Jed Margolin 1981 Empire Rd. VC Highlands, NV 89521-7430
775-847-7845
May 1, 2011

Storey County Commissioners
Storey County, Nevada

Reference: Taormina Towers Comments #2

Dear Storey County Commissioners,

This is regarding Tom and Midge Taormina's application for a Special Use Permit Case No. 2011-010. Please put this in the permanent public file for the issue.

I agree with the recommendations of the Planning Commission "to maintain the four (4) existing amateur ham radio antenna towers applicable to this SUP in accordance with the limitations set forth hereby and deny installation of any additional towers on the property located at 370 Panamint Road (APN 003-431-18), Highland Ranches, Storey County, Nevada and to include all applicable conditions presented in the addendum (See Planning Commission Minutes dated 3/3/11)."

I urge you to adopt their recommendation.

I am sending this letter to support their recommendation. Because of the amount of material I am splitting up my comments into several letters. This is letter #2.

This is in response to Fred Hopengarten's posting on the Yahoo group (posted by Tom Taormina on March 25, 2011). Because of its length I am dividing it into several separate letters. This is part 2.

Part 2 - Signal-to-Noise Ratio

This is about Signal-to-Noise Ratio (SNR). This is a central issue because Tom's justification for the need for 195' towers is based on having reliable communications with Europe and Asia, and if the signal is buried in the noise you can't hear anything.

The following is Hopengarten's entire Yahoo Group posting.

Posted by Tom Taormina March 25, 2011
Prepared by Fred Hopengarten, Esq.
March 24, 2011

At the Planning Commission hearing, the claim was been made that "Tom wants quality comparable to the Voice of America in their shortwave broadcasts." In e-mail to the VCH listserv, this claim was repeated: "His technical arguments are bogus. He wants to have reliable communications with Europe and Asia with the same quality of communications that the Voice of America strives for in its short wave broadcasts. "

Response

This claim is not true, and contains several misunderstandings.

1. The claim confuses the use of a widely accepted software tool (Voice of America Coverage Analysis Program, or VOACAP) with a reliability or performance goal (such as 90% reliability, or 57% reliability).

2. The VOA reliability goal is 90% (6.3 days out of 7). The Taormina reliability goal is a more modest 57% (4 days out of 7).

Explanation

VOACAP is a piece of software. It is a tool developed over many years under contracts 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

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 or for radio amateurs. Anyone can use this tool to predict shortwave communications reliability. Using VOA software does not mean you want VOA reliability.

The VOA reliability goal is 73 dB/1-Hz SNR (Signal-to-Noise Ratio) target for a VOA 6 kHz bandwidth AM signal. VOA designs are aimed at achieving this goal 90% of the time.

The Taormina reliability goal is 40 dB/1-Hz SNR target for a ham radio 2.4 kHz bandwidth single-sideband (SSB) voice signal. The Taormina design is aimed at achieving this goal 57% of the time, assuming the legal limit for amateur radio of 1,500 watts transmitter power.

The difference between the VOA reliability goal and the Taormina goal is 33 dB, or a factor ~2000:1

The opponent's claim makes an error common to neophytes trying to understand the VOACAP software. It fails to recognize that in VOACAP the Required SNR is the signal-to-noise ratio in a 1-Hz receiving bandwidth. The reason VOA chose to express the required SNR in a 1-Hz bandwidth is because it makes VOCAP a universal tool, capable of being used for various modes of communications. Voice, CW (continuous wave, i.e., "Morse Code"), RTTY (radio teletype), and other digital modes have different bandwidths. A user of VOACAP need only enter the required SNR for the particular mode.

VOA looks for a 73 dB/1-Hz required SNR with a 90% reliability for an AM DSB (double sideband with carrier) signal. A typical bandwidth for such a signal is 6000 Hz. Thus, the required SNR in a 6000 Hz bandwidth would be: 73 - 10 log10 (6000/1) = 35 dB/6000-Hz SNR, their desired level of service, sometimes referred to as "armchair copy." A 73 dB/1-Hz (35 dB/6000-Hz) SNR would be suitable for reasonably good reception of music, as well as voice.

To achieve its goal of 90% reliability or 73 dB SNR/1-Hz, VOA employs shortwave transmitters of up to 500,000 watts, with gigantic antenna fields, with many 300-foot high towers. See, for example, VOA Sao Tome (21 tall antenna towers on 346 acres, using four 100 kW shortwave transmitters for broadcasts from 6-21 MHz), or VOA Greenville, NC (28,000 acres, with 300-foot towers supporting curtain arrays, two 500kW, four 250 kW shortwave transmitters targeting Latin America, Cuba, the Caribbean and Africa).

By contrast, for an amateur radio SSB (single sideband voice) signal, a typical receiver bandwidth would be 2400 Hz. A 40 dB/1-Hz SNR (that is, in a 1-Hz bandwidth) would be 40 dB - 10 log10 (2400/1) = 6 dB Hz SNR, in a 2400 Hz bandwidth. It is commonly recognized by communications engineers that a 10 dB SNR in a voice bandwidth (that is, 2400 Hz) yields comfortable copy of a signal by trained operators. A 6 dB SNR in a 2400 Hz bandwidth would yield copy with "annoying" noise, but it would still be readable by trained, persistent operators.

The Taormina project is aimed at yielding copy with "annoying" noise, readable by trained, persistent operators, 57% of the time, or four days out of seven.

In contrast to VOA Greenville, Taormina seeks only a goal of 57% reliability (seen as REL on the graphs included in the Taormina Needs Analysis) at a 40 dB/1-Hz SNR, to his desired coverage areas, using a maximum of 1500 watts, a difference of 498,500 watts.

Taormina does not seek "the same quality of communications that the Voice of America strives for in its short wave broadcasts."

To repeat: The difference between the VOA reliability goal (73 dB SNR/1-Hz) and the Taormina reliability goal (40 dB SNR/1-Hz) is 33 dB, or a factor of approximately 2000:1.

Additional sources:

Lane, G., "Signal-to-Noise Requirements for Speech Communication in Short Wave Broadcasting," Voice of America Technical Report ESBA-84-1, 14 p., July 1984.

Lane, G. and Toia M., July 31, 1985. "High Frequency (Shortwave) Broadcast System Design; Requirements Definition", Voice of America Engineering Standard 16775.01, Washington DC USA.

Lane, G., A. B. Richardson, and L. M. DeBlasio, "Signal-to-Noise Ratio and Aural Assessment of Broadcast Reception Quality," IEE 6th International Conference on HF Radio Systems and Techniques (Univ. of York, York, UK), IEE Conference Publication No. 392, 129 - 133, July 4 - 7, 1994.

My Response

We need to start with a short explanation of SNR.

SNR is the Signal-to-Noise Ratio, which means it is the Ratio of Signal to Noise. Mathematically,

$$SNR = Signal/Noise$$

Most commonly, it is the Signal Power and Noise Power, as opposed to Signal Voltage and Noise Voltage. (A discussion of the difference is not necessary here.)

Because the ratio of signal to noise can range from very small to very large, it is most often expressed logarithmically, in decibels (dB).

$$SNR(dB) = 10 * \log_{10}(Signal/Noise)$$

Deci-Bel literally means 1/10 of a Bel. Deci comes from the Latin “decimus” meaning “tenth”. The Bel is considered too large to be useful so it is divided by ten. Bel is capitalized because the unit is named to honor Alexander Graham Bell.

The ratio of Signal/Noise is dimensionless. The dimensional units (Power) divide out.

Sometimes, we just want to talk about noise with no signal. Although we can use the actual noise power (in watts, or milliwatts, or microwatts) we can still use dBs by using a reference. Common references are watts or milliwatts.

$$Noise(dB) = 10 * \log_{10}(Noise/Reference)$$

When we do that, the reference must be stated. If the reference is 1 Watt it is **dBW**. If the reference is 1 milliWatt it is **dBmW**, usually shortened to **dBm**.

(The Watt is named after James Watt. Technically, the unit Watt should always be capitalized but frequently it isn’t.)

We can also talk about the signal by itself, in which case the discussion is the same, only substituting “signal” for “noise.”

$$Signal(dB) = 10 * \log_{10}(Signal/Reference)$$

Noise Bandwidth

There are several types of noise, which we will discuss later. For now we will assume that the noise is:

1. Random
2. Evenly distributed throughout the bandwidth (frequencies) of interest.

For example, Figure 1 shows a bandwidth that goes from to 2,994 KHz to 3,006 KHz, centered at 3,000 KHz, and the noise is evenly distributed within that bandwidth. When we say that the noise is random we mean that the amplitude at each frequency is random. It is not a simple average because the simple average is zero. It is an RMS average performed by squaring each value, adding the squared values, dividing by the number of values, and taking the square root. RMS means Root Mean Squared (Square Root of the Mean of the Squares) so it can be considered as having a constant amplitude if you pick a good averaging time.

Note that:

1 KHz = 1,000 Hz
1 MHz = 1,000,000 Hz = 1,000 KHz

So, this noise is centered at 3.000 MHz.

The total amount of noise is the crosshatched area.

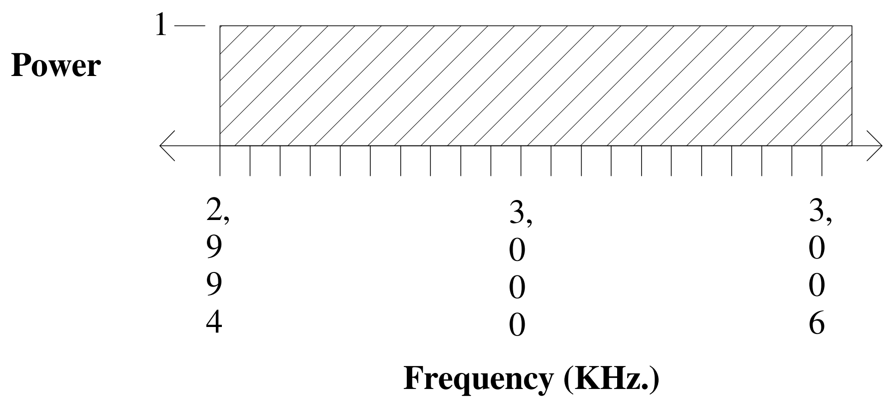


Figure 1

Let's add a signal. It's at one frequency (3,000 KHz = 3.000 MHz)

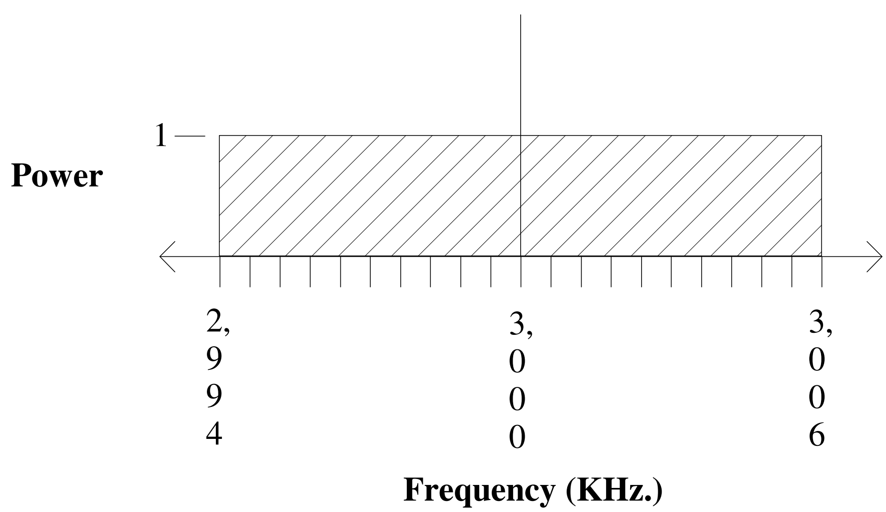


Figure 2

The signal to noise ratio is the signal power divided by the noise power in the crosshatched area.

If we want to reduce the noise all we have to do is reduce the crosshatched area. See Figure 3.

In Figure 3 we have reduced the crosshatched area in half. This reduces the noise in half. Since the noise is ½ and the signal is the same we have doubled the signal-to-noise ratio.

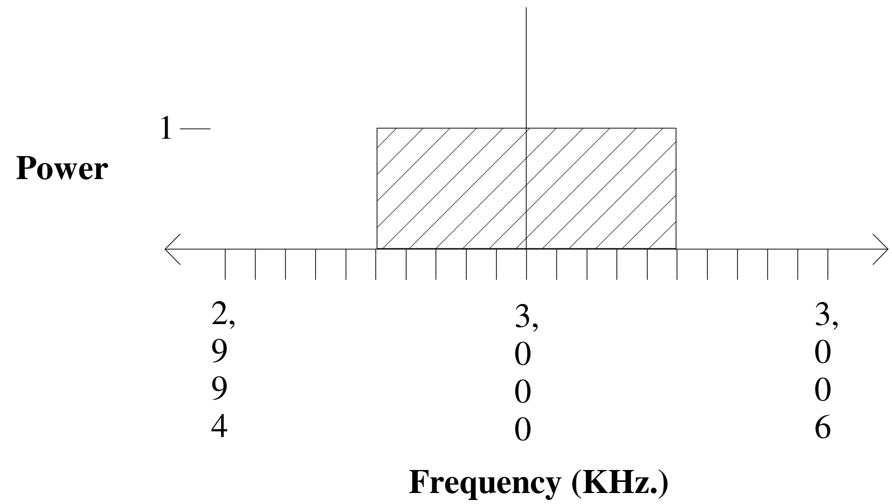


Figure 3

We can reduce it even more. How about reducing it to about the same bandwidth as the signal? (I have left it a little bigger to show some crosshatching.)

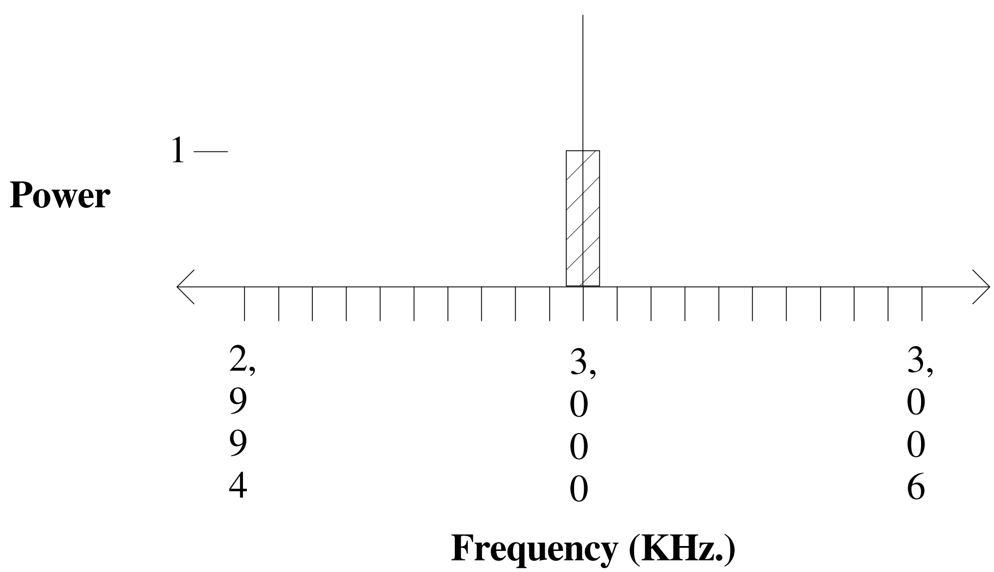


Figure 4

In the extreme we can reduce it to 1 Hz. (We'll use a really good filter.)

But suppose we are the Voice of America and want to broadcast a program and the program audio has a bandwidth of 6 KHz?

If our filter is 1 Hz we won't hear much.

The Voice of America uses Amplitude Modulation, otherwise known as AM. This is the same method used by broadcast stations in the AM band (which is why it's called the AM broadcasting band). Without getting too technical, Amplitude Modulation produces a carrier and two sidebands. Each sideband contains the full bandwidth of the program, in this case 6 KHz. Thus, the bandwidth of our AM broadcast is 12 KHz. And, by the way, with AM the carrier contains 2/3 of the transmitted power. The two sidebands contain the remaining 1/3 so that each sideband contains only 1/6 of the transmitted power. (This assumes a pure sine wave.)

The spectrum looks like Figure 5. The crosshatch in the lower area is the noise, The crosshatch in the upper area is the signal.

The line sticking up is the carrier.

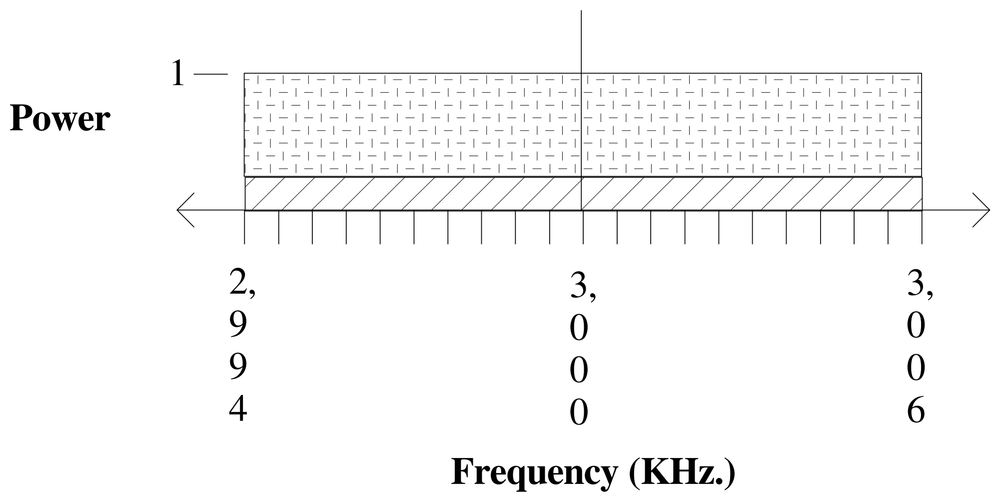


Figure 5

Why would we waste so much power in the carrier?

The carrier makes the signal much easier to demodulate. The receiver is much easier to build. Broadcasting got started before there were integrated circuits or even transistors. The philosophy was one transmitter, many receivers. The simpler the receiver, the better.

Even Hams used AM for a very long time.

Then Single Sideband was invented. In Single Sideband you transmit only one sideband and no carrier.

See Figure 6.

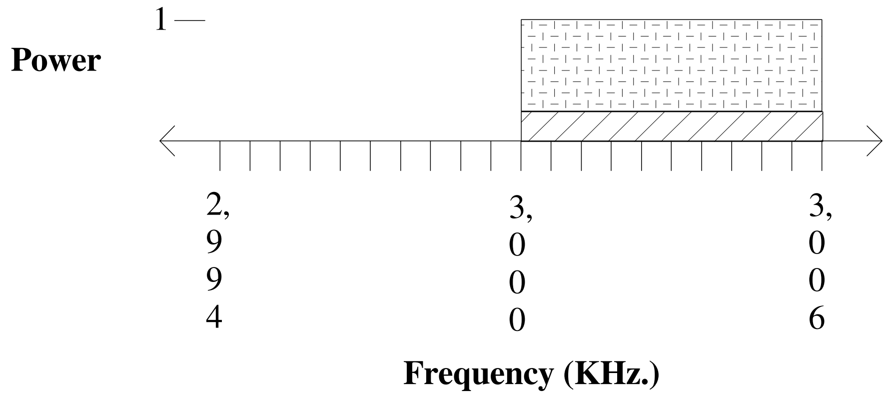


Figure 6

Since all of the transmitted power goes into the sideband you effectively get 6 times the power. And by reducing the bandwidth by half you also get half the noise. Thus, in the ideal case, you effectively increase the signal-to-noise ratio by a factor of 12. This is about a 10 dB improvement in signal-to-noise.

In the old days an SSB signal was much more difficult to generate than an AM signal. Nowadays, it's still more difficult to generate but it's cheap to do.

The problem is with the receiver.

In order to demodulate the SSB signal you have to, in effect, re-insert a carrier whose frequency you don't know.

If you insert a carrier that is off by 100 Hz, then the audio will be demodulated with a frequency offset of 100 Hz.

That means that octaves will no longer be octaves.

For example:

Here are some octaves in a signal	Here they are when they are off by 100 Hz.
400 Hz.	500 Hz.
800 Hz.	900 Hz.
1600 Hz.	1700 Hz.
3200 Hz.	3300 Hz.

The human ear is very tuned to octaves. (Actually, the human ear is very tuned to tones that are whole number ratios of each other. We find them very pleasing.) When octaves are supposed to match, but don't, it sounds bad. When the sound is the human voice it doesn't take much for it to become unrecognizable.

An improperly demodulated SSB signal makes the human voice sound like a duck.

Indeed, when a receiver is not properly adjusted to demodulate an SSB signal containing voice, the result is called "ducktalk."

How does the above discussion of signal-to-noise ratio relate to VOACAP?

One of the parameters that you feed the VOACAP program is the **Required Signal-to-Noise**. That parameter is designated **[REQ. SNR].** And it is always referenced to a 1-Hz noise power bandwidth.

George Lane is one of the contributors to VOACAP. (See http://www.voacap.com/overview.html).

He is the "Lane G." cited as the author or co-author in Hopengarten's references.

He wrote the book on signal-to noise predictions using VOACAP.

Indeed, it's called **Signal-to-Noise Predictions Using VOACAP - A User's Guide**, by George Lane, published by Rockwell Collins, Copyright 2000, 2001. (It's available for $5 on CD from Rockwell Collins through http://greg-hand.com/pc_hf/rockwell/ .)

In the following passage starting at **5.2 Required SNR** (reproduced in Exhibit 1) note that he is always careful to refer to the VOACAP SNR parameter as "**[REQ. SNR]**" and when he refers to "SNR" he means the standard definition of SNR which is the ratio of signal to noise in the bandwidth used. Also note that:

1. The units for **[REQ.SNR]** are "dB•Hz". This is opposite of what you might think it should be. You might expect it to be "dB/Hz" because **[REQ.SNR]** is for a one Hz noise bandwidth.

Consider the example:

[REQ.SNR] = X.dB • Hz
X.dB = **[REQ.SNR]** / Hz.

Otherwise, if **[REQ.SNR]** was X.dB/Hz, when you multiply by the bandwidth you would be increasing the signal to noise ratio. This is a common mistake that neophytes make.

2. Although the units for **[REQ.SNR]** are "dB•Hz" the raised dot "•" is not a standard symbol in fonts other than math fonts. Frequently you will see "dB•Hz" as dB-Hz". (I don't know why they do that since they could have standardized on "dB*Hz".)

Here is Lane.

5.2 Required SNR

The required signal-to-noise ratio **[REQ. SNR]** is the single most important variable which the VOACAP user must input to the program. As we noted before, if **[REQ. SNR]** is not correct, then the computation of reliability **[REL]** and required power gain **[RPWRG]** will be incorrect, also. We also have seen that the

[REQ. SNR] is used to determine most reliable mode. Now we need to discuss how we select **a [REQ. SNR]** for the system we wish to model.

> **Note:** If we are only interested in the signal-to-noise ratio probability distribution, then **REQ. SNR** and **REQ. REL** can be left at the default settings. These input parameters have little effect on the predicted SNR distribution.

The actual determination of **[REQ. SNR]** for a modern HF radio system can be very time consuming and expensive. Historically, the values of **[REQ. SNR]** for Morse code, radiotelephony, radioteletype and international broadcasting service are well documented. However, that is not the case for modern high-speed data systems or systems employing automatic link establishment (ALE) techniques.

Let us start with some fairly well known examples which have been long recognized by the radio amateur community and the US Army Signal Corps. First is manual Morse code (telegraphy) (Lane 1975). Typically, the receiver uses a narrow band filter to reduce the noise power. In actual measurements with a receiver bandwidth of 1,200-Hz, trained operators could copy 15 words/minute with at least 90% correct words when the SNR was 0 dB in the bandwidth of the receiver for fading skywave signals and -1 dB for non-fading groundwave or laboratory measurements. For use in VOACAP, we must convert the measured SNR in the bandwidth of the receiver to the **[REQ. SNR]** which is always referenced to a 1-Hz noise power bandwidth, so that:

[REQ. SNR] = SNR + 10 Log B_{Hz}
= 0 dB + 10 Log (1,200 Hz)
= 30.8 dB•Hz

Next, let us consider voice communications over a skywave link. Again, it is well known that trained radio operators can communicate with 90% sentence intelligibility at a SNR of 13 dB[1] in the bandwidth of the receiver (Akima et al. 1969). Most amateur and military HF receivers are set up to operate in a 3-kHz bandwidth for voice communications. Older radios and those used for shortwave broadcast reception require the carrier as well as the upper and lower sidebands and have a bandwidth ranging from 5 to 10 kHz. Using the bandwidth conversion above, we can calculate the **[REQ. SNR]** for just-usable voice communications (i.e., 90% sentence intelligibility with trained radio operators) for a 3-kHz single-side-band (SSB) system and a 6-kHz double-side-band (DSB) system:

SSB:
[REQ.SNR] =13dB + 10Log(3,000Hz)
= 48 dB•Hz

DSB:
[REQ.SNR] = 13 dB + 10 Log (6,000 Hz)
= 51 dB•Hz

In 1994, a comparison between measured values of SNR and subjective aural assessment was published (Lane et al. 1994). Conservative values of required SNR for DSB reception are presented in Figure 5.1. Grades of Radiotelephony Service. Remember that these required SNR values are 3 dB higher than needed for SSB reception in a 3 kHz bandwidth. It is interesting to note that with 39 dB•Hz for DSB reception (or 36 dB•Hz for SSB reception) the listener is unable to recognize the voice signal as being wanted or unwanted. However, a highly trained operator can still copy just-usable telegraphy traffic at 31 dB•Hz.

---

[1] One dB of fade protection against slow Rayleigh-type fading is included in this required SNR.

The aural telegraphy value of 44 dB•Hz for DSB, shown in Figure 5. 1, is for 95% correct copy and includes a 3-dB protection for differences between operators (Silva 1964). However, for just-usable voice comprehension, the **[REQ. SNR]** must increase to about 51 dB•Hz (DSB) and 48 dB•Hz (SSB). An additional 10 dB is needed to assure 99% sentence intelligibility for 90% of the listeners. Another 10 dB is needed to overcome the annoying level of noise. And, another 10 dB is needed to make the background noise only slightly perceptible. A further 10 dB is needed so that the listener hears no noise at all.

This presentation is made because it bounds the full range of values for **[REQ. SNR]** from 30 to 90 dB•Hz. Some very sophisticated HF data systems will retain connectivity at **[REQ.SNR]** in the 30 to 40 dB•Hz range. These systems either slow the transmission rate, repeat missed packets of data, and/or search for a better frequency during periods of low SNR. Somewhat better throughput is afforded if the **[REQ. SNR]** is in the range of 40 to 50 dB•Hz. A voice system will definitely need a **[REQ. SNR]** of 48 to 55 dB•Hz, depending on the training of the user. This range will also be needed to achieve a throughput of 60 to 100 words/minute for HF email systems. Generally, **[REG. SNR]** values of 70 dB•Hz or higher are only needed by systems where the user demands a very high rate of data transfer and at 90% reliability or by users who require broadcast quality program reception. These typical values of **[REQ. SNR]** are shown in Figure 5.2. Required SNR for Modern HF Systems.

In Hopengarten's Yahoo Group posting he got some of the math right even though his explanation is wrong and parts of it are misleading.

The Taormina reliability goal is 40 dB/1-Hz SNR target for a ham radio 2.4 kHz bandwidth single-sideband (SSB) voice signal. The Taormina design is aimed at achieving this goal 57% of the time, assuming the legal limit for amateur radio of 1,500 watts transmitter power.

{Emphasis added}.

This is wrong for several reasons.

1. As shown in Lane, VOACAP doesn't use a parameter in the form "40 dB/1-Hz SNR"

Hopengarten presumably means "40 dB•Hz". Appending SNR to it is just plain wrong. Hopengarten is attempting to confuse (real) SNR, which is over the full bandwidth, with VOACAP's **[REG. SNR]**, which is for a 1-Hz bandwidth.

Why is he trying to do this?

It is because, in Tom's Showing of Need for Height of Amateur Radio Antenna Support Structure (August 12, 2008 - R. Dean Straw) he says on the bottom of page 5 to the top of page 6:

> **Application to HF analysis**
>
> If we turn closer to our radio domain, High Frequency (HF) shortwave broadcasters, like the Voice of America or the BBC World Service, look for Reliability numbers in the 80 to 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 (such as noise caused by nearby thunderstorms). Commonly required SNR numbers range anywhere 40-70 dB (a higher number means better quality reception).
>
> <u>In the analysis presented below, the Reliability (REL) threshold is set at 57%, using an SNR of 40 dB, for Single Sideband (SSB) voice communications</u>. This is a *very* conservative (low) value for measuring acceptable communications quality.
>
> HF radio communications 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 (ie, not constant) and depends on many factors, including the time of year, time of day, solar (sunspot) activity, local noise sources and other geomagnetic atmospheric conditions. In our test cases we have consistently used very conservative models and accepted a low Reliability REL) factor (57%).

{Emphasis added, and the pages from Tom's Need For Height are reproduced in Exhibit 2}

If Tom's expert meant to say the "**[REG. SNR]** value of 40 dB•Hz" he should have said it.

Indeed, he repeated his mistake on page 6:

> 2. The MAL (Minimum Acceptable Level) is expressed as a percentage of time that communications are available at a specified Signal-to-Noise Ratio (SNR). <u>The SNR value of 40 dB is commonly used in Amateur Radio.</u> It is the *minimum required* SNR for a Single Sideband (Voice) transmission. Single sideband transmissions sometimes require an SNR of up to 50 dB or more, which would further lower the results presented here (ie, this would require a larger/taller antenna system). In other words, in presenting the results here, the assumptions about required Reliability are very modest indeed.

{Emphasis added}

We have three choices:

1. Tom's Expert really meant an SNR of 40 dB, in which case Tom really wants a quality of signal comparable to what the Voice of America strives for.

2. Tom's Expert made a mistake. If he did, what other mistakes did he make?

3. Tom's Expert deliberately confused SNR with VOACAP's **[REG. SNR]** parameter in order to cook the books to justify Tom's desire for a 195' tower (the "I Want It Factor").

Note that:

<u>1.</u> Hopengarten deliberately misquoted Tom. Hopengarten quotes Tom as, "The Taormina reliability goal is 40 dB/1-Hz SNR" when Tom's Need For Height actually says, "In the analysis presented below, the Reliability (REL) threshold is set at 57%, using an SNR of 40 dB, for Single Sideband (SSB) voice communications."

<u>2.</u> CW (Morse Code) requires less SNR than voice. On Page 7 of Tom's *Showing of Need for Height of Amateur Radio Antenna Support Structure,* Item 8, he says:

> 8. SNR required: 40 dB for SSB (voice) communications. This is the minimum acceptable signal-to-noise value needed for voice communication. A minimum SNR of 24 dB can be used for narrow-band CW (Morse code) transmissions if voice isn't possible."

This is a difference of (24-40) = -16 dB. That's huge. It's a factor of 40 (or 0.025 depending on which way you are going). $\{10^{(-16/10)}\}$

You only need 1/40 the amount of signal for CW than you do for voice. I don't know how that affects the Need For Height. Tom does not provide that information.

Most of the countries in Europe and Asia do not have English as their official language or one of their official languages.

While many hams do speak English there is no guaranty that, in an emergency, the ham that Tom contacts will be fluent in English.

Since the purpose of Tom's emergency communications is to relay messages the chances are good that even under the best SNR the message will be garbled.

Morse Code is an International code. (That's why it's called the International Morse Code.)

Assuming that a message sent in Morse Code is properly received it will not be garbled due to language differences.

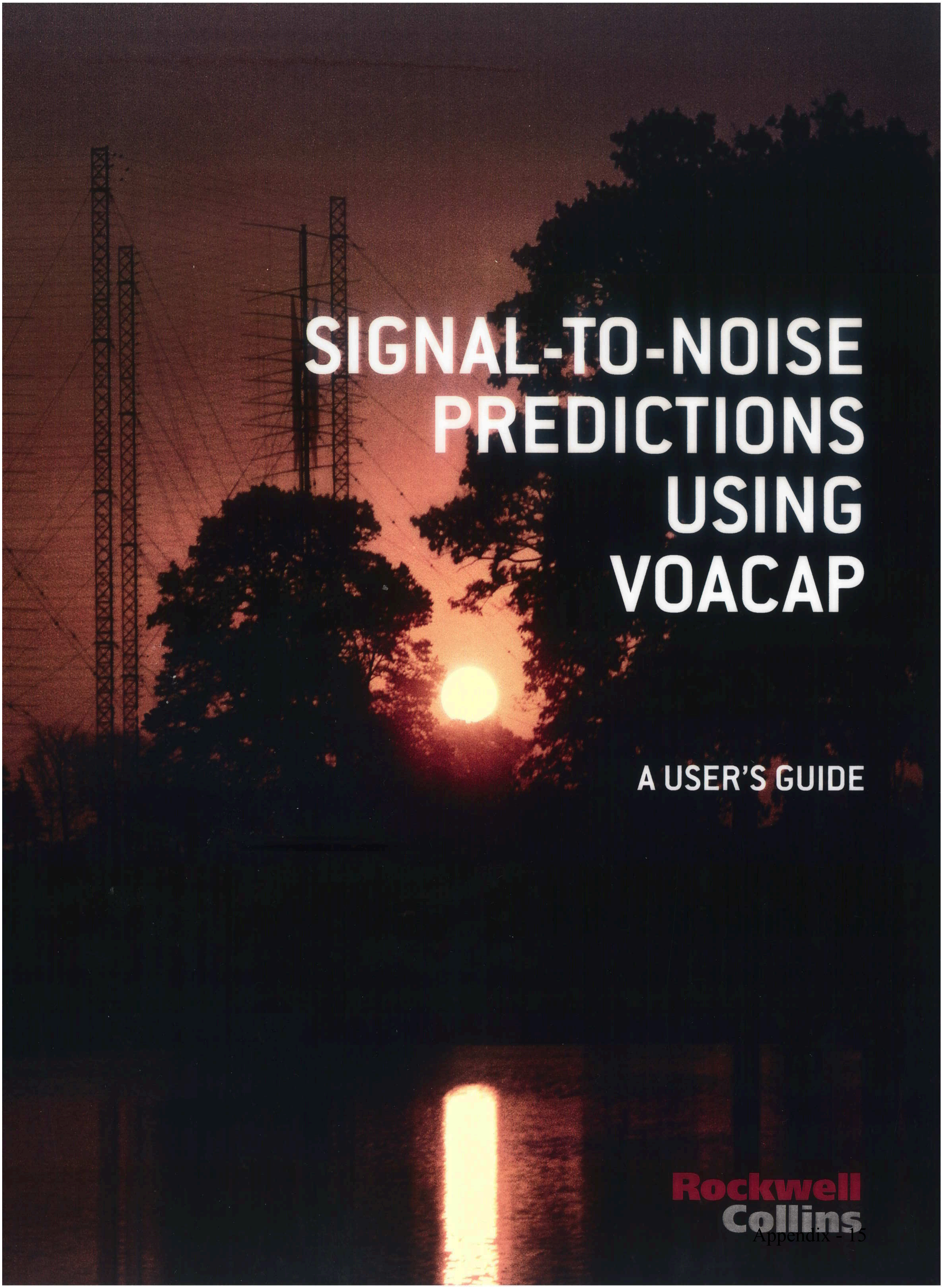
Unless Tom is fluent in a great many languages why does he want to communicate emergency messages only by voice?

73,

Jed Margolin
WA2VEW

Exhibit 1

Exhibit 1



SIGNAL-TO-NOISE PREDICTIONS USING VOACAP

A USER'S GUIDE

Rockwell Collins

Rockwell
Collins

Signal-to-Noise Predictions Using VOACAP, Including VOAAREA

A User's Guide

George Lane
Lane Consultant
Silver Spring, MD

Prepared Under a Consultant Agreement
with
Rockwell Collins, Inc.

Rockwell Collins
350 Collins Road NE
Cedar Rapids, Iowa 52498

523-0780552-10111R
1 April 2001

5.2 Required SNR

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$$
\begin{aligned}
\textbf{\textit{[REQ. SNR]}} &= \text{SNR} + 10 \text{ Log } B_{Hz} \\
&= 0 \text{ dB} + 10 \text{ Log } (1{,}200 \text{ Hz}) \\
&= 30.8 \text{ dB}\bullet\text{Hz}
\end{aligned}
$$

Next, let us consider voice communications over a skywave link. Again, it is well known that trained radio operators can communicate with 90% sentence intelligibility at a SNR of 13 dB[1] in the bandwidth of the receiver (Akima et al. 1969). Most amateur and military HF receivers are set up to operate in a 3-kHz bandwidth for voice communications. Older radios and those used for shortwave broadcast reception require the carrier as well as the upper and lower sidebands and have a bandwidth ranging from 5 to 10 kHz. Using the bandwidth conversion above, we can calculate the ***[REQ. SNR]*** for just-usable voice communications (i.e., 90% sentence intelligibility with trained radio operators) for a 3-kHz single-side-band (SSB) system and a 6-kHz double-side-band (DSB) system:

SSB:

$$
\begin{aligned}
\textbf{\textit{[REQ. SNR]}} &= 13 \text{ dB} + 10 \text{ Log } (3{,}000 \text{ Hz}) \\
&= 48 \text{ dB}\bullet\text{Hz}
\end{aligned}
$$

DSB:

$$
\begin{aligned}
\textbf{\textit{[REQ. SNR]}} &= 13 \text{ dB} + 10 \text{ Log } (6{,}000 \text{ Hz}) \\
&= 51 \text{ dB}\bullet\text{Hz}
\end{aligned}
$$

In 1994, a comparison between measured values of SNR and subjective aural assessment was published (Lane et al. 1994). Conservative values of required SNR for DSB reception are presented in Figure 5.1. Grades of Radiotelephony Service. Remember that these required SNR values are 3 dB higher than needed for SSB reception in a 3 kHz bandwidth. It is interesting to note that with 39 dB•Hz for DSB reception (or 36 dB•Hz for SSB reception) the listener is unable to recognize the voice signal as being wanted or unwanted. However, a highly trained operator can still copy just-usable telegraphy traffic at 31 dB•Hz.

The aural telegraphy value of 44 dB•Hz for DSB, shown in Figure 5.1, is for 95% correct copy and includes a 3-dB protection for differences between operators (Silva 1964). However, for just-usable voice comprehension, the ***[REQ. SNR]*** must increase to about 51 dB•Hz (DSB) and 48 dB•Hz (SSB). An additional 10 dB is needed to assure 99% sentence intelligibility for 90% of the listeners. Another 10 dB is needed to overcome the annoying level of noise. And, another 10 dB is needed to make the background noise only slightly perceptible. A further 10 dB is needed so that the listener hears no noise at all.

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[1] One dB of fade protection against slow Rayleigh-type fading is included in this required SNR.

This presentation is made because it bounds the full range of values for ***[REQ. SNR]*** from 30 to 90 dB•Hz. Some very sophisticated HF data systems will retain connectivity at ***[REQ. SNR]*** in the 30 to 40 dB•Hz range. These systems either slow the transmission rate, repeat missed packets of data, and/or search for a better frequency during periods of low SNR. Somewhat better throughput is afforded if the ***[REQ. SNR]*** is in the range of 40 to 50 dB•Hz. A voice system will definitely need a ***[REQ. SNR]*** of 48 to 55 dB•Hz, depending on the training of the user. This range will also be needed to achieve a throughput of 60 to 100 words/minute for HF email systems. Generally, ***[REQ. SNR]*** values of 70 dB•Hz or higher are only needed by systems where the user demands a very high rate of data transfer and at 90% reliability or by users who require broadcast quality program reception. These typical values of ***[REQ. SNR]*** are shown in Figure 5.2. Required SNR for Modern HF Systems.

Actual ***[REQ. SNR]*** for modern HF radio systems which use sophisticated signal processing schemes are not expressed in terms which are the same as we have defined for use in VOACAP. Great care must be used to insure that required signal-to-noise ratio is converted correctly to conform to the boundary conditions assumed in VOACAP. We must be careful to determine the point in transmission cycle which is both critical and requires the highest ***[REQ. SNR]***. Often, this is when the system is in the initial message-recognition phase.

Many systems can operate at very low SNR, but in order to recognize that a signal is intended for that receiver the SNR must be much higher. Unless the receiver demodulator knows that there is a signal, nothing will be received.

Other systems require a "handshake" from the receive site in order to pass traffic. In this case, the circuit which presents the lowest SNR at the terminus must be used to define system performance. For example, if a system operates from a base station to an out station using a type of service that requires full-duplex connectivity, the out station with small transmitter power and inferior antennas may present the weaker circuit. In this case grade of service should be based on VOACAP link analyses of the out station to base station.

Only a few reports of performance requirements for digital radio transmission systems are known. The US Army commissioned a study of current HF data communication systems (Systems Technology Associates 1975); however, that report is now almost obsolete. Later, the Office of Telecommunications prepared a theoretical study of PCM/PSK systems for possible use on HF SSB radios (Akima 1976). Unfortunately, that study did not include consideration of signaling rate and bandwidth. A more recent study (Lane and Corrington 1982) of a digital message device group (300 baud signaling rate with information transfer at 180 characters/sec) for the US Army presented ***[REQ. SNR]*** in terms designed for use with IONCAP. In that study, the preamble was found to be the weakest portion of the entire signal. Errors in the preamble resulted in a "lost message". That study also looked at message repeats which are often used to increase the probability of reception but to the

Exhibit 2

Exhibit 2

Showing of Need for Height
of Amateur Radio Antenna Support Structure

Submitted on Behalf of
Thomas S. Taormina
Midge A. Taormina
370 Panamint Road
VC Highlands, NV 89521

Prepared by
R. Dean Straw, BSEE
Senior Assistant Technical Editor, ARRL (Retired)
5328 Fulton Street
San Francisco, CA 94121
mailto:n6bv@arrl.net

HF Communications Reliability

For the reader to meaningfully interpret the reliability and signal-strength 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.

DEFINITIONS

Reliability (REL) in a radio communications context, answers the question “How often, on average, can this communication take place at a 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” (or MAL) in use. Several different MALs are commonly accepted in the engineering community.

Measures of Reliability

Imagine watching a distant VHF or UHF analog TV station (not cable), which occasionally fades in and out. If we define the MAL as “a completely clear picture without snow or fuzziness,” then the measured Reliability might be as low as 20 to 30%. On the other hand, if we are willing to accept an MAL of “we can just make out the picture,” then the measured Reliability might jump to 80 to 90%… for the same picture.

Or consider this real-world example. Many areas of the communications industry (broadcasting and networking, to pick two) routinely use a Reliability figure of 99.99% (commonly referred to as the ‘four nines’). In this case, the MAL is usually ‘the transmission (or network) is functioning, and of first quality’ — nothing less. Being “up” 99.99% of the time, conversely, means you are “down” no more than 0.01% or, equivalently, no more than 52 minutes per year. Radio amateurs do not, generally speaking, require such a high level of Reliability.

Application to HF analysis

If we turn closer to our radio domain, High Frequency (HF) shortwave broadcasters, like the Voice of America or the BBC World Service, look for Reliability numbers in the 80 to 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 (such as noise caused by nearby thunderstorms). Commonly required SNR numbers range anywhere from 40-70 dB (a higher number means better quality reception).

In the analysis presented below, the Reliability (REL) threshold is set at 57%, using an SNR of 40 dB for Single Sideband (SSB) voice communications. 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 (ie, 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. In our test cases we have consistently used very conservative models and accepted a low Reliability (REL) factor (57%).

1. A Reliability threshold of 57% is equivalent to four days a week. Imagine if your cell phone or cable TV service worked only four days out of seven during the week — that would be a Reliability of 57%. If your cell phone or cable TV service worked only five days out of seven, that would be a Reliability of 71%. In the area-coverage maps that follow, the Reliability contours are 14, 29, 43, 57, 71 and 86%, to correspond to easily understood levels of one to six days per week.

2. The MAL (Minimum Acceptable Level) is expressed as a percentage of time that communications are available at a specified Signal-to-Noise Ratio (SNR). The SNR value of 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 of up to 50 dB or more, which would further lower the results presented here (ie, this would require a larger/taller antenna system). In other words, in presenting the results here, the assumptions about required Reliability are very modest indeed.

High Frequency (HF) Analysis

PROCEDURE

For the High Frequency (HF or shortwave) radio spectrum, the reliability (REL) of a given path (say, Reno to Europe or to Asia) is commonly defined as the percentage of days that the signal at the receiver's end meets or exceeds a defined Signal-to-Noise ratio (SNR). The REL value depends on many parameters. Several directly or indirectly affect the "take-off" angle as described in the well-documented American Radio Relay League (ARRL) publication that accompanies this report. Other parameters include transmitter power, local terrain, and the hourly and daily absorptive and reflective properties of the ionosphere.

In this section, we use two industry standard software tools: the High Frequency Terrain Analysis (*HFTA*) program, which computes the effect of local terrain on the launch of HF signals into the ionosphere, and the Voice of America Coverage Analysis Program (*VOACAP*), which predicts the reliability (REL) and signal strength (SDBW) value to Asia and to Europe, using two different antenna heights for 3.7 and 7.1 MHz (80 and 40 meters).

The process starts by using the USGS National Elevation Dataset terrain data for the exact latitude and longitude of each of the antenna-support locations in VC Highlands, Nevada. This terrain data is used as input for the *HFTA* (High Frequency Terrain Assessment) program. *HFTA* uses the Taorminas' actual (not theoretical) terrain profiles from each proposed support structure location and the actual antenna parameters (free-space antenna gain and height) as inputs. It provides the actual antenna gain and take-off (elevation) angle data as output.

The output from *HFTA* is then used as the antenna input to the *VOAAREA* program (a subset of *VOACAP*) to produce Area Coverage maps. *VOACAP* is an HF Propagation Analysis software tool developed by the US Department of Commerce / Institute for Telecommunication Sciences over the last four decades. This software suite is in the public domain, and was made possible by funding from the Voice of America (VOA), the US Army, and the US Air Force. Area Coverage is one of many calculations that *VOACAP* can perform. It displays a number of calculated quantities (including REL and signal strength SDBW) for a specified transmitter to a desired reception area, for a specified date, time of day, frequency and sunspot level. The results appear as contours plotted on a world-map background.

On the resulting map, reliability contours that meet our criteria are shown dark green (86%, occurring 6 out of 7 days per week), light green (71%, occurring 5 out of 7 days a week) and then yellow (57%, occurring 4 out of 7 days a week). Those areas that fail to meet the standard 57% reliability criteria are shown in blue, dark gray, light gray or white. **Table 1** shows the relationships.

Table 1, VOAAREA REL Color Coding

Color	% Availability	Days per Week
Dark Green	86%	>6 out of 7
Light Green	71%	5 out of 7
Yellow	57%	4 out of 7
Light Blue	43%	3 out of 7
Dark Gray	29%	2 out of 7
Light Gray	14%	1 out of 7
White	<14%	< 1 out of 7

DETAILED DESCRIPTION OF *VOAAREA* INPUT PARAMETERS

Some parameters are held constant for all the cases analyzed in *VOAAREA*. They are:

2. Transmitter locations: the Taormina antenna-support locations in VC Highlands, Nevada.
3. Transmitter power: 1.5 kW (kilowatts). This is the maximum legal power limit for Amateur-Radio stations.
4. Transmitter frequency: 3.7 and 7.1 MHz (80 and 40 meters).
5. Receiving antenna type: a 75-foot high dipole over flat ground.
6. The Smoothed Sunspot Number (SSN): 100. This is an acceptable average value over the entire 11-year solar sunspot cycle.
7. Month: November.
8. SNR required: 40 dB for SSB (voice) communications. This is the minimum acceptable signal-to-noise value needed for voice transmissions. A minimum SNR of 24 dB can be used for narrow-band CW (Morse code) transmissions if voice isn't possible.
9. Level of local noise: Quiet rural man-made noise.
10. Absorption model: IONCAP.

The transmitting antennas created in *HFTA* and used in *VOAAREA* were:

1. 3-element Yagis at 195 and 70 feet to Europe for 3.7 MHz (RC80HIEU.ELE)
2. 3-element Yagi at 45 feet to Europe for 3.7 MHz (RC80LOEU.ELE)
3. 3-element Yagis at 195 and 70 feet to Japan for 3.7 MHz (RC80HIJA.ELE)
4. 3-element Yagi at 45 feet to Japan for 3.7 MHz (RC80LOJA.ELE)