

Comparative Analysis Of Interplanetary Magnetic Field And Moving Charged Particles

Jaiyeola O. Paul, Abdullahi Ayegba

Abstract— The discussion reviews the wave-particle duality of clouds of ions, protons and electron blown out from Sun and enter Earth's magnetic field. They behave as particles when they are at rest or moving with uniform motion-velocity from the source or co-rotate with Sun and behave as waves when they are moving with non-constant motion-velocity (non-uniform motion) in other word accelerating. We then compared Velocity Field with Radial component of Interplanetary Magnetic Field (IMF) and Acceleration Field with Azimuthal component of Interplanetary Magnetic Field (IMF) using Koskinen, Linard-Wiechert Equation and Lorentz force equation. It was then discovered that the velocity field is equivalent to Radial Component of Interplanetary Magnetic Field (IMF) and the Acceleration Field is Equivalent to Azimuthal component of Interplanetary Magnetic Field. The interplanetary magnetic field component can be expressed as: (i). Velocity-Radial component of IMF (ii). Acceleration-Azimuthal component of IMF

Index Terms— Interplanetary Magnetic Field Components, Moving charged particle Field components, Plasma Flow, and Sun.

I. INTRODUCTION

Light has a dual nature, in some cases it behaves as a wave, and in other it behaves as a photon. This wave – particle duality is the basis of the quantum theory of light.

It was stated that “**Geomagnetic storms occur when clouds of ions, protons and electrons are blown out from the Sun and enter Earth's magnetic field**”.

The above particles also exhibit wave nature as they flow into interplanetary space or medium.

Charges at rest generate a purely electric field and if it is in motion (uniform motion) it generates both electric field (\vec{E})

and magnetic field (\vec{B}). Particle at rest or with a uniform motion cannot generate or radiates energy. However, if the charge is accelerating (non-uniform motion), it actually emits electromagnetic radiation.

So, the accelerating charges generate electromagnetic wave or electromagnetic radiation field. This radiates energy and we all know wave is a device or disturbances that carry energy from one point to another point in medium.

The changing in the acceleration of the particle's electric field (\vec{E}) and magnetic field (\vec{B}) as they interact with each other in the interplanetary space brings about unification theory of electric field and magnetic field in the interplanetary space called electromagnetic wave or electromagnetic field.

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So, it can be stated that the accelerating charged particles (ions, electrons or charged plasma) from the Sun generate or radiate electromagnetic wave or electromagnetic radiation field in the interplanetary space. This might formed the basis of interplanetary magnetic field, because both the solar wind, corona mass ejections (CMEs), solar flare and sunspots activities all deal with ejection or production of accelerating particles from the Sun's surface or atmosphere.

The charged particles carried energy and as a wave carried energy and momentum as they are accelerating. These constitute interactions energies at the magnetosphere.

The field carried two components:

- Radial Magnetic Field Component (B_r)
- Azimuthal Magnetic Field Component (B_ϕ)

H. E. J. Koskinen (2011), Physics of Space Storms: The Carrier to the Earth: Solar Wind; page 21-32, shows the relationship between the distance and the two components of the field as (1 and 2):

$$\begin{aligned} B_r &\propto \frac{1}{r^2} \dots\dots\dots 1 \\ B_\phi &\propto \frac{1}{r} \dots\dots\dots 2 \end{aligned}$$

The radial magnetic field (B_r) decreases faster but inversely proportional to the square of r —(distance) from the Sun. And B_ϕ , decrease at a slower rate been inversely proportional to r — (distance) from the Sun.

A. Linard-Wiechert Equation

The Linard-Wiechert equation can be expressed as (3):

$$E(r, t) = \frac{1}{4\pi\epsilon_0} \left[\frac{q(n-\beta)}{\gamma^2(1-n.\beta)^3|r-r_s|^2} + \frac{qn \times (n.\beta) \times \beta}{c(1-n.\beta)^3|r-r_s|} \right]_{t_r} \dots\dots (3)$$

And since $B(r, t)$ is given as (4)

$$B(r, t) = \frac{n(r)}{c} \times E(r, t) \dots (4),$$

Then, substituting (3) into (4), it gives (5) as:

$$B(r, t) = \frac{\mu_0}{4\pi} \left[\frac{qc(\beta \times n)}{\gamma^2(1-n.\beta)^3|r-r_s|^2} + \frac{qn \times (n \times ((n-B) \times \beta))}{(1-n.\beta)^3|r-r_s|} \right]_{t_r} \dots(5)$$

$$\beta = \frac{\text{charge's velocity}}{c} = \frac{v_g}{c}$$

$$\dot{\beta} = \frac{\text{charge's acceleration}}{c} = \frac{a_g}{c}$$

$$n(t) = \frac{r - r_s(t)}{|r - r_s(t)|}$$

$$\gamma(t) = \frac{1}{\sqrt{1 - |\beta(t)|^2}} \text{ the Lorentz force}$$

(Griffith, 1999, Larmor, 2001, Jackson, 2010)

The right-hand side of the Linard-Wiechert Potential equation (5) has two components:

- The 1st –term is the velocity component which inversely proportional to $|r - r_s|^2$ and depend on β . This component is called Velocity Field Component (B_v)
- The 2nd – term is the acceleration component which is inversely proportional to $|r - r_s|$ and depend on β and $\dot{\beta}$.

This is called Acceleration Field Component (B_a)

The 1st and 2nd terms can be expressed as (6 and 7):

$$B_v \propto \frac{1}{|r - r_s|^2} \approx \frac{1}{R^2} \quad \dots (6)$$

$$B_a \propto \frac{1}{|r - r_s|} \approx \frac{1}{R} \quad \dots (7)$$

R , is the distance traveled by the charged particle from the source (e.g. Sun's Surface)

Comparing equations (1 and 2) with equation (6 and 7)

The Velocity Field Component of Linard-Wiechert equation (from equation-2) is equivalent to the Radial Field component of Interplanetary Magnetic Field (from equation-1). The similarities are as follows:

- They are inversely proportional to the square of the distance from the source. (i.e. $B_v \propto \frac{1}{R^2}$, $B_r \propto \frac{1}{r^2}$). They fall quickly with distance from the source
- They depend on the velocity of the charged particle's motion (i.e. uniform motion)
- They cannot generate electromagnetic wave or electromagnetic radiation, because they are independent of acceleration. They carried no energy

The Acceleration Field Component of Linard-Wiechert equation (from equation-7) is equivalent to Azimuthal Field Component of Interplanetary Magnetic Field. The similarities are as follows:

- They are inversely proportional to the distance from the source (i.e. $B_v \propto \frac{1}{R}$, $B_r \propto \frac{1}{r}$). They fall slowly with distance from the source
- They depend on the velocity and the acceleration of the charged particle's motion
- They can generate electromagnetic wave or electromagnetic radiation, because they are dependent of acceleration (non-uniform velocity)
- They carried energy

B. Lorentz Force Equation

The Lorentz Force Equation is given as (8):

$$f = q(E + v \times B) \dots (8)$$

1.2.1 Charged Particle with Constant Velocity

Consider charged particle with constant velocity, which is equivalent to plasma charged particles inside Alfven's radius that co-rotates with Sun.

Since the velocity is constant, hence no acceleration. The rate of change of velocity is zero. If m is the mass of the charged particle, then we have

$$f = m \frac{dv}{dt} = 0 = -q(E + v \times B)$$

$$E = v \times B$$

$$v = \frac{E}{B} \quad \dots (9)$$

The charge moving at a constant velocity or uniform motion generates both \vec{E} and \vec{B} , (i.e. Electric field E and Magnetic field B).

The equation (9) can represent:

- Velocity Field Component: It is independent of acceleration.
- Radial Field Component: the electric and magnetic field depends on the velocity of the charged particle and independent of the charged particle acceleration, the field is therefore radial. Also within the Alfven's radius the charged particle co-rotates with the velocity of the Sun (i.e. with constant velocity).

Generally, the two can be termed 'Static Part' of Electromagnetic Field if the charged particles continue to move constant velocity. The fields only radiates out from a point charged. The field is constant within Alfven's radius (Alfven radius will see in detail later).

1.2.2 Charged particle with Non-uniform Velocity

Consider Lorentz equation (8) written as:

$$f = m \frac{dv}{dt} = q(E + v \times B) \quad \dots (8)$$

If the motion of the charged Particle is Non-uniform (i.e. there is motion with change in the velocity), then the charged particle is accelerating, we will expect electromagnetic radiation generation

Since we are dealing with interplanetary magnetic field and the magnetic of the moving charges, we will consider magnetic field component without electric field, in simple form the above equation becomes.

$$m\Delta v = qvBt \quad \dots 8a$$

Taken R to be distance cover by the charged particle,

$$R = vt \quad \dots 9a$$

$$m\Delta v = qRB \quad \dots 9b$$

$$B = \frac{m\Delta v}{qR} \dots\dots\dots 10$$

Shows that

$$B \propto \frac{1}{R} \dots\dots (11)$$

Comparing equation (11) with equation (2 and 7) shows:

- $B_\phi \propto \frac{1}{R}$ (i.e $r = R$), the Azimuthal component of interplanetary magnetic field
- $B_a = \frac{1}{R}$, Acceleration field from Linard-Wiechert equation

The magnetic field components fall slowly with respect to R (R, is the distance traveled by the charged particles from the source).

The fact that equation (10) shows changing in the velocity (Δv), signified change in acceleration.

If we perform integration operation on equation (8) neglecting Electric field, it becomes (12):

$$v_t = v_0 e^{qBt/m} = v_0 e^{\omega t} \dots\dots (12)$$

There is change in the velocity from v_0 to v_t . Signified charged particle is accelerating. Then, the magnetic field depends on the changed in the velocity of the charged particle (i.e. depend on acceleration gain).

The charged particle that is ejected into interplanetary space sometime had collisions with other particles or object that can change it direction or slow down it velocity. For every impacts the charged particles had on other particles in the interplanetary medium, we assumed there might be:

- Change in direction of the charged particles
- Change in the velocity of the charged particles
- Interchange of energy

The change in the velocity and direction of charged particle gives evident of acceleration of the charged particle. The accelerated charged particles produced acceleration field that generates electromagnetic radiation field or electromagnetic wave. This generation of acceleration field is also called Azimuthal field. This is just similar to the charged particle motion outside Alfven radius. The field outside Alfven's radius is a function of Azimuthal Field component of interplanetary magnetic field.

But outside Alfven radius the angular velocity or the frequency of the charged particle varies due Archimedes Spiral Arm outside Alfven radius. The spiral effects change the direction of the charged particle.

It can be clearly understood that:

- When the particle is at rest and unaccelerated with respect to us, the field reduces simply to Coulomb's law $q\vec{n}/R^2$.

Whatever corrections that are introduced do not alter the empirical law.

• We also see a clear separation velocity field or radial field (which falls off as $1/R^2$) and the accelerated field or radiation field or Azimuthal field (which falls off at $1/R$).

• So, unless the particles is accelerating ($\dot{\beta} \neq 0$ or $\frac{dv}{dt} \neq 0$), the field falls off rapidly at large distance. But when radiation field or accelerated field or Azimuthal field is present, it dominates over the Velocity or radial field. In fact the $\frac{1}{R}$ fall-off of the acceleration term is characteristics of electromagnetic wave.

II. METHODOLOGY

This paper was based on intense reviewed of other people's work on interplanetary magnetic field and accelerated charged particle as secondary data. We then do comparative analysis using the Koskinen Equation, Linard-Wiechert Equation and Lorentz force Equation

III. DISCUSSION OF FINDINGS

From Linard-Wiechert Equation and Koskinen Equation:

- The velocity field (B_v) is equivalent to Radial Component (B_r) of Interplanetary Magnetic Field (IMF) and are related as (3.1):

$$B_v \propto \frac{1}{|r-r_s|^2} \approx \frac{1}{R^2} \dots\dots 3.1$$

$$B_r \propto \frac{1}{r^2} \dots\dots\dots 3.2$$

Taking $r = R$, the two fields are inversely proportional to square of the distance traveled by charged particles. They both rapidly fall as $\frac{1}{r^2}$ or $\frac{1}{R^2}$.

- The Acceleration Field (B_a) is Equivalent to Azimuthal component (B_ϕ) of Interplanetary Magnetic Field.

$$B_a \propto \frac{1}{|r-r_s|} \approx \frac{1}{R} \dots\dots 3.3$$

$$B_\phi \propto \frac{1}{r} \dots\dots 3.4$$

Taking $r = R$, the two fields are inversely proportional to the distance traveled by charged particles. They both slowly fall as $\frac{1}{r}$ or $\frac{1}{R}$

From Lorentz Force Equation.

- For constant velocity, it is given as (3.5):

$$v = \frac{E}{B} \dots\dots 3.5$$

The charge moving at a constant velocity or uniform motion generates both \vec{E} and \vec{B} , (i.e. Electric field E and Magnetic field B). But the charged particle at rest generates electric field. The fields only radiate out from a point charged. It is independent of acceleration. It is velocity field. Since the field only radiates at a point, it is radial field. The equation therefore, is a representative of both velocity field and radial field because the Electric Field and Magnetic Field depends

on the velocity of the charged particle and are independent of the acceleration of the charged particle. The field is radial because it is similar to the motion of the charged particles inside Alfven's radius (i.e. the charged particle is in co-rotation with Sun). Generally, the two can be termed 'Static Part' of Electromagnetic Field since the charged particle motion is a continuous constant velocity.

▪ **For non-uniform motion**, it is given as (3.6-3.8)

$$B = \frac{m\Delta v}{qR} \quad \text{----- 3.6}$$

$$B \propto \frac{1}{R} \quad \text{---- 3.7}$$

$$v_t = v_0 e^{qBt/m} = v_0 e^{\omega t} \quad \text{---- 3.8}$$

The field depends on the changes that occurred in the velocity of the charged particle ($\Delta v, v_0, v_t, \Delta v = v_t - v_0$). The field is also inversely proportional to the distance R, traveled by the charged particle from the source. The charged particle produces acceleration due to change in the velocity, so generating acceleration field that is inversely proportional to the distance R. The Azimuthal field component of interplanetary magnetic field is also proportional to $\frac{1}{R}$. The charged particle outside Alfven radius become supersonic, the Azimuthal field predominates at distance much greater than Alfven radius. For non-uniform motion of the charged particle, the acceleration field is equivalent to Azimuthal field.

IV. CONCLUSION

The clouds of ions, protons and electron blown out from Sun and enter Earth's magnetic field review wave-particle duality. They behave as particles when they at rest or moving with uniform motion or velocity from the source or co-rotate with Sun as per plasma flows and behave as waves when they are moving with non-constant motion or velocity (non-uniform motion), in other word accelerating to generate electromagnetic wave or electromagnetic radiation.

Relating Koskinen Equation, Linard-Wiechert Equation and Lorentz force Equation. It was then discovered that the velocity field is equivalent to Radial Component of Interplanetary Magnetic Field (IMF) and the Acceleration Field is Equivalent to Azimuthal component of Interplanetary Magnetic Field

The fields created by moving charged particle are the same with the fields generated by flows of plasma charged particles from the Sun. The Velocity field generated from the uniform motion moving of the charged particle is equivalent to the Radial field of interplanetary magnetic field component and the acceleration field generated by non-uniform motion of the moving charged particles is equivalent to Azimuthal field of the interplanetary magnetic field component.

V. RECOMMENDATION.

As with theory of unification the component can be written as follows

- Velocity-Radial field component of interplanetary magnetic field.

Radial Component is generated within the Alfven radius at a constant velocity (charged particle plasma co-rotate with the Sun inside Alfven radius). Then we have radial field component. For a constant velocity inside Alfven radius we have velocity field component.

- Acceleration-Azimuthal field component of interplanetary magnetic field.

Azimuthal Component is generated outside the Alfven radius at non-uniform velocity (plasma charged particle move with increase in velocity outside Alfven radius at supersonic rate and as it is getting out of the Sun's magnetic field influence). Then we have Azimuthal field component. For a non-uniform velocity (accelerating charged particle) outside Alfven radius we have acceleration field component.

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