Study of Methods of Analysis of Spaced Receiver Drift Records

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A review of the close-spaced receiver method for the investigation of the movements of small scale ionospheric irregularities is made with special reference to the method of analysis. The deficiencies of the full correlation method are pointed out. Results of multi-aerial experiments, carried out to test some of the assumptions underlying the full correlation method, are given. One of the experiments, in which two different geometries of aerial arrays are simultaneously used, showed that the axial ratio and orientation of the characteristic ellipse, which describes the properties of the ground diffraction pattern, show dependence on the geometry of the array. From some considerations the use of an equilateral triangle array is recommended. In another experiment, in which seven receiving aerials are deployed in a straight line, it is found that the fading velocity shows marked dependence on the aerial spacing. This shows that the assumption that the fading statistics are stationary is not valid in practical situations.

1. Introduction

EVIDENCE of movements at ionospheric heights was first reported by Otto Jesseyl who made purely visual observations of movements of noctilucent clouds. Later, Stormer1 also used the same method. But these observations were confined to certain times in the night and also the motions related to the neutral constituent of the atmosphere. To study the motion of ionization irregularities radio observations are required. Of the various radio techniques used to investigate the ionospheric drift, the close-spaced receiver method and the meteor radar method have been extensively used for investigations in the D- and E-regions; the close-spaced receiver method and the radio-star scintillation method are useful for investigations in the F-regions. The scope of this paper extends to a critical discussion of (i) the close-spaced receiver technique were those of Ratcliffe and Pawsey3 and Pawsey4 simultaneously and independently developed a radio method of measuring ionospheric drift characteristics. In this method the amplitude of the ionospheric echo of a pulsed radio wave transmission is recorded as a function of time at three receiving sites located at the corners of a right-angled isosceles triangle of side of the order of a wavelength. Using time shifts between similar features in the fading records from the three stations and by simple triangulation, the velocity and the direction of the drift can be deduced. This method is called the 'similar fades method', and assumes that all the fading is due to steady drift of the ionospheric irregularities. Some of the merits of the Mitra method are the conceptual simplicity and ease of application and the method has been extensively used during the IGY, IGC and IQSY.

2. Historical Background for the Fading Experiment

The first observations which paved the way for the close-spaced receiver technique were those of Ratcliffe and Pawsey3 and Pawsey4. They observed fluctuations in the amplitude of pulsed radio waves reflected from the ionosphere, which is called 'fading', and measured the correlation between the fading recorded at two receivers placed at various separations on the ground and showed that the mechanism for the fading is the diffractive interference of radio waves reflected from scattering centres in the ionosphere. Pawsey was the first to notice a time lag of the order of 1 sec between the fading at two spaced receivers which was the first indication of drift of ionization irregularities in the ionosphere. Employing these early ideas of Ratcliffe and Pawsey, Mitra5 and Krautkramer6 simultaneously and independently developed a radio method of measuring ionospheric drift characteristics. In this method the amplitude of the ionospheric echo of a pulsed radio wave transmission is recorded as a function of time at three receiving sites located at the corners of a right-angled isosceles triangle of side of the order of a wavelength. Using time shifts between similar features in the fading records from the three stations and by simple triangulation, the velocity and the direction of the drift can be deduced. This method is called the 'similar fades method', and assumes that all the fading is due to steady drift of the ionospheric irregularities. Some of the merits of the Mitra method are the conceptual simplicity and ease of application and the method has been extensively used during the IGY, IGC and IQSY.

3. Methods of Analysis

Two chief assumptions in the similar fades method are that the irregularities remain unchanged as they move and that they are isotropic. It is further assumed that the corresponding points on the pattern moving across the receiving points may be straight lines at right angles to the direction of drift. But, in practice, the time shifts showed great variability and even reversed sign in a very short time, which means varying drift. Various attempts have been made by several workers, notably Putter7, Banerji8 and recently Datta9, to improve the similar fades method.

Ratcliffe10 outlined the theory of random fading. Booker et al.11 worked out in detail a theory of diffractive reflection from an irregular ionosphere for two extreme cases, one a frozen ionosphere drifting steadily, and the other a stationary ionosphere containing irregularities moving randomly with a mean velocity of zero in any direction. Briggs et al.12 have given a practical application to their theory for the case when both the movements are
This led to their correlation method of analysis, in which the fading was considered as due to the combined effect of a statistically isotropic diffraction pattern drifting horizontally on the ground, with the random motions superimposed. This method gives information with regard to the random motions by a parameter called $V_e$, which has the dimensions of velocity. The relative values of the true drift velocity $V$ and the random velocity $V_e$ determine the relative predominance of steady drift and random motions.ler $V_e < V$, it can be supposed that the assumption of isotropy is not correct and the simple cross-correlation method would give nearly accurate results. Phillips and Spencer considered the case of anisotropy of the irregularities into account and extended the method of Briggs et al. by making a less stringent assumption that the drifting ground pattern although anisometric will be statistically stationary in time. In this method information is provided, in addition to $V$ and $V_e$, about the sizes and shapes of the irregularities of a diffraction pattern on the ground. This information is provided in the form of a correlation ellipse, called the 'characteristic ellipse', whose radius gives the receiver separation required for correlation of a particular value, say 0.61 or 0.5 in any direction. The actual size of this correlation ellipse is related rather indirectly to the irregularities in the layer, but its orientation and axial ratio almost certainly indicate the orientation and elongation of the ionospheric irregularities. Phillips and Spencer have shown that in cases where the elongation is not too much (for axial ratios less than 1:5) the errors that will result by the application of simple correlation analysis are very small. The full correlation method of Briggs et al. as extended by Phillips and Spencer is considered to be the most reliable and highly resourceful method, giving all the information in respect of the turbulent drift characteristics, viz., the true drift velocity ($V_t$), the true drift direction ($\phi$), and the random velocity ($V_r$) and the anisotropy parameters of the ionospheric irregularities, viz., the axial ratio ($\alpha$), the tilt angle ($\phi$) and the structure size ($a$). But it is very laborious and time-consuming. So, a less laborious but still nearly accurate method was developed by Yerg. Ramana, Poons and Jones made a comparative study of the results obtained by the different methods of analysis available at that time and clearly stressed the necessity to adopt the full correlation method of analysis to obtain reliable and detailed information regarding the movements of small scale irregularities. However, in order to take full advantage of the correlation technique described above, a large number of fading records is required, and the fading statistics have to be uniform in space and stationary in time with respect to the sample of analysis. Several convenient techniques exist to make a better use of the entire correlation functions or rather the statistically significant parts of them for a better evaluation of the parameters. Mirisotan and Kushnerevski describe a graphical procedure for the correlation analysis which follows an approach of Phillips and Spencer. Keneshea et al. used analytical procedure to derive the parameters of drift and random motion. Kellher and Mall suggested a new method of applying the correlation analysis by confining to the maximum value of the cross-correlation function alone, since the errors involved will then be smaller. This modification is obviously important when dealing with highly elongated diffraction patterns. Recently, Fedor has developed a computational procedure based on the method of least squares analysis of the data. This method extracts the best fitting value of all the parameters desired. The analysis is developed in three dimensions (plus time), anticipating information about vertical movements from comparisons of amplitude variations between closely spaced radio frequencies. In all these methods an indirect estimate of the most important parameter $V$ from a limited number of fading records taken continuously in time at fixed spatial positions. Recently, Briggs described the spatial correlation technique to compute the velocity and other parameters using a large array of receiving sites, the number of which is sufficiently large so as to obtain a record of the diffraction pattern continuous in space. In this method the two-dimensional spatial correlation function between two observations of the pattern separated by a known time interval is computed. This leads to a more direct estimate of the velocity, free from the particular assumptions of the earlier correlation analysis which must necessarily be used when only a small number of aerials are employed. But this method is not likely to be used in a large majority of stations because of the very large number of recording stations required and the associated complexity of the experimental set-up.

4. Deficiencies in the Correlation Method of Analysis

The correlation technique for the analysis of spaced aerial fading records was introduced by Briggs et al. and extended by Phillips and Spencer. It is regarded as a definite improvement over the simple similar fades method of analysis, as it takes into account both the random motions and the anisotropy of the diffraction pattern and also provides very useful information about the turbulent structure in the ionosphere in addition to the true drift. However, in practice difficulties are encountered in interpreting the results obtained by the application of the full correlation method of analysis to the fading experimental data. These difficulties lead to doubt about the validity of the basic assumptions inherent in the method of analysis in practical situations. The underlying concept of the correlation analysis is a turbulent motion of small scale irregularities of equal statistical shape and orientation imbedded in a medium of constant drift motion. Consequently, a higher quality of the correlation can be described by a family of concentric ellipsoids in space and time coordinates. The object of the correlation analysis is to find the parameters of a particular ellipsoid and to translate them into the parameters of drift and random motion. For a two-dimensional diffraction pattern on the ground the ellipsoid is described by six independent parameters which can be expressed by the drift velocity ($V$), the direction ($\phi$), the random velocity ($V_r$), the length of semi-major axis ($a$), axial ratio ($\alpha$) and orientation ($\phi$). In spite of the fact that the correlation method of analysis has been successfully employed for the evaluation of drift parameters, the following observations...
bring out the inadequacy of the underlying assumptions:

1. Experimentally it is observed that in a number of records the data lead to hyperboloids rather than ellipsoids giving imaginary values for $V_s$ and $r$. This is physically unrealistic.

2. In some cases the apparent velocities cannot be fitted into a single front or the Briggs-Phillips-Shinn line is far from straight.

3. It is experimentally found that the parameter $V'_s$ is not statistically stationary.

4. The drift and anisotropy parameters are found to exhibit short-period variations.

Frequently these observed deficiencies are attributed to sampling errors or lack of statistical uniformity. The short-period variations of the drift parameters in the F-region were explained by MacDougal$^{22}$ in terms of the movement of the point of reflection over an ionospheric surface which is believed to be tilted by the passage of travelling ionospheric disturbances.

Special experiments have been conducted to examine the validity of the assumptions made in the correlation analysis concerning the nature of the ground diffraction pattern and also the precise physical nature of the information obtained from the fading experiment. Arrays of receiving aerials with different spacings and geometries are used in these experiments. Multiple aerial experiments have been made in regard to the former (Kellher$^{23}$, MacDougal$^{22}$, Haubert and Goyen$^{24}$, Beynon and Wright$^{25}$, Golley and Rossiter$^{21}$ and Sastry and Rao$^{26}$). All this work leads to the conclusion that the diffraction pattern does not have the simple statistical properties normally assigned to it, and that the measured drift velocities are likely to be in error. The results of a recent experiment conducted in this laboratory using two different geometries, presented in section 5, lend support to this view. Various alternative possibilities were, however, suggested for this observed behaviour. With regard to the latter, viz. the precise physical nature of the information obtained from the fading experiments, cross spectral analysis was attempted by Jones and Maude$^{28}$, McGee$^{29}$ and Gossard$^{30}$. In this method the assumption is made that a given Fourier component in the records arises from the passage over the receiving system of a sinusoidal waveform with a certain velocity, and this velocity is calculated for each frequency. By analogy with the terminology used in the study of wave propagation, the variation of velocity with frequency is referred to as dispersion, and the dispersion is considered as positive if the velocity increases with frequency and vice versa. This method of analysis has shown that it is possible that in some cases the results of fading experiments could be interpreted in terms of reflections from ionospheric regions disturbed by wave-type motions. Hines and Rao$^{31}$ suggested from theoretical considerations that small scale irregularities in the ionosphere may produce fading by wave motions in the ionosphere. However, some caution is to be exercised in this direction. Recently, Felgate and Golley$^{32}$ have shown that drift records which show naturally occurring velocity variations also show positive dispersion, indicating that the three-receiver dispersion analysis must be treated with some caution, unless it is shown that the records are statistically stationary.

5. Results of Analysis of Multi-aerial Records

In this section are presented experimental results on some aspects of the structure of the ground diffraction pattern obtained by correlation analysis.

Beynon and Wright$^{33}$ noticed an apparent dependence of the orientation of the characteristic ellipse on the disposition of the aerial array which was explained as due to distortion of the ground diffraction pattern from assumed simple ellipse. Usually measurement of drift and anisotropy parameters is carried out using three aerials located at the corners of a right-angled isosceles triangle, the equal sides of which are of the order of a wavelength of the exploring signal. It is found that the orientation of the major axis of the characteristic ellipse shows a preferential direction. This preferential direction is more or less along the longer side of the aerial. So, there has been a doubt as to whether this result is fictitious owing to some physical and yet unidentified process, vitiating the special experiments have been conducted to observe or confirm it. In the direction of the longer side, these experiments, cross spectral analysis was attempted by Jones and Maude$^{28}$, McGee$^{29}$ and Gossard$^{30}$. In this method the assumption is made that a given Fourier component in the records arises from the passage over the receiving system of a sinusoidal waveform with a certain velocity, and this velocity is calculated for each frequency. By analogy with the terminology used in the study of wave propagation, the variation of velocity with frequency is referred to as dispersion, and the dispersion is considered as positive if the velocity increases with frequency and vice versa. This method of analysis has shown that it is possible that in some cases the results of fading experiments could be interpreted in terms of reflections from ionospheric regions disturbed by wave-type motions. Hines and Rao$^{31}$ suggested from theoretical considerations that small scale irregularities in the ionosphere may produce fading by wave motions in the ionosphere. However, some caution is to be exercised in this direction. Recently, Felgate and Golley$^{32}$ have shown that drift records which show naturally occurring velocity variations also show positive dispersion, indicating that the three-receiver dispersion analysis must be treated with some caution, unless it is shown that the records are statistically stationary.
characteristic ellipse which describes the statistical properties of the ground diffraction pattern in the two cases. It is clear from Fig. 1 that the major axis shows a strong preference to align along the longer side in the case of the right-angled triangle array and that this feature is strikingly missing in the case of the equilateral array in which the parameter \( \psi \) takes all values through 180° north of east with two peaks in the NNW sector which are to be expected due to the influence of the earth's magnetic field.

Goley and Rossiter, while testing the full correlation analysis technique for obtaining the drift and anisotropy parameters, reported that this feature is noticeable in small-sized triangle arrays.

Fig. 1C shows the scatter plot of points of values of axial ratio \( r \) of the characteristic ellipse and it is clear that the right-angled triangle array gives consistently large values of \( r \), the slope of the regression line being 1:42. This is to be expected as a consequence of the observed deviation in the results of \( \psi \), since any fictitious elongation of the characteristic ellipse along the hypotenuse will increase the value of \( r \). This is so because the pattern, which will, to some extent, be elongated in the magnetic field direction, viz. NS, appears to be further elongated, since the hypotenuse in this case is along NW-SE direction. It may be pointed out that, since the parameters \( r \) and \( \psi \) enter into computation of other parameters and since it is found that these parameters influence the results very sensitively if \( r \) is large, any error in the measurement of these two parameters will seriously affect the other results. In fact all the other parameters, viz. true drift velocity, true drift direction, random velocity and length of the semi-major axis of the characteristic ellipse, showed general disagreement in the two cases. Barber\(^{24}\) had shown that the error in the final measurement of true velocity and true direction of drift due to errors in reading time shifts, which are obvious to creep in and sometimes may be large, will be minimum when an equilateral array is used. With these points in mind and the resultant investigation that the characteristic ellipse which describes the statistical properties of the ground diffraction pattern tends to align along the longer side of the triangle in view, we stress the need to choose an equilateral triangle array for future drift work by the D\(_1\) technique to avoid any error in the measurement of drift and anisotropy parameters.

Another experiment has been carried out to test the stationary character of the ground diffraction pattern. If the ground diffraction pattern possesses stationary character, the fading velocity in any direction has to remain independent of spatial separation. To test this aspect, simultaneous fading records of 2.4 MHz pulsed radio signals reflected from the ionosphere are obtained at seven receiving points on the ground along the EW direction at equal spacings of 32.5 m. The fading velocity \( V_F \) is found to show a marked dependence on the separation. In all the cases the velocity increased with spacing. A typical plot of \( V_F \) versus spacing between receivers is shown in Fig. 2. This figure shows that the basic assumption in the correlation analysis, viz. the stationary character of the fading statistics, is found to be not valid in practical situations. It may be noted that this result is in good agreement with that of Kellher\(^{24}\), who made similar study with only four aerials in one line.

Further work is planned with a large number of aerials to ascertain the spacing to be used for improving the reliability of the results.

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References