PREDICTING SIGNAL-to-INTERFERENCE PROBABILITY IN THE HIGH FREQUENCY BAND

G Lane and G Hand

USA

Performance of high frequency (HF) radio systems is dependent on the ratio of the wanted signal power at the receiver to the unwanted noise power. The unwanted noise is usually the composite of atmospheric, man-made and galactic radio noise. In some cases, the systems engineer may wish to include the presence of an interfering signal along with the noise power when making performance assessments.

A modification has been incorporated in two commonly used IONCAP-family of HF sky-wave prediction programs (ICEPAC and VOACAP) which allow the user to specify the system parameters for a potentially interfering transmitter. The signal power probability distribution over the days of the month at a given frequency, hour, month and sunspot number is computed for the wanted and the unwanted signals at a common receiver location. The unwanted signal power distribution is combined with the composite noise power distribution at the receive site to provide an interference power distribution. The method of combining power distributions is consistent with the method used within IONCAP, as developed by Lloyd et al (1). A number of new prediction output terms have been introduced which describe the signal-to-interference probability as compared to a maximum tolerable signal-to-interference ratio for a desired level of system performance. The computation methodology is described and the new prediction terms are defined in this paper.

INTRODUCTION

Modern HF radio performance prediction programs calculate a signal power distribution as well as a noise power distribution as a function of geographic location, frequency, hour, month and sunspot number. Consequently, it is possible to compute the power distribution for an unwanted signal if the circuit parameters of that signal are known. This is often the case for international broadcasters or when evaluating situations common in electronic warfare. Unfortunately, the calculation of a signal-to-interference ratio is only valid for the median situation. Auto-correlation coefficients for the time dependence of the wanted signal, unwanted signal and the noise are neither known for within an hour or for an hour block over the days of the month. Therefore, it is not possible to compute the level of interference that will be encountered during a particular hour for a given day of the month. However, under certain conditions it is reasonable to expect that the predicted distribution of the interference level over the days of the month will reasonably represent the actual distribution. In general it is common to assume that the hourly median power levels of the signals and the noise are independent of each other and normally distributed. This tends to be the case when the sources of the two signals and the noise are not on a common ionospheric path. For most situations the paths are not common. As the sources of the wanted and unwanted signals become close to the receive location (i.e. short path lengths) more of a common volume of the ionosphere is controlling the received power levels. The model of signal-to-interference ratio discussed in this paper treats the longer paths where a more random distribution of the power levels is more likely to occur.

METHODOLOGY

The signal-to-interference ratio is often used to specify the limits on the deleterious effects caused by one signal interfering with another. At HF this is further complicated by the high level of external noise present in this region of the spectrum. For HF radio systems it is necessary to determine the ratio of wanted signal power to the summation of the unwanted signal and the external noise power.

Although most laboratory measurements to determine the minimum acceptable level of signal-to-interference are made for steady signals and noise, in the real world the wanted and unwanted signals plus the noise powers are time variant, as discussed by Lane (2). Thus, when one predicts the signal-to-interference ratio, it is necessary to find the joint distribution which results from these various independent parameters.

The signal-to-interference ratio established in the laboratory is used as a reference point in the predicted distribution in order to establish the probability that the actual signal-to-interference ratio will exceed that which is minimally acceptable. Another approach commonly used is to fix the probability, say at 90%, and calculate the signal-to-interference ratio that has that probability. The former is more useful in point-to-point analyses whereas the latter is most often used to plot maps of interference free coverage. Both approaches will be developed in this report.

The parameters which must be known in order to determine the signal-to-interference ratio (S/I) are usually obtained from a performance prediction model for HF radio systems. In the USA, this has normally involved the IONCAP-family of HF prediction models which have evolved from the first such computer model, ITSA-1 by Lucas and Haydon (3). The Ionospheric Communications Analysis and Prediction (IONCAP) program (4), officially released in 1985, has been enhanced under sponsorship of two different US Government Agencies for different applications. The resulting programs, the Ionospheric Communications Enhanced Profile Analysis and Circuit prediction program (ICEPAC) (5) and the Voice of America Coverage Analysis Program (VOACAP) (6), are now the two most accepted HF prediction programs in use within the US Government. Both of these programs allow the user to obtain median, upper decile and lower decile values of the wanted signal, unwanted signal and the combined external noise powers at the receive location. It should be noted that the noise power calculations used in these IONCAP models were updated by Spaulding and Stewart (7). In this paper the prediction program will be called “IONCAP”, although the S/I prediction model has only been implemented in ICEPAC and VOACAP.

Required IONCAP Variables for S/I calculations

The following are the standard IONCAP output variables that are required for the S/I calculations:

for the Wanted signal:

W = S DBW = median signal power (dBW)
ΔW_{low} = SIG LW = range to lower decile (dB)
ΔW_{up} = SIG UP = range to upper decile (dB)

for the Unwanted signal:

U = S DBW = median signal power (dBW)
ΔU_{low} = SIG LW = range to lower decile (dB)
ΔU_{up} = SIG UP = range to upper decile (dB)

for the Noise power in 1Hz bandwidth:

N = N DBW = median signal power (dBW)
ΔN_{low} = N dl = range to lower decile (dB)
ΔN_{up} = N du = range to upper decile (dB)

Median Parameters

The median S/I ratio in dB is defined as the median of the hourly median values over the days of the month at a given hour. It can be expressed as follows:

$$S/I = W - I \qquad (1)$$

The median interference power, I, in dBW is the power sum of the unwanted signal and the noise in the bandwidth of the receiver as shown below:

$$I = 10\,\mathrm{Log}(10^{U/10} + b10^{N/10}) \qquad (2)$$

where:

b = bandwidth of the receiver (Hz).

Decile Limits

The distributions of the median parameters derived from VOACAP are assumed to be "split" Gauss. In other words the distribution has a different upper standard deviation than it does below the median. First we will compute the decile values for the interference, I. It is assumed that the decile is 1.28 times the standard deviation in all of the following equations. A fair approximation for the sum of two independent power distributions is to assume random phase, in which case:

$$I_{up} = 10\mathrm{Log}(10^{Uup/10} + b10^{Nup/10}) \qquad (3)$$

$$I_{low} = 10\mathrm{Log}(10^{Ulow/10} + b10^{Nlow/10}) \qquad (4)$$

where:

$$U_{up} = U + \Delta U_{up}$$
$$U_{low} = U - \Delta U_{low}$$
$$N_{up} = N + \Delta N_{up}$$
$$N_{low} = N - \Delta N_{low}$$

The upper (up) and lower (low) decile values correspond to those values that are exceeded 90% and 10% of the time. For example, I_{up} is the interference power that is exceeded 90% of the time. The same applies to the other variables describing the unwanted signal power, U, and the noise power, N.

The upper and lower decile of the S/I distribution can be estimated quite accurately by using the root sum square of the standard deviations of the independent distributions of the wanted signal, W, and the interference, I.

$$\Delta S/I_{low} = \sqrt{\Delta W_{low}^2 + \Delta I_{up}^2} \qquad (5)$$

$$\Delta S/I_{up} = \sqrt{\Delta W_{up}^2 + \Delta I_{low}^2} \qquad (6)$$

where:

$$\Delta I_{up} = I_{up} - I$$
$$\Delta I_{low} = I - I_{low}$$

S/I PREDICTIONS

We have now defined three new parameters which describe the signal-to-interference distribution. These are:

- the median S/I ratio (S/I = W - I) which has a probability of 50%

- the lower decile of the S/I ratio ($S/I - \Delta S/I_{low}$) which has a probability of 90%
- the upper decile of the S/I ratio ($S/I + \Delta S/I_{up}$) which has a probability of 10%

As may be noted, these computations deal with only the variation in the hourly median values about the monthly median for a specified hour of the day. It has been common to refer to this variation from day to day as the "long term" fade factor. The wanted and unwanted signals plus the noise power also have a within the hour fading, normally termed "short term" fading. Historically, a protection factor against short term fading has been added to the required signal-to-noise ratio used in the IONCAP. Lane (2) has also proposed such a method for developing the required signal-to-interference ratios. A discussion of this rationale is given by Akima et al (8). The treatment of short term and long term fade is the only significant difference between the S/I computation in the present method and that approved by the International Telecommunications Union (9). The divergence used in the present method is necessary in order to use the statistical data base employed in IONCAP.

PROBABILITY OF EXCEEDING A REQUIRED S/I

A frequency manager may wish to know what the probability is that the S/I ratio will equal or exceed a specified minimum acceptable S/I. This may be computed in the same way as IONCAP computes circuit reliability in subroutine RELBIL. However, a high probability of meeting the S/I criteria cannot be used alone to determine if there will be good reception. One must consider first the circuit reliability of the wanted signal to determine if the service is adequate in the absence of interference and then look at the probability of meeting the S/I requirement.

For area coverage mapping, it will be necessary to incorporate the two criteria. An easy way to do this is to mask any coverage which falls below a user's specified SNR90. For example, one might not be interested in any coverage where the signal-to-noise ratio at 90 percent reliability falls below 65 dB/Hz. Any grid point used to make the map having a value of SNR less than 65 could be blanked out. Only the remaining grid points on the map would be used for contouring the S/I ratio.

CONCLUSION

The method developed for computing the S/I distribution where interference consists of the power summation of rf noise and one unwanted signal is totally consistent with the prediction methodology in the IONCAP-family of prediction programs. Care should be exercised in the use of the S/I computation when the wanted and unwanted signals traverse the same common volume of the ionosphere, such as occurs on very short paths. These programs, including any recent changes, are available from the Internet web page:

http://elbert.its.bldrdoc.gov/hf.html

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