A DISCUSSION OF IONOSPHERIC DEMODULATION NEAR GYRO FREQUENCY

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Summary

Observations made in Adelaide of the ionospheric demodulation of radio waves near gyro frequency at vertical incidence are discussed. The effect occurs in the region of about 90 km, and does not appear to decrease through dawn. An F-layer reflected wave is demodulated by unequal amounts during its two passages through the region. The large magnitude of the effect and its lack of dependence on modulation frequency seem to be inconsistent with the theory of wave interaction.

I. Introduction

The demodulation of radio waves was observed near gyro frequency by Cutolo (1952, 1953) and Mitra (1954), who received signals reflected from the ionosphere (probably the E region) at oblique incidence. Aitchison and Goodwin (1955) measured demodulation at a frequency of $1\cdot55$ Mc/s, near gyro frequency (approximately $1\cdot60$ Mc/s), by means of signals reflected at almost vertical incidence from the E_s layer and from the F layer, and subsequently confirmed their results by further observations. These results, which are discussed in the present communication, agree substantially with those of Cutolo and Mitra with regard to the magnitude of the observed demodulation, but cannot be explained by means of the theory of wave interaction.

II. Experimental Procedure

The experiments had already been designed to avoid possible sources of error mentioned later by Hibberd (1956).

Errors due to fading between a ground wave and waves reflected from the E_s and F layers were reduced to a small known amount by the following procedure: first, the ground wave was made very small by using a loop-aerial accurately adjusted during the day-time; secondly, measurements were not accepted unless the amplitude of one reflected wave was greater than three times the sum of the amplitudes of the other reflected waves and the ground wave. Comparatively few measurements (about 12 per cent. of those accepted) corresponded to an amplitude ratio greater than five. In practice, the accepted measurements represented signals for which one reflection was roughly four-fifths of the amplitude of the received signal.

It is conceivable that the modulation coefficient of the signal might possibly be reduced owing to sideband attenuation in the receiver, the effect being more

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pronounced at the higher modulation frequencies. In calibrating the receiving equipment, the signal was transmitted at each modulation frequency with a series of known modulation coefficients. The ground wave was received on a short simple aerial of variable length, and for each coefficient a calibration curve of audio-frequency amplitude against radio-frequency amplitude was drawn using arbitrary scales. The coefficient of an ionospherically reflected signal received with a loop-aerial could be found directly from the calibration curves, which were checked at intervals of about 2 min. Since any possible sideband attenuation in the receiver would affect equally the calibration and the measurements, it is extremely unlikely that errors due to this cause were present.

III. Interpretation of Results

The present experiments were carried out in Adelaide on 25 nights from May to December 1954 (Aitchison and Goodwin 1955) and confirmed by observations made on 15 nights from February to April 1955.

The mean virtual height of the E_s layer was estimated by means of regular pulse-modulated signals. At each modulation frequency, the coefficient of E_s-layer reflected signals was largely independent of the virtual height of the layer. The mean coefficient of F-layer reflected signals was approximately constant at each frequency when the virtual height of the E_s layer was between 98 and 122 km, but tended to be somewhat larger for heights outside this range; e.g. at 1000 c/s, the mean coefficients for F-layer reflections were 0·128, 0·116, and 0·142 respectively for the three ranges 86–98, 98–122, and 122–134 km. The data in Figure 1 are therefore restricted to observations made when the height of the E_s layer was between 98 and 122 km.

The received signal generally consisted of two waves reflected from the E_s and F layers, with a ground wave of much smaller amplitude, which may be neglected in this discussion. The coefficient of predominantly F-layer reflections depended markedly on the modulation frequency, whereas the coefficient of predominantly E_s-layer reflections was fairly constant, although a statistical analysis showed a small difference (at the 15 per cent. level of significance) between values observed at different frequencies. In particular, the coefficient of predominantly E_s-layer reflections oscillated with a " periodicity " similar to that of predominantly F-layer reflections, but with about one-quarter the amplitude, as illustrated in Figure 1. Taking into account the accuracy of the data, it is concluded that the oscillation was due solely to a small F-layer reflection received simultaneously with a larger E_s-layer reflection. The coefficient of a pure E_s-layer reflection would therefore be effectively constant without any marked dependence on frequency (at least between 120 and 4000 c/s), being about 0·165 for a transmitted coefficient of 0·2.

The oscillation in the coefficient of an F-layer reflected signal, which is exhibited by both sets of points in Figure 1, occurred about a mean coefficient of approximately 0·12. It remained essentially constant in amplitude for at least two " cycles ", being closely represented by a sine curve (full line in Fig. 1) with a " periodicity " of 900 c/s, and an amplitude equivalent to a coefficient of 0·02.

We shall consider the possibility that the theory of wave interaction (Bailey and Martyn 1934 ; Bailey 1937 ; Huxley 1952, 1956) may provide an explanation for the observations of demodulation close to gyro frequency. Since the " extraordinary " magneto-ionic component is very strongly absorbed in the E region, the " ordinary " is the only component received with appreciable amplitude after reflection from the E or F region. The " ordinary " and " extraordinary " components may be assumed to act as " wanted " and " disturbing " waves respectively. (Hibberd (1957) has also considered the possible disturbing effect of the " ordinary " component on itself.)

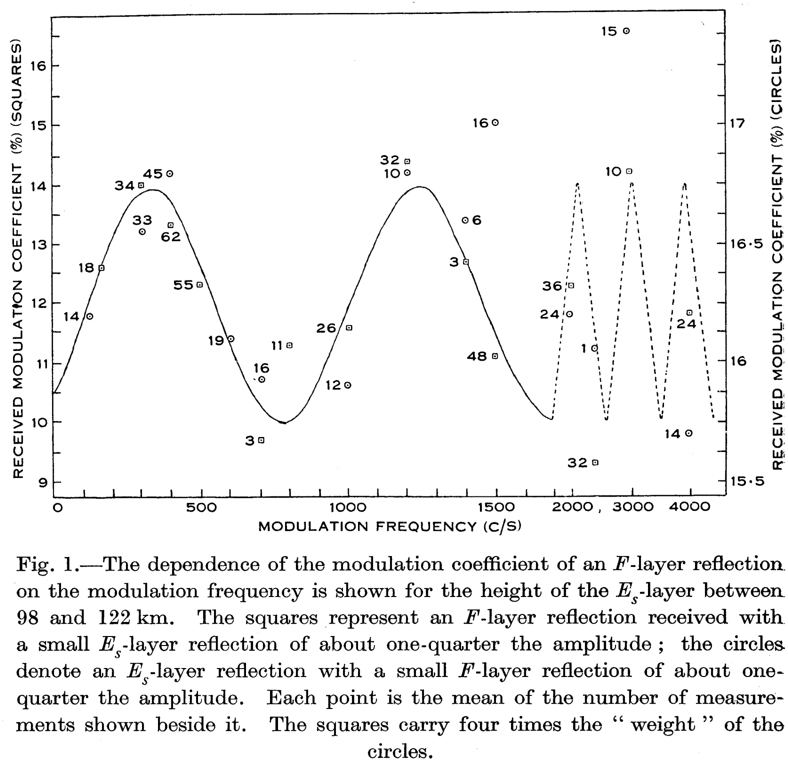

Fig. 1.—The dependence of the modulation coefficient of an F-layer reflection on the modulation frequency is shown for the height of the E_s-layer between 98 and 122 km. The squares represent an F-layer reflection received with a small E_s-layer reflection of about one-quarter the amplitude ; the circles denote an E_s-layer reflection with a small F-layer reflection of about one-quarter the amplitude. Each point is the mean of the number of measurements shown beside it. The squares carry four times the " weight " of the circles.

Let us consider a radio wave (originally modulated with a coefficient M) which has passed once through a demodulating region in the ionosphere. It may be shown (by extending the discussion of Aitchison (1957)) that (after detection) the amplitude of the audio component of the wave which is depicted in Figure 2 (a), may be written

$$M \cos \omega t - T_0 \cos \varphi_\omega \cos (\omega t - \varphi_\omega) = (M - \tfrac{1}{2}T_0) \cos \omega t - \tfrac{1}{2}T_0 \cos (\omega t - 2\varphi_\omega)$$
$$= M_1 \cos (\omega t + \chi_\omega),$$

where T_0 is the modulation coefficient transferred at an angular frequency $\omega \to 0$, φ_ω is given by the expression

$$\cos \varphi_\omega = 1/\{1+(\omega/Bn)^2\}^{\frac{1}{2}}, \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

χ_ω is a phase angle, and the received modulation coefficient is

$$M_1 = \{(M - \tfrac{1}{2}T_0)^2 + (\tfrac{1}{2}T_0)^2 - T_0(M - \tfrac{1}{2}T_0) \cos 2\varphi_\omega\}^{\frac{1}{2}}. \quad \ldots\ldots \quad (2)$$

In experiments on cross-modulation (Ratcliffe and Shaw 1948; Huxley 1952) the value of Bn (or $G\nu$) was found to be about 2×10^3, n being the number of gas molecules in unit volume and B a constant. Assuming that this value might also apply for demodulation near gyro frequency, it would follow from equations (**1**) and (**2**) that M_1 is a known function of ω, if T_0 is known. In the case of an E_s-layer reflected wave, T_0 was approximately $0\cdot035$. The curves in Figure 3 corresponding to $Bn=2\times10^3$ and 8×10^3 lie above the experimental points (plotted with their standard deviations) and at the higher frequencies the curves are outside the limits of experimental error. It would appear that Bn is large, certainly greater than 8×10^3. This conclusion is substantiated by considering an F-layer reflected wave and neglecting initially the comparatively small sinusoidal oscillation observed in the modulation coefficient as the frequency is varied. This would also correspond to a wave which has passed once through

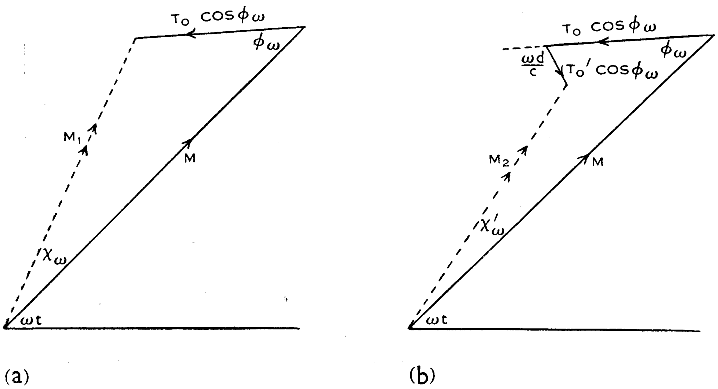

Fig. 2.—The expected modulation coefficient is shown for a wave which has passed (*a*) once, (*b*) twice, through the demodulating region in the ionosphere. (In the present experiments, φ_ω was found to be small.)

the demodulating region. The received coefficient M_1 is taken to be essentially constant at $0\cdot12$ with a standard deviation of about $0\cdot025$, at least up to 4000 c/s. Since $T_0=0\cdot08$ and $M_1<0\cdot145$, it may be shown from equation (**2**) that $\varphi_\omega<30°$. In particular, when $\omega/2\pi=4000$, it follows from equation (**1**) that $Bn>4\cdot3\times10^4$. Thus, Bn is large, certainly greater than $4\cdot3\times10^4$.

If we consider the case of an F-layer reflected wave which has passed twice through the demodulating region and assume that Bn has the generally accepted value of 2×10^3, it may be shown that the received modulation coefficient M_2 is expected to be a minimum when $\omega d/c$ is approximately 2π or multiples thereof, but that minima beyond the first should be of no consequence because of an increase expected in the value of φ_ω with increasing ω (Aitchison 1957). (Here, d is the group path length travelled by the wave between its two passages through the demodulating region and c is the velocity of the wave.) However, in the present experiments at least two maxima and two minima were present in the oscillation of M_2 (Fig. 1). It would appear therefore that the angle φ_ω was small and did not change appreciably with increasing ω, in agreement with the previous conclusion that φ_ω was certainly less than 30°.

If we take as an approximation $\varphi_\omega=0$, it may be shown that (after detection) the audio component of a wave which has passed twice through the demodulating region has the form

$$M_2 \cos(\omega t+\chi'_\omega)=(M-T_0)\cos\omega t-T'_0\cos(\omega t+\omega d/c),$$

where T_0 and T'_0 are the coefficients of transferred modulation, χ' is a phase angle, as shown in Figure 2 (*b*), and the received modulation coefficient is

$$M_2=\{(M-T_0)^2+T_0'^2-2T'_0(M-T_0)\cos\omega d/c\}^{\frac{1}{2}}.$$

If $T'_0 \ll (M-T_0)$, the expression for M_2 may be simplified further, and becomes

$$M_2=(M-T_0)-T'_0\cos\omega d/c. \quad \ldots\ldots\ldots\ldots \quad (3)$$

Equation (3) indicates that to a close approximation M_2 has a constant component $(M-T_0)$ and a sinusoidal component of constant amplitude (T'_0). These implications of the theory agree very well with the experimental results.

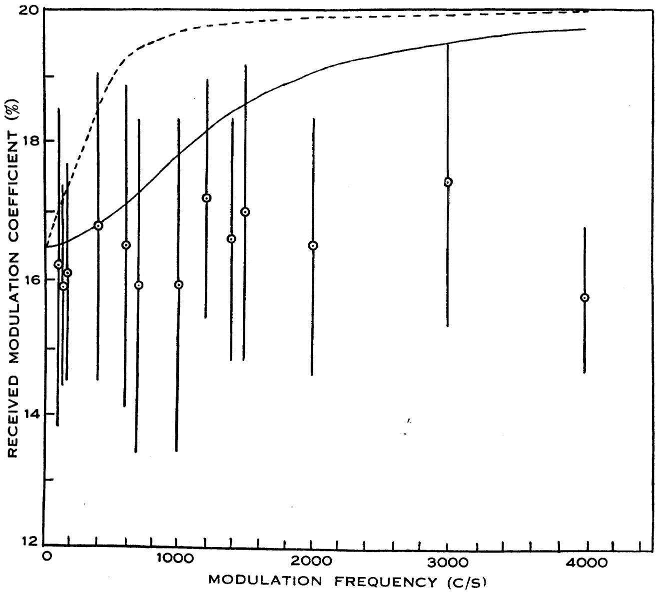

Fig. 3.—The modulation coefficients observed for E_s-layer reflections are shown with their standard deviations. The full line represents the theoretical variation of M_1 if $Bn=8\times10^3$ and the dotted line if $Bn=2\times10^3$.

Since reflections take place almost at vertical incidence, it would be expected from simple theory that T_0 and T'_0 would be practically equal. However, the present experimental observations suggest that $(M-T_0)$ was approximately 0·12 (at least up to 4000 c/s) and T'_0 was approximately 0·02 (at least up to 1500 c/s). It is concluded that in the present experiments an *F*-layer reflected wave, originally modulated with a coefficient of 0·2, was demodulated by about 0·08 and 0·02 during its two passages through the demodulating region ; that is, T_0 is approximately equal to $4T'_0$. The magnitudes of the two demodulations changed extremely slowly, if at all, with modulation frequency. It is difficult to find a simple explanation for the observed inequality of T_0 and T'_0.

In the above discussion, it appeared from the theory that Bn was very large, certainly greater than $4 \cdot 3 \times 10^4$. B has a value of $1 \cdot 25 \times 10^{-11}$ (personal communication from Professor L. G. H. Huxley), which suggests that $n > 3 \cdot 4 \times 10^{15}$ cm^{-3}. It would follow from Table 1 of Huxley (1953) that demodulation near gyro frequency was a maximum at a height below 68 km. This theoretical estimate of the height may be compared with the following derivation from the experimental results. A periodicity of about 900 c/s was observed in the modulation coefficient of F-layer reflections, indicating that there

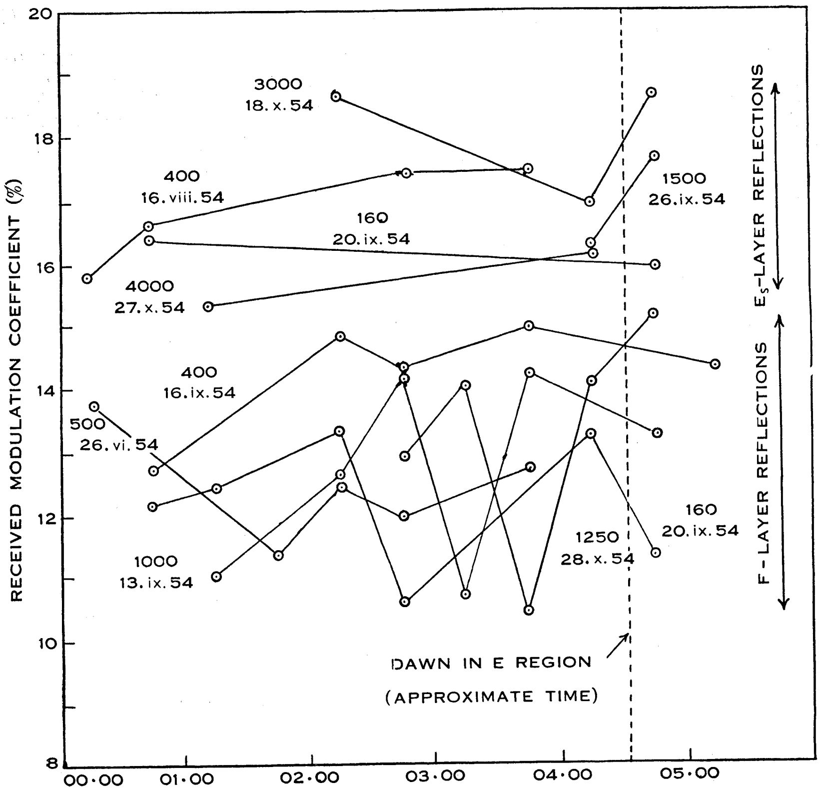

Fig. 4.—The received modulation coefficient is shown as a function of time for some typical results. The modulation frequency and date are given. Each point is the average of about seven measurements.

was a time interval of 1/900 sec between the emergence of a radio wave from the demodulating region and its return to it after reflection from the F layer. Since the wave was almost vertically incident on the ionosphere, this suggests that the distance ($\frac{1}{2}d$) between the demodulating region and the reflection point in the F layer was of the order of 167 km. From pulse-modulated transmissions, the mean virtual height of the F layer for the data in Figure 1 was found to be 256 ± 17 km. It follows that demodulation was a maximum at a height of roughly 90 km.

The deduction from theory that demodulation occurred largely below a height of 68 km disagrees with the direct estimate of 90 km. From a physical viewpoint, too, it is inconceivable that demodulation would occur below 68 km.

A statistical analysis of the results showed that a diurnal variation in the modulation coefficient was not present at the 5 per cent. level of significance for reflections either from the E_s layer or from the F layer, between 00·00 and 05·30 L.M.S.T. Some typical results are shown in Figure 4. In particular, there was apparently no decrease in demodulation through dawn in the present observations near gyro frequency, although such a " dawn " effect was observed by King (1957) at a frequency of 200 kc/s, which is remote from gyro frequency.

A discussion similar to that of Hibberd (1957) would show that the magnitude of demodulation, T_0, predicted by the theory, is about one hundred times smaller than the values observed in the present experiments.

The large magnitude of demodulation and its lack of dependence on modulation frequency at least up to 4000 c/s, appear to be inconsistent with the theory of wave interaction.

Carlevaro (1956) and Hibberd (1957) have also pointed out discrepancies between the theory and observations. It is concluded that the theory of wave interaction is inadequate to explain the present observations of demodulation near gyro frequency.

IV. Acknowledgments

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