Effect of Spread-F on A1 Absorption Measurements

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An implicit assumption of the A1 or pulse reflection method of measuring ionospheric radio wave absorption is that a single echo is returned from the ionosphere at any one time. This assumption breaks down during spread-F conditions because a number of echoes are then observed to overlap, leading to an overestimation of the A1 system calibration constant. The difference between the normal- and spread-F calibration constants depends on the number and fading characteristics of the echoes, and the degree to which the various echoes interfere with each other. A simple model is invoked to simulate the A1 amplitude observations during spread-F conditions.

1 Introduction

Reflections from the ionospheric F-region at night are used to calibrate pulse-reflection (or A1) systems. Since HF radio wave absorption is assumed to be negligible at night, the calibration constant corresponds to the amplitude of the unabsorbed field strength for a lossless reflector at some standard height. The amplitude measurements obtained during the day are then subtracted from the calibration constant to obtain an absorption value, once allowance has been made for the spatial attenuation of the pulse when the equivalent height of reflection is different from the standard height.

This paper compares the calibration constant for normal F-region reflections with that obtained during spread-F conditions.

2 Nighttime A1 Data

The A1 system samples across the received echo every 14 μsec, storing the values in the random access memory of an M6800 microprocessor. The peak amplitude and its associated time of arrival (TOA) are stored separately each second, with the median amplitude and average TOA for each 1-min period being routinely recorded on magnetic tape. A sample of the data is shown in Fig. 1. The top diagram shows the variation of the amplitude with time and the bottom one shows the corresponding variation of the TOA, which has been converted to an equivalent (or virtual) reflection height. The fluctuation in amplitude from sample to sample is due to ionospheric fading. The amplitude measurements obtained during the period for which spread-F was observed on ionograms can be seen to be systematically higher (by about 7 dB) when compared with those for the normal F-region. The amplitude data are referenced to the same standard height (100 km) and thus spatial attenuation effects have been removed. The virtual reflection heights are observed to be much more variable from sample to sample during spread-F conditions (lower diagram). In this example the onset of spread-F is accompanied by an increase in the ionospheric reflection height, consistent with other observations.

During the period July-Nov. 1982, the echo amplitude information for each night was averaged and assigned to either the 'normal-F' or 'spread-F' condition.

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category by using ionograms. In Fig. 2, the upper graph is a plot of the spread-F values and the lower graph is for normal-F. The calibration constants deduced from these graphs, namely \( A_n \) for normal-F and \( A_s \) for spread-F are represented by the horizontal lines through each graph. The difference between the respective calibration constants for the overall period is about 4 dB.

3 Echo Observations during Spread-F

Examples of the amplitude-time profiles observed during normal- and spread-F conditions are shown in Figs 3(a) and 3(b)-3(f), respectively. During normal-F conditions a single (or 'primary') echo is received, whereas during spread-F, there is a primary echo plus additional (or 'satellite') echoes. Each amplitude-time envelope results from the vector addition of the amplitudes and phases of the primary and satellite echoes. The signal processing programme selects the maximum amplitude \( A_{\text{max}} \), which is indicated in each diagram. This is satisfactory when there is a single echo (normal-F) as only the peak amplitude and corresponding TOA are selected for further processing. During spread-F, however, the peak amplitude and TOA of either the primary echo or one of the satellites is selected, depending on which has the greater amplitude. This leads to a dearth of low amplitude values and to variable TOAs being recorded (ref. Fig. 1). The magnitude of the enhancement in the recorded amplitudes depends on the number of echoes, their fading characteristics, interference effects between echoes and the way the signals are processed.

A simple model is now proposed which demonstrates the effects of fading and simulates the amplitude observations recorded during spread-F. Consider two echoes, the primary echo and one satellite and assume that the fading of the two echoes is statistically independent, i.e. they do not interfere with each other. Now the A1 system selects the larger of the peak values, so that the probability of recording the amplitude \( A_1 \) of the primary echo also depends on the magnitude of \( A_2 \) relative to the peak amplitude \( A_{\text{max}} \) of the satellite echo. If \( A_1 \geq A_2 \), then \( A_1 \) will be recorded but if \( A_1 < A_2 \), then \( A_2 \) rather than \( A_1 \) will be recorded. Hence the modified probability \( P_2(A_1) \) of recording \( A_1 \) can be written as

\[
P_2(A_1) = p_1(A_1) \cdot p_2(A_2 < A_1)
\]

where

\[
p_1(A_1) = \text{Probability of the amplitude of the primary echo being } A_1
\]

\[
p_2(A_2 < A_1) = \text{Probability of the amplitude of the satellite echo being less than the amplitude of the primary echo}
\]

If the fading of the two echoes follows a Rayleigh distribution\(^1\) then Eq. (1) can be evaluated analytically giving

\[
P_2(a) = (2a \cdot S^2) \cdot \exp(-a^2/S^2) \cdot [1 - \exp(-a^2/S^2)]
\]
where

\[ p_1(a) = p_2(a) = \frac{2a}{S^2} \exp \left( -\frac{a^2}{S^2} \right) \]

Rayleigh distribution

\[ a = \text{Linear amplitude} \]

\[ S = \text{RMS value} \]

It was found that the log-normal distribution provides a better description of the nighttime amplitude fluctuations associated with fading. If the primary echo and the satellite are assumed to have amplitude distributions which have the same mean value \((A)\) and standard deviation \((D)\), then Eq. (1) can be written as

\[ P_2(A) = p_2(A) \cdot \text{erf} \left( \frac{A}{D} \right) \]

or

\[ P_2(A) = (1 - 2\pi D^2) \exp \left( -\frac{(A - \bar{A})^2}{2D^2} \right) \]

\[ \times \int_{-\infty}^{\infty} \exp \left[ -\frac{(A - \bar{A})^2}{2D^2} \right] dA \]

Fig. 4 shows the plots of the probability distributions for a single echo \([P_1(A)]\) and the modified distributions (which are not normalized) for two \([P_2(A)], three [P_3(A)], four [P_4(A)]\) and five \([P_5(A)]\) echoes, assuming the amplitude distributions of the primary echo and each of the satellites are the same. The amplitudes have been standardised using the transformation for the standard normal form, which is given by

\[ (A - \bar{A})/D \]

The transformed values have zero mean and are measured in units of standard deviations. The curves shift to higher amplitudes, with the probability of recording a low amplitude decreasing as the number of satellites increases. This model simulates the dearth of low-amplitude values recorded by the AI system during spread-F conditions (ref. top diagram of Fig. 1).

The model predicts a shift in the mean value of between 1/2 and 1 standard deviation, depending on the number of satellites. Since the standard deviation associated with normal F-region reflections varies from 2-6 dB (Ref. 4), the model accounts for only part of the observed enhancements which vary from 3 (the limit for which the enhancement is considered to be significant) to as high as 10 dB. Clearly, the interference effect, which depends on the number, range, amplitude, and phase of each of the overlapping echoes, would have to be included for a complete description of the observations. This was not possible as the echo phase information is not recorded with the present AI system.

References