Mach’s Principle, Flux Capacitors, and Propulsion

James F. Woodward1 and Peter Vandeventer2

1 Departments of History and Physics, California State University, Fullerton, CA 92834
2 Department of Physics, California State University, Fullerton, CA 92834
1 714-278-3596, jwoodward@fullerton.edu

Abstract. Mass fluctuations that arise from Mach effects when objects that can store internal energy are accelerated and their application to the production of propellantless thrusts are briefly reviewed. Follow-on experimental work to that reported at STAIF 2004 and 2005 is described. In particular, thrusts in “flux capacitors” made with high voltage disk capacitors wound with coils that produce a magnetic flux therein were sought. An effect of the sort expected continues to be observed. And it displays scaling behavior distinctive to the presence of Mach effects. Various tests for the genuineness of the observed thrusts are described and discussed. The observed effect suggests that the objective of this work, useful propellantless propulsion, may be achievable.

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INTRODUCTION

Mach’s principle is the assertion that the manifestations of inertia cannot be entirely innate and inherent to massive objects. A reasonable reading of Mach (and Einstein) makes plain that they thought that inertia, moreover, cannot be imbued in them simply by virtue of their existence in space, or in the presence of local “zero point” quantum mechanical fields. Rather, the manifestations of inertia in matter – everything that gravitates – must be a consequence of the presence of the rest of the material contents of the universe. This means that \( ma \) in Newton’s second law only has meaning when objects accelerate with respect to the bulk of the matter in the universe, for the distant matter is required to produce the inertial reaction forces accelerating agents feel via the only truly “universal” field: the gravitational field. Note that if it is true that inertial reaction forces are gravitational in origin, then inertial mass itself must be gravitationally induced. Were inertial mass induced by a local “zero point” field (whose existence is not contingent on the existence of distant matter in the universe), the Higgs field for example, then inertial reaction forces would be independent of the existence of the rest of the matter in the universe. Mach’s principle has a tortuous history that we will not, even briefly, recount here.

In the context of Newton’s laws of mechanics, Mach’s principle can be stated very simply: Inertial reaction forces arise from the gravitational action of the rest of the matter in the universe on accelerating objects. Matter here is to be understood as any substance that exerts a gravitational action on other matter, as in general relativity theory (GRT), not simply as electrons, neutrons, and protons. The equivalence of inertial and passive gravitational mass (the “weak” Equivalence Principle), and the implausibility of the proposition that inertia is a completely innate property of matter, suggests that Mach’s principle is correct. If so, does this open up possibilities for the solution of propulsion challenges? That is, can means be found to accelerate objects without the expulsion of material propellants? And more radically, can “exotic” matter be induced in sufficient quantities to make traversable wormholes? If the results of the continuing investigation reported here are valid, it seems that the answers to these propulsion questions may indeed be “yes”. It may indeed be possible to achieve the objective of this work, useful “propellantless” propulsion.

MACH EFFECTS

As shown by Dennis Sciama in (1953), inertial reaction forces can be viewed as the reaction to the radiative action...
of cosmic matter on accelerating objects. Raine (1975) showed that this is also true in GRT for FRW cosmologies. From the case of electrodynamics we know that radiation reaction includes third, as well as second, time-derivatives in the equations of motion, and consequently several peculiar phenomena not encountered in normal mechanics (for example, “pre-acceleration”) appear. In electrodynamics, electric charge is a “Lorentz invariant” quantity; that is, all observers, irrespective of their states of motion, agree on the numerical value of the quantity of any given charge. Mass-energy, the charge of both gravity and inertia, is not a Lorentz invariant quantity (though rest mass is).

This raises the question: What happens to the mass-energy of some object when it is accelerated by some external force and the gravitational (or inertial as you choose) field of cosmic matter acts on the object radiatively to resist the acceleration? The way to “reverse engineer” the answer to this question is to write down the inertial reaction force in the form of a field that acts on the object, take the “divergence” of the field strength, and set it equal to the local source of the field. When this is done four-dimensionally (that is, correctly from the relativistic point of view) and Mach’s principle is used to simplify the resulting equations, one finds that the expression for the local source of the inertial (or gravitational) field has time-dependent terms that can be engineered to be surprisingly large. They are only non-zero for sources that change their state of internal energy as they are accelerated. That is, they are zero for rigid bodies. And one of the terms is always negative, though normally exceedingly small. These transient “Mach effects” can be generated in simple electrical circuits using high dielectric constant materials operated at high frequencies. Since they hold out the promise of solving propulsion challenges, the obvious question is: Do such effects actually occur?

**THE MATH OF MACH EFFECTS**

The Mach effect that holds out promise for propellantless propulsion follows from a differential field equation constructed by considering the inertial reaction force on an object accelerated by an external force and asking what the local sources of the “gravinertial” field are. With the help of Mach’s principle, one finds:

\[
\nabla^2 \phi - \frac{1}{c^2} \frac{\partial^2 \phi}{\partial t^2} = 4\pi G \rho_0 + \frac{\phi}{\rho_0 c^4} \frac{\partial^2 E_0}{\partial t^2} - \left( \frac{\phi}{\rho_0 c^4} \right)^2 \left( \frac{\partial E_0}{\partial t} \right)^2 - \frac{1}{c^4} \left( \frac{\partial \phi}{\partial t} \right)^2,
\]

where \( \phi \) is the gravitational potential, \( c \) the speed of light, \( G \) Newton’s constant of universal gravitation, \( \rho_0 \) the local proper matter density, and \( E_0 \) the local proper energy density. It is the transient source terms on the RHS of Equation (1) that are of interest. They can be written:

\[
\delta \rho_0(t) \approx \frac{1}{4\pi G} \left[ \frac{1}{\rho_0 c^2} \frac{\partial^2 E_0}{\partial t^2} - \left( \frac{1}{\rho_0 c^2} \right)^2 \left( \frac{\partial E_0}{\partial t} \right)^2 \right],
\]

where, as follows from Mach’s principle (Sciama, 1953), \( \phi / c^2 = 1 \) has been used and the last term in Equation (1) has been dropped as it is always minuscule.

The obvious way to test for the presence of proper matter density fluctuations of the sort predicted in Equation (2) is to subject capacitors to large, rapid voltage fluctuations. Since capacitors store energy in dielectric core lattice stresses as they are polarized, the condition that \( E_0 \) vary in time is met as the ions in the lattice are accelerated by the changing external electric field. If the amplitude of the proper energy density variation and its first and second time derivatives are large enough, a detectable mass fluctuation should ensue. That mass fluctuation, \( \delta m(t) \), is just the integral of \( \delta \rho(t) \) over the volume of the capacitor, and the corresponding integral of the time derivatives of \( E_0 \), since \( \partial E_0 / \partial t \) is the power density, will be:

\[
\delta m(t) = \frac{1}{4\pi G} \left[ \frac{1}{\rho_0 c^2} \frac{\partial P}{\partial t} - \left( \frac{1}{\rho_0 c^2} \right)^2 \frac{P^2}{V} \right],
\]

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where $P$ is the instantaneous power delivered to the capacitor and $V$ its volume. The predicted mass fluctuation can be computed using Equation (3) above which, after differentiation of $P = P_0 \sin(2\omega t)$ and ignoring the second term on the RHS, reads:

$$
\delta m(t) = \frac{\omega P_0}{2\pi G \rho c^2} \cos(2\omega t).
$$

As explained, for example, in Woodward (2004a, 2004b, and 2005), such Mach effect mass fluctuations can be converted into sustained thrust by acting on capacitors in which mass fluctuations are driven with a magnetic field of the same frequency as the applied electric field. One of the devices of this sort used to obtain the results reported below is shown in Figure 1. In it two 2.2 nf 15kV Vishay Cera-Mite capacitors are glued between the halves of a toroidal inductor core as shown in the left hand panel. The magnetic flux through the capacitors (hence "flux capacitors") needed to produce thrust in this device is generated in the two coils wound over the capacitors as shown in the right hand panel of Figure 1. Also shown in the right hand panel of Figure 1 is the plastic mounting frame and the top of the steel shielding case for the thrust/weight sensor.

**FIGURE 1**. (a) A Partially Constructed Flux Capacitor and (b) Completed and Mounted on the Thrust Sensor.

The electric field, in addition to producing the mass fluctuations, drives an alternating displacement current, $i_d$, in the capacitors. (Quantities printed in bold are vectors.) The action of the magnetic $B$ flux on the displacement current $i_d$ follows from the Lorentz force law:

$$
F_B = i_d \times B \times L,
$$

where $L$ is the length of the displacement current (the distance between the plates of the capacitors). Since $i_d$ and $B$ are orthogonal by construction and have the same frequency, we may write:

$$
F_B = B i_d L \cos \varphi,
$$

where $\varphi$ is now the relative phase of $B$ and $i_d$. The device is mounted with two nylon screws in a plastic frame that is in turn bolted to the stage of a very sensitive force sensor.

The total force on the mechanical supports of the device (the plastic frame in which it is mounted in Figure 1), and
thus the force that it exerts on the thrust/weigh sensor (in the steel shielding case in Figure 1), will be the inertial reaction forces to magnetic and the induced lattice restoring forces acting on the dielectric core material in the flux capacitors, or:

\[ F_{tot} = -(F_B + F_{lat}). \]  

(7)

In the absence of Mach effect mass fluctuations, this will time-average to zero as \( F_B \) and \( F_{lat} \) act in opposite directions, each for half a cycle, with equal strength once stationary operating conditions have been established. When Mach effect mass fluctuations are added to this behavior, the time-average of \( F_{tot} \) no longer vanishes in stationary circumstances if the phase relationship between \( F_B \) and \( i_L \) and \( \delta m_0 \) is such that \( F_B \) acts in phase with the mass fluctuation. The fractional part of the total proper mass due to the fluctuation will produce an inertial reaction force on the supports during the half-cycle that it acts that is not compensated during the other half cycle when the lattice forces act, for during that half-cycle the oppositely directed lattice force acts on a total proper mass that has a fractional component of the opposite sign due to the mass fluctuation. Since the signs of the force direction and mass fluctuation change together, that part of the inertial reaction force (relative to the force in the absence of mass fluctuations) will have the same sign as the fractional part of the force during the other half-cycle. This means that we can write for the time-averaged inertial reaction force on the device supports:

\[ \langle F_{lat} \rangle \approx -2 \left( \frac{\delta m_0}{m_0} \right) F_B \sin \varphi, \]  

(8)

where the phase angle \( \varphi \) is that between the voltage applied to the capacitors and the current in the inductors. The factor of 2 arises from the fact that the mass fluctuation peaks with reversed sign when the lattice restoring forces act during each cycle.

**EXPERIMENT**

Devices of the type shown in Figure 1 were constructed as improved versions of the devices described in Woodward (2004a, 2004b, and 2005). Data was collected in the system described in detail in Woodward (2004b). (References to the work of others on devices of this sort can be found in Woodward (2004b).) The flux capacitors were mounted on the thrust sensor as shown in the right hand panel of Figure 1 and the vacuum chamber was then fitted over the test device and evacuated. Each cycle of data acquisition lasted 7 seconds. At 2.3 seconds into a cycle the inductor circuit was switched on, followed by the capacitor circuit which was switched on at 3.0 seconds. At 4.0 seconds the inductors were switched off, followed by the capacitors at 4.3 seconds. As in earlier work, staggered switching of the L and C circuits was use to insure that any thrust signal was only present when both the L and C signals were applied, for a signal present with only the capacitor or inductor energized clearly could not be of Mach effect origins.

Since the signals expected are only on the order of several tens of micronewtons, substantial signal averaging was required to suppress the noise present in the data. Moreover, since the direction of the predicted thrust should reverse with 180 degree phase reversal between the capacitor and inductor circuit applied voltages (see Equation (8) above), alternating the phase of the applied voltages every cycle or two during a run (of typically 14 to 20 cycles) made it possible to suppress common mode noise by subtracting the averages of the cycles of the two phases collected in a run. Data in a cycle were acquired at a 100 Hz rate. Post acquisition, averaging, and phase differencing processing was applied to suppress extraneous high frequency noise by performing running averages of several acquisitions in the 0 to 3 second, 3 to 4 second, and 4 to 7 second intervals. Several intervals were used so as to not smear prompt features at 3 and 4 seconds in each cycle too much.

As indicated by Equation (8), no thrust effect is expected when the relative phase of the capacitor voltage and inductor current is either 0 or 180 degrees; and when data for these two phases are differenced no effect is expected likewise. When the relative phases are 90 and 270 degrees, however, equal, opposite thrust effects are predicted; and accordingly when data for these phases are differenced a prompt effect between 3 and 4 seconds should be in evidence. Results for the device shown in Figure 1 for 270 minus 90 degrees [left panel] and 180 minus 0 degrees
of phase [right panel] are displayed in Figure 2. Ignoring long-term drift in the right panel for 180 minus 9 degrees (largely a consequence of the fact that less than half the number of cycles were averaged compared to the left panel), inspection of the (red and noisy) thrust traces reveals that the predicted effect is present in the left panel and absent in the right panel — exactly as expected. The inductor and capacitor power traces are blue (switched at 2.7 and 4.9 seconds) and green (switched at 3.0 and 4.3 seconds) respectively. The right hand scale applies only to the capacitor power.

A distinctive test for the genuineness of the thrust signal in the left panel of Figure 2 is capacitor voltage scaling. Since the Mach effect mass fluctuation scales with the power applied to the capacitors (Equation (4) above), and the power scales with the square of the applied voltage, the mass fluctuation scales with the square of the applied voltage. But the polarization, or displacement current in the capacitors driven by the applied voltage also scales with the voltage — linearly in this case. Thus, by Equations (6) and (8), it follows that the thrust produced in one of these devices should scale with the cube of the voltage applied to the capacitors — as long as all other parameters, like the inductor current, are held constant. This test was carried out with this device by reducing the voltage applied to the capacitors to 80% of the operating full power value. With cube scaling, this voltage amplitude reduction should reduce the measured thrust to about 50% of the full-power value. The full and reduced power thrust traces actually obtained are shown in Figure 3.

The reduced power thrust shown in Figure 3 seems to be even less than the 50% reduction predicted by Mach effect theory. But when the thrust measurement is taken as the shift at 4.0 seconds, considering only the parts of the thrust traces 0.25 seconds before and after 4.0 seconds, the change turns out to be almost exactly 50% — as predicted. A deleted data statistical analysis of this result shows, the noise in the thrust traces notwithstanding, that this is a three standard deviation result. That is, the result is quite unlikely to be a statistical fluke.
In the course of the present work several other genuineness tests were also performed. One was to build a device like that in Figure 1, but with the sense of the winding of the coils reversed. The coils on the two halves are connected in parallel and the external parts of the windings are connected to ground. This was done to eliminate strong electric fields exterior to the coils. So simply reversing the direction of the currents in the coils to see if the direction of the thrust reversed too could only be accomplished with a separate device with counter-wound coils. The results obtained with this device are shown in Figure 4. As expected, the thrust trace shift in the 3.0 to 4.0 seconds interval is inverted.

A currents emulation test was also performed with the first device by shorting the capacitors (at the capacitors) and introducing a dummy pair of identical capacitors elsewhere in the circuit. In this case, the electromagnetic fields present around the device during operation are mimicked, but no mass fluctuations are induced. So the thrust signal should not be present. The results of this test are shown in Figure 5. No signal like that in Figure 2 is present, showing that the thrust signal there cannot be attributed to thrust sensor coupling to stray electromagnetic fields.

Further work was done with the devices that produced the results reported so far, especially an investigation of both the short-term and long-term degradation of the thrust generated under various duty cycle conditions – and the extent to which improved performance could be restored by “annealing” the capacitor dielectric by baking at modest temperatures for several hours. The data collected in such tests are useful for understanding the behaviors that will dictate the design of devices of this sort. Rather, however, than present that material here, we mention only that repeated cycling of these devices causes changes in the dielectric material in the capacitors that degrades their performance. Ageing in perovskites is independently studied in a recent Cal Tech doctoral dissertation (Zhang, 2004). Instead we report work done with a successor device similar to that shown in Figure 1. The successor device is shown in Figure 6. It consists of eight 500 pf, 15 kV, Y5U dielectric capacitors glued into segments of a 2.6 cm OD toroidal inductor core with a relative permeability of 10. As shown in the left panel, it has all of the capacitors glued in place between segments of the inductor core and is partially finished with epoxy filler. After further
finishing, the ring of capacitors and core segments was wound with 350 turns of #22 AWG magnet wire, and the capacitors were wired in parallel. The assembled and mounted device is shown in the right panel.

**FIGURE 6.** (a) The Partially Assembled Device and (b) the Mounted, Completed Device.

Initial work with this device was done in a 10 to 15 milliTorr vacuum with the sensor (and vacuum chamber) upright, as shown in the angled top view of the right panel of Figure 6. Because the capacitance of the device (4.4 nf) was a bit smaller than that for the previous devices (5.1 nf), the tuning of the capacitor circuit was degraded a bit and would only accept less than 2 kW of power before the voltage waveform would degrade. The initial results obtained with this device are displayed in Figure 7. Each panel is the average of 600 differenced (270 degrees of phase minus 90 degrees) cycles of data. The weight/thrust traces show more high frequency noise than the traces in Figures 2 through 5 because no segmented running average was performed to suppress it. The two panels of data show that the thrust signal is essentially insensitive to the order in which the capacitors and inductors are switched – excluding the possibility that the thrust signal might be produced by a switching transient in either circuit that is only present when the other circuit is already on.

Although it is particularly pronounced in Figure 7, much of the data presented to this point shows a characteristic behavior: when the second circuit is switched on, the shift in the thrust signal is not truly prompt. As much as a half second or more is required for the thrust effect to come to full force. To some extent this may be due to switching transients. But, especially in Figure 7, it appeared that this might have been due in part to the mechanical response of the system. To investigate this possibility, and to also suppress seismic noise, a significant upgrade of the system was undertaken. Since most of the seismic noise in the already highly vibration isolated system is in the vertical direction, seismic noise can be further eliminated by turning the whole vacuum chamber on its side so that the

**FIGURE 7.** Results Obtained with the Device Shown in Figure 6 Running Vertically Oriented in a 15 milliTorr Vacuum.
direction of the action of the thrust sensor is horizontal instead of vertical, that is, perpendicular to the direction of most of the noise.

Removal of the weight loading of the sensor combined with careful tuning of the mechanical suspension, it was hoped, would improve the initial thrust response. And horizontal operation also shows that the effect is a thrust effect, rather than a weight or mass effect masquerading as a thrust. To affect this solution, a system of three 3 cm diameter plastic rods were fitted to the base plate of the vacuum chamber and 3 cm thick plastic rings were mounted on the rods so that the thrust sensor’s weight could be suspended from the rods. This reduced dramatically the load on the vibration isolation washers on the sensor mounting studs in the base of the vacuum chamber, making them much more effective than in the vertical position. Since major upgrades were underway, the system was fitted with new shielded vacuum feedthroughs for the power feeds. The rod system is shown in Figure 8. It worked quite well, reducing the seismic noise in the system to less than half the best previous value. However, when the system was first assembled and run, the ground fault indicated in the left panel of Figure 8 that created a ground loop between the power sensor circuits produced some interesting results. They are presented in three panels in Figure 9. Enormous signals are present for both the 90 and 270 degrees of relative phase. Aside from the fact that the differencing of the 90 and 270 degree results protocol precisely eliminates the ground fault signal as common mode noise, note that the thrust signal is now prompt at 3, as well as 4, seconds.

![Figure 8](image1.png)

**FIGURE 8.** The Rod and Ring Suspension System for the Thrust Sensor (left) and the Horizontal Vacuum Chamber.

![Figure 9](image2.png)

**FIGURE 9.** The Ground Fault (Figure 8) Led to the Very Large, Spurious Signals in the 90 Degree (left) and 270 Degree (center) Results, but when Differenced the Ground Fault Signal is Removed as Common-Mode Noise.

When the ground fault was fixed (by insulating the feeds shields from the tensioning screws in the sensor suspension ring with some electrical tape), the results shown in Figure 10 were obtained. No segmented running average
filtering of the thrust trace was performed. Note the dramatic improvement in the noise for 200 averaged cycles over that in Figure 7 where 600 cycles were averaged. And, of course, as in Figure 9, the thrust effect is promptly switched at both 3 and 4 seconds.

FIGURE 10. Results for 200 Differenced Cycles of Data with the Ground Fault Fixed. The Displayed Phases Follow the Order of Figure 9.

Now we ask: Are the observed thrusts – 30 to 40 micronewtons (half of the full shift) in the right hand panels of Figures 9, 10, and 12 – consistent with prediction? Well, the amplitude of the B flux in the device in question was 0.015 Tesla (measured with a 10 turn test coil underlying the inductor windings). Together with a 1.0 amp displacement current amplitude and a 0.008 m plate separation for the capacitors, the amplitude of the Lorentz force on the ions then turns out to be 120 micronewtons. The value of \( \delta m_0 \) computed from the operating frequency (53.6 kHz) and applied power (1.8 kW) turns out to be 1.6 grams. Since the mass of the dielectric in the capacitors is about 20 grams, the fractional mass fluctuation is 0.08, and multiplied by 2 we have 0.16. This multiplied times 120 micronewtons yields a predicted thrust of 2 micronewtons – within a factor of 2 of the observed thrust.

ARE THE THRUST SIGNALS REAL?

In the course of experiments on flux capacitors special attention has been paid to ensuring that the observed thrust signals were real and due to the action of Mach effects. The tests that have been done in earlier work by one of us (JFW) and here above include:

- Use of multiple devices (Figures 1 and 6)
- Phase differencing (Figure 2)
- Capacitor applied voltage scaling (Figure 3)
- Magnetic flux reversal by coil winding sense (Figure 4)
- Emulation of the currents present in the absence of Mach effects (Figure 5)
- Order of switching (Figure 7)
- Operation in vacua and air (there being negligible differences in the thrust signals; Figures 7, 9, and 10)
- Isolation of the devices in Faraday cages of several designs (previous work)
- Variation of the power feeds to the devices and their configuration (previous work)
- Frequency scaling (previous work)
- Presence of large electric and magnetic fields (previous work)
- Operation in two different vacuum systems (previous work)

Only one test is missing: What is the response of the system if the mounting stage of the thrust sensor is locked in position? While the currents emulation test makes clear that thrusts are not registered in the absence of the capacitors being charged, all of the electromagnetic circumstances of operation are not exactly mimicked since high voltage is not applied to the capacitors since they are shorted. The thrust signals might be a purely electromagnetic effect that only takes place when high capacitor voltages are present. To test this, the mounting stage was locked in place, as shown in Figure 11. A real thrust signal arising from Mach effects should disappear with the stage locked. An electromagnetic signal masquerading as a real thrust should still be present. The results of this test are displayed in Figure 12. The thrust disappears when the stage is locked. The thrust signal is real. And given the battery of
tests to which it has been subjected, it seems reasonable to assume that the signal arises from the production of Mach effect mass fluctuations as described in the early part of this paper and elsewhere.


**FIGURE 12.** The Thrust Registered with the Sensor Stage Locked (left) and Free to Move (right).

**CONCLUSION**

Inasmuch as three flux capacitor devices of several different designs all display the presence of Mach effect thrusts, and careful tests for spurious effects that might masquerade as the Mach effect all suggest the effect is genuine, it would seem that further exploration of this technique of propellantless thrust generation is warranted. Admittedly, the thrusts produced to date are only a few dynes. But the dissipated powers (as opposed to reactive powers) required to produce those thrusts have only been a few watts. The next steps are to engineer the system to produce larger effects, a goal that seems attainable. This is especially the case as the scaling dependence of the effect indicates that at higher frequencies, and especially at higher operating voltages, much larger effects should be obtainable. Indeed, practical levels of thrust should be achievable. That work is now in progress.

Finally, we would like to point out that the results of these experiments indicate that the origin of inertia is to be
found in the gravitational interaction, not in some local quantum zero point field whose existence is not contingent on the existence of the bulk of the matter in the universe. This suggests that the long sought Higgs field of quantum field theory may not be found.

**NOMENCLATURE**

B, B = magnetic induction (T)

\( c \) = vacuum speed of light (m/s)

\( \delta m_0 \) = mass fluctuation amplitude (kg)

\( E_0 \) = proper energy density (J/m^3)

\( \varepsilon_r \) = relative permittivity

\( F_{\text{tot}} \) = total force (N)

\( F_B \) = magnetic part of the Lorentz force (N)

\( F_{\text{lat}} \) = lattice restoring force (N)

\( <F> \) = time-averaged force (N)

G = Newtonian constant of universal gravitation (Nm²/kg²)

i, i_d = electric displacement current (A)

L = length (m)

m_0 = proper mass (kg)

n = number of turns

\( \omega \) = angular frequency (rad/s)

\( P \) = power (W)

\( \phi \) = scalar gravitational potential (m²/s²)

\( \rho_0 \) = proper mass density (kg/m³)

\( \varphi \) = relative phase (degrees)

V = voltage (V); or volume (m³)

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