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New Directions in Electromagnetism for Propulsion and Power

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Abstract

Except for Quantum Electrodynamics, there has been no real extension of Maxwell's classical electromagnetic (EM) field theory since his electromagnetic EM field equations were developed in 1864. These equations describe the behavior of vector fields of low (U1) group symmetry. Topology, group and gauge theory has been used to extend Maxwell theory into tensor fields of higher SU(2) symmetry form. These tensor fields of higher symmetry form describe the behavior of specially conditioned EM radiation, and theoretical and experimental work on such radiation, together with its application to future propulsion and power systems is described.

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1. Introduction

In 1864 Maxwell described a unification of electricity and magnetism with equations that later followers distilled into the four equations now known as the "Maxwell equations" that conform to the laws of electromagnetism (EM) formulated by Gauss, Ampere, Coulomb and Faraday. In the 1950's Feynman and others made Maxwell's classical EM theory compatible with Quantum theory and this resulted in Quantum Electrodynamics (QED). Here, QED was consistent with both quantum mechanics and special relativity and precisely predicted interactions between radiation and matter. But, despite its reformulation from quaternonic to vector algebra form, no extension of the Maxwell theory has been

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made during its 146 years of life - despite its inability to accurately explain many observed EM phenomena.

In most cases, EM radiation fields are correctly and adequately described by the classical Maxwell equations which is a theory of U(1) symmetry form. However, in special topologies or situations or boundary conditions, radiation fields are produced that require an extension of Maxwell theory to higher symmetry. Addressing such situations, Barrett [1] has used topology, group and gauge to derive SU(2) EM radiation fields for those cases of specially conditioned radiation. Even more complex EM behavior is describable by even more complex groups, e.g. SU(3) and higher symmetry groups - but the present paper only addresses SU(2) EM radiation. Briefly described are two ways of emitting SU(2) EM radiation, and some possible propulsion and power advancements they might enable.

2. Maxwell Equations for Ordinary and Conditioned EM Fields

Using group theoretic methods, EM radiation fields of SU(2) symmetry can be created by special conditioning of conventional U(1) EM fields. Table 1 shows Maxwell's four U(1) symmetry equations that describe electric field strength (***E***), magnetic flux density (***B***) and current density (***J***). The ***E*** and ***B*** fields of force can be related to a vector potential" (***A***) and "scalar electric potential" (φ). These potentials are unphysical and mere mathematical conveniences in terms of the U(1) field theory. However, in the SU(2) field theory, the potentials ***A*** and φ do have physicality [1]. Table 2 shows extended Maxwell equations that describe propagation of specially conditioned SU(2) EM fields. These Maxwell equations are based on tensor, rather than vector field terms. These tensor terms include ***E*** and ***B*** fields as U(1) Maxwell equations do. But they include additional tensor terms that include: (i) viewed as the square root of -1 or as an orthogonal rotation occurring in x, y, z, ct spacetime; electron charge (q). These equations are based on tensor, rather than vector, field terms and include additional terms such as ***A x E, A x B, A • E***; and ***A • B*** interactions ([1] pp 145-147). These tensors, or matrices function as operators that obey non-commutative, non-Abelian algebra. Thus, ***A x B*** does not equal ***B x A*** for SU(2) EM fields.

The well known Lorentz force (***F***) arises from an electromagnetic interaction that involves ***B*** and ***E*** fields and the velocity (***v***) of charge clusters with charge (e). Table 3 shows force equations for both the U(1) EM vector fields in terms of the magnetic vector potentials and electric scalar potentials that underlie these U(1) vector fields and SU(2) tensor fields in terms of the vector and scalar potentials and its noted that extra terms are in the SU(2) force equation. Thus, SU(2) field interaction forces can be different in magnitude and direction than U(1) field forces.

Table 1. Maxwell Equations for Ordinary U(1) EM Fields.

Gauss's Law	$\nabla \bullet \boldsymbol{E} = \boldsymbol{J}_0$
Ampere's Law	$\frac{\partial \boldsymbol{E}}{\partial t} - \nabla \times \boldsymbol{B} - \boldsymbol{J} = 0$
Coulomb's Law	$\nabla \bullet \boldsymbol{B} = 0$
Faraday's Law	$\nabla \times \boldsymbol{E} + \frac{\partial \boldsymbol{B}}{\partial t} = 0$

$$E = -\frac{\partial A}{\partial t} - \nabla \phi;\ B = \nabla \times A$$

Table 2. Maxwell Equations for Specially Conditioned SU(2) tensor EM Fields [1].

$$\nabla \bullet \boldsymbol{E} = \boldsymbol{J}_o - iq\left(\boldsymbol{A} \bullet \boldsymbol{E} - \boldsymbol{E} \bullet \boldsymbol{A}\right)$$

$$\frac{\partial \boldsymbol{E}}{\partial t} - \nabla \times \boldsymbol{B} - \boldsymbol{J} + iq\left[\boldsymbol{A}_0, \boldsymbol{E}\right] - iq\left(\boldsymbol{A} \times \boldsymbol{B} - \boldsymbol{B} \times \boldsymbol{A}\right)$$

$$\nabla \bullet \boldsymbol{B} + iq\left(\boldsymbol{A} \bullet \boldsymbol{B} - \boldsymbol{B} \bullet \boldsymbol{A}\right) = 0$$

$$\nabla \times \boldsymbol{E} + \frac{\partial \boldsymbol{B}}{\partial t} + iq\left[\boldsymbol{A}_0, \boldsymbol{E}\right] = iq\left(\boldsymbol{A} \times \boldsymbol{E} - \boldsymbol{E} \times \boldsymbol{A}\right) = 0$$

Table 3. Lorentz Force comparison for U) EM and SU(2) EM Fields [1].

U(1) Lorentz Force	$\mathscr{F} = e\boldsymbol{E} + ev \times \boldsymbol{B} = e\left(-\frac{\partial \boldsymbol{A}}{\partial t} - \nabla\phi\right) + ev \times \left(\left(\nabla \times \boldsymbol{A}\right)\right)$
SU(2) Lorentz Force	$\mathscr{F} = e\boldsymbol{E} + ev \times \boldsymbol{B} = e\left(-\left(\nabla \times \boldsymbol{A}\right) - \frac{\partial \boldsymbol{A}}{\partial t} - \nabla\phi\right) + ev \times \left(\left(\nabla \times \boldsymbol{A}\right) - \frac{\partial \boldsymbol{A}}{\partial t} - \nabla\phi\right)$

3. Two Examples Of SU(2) Conditioned EM Radiation

Barrett [2, 3] described emission of SU(2) EM radiation by driving alternating current through toroidal coils at a resonant frequency or its harmonics that will be determined by the specific toroid geometry. Figure 1 shows an SU(2) (Φ) $\boldsymbol{A}$ tensor field pattern of a transmitting toroid - composed of two U(1) $\boldsymbol{A}$ vector potential fields, ϕ_1 and ϕ_2, overlapping in polarity across the hole or obstruction of the toroid. Also shown is a resonant frequency when the phase is such that (φ_1- φ_2) is maximal, and the various resonant harmonic frequencies that can occur for a given toroid. At every resonant frequency and its harmonics, the alternating difference in the overlapping U(1) vector potential fields is maximized for a given toroid dimensions, resulting in a concomitant maximization of a SU(2) tensor potential field. Toroid testing described in Froning and Hathaway [4] and Barrett [3] revealed resonant harmonic frequencies in good agreement with predictions, and increased signal occurred at the predicted resonances.

Another example of SU(2) conditioned EM radiation is described by Barrett ([1], p. 62). Oscillating input energy is arbitrarily divided into two equal parts. One half is used in providing phase modulation ($\partial\varphi/\partial t$); the other half is divided into 2 orthogonally polarized beams, one of which being rapidly phase modulated, that are combined into an EM beam of SU(2) symmetry. The SU(2) radiation is of rapidly changing polarization form. Figure 2 (from [1]) shows 1 cycle of such a beam with rapidly changing polarization and concomitant rapid changes in orientation of the combined E-B instantaneous field vector as the beam travels over a very short distance in a very short time.

4. Advances In Electromagnetism For Near-Term Power Transmission And Propulsion

Near-term payoffs for specially conditioned EM beams are predictable for beamed energy systems that accomplish air breathing and rocket propulsion by laser or microwave beam heating of air and propellant inside vehicles. As an example, Figure 3 - from Froning *et al.*[5] - shows the effect of laser wavelength and the atmosphere on ground-based laser beam power available for heating of vehicle propellant for earth-to-orbit vehicle thrust. This is shown at the range and altitude where vehicle orbital speed must be reached. It is seen that significant EM energy is lost from the beam during its atmospheric propagation due to its adverse electromagnetic interaction with air. If this large EM energy loss could be significantly reduced by special conditioning or modulating of the laser beam, it's seen that beam power for vehicle thrust generation could be 2 to 4 times greater for the most promising laser wavelengths.

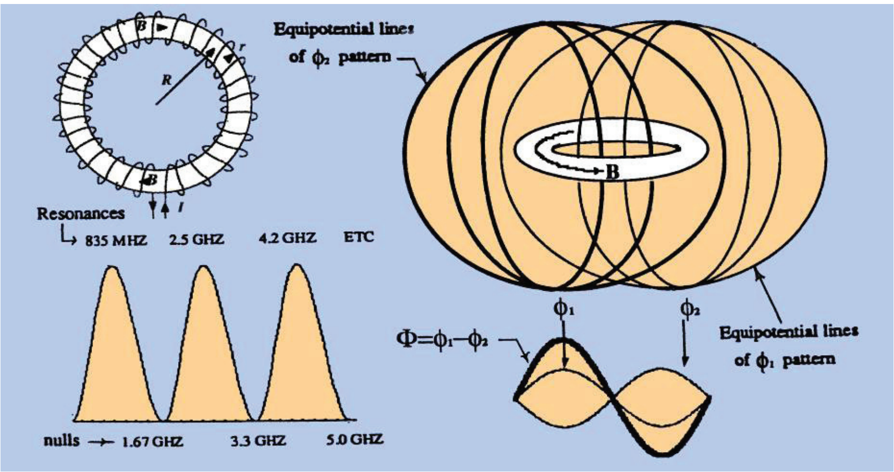

Figure 1. Resonances from the U(1) *A* vector potential patterns (ϕ_1 and ϕ_2) surrounding transmitting toroidal resulting in a maximum SU(2) *A* tensor field (Φ). From Barrett [3].

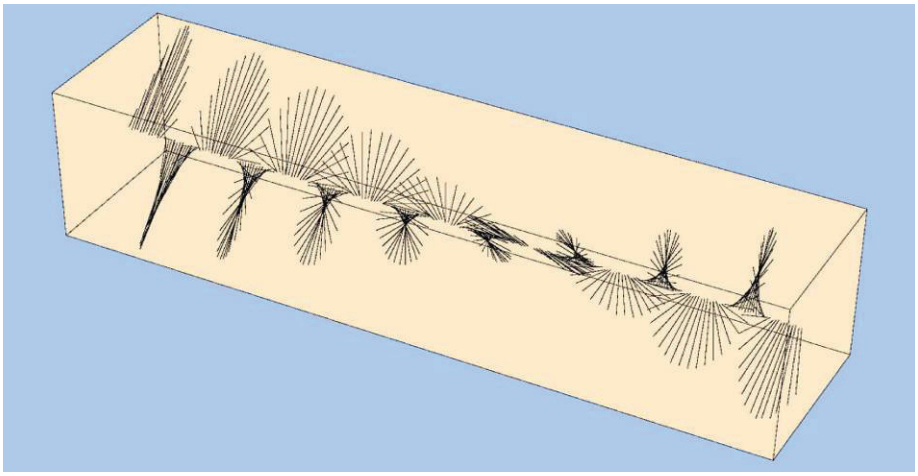

Figure 2. Changes in orientation of the combined E-B field vector during travel over a very short distance/in a very short time (for a representative polarization-modulation taken from Barrett [1]).

Calculations by Nukove Scientific Consultants support this view. Figure 4 shows laser Earth-to-Satellite tracking - even with precision optics and tracking dynamics - resulting in significant pointing errors and beam distortion in a given direction (right). These errors and distortions are due to air turbulence - eddies (vortices) in the direction of prevailing winds that cause density and refractive index fluctuations in the air that a laser beam is passing through. However, specially conditioned (SU(2) modulated) radiation (left) results in a beam that's insensitive to refractive index fluctuations caused by air density variations, and it is seen that very precise pointing of the laser beam results.

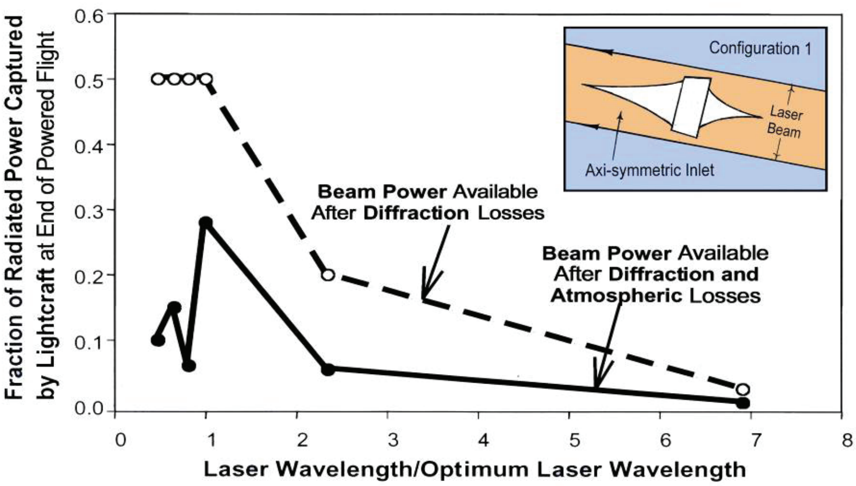

Figure 3. Influence of atmosphere and laser wavelength on available beam power for earth-to-orbit propulsion.

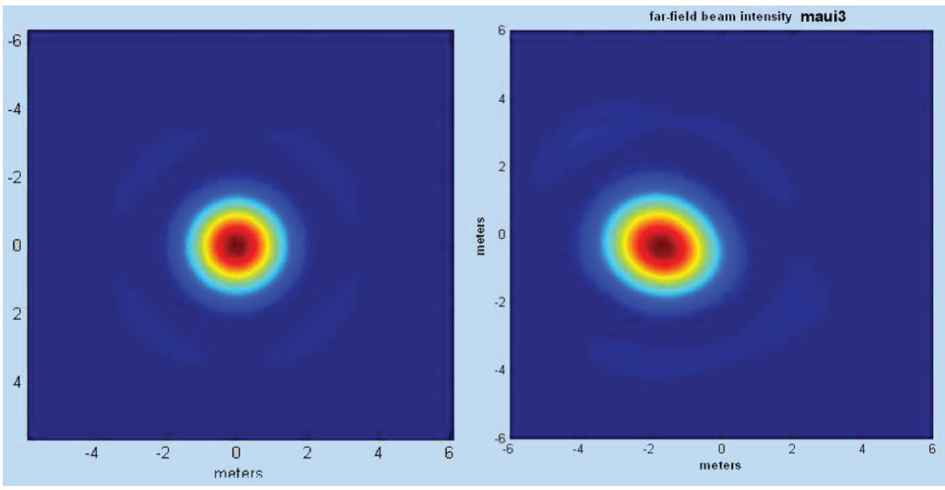

Figure 4. Elimination of laser beam tracking error due to atmospheric turbulence by conditioned SU(2) radiation. (Images courtesy of Nukove Scientific Consultants).

5. Advances In Electromagnetism That May Enable Advances In Future Propulsion And Power

The preceding section mentioned the possibility of improving electromagnetic energy propagation by polarization-modulation of laser beams - an immediate, near-term possibility for applying our current understanding of specially conditioned EM radiation to today's beam power and propulsion needs. However, further advancement in specially conditioned EM research might reveal developments that help overcome the formidable obstacles that prevent the breakthroughs in energy research that are desperately needed for future terrestrial and space power and propulsion.

One energy and propulsion breakthrough might be clean "aneutronic" fusion reactions, which emit no neutrons and result in no radioactivity. An enormous challenge for such fusion is limiting radiation lost from intensely excited electrons and ions before the high energies and temperatures (above 100 keV and 1.1 billion K) needed for fusion of aneutronic fuels (such as pB_{11}) are reached. Control of high temperature plasmas and limiting their radiation loss would be much easier if plasma electrons and ions could, cluster together into small regions of high temperature - rather than immediately radiating their energy away. Such EM structures were first detected by Victorio Nardi (Nardi *et al*. [6]) during Dense Plasma Focus (DPF) fusion tests. In such tests, electric discharges in DPF devices transform nuclear fuels into plasma that accelerates along electrodes and is magnetically pinched into discrete plasmoids - extremely hot regions that are tens of microns in size. Figure 5 shows accelerated plasma from a DPF anode being focused into a hot pinch region by enormous magnetic pressures that are hundreds of teslas in strength.

Figure 5. Magnetic compression of nuclear fuels into a 'pinched' plasma that contains discrete "plasmoid" regions of very hot temperature (photo taken at Stevens Institute of Technology over an exposure time of 5.0 nanoseconds).

Lerner [7] reports achieving ion energies above 100keV (equivalent to 1.1 billion K temperature) and a density-confinement-time-energy product of 5×10^{15} keVsec/cm^3 in DPF tests at Texas A&M using deuterium fuel. But, despite these encouraging results, Lerner mentions lack of a quantitative theory as impeding DPF progress. Such a theory would presumably include more detailed modeling of vital EM structures like plasmoids and the complex interplay of electron and ion beams they emit. And here, only higher order fields – such as SU(2) symmetry fields - may be able to properly describe such coherent EM structures and the complex interplay of EM beams they cause.

Hydrogen fusion in our Sun's plasma core would not occur without the weak interaction, which converts u-quarks into d-quarks, and is described by a matter field of SU(2) symmetry. Such fusion on Earth would require electro-magnetic compressing of matter into hot plasma before SU(2) symmetry matter fields in the nuclei of the electro-magnetically compressed plasma can complete the fusion process. Strategies for electromagnetic compression of matter into plasma state is presently described with knowledge of U(1) symmetry EM fields. But, plasmoids in DPF systems are not formed or maintained by U(1) symmetry EM fields. So, EM field action that would satisfactorily compress matter into the plasma state where fusion could be completed may have to be higher symmetry than U(1) - just as SU(2) symmetry matter fields that enable fusion to be accomplished in nuclei are higher symmetry than U(1).

Thus, just as SU(2) and SU(3) symmetry matter fields control matter (quarks, mesons etc) in those microscopic regions of 10^{-13} cm. size (wherein desirable nuclei like p and B_{11} ions could be fused), so, SU(2) or SU(3) symmetry EM fields might effectively confine such yet-to-be-fused p and $\mathbf{B_{11}}$ ions in a much larger macroscopic domain. And the result might be these higher symmetry EM fields causing this p and B_{11} enclosing domain to be swiftly shrunk to the very small size and heated to the very hot state needed for SU(2), SU(3) matter fields to complete pB^{11} fusion.

6. Advances In Electromagnetism That Could Enable Economies In Energy And Power And Propulsion

Plasmas formed by electromagnetic discharges that are emitted from the front end of vehicles and interact with oncoming airflow to reduce vehicle drag are of interest for future power and propulsion systems that would reduce vehicle size and the fuel and propulsive energy needed for high-speed atmospheric flight. Russian researchers such as Leonov *et al*. [8], report modest reduction of vehicle supersonic drag with EM discharges of modest intensity from the front end of air vehicles into air - as shown in Figure 6. These discharges reduce vehicle drag about 5 percent and associated engine power savings are 15-20 times the electric power that must be expended for discharge generation. Also shown is the weakly-ionized plasma that reduces drag by shock wave weakening and bifurcation.

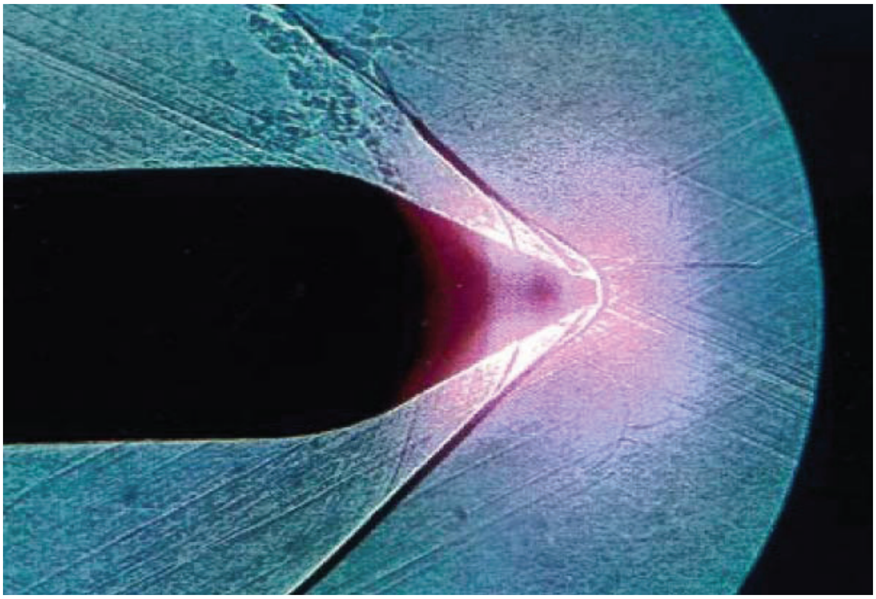

Figure 6. Modest aerodynamic drag reduction at Mach 2 speed by electromagnetic discharges from a vehicle's front-end.

More dramatic drag reductions; much greater than expected energy efficiencies; and unexpected interaction products are also reported. These more dramatic and unexpected results are often associated with intense radio-frequency (RF) discharges that are carefully combined with microwave (MW) radiation. Such combined emissions often result in EM structures that are somewhat similar in appearance to "ball lightning" – rather than being a faint glow or diffuse isotopic distributions of ions. These coherent structures possess a bubble-like appearance - with very thin outer surface and a somewhat opaque interior. Brovkin *et al.* [9] describe the interiors of such "plasmoids" as being densely interwoven with thin strands of "hot streamers". These streamers appear to be electric currents that may result from the incident MW radiation that is deposited in the plasma that has been formed by the RF discharge.

Conventional U(1) symmetry electromagnetics may be able to model certain plasmoid features - such as the electric current flow in its streamers - but U(1) electromagnetics (EM) or electrostatics (ES) cannot accurately describe or provide any real insight into their complex, coherent structure. But if the geometry and texture and internal-external energetics of these complex electromagnetic structures could be described and modeled by higher order electromagnetics, such as SU(2) symmetry EM fields, their currently anomalous behavior might be much better understood for the design and development of advanced EM/ES field systems that would dramatically reduce vehicle drag - and, thus, dramatically reduce propulsion and power and fuel needs for high speed atmospheric flight.

7. Conclusions

Barrett's work [1-3, 10-15] lays the foundation for the development of the theory of SU(2), SU(3), etc. electro-magnetic radiation fields that are of higher order symmetry than the U(1) symmetry EM radiation fields described by the conventional Maxwell equations. Higher order symmetry SU(2), SU(3) radiation fields would act over much larger scales of time and distance than the SU(2), SU(3) symmetry matter fields that describe the weak and strong interactions in atomic nuclei. In analogy with SU(2), SU(3) symmetry matter fields, coherent EM radiation fields can be described by complex, spatiotemporal patterns, and by similar topology, group theory and gauge symmetries.

The nature of two specific SU(2) symmetry EM conditioned radiation fields have been described, together with near-term application of such EM fields in advancing the power and propulsion capabilities of ground-based beamed energy systems today. Also described are further-term applications of SU(2), SU(3) and higher order symmetry EM fields that might assist in producing clean fusion energy for breakthroughs in power and propulsion for terrestrial and spaceflight needs. Finally, emission of higher order symmetry EM/ES fields from high speed aircraft may allow dramatic reductions of the vehicle's engine thrust, power and propellant by dramatic reduction of the vehicle's drag.

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