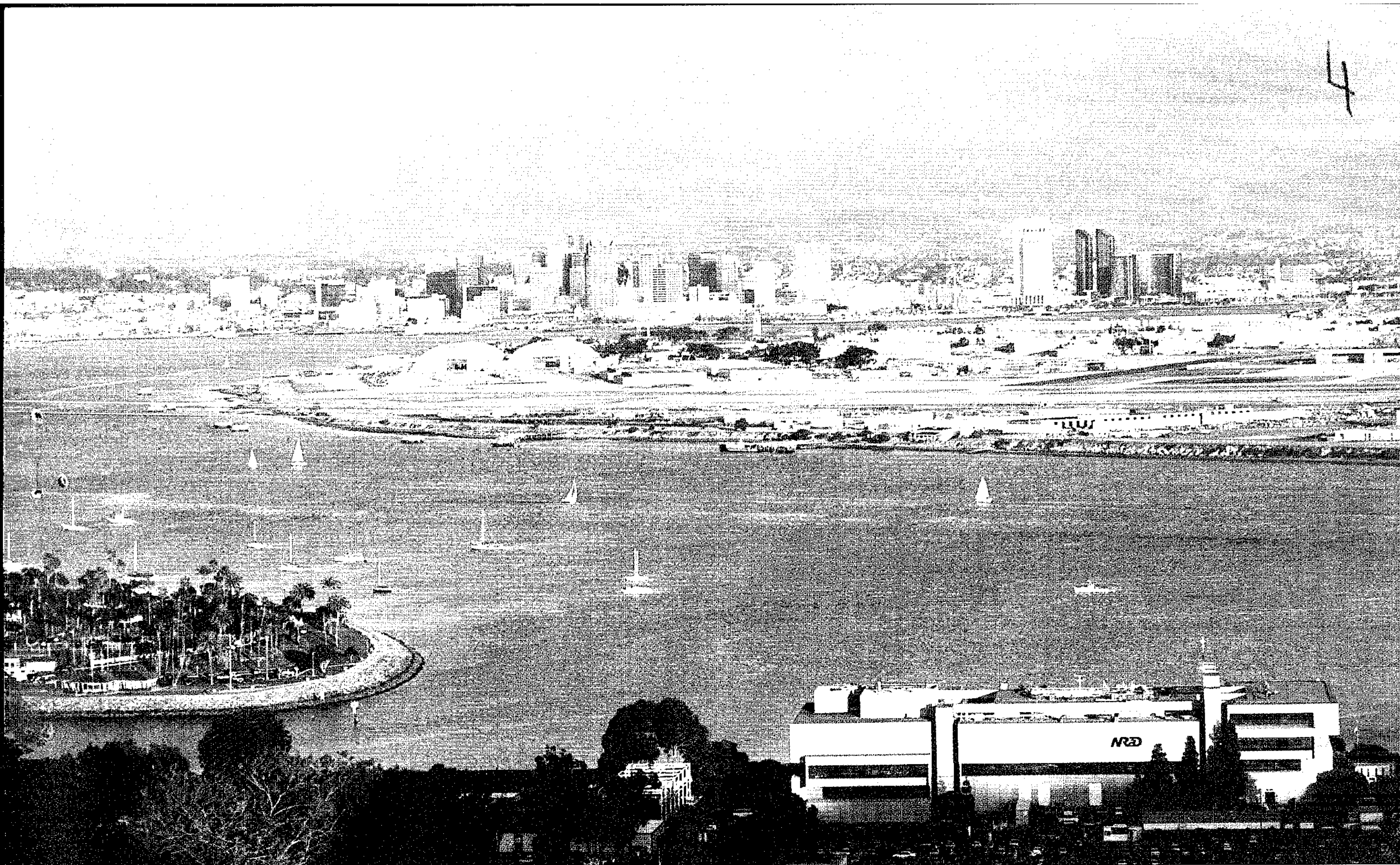

CCIR Report 322 Noise Variation Parameters

D. C. Lawrence

Technical Document 2813
June 1995

Naval Command, Control and
Ocean Surveillance Center
RDT&E Division

San Diego, CA
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NAVAL COMMAND, CONTROL AND
OCEAN SURVEILLANCE CENTER
RDT&E DIVISION
San Diego, California 92152–5001

K. E. EVANS, CAPT, USN
Commanding Officer

R. T. SHEARER
Executive Director

ADMINISTRATIVE INFORMATION

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D. M. Bauman, Head
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Division

SB

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1.0 INTRODUCTION

Naval Command, Control and Ocean Surveillance, RDT&E Division (NRaD) researchers require both signal and noise level predictions to predict the coverage of the Navy's very low frequency (VLF) and low frequency (LF) transmitters. They have performed this task for many years. Currently, researchers use digitized noise level predictions based on a report issued by the Comité Consultatif International Des Radiocommunications, CCIR Report 322-3 (International Telecommunications Union, 1968). Translated from French into English, the name of this international committee is the International Radio Consultative Committee. This technical document addresses the statistical parameters that specify the atmospheric noise variability around the predicted values of F_{am} in CCIR Report 322 (International Telecommunication Union, 1963). These parameters are designated as σ_{Fam}, D_u, D_l, σ_{Du}, and σ_{Dl}. Later revisions of this document, the latest of which is CCIR Report 322-3, have not changed these uncertainty parameters' values.

CCIR Report 322-3 defines these parameters as follows:

σ_{Fam} Standard deviation of F_{am}

F_{am} Median of the hourly values of F_a within a time block

F_a Effective antenna noise figure ($F = 10 \log f$)

fa Effective antenna noise factor that results from the external noise power available from a loss-free antenna

D_u Upper decile, value of the average noise power exceeded 10% of the hours within a time block (dB above the median value for the time block)

D_l Lower decile, value of the average noise power exceeded 90% of the hours within a time block (dB below the median value for the time block)

σ_{Du} The standard deviation of D_u

σ_{Dl} The standard deviation of D_l

The first part of this technical document describes the methods that National Bureau of Standards (NBS) researchers originally used to calculate the predicted CCIR noise variation parameters from the measured data.* The remainder of this document gives suggestions for interpreting and using the CCIR Report 322 noise variation parameters.

* The author of this document, Doug Lawrence, clarified details of this method during several telephone conversations with Mr. Don Spaulding of the National Telecommunications and Information Administration.

2.0 CALCULATION METHOD

Figure 1 shows a diagram that depicts the measured data used to generate each noise contour map in CCIR Report 322. The 4x6 array, labeled "Noise Maps," at the top of the figure, represents all 24 noise contour maps in CCIR Report 322. As an example, the shaded cell represents the noise contour map in CCIR Report 322 for the 1600-hour to 2000-hour time block during the summer. Local time (LT) is used in this 322 series of CCIR reports. This is so that for every measurement site, the data is for the time block interval in local time (e.g. 1600 to 2000, local time, no matter where each site is on the surface of the earth). The 16x8 array, labeled "MEASURED DATA," in the middle of the figure, represents the measured data used to generate this map. Each row corresponds to 1 of the 16 different measurement sites, and each column corresponds to 1 of the 8 different measurement frequencies. As an example, the shaded cell in this array represents the measured data point from measurement site number 14 at frequency E. The 90x4 array at the bottom of the figure, labeled "Time Block," represents all of the individual hourly measurements on which this data point is based. This time block includes four successive hours for each of the approximately 90 days of the season. The total is approximately 360 hourly measurements per year. National Bureau of Standards (NBS) researchers took each hourly measurement during 15 minutes out of the hour, and used this to represent the noise level during the entire hour.

The researchers calculated the median value and upper and lower deciles for each time block based on the 360 hourly noise samples taken per year. This document designates these as FM_{am}, DM_u, and DM_l. The capital M distinguishes parameters directly calculated from measured data from the *predictions* given in CCIR Report 322, which are designated as F_{am}, D_u, and D_l.

2.1 PARAMETERS F_{am} AND σ_{Fam}

CCIR Report 322 presents the predicted values of the median noise level (F_{am}) as one noise level contour map of the world for a frequency of 1 MHz, along with a chart titled "Variation of radio noise with frequency." This chart is used to convert to frequencies other than 1 MHz. Figure 2 depicts this contour map and the frequency variation chart, along with the implied predicted contour maps that researchers could prepare for each of the eight frequencies at which the measurement sites collect data. Curves on each map represent contours of constant noise level. Small rectangles (points) represent the measurement sites. Each map's contours will look the same, but each contour will be labeled differently, following the Frequency Variation Chart. The sites' measured data will also be different on each map because of the different measurement frequencies.

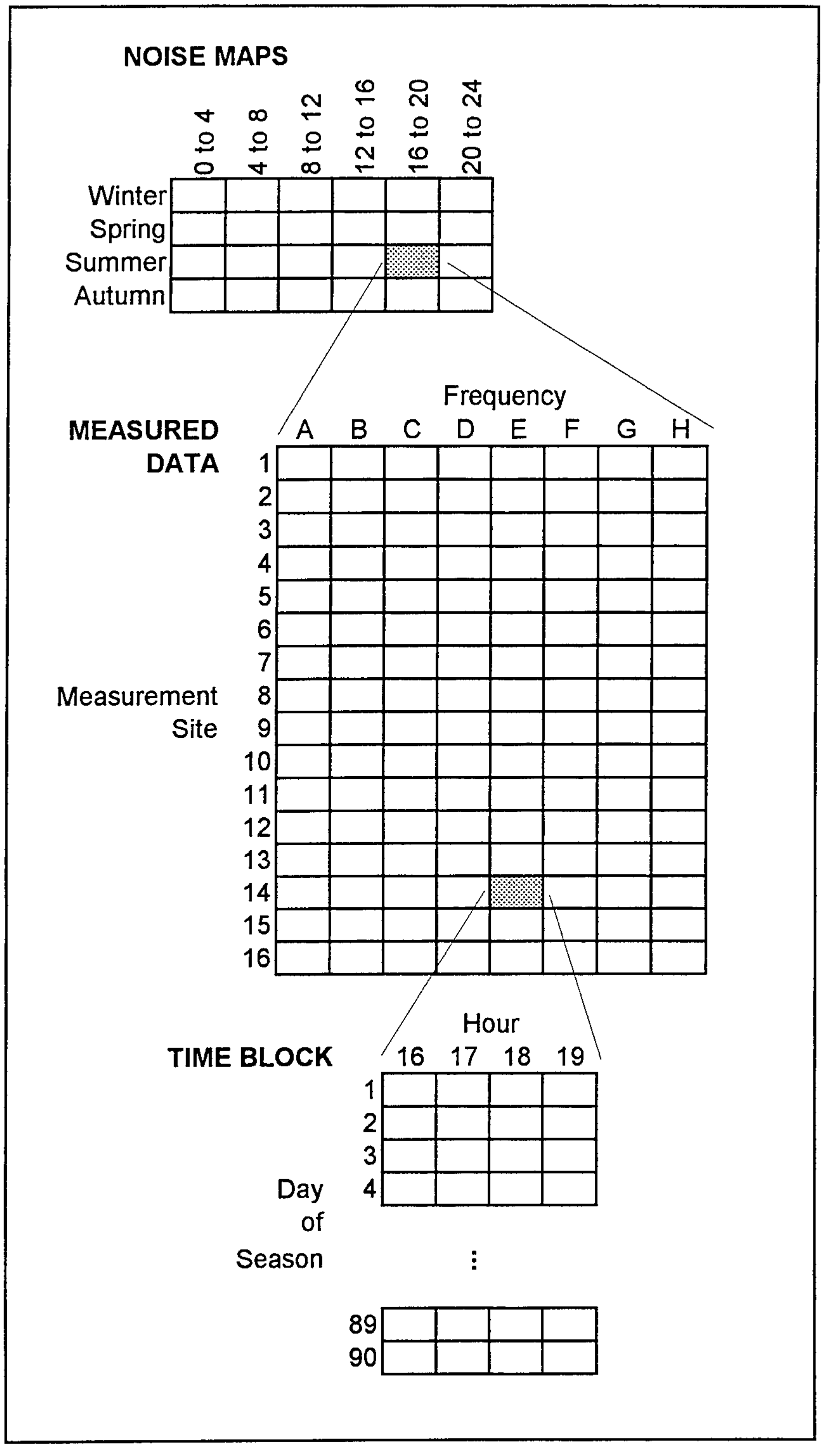

Figure 1. Diagram of supporting measured data for the CCIR Report 322 atmospheric noise contour maps.

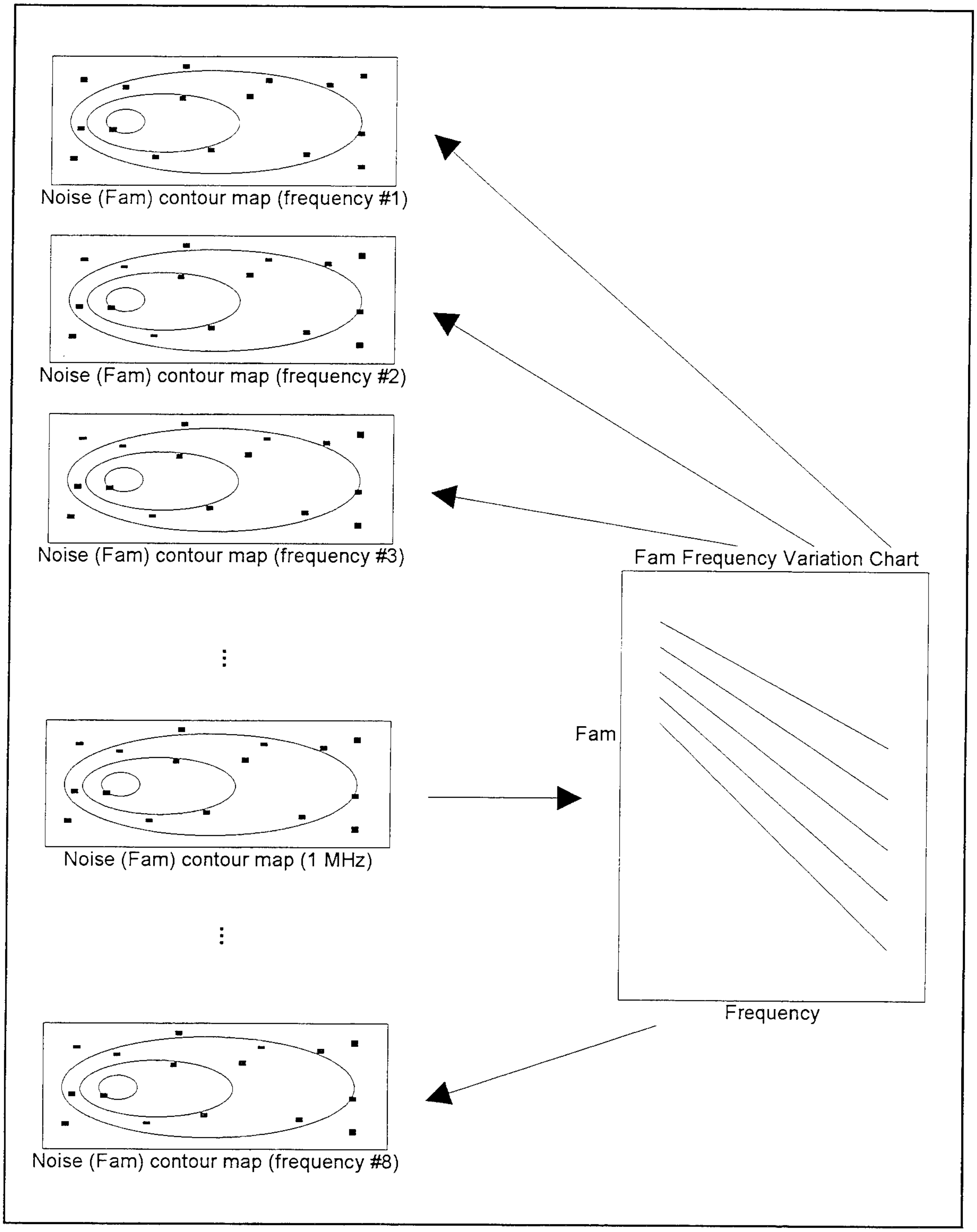

Figure 2. Noise contour variation with frequency.

Researchers originally generated each 1 MHz contour map using the following two steps:

1. For each measurement site, they used the measurements at the other frequencies to interpolate/estimate the 1 MHz values of FM_{am}. In terms of the diagram of figure 1, they used the data in each row of the "Measured Data" array to estimate an associated 1-MHz value.

2. They produced the contours that are on the CCIR Report 322 1 MHz noise contour maps. They accomplished this by various interpolation methods, including reference to thunderstorm day maps, plus some engineering judgment. See CCIR Report 65 (International Telecommunications Union, 1959), CCIR Report 322 (International Telecommunications Union, 1963), CCIR Report 322-3 (International Telecommunications Union, 1968) and National Telecommunications and Information Administration (NTIA) Report 85-173 (Spaulding & Washburn, 1985) for details. Note that the only data points used in this contour generation process were the estimated 1-MHz values of FM_{am}.

Researchers generated the associated Frequency Variation Charts in CCIR Report 322 by a form of constrained least squares fit of the eight implied maps in figure 2 (one map for each measurement frequency) to the measurement data points associated with each map. The curves on the Frequency Variation Charts were computed using least squares mapping as documented in NTIA Report 85-173 (Spaulding & Washburn, 1985, p.106):

$$F_{am}(x,z) = A_1(z) + A_2(z)x + A_3(z)x^2 + \ \dots\ + A_7(z)x^6$$

where $A_i(z) = B_{i,1} + B_{i,2}z, \quad i = 1,7$

$z =$ the 1-MHz F_{am} value (from the contour maps),

and $x = \dfrac{(8)(2^{\log_{10}(f)}) - 11}{4}$

and where f is the desired frequency in MHz.

(This mapping was subject to the constraint $F_{am}(-0.75, z) = z$

i.e., the 1-MHz values must equal z)

The root-mean-square (rms) average of the deviations of the measured data points from the predicted noise values (F_{am}) at these measurement points (after translation by the Frequency Variation Chart), on each of the implied maps in figure 2, is the value of σ_{Fam} given in CCIR Report 322 (International Telecommunication Union, 1963). There is one value of σ_{Fam} for each implied map and its associated frequency. The CCIR Report 322 chart plots this parameter (and others) as a function of frequency by drawing a smooth curve through the values of

σ_{Fam} calculated in this way for each of the eight measurement frequencies. According to Spaulding and Washburn (1985, p. 135), the smooth curves are of the following form:

$$P(x) = a_0 + a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4$$

where $x = \log_{10}(f_{MHz})$

and f_{MHz} is the frequency in MHz.

2.2 PARAMETERS D_u, D_l, σ_{Du}, AND σ_{Dl}

This section describes how NBS researchers calculated the predicted values of the upper and lower deciles of F_{am} from the measured data. They calculated the upper and lower deciles for each time block, (along with the median), which has already been discussed. This document designates the deciles calculated from actual measured time block data as DM_u and DM_l. Refer to the 16x8 array in the middle of figure 1 labeled "MEASURED DATA." A value of DM_u (along with values of DM_l and FM_{am}) is associated with each cell in this array. Only one value of D_u is predicted for the entire contour map of the world. This is different from how F_{am} is treated, with contours showing the variation with geographic location. The NBS researchers calculated the predicted values of D_u by averaging the values of DM_u over all 16 measurement sites. The measurement frequency is held constant (averaging over a single column of the "MEASURED DATA" array in figure 1). They averaged data taken at each measurement site during the same *local* time block (which is the convention in these CCIR reports), and the same season. The associated standard deviation over this same column of measured data is the value of σ_{Du} presented in CCIR Report 322. D_l and σ_{Dl} are calculated in a similar manner. Researchers performed this process at each of the eight measurement frequencies and used it to plot the smooth curves of these parameters in CCIR Report 322.

Although not covered in detail in this technical document, CCIR Report 322 researchers calculated the values of V_{dm} and σ_{Vd} using the same methods that they used to calculate the upper and lower deciles and their associated standard deviations.

3.0 INTERPRETATION AND USE

This section gives suggestions for interpreting and using the CCIR Report 322 (International Telecommunications Union, 1963) noise variation parameters. Topics covered include the CCIR uncertainty parameters themselves, combining these CCIR uncertainty parameters with predicted daily signal variations, plots of the CCIR Report 322 noise variation parameters, and interpolation between time blocks and seasons.

The following factors may affect communication system performance, but are not covered in this technical document.

1. Signal fluctuations caused by sea state
2. Nuclear effects and orbiting airborne transmitters
3. Other types of interference such as platform EMI and jamming transmitters
4. TE-TM effects on airborne receivers

These topics are outside the scope of this technical document, but are covered in DNA Report TR91-35 (Defense Nuclear Agency, 1991); DNA Report TR90-19, (Defense Nuclear Agency,1990); and Pacific Sierra Research Corporation (PSR) Report 2380 (Buckner & Doghestani, 1993).

3.1 UNCERTAINTY PARAMETERS

CCIR Report 322 (International Telecommunications Union, 1963) and CCIR Report 322-3 (International Telecommunications Union, 1968) provide examples in which the noise variation parameters are separated into a time availability parameter and a prediction uncertainty parameter. This approach is based on the method used in NBS Tech Note 102 (Barsis et al., 1961) for a tropospheric communication link. Its usefulness for VLF communication links is questionable. Section 3.1.1 describes this approach. Section 3.1.2 describes a more straightforward method that simply combines all uncertainty parameters into a single overall uncertainty parameter.

Note that CCIR Report 322 assumes that the probability distribution of each noise and signal variation parameter is log-normal. When the parameter is expressed in dB it will be the well-known, normal distribution.

For either approach to using the CCIR noise variation parameters, researchers calculate the expected value of the signal-to-noise ratio (SNR) in dB as the difference between the expected signal level (in dB) and the expected noise level (in dB). They obtain the expected signal value from propagation calculations not addressed in this document. The expected noise value is the predicted median noise level from CCIR Report 322 (F_{am}).

3.1.1 Separate Time Availability and Prediction Uncertainty Parameters

Researchers assume that the time availability parameter (random variable D_{TA}, the deviation from F_{am} due to time variability) has the following log-normal probability distribution (variables are expressed in dB so the expression is for a normal distribution):

$$p(z) = \frac{1}{\sigma_{TA}\sqrt{2\pi}} e^{-\frac{z^2}{2\sigma_{TA}^2}}$$

$$\text{where} \quad \sigma_{TA} = \frac{D_u}{1.28}$$

The associated cumulative distribution is:

$$P_{TA}(D_{TA}) = \int_{-\infty}^{D_{TA}} \frac{1}{\sigma_{TA}\sqrt{2\pi}} e^{-\frac{z^2}{2\sigma_{TA}^2}} dz$$

where

$P_{TA}(D_{TA})$ is the time availability probability corresponding to a deviation from F_{am} of D_{TA}

which can also be expressed as follows using the standard normal deviate (t) that is readily available via software routines and tables:

$$P(t) = \int_{-\infty}^{t} \frac{1}{\sqrt{2\pi}} e^{-\frac{z^2}{2}} dz$$

where

$$t = \frac{D_{TA}}{\sigma_{TA}}$$

and $t(P)$ is used to represent the inverse of this function (standard normal deviate associated with cumulative probability P)

A useful expression for calculating the D_{TA} corresponding to a time availability of P_{TA} when the associated standard deviation is σ_{TA} can be written as follows:

$$D_{TA}(P_{TA}) = t(P_{TA}) \cdot \sigma_{TA}$$

Note that D_l is normally not used except when estimating receive systems' sensitivity requirements. Researchers combine all of the other variation parameters into a single prediction uncertainty parameter (random variable D_{SP}, the deviation from F_{am} due to prediction uncertainties), used in CCIR Report 322 (International Telecommunications Union, 1963) examples, to determine the "service probability." The researchers assume that this prediction uncertainty parameter has the following log-normal probability distribution (because all of the parameters on which it is based are assumed to be log-normal, with the dB values of the contributing errors adding):

$$p(z) = \frac{1}{\sigma_{SP}\sqrt{2\pi}} e^{-\frac{z^2}{2\sigma_{SP}^2}}$$

where

$$\sigma_{SP} = \sqrt{\sigma_S^{\ 2} + \sigma_R^{\ 2} + \sigma_{Fam}^{\ \ 2} + \left(t(P_{TA}) \frac{\sigma_{Du}}{1.28} \right)^2}$$

where σ_S is the standard deviation of the signal level prediction

σ_R is the standard deviation of the required signal to noise ratio

σ_{Fam} is the standard deviation of F_{am} from CCIR - 322

σ_{Du} is the standard deviation of D_u from CCIR - 322

$t(P_{TA})$ is the standard normal deviate corresponding to the cumulative probability, P_{TA}

The associated cumulative distribution is:

$$P_{SP}(D_{SP}) = \int_{-\infty}^{D_{SP}} \frac{1}{\sigma_{SP}\sqrt{2\pi}} e^{-\frac{z^2}{2\sigma_{SP}^2}} dz$$

where $P_{SP}(D_{SP})$ is the prediction uncertainty probability corresponding to a deviation from F_{am} of D_{SP}

Again, this can also be expressed using the standard normal deviate (t), but in this case with:

$$t = \frac{D_{SP}}{\sigma_{SP}}$$

A useful expression for calculating the D_{SP} corresponding to a time availability of P_{SP} when the associated standard deviation is σ_{SP} can be written as follows:

$$D_{SP}(P_{SP}) = t(P_{SP}) \cdot \sigma_{SP}$$

In the equation for σ_{SP}, σ_S represents the standard deviation of the signal-level prediction instead of the σ_p used in an example in CCIR Report 322-3 (International Telecommunications Union, 1968). The values of σ_S associated with NRaD VLF/LF signal predictions cannot be easily broken apart into separate time availability and prediction uncertainty components. Therefore, this standard deviation is a mixture of these two components. Because of this, working with a separate σ_{SP} and σ_{TA} appears to not be a useful way of viewing the uncertainties associated with NRaD VLF/LF propagation predictions (even though this is the approach implied by the CCIR Report 322 examples). Combining them into a single overall standard deviation, as discussed in section 3.1.2, appears to be the best approach.

Also, for the VLF predictions done at NRaD, researchers currently give σ_R a zero value because field measurements show that the Navy's current VLF receive systems are fairly insensitive to the V_d parameter of atmospheric noise. In the CCIR Report 322 (International Telecommunications Union, 1963) example, researchers used the standard deviation of V_d to estimate a value to use for σ_R. Also note that the reason σ_{Du} is divided by 1.28 and then multiplied by $t(P_{TA})$ in the expression for σ_{SP} is to scale it to the appropriate standard deviation that corresponds to P_{TA}. This follows the approach implied by figure 28 in CCIR Report 322-3 (International Telecommunications Union, 1968).

So far, this section has specified two log-normal distributions.

1. Random variable D_{TA} with standard deviation σ_{TA} for the time variation of the expected SNR (mainly over day in the season, but also influenced by the hour-to-hour variation over the associated 4-hour time block)

2. Random variable D_{SP} with standard deviation σ_{SP} for the variation of the expected SNR due to the prediction uncertainties

The actual value of SNR will be greater than or equal to the expected value of SNR 50% of the time. Since we are dealing with log-normal distributions, researchers can calculate the SNR for time availabilities other than 50% by using the cumulative probability distribution of the Standardized Normal Random Variable (when all parameters are expressed in dB). Table 1 provides some points on this cumulative distribution. The general expression for calculating the SNR for other time availabilities and service probabilities is as follows:

$$SNR(P_{TA},P_{SP}) = SNR(50\%,50\%) - D_{TA}(P_{TA}) - D_{SP}(P_{SP})$$

or

$$SNR(P_{TA},P_{SP}) = SNR(50\%,50\%) - t(P_{TA})\cdot\sigma_{TA} - t(P_{SP})\cdot\sigma_{SP}$$

Table 1. Cumulative probability points of the standardized normal random variable.

Cumulative Probability %	Corresponding Value of the Standardized Normal Random Variable
50	0.00
70	0.52
80	0.84
90	1.28
95	1.64
97	1.88
98	2.06
99	2.33
99.5	2.59
99.9	3.10
99.99	3.62

The following equation is an example of this type of calculation for a time availability of 95% and a prediction uncertainty of 99%. The SNR that can be achieved with a 95% time availability would be the expected value of SNR, designated as SNR(50%, 50%), minus 1.64 times σ_{TA}, where the 1.64 factor was read from table 1. However, this still leaves only a 50% probability (confidence) that this 95% time availability will be achieved (because of the uncertainties associated with the prediction process). To improve this prediction confidence to 99%, researchers would subtract an additional term from SNR(95%, 50%), which was just calculated. This term would be 2.33 times σ_{SP}, and the result would be designated SNR(95%, 99%). The expression for these calculations is as follows:

$$SNR(95\%,99\%) = SNR(50\%,50\%) - 1.64 \cdot \sigma_{TA} - 2.33 \cdot \sigma_{SP}$$

Researchers can then describe the uncertainties associated with SNR(95%, 99%) as follows: "For the location, season, time, etc. of this prediction, we will have a SNR greater than or equal to SNR(95%, 99%) for 95% of the days of the season with a prediction confidence of 99%." CCIR Report 322 (International Telecommunications Union, 1963) refers to this prediction confidence as "Service Probability." One way of describing this prediction confidence (assuming there were no time variation components in σ_{SP}) is to say that "for 99% of the geographic points on the world map, for this season and time block, the actual SNR will be large enough to provide the specified time availability (95% time availability in this example)." The prediction uncertainty term could also be thought of as a "safety factor," applied to make sure prediction uncertainties do not prevent meeting the predicted time availability.

3.1.2 A Single Combined Uncertainty Parameter

The previous section mentioned that the σ_S used in NRaD VLF/LF coverage predictions cannot be easily separated into distinct time availability and prediction uncertainty components. Therefore, σ_{SP} is also a mixture of these components. Because of this lack of complete separation of components, they might as well be combined into a single overall variability parameter, which is also easier to understand and use. This document designates the random variable for this overall variability parameter as D_{OV}. Researchers assume that it has a log-normal distribution (with the dB values of the two contributing errors adding) and a standard deviation of σ_{OV}, calculated as follows:

$$\sigma_{OV} = \sqrt{\sigma_{TA}^{\ 2} + \sigma_{SP}^{\ 2}}$$

where $$\sigma_{TA} = \frac{D_u}{1.28}$$

and $$\sigma_{SP} = \sqrt{\sigma_S^{\ 2} + \sigma_R^{\ 2} + \sigma_{Fam}^{\ 2} + \left(\frac{\sigma_{Du}}{1.28}\right)^2}$$

where σ_S is the standard deviation of the signal level prediction

σ_R is the standard deviation of the required signal to noise ratio

D_u is the upper decile value from CCIR - 322

σ_{Fam} is the standard deviation of F_{am} from CCIR - 322

σ_{Du} is the standard deviation of D_u from CCIR - 322

See the previous section for more details on σ_{TA} and σ_{SP}. In the expression for σ_{SP}, $t(P_{TA})$ has been set to a value of one to account for the use of the D_u term as a standard deviation ($D_u/1.28$). The above calculation specifies a single log-normal distribution (random variable D_{OV} with standard deviation σ_{OV}) of the overall variation of the SNR predictions around the predicted expected value of SNR. D_{TA} and D_{SP} are assumed to be independent log-normal random variables. Researchers can use table 1 again to find the factor needed to calculate the term to achieve a desired overall confidence level. The general expression for calculating the SNR for a desired overall availability is as follows:

$$\text{SNR}(P_{OV}) = \text{SNR}(50\%) - D_{OV}(P_{OV})$$

or

$$\text{SNR}(P_{OV}) = \text{SNR}(50\%) - t(P_{OV})\cdot\sigma_{OV}$$

The following expression is an example. The SNR that can be achieved with an overall availability level of 90% (designated as SNR(90%)), would be the expected value of the SNR

(50% confidence level) minus 1.28 times σ_{OV}, where the 1.28 factor was read from table 1. The expression for these calculations is as follows:

$$SNR(90\%) = SNR(50\%) - 1.28 \cdot \sigma_{OV}$$

This confidence level means that for the season and time block of this prediction, 90% of the measured values will be greater than or equal to the corresponding predicted SNR(90%), when calculated over both day of the season and all geographic locations on the world map.

If researchers must calculate the overall availability when the SNR margin above a receiver "good copy" threshold is known, straightforward use of the cumulative standard normal distribution will provide the corresponding overall confidence value directly from the value of the margin after being normalized by dividing it by σ_{OV} (see table 1 for a number of points in this cumulative distribution).

In the calculations of the overall uncertainty probability distribution, researchers assume the log-normal distribution for time variability (random variable D_{TA} with standard deviation σ_{TA}) to be a symmetrical log-normal distribution with a standard deviation of $D_u/1.28$. Generally, it is not symmetrical because in CCIR Report 322 (International Telecommunications Union, 1963), D_u specifies the positive half of the distribution and D_l specifies the negative half of the distribution. Since D_u does not necessarily equal D_l, this distribution is not necessarily symmetrical. Because of this asymmetry, the probability distribution of D_{TA} is not exactly a log-normal distribution. However, the impact on the overall confidence level term is not very significant for the following reasons.

1. D_u and D_l are close to equal for all seasons except winter (refer to plots of these parameters in section 3.3).

2. In the winter (when they are significantly different), D_u is always larger than D_l, which means this approximate uncertainty calculation, using D_u only, is more conservative than it would be if an exact calculation of the distribution were done.

3. The inaccuracy in the shape of the distribution becomes less and less significant as you move out on the tail of the distribution on the side controlled by D_u. Because the noise level is *subtracted* from the signal level when calculating SNR, the tail of the SNR distribution controlled by D_u is the lower side, rather than the upper.

Each reason reduces the impact of the inaccuracy. Researchers should be able to safely ignore the impact of this asymmetry when performing the calculations described in this document.

3.2 COMBINING PREDICTED DAILY SIGNAL VARIATIONS WITH CCIR-BASED NOISE PARAMETERS

NRaD researchers currently predict signal levels as a function of a number of parameters, including time of day and geographic location. These predictions are normally done for each half-hour of the day. For each of these half-hour signal-level predictions, a SNR is calculated. Each of these SNRs have all of the variability parameters (described in this document) associated with them.

It may be desirable to combine this predicted time variation of the expected SNR with the associated CCIR-derived variability parameters to produce an overall time availability or overall general availability number.

Researchers can do this by calculating the probability of exceeding the "good copy" SNR threshold of the receiver system for each half-hour of the day (and each geographic point of interest). They use the variability parameters discussed earlier to specify the appropriate log-normal probability distributions needed to calculate this probability.

Now researchers can combine the probabilities of exceeding the receiver threshold associated with each half-hour by averaging them over the day (48 probabilities, one for each half-hour). This calculation results in either an overall time availability at a fixed service probability for the day, or an overall availability number for the day, depending on whether the researchers used σ_{TA} and σ_{SP}, or just σ_{OV} to specify the log-normal distribution(s). If the researchers desire a number representing the expected number of hours of coverage per day, then they should multiply this overall availability probability by 24 (the number of hours per day).

3.3 PLOTS OF CCIR REPORT 322 NOISE PARAMETERS

Figures 3 through 6 contain plots of CCIR Report 322 (International Telecommunications Union, 1963) noise variation parameters for a frequency of 30 kHz, scaled, if necessary, to be in the form of an appropriate standard deviation. Researchers can scale these standard deviation values to other points on the cumulative normal curve by using the factors in table 1. There is one plot for each season, showing the noise parameters expressed in dB vs. Time-Block. In the legend, "SIG" is used in place of the Greek letter "σ." These CCIR Report 322 parameters do not depend on geographic location. They are the same for every point on the earth. These plots also represent the noise variation parameters in CCIR Report 322-3 (International Telecommunications Union, 1968) since they are unchanged from those of CCIR-322. Table 2 shows the spreadsheet which provided the data for figures 3 through 6.

SIGdu/1.28 and SIGdl/1.28 are both significantly smaller than the other noise variation parameters. Because of this, when SIGdu/1.28 is combined with Du/1.28 and SIGFam in the square root of sum of squares equation to arrive at the standard deviation of the overall variation (SIGov), it has a relatively minor effect on the value of SIGov. The calculation of SIGov for these charts does not include the signal-level variation parameter σ_S or the required SNR variation parameter σ_R, which were described earlier in this report. For a complete picture, researchers would need to combine these two standard deviations with SIGov using the square root of sum of squares formula. Also, the reason SIGdu is divided by 1.28 is to scale it to the appropriate standard deviation that corresponds to Du/1.28. This agrees with the approach implied by figure 28 in CCIR Report 322-3 (International Telecommunications Union, 1968). This comment also applies to SIGdl.

Time blocks have units of local time (LT). This is the convention used in CCIR Report 322 (International Telecommunications Union, 1963) and CCIR Report 322-3 (International Telecommunications Union, 1968). At first it may seem unusual that each noise contour map (and its associated table of noise variation parameters) is for a single *local* time block over the whole world, i.e., 8 to 12 (LT) at every point on the surface of the earth. This approach gives the needed noise predictions correctly, as long as this detail is considered. Drawing the contours using this local time convention gave better accuracy. Apparently, this was because there was not as much difference in the noise levels recorded at a single local time at every point on the earth (thunderstorm activity is usually correlated with local time) when compared to using a single universal time (UT) where local times vary as they do in the real world. The associated chart of noise variability parameters (such as Du) is also for local time blocks. Note that this means that the averaging process used to compute these noise variation parameters is also based on measurements over the entire world taken at the same local time (not at the same universal time) and season.

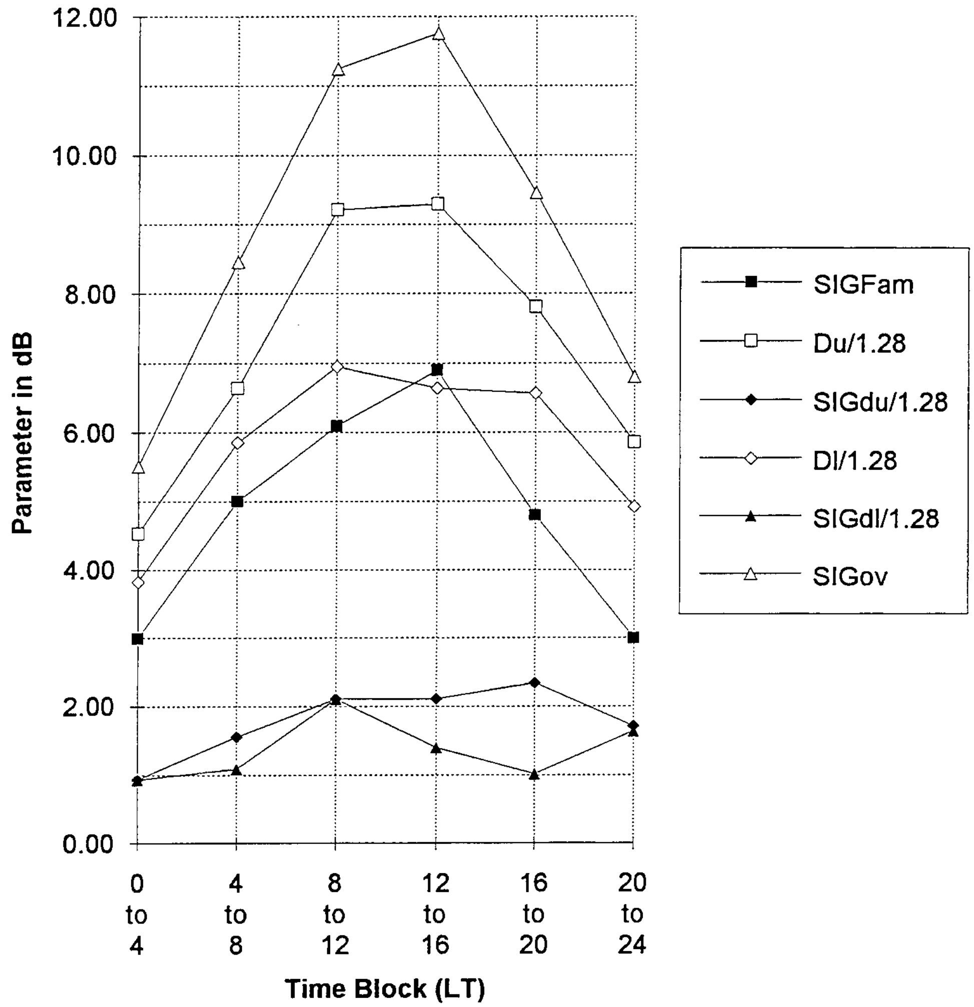

Figure 3. CCIR 322 noise parameters, winter, 30 kHz.

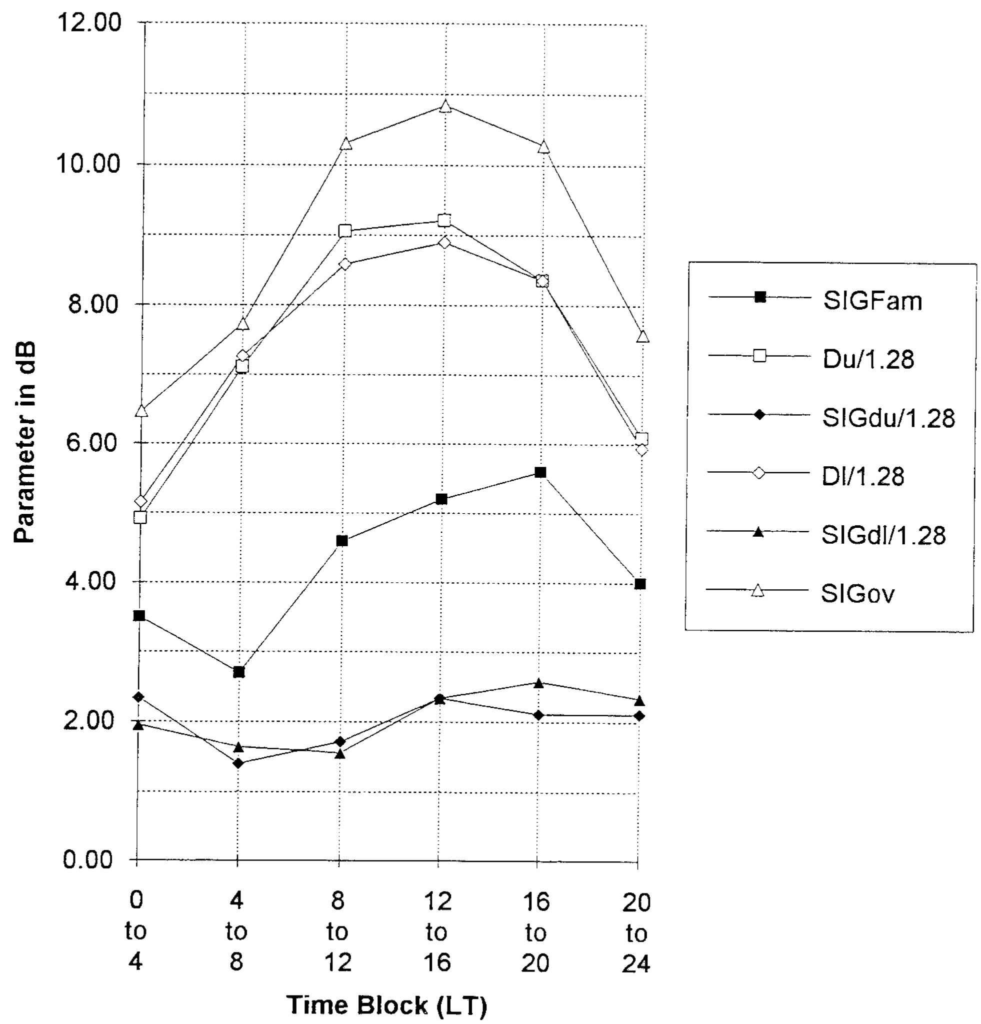

Figure 4. CCIR 322 noise parameters, spring, 30 kHz.

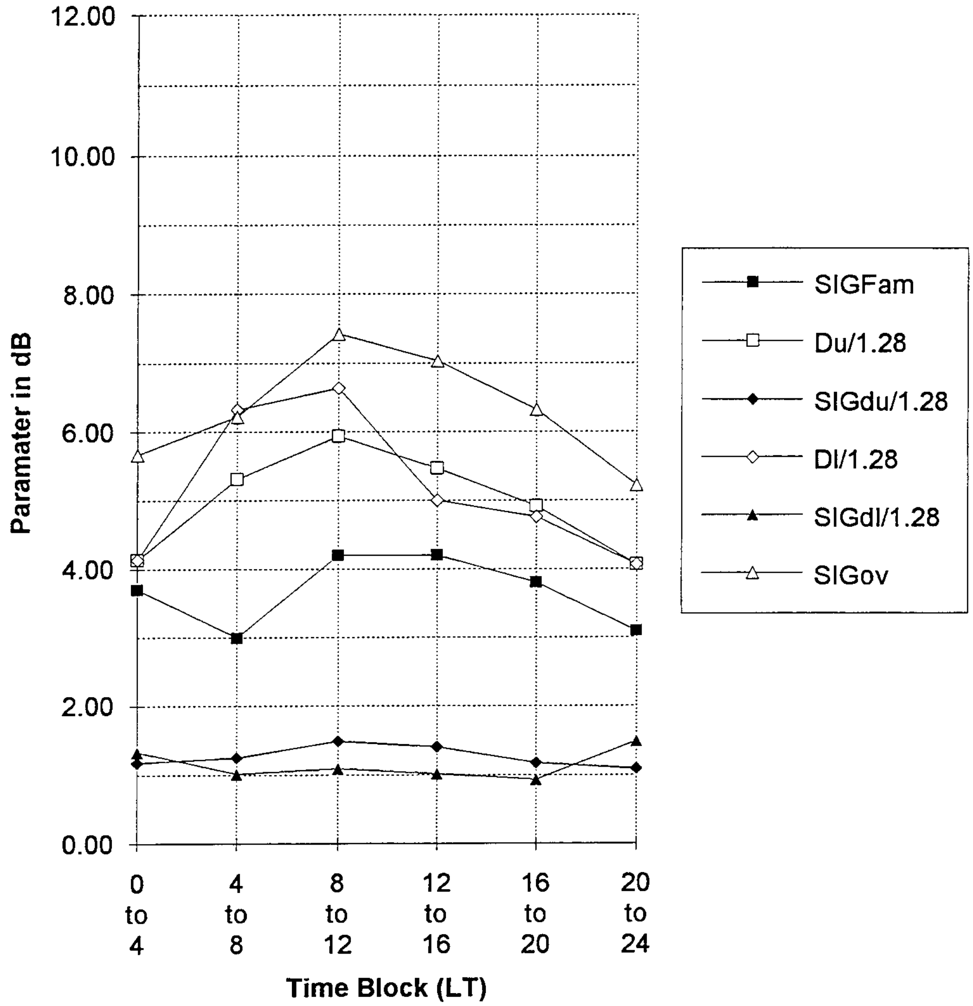

Figure 5. CCIR 322 noise parameters, summer, 30 kHz.

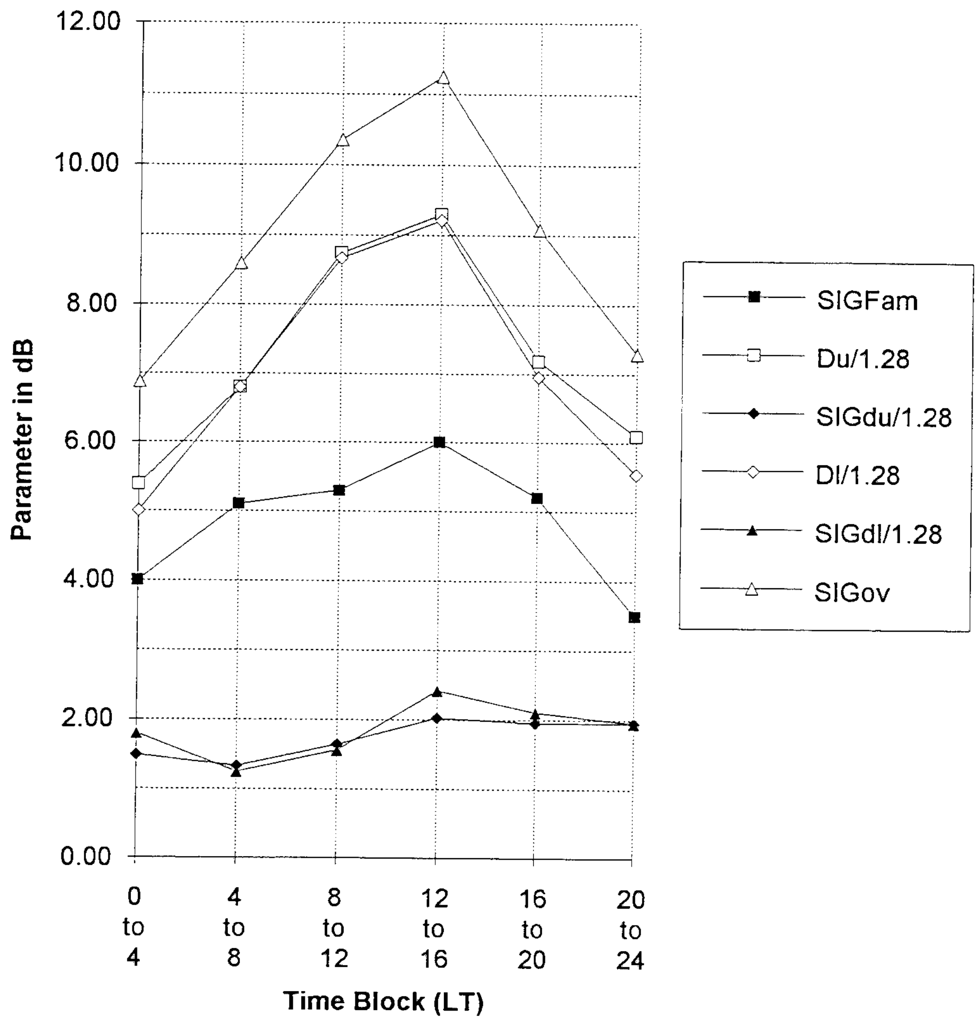

Figure 6. CCIR 322 noise parameters, autumn, 30 kHz.

Table 2. CCIR-332 (&CCIR332-3) statistical parameters (at 30 kHz).

SIGov=SQRT(SIGFam^2+(Du/1.28)^2+(SIGdu/1.28)^2)

Season	Time-Blk	Du	SIGdu	Dl	SIGdl	SIGFam	Du/1.28	SIGdu/1.28	Dl/1.28	SIGdl/ 1.28	SIGov
Winter	0 to 4	5.80	1.20	4.90	1.20	3.00	4.53	0.94	3.83	0.94	5.51
Winter	4 to 8	8.50	2.00	7.50	1.40	5.00	6.64	1.56	5.86	1.09	8.46
Winter	8 to 12	11.80	2.70	8.90	2.70	6.10	9.22	2.11	6.95	2.11	11.25
Winter	12 to 16	11.90	2.70	8.50	1.80	6.90	9.30	2.11	6.64	1.41	11.77
Winter	16 to 20	10.00	3.00	8.40	1.30	4.80	7.81	2.34	6.56	1.02	9.46
Winter	20 to 24	7.50	2.20	6.30	2.10	3.00	5.86	1.72	4.92	1.64	6.80
Spring	0 to 4	6.30	3.00	6.60	2.50	3.50	4.92	2.34	5.16	1.95	6.48
Spring	4 to 8	9.10	1.80	9.30	2.10	2.70	7.11	1.41	7.27	1.64	7.73
Spring	8 to 12	11.60	2.20	11.00	2.00	4.60	9.06	1.72	8.59	1.56	10.31
Spring	12 to 16	11.80	3.00	11.40	3.00	5.20	9.22	2.34	8.91	2.34	10.84
Spring	16 to 20	10.70	2.70	10.70	3.30	5.60	8.36	2.11	8.36	2.58	10.28
Spring	20 to24	7.80	2.70	7.60	3.00	4.00	6.09	2.11	5.94	2.34	7.59
Summer	0 to 4	5.30	1.50	5.30	1.70	3.70	4.14	1.17	4.14	1.33	5.68
Summer	4 to 8	6.80	1.60	8.10	1.30	3.00	5.31	1.25	6.33	1.02	6.23
Summer	8 to 12	7.60	1.90	8.50	1.40	4.20	5.94	1.48	6.64	1.09	7.42
Summer	12 to 16	7.00	1.80	6.40	1.30	4.20	5.47	1.41	5.00	1.02	7.04
Summer	16 to 20	6.30	1.50	6.10	1.20	3.80	4.92	1.17	4.77	0.94	6.33
Summer	20 to 24	5.20	1.40	5.20	1.90	3.10	4.06	1.09	4.06	1.48	5.23
Autumn	0 to 4	6.90	1.90	6.40	2.30	4.00	5.39	1.48	5.00	1.80	6.87
Autumn	4 to 8	8.70	1.70	8.70	1.60	5.10	6.80	1.33	6.80	1.25	8.60
Autumn	8 to 12	11.20	2.10	11.10	2.00	5.30	8.75	1.64	8.67	1.56	10.36
Autumn	12 to 16	11.90	2.60	11.80	3.10	6.00	9.30	2.03	9.22	2.42	11.25
Autumn	16 to 20	9.20	2.50	8.90	2.70	5.20	7.19	1.95	6.95	2.11	9.08
Autumn	20 to 24	7.80	2.50	7.10	2.50	3.50	6.09	1.95	5.55	1.95	7.29

3.4 INTERPOLATION BETWEEN TIME BLOCKS AND SEASONS

There are fairly large jumps in F_{am} and in the noise variation parameters from hour-to-hour and from season-to-season. Researchers should consider interpolation methods and use the most appropriate method.

Dave Niemoller, Science Applications International Corporation, presented an interesting method at the Fifth Office of Naval Research Workshop on ELF/VLF Radio Noise (Physical Research, Inc.for ONR, 1990).* See appendix A for viewgraphs from his 1990 ELF/VLF Radio Noise presentation. Mr. Niemoller used the interpolation method presented at this workshop for interpolating between the time blocks (e.g., to get hourly F_{am} values instead of just 4-hour time block values). This method preserves the time block F_{am} values (when a number of evenly spaced interpolated values within a time block are averaged), and can also estimate the reduction in D_u attributable to the change with time of the finer (interpolated) F_{am} values. Note that since D_u is an average over all points on the world map, this estimated reduction in D_u should have been based on an average over the world map of these estimated reductions. This is because the range of noise level variation is different at different spots on the surface of the earth. This interpolation method could probably also be applied to interpolating between seasons (e.g., to get monthly F_{am} values instead of just seasonal values). Mr. Niemoller has computer programs written in FORTRAN that implement his interpolation method.

* The author of this document, Doug Lawrence, clarified details of this interpolation method during several telephone conversations with Mr. Niemoller.

Figures 7 through 16 are plots of F_{am} vs. (*local*) time block and of F_{am} vs. season for the following locations:

20N, 60W	(near Puerto Rico)
60N, 30W	(between Iceland and Greenland)
35N, 30E	(East Mediterranean)

The range and character of the variations are different for different locations. The figures also show the size of the jumps in F_{am} from time-block to time-block and from season to season. Table 3 is the spreadsheet with the data on which figures 7 through 16 are based.

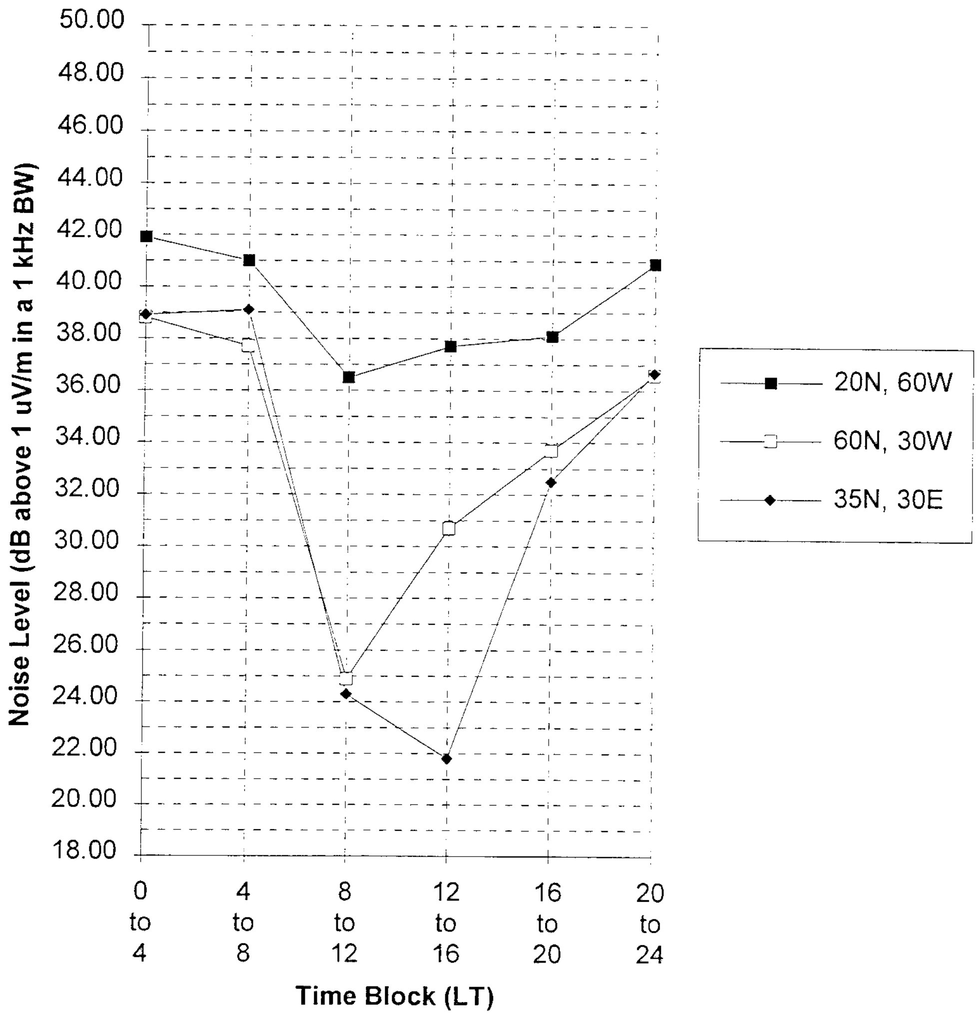

Figure 7. CCIR 322-3 noise levels for three different locations, winter, 30 kHz.

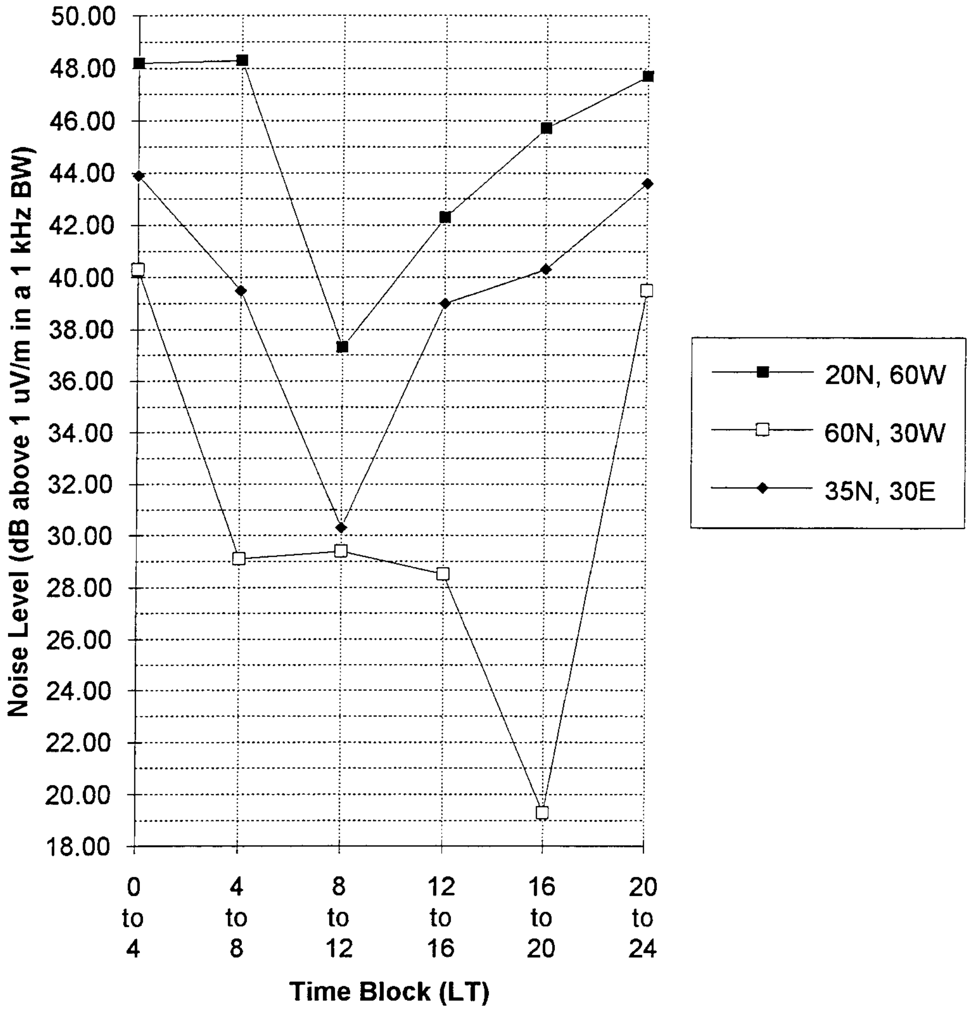

Figure 8. CCIR 322-3 noise levels for three different locations, spring, 30 kHz.

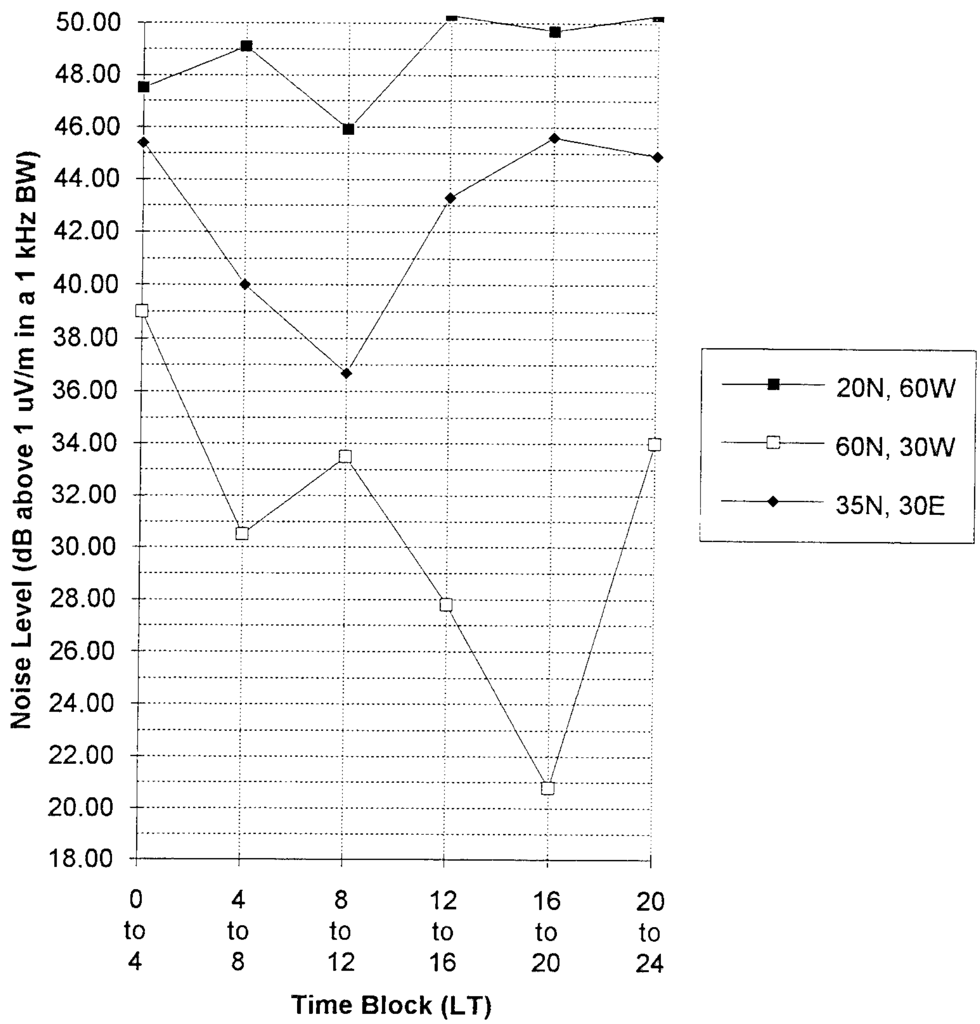

Figure 9. CCIR 322-3 noise levels for three different locations, summer, 30 kHz.

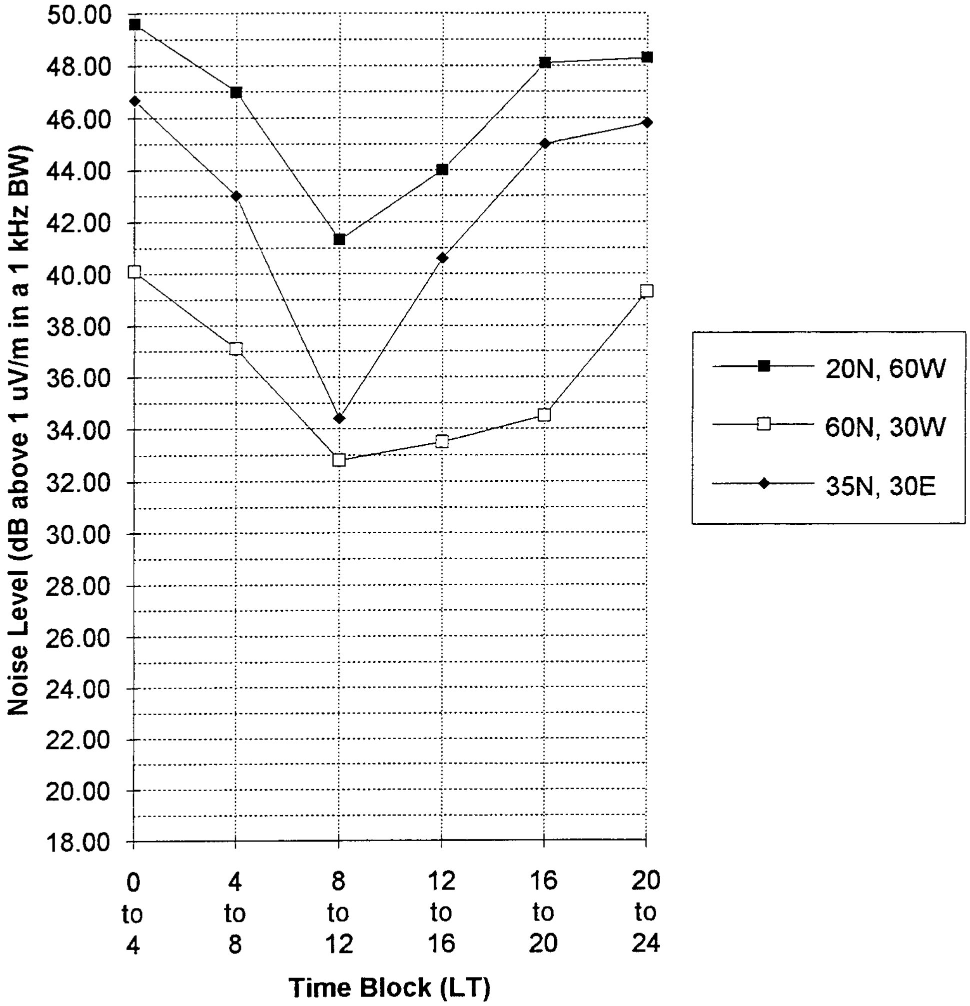

Figure 10. CCIR 322-3 noise levels for three different locations, autumn, 30 kHz.

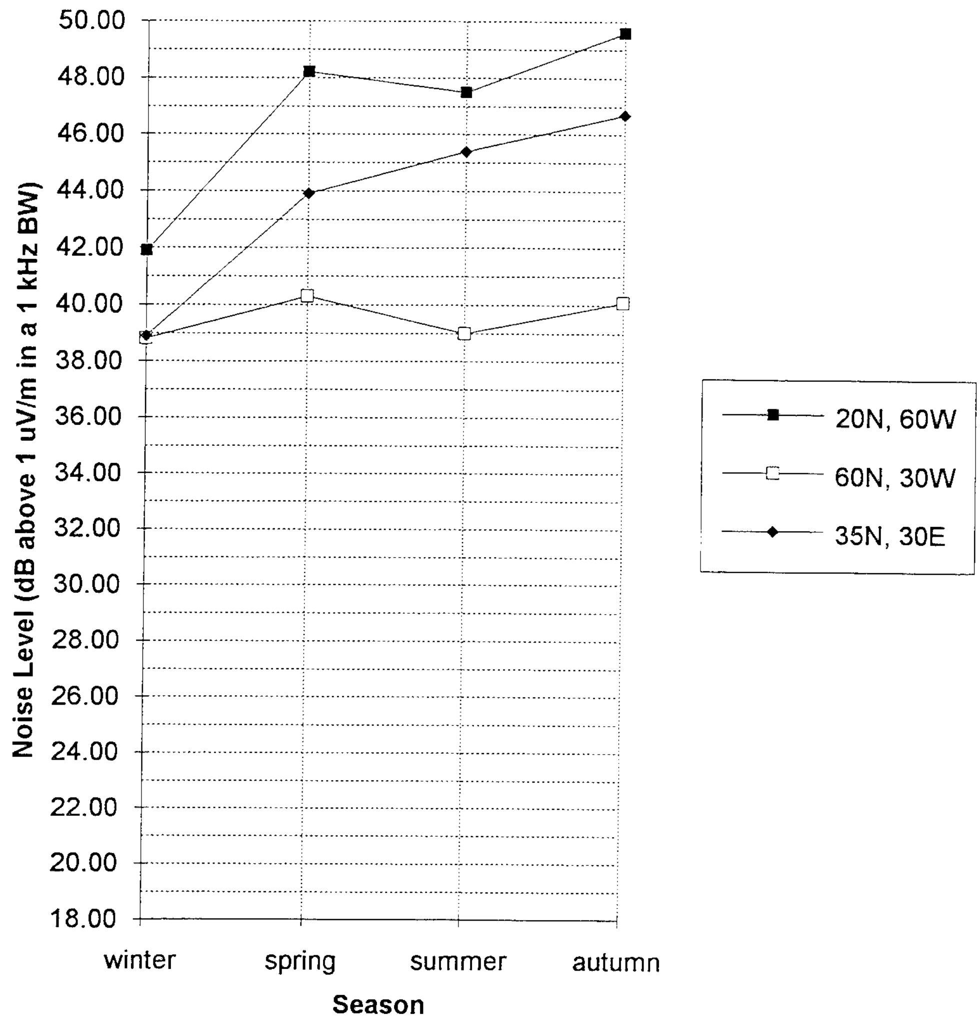

Figure 11. CCIR 322-3 noise levels for three different locations, time block: 0 to 4 LT, 30 kHz.

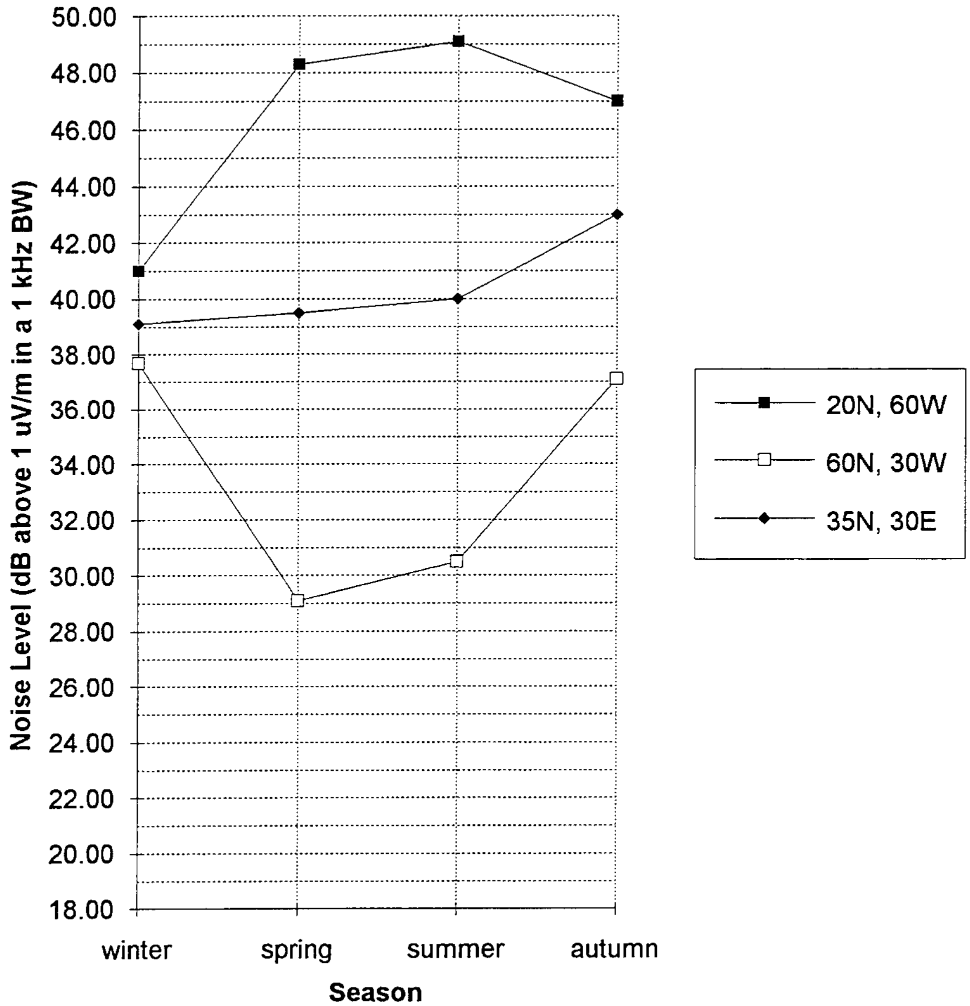

Figure 12. CCIR 322-3 noise levels for three different locations, time block: 4 to 8 LT, 30 kHz.

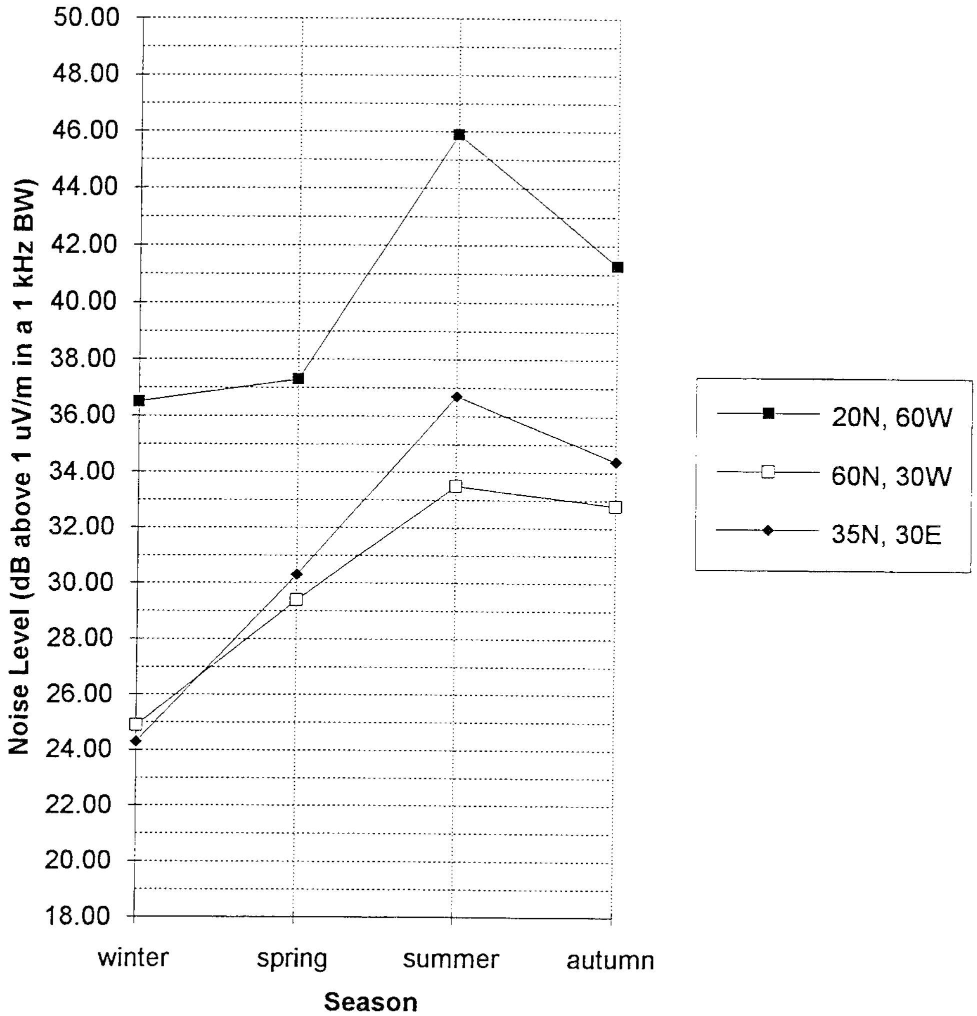

Figure 13. CCIR 322-3 noise levels for three different locations, time block: 8 to 12 LT, 30 kHz.

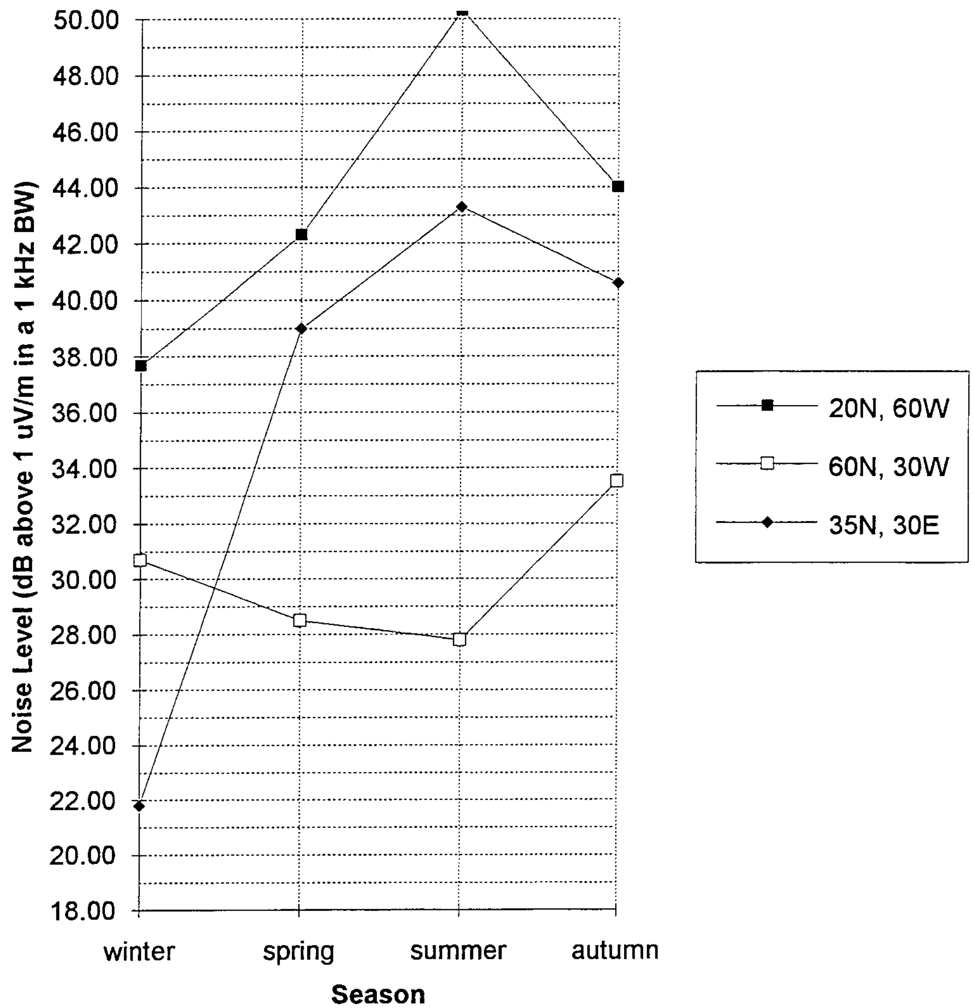

Figure 14. CCIR 322-3 noise levels for three different locations, time block: 12 to 16 LT, 30 kHz.

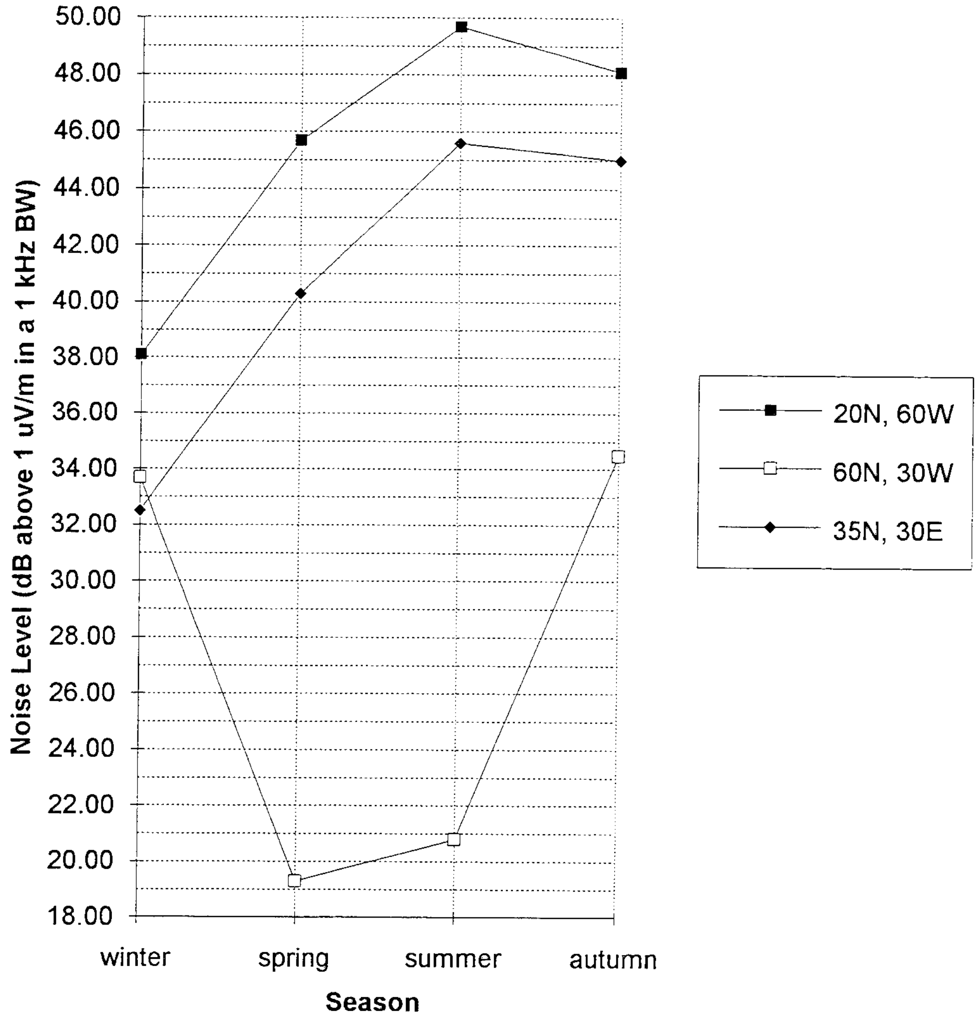

Figure 15. CCIR 322-3 noise levels for three different locations, time block: 16 to 20 LT, 30 kHz.

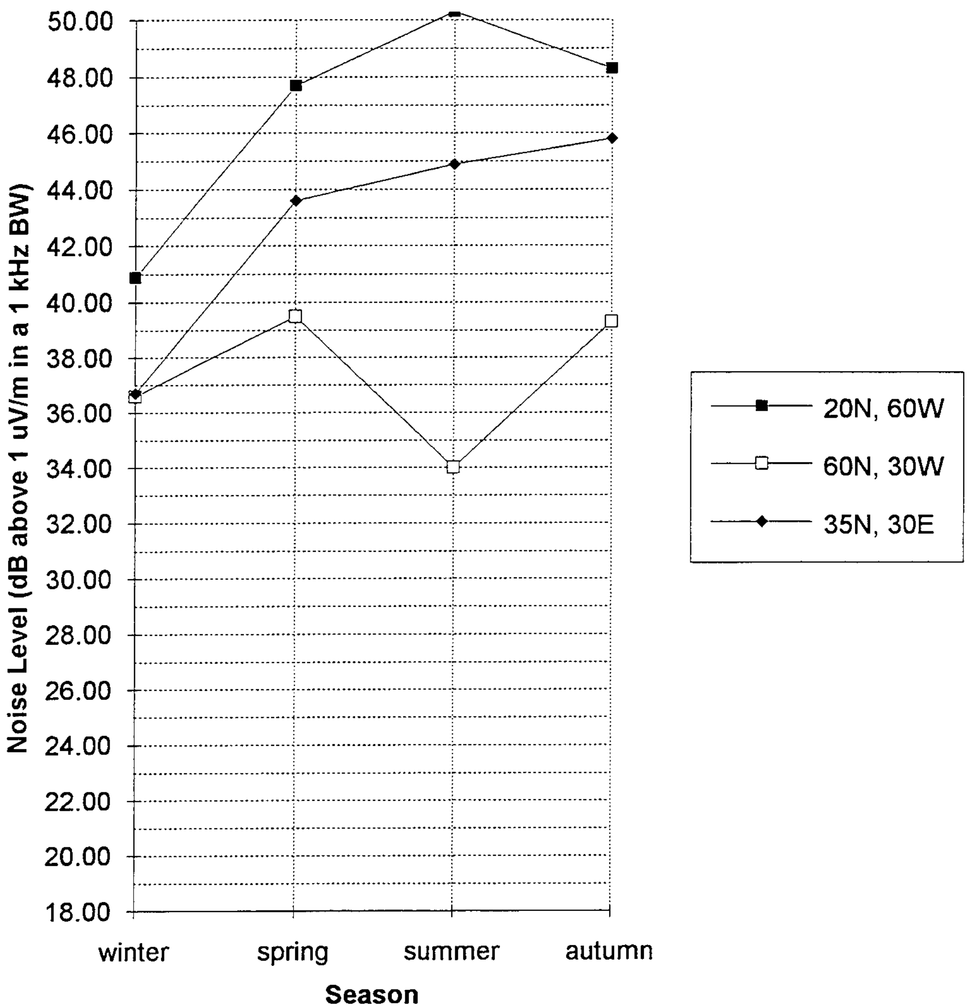

Figure 16. CCIR 322-3 noise levels for three different locations, time block: 20 to 24 LT, 30 kHz.

Table 3. CCIR 332-3 values of F_{am} for three locations: 20N, 60 W; 60N, 30 W; 35N,30E (noise level at 30kHz in a bandwidth of 1 kHz, local time)

Season	Time Blk (LT)					20N, 60W	60N, 30W	35N, 30E			
Winter	0 to 4					41.90	38.80	38.90			
Winter	4 to 8					41.00	37.70	39.10			
Winter	8 to 12					36.50	24.90	24.30			
Winter	12 to 16					37.70	30.70	21.80			
Winter	16 to 20					38.10	33.70	32.50			
Winter	20 to 24					40.90	36.60	36.70			
Spring	0 to 4					48.20	40.30	43.90			
Spring	4 to 8					48.30	29.10	39.50			
Spring	8 to 12					37.30	29.40	30.30			
Spring	12 to 16					42.30	28.50	39.00			
Spring	16 to 20					45.70	19.30	40.30			
Spring	20 to 24					47.70	39.50	43.60			
Summer	0 to 4					47.50	39.00	45.40			
Summer	4 to 8					49.10	30.50	40.00			
Summer	8 to 12					45.90	33.50	36.70			
Summer	12 to 16					50.30	27.80	43.30			
Summer	16 to 20					49.70	20.80	45.60			
Summer	20 to 24					50.30	34.00	44.90			
Autumn	0 to 4					49.60	40.10	46.70			
Autumn	4 to 8					47.00	37.10	43.00			
Autumn	8 to 12					41.30	32.80	34.40			
Autumn	12 to 16					44.00	33.50	40.60			
Autumn	16 to 20					48.10	34.50	45.00			
Autumn	20 to 24					48.30	39.30	45.80			

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* This report is a working document and is issued primarily for the information of U.S. Government and contractor scientific personnel. It is not considered part of the scientific literature and should not be cited as such.

APPENDIX A
NIEMOLLER INTERPOLATION METHOD

This appendix includes viewgraphs from Dave Niemoller's ONR ELF/VLF Radio Noise Workshop briefing titled "CCIR-322: A Case Study In Noise Model Application."

Additional information, enclosed in square brackets, has been added based on telephone conversations with Mr. Niemoller.

CCIR - 322

Characterization of Mean Noise Density (F_{am})

$$F_{am}(t) = M_j \text{ for } T_j \le t < T_{j+1}$$

$$T_j = j \cdot 4.0\, hrs \quad j = 0 \,..\, 5$$

$$\left. \begin{array}{l} M_{-1} = M_5 \\ M_6 = M_0 \end{array} \right\} \text{periodic conditions}$$

Figure A-1. CCIR 322 characterization of mean noise density viewgraph.

CCIR - 322

AVERAGE PRESERVING INTERPOLATION

Find an Interpolator, I(t), for the CCIR - 322 mean noise density which:

- Is a piecewise polynomial (of order N)

  $I(t) = I_j(t)$ for $T_j \le t < T_{j+1} \quad j = 0 .. 5$

  $$I_j(t) = \sum_{n=0}^{N} C_{j,n} t^n; \quad t = \frac{(t - T_j)}{Dt}$$

  $6 \cdot (N - 1)$ coefficients $C_{j,n}$

- Preserves the CCIR - 322 mean value on each interval

  $$M_j = \frac{1}{Dt} \int_{T_j}^{T_{j+1}} I_j(t) = \sum_{n=0}^{N} \frac{C_{j,n}}{(n+1)} \qquad \text{6 equations}$$

- Belongs to periodic class $C^{(N-1)}$

  $$C_{j,k} = \sum_{n=k}^{N} \binom{n}{k} C_{j-1,n} \quad k = 1 .. N-1; \ C_{-1,n} = C_{5n} \qquad 6 \cdot N \ \text{equations}$$

  [assures first N - 1 derivitives are continuous (conventional spline theory)]

  [also, $C_{-1,n} = C_{5n}$ assures it is periodic]

Figure A-2. CCIR 322 average preserving interpolation viewgraph.

CCIR - 322

Average Preserving Quadratic Interpolator

There is a solution for N = 2

$$C_{j,1} = \sum_{k=0}^{5} F_{j,k} \cdot M_k; \quad F_{0,k} = \left(\frac{11}{5}, -\frac{3}{5}, \frac{1}{5}, -\frac{1}{5}, \frac{3}{5}, -\frac{11}{5}\right); \quad F_{i,k} = F_{i-1,\,k-1}$$

$$C_{j-1,2} = \frac{\left(C_{j,1} - C_{j-1,\,1}\right)}{2} \qquad C_{j-1,2} = M_{j-1} - \frac{\left(C_{j,1} + 2C_{j-1,\,1}\right)}{6}$$

[Even though it was quite an effort to find this solution, now that we have it, the coefficient calculation above and the actual interpolation calculations are relatively easy]

Figure A-3. CCIR 322 average preserving quadratic interpolator viewgraph.

CCIR - 322

RECOMPUTATION OF INTERVAL VARIANCE

If the noise process on the j[th] interval is characterized as

$$F_{am}(t) = I(t) + Z\sigma_r^2$$

[Z is a random variate Dave was using in Monte Carlo simulations]

[σ_r^2 is the residual variance after the contribution of the new interpolated time variation has been taken into account]

then

$$\sigma_{F_{am}}^2 = \sigma_I^2 + \sigma_r^2$$

where

$$\sigma_I^2 = \frac{1}{\Delta t}\int_{T_j}^{T_{j+1}} I_j^2(t)dt - M_j^2$$

which allows the solution

$$\sigma_r^2 = \sigma_{F_{am}}^2 - \sigma_I^2$$

[Note that actually $\frac{D_u}{1.28}$ should be used in this slide instead of $\sigma_{F_{am}}$ because D_u is related to the time variations in the measured data whereas $\sigma_{F_{am}}$ is related to the prediction uncertainty. In addition, since D_u was calculated as an average over the 16 measuring sites spread over the surface of the earth, the above residual variance calculations really should be done at an adequate number of representative locations on the surface of the earth and then averaged to determine the residual variance for a particular (local) time block.]

Figure A-4. CCIR 322 recomputation of interval variance viewgraph.

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Naval Command, Control and Ocean Surveillance Center, RDT&E Division (NRaD) researchers require both signal and noise level predictions to predict the coverage of the Navy's very low frequency (VLF) and low frequency (LF) transmitters. They have performed this task for many years. Currently, researchers use digitized noise level predictions based on a report issued by the Comité Consultatif International Des Radiocommunications, CCIR Report 322–3. This technical document addresses the statistical parameters that specify the atmospheric noise variability around the predicted values of F_{am} in CCIR Report 322. These parameters are designated as σ_{Fam}, D_u, D_l, σ_{Du}, and σ_{Dl}. This technical document describes the CCIR Report 322 methods for calculating the predicted noise variation parameters from the measured data. It also provides suggestions for interpreting and using the CCIR Report 322 noise variation parameters. Topics covered include the CCIR uncertainty parameters themselves, combining these CCIR uncertainty parameters with predicted daily signal variations, plots of the CCIR Report 322 noise variation parameters, and interpolation between time blocks and seasons.

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