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STUDIES ON NORMALIZED ELECTRON TEMPERATURE DURING ARTIFICIAL MODIFICATION OF THE IONOSPHERE

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The phenomenon of the heating of the ionospheric medium during the passage of high power radio waves has been investigated taking into account the influence of the geomagnetic field and the variation of the effective collision frequency within the medium. The result is used to study the variation of normalized electron temperature within such a modified situation.

I. INTRODUCTION

The transient heating of the upper atomsphere caused by the dissipation of energy from various natural sources as well as due to the propagation of high power radio waves is well known. The dynamical response of various phenomena to transient heating has been studied by different authors [1—7]. During high power transmitter operations (in cross-modulation experiments, back-scatter, radar operations), the average energy received by the electrons from the field will gradually heat up the medium which in turn changes the equilibrium distribution of the temperature within the medium. The electrons receive a considerable amount of energy from the field because of their large free-path length. For this, the dielectric constant becomes a function of the electric field and thus there will be modifications in the electromagnetic processes within the atmosphere.

Long distance TV receptions are possible under abnormal conditions which are examined generally by continuous monitoring. The experiments of Saksena [8] yield some peaks around noon for channel 2 and channel 3. All

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India Radio is operating two 250 kW transmitters at Delhi, one 100 kW transmitter at Bombay and one at Madras at high frequencies. These should be modifying the ionospheric layers. Gurevich et al. [9] had used intermittent heating and obtained density fluctuations in ionizations in the E-layer. In this presentation, a continuous heating process is considered. A theoretical analysis will be described which yields results about the variation of normalized electron temperature within such a modified atmosphere taking into consideration the influence of the geomagnetic field and the explicit expression of the collision frequency.

II. THEORETICAL ANALYSIS

The appropriate situation can be studied with the help of the following momentum transport equation, energy balance equation and continuity equation:

$$\frac{\partial \boldsymbol{v}}{\partial t} + (\boldsymbol{v}.\nabla)\boldsymbol{v} = -\frac{e}{m}\boldsymbol{E}(t) - \nu_e(T_e)\boldsymbol{v} - \frac{e}{m}\boldsymbol{v}\times\boldsymbol{H} \tag{1}$$

$$\frac{3}{2}\frac{\partial}{\partial t}(NKT_e) + eN\boldsymbol{v}.\boldsymbol{E} + \frac{3}{2}\delta\nu_e NK(T_e - T) + Q_i\frac{\partial N}{\partial t} - \nabla.\boldsymbol{W} = 0 \tag{2}$$

$$\frac{\partial N}{\partial t} = q - \alpha N^2, \tag{3}$$

where e = electronic charge, m = mass of the electron, T_e = electron temperature, T = equilibrium plasma temperature, δ = fraction of energy lost by an electron in a collision with a heavy particle, q = rate of production of ion/electron pairs, α = recombination coefficient, ω = angular frequency of the time-varying field, ν_e = effective collision frequency of electrons, N = electron number density, $\boldsymbol{E}(t)$ = applied electric field, $\boldsymbol{v}$ = average electron velocity due to the applied field, Q_i = ionization energy of the plasma medium, $\boldsymbol{H}$ = geomagnetic field, $\boldsymbol{W}$ = heat flow vector = $-\lambda(T_e)\nabla T_e$, $\lambda(T_e)$ = effective coefficient of electron energy conduction

$$\lambda = K_T(1 - \mu\tau'/\sigma^0 K_T),$$

where K_T = coefficient of electron energy conduction, μ = coefficient of electron energy conduction due to electric field, τ' = current flow coefficient due to thermal gradients at constant electron pressure, $p = NKT_e$, σ^0 = dc electrical

conductivity. From (1), the expression of the average electron velocity can be obtained as

$$\boldsymbol{v} = -\frac{e}{m}\exp\left[(-A) - \frac{e}{m}\int_{t'}^{t} X\,\mathrm{d}t''\right]\left[\int_0^t \boldsymbol{E}(t')\exp\left\{A + \frac{e}{m}\int_{t'}^{t} X\,\mathrm{d}t''\right\}\mathrm{d}t'\right] \tag{4}$$

where

X stands for the matrix $\begin{pmatrix} 0 & H_z & -H_y \\ -H_z & 0 & H_x \\ H_y & -H_x & 0 \end{pmatrix}$

and $A = \int_{t'}^{t} [(\boldsymbol{v}.\nabla) + \nu_e(T_e)]\,\mathrm{d}t''$.

Substituting (4) and (3) in (2),

$$\frac{3}{2}NK\frac{\partial T_e}{\partial t} + \frac{3}{2}K\left[q - \alpha N^2 + \delta\nu_e(T_e)N - \frac{2k^2}{3K}\lambda(T_e)\right]T_e =$$
$$= \frac{3}{2}\delta\nu_e(T_e)NKT - Q_i(q - \alpha N^2) + e^2\frac{N}{m}\boldsymbol{E}.\left[\exp\left\{(-A) - \frac{e}{m}\int_{t'}^{t} X\,\mathrm{d}t''\right\}\right].$$
$$.\left[\int_0^t \boldsymbol{E}(t')\exp\left\{A + \frac{e}{m}\int_{t'}^{t} X\,\mathrm{d}t''\right\}\mathrm{d}t'\right]. \tag{5}$$

The equation (5) can be transformed as

$$\frac{\partial\Theta}{\partial\tau} + \frac{1}{\delta\nu_e(T_e)}\left[q - \alpha N^2 + \delta\nu_e(T_e)N - \frac{2k^2}{3K}\lambda(T_e)\right]\Theta =$$
$$= 1 - \frac{2Q_i}{3NKT\delta\nu_e(T_e)}(q - \alpha N^2) + \frac{2e^2}{3mKT\delta\nu_e(T_e)}\boldsymbol{E}.$$
$$.\left[\exp\left\{(-A) - \frac{e}{m}\int_{t'}^{t} X\,\mathrm{d}t''\right\}\right]\left[\int_0^t \boldsymbol{E}(t')\exp\left\{A + \frac{e}{m}\int_{t'}^{t} X\,\mathrm{d}t''\right\}\mathrm{d}t'\right], \tag{6}$$

where $\Theta = \frac{T_e}{T}$, $\quad \tau = \delta\nu_e(T_e)t$ and $k = \omega/c$.

Let a linearly polarized electric field be considered to be applied suddenly at the time $t = 0$, such that

$$\left.\begin{aligned} \boldsymbol{E}(t) &= 0 && \text{for } t < 0 \\ &= \boldsymbol{E}_0 \sin\omega t && \text{for } t > 0. \end{aligned}\right\} \tag{7}$$

Using (7), the equation (6) becomes

$$\frac{\partial \Theta}{\partial \tau}+\frac{1}{\delta \nu_e(T_e)}\left[q-\alpha N^2+\delta \nu_e(T_e)N-\frac{2k^2}{3K}\lambda(T_e)\right]\Theta=$$

$$=1-\frac{2Q_i}{3NKT\delta\nu_e(T_e)}(q-\alpha N^2)+\frac{2e^2}{3mKT\delta\nu_e(T_e)}E_0\sin\omega t\left[\exp\left\{(-A)-\right.\right.$$

$$\left.\left.-\frac{e}{m}\int_{t'}^{t}X\,dt''\right\}\right]\left[\int_0^t E_0\sin\omega t'\exp\left\{A+\frac{e}{m}\int_{t'}^{t}X\,dt''\right\}dt'\right]. \quad (8)$$

In the numerical analysis, the expression for the effective collision frequency has been taken from the works of Stubbe [10], Aggarwal et al. [11] and Savita M. Datta et al. [12]. This can be written as

$$\nu_e=\nu_{en}+\nu_{ei}+\nu_{in}=$$

$$=n[a_1T_e^{1/2}+a_2T_e+a_3T_e^{3/2}+a_4(\ln\beta)T_e^{3/2}]+\frac{8\pi Z^2e^4N_i\ln\Lambda}{3(2m\pi)^{1/2}(KT_e)^{3/2}}+$$

$$+\frac{4\pi}{3}\frac{n\mu_{in}}{KT}\left(\frac{\mu_{in}}{2\pi KT}\right)^{3/2}\int_0^\infty Q(g)\exp\left[-\frac{\mu_{in}}{2KT_R}g^2\right]g^5\,dg, \quad (9)$$

where

$$\Lambda=\frac{K^{3/2}}{1.78\,Ze^3}\left[\frac{T_e^3}{N\pi}\right]^{1/2}\left[\frac{T_i}{T_e+T_i}\right]^{1/2},$$

g = relative thermal velocity, $\beta=\sqrt{E/E_p}$, Z = residual charge, n = number density of neutral particles, $\mu_{in}=(m_im_n)/(m_i+m_n)$ = reduced mass, $Q(g)$ = momentum transfer cross-section, m_i = ion mass, m_n = neutral particle mass,

$$T_R=\mu_{in}\left(\frac{T_i}{m_i}+\frac{T_n}{m_n}\right)=\text{reduced temperature}$$

$$E_p=\left[\frac{3mKT}{e^2}\delta(\omega^2+\nu_e^2)\right]^{1/2}=\text{plasma field},$$

$$=\left[\frac{3mKT}{e^2}\delta\omega^2\right]^{1/2}\text{ for }\omega\gg\nu_e,$$

T_i = ion temperature, T_n = neutral particle temperature. The other symbols have been defined in the respective papers.

III. NUMERICAL ANALYSIS AND DISCUSSION

The experimental data of the radio signal from Mogra (lat. 22°30′ N; long. 88°25′ E) near Calcutta have been used for the numerical analysis. The transmission characteristics of the Mogra transmitter are as follows: power of the transmitter is 1 MW, frequency is 1.13 MHz, local gyrofrequency at a height of 100 km, from the earth's surface is 1.22 MHz, angle of dip is 32°N. The other data are taken from CIRA 1972 considering $T_i=T_n=T$. Using equation (8), the numerical values of normalized electron temperature at different frequencies and power output have been computed and are given in the following table 1.

Table 1

ω	T_e/T			
	1 MW	10 MW	100 MW	1000 MW
10^6	1.0059	1.0897	2.0458	2.4160
10^7	1.0031	1.1130	1.0850	1.2150

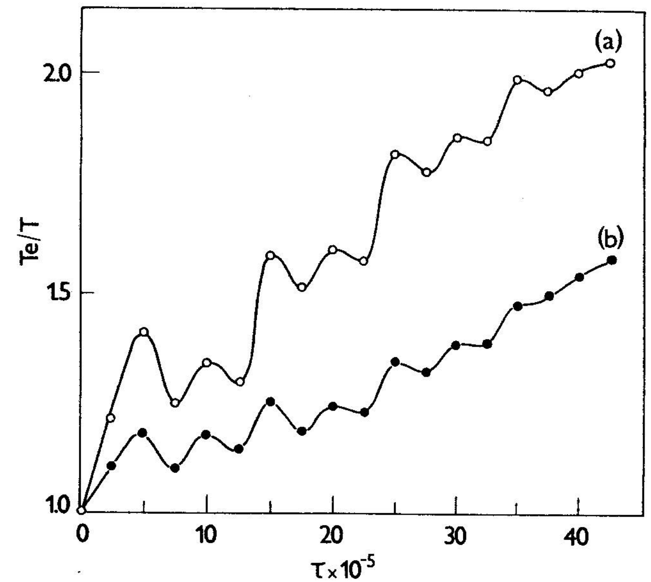

Fig. 1. Normalised electron temperature as a function of time. The curve (*a*) is the profile for $E_0/E_p=11.5$ and the curve (*b*) is the profile for $E_0/E_p=2.3$.

The variation of the normalized electron temperature as a function of time is shown in Fig. 1. Two values of $\left|\frac{E_0}{E_p}\right|$ have been considered in the analysis. The graphs show higher variations at the increased value of the ratio. The influence of the geomagnetic field has been taken into account in the formulation. The modiffication in the normalized electron temperature may be due to the generation of plasma instability developed during the high power wave propagation.

It is seen that the variation of the normalized electron temperature at the frequency of the applied field decays with the time constant δ, i.e., $\frac{1}{\nu_e}$ sec. The ratio $\frac{T_e}{T}$ also approaches a constant value after a long time $\left(\tau \gg 1, \text{ or } t > \frac{1}{\delta \nu_e}\right)$, which agrees with steady state results.

The changes in the electron density are also noted [9]. These changes are likely to be modified to a perturbed structure in the presence of a magnetic field. Field alignment of such extra-ionization to striations is likely. Such structures would support the VHF propagation through scattering processes.

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ИЗУЧЕНИЕ НОРМАЛИЗОВАННОЙ ТЕМПЕРАТУРЫ ЭЛЕКТРОНА ПРИ ИСКУССТВЕННЫХ ИЗМЕНЕНИЯХ В ИОНОСФЕРЕ

Исследуется явление нагрева ионосферической материи мощными радиоволнами. Учтено влияние геомагнитного поля а изменений эффективной частоты взаимодействия с веществом.

Результат используется при изучении изменений нормализованной температуры электрона при такой обстановке.