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# Geomagnetic Micropulsation and the Equatorial Ionosphere

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## ABSTRACT

The characterestics of geomagnetic micropulsations undergo appreciable changes as they penetrate the ionosphere before being detected by the ground based instruments. These changed properties at the low and equatorial stations are distinctly different from those at the high latitudes. This article discusses these properties with respect to the equatorial magnification of a geomagnetic signal. We also discuss the changes in the polarisation angles of the geomagnetic signals associated with the micropulsations imparted by the ionosphere. At the low and equatorial stations these are not merely a rotation by $\pi/2$ as is the case for the high latitude stations where the ambient geomagnetic field can be assumed to be almost vertical as opposed to being almost horizontal in the equatorial regions. The amount of rotation is also discussed.

## INTRODUCTION

The geomagnetic fields fluctuate over a wide range of periods from seconds to a few minutes. These are called geomagnetic micropulsations. These are basically hydromagnetic (MHD) waves generated in the magnetosphere or beyond by various plasma instabilities or large scale motions of the plasma in the distant space. Therefore, the wave-characteristics of these signals reflect the properties of the generation regions in the distant space. However, before arriving on the ground, these waves encounter the ionosphere which has a completely different set of plasma properties than those of the magnetosphere. The magnetosphere essentially is a collision less region where the conductivity along the magnetic field lines is very large; the plasma fluid is tied up with the magnetic field in such a manner that the fluid motion and the field motion are similar. The ionosphere, on the other hand, is a metallic medium with highly an-isotropic conductivities. Just below the ionosphere, the non-conducting atmosphere, again, behaves as vacuum before the pulsation signals are detected by the ground based instruments. Therefore, it is rather important that the effect of the ionosphere on a micropulsation signal is properly worked out.

There are two aspects of the ionospheric effects. First is the magnitude of the signal. Second is the polarisation property. It is only expected that the signal will be attenuated as it penetrates the conducting ionosphere. The degree of attenuation should be proportional to the local ionospheric condutivities. Or in other words, the attenuation should be latitude dependent. This is observed to be more or less true. However, the special effect of the equatorial electrojet as an intensified signal at the geomagnetic equator compared to an off-equatorial station is found to be valid even in the case of the geomagnetic signals associated with the micropulsation phenomena, just like any other geomagnetic variations. Any large scale current system flowing in the low latitude ionosphere exhibits enhanced east-west currents because of the large cowling conductivity at the sun lit part of the equatorial ionosphere. As a result, a large variety of geomagnetic signals at the equatorial ground station exhibit enhanced intensity in the horizontal component compared to the same at a nearby slightly off equatorial station.

In this article, first, we shall discuss the electrojet magnification of the micropulsation and the properties of the polarisations of these signals vis-a vis- equatorial and low latitude ionosphere will be discussed later.

## ELECTROJET MAGNIFICATION

It is well known (Sastry, Sarma & Sarma 1979) that the geomagnetic signal on the ground near the equatorial region is more than that at the off-equatorial station at the same local time during the day time when the ionospheric conductivities are expected to be significant. This is observed to be true for almost all frequencies. The signals in the range of pulsation frequencies also generally undergo electrojet magnification. But there are some exceptions. It was observed by Sarma & Sastry (1995) that the electrojet effect is attenuation rather than magnification if the periods are less than about 20 seconds. It must be remembered that the electrojet magnification is caused by the ionospheric conductivities. The electron gyro-frequency at this height is several orders of magnitude higher than the frequencies of the micropulsations. Therefore, the intrinsic frequency dependence of the conductivities should not be responsible for this anomalous electrojet effect. Later on Roy & Rao (1998) have shown that the electrojet magnification is a function of the frequency of the micropulsation signal. It is not because of the frequency dependence of the conductivities themselves. It decreases with increasing frequency and becomes less than one (attenuation) for periods of the order of 20 seconds. However, for further higher frequencies, the electrojet effect again becomes

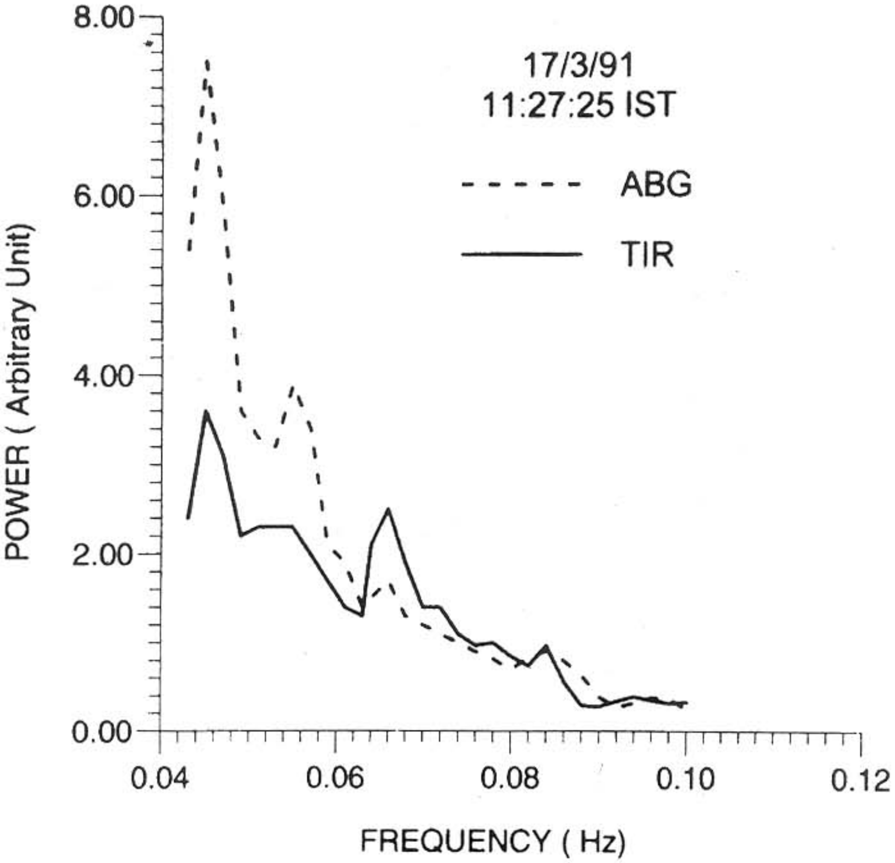


**Figure 1(a).** Power spectra of the horizontal component of the geomagnetic field variation from two stations Tirunelvelli ( TIR) and Alibag (ABG) for 17th. March,1991.

magnification (greater than one). The magnification versus frequency curve shows a minimum. An example of this anomalous behaviour is shown in Fig.1. Here the simultaneous power spectra of the micropulsation signals in the range of Pc 3-4 for the electrojet station of Tirunelvelli (TRV) and an off-equatorial station of Alibag (ABG) show the usual electrojet magnification for the lower frequencies. But, for frequency of the order of 0.05 Hz ( t=20 sec.) Alibag power is more than TRV power. This is the anomalous attenuation. Again for a higher frequency of 0.07 Hz (T= 14 sec.) the normal magnification is observed.

This peculiar behaviour indicates that for certain freqiuencies the micropulsation signal just above the ionosphere over ABG is stronger than that over TRV. In fact, the signal above Alibag is so strong that the usual electrojet magnification effect is nullified resulting in an attenuation rather than an amplification. This preferential magnification at Alibag occurs only over a narrow band of periods around 24 seconds or so. One may speculate that this is probably similar to the field line resonance (FLR) effect often observed at higher latitudes with lower frequencies. One may argue that the field line above a very low latitude station like Alibag is mostly embedded in the ionosphere. Therefore, this field line will not oscillate in the manner as the high latitude field lines do. However, it is physically feasible that a highly loaded field line also may have an eigen- frequency which may be somewhat different than the usual FLR mechanism. In fact Poulter, Allan & Bailey (1988) have calculated the eigen frequency of low latitude field lines (FL) where most of the FL is embedded in the ionosphere. Their calculation actually shows that the eigen period of a FL corresponding to a geomagnetic latitude of Alibag is of the order of 18 to 20 seconds for a typical mid day ionosphere which agrees well with our observation that Alibag response at this period is larger than the response at TRV.

Since it is highly loaded only strong input incident external signals will be able to excite such preferential response at the eigen frequency. One , however, recognizes the speculative nature of this argument. More extensive observation is required for reaching a definite conclusion.

Another interesting feature of equatorial electrojet effect is on very low frequency PS 6 pulsations with periods ranging from a few minutes to tens of minutes. These signals generally originate in the interplanetary space or at far region of the geo-tail. It has been observed that on many occasions,

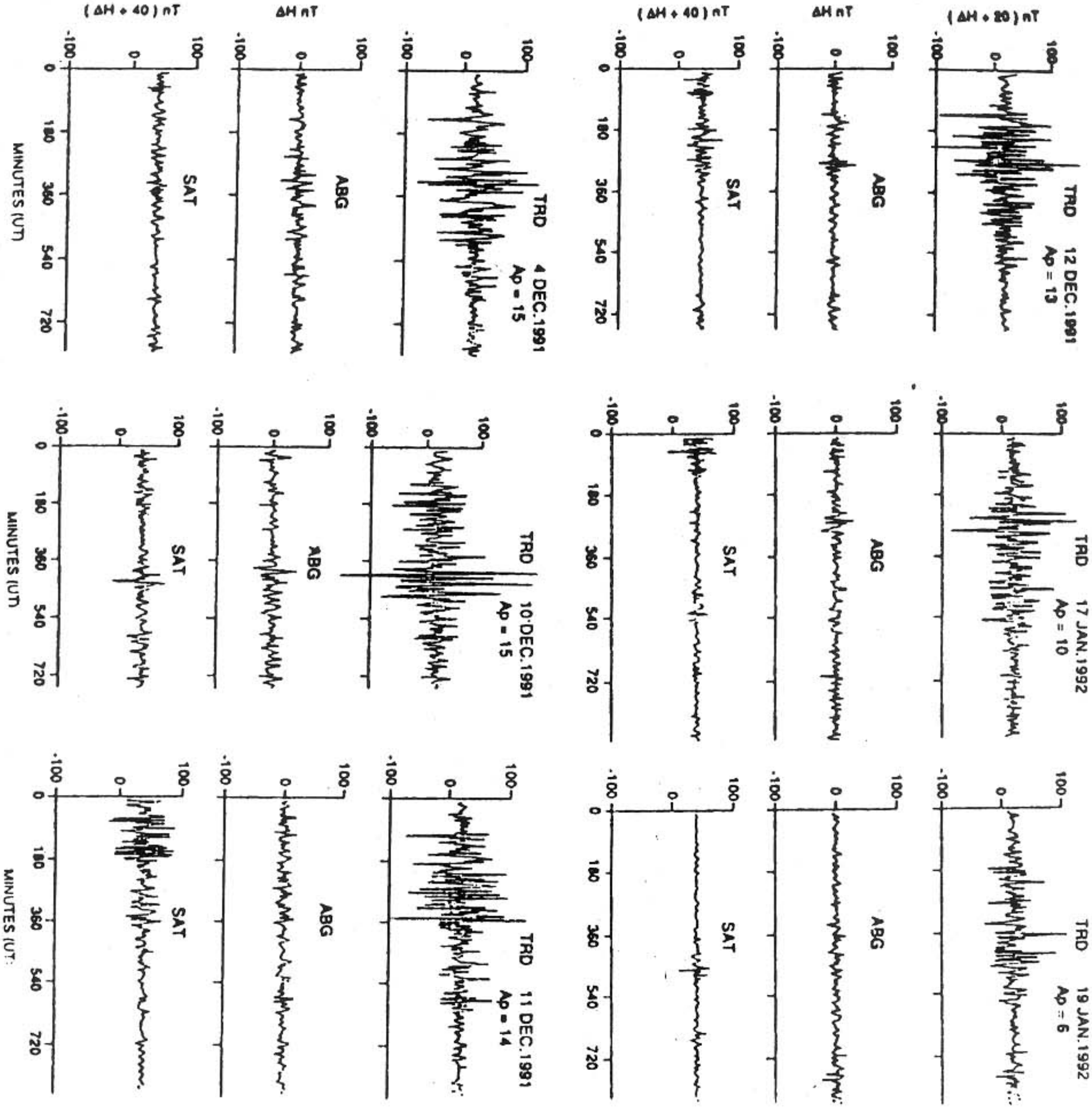


**Figure 1(b).** Horizontal component of magnetic field (after de trending) from two Indian Stations : Trivandrum (TRV), Alibag (ABG) and at a geostationary satellite (SAT) for December 12, 1991.

the electrojet magnifications are unusualy large for these pulsation signals. We have chosen about six such days from October 1991 to January 1992. The common characteristics of all the six event days are that they are geomagnetically quiet. The highest electrojet strength for the Sq currents (defined by the ratio of the horizontal magnetic field variation H at TRV to H at ABG) is of the order of 1.5 at the local noon. But the magnification factor for these Ps 6 signals are much higher. This is because the signal strengths at TRV are anomalously large. At such frequencies while those at Alibag are quite negligible. To rule out the possibility of locally generated Ps 6 source (like internal gravity waves) only at the equatorial region we have examined the micropulsation signals at a Geo-stationary height corresponding to the event days. One such representative sample of de-trended data are shown in Fig.2.

Since the Geo-stationary satellite data also show the similar fluctuations, one is certain about the global nature of these Ps 6 signal. The power spectrum analysis show that the average periods are between 9 minutes to 25 minutes. The magnification factor is sometimes as large as 4. It is observed that for these event days the elctrojet magnification at these frequencies are rather significantly larger than the regular Sq magnification almost throughout the day time hours. The reason for such anomalous electrojet effect is not known yet. However, we have noticed that corresponding ionospheric irregularities in the equatorial ionosphere seem to be quite strong during all the event hours. This suggests that some special type of plasma phenomena (or instabilities) may be responsible for this unusual magnification of the Ps 6 waves at the equatorial ionosphere.

## POLARISATIONS

The plasma properties of the ionosphere is distinctly different from those at the magnetosphere. Therefore the propagation properties in the ionosphere is expected to be much different from those in the magnetosphere. The role of the ionosphere in modifying the micropulsation signal has been discussed by Hughes (1974), Hughes & Southwood (1976) mostly for high latitude regions. Their model is not suitable for very low and equatorial latitudes. For such regions the model proposed by (Roy 1996) assumes that the micropulsation signal encounters a discontinuity in space as it penetrates the ionosphere before reaching the ground. It can be shown (Roy 1996) that the north-south ($x$) and east-west ($y$) magnetic variation just above the ionosphere ($b_x^m$ , $b_y^m$ ) are related to the components of the magnetic variations on the ground ($b_x^g$ , $b_y^g$ ) through the expression below.

$$b_x^m = (1.+\alpha\Sigma_{yy})b_x^g + \alpha\Sigma_{xy}\, b_y^g$$

$$b_y^m = -\alpha\Sigma_{xy}\, b_x^g + (1+\alpha\Sigma_{xx})b_y^g$$

$$\alpha = \frac{i4\pi\omega z_0}{c^2}$$

where $\omega$ is the frequency and $z_0$ is the height of the ionosphere from the ground. The $\Sigma$' s are the height integrated ionospheric conductivities and are very sensitive functions of the latitude (Matsushita & Campbell 1967).

The angle the horizontal vector makes with the $y$ (east-west) direction is measured by the ratio $b_x / b_y$ . Therefore, the polarisation angle of the magnetospheric signal $b_m$ is different from the polarization angle of the ground signal as can be seen from the above matrix equation. The difference between these two angles will depend on the orientation of the ground vector representing the horizontal component. It is clear from the above equations that the transformation from $b_m$ to $b_g$ is not at-all a just simple rotation. At high latitude, however, $\Sigma_{xx} = \Sigma_{yy}$ , and therefore the transformation can be looked upon as a sort of rotation. At the equator, on the other hand, the $\Sigma_{xy}$ is zero and $\Sigma_{xx}$ is about three orders of magnitude larger than $\Sigma_{yy}$ for a typical day time ionosphere. Therefore the y-component (east-west) of the magnetospheric signal will be heavily damped in passing through the ionosphere. As a result, the ground signal should be predominantly along the north-south direction. Since the east-west magnetospheric signal is almost totally suppressed, the magnetospheric wave with polarisation almost close to the east-west will appear to be rotated by 90 degree on the ground. This only means that it is very difficult to predict the east-west component from the ground observation if the station is exactly on the dip equator. This uncertainty, however, is less if the station is not exactly on the equator.

The amount of rotation suffered by the magnetospheric signal in crossing the ionosphere is very much a function of not only the latitude but also on the frequency although the latter dependence is much weaker than the former. For a typical day time ionosphere the relationships between the polarisation angle $\theta_m$ of the magnetospheric signal and the angle $\theta_g$ of the ground signal for different I are shown in the Figs 3a and 3b, for two periods : T=10 sec. and T=100 sec. respectively. Here I represents the angle of inclination of the ambient magnetic field which defines the geomagnetic latitude of the station. The first point to notice is that the polarisation changes are less frequency dependent for very low latitudes. The difference between the dashed curve (which represents no change in the polarisation angle) and the solid curve is more pronounced for I=10 than for I=3. The second point to notice is that a very small east-west inclination of the ground polarisation vector signifies a large east-west component in the magnetospheric signal. This means that the magnetospheric signal is rotated by an angle which depends on its polarisation direction, and not by a fixed amount of 90 degree as is generally assumed.

To see how the ionosphere modifies the polarisations of the micropulsation signals we have plotted some hypothetical ellipses both on the ground and at the magnetosphere just above the ionosphere in Fig.3 for I=10 degrees and T= 100 seconds.. Ionospheric conductivities are taken from Matsushita & Campbell (1967). The magnitude of the signals are normalised by the east-west component of the variations just above the ionosphere. It should be noted that the nature of the polarisation ellipse also changes as the signal penetrates the ionosphere. This can very well be used to determine the wave properties of the magnetospheric signal from ground measurements.

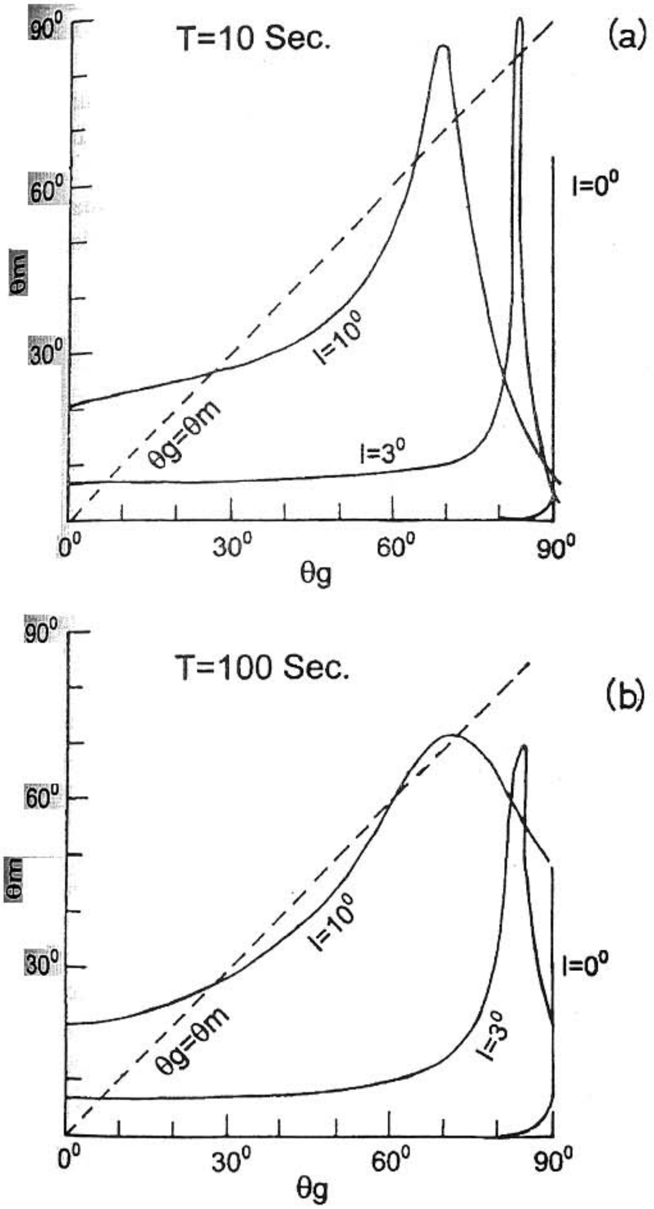


**Figure 2(a, b).** Relationship between the polarisation angle $\theta_g$ of a micropulsation signal at the ground and the angle $\theta_m$ above the ionosphere for two periods : T= 10 sec (2a); for T= 100 sec (2b). The values of the ionospheric conductivities are taken from Matsushita & Campbell (1967) for a typical mid day ionosphere.

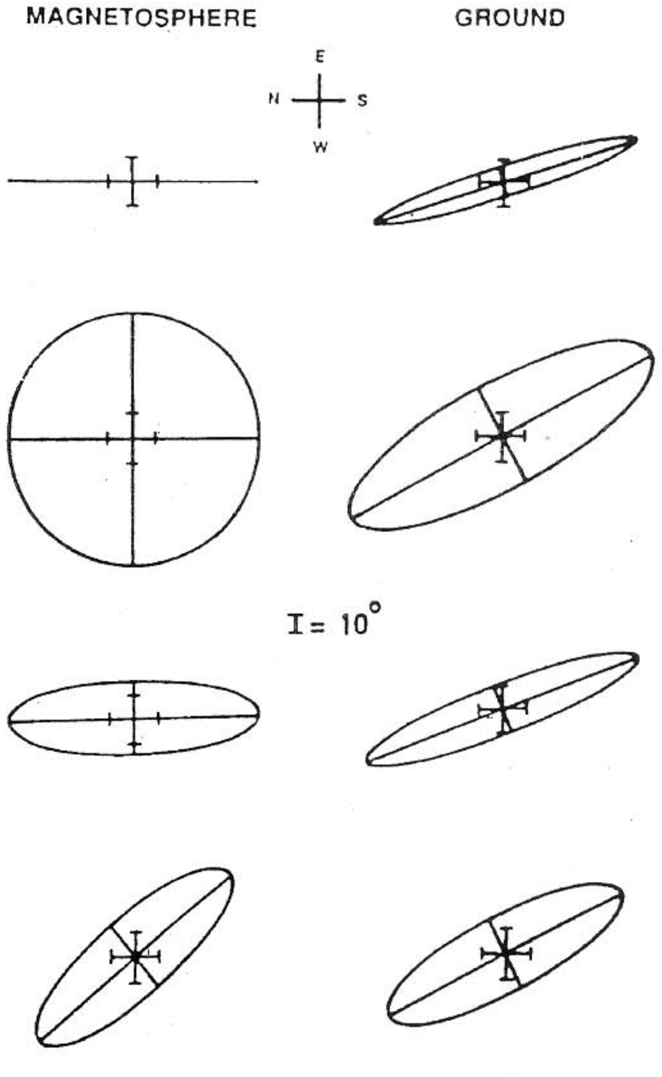
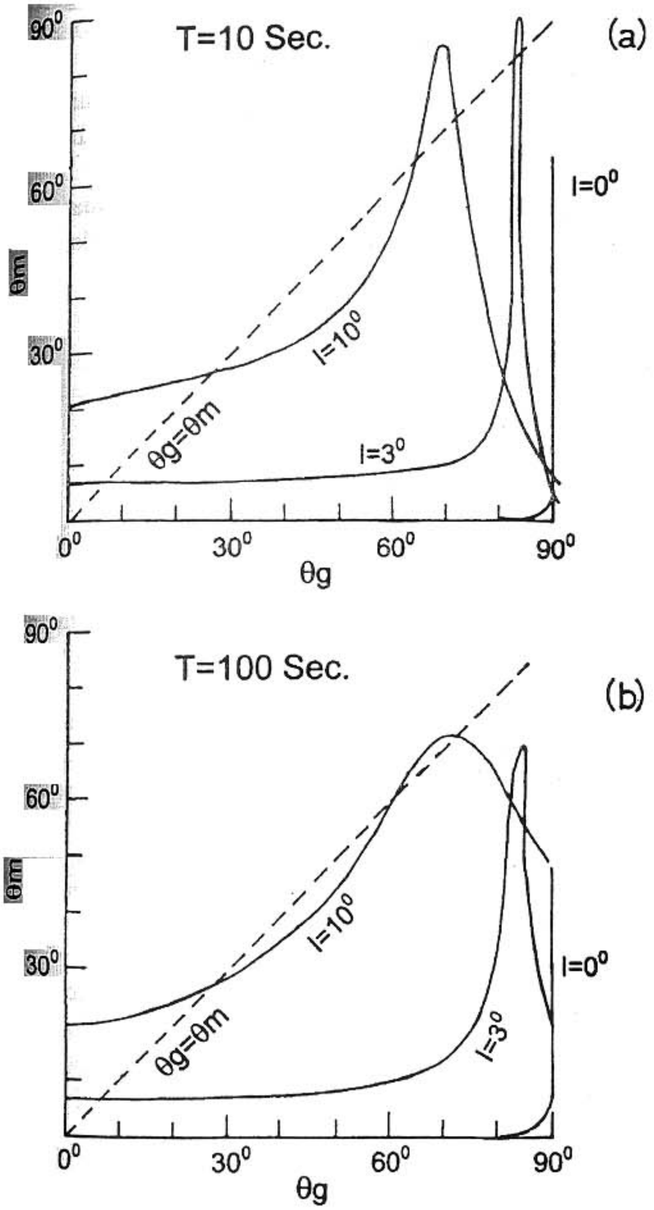


**Figure 3.** A few hypothetical Polarisation ellipses of micropulsation signals both at the ground and at magnetosphere for T=100 sec and I=10, for a typical noon time ionosphere.



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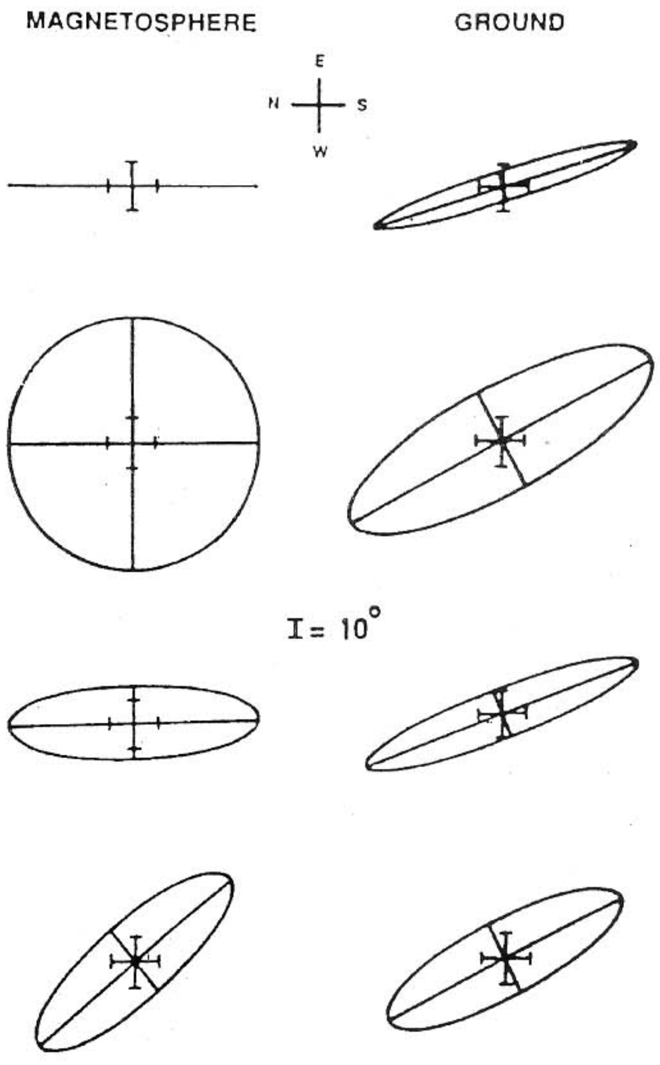

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