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Effect on the amplitude of magnetic field component of transmitted electromagnetic wave during geomagnetic storm

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Abstract— ***In this paper effect of geomagnetic storm on the transmitted electromagnetic wave due to solar flare event are presented. Solar eruption produced class X4.9 solar flare on 25 February -2014. Ground data at Allahabad, Uttar Pradesh dated 26, 27, 28 February-2014 and 1st March-2014 is evaluated. Earth magnetic field is suppressed during geomagnetic storm. In the same way this effect may be seen on the transmitted electromagnetic wave. Geomagnetic storm tries to decrease the amplitude of magnetic field component of transmitted electromagnetic wave. Equations are derived and results obtained.***

I. INTRODUCTION

Sunspot AR1967 returned to the earth side of the sun on Feb. 25th and promptly erupted, producing an X4.9-class solar flare. This is the strongest flare of the year so far and one of the strongest of the current solar cycle. Radio emissions from shock waves at the leading edge of the CME suggest an expansion velocity near 2000 km/s or 4.4 million mph. If such a fast-moving cloud did strike Earth, the resulting geomagnetic storms could be severe. However, because its trajectory is so far off the Sun-Earth line, the CME will deliver a no more than a glancing blow. The source of the eruption is long-lived sunspot AR1967, now beginning its third trip across the earth side of the sun. This region was an active producer of flares during its previous transits, and it looks like the third time will be no different. Solar flares send energetic particles that travel at near the speed of light. These particles (mainly protons and electrons) enter the upper atmosphere in the regions near the magnetic poles. As a result, the lower level of the polar ionosphere becomes very ionized, with severe absorption of HF and VHF radio signals. During magnetic storm the ionosphere gets disturbed. Radio waves interact with the ionosphere in a variety of ways depending on their frequencies. For frequencies below about 30 MHz, the ionosphere can act as a reflector. At higher frequencies, above 30 MHz, radio signals usually pass through the ionosphere. The ionosphere sometimes becomes disturbed as a reaction to some types of solar activity and, as a result, radio wave propagation may be interrupted. Solar flares emit electromagnetic radiations, such as x-ray emissions which can cause increases in ionization in the lower ionosphere, with consequent phase shifts in low frequency radio signals and increased absorption (fading) in HF and VHF radio signals. The wide spectrum of radio noise emitted from a flare may interfere with a wanted radio signal.

II. DATA

The Dst-Index data is taken from http://wdc.kugi.kyoto-u.ac.jp/dst_realtime/201402/index.html. H and Z component of earth magnetic field are recorded at Allahabad, Uttar Pradesh, India.

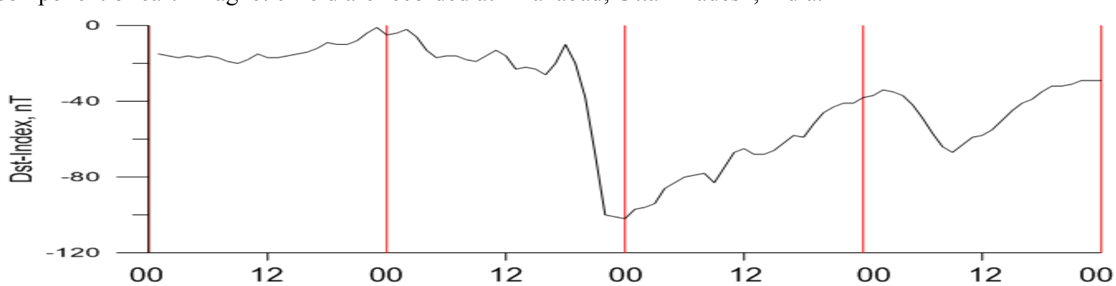

Figure 1: Dst Index dated 26, 27, 28 February-2014 and 1st March-2014

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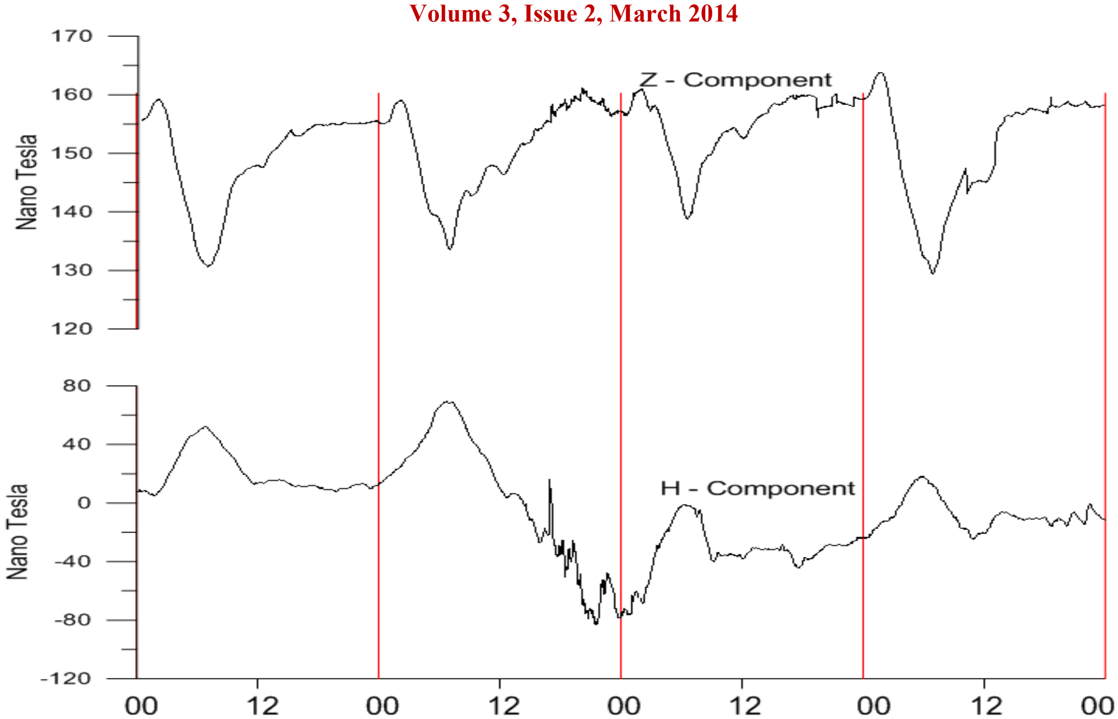

Figure 2: H-Component and Z-Component of Geomagnetic field dated 26, 27, 28 February-2014 and 1st March-2014 at Allahabad, Uttar Pradesh, India.

On 26 February -2014 the H-Component and Z-Component of geomagnetic field at Allahabad was quiet normal as corresponding Dst Index were also normal as shown in figure1 and 2, but On 27 February -2014 the H-Component and Z-Component of geomagnetic field are not normal. H-Component of geomagnetic field first become increased maximum at local noon than the previous day. Then sudden storm commencement (SSC) start. In main phase of storm the H-component of earth magnetic field considerably reduces shows the sign of magnetic storm. Corresponding Dst index on 27 February -2014 is also much negative a signature of magnetic storm approximately at the same duration. Dst Index goes to negative from 21hr to 00 hr. Z- Component of earth magnetic field is less sensitive than H-Component of earth magnetic field. On 27 February -2014 the sign of magnetic storm shows less variation in Z-Component of earth magnetic field. The range of Dst Index 0 -50 nT indicates the very weak magnetic storm. The range of Dst Index 50 -100 nT indicates the weak magnetic storm. The range of Dst Index 100 -150 nT indicates the moderate magnetic storm. Now the magnetic storm on 27 February -2014 is moderate category. At Allahabad ground data shows that the main phase of SSC continues 24.00 hr and on 28 February -2014 it turn to recovery phase at approximately 00 hr. On 28 February -2014 Dst index shows range -97 to -38 indicates the effect of storm is turn to reduce as Allahabad ground data also shows the compression of magnetic field. On 1st March the magnetic storm become subsided as Dst index is shifting to zero and earth magnetic field is trying to achieve its normal magnetic field.

III. ANALYTICAL APPROACH TO THE ELECTROMAGNETIC TRANSMITTED WAVE DURING MAIN PHASE OF GEOMAGNETIC STORM

During normal quiet day the wave shape of magnetic field component and electric field component of transmitted electromagnetic wave are shown in figure 3. In the main phase of magnetic storm the amplitude of magnetic field component of transmitted electromagnetic wave tries to decrease. Reduction in amplitude of magnetic field component of transmitted electromagnetic wave is seen in figure 4 and 5 below during magnetic storm.

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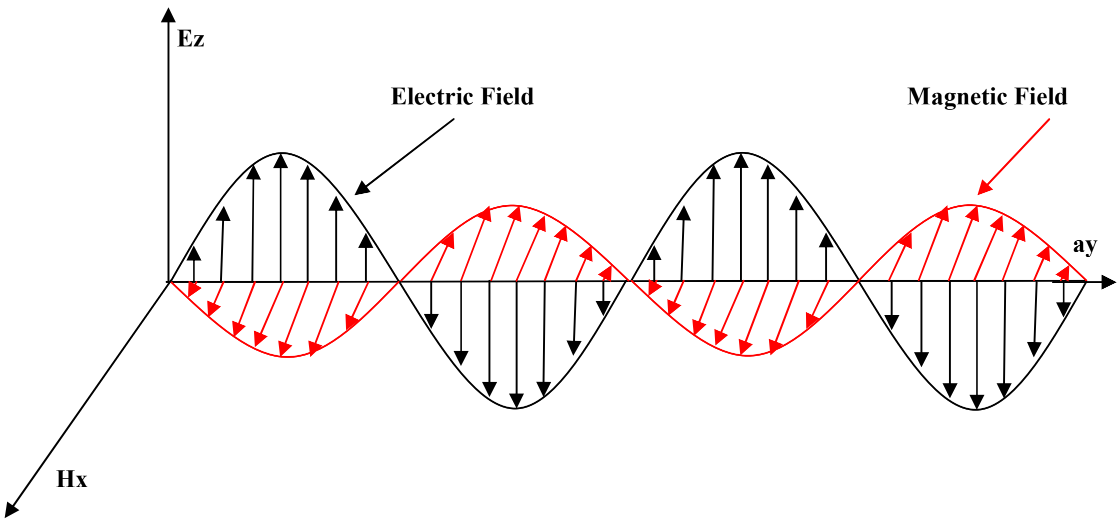

Figure 3 : Transmitted Electromagnetic shape during quiet geomagnetic days

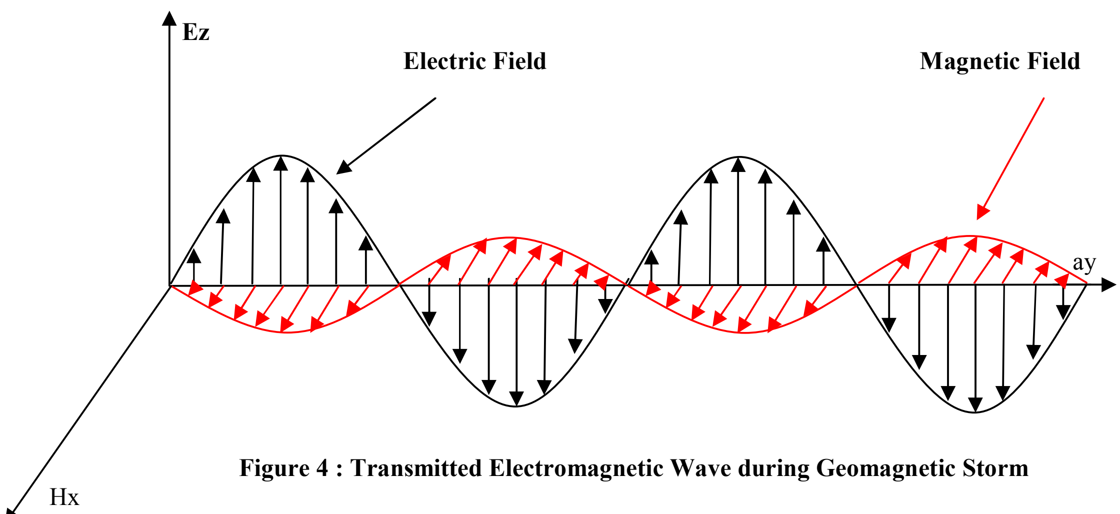

Figure 4 : Transmitted Electromagnetic Wave during Geomagnetic Storm

On 27 February-2014, H-Component of Allahabad ground data in figure 2 shows the sudden storm commencement and main phase of magnetic storm. When storm start the Allahabad ground H Component start to depress or reduce sharply. High energy charged particles rush towards the earth but are deflected around the earth (Flemming's right hand rule law) in circular orbits in the equatorial plane, forming a ring current at several earth radius , which cause large geomagnetic field reduction at several ground places. Drifting ions and electrons,trapped by the geomagnetic field, constitute westward flowing ring current (Williams, 1985). A systematic depression and subsequent recovery lasting up to a few days is clearly observed in the Dst index due to intensification and decay of the intensity of the ring current (Sugiura, 1964).

During main phase of magnetic storm, the H-Component of magnetic field is reduce sharply as shown in figure 2 On 27 February-2014. In the same manner this effect is seen on the magnetic component of the transmitted electromagnetic wave. The magnetic field component of the transmitted electromagnetic wave is depress (amplitude of the magnetic field component of the transmitted electromagnetic wave reduce) during transmission. Due to reduction of magnetic field component of the transmitted electromagnetic wave, deteriorate it self as shown in figure 6.

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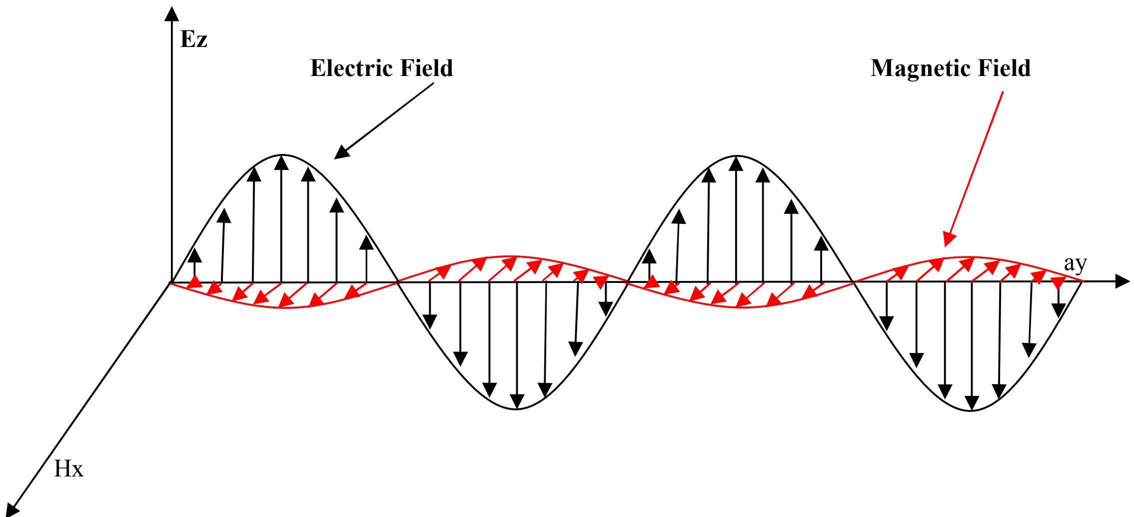

Figure 5 : Transmitted Electromagnetic Wave during Geomagnetic Storm

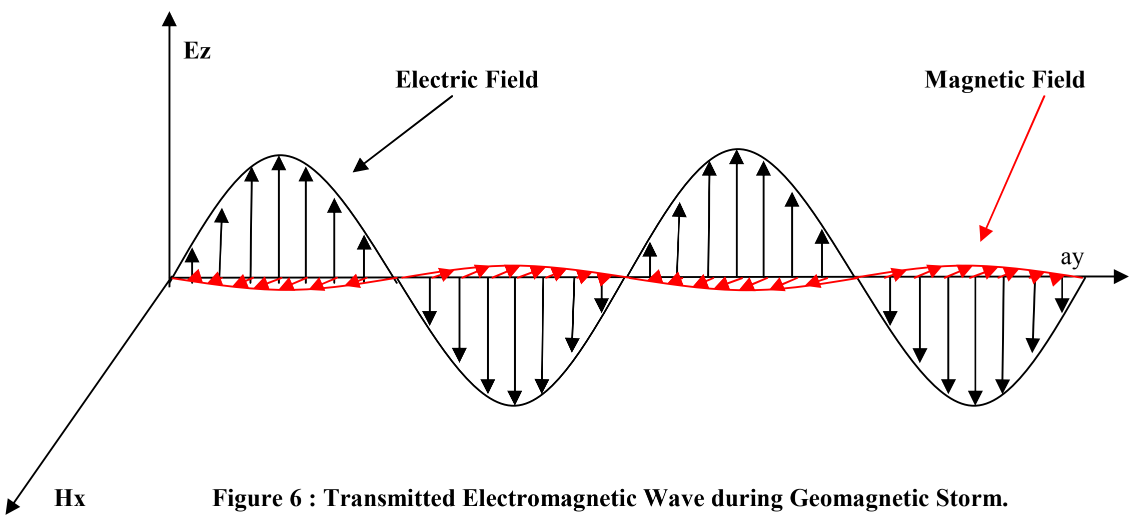

Figure 6 : Transmitted Electromagnetic Wave during Geomagnetic Storm.

The electromagnetic transmitted wave has own Electric field intensity E and magnetic field intensity H. The magnetic field density of electromagnetic transmitted wave is B

During quiet normal magnetic day, electromagnetic transmitted magnetic field density = B

$B = \mu H$

Electromagnetic transmitted magnetic field density in main phase during magnetic storm = $B - \Delta B$

$B - \Delta B = \mu (H - \Delta H)$

Maxwell equation

$\nabla . E = 0$

$$\nabla \times E = -\frac{\partial B}{\partial t} = -\mu_r \frac{\partial H}{\partial t}$$

$$\nabla \times H = J + \frac{\partial D}{\partial t} = \sigma\varepsilon + \varepsilon\frac{\partial E}{\partial t}$$

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$\nabla . D = \rho_V$
$\nabla . B = 0$

III. EQUATION IN PHASOR FORM

$\nabla \times E = -j\omega\mu H_s$
$\nabla \times H = (\sigma + j\omega\varepsilon)E_s$

$\nabla \times \nabla \times H_s = \nabla(\nabla . H_s) - \nabla^2 H_s$

LHS $\nabla \times \nabla \times H_s = \nabla \times (\sigma + j\omega\varepsilon)E_s$

$\nabla \times \nabla \times H_s = (\sigma + j\omega\varepsilon)\nabla \times E_s$
$\nabla \times \nabla \times H_s = (\sigma + j\omega\varepsilon) - j\omega\mu H_s$

In main phase during magnetic storm

$\nabla \times \nabla \times H_s = (\sigma + j\omega\varepsilon) - j\omega\mu(H - \Delta H)_s$

RHS $\nabla(\nabla . H_s) - (\nabla^2 H_s) = \nabla(\nabla . \frac{B}{\mu}) - \nabla^2 H_s$

$\nabla . B = 0$
$\nabla(\nabla . H_s) - \nabla^2 H_s = 0 - \nabla^2 H_s$

In main phase during magnetic storm

$\nabla(\nabla . H_s) - \nabla^2 H_s = 0 - \nabla^2 (H - \Delta H)_s$

RHS=LHS $\nabla^2 H_s = (\sigma + j\omega\varepsilon)j\omega\mu H_s$

$\nabla^2 H_s = (\sigma + j\omega\varepsilon)j\omega\mu H_s$

$\gamma^2 == (\sigma + j\omega\varepsilon)j\omega\mu$
$\nabla^2 H_s = \gamma^2 H_s$

In main phase during magnetic storm $\nabla^2 (H - \Delta H)_s = (\sigma + j\omega\varepsilon) - j\omega\mu(H - \Delta H)_s$

$\gamma^2 == (\sigma + j\omega\varepsilon)j\omega\mu$

$$\nabla^2 (H - \Delta H)_s = \gamma^2 (H - \Delta H)_s$$

IV. EQUATION IN TIME DOMAIN

The uniform plane wave shown in figure 3 has a z-component of electric field and an x-component of magnetic field which is both functions of y. Components of E and H are perpendicular to the direction of propagation. The polarization of a plane wave is defined as the direction of the electric field (this transmitted wave is a z-polarized plane wave). For this uniform plane wave, the component wave equations for the only two field components (Ezs, Hxs) can be simplified significantly given the field dependence on y only.

$Es = Ezs$ **(y) az**
$Hs = Hxs$ **(y)ax**

$$\frac{\partial^2 Ezs}{\partial x^2} + \frac{\partial^2 Ezs}{\partial y^2} + \frac{\partial^2 Ezs}{\partial z^2} = \gamma^2\ Ezs$$

$$\frac{\partial^2 (H - \Delta H)xs}{\partial x^2} + \frac{\partial^2 (H - \Delta H)xs}{\partial y^2} + \frac{\partial^2 (H - \Delta H)xs}{\partial z^2} = \gamma^2\ (H - \Delta H)xs$$

The remaining single partial derivative in each components wave equation become pure derivative since Ezs and $(H - \Delta H)xs$ are functions of y and z.

$$\frac{\partial^2 Ezs}{\partial y^2} - \gamma^2\ Ezs = 0$$

Linear Homogeneous second order Differential Equation

$$\frac{\partial^2 (H - \Delta H)xs}{\partial y^2} - \gamma^2\ (H - \Delta H)xs = 0$$

The general solution to the reduce wave equation are

$Ezs\,(y) = E_1\, e^{\gamma y} + E_2\, e^{-\gamma y}$

$Ezs\,(y) = E_1\, e^{(\alpha + j\beta)y} + E_2\, e^{-(\alpha + j\beta)y}$

$Ezs\,(y) = E_1\, e^{\alpha y}\, e^{j\beta y} + E_2\, e^{-\alpha y}\, e^{-j\beta y}$

$Ezs\,(y\omega) = E_1\, e^{\alpha y}\, e^{j\beta y} + E_2\, e^{-\alpha y}\, e^{-j\beta y}$ **Frequency Domain**

E_1 *and* E_2 **are constant electric field amplitude**

$(H - \Delta H\,)xs\,(y) = H_1\, e^{\gamma y} + H_2\, e^{-\gamma y}$

$(H - \Delta H\,)xs\,(y) = H_1\, e^{(\alpha + j\beta)y} + H_2\, e^{-(\alpha + j\beta)y}$

$(H - \Delta H\,)xs(y) = H_1\, e^{\alpha y}\, e^{j\beta y} + H_2\, e^{-\alpha y}\, e^{-j\beta y}$

H_1 *and* H_2 **are constant magnetic field amplitude**

Solution in time domain for electric field component

Ez(yt)=Re{ $Ezs(y)\, e^{j\omega t}$**}**

Ez(yt)=Re{ $(E_1\, e^{\alpha y}\, e^{j(\omega t + \beta y)}) + (E_2\, e^{-\alpha y}\, e^{-j(\omega t - \beta y)})$**}**

Ez(yt)=$(E_1\, e^{\alpha y}\, Cos(\omega t + \beta y) + (E_2\, e^{-\alpha y}\, Cos(\omega t - \beta y)$ **Time Domain**

Amplitude = $E_1\, e^{\alpha y}$	**Amplitude =** $E_2\, e^{-\alpha y}$
Phase = $\omega t + \beta y$	**Phase =** $\omega t - \beta y$
Grows in +ay direction	**decay in +ay direction**
decay in -ay direction	**Grows in -ay direction**

Solution in time domain for magnetic field component. The $(H - \Delta H)$ **is less than the** H.

$(H - \Delta H\,)$**z(yt)=Re{** $Hzs(y)\, e^{j\omega t}$**}**

$(H - \Delta H\,)$**z(yt)=Re{** $((H - \Delta H\,)_1\, e^{\alpha y}\, e^{j(\omega t + \beta y)}) + ((H - \Delta H\,)_2\, e^{-\alpha y}\, e^{-j(\omega t - \beta y)})$**}**

$(H - \Delta H\,)$**z(yt)=**$((H - \Delta H\,)_1\, e^{\alpha y}\, Cos(\omega t + \beta y) + ((H - \Delta H\,)_2\, e^{-\alpha y}\, Cos(\omega t - \beta y)$ **Time Domain**

Amplitude = $(H - \Delta H\,)_1\, e^{\alpha y}$	**Amplitude =** $(H - \Delta H\,)_2\, e^{-\alpha y}$
Phase = $\omega t + \beta y$	**Phase =** $\omega t - \beta y$
Grows in -ay direction	**decay in -ay direction**
decay in +ay direction	**Grows in +ay direction**

V. RESULT

During geomagnetic storm the magnetic field of Allahabad ground data decreased. Then the amplitude of magnetic field component of transmitted electromagnetic wave during geomagnetic storm is affected and the relation of electric field and magnetic field component become disturbed. The amplitude of magnetic field component is decreased during the magnetic storm. The solution of transmitted electromagnetic wave equation has new analytical approach in phasor form and time domain. The reduction in the amplitude of magnetic field component of transmitted electromagnetic wave during magnetic storm may be a cause of communication failure.

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