 Giles Way (Exhibit B1)
   -- 4750 Giles Way (Exhibit B2)
   -- 4730 Giles Way (Exhibit B3)
   -- 4710 Giles Way (Exhibit B4)
C. FCC TOWAIR Report showing that the height complies with all FCC and FAA regulations

D. Propagation Maps demonstrating that the height proposed is necessary to meet the Applicant's needs, prepared by Dennis Egan

E. Antenna Height and Communications Effectiveness, 2d. Ed., Straw and Hall

EXHIBIT A

Board of Adjustment Staff Report dated July 11, 2017

Board of Adjustment Staff Report

Meeting Date: August 3, 2017

Subject:	Appeal of Administrative Decision for Building Permit Number WBLD17-101171
Appellant:	Richard Stone
Agenda Item Number:	**9A**
Project Summary:	Appeal of the administrative decision by the Director of the Planning and Building Division to reject a building permit for Richard Stone
Recommendation:	**Denial**
Prepared by:	Trevor Lloyd, Senior Planner Washoe County Community Services Department Planning and Building Division
Phone:	775.328.3620
E-Mail:	tlloyd@washoecounty.us

Description

Appeal Case Number WBLD17-101171 (Richard Stone) – For possible action, hearing, and discussion on an appeal of the Planning and Building Division Director's decision to deny a building permit application for a retractable private communication antenna taller than 45-feet tall. The antenna was proposed to be retractable, and was less than 45 feet tall in its retracted mode, but the antenna could be raised up to 72-feet tall when fully extended.

- Owner/Appellant: Richard Stone
- Location: 4765 Giles Way
- Assessor's Parcel Number: 050-530-30
- Parcel Size: ±1.55 acres
- Master Plan Category: Suburban Residential (SR)
- Regulatory Zone: Low Density Suburban (LDS)
- Area Plan: South Valleys
- Citizen Advisory Board: South Truckee Meadows/Washoe Valley
- Development Code: Authorized in Article 912, Establishment of Commissions, Boards and Hearing Examiners
- Commission District: 2 – Commissioner (Lucey)
- Section/Township/Range: Section 31, T17N, R20E, MDM, Washoe County, NV

Staff Report Contents

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Exhibits Contents

Appeal Application/Letter dated May 18, 2017 and appeal materials ....Exhibit A

Background

On May 2, 2017, Mr. Richard Stone submitted plans to the Washoe County Building and Safety Division (the Division merged into the current Planning and Building Division on July 1, 2017) for a retractable private communication antenna on a 1.55 acre residential property at 4765 Giles Way. The plans were denied by the Planning and Development Division staff because the antenna/tower, when extended to its full height of 72-feet, exceeds the maximum allowable height of 45 feet for a private communication antenna. The code allows private antennas to exceed 45 feet with the approval of an administrative permit.

Washoe County Code (WCC) Section 110.3234.20 limits the height for private communication facilities. The height limitation for main structures in the Low Density Suburban (LDS) regulatory zone district is 35 feet and the 10 foot bonus is allowed for private antennas. Therefore, the allowable height for a private communication antenna on Mr. Stone's property is 45 feet. WCC Section 110.324.30 allows additional height with the granting of an administrative permit. Staff interprets this section of code to read that any time a private communication antenna exceeds 45 feet tall in the LDS regulatory zone, the owner or applicant is required to obtain approval of an administrative permit prior to the issuance of a building permit, regardless of whether the antenna is retractable or not.

Mr. Stone also contends that federal and state law requires the county to allow his tower in this case. In state law, NRS 278.02085 imposes limitations on the ability to regulate amateur radio communications towers. In essence, it says, the county cannot “preclude” amateur service communications, and that the county’s regulations must comply with 47 C.F.R. 97.156 and a 1985 FCC interpretation (FCC 85-506, PRB-1). A pdf copy of the FCC ruling can be found at the following address: http://www.arrl.org/files/file/prb-1.pdf. The National Association for Amateur Radio webpage includes a summary which says that its interpretation of the FCC’s memo is that local authorities may still “zone for height, safety, and aesthetics concerns.” The association’s webpage can be found at: http://www.arrl.org/prb-1.

As to regulations of a station antenna structure that are based on health, safety or aesthetic considerations, they must “reasonably accommodate amateur service communications” and “constitute the minimum level of regulation practicable to carry out the legitimate purpose of the governing body.” However, the FCC ruling in question specifically avoids imposing a black-and-white rule about antenna height, leaving that to the discretion of the local authorities. But the FCC did point out that height restrictions do directly affect amateur communications and indicated that any height restrictions must be based on a legitimate government interest.

> **Section 110.324.20 Private Communication Antennas: General.** Private communication antennas, including antenna support structures, are allowed as accessory uses in all regulatory zones pursuant to the provisions of this article.
>
> (a) Height. The retractable height of a private communication antenna is limited to the height limitation of a main structure allowed in the regulatory zone in which the antenna is erected with a bonus of up to ten (10) feet.
>
> **Section 110.324.30 Private Communication Antennas: Additional Height.** A private communication antenna support structure may exceed the height restrictions within this article if an administrative permit is obtained pursuant to Article 808, Administrative Permits, and in accordance with the provisions of this section.

The appellant, Richard Stone, has filed an appeal of staff’s decision. Mr. Stone contends that the code allows private communication antennas to be taller than 45 feet tall when the antenna retracts to a height below 45 feet tall. Mr. Stone also contends that the code has not been interpreted consistently and that other retractable towers have been permitted taller than 45 feet tall. It is Mr. Stone's position that an administrative permit should not be required because Washoe County has changed its interpretation of code and has allowed for retractable towers to extend beyond 45 feet tall when they retract below 45 feet in height. It is possible that Washoe County may have approved retractable antennas that extend beyond 45 feet tall without an administrative permit in the past; however, staff was unable to find any such recent permits. The complete appeal is attached as Exhibit A to this staff report.

Pursuant to WCC Section 110.912.10(j)(iv), the Board of Adjustment hears any appeal of a decision of the Director of the Planning and Building Division made in the course of administration of any zoning regulation or any regulation relating to the location or soundness of structures if the decision cannot be appealed to an administrative hearing officer. The appellant is exercising his right to appeal the decision of the Director to deny his building permit based on the administration of a zoning regulation.

Recommendation

After a thorough analysis and review, the Appeal for Building Permit Number WBLD17-101171 is being recommended for denial. Staff offers the following motion for the Board's consideration.

Motion

I move that, after giving reasoned consideration to the information contained in the staff report and information received during the public hearing, the Washoe County Board of Adjustment deny Appeal of Building Permit Number WBLD17-101171 for Richard Stone and affirm the decision by the Director of the Planning and Building Division to reject a building permit for a private retractable antenna taller than 45 feet tall at 4765 Giles Way.

Appeal Process

Board of Adjustment action will be effective 10 calendar days after the written decision is filed with the Secretary to the Board of Adjustment and mailed to the original applicant, unless the action is appealed to the Washoe County Board of County Commissioners, in which case the outcome of the appeal shall be determined by the Washoe County Board of County Commissioners. Any appeal must be filed in writing with the Planning and Building Division within 10 calendar days after the written decision is filed with the Secretary to the Board of Adjustment and mailed to the original applicant.

Appellant: Richard Stone
4765 Giles Way
Washoe Valley, NV 89704

Exhibit B1

Bianca Daykin
4755 Giles Way
Washoe Valley NV 89704

September 22, 2017

The Board of Adjustment
Washoe County
Reno, NV

Ladies and Gentlemen:

I live next door to the Stone family, who are at 4765 Giles Way. Mr. Stone has explained his antenna project to me, and has satisfactorily answered all of my questions about it.

I support the granting of a permit for additional height of his antenna support structure, and I encourage the Board to do so.

I see great value in having radio hams in this County, When all else fails, radio hams can still provide communications.

Sincerely,

Bianca Daykin

C: Richard Stone

Exhibit B2

Bruce and Annette Miller
4750 Giles Way
Washoe Valley NV 89704

September 22, 2017

The Board of Adjustment
Washoe County
Reno, NV

Ladies and Gentlemen:

I live next door to the Stone family, who are at 4765 Giles Way. Mr. Stone has explained his antenna project to me, and has satisfactorily answered all of my questions about it.

I have no objection to the granting of a permit for his antenna support structure to him, and I encourage the Board to do so.

I see great value in having radio hams in this County, When all else fails, radio hams can still provide communications.

Sincerely,

Bruce and Annette Miller

C: Richard Stone

Exhibit B3

Eric and Mackenzie Yount
4730 Giles Way
Washoe Valley NV 89704

September 22, 2017

The Board of Adjustment
Washoe County
Reno, NV

Ladies and Gentlemen:

I live down the street from the Stone family, who are at 4765 Giles Way. Mr. Stone has explained his antenna project to me, and has satisfactorily answered all of my questions about it.

I support the granting of a permit for additional height of his antenna support structure and I encourage the Board to do so.

I see great value in having radio hams in this County, When all else fails, radio hams can still provide communications.

Sincerely,

Eric Yount Mackenzie Yount

Eric and Mackenzie Yount

C: Richard Stone

Exhibit B4

Ruth Ackley
4710 Giles Way
Washoe Valley NV 89704

September 15, 2017

The Board of Adjustment
Washoe County
Reno, NV

Ladies and Gentlemen:

I live down the street from the Stone family, who are at 4765 Giles Way. Mr. Stone has explained his antenna project to me, and has satisfactorily answered all of my questions about it.

I Support the granting of a permit for additional height for his antenna support structure, and I encourage the Board to do so.

I see great value in having radio hams in this County, When all else fails, radio hams can still provide communications.

Sincerely,

Ruth Ackley

C: Richard Stone

Exhibit C

FCC TOWAIR Report showing that the height complies with all FCC and FAA regulations

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The TOWAIR Report that follows may be replicated by entering data at
http://wireless2.fcc.gov/UlsApp/AsrSearch/towairSearch.jsp

Antenna Structure Registration

TOWAIR Determination Results

***** NOTICE *****

TOWAIR's findings are not definitive or binding, and we cannot guarantee that the data in TOWAIR are fully current and accurate. In some instances, TOWAIR may yield results that differ from application of the criteria set out in 47 C.F.R. Section 17.7 and 14 C.F.R. Section 77.13. A positive finding by TOWAIR recommending notification should be given considerable weight. On the other hand, a finding by TOWAIR recommending either for or against notification is not conclusive. It is the responsibility of each ASR participant to exercise due diligence to determine if it must coordinate its structure with the FAA. TOWAIR is only one tool designed to assist ASR participants in exercising this due diligence, and further investigation may be necessary to determine if FAA coordination is appropriate.

DETERMINATION Results

Structure does not require registration. There are no airports within 8 kilometers (5 miles) of the coordinates you provided.

Your Specifications

NAD83 Coordinates

Latitude	39-17-52.1 north
Longitude	119-47-20.7 west

Measurements (Meters)

Overall Structure Height (AGL)	28
Support Structure Height (AGL)	22
Site Elevation (AMSL)	1536

Structure Type

LTOWER – Lattice Tower

Federal Communications Commission
445 12th Street SW
Washington, DC 20554

Phone: 1-877-480-3201
TTY: 1-717-338-2824

In accordance with Section 110.324.00 Purpose, I am pleased to verify that the proposed installation will be "consistent with applicable directives and standards issued by the Federal Communications Commission (FCC), the Federal Aviation Administration (FAA) and contained within Nevada Revised Statutes (NRS)."

Source: wireless2.fcc.gov/UlsApp/AsrSearch/towairSearch.jsp

To convert decimal locations to degrees, minutes and seconds: https://www.fcc.gov/media/radio/dms-decimal

Exhibit D

Propagation Maps demonstrating that the height proposed is necessary to meet the Applicant's needs, prepared by Dennis Egan

Showing of Need for Height

of an Amateur Radio Antenna Support Structure

with Propagation Maps

Submitted on Behalf of
Richard Stone, KD6BQ
4765 Giles Way
Washoe Valley, NV 89704

September 28, 2017

Prepared by

Dennis G. Egan, B.S. Mathematics (Computer Science)
166 Wilson Street
Marlborough, MA 01752
w1ue@arrl.net

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Executive Summary

The purpose of this report is to show the need for an antenna system of sufficient height and dimension to provide reliable High Frequency (HF), or 'shortwave', communications, under the changing variables that impact Amateur Radio communications. It was prepared for Richard Stone, amateur radio call sign KD6BQ, located in Washoe Valley, NV.

As described to me by Mr. Stone, under local ordinance he can erect an antenna structure up to 45 feet tall; as he does not feel that is adequate for his needs, he has requested that he be allowed to erect an antenna structure 75 feet tall. Those are then the two heights used for this study.

Target Areas:	France (35 degree heading), Australia (223 deg heading), and American Samoa (223 degree heading)
Target Frequencies:	14 MHz and 7 MHz
Antennas:	3 element Yagi antenna for 14 MHz, 2 element Yagi antenna for 7 MHz

It is the conclusion of this report that this 75-foot structure height – which ideally should be significantly taller – is an acceptable compromise, adequate only for the modest needs of the amateur radio operator applicant, when measured against commonly used engineering metrics.

An antenna structure of 45 feet for this specific high frequency (HF) antenna and location results in reduced performance which cannot meet the needs of the amateur radio operator when measured against commonly used engineering metrics.

Outline

This report is organized as follows:

1. Background of the author.
2. A brief discussion of communications reliability as it pertains to Amateur Radio.
3. An HF communications reliability study of the installation, using industry standard tools.
4. A reprint of a publication from the American Radio Relay League, "Antenna Height and Communications Effectiveness," that provides the basic technical background as to why, for certain needs, higher antennas perform more reliably.

Background of the Author

Dennis G. Egan is a graduate of California State University at San Jose. His degree was in mathematics, with a concentration in computer science. For many years he served in a variety of management positions for the United States Postal Service, retiring in 2007. While working for the Postal Service, he worked on major computer programs including Delivery Systems Information System and Carrier Optimal Routing.

An active radio amateur since 1969, he holds the FCC's Amateur Extra Class license – the highest class of license available. Egan's principal activity since 1980 has been radio contesting. He has been a member of teams holding several North American and Caribbean records. He has been the top scoring USA Single Operator in the CQ WW RTTY contest for three years running, and did hold the USA and North American score records for that contest at one time.

He has done simulations of antenna systems and propagation maps for the purpose of optimizing antenna system designs at major multi-tower amateur radio installations W1KM and K1TTT. He is the manager of several major "home-brew" construction projects for one of the largest contest clubs in the world, the Yankee Clipper Contest Club, and currently serves as the club President. He has created Propagation Maps for amateur radio stations AG1LE, N2QV, KF0KR, N2IS, WB6RMY, N5VR, N9GB, K9JN and others.

Mr. Egan has no affiliation with Mr. Stone other than his request for this report; he has never met Mr. Stone, nor has he ever been to his residence in Washoe Valley, NV. Mr. Stone provided latitude, longitude, and height above sea level data used in preparing this report. The databases and programs used in generating this report are all in the public domain and, while some basic tests are used to verify the data from the databases, the information from the databases is assumed to be correct. Mr. Egan is available to testify if needed. This independent report is being produced using readily available software, standard methodology, and reasonable assumptions as to propagation conditions.

High Frequency (HF) Communications Reliability

For the reader to meaningfully interpret the reliability study presented herein, a brief discussion of the major concepts and terms involved is relevant. The reader is also urged to review the document prepared by technical staff at the American Radio Relay League, “Antenna Height and Communications Effectiveness,” which provides the physical explanation as to why radio communications reliability and effectiveness is strongly affected by antenna height.

For communications to be acceptable, amateur radio operators expect the signal to be above the noise level so that they may understand what is being communicated. The ratio of Signal to Noise (SNR) is measured in decibels (dB), and a minimum acceptable level is approximately 40 dB SNR.[1]

Reliability (REL) in a radio communications context, answers the question “How often, on average, can this communication take place at the specified ‘minimum acceptable level’?” Reliability is normally expressed as a percentage, and arriving at a specific value depends on the definition of “Minimum Acceptable Level” (MAL) in use. Several different MALs are commonly accepted in the engineering community. Take, for example, a distant TV station received over-the-air. If we define our MAL to be “we can tolerate an occasional pixelation,” then the measured REL might be as low as 20-30%. If we define our MAL as “a completely clear picture without any pixelation ever,” then the measured REL may jump to 80-90%. For another example, many areas of the communications industry (broadcasting and networking) routinely use a REL of 99.99% (commonly called “four nines”) which means they are “down” no more than 52 minutes each year. Radio amateurs do not, generally speaking, require such a high level of REL; a REL of 50-60% is usually sufficient. This would mean that the communications path at a given time and frequency would be available 5 to 6 days out of 10.

Application to HF Analysis

Turning closer to our domain, High Frequency (HF) shortwave broadcasters, like the Voice of America or the BBC World Service, look for Reliability numbers in the 80-90% range when planning their time and frequency schedules, to achieve an area coverage goal. In their cases, the MAL parameter (yardstick) is the Signal-to-Noise ratio, or SNR. This is basically the ratio of how loud the broadcast is in relation to background radio ‘hiss’ and static levels. Commonly used numbers are anywhere from 40-70 dB (a higher number means better quality reception).

The analysis presented below was created using VOACAP software. It is a tool developed over many years sponsored by:

- U.S. Army Strategic Communications Command, Fort Huachuca, AZ,
- U.S. Department of Commerce, National Telecommunications & Information Administration, Institute for Telecommunication Sciences, Boulder, CO, and
- Voice of America, Washington, DC

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[1] A signal to noise ratio (SNR) of 40 dB for radio communications is defined as yielding copy “with annoying noise, readable by trained, persistent operators.” Put into context, VOACAP software defines Required SNR as: “For a reasonable BC listening quality, use 67. For a reasonable CW reception quality, use 24 (or 27) and for SSB, 45.” To be very conservative, *i.e.*, less than “reasonable” reception, this study uses 40 dB SNR.

As a piece of software, VOACAP is the most widely used high-frequency (shortwave) performance prediction software in the world. It was not developed by radio amateurs, neither was it developed for, nor prejudiced by, amateur radio. Anyone can use the same tool to predict shortwave communications reliability.

The Reliability threshold was set at 60%, using an SNR of 40 dB for Single Sideband (SSB) voice communication. This is a *very* conservative (low) value for measuring acceptable communications quality.

HF radio communication is made possible by reflecting signals off an ionized portion of the earth's atmosphere known as the ionosphere. The very nature of this communication is variable (*i.e.*, not constant) and depends on many factors, including the time of year, time of day, solar (sunspot) activity, local noise sources and other geomagnetic and atmospheric conditions. The test cases presented consistently used very conservative models and accepted a low Reliability (REL) factor (60%).

- **A Reliability threshold of 60% is equivalent to 6 days out of 10.** Imagine if your cell phone or cable TV service worked only six days out of ten – that would be a Reliability of 60%. If your cell phone or cable TV service worked seven days out of ten, that would be a Reliability of 70%. In the figures that follow, the Reliability contours are under 20, 20, 30, 40, 50, and over 60%, to correspond to easily understood levels of less than 2, 2, 3, 4, 5, and 6 or more days out of ten.

- The MAL (Minimum Acceptable Level) is expressed as a Signal-to-Noise Ratio (SNR). This value (40 dB) is commonly used in Amateur Radio; it is the **minimum required SNR** for a Single Sideband (voice) transmission. Single sideband transmissions sometimes require an SNR up to 50 dB or more, which would further lower the results presented here (*i.e.*, require a larger/taller antenna system). In other words, in presenting the results here, the assumptions about required REL are *very* modest.

Some Generalizations:

- The higher an HF antenna, the lower the angle of radiation
- The lower the angle of radiation, the further the signal travels before reflecting against the ionosphere
- The farther a signal travels, the more loss in signal level
- The more times a signal is reflected, the more loss in signal level
- Solar activity, as measured by the Sun Spot Number (SSN), varies over an 11 year cycle
- Solar activity changes the reflection properties of the ionosphere
- The time of year or position of the sun changes the ionosphere's properties
- The more power used in generating a signal, the stronger the signal. The maximum power allowed in generating an amateur radio signal is 1500 watts.

High Frequency (HF) Analysis of the Installation

A 75-foot antenna structure has been requested. Only 45 feet is allowed without further proceedings. This section compares the expected performance of an antenna at the different heights. Design parameters:

- Communications to France, Australia, and American Samoa
- SNR 40 dB
- REL 60%
- Smoothed Sunspot Average 100 (11 year average figure)
- December is the month used for all analysis
- Peak times to communicate
- Low geomagnetic Activity
- Low noise levels
- Transmission power 1400 watts (to account for feed line and switching losses)
- Frequency of 14 MHz (20 meter amateur band) and 7 MHz (40 meter amateur band)
- Structure heights: 45 feet, 75 feet
- Receiving antenna at both locations: a dipole at 60 feet above ground and oriented for maximum received signal strength
- Antenna for 14 MHz is a 3 element Yagi; antenna for 7 MHz is a 2 element Yagi
- Scale and color coding on all maps is the same
- REL colors: Dark Blue is 60% or above, Grey is 50%, Yellow is 40%, Pink is 30%, Lt Blue is 20%, Green is 10%, and White is <10%
- Communication mode: Single Sideband (SSB), 2.4 kHz bandwidth (SNR 40dB)

The process starts with terrain data entered for the Washoe Valley, NV location in the direction of the desired geographic locations (target areas), fed as input to the HFTA (High Frequency Terrain Assessment) program from the American Radio Relay League. This program uses Mr. Stone's terrain, elevation, and antenna parameters as input, and provides antenna gain and take-off (elevation) angle data as output.

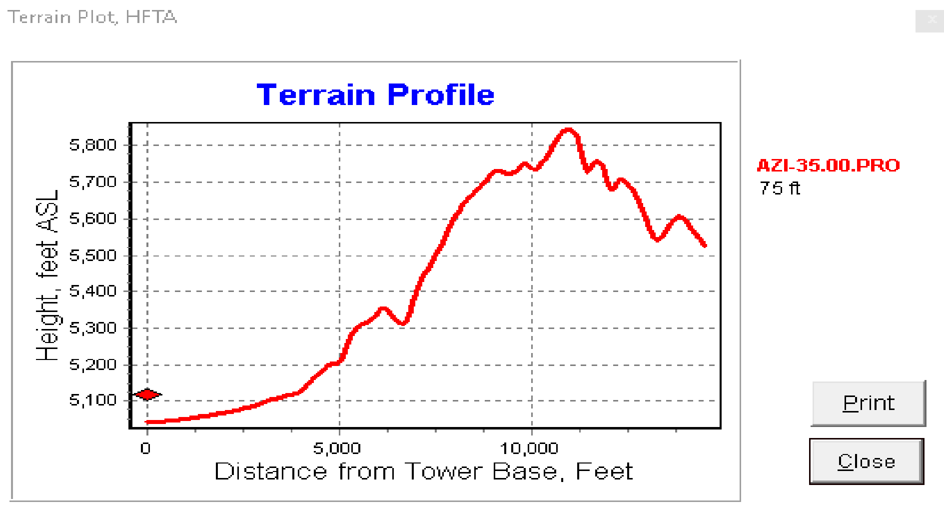

Figure 1 (Terrain Profile Toward France)

Figure 1 above is the terrain from the KD6BQ location at a 35 degree heading - toward France. It is a steady uphill, peaking about 800 feet above his location height in a little over 2 miles. Don't be misled by the different axes - the vertical scale goes from 5050 to 5840 feet, and the horizontal scale goes from 0 to 15000 feet.

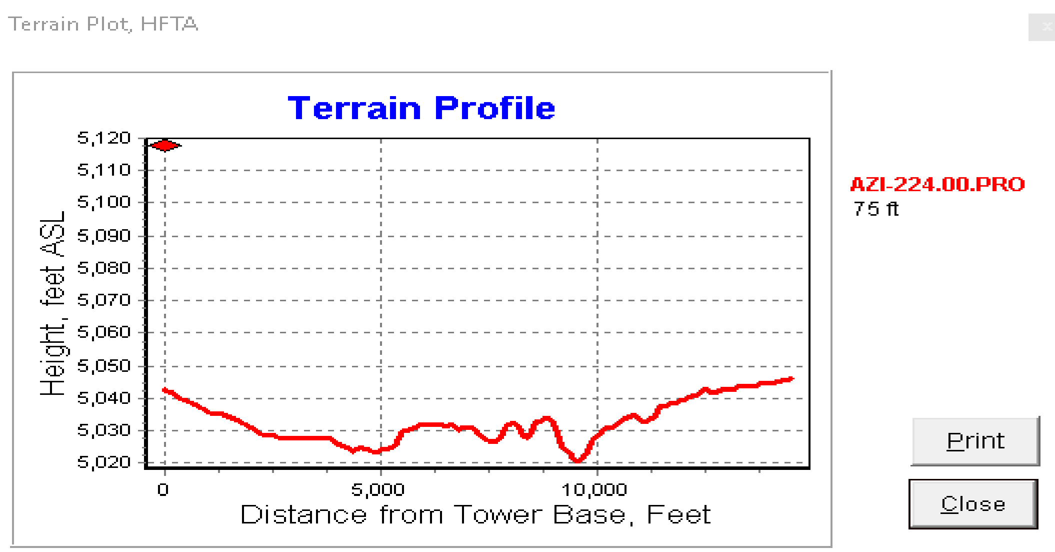

Figure 2 (Terrain Profile Toward American Samoa and Australia)

Figure 2 above is the terrain from the KD6BQ location at a 224 degree heading - toward American Samoa and Australia. It is essentially flat, with a drop off of 20 feet in the first mile. Don't be misled by the different scales used for the two axes.

The terrain characteristics are then combined with the antenna characteristics to produce an output file from HFTA that is used for input to VOAAREA. VOAAREA is an HF Propagation Analysis software tool developed by the U.S. Department of Commerce / Institute for Telecommunication

Sciences, public domain software made possible by funding from the Voice of America (VOA), the U.S. Army, and the U.S. Air Force. In other words, the software was not designed to favor amateur radio, or a particular radio amateur. Area Coverage is one of many calculations that VOAAREA can perform. It displays a number of calculated quantities (including REL) for a specified transmission system to a specified reception area for a specified date, time of day, frequency, and sunspot level. The results appear as contours plotted on a world map background.

In the discussion that follows, 60% is used as the minimum acceptable reliability (REL) value, *i.e.* successful communications is defined as a path reliability of 60% or greater – six or more days out of ten -- of otherwise available time (blackout times are not included) under the changing variables that impact amateur radio communications. This is a very conservative service goal, as *Snook v. City of Missouri City* (Texas), an amateur radio case tried in the U.S. District Court, Southern District of Texas (2003)[2], accepted a service reliability standard of 75-90%.

Propagation Map Study #1 – 14 MHz to France

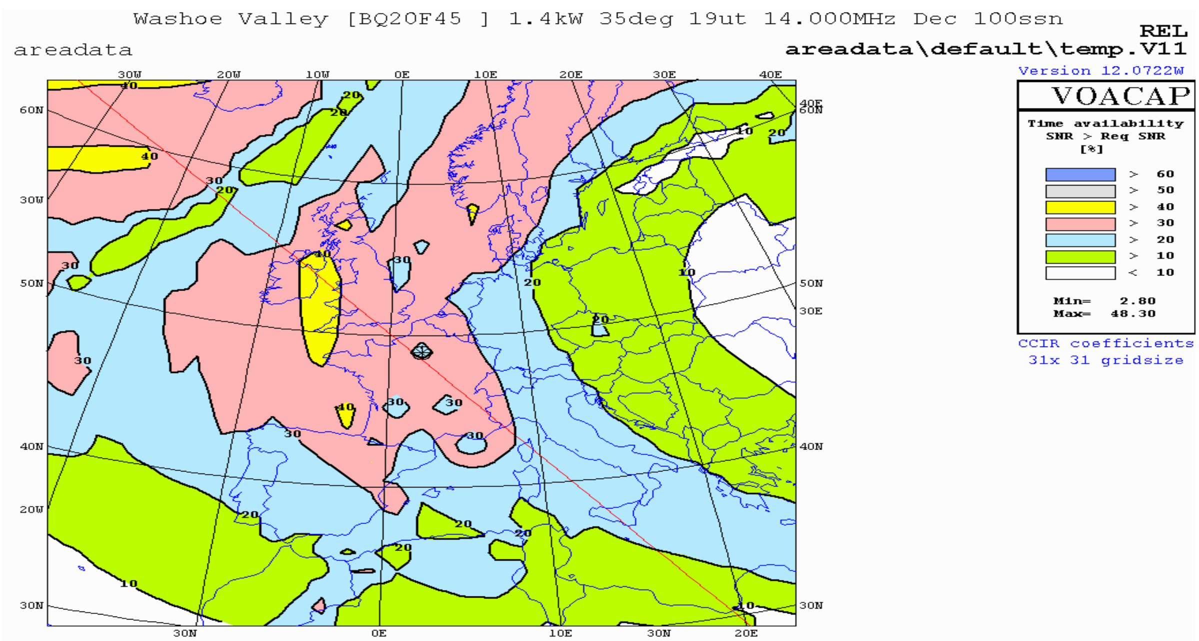

Figure 3 (45 foot structure, 14 MHz, to France)

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2 *Snook v. City of Missouri City*, 2003 U.S. Dist. LEXIS 27256, 2003 WL 25258302 (S.D. Tex. Aug. 27, 2003, Hittner, J.) (the Order). Available on the internet at http://www.arrl.org/files/file/Snook%2520KB5F%2520Decision%2520%26%2520Order%252034.pdf (retrieved Sept. 27, 2017). See also the Final Judgment, Slip Opinion, 2 pp. available at: (PACER citation) https://ecf.txsd.uscourts.gov/cgi-bin/login.pl?387442335892775-L_238_0-14:03-cv-00243_Snook v._City_of_Missouri, (S.D. Tex. 2003) or (Internet) http://www.arrl.org/files/file/Snook%2520KB5F%2520Final%2520Judgment%252035.pdf (retrieved Sept. 27, 2017)

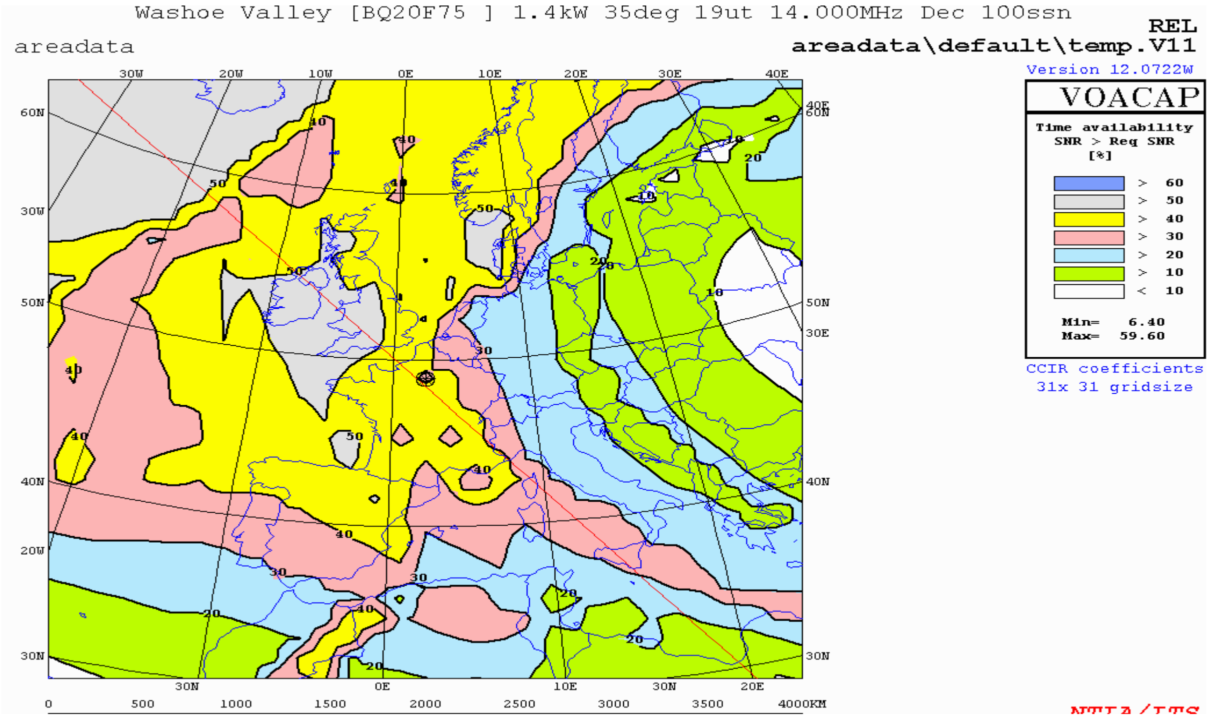

Figure 4 (75 foot structure, 14 MHz, to France)

France was selected for this propagation study at 14 MHz as representative of Western Europe, a favorite target for Mr. Stone's shortwave communications. As I understand it, the FCC rule is found in its original PRB-1 Report and Order, which has the same power as a federal statute:

> 25. Because amateur station communications are only as effective as the antennas employed, antenna height restrictions directly affect the effectiveness of amateur communications. Some amateur antenna configurations require more substantial installations than others if they are to provide the amateur operator with the communications that he/she desires to engage in.

I am informed that the correct citation for this FCC Report and Order is: MEMORANDUM OPINION AND ORDER (FCC 85-506), Federal Preemption of State and Local Regulations Pertaining to Amateur Radio Facilities. FCC Order PRB-1, 101 FCC 2d 952, 50 Fed. Reg. 38813 (September 25, 1985), ("PRB-1"), which may be found on the internet at http://wireless.fcc.gov/services/amateur/prb/index.html

This is a subjective test, and Mr. Stone informs me that contacts with Western Europe are among his desired communications.

Figure 3 is a picture of the REL for the 45 foot structure; *Figure 4* is a picture of the REL for the 75 foot structure. With the 45 foot structure, most of France would have a REL between 30 and 39%. Communications would be possible on somewhere about 3 days out of 10.

Figure 4, with the 75-foot structure, shows a REL for most of France to be between 40 and 49%. Communications with most of France should now be possible about 4 days out of 10. While a higher structure could result in attaining the 60% threshold, Mr. Stone expresses a willingness to live with this sub-par performance.

While it is true that increasing the power output could generate an increased signal into France, there are two problems with that strategy:

- It is illegal to exceed the FCC's maximum permitted output, which was already modeled into this analysis, and
- Increasing transmitter output has no impact on received signals, which would still be unreadable.

Propagation Map Study #2 – 14 MHz to Australia

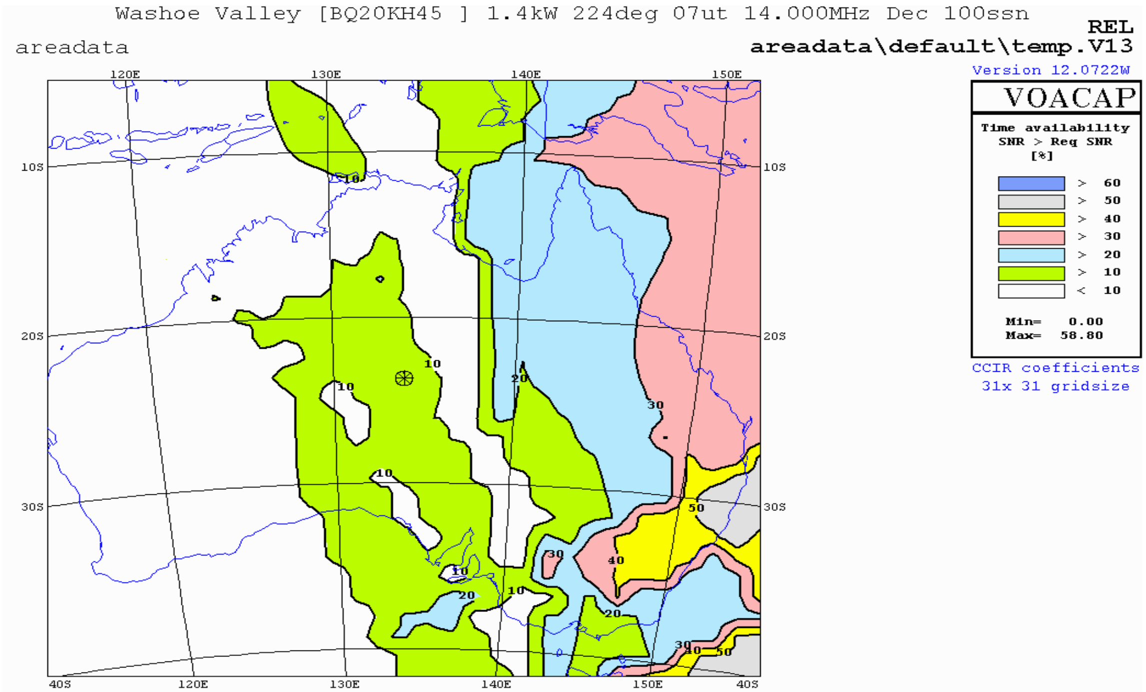

Figure 5 (45 foot structure, 14 MHz, to Australia)

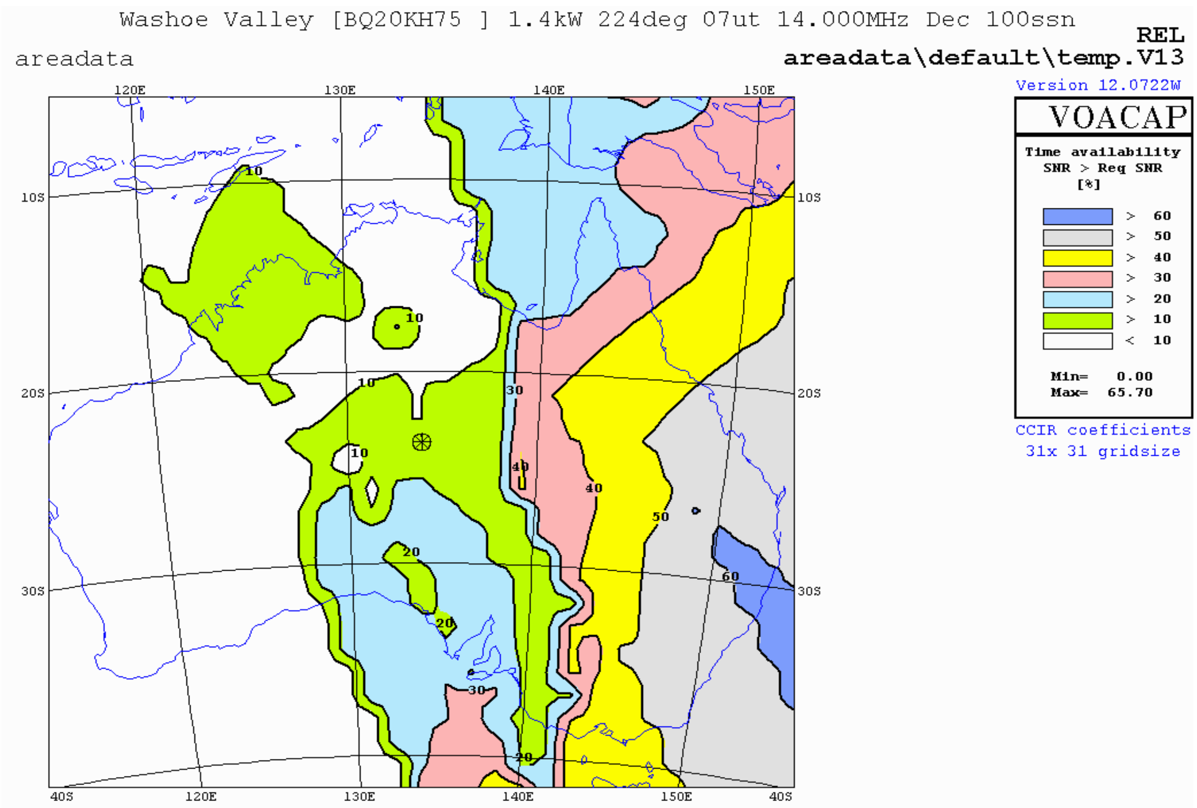

Figure 6 (75 foot structure, 14 MHz, to Australia)

Australia was selected for this study at 14 MHz as representative of Oceania, a favorite target for Mr. Stone's shortwave communications.

Figure 5 is a picture of the REL for the antenna on a 45 foot structure; *Figure 6* is a picture of the REL for the antenna on a 75 foot structure. With the 45 foot structure, most of Australia has a REL in the 0-29% range; that means communication would be possible 0-3 days out of 10.

Figure 6 with the 75 foot structure the eastern third of Australia now has a REL between 30 and 69%. Communications would now be possible on 3-7 days out of 10 for the eastern third of the country. This will not attain the stated REL of 60% but is still significantly better than the 45 foot structure. While a higher structure could result in attaining the 60% REL for more of Australia, Mr. Stone expresses a willingness to live with this sub-par performance.

While it is true that increasing the power output could generate an increased signal into France, there are two problems with that strategy:

- It is illegal to exceed the FCC's maximum permitted output, which was already modeled into this analysis, and
- Increasing transmitter output has no impact on received signals, which would still be unreadable.

Propagation Map Study #3 – 7 MHz to American Samoa

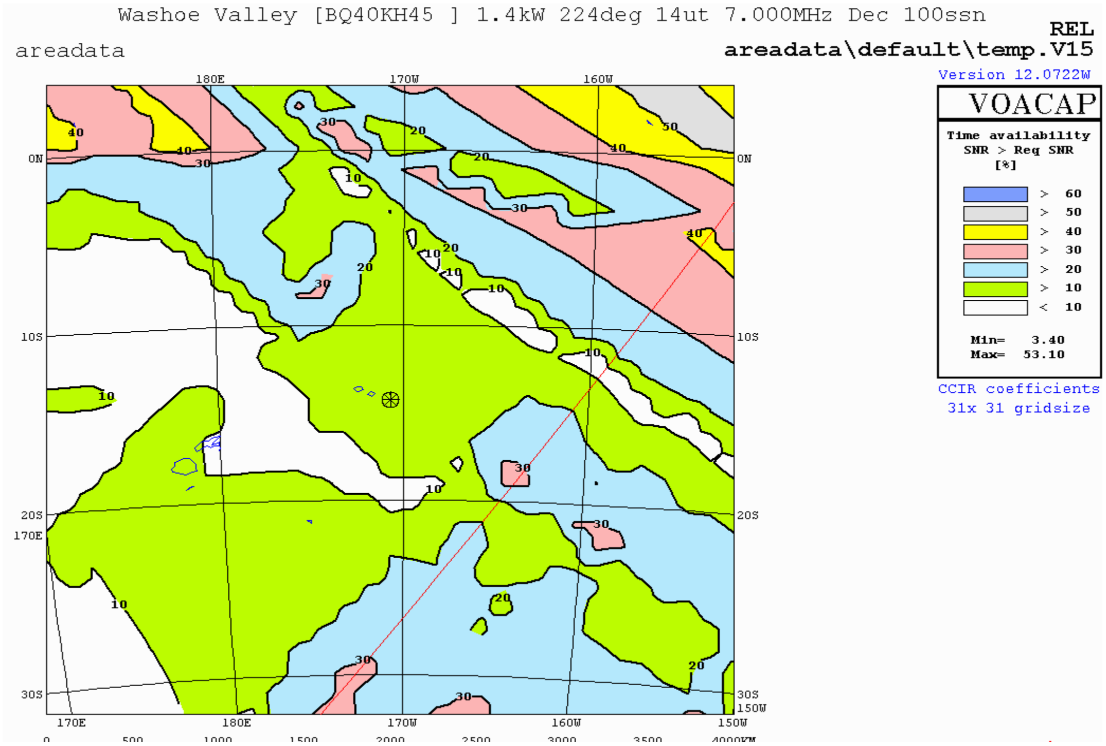

Figure 7 (45 foot structure, 7 MHz, to American Samoa)

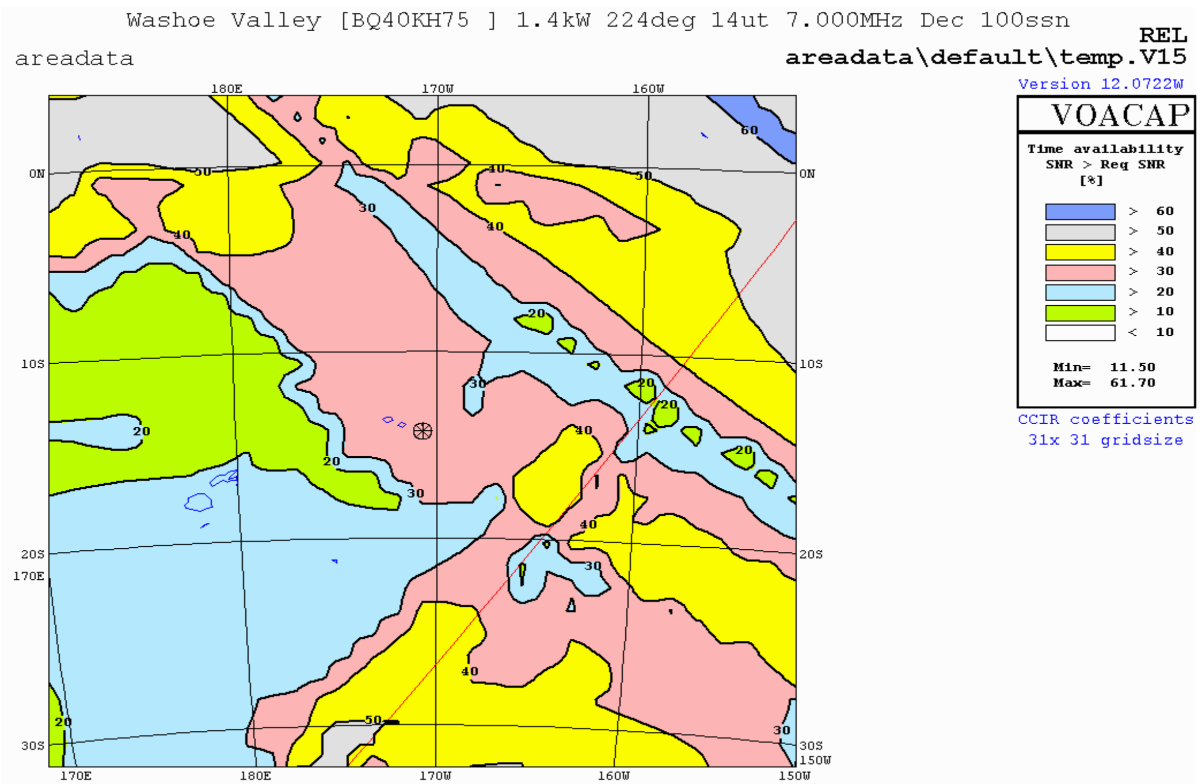

Figure 8 (75 foot structure, 7 MHz, to American Samoa)

American Samoa was selected for this study at 7 MHz as representative of the South Pacific, a favorite target for Mr. Stone's shortwave communications.

Figure 7 is a picture of the REL for the antenna on a 45 foot structure, and *Figure 8* is a picture of the REL for the antenna on a 75 foot structure. For the 45 foot structure, the REL is in the 10-19% range; communications would be possible 1-2 days out of 10.

Figure 8, with the 75 foot structure, shows a REL of 30-39%; communications would now be possible to American Samoa 3-4 days out of 10. While this does not meet the desired REL of 60%, it is significantly improved over that of the 45 foot structure. While a higher structure could result in attaining the 60% threshold, Mr. Stone expresses a willingness to live with this sub-par performance.

While it is true that increasing the power output could generate an increased signal into American Samoa, there are two problems with that strategy:

- It is illegal to exceed the FCC's maximum permitted output, which was already modeled into this analysis, and
- Increasing transmitter output has no impact on received signals, which would still be unreadable.

High Frequency (HF) Communications Analysis Conclusions

The heights of the proposed antenna support structure and antennas were analyzed for the purpose of determining whether they would meet the needs of the amateur radio operator. Commonly used engineering metrics were employed to determine the effectiveness of communications.

The 75-foot structure to support the antenna system more nearly meets the need for reliable communications to France, Australia and American Samoa at 14 and 7 MHz than a 45-foot structure. While the taller structure does not meet the required REL to any of the target areas, Mr. Stone is apparently willing to live with this antenna height, despite the limitations it presents, as an acceptable compromise.

Erecting a structure at 45 feet does not meet Mr. Stone's needs on 14 and 7 MHz, and does not provide reliable coverage to any of the desired target geographic areas.

Respectfully submitted,

Dennis G. Egan, B.S.

Affidavit of Dennis G. Egan
B.S. Mathematics (Concentration in Computer Science)

The facts or denial of facts set forth in the foregoing document are based upon either my personal knowledge, or information and belief. I prepared the document myself, including all of the terrain data and propagation maps, based on information about frequencies, desired directions, and power output provided by the applicant and, based on my experience and history using the software employed, I believe the reported results to be reliable. I did not modify the software used to prepare the document so as to achieve a particular outcome, and I used standard assumptions, stated in the report, about propagation.

I acknowledge that this document is being submitted to the Planning and Zoning Commission of Washoe Valley, NV, in support of the application of Richard Stone, KD6BQ, and will be considered in those proceedings.

I certify under penalty of perjury that the foregoing submission is true and correct to the best of my knowledge and belief.

A reprint of "Antenna Height and Communications Effectiveness" follows. It is an engineering study by the technical staff of the American Radio Relay League (ARRL), and provides the basic technical background as to why, for certain amateur radio applications, higher antennas perform more reliably.

Exhibit E

Antenna Height and Communications Effectiveness, 2d. Ed., Straw and Hall

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

The American Radio Relay League, Inc.
225 Main Street
Newington, CT 06111

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.

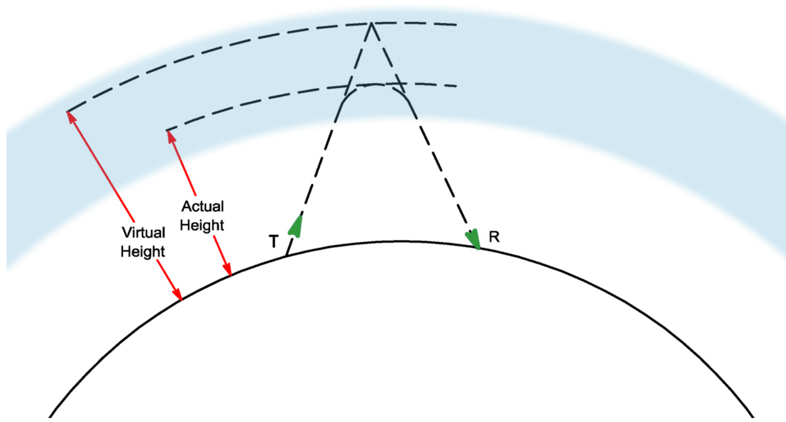

Fig 1—A simplified cross-sectional representation of ionospheric propagation. The simple triangle goes from the Transmitter T up to the virtual height and then back down to the Receiver R. Typically the F layer exists at a height of 150 miles above the Earth at mid-latitudes. The distance between T and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

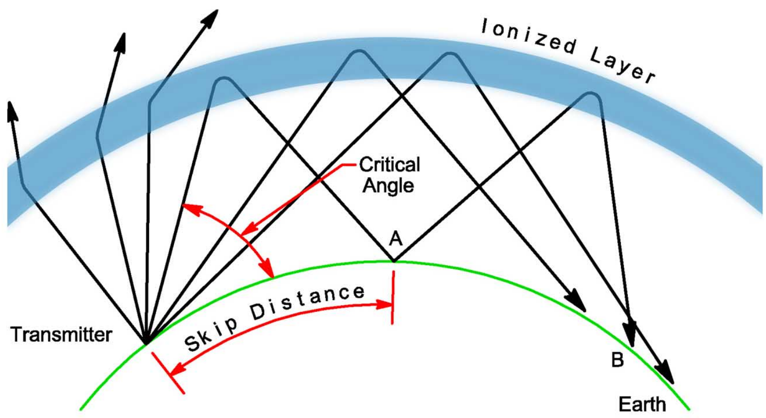

Fig 2—Behavior of radio waves encountering the ionosphere. Rays entering the ionized region at angles above the critical angle are not bent enough to return to Earth and are lost to space. Waves entering at angles below the critical angle reach the Earth at increasingly greater distances as the angle 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, 15º 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 (3^{rd}) hop, and only 1/10 of that 1/10 for the second additional (4^{th}) 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 30º, while the higher antenna has two main lobes, one peaking at 15º and the other at about 50º elevation angle.

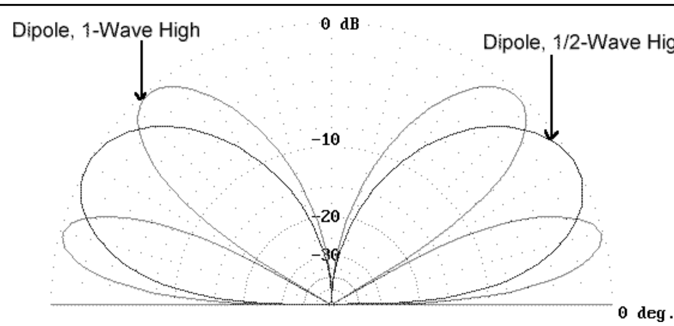

Fig 3–Comparison of elevation responses for two dipoles: one ½-wavelength high, and the other 1-wavelength high.

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 30º. 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 15º. 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 1º to 30º, Fig 4 shows the percentage of time when the 14-MHz band is open at each elevation angle. For example, 5º is the elevation angle that occurs just over 12% of the time when the band is available for communication, while 11º 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 1º to 28º.

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.

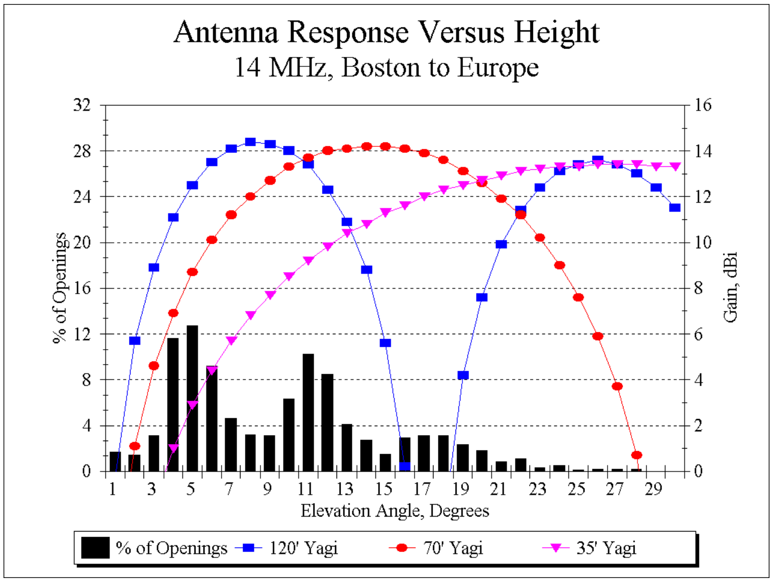

Fig 4—Elevation response patterns of three Yagis at 120, 70 and 35 feet, at 14 MHz over flat ground. The patterns are overlaid with the statistical elevation-angles for the path from Boston to continental Europe over the entire 11-year solar sunspot cycle. Clearly, the 120-foot antenna is the best choice 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 2º, 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.

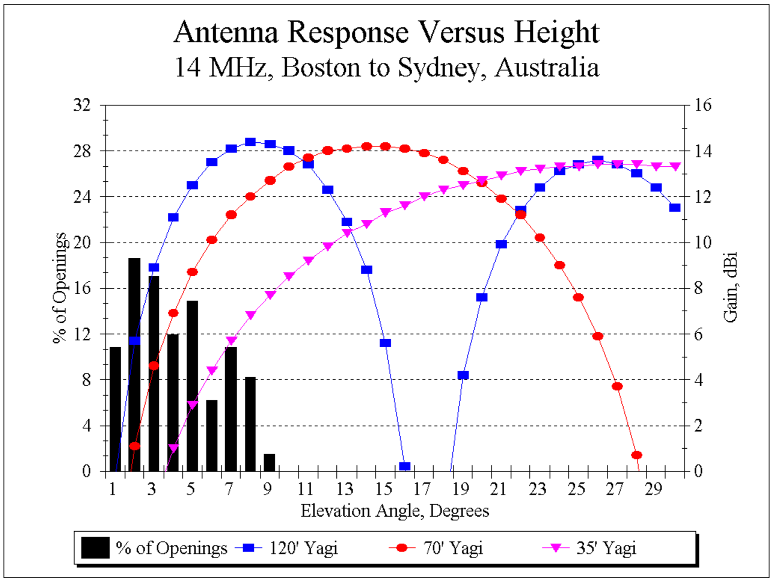

Fig 5—Elevation responses for same antennas as Fig 4, but for a longer-range path from Boston to Sydney, Australia. Note that the prevailing elevation angles are very low.

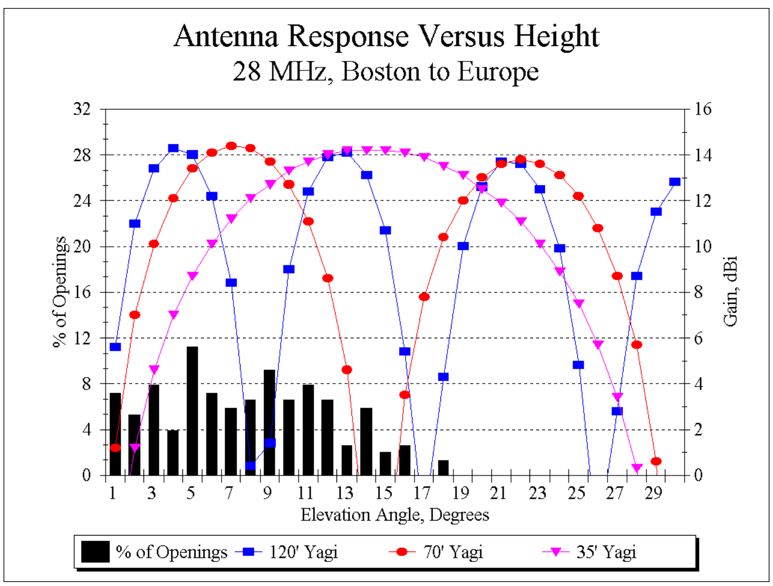

Fig 6—Elevation angles compared to antenna responses for 28-MHz path from Boston to Europe. The 70-foot antenna is probably the best overall choice on this path.

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.

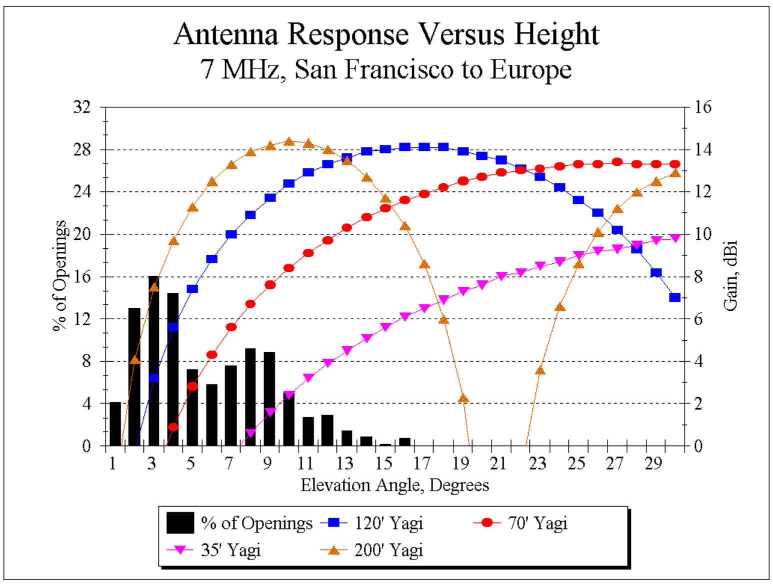

Fig 7—Comparison of antenna responses for another propagation path: from San Francisco to Europe on 7 MHz. Here, even a 120-foot high antenna is hardly optimal for the very low elevation angles required on this very long path. In fact, the 200-foot high antenna is far better suited for this path.

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.

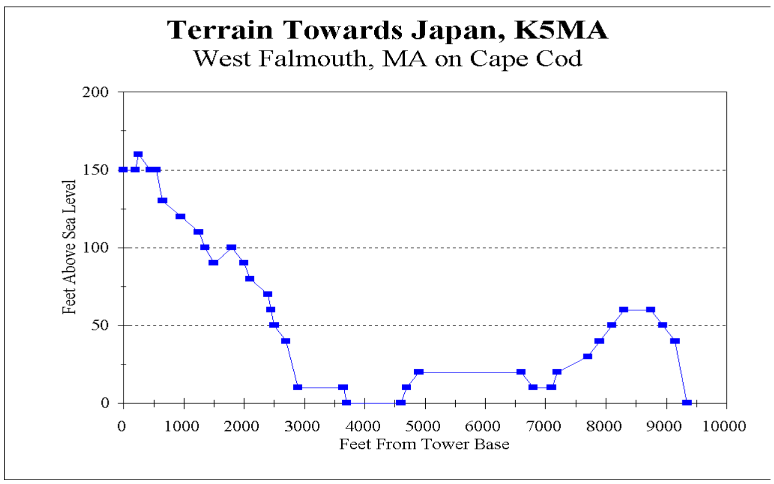

Fig 8—Terrain profile from location of K5MA, Jan Carman, in West Falmouth, MA, towards Japan. This is a moderately complicated real-world terrain on one of the highest hills on Cape Cod.

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.

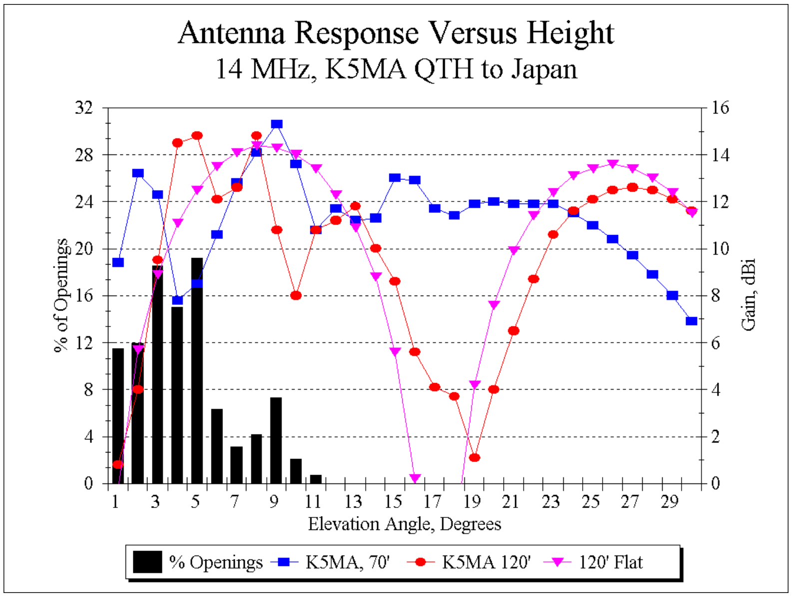

Fig 9—Computed elevation responses of 120- and 70-foot high Yagis, at the K5MA location on Cape Cod, in the direction of Japan and over flat ground, for comparison. The elevation response of the real-world antenna has been significantly modified by the local terrain.

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.

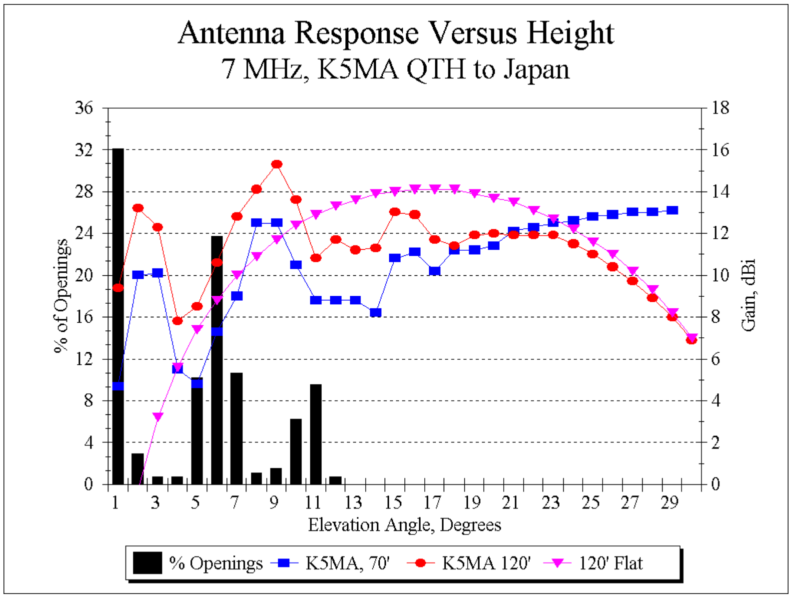

Fig 10—Elevation response on 7 MHz from K5MA location towards Japan on 7 MHz. The 120-foot high Yagi is definitely superior to the one only 70-feet high.

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.**