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Generation of High-Frequency Gravitational Waves (HFGW) by Means of an Array of Micro- and Nano-Devices

by
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ABSTRACT

The process by which High-Frequency Gravitational Waves (HFGW) are generated by means of the time rate of change of the acceleration of a mass or masses, termed a "jerk" or a "shake," is developed. Arrays of micro- and nano-devices, termed energizing and energizable elements, are utilized to generate a train of coherent gravitational waves. As the waves progress along the axis of such devices they are reinforced by the energizable elements, under the control of a computer logic system in order to be modulated for applications such as communication. Starting with a theoretical non-rotating, but ratcheting or jerking rim or ring, linear devices, such as a stack of ratcheting rims or rings, evolve. These devices emulate a rotating rim. But the changing centrifugal force vector of a rotating rim or ring, which is tangent to rim and represents a jerk, is replaced by the electromagnetically, reciprocally jerked energizable elements of a non-rotating rim that do not involve large g loads. Two specific devices are described to illustrate the concept: the first such device involves a barrel or stacks of concentric rims whose surface or edges are covered with an array of ultra-small micromagnets (energizable elements) surrounded by a sheath of ultra-small microcoils (energizing elements); it generates approximately 380 kW of HFGW. The second is much smaller, 18 mm in length, and through use of a superconducting lens delivers a flux of 6.3×10^{-7} watts per square meter at a 7 km distant receiver – about that of a handheld radio transceiver. Other HFGW generators utilizing nanowire lattices for a high-frequency nanomechanical resonators and parallel current-carrying plates are also investigated and the question of null GW generation for symmetrical systems is considered.

The problem, which all of the devices discussed in this paper solve, is to cause a system of masses, which could be mini-magnets, micro-devices, nano-devices, individual molecules, submicroscopic particles, or individual electrons (as in a superconductor), under computer logic control, to move in concert with a jerk in order to *build up* (generate) HFGW with either planar or cylindrical wave propagation. Such jerking masses produce a very long sequence of HFGW pulses having significant average power and ability to carry information without generating incapacitating heat, causing disruptive g loads, or producing overpowering EM radiation.

Nomenclature

A	area
a	semi-major axis of a two-body orbit
a	acceleration
B	magnetic flux density
c	speed of light or, alternatively, the electron mobility speed

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$D_{\alpha\beta}$	quadrupole moment-of-inertia tensor
d	diameter or distance between conductors
E	energy
e	eccentricity of a two-body orbit
F	force per unit length
f	force
$\mathbf{f_{cf}}$	centrifugal-force vector
G	universal gravitational constant
h	strain in the space-time continuum , ? *l/l* caused by GW passage
I	moment of inertia
i	current
l	length
M	mean anomaly for a two-body orbit
m	mass of an object on orbit in characteristic units or of any object in kilograms
m	sum of the masses of a pair of binary stars or mass of a rod in kilograms
N	noise or index of GW refraction or number of pulses in an activation time interval
n	mean motion for a two-body orbit or number of objects or elements or number of rim or ring sections in a stack
n	number of coil turns or number of concentric rims or rings
P	the magnitude of the power of a gravitational-radiation source
p	parameter or semilatus rectum = $a(1-e^2)$
q	charge or periastron distance, $a(1-e)$
R	resistance or range
r	radial distance to an object on orbit; alternately, the effective radius of gyration
r	radius of a magnetic core, piston or barrel or stack of rims
S	GW flux
s	distance or displacement
t	time
t\`	spinning- rod time
V	volume or speed
v	true anomaly of a two-body orbit
v	velocity or frequency
x	axis of orthogonal coordinate system
y	axis of orthogonal coordinate system
z	axis of rotation orthogonal to x and y axis
α	attenuation or diffraction angle
Δ	small increment
Δf_{cfx}	incremental x component of centrifugal force
Δf_{cfy}	incremental y component of centrifugal force
Δt	time increment
d	fraction of a linear-motor, GW generator's barrel radius that is an energizing-element sheath and/or energizable-element core
δl	thickness of a given rim or ring
δm	differential mass
δt	differential time or activation time interval
?	the central angle of a rotating rod
κ_{I3dot}	coefficient (constant or function) of the kernel in the d^3I/dt^3 formulation of the quadrupole
λ	wavelength
μ	$= m_1 + m_2$ = sum of masses on a two-body orbit in characteristic units
μ_0	permeability of free space
ν	frequency
σ	absorption cross section
τ	characteristic time; for heliocentric unit systems = 5.022×10^5 seconds
ω	angular rotational rate

Subscripts

1	refers to mass one
2	refers to mass two
a	current in one wire
b	current in adjacent wire
cf	centrifugal
d	diffraction
GW	gravitational wave
l	longitudinal
p	phase
r	radial
t	tangential
x	x component
y	y component

1. INTRODUCTION

The general concept of the devices discussed in this paper is to simulate scientifically acceptable generation of gravitational waves (GW) like those that are produced by energizable celestial systems such as rotating binary stars, star-black-hole collisions, star explosions, star collapse, binary black holes, spinning black holes, etc. through the use of smaller macro- and micro-, terrestrial or laboratory energizable systems. Such terrestrial systems generate well over 40 orders of magnitude more force intensity by virtue of their use of non-gravitational forces (nuclear or electromagnetic compared to gravitational) than a typical celestial system and well over 12 orders of magnitude greater frequency (THz or QHz {10^{15} Hertz; the term Quadrahertz, QHz, is preferred over Petahertz or PHz} and higher compared to kHz or very small fractions of a Hz) than a typical celestial system. Terrestrial energizable systems produce significant and useful GW according to the various designs of the devices to be described, even though they are orders of magnitude smaller and less massive than the extraterrestrial celestial systems. In the various designs of these devices, large numbers of small energizable elements are energized in sequence or in concert, by energizing or stimulating elements, to emulate the motion of a much larger and extended body in order to enhance the generation of GW.

The specific concept, which will be expanded upon, requires applying a long series of rapid "jerks" or "shakes" or third-time-derivative motion to a mass or series of masses, using relatively strong magnetic, electric, or nuclear forces. The devices described in the present paper will be shown to generate significant *High-Frequency Gravitational Waves* or **HFGW** without disruptive g loads. The effect will be measurable in the laboratory since it affects or warps the *spacetime* geodesic over very small distances (due to high frequency and short GW wavelength) and thereby will produce HFGW detectable by utilizing detectors described in this Conference. If the energizable elements are uncharged, then there may be little or no attendant electromagnetic (EM) radiation.

In order to illustrate the concept, a circular rim, which does not rotate, but ratchets or jerks, is described. This rim is then evolved into a practical gravitational-wave generator. The system of masses described in this paper (and subject to jerks) can be small or mini magnets micro- or nano-devices, molecules, sub-microscopic particles, electrons (e.g., in a superconductor; about 10^{20} per cubic centimeter), etc. The misconception that the laboratory generation of GW is not feasible is fed by the example of a spinning rod given in most introductory textbooks. Such a rod utilizes the change in the centrifugal force vector to generate GW and is torn apart well before any significant GW is generated. The devices discussed herein are completely different and utilize electromagnetic forces and reciprocating, not rotational, motion in order to generate GW.

2. JERK FORMULATION OF THE QUADRUPOLE EQUATION

There is no new Physics here, simply a different approach or formulation of the conventional equations utilized to estimate GW power in order to render engineering applications more apparent. I will employ the standard quadrupole equation, which was originally formulated by Einstein in 1918, to compute the HFGW power. I will formulate that basic quadrupole approximation in terms of a change in force, ?f, over a short time interval, ?t, which is defined as a "***jerk***." The derivation of this basic jerk equation will be accomplished by two separate analysis paths: one starting with the third derivative of the moment of inertia formulation of the quadrupole equation and the other starting with the spinning rod (or binary orbit) formulation of the quadrupole equation. The resulting jerk equation will be numerically checked against the known result for the binary star pair PSR 1913 + 16.

2.1 *Derivation from Third Time Derivative of the Moment of Inertia*

As is well known and noted specifically in a letter (dated January 19, 2000) to me from Dr. Geoff Burdge, Deputy Director for Technology and Systems of the *National Security Agency*: "Because of symmetry, the quadrupole moment can be related to a principal moment of inertia, I, of a three-dimensional tensor of the system and … can be approximated by

$$-dE/dt \approx -G/5c^5 \, (d^3I/dt^3)^2 = -5.5\times10^{-54} \, (d^3I/dt^3)^2 ." \quad (1A)$$

or from Eq. (110.16), p. 355 of Landau and Lifshitz [5] :

$$P = ¦ - dE/dt ¦ =? (G/45c^5)(d^3D_{\alpha\beta}/dt^3)^2$$
[watts] (1B)

or

$$P = 1.76x10^{-52} (d^3I/dt^3)^2 \quad [watts]. \quad (1C)$$

This is Einstein's ***quadrupole equation***.

In Eq. (1A), k in Burdge's notation is G (not, however, the Einstein tensor) and the units in Eq. (1C) are in the MKS system [watts] not the cgs. In order to introduce the jerk concept let us consider the hypothetical example of a rim that, like the ratchet wheel of a mechanical watch, need not be uniformly rotating or, in fact, not rotating at all. In this case, for a collection of masses, which are small permanent magnets, along the rim,

$$I = \delta m\, r^2 \quad [kg\text{-}m^2], \qquad (2)$$

where

δm = mass of an individual magnetic sites around the rim [kg], and

r = the distance from a pivot out to any single δm on the rim [m] (or more exactly, the *radius of gyration* of the rim). Thus

$$d^3I/dt^3 = \delta m d^3 (r^2)/dt^3 = 2r\delta m(d^3r/dt^3) + \ldots \qquad (3A)$$

Approximately, by delta differentiation,

$$2r\{dm(d^3r/dt^3)\} \;\tilde{}\; 2r\{dm?(d^2/dt^2)/?t\} \qquad (3B)$$

and, by noting that by Newton's second law of motion,

$$f_r = dm(d^2r/dt^2), \qquad (4A)$$

we have, again by delta differentiation,

$$dm?(d^2r/dt^2) = ?f_r \qquad (4B)$$

where f_r = radial force on δm and $?f_r$ is the rapid increase in f_r over time ?t (**the jerk**). The third derivative of I is, therefore, approximated by

$$d^3I/dt^3 \cong 2r\,\Delta f_r/\Delta t\,, \qquad (5)$$

in which Δf_r is the nearly instantaneous **increase** in the force on magnetic (or other energizable element) sites, δm, caused by the magnetic field of current-carrying coils (or other energizing elements) when they are turned on and off or pulsed by transistors or ultra-fast switches resulting in a jerk.

Let us now visualize a stack of such rims; each one composed of a circle of small permanent magnets that are surrounded by a close-by ring of coils (please see FIG. (3B)). In this regard, the coils adjacent to the periphery of each rim are sequenced (at the local GW speed, say the speed of light) along the stack of rims from one rim to the next in order to generate or build up the train of coherent HFGW as they move through the stack of rims (energizable magnetic sites). In order **not** to build up acceleration the jerks are reciprocating; but (arguably) due to the square in the kernel of the quadrupole equation, the GW radiates in both directions along the axis of the circular rims (through their centers) no matter which direction the peripheral magnetic masses are jerked. In summary, by substituting Eq. (5) into Eq. (1C),

$$P = 1.76x10^{-52} (2r\Delta f_r/\Delta t)^2 \; [watts], \qquad (6)$$

which is the **jerk formulation of the quadrupole equation.**

2.2 *Derivation from a Spinning Rod*

An alternative derivation of Eq. (6) is as follows: From Eq. (1), p. 90 of Joseph Weber [1] one has for Einstein's formulation of the gravitational-wave (GW) radiated power of a rod spinning about an axis through its midpoint having a moment of inertia, I [kg-m^2], and an angular rate, ω [radians/s] (also please see, for example, pp. 979 and 980 of Misner, Thorne, and Wheeler [2], in which I in the kernel of the quadrupole equation also takes on its classical-physics meaning of an ordinary moment of inertia):

$$P = 32GI^2 \omega^6 /5c^5 = G(I\omega^3)^2/5(c/2)^5$$
[watts] (7)

or , with $I = r^2m$ (r being the radius of gyration of the rod)

$$P = 1.76x10^{-52}(I\omega^3)^2 = 1.76x10^{-52}(r\{rm\omega^2\}\omega)^2 \quad \text{[watts]} \quad (8)$$

where $\{rm\omega^2\}$ can be associated with the magnitude of the rod's centrifugal-force vector, $\mathbf{f_{cf}}$. Equation (8) is the *same equation as that given for two bodies on a circular orbit* on p. 356 of Landau and Lifshitz [5] ($I=\mu r^2$ in their notation) where $\omega = n$, the orbital mean motion [radians/s].

The $\mathbf{f_{cf}}$ vector reverses every half period at **twice the angular rate of the rod** (and a $\mathbf{f_{cf}}$ component's magnitude completes one complete period in half the rod's period). Thus the GW frequency is $2(\omega/2p)$, where ? is in [radians/s]. The change in the centrifugal-force vector itself (which I call a "jerk" when divided by a time interval) is a differential vector at right angles to the $\mathbf{f_{cf}}$ vector and directed tangentially along the arc that the dumbbell or rod moves through. The differential change in, for example, the x-component of the change in centrifugal force, $?f_{cfx}$, is f_{cfx} ?? and the change in the y-component is $?f_{cfy}$ is f_{fy} ?? , where ? is the central angle of the rotating rod in radians. By delta differentiation of $f_{cf}^2 = f_{cfx}^2 + f_{cfy}^2$,

$$f_{cf}\ ?\ f_{cf} = f_{cfx}\ ?\ f_{cfx} + f_{cfy}\ ?\ f_{cfy} \qquad (9A)$$

and when one associates the components $?f_{cfx,y}$ with $f_{cfx,y}$?? and, after dividing by ?t\` (t\` being spinning-rod time), and noting that ??/?t\` =? ,

$$f_{cf}\ ?\ f_{cf} / ?t` = (f_{cfx}^2 + f_{cfy}^2)? \; . \qquad (9B)$$

Thus ? f_{cf} / ?t\` = $f_{cf}$? ; but ?t\` = ½?t since the period of the GW is half the period of the rod, so that

$$2\ ?\ f_{cf} / ?t = f_{cf}? \; , \qquad (9C)$$

but $f_{cf} = \{rm?^2\}$ so

$$2\ ?\ f_{cf}/?t = \{rm?^2\}? \qquad (9D)$$

and substituting Eq. (9D) into Eq. (8) yields

$$P = 1.76x10^{-52}(2r\Delta f_{cf} /\Delta t)^2, \qquad (10)$$

where $(2r\Delta f_{cf}/\Delta t)^2$ is the kernel of the quadrupole approximation equation and $\Delta f_{cf} /\Delta t$ is, again, the **jerk.** Equation (10) is identical to Eq. (6), but arrived at by a different analysis path.

Equation (6), like Eqs. (1), (7), (8) and (10), are approximations for GW power and may **only hold accurately** for $r << \lambda_{GW}$ and for speeds of the GW generator components far less than the speed of light, c. Please see, for example, Pais [3], p. 280 and Thorne [4], p. 357. (On the other hand, Leonid P. Grishchuk at this Conference suggested that the requirement that $r << \lambda_{GW}$ may not be a stringent one.)

2.3. *Validation Based on Orbit of PSR 1913+16*

As a numerical validation of Eq. (10), that is a validation of the use of a jerk to estimate gravitational-wave power, let us utilize the approach for computing the gravitational-radiation power of the pulsar **PSR 1913+16** observed by Hulse and Taylor [6] to demonstrate the existence of GW.

2.3.1 *Orbital Elements*

Since the observation of the binary pulsar PSR 1913+16 (identifies right ascension of 19 degrees 13 minutes and declination of 16 degrees North) represents the only *experimental confirmation* of gravitational waves, insight into the jerk approach can be found in the analyses of such a double-star system. Thus please bear with the following rather laborious arithmetic.

The pair of PSR 1913+16 stars will coalesce in $3.5x10^8$ years due to GW radiation and produce a rather continuous GW until that time. It is the pair's coalescing that **exactly** agrees with GW-generation theory (utilizing orbital mechanics) that indirectly confirms the existence of GW. According to J. H. Taylor, Jr. [6], the period of their mutual rotation is 7.75 hours (or $\mathbf{2.79x10^4}$ **[s]**), periastron is 1.1 solar radii (one solar radius is $6.965x10^8$ [m]), and apastron is 4.8 solar radii. It's radius of gyration is essentially the semi-major axis a = (1.1 + 4.8)/2 = 2.95 solar radii = $(2.95)(6.965x10^8)$ = $\mathbf{2.05x10^9}$ **[m]**. Each star exhibits a mass of about 1.4 solar masses (one solar mass is $1.987x10^{30}$ [kg]) so that together their mass is $m = m_1+m_2 = (2)(1.4)(1.987x10^{30})$ = $\mathbf{5.56x10^{30}}$ **[kg]**. According to a perusal of binary-star catalogs by John Mosley of the *Griffith Observatory*, the binary pulsar PSR 1913+16 is at a distance from our Sun of 23,300 light years (one light year is $9.5x10^{15}$ [m]). If there was complete diffraction, then the reference area over which the GW would spread at the Sun's distance would be a sphere having an area of $(4\pi)(2.33x10^{4}$ x $9.5x10^{15})^{2} = 6.2x10^{41}$ [m^2].

2.3.2 *Gravitational-Wave Power—the Quadrupole Equation*

In the case of a binary star pair such as PSR 1913+16, the magnitude of the GW power, P, is computed from the quadrupole equation, which for two masses on orbit about one another is given, for example, by an equation on p. 356 of L. D. Landau and E. M. Lifshitz [5] or Peters and Mathews [7]. The time-constant factor in the equation for P is

$$8G^{4}m_1^{2}m_2^{2}\mu/(15c^{5}). \qquad (11)$$

The *time-variable factor* in P is a function of the true anomaly, v, and orbital eccentricity, e, as given in [5] :

$$(1+e\cos v)^{4}([1+\{e/12\}\cos v]^{2}+e^{2}\sin^{2}v)/(a[1-e^{2}])^{5}. \qquad (12)$$

In conventional astrodynamic/celestial-mechanics notation (see Samuel Herrick [8]) this factor (i.e., Eq. (12)) is

$$p/r^{6}+(dr/d\tau)^{2}/12\mu r^{4}, \qquad (13)$$

where p is the orbital "parameter" or semilatus rectum (= $a\{1 - e^{2}\}$) in [AU], r is the radial distance between the two masses [AU], τ is the characteristic time measured in $k_s$days or in units of $5.022x10^{6}$ [s] for a heliocentric-unit system (utilized by Taylor [6] and others for PSR 1913+16), μ is the sum of the two masses, i. e., $\mu = m_1 + m_2$ [solar masses], and as usual G = $6.67423x10^{-11}$ [m^3/kg-s], and c is the speed of light = $3x10^{8}$ [m/s]. Note that one AU (astronomical unit) = $1.496x10^{11}$ [m].

The GW power radiated, P, which causes a perturbation in the semi-major axis, a, (and an attendant secular decrease in the orbital period) is obtained by integrating the time-variable factor, Eq. (13), over the orbital period using the mean anomaly, M, as independent variable, which is directly proportional to the time (that is, M = n [t-T], where n is the mean motion {ω in Landau and Lifshitz's [5] notation, p. 357} n= 2p/Period = 2p/$2.79x10^{4}$ = **$2.25x10^{-4}$ [1/s]**, and T is the time of periastron passage).

2.3.3 *Accuracy of the Results*

The value of the average GW power, P, is computed from observations that define the eccentricity (based primarily upon Doppler-shift determination of the range rate at periastron and apastron), semi-major axis, and orbital orientation angles of PSR 1913+16. The error in the computed value of P is related to the observational error leading to the determination of the orbital elements as well as the determination of the masses of the pair of neutron stars. For example, a 0.1 percent change in the measurement of range rate at periastron results in a 0.28 percent change in GW power, P, and a 0.1 percent change in the mass of the stars results in a 0.33 percent change in GW power.

2.3.4 *Centrifugal Force and Acceleration*

The x and y average delta **centrifugal force** component(s), $\Delta f_{cfx,y}$ (which will later be utilized to validate the fundamental jerk equation numerically) are both

$$man^{2} = (5.56x10^{30})(2.05x10^{9})(2.25x10^{-4})^{2} = \mathbf{5.77x10^{32}\ [N]} \qquad (14)$$

divided by *m* yields the average centrifugal acceleration = 103.78 [m/s^2] = 10.6 [g's]. At periastron, r = q = a(1-e) = $(2.05x10^{9})(1-0.641)$ = $7.36x10^{8}$ [m] (with e = 0.641), the centrifugal acceleration is $q(dv/d\tau)^{2}$ where $dv/d\tau = \sqrt{(\mu p)}/r^{2}$ (please see Baker [9] , p. 13). In this latter case μ = 2.8 [solar masses], a = 2.95 [solar radii] = $(2.95)(6.965x10^{8}$ [m/solar radii]$)/1.496x10^{11}$ [m/AU] = 0.01373 [AU], p = $a\{1-e^{2}\}$ = 0.01373{1- 0.4109} = 0.00809 [AU], and q = r = $7.36x10^{8}$ [m]/$1.496x10^{11}$[m/AU] = 0.00495 [AU]. After inserting these numbers I have $dv/d\tau$ = $(\sqrt{[2.8x0.00809]}/[0.00495]^{2})/5.022x10^{6}$ [s/$k_s$day] = 1. $223x10^{-3}$ [radians/s]. Thus the centrifugal **acceleration** at periastron of the star pair is $q(dv/dt)^{2}$ = $(7.36x10^{8}$ [m] $)(1.223x10^{-3}$ [radians/s]$)^{2}$ = $1.101x10^{3}$ [m/s^2] = **112 [g's] –** apparently *still within the weak-field approximation of Einstein's GW equations*.

2.3.5 *Comparison of Results*

From Eq. (14) I computed that each of the components of force change, $\Delta f_{cfx,y}$ = $5.77x10^{32}$ [N] (multiplied by two since the centrifugal force reverses its direction each half period) and $\Delta t = (1/2)(7.75hrx60minx60sec) = 1.395x10^4$ [s] for the half period. Thus using the jerk approach:

$$P = 1.76x10^{-52}\{(2r\Delta f_{cfx}/\Delta t)^2 + (2r\Delta f_{cfy}/\Delta t)^2\} =$$

$$1.76x10^{-52}(2x2.05x10^9x5.77x10^{32}/1.395x10^4)^2x2$$

$$= \mathbf{10.1x10^{24}} \text{ [watts]} \qquad (15)$$

versus the result of $\mathbf{9.296x10^{24}}$ [watts] using Landau and Lifshitz's more exact two-body-orbit formulation given by Eqs. (1.1) and (1.2) of Baker [10] integrated using the mean anomaly not the true anomaly as independent variable. The most stunning closeness of the agreement is, of course, fortuitous since due to orbital eccentricity there is little symmetry among the $\Delta f_{cfx,y}$ components around the orbit and there are small errors inherent in the approximations of Eqs. (3A) and (3B) and, of course Eq. (5) leading to Eq. (10). Nevertheless, since the results for GW power are so close, orbital-mechanic formulation compared to the utilization of a jerk, **the correctness of the jerk formulation is well demonstrated!**

3. COMPUTATION OF HFGW POWER

There are some very sophisticated and exact computer simulations of the generation of gravitational waves (please see, for example, S. F. Ashby, *et al* [11]). The quadrupole approximation utilized herein by me and, for example, by Romero and Dehnen [12] and others at this Conference is probably less exact. On the other hand, the computer simulations are less relevant to the devices involved in the generation and detection of HFGW in the laboratory. These computer simulations describe GW generation by strong-field astrophysical phenomena (e.g., neutron stars, black holes, etc.), coupled spacetime and general relativistic hydrodynamic equations, and are usually restricted to gravitational forces ; not non-gravitational forces involved in laboratory HFGW generation. I will first discuss the meaning of the term quadrupole

3.1 *Meaning of Quadrupole*

The basic physical process for generating a gravitational wave is the third (or higher) time derivative of the motion of a mass, termed a "jerk" or "shake" or ?f/?t, that is, ?f is an increase in force, f, on the mass carried out over a small time interval, ?t. As noted in Baker [10], that physical process produces a gravitational wave with a **power** given by, for example, the quadrupole approximation (as originally derived by Einstein) or it could be determined directly from the special and general relativity equations (using a computer-implemented numerical integration as, for example, discussed in. Ashby, *et al* [11]). As noted in Conference paper HFGW-03-101, the quadrupole is the lowest-order solution to the GW propagation problem That is, the quadrupole itself is **not** the physical process at all, but only one means of establishing the power of the generated gravitational waves – the lowest-order solution.

Other algorithms, often most complicated, can define other GW properties such as direction, polarization, constructive/ destructive interference, etc. This situation is similar to Newton's Laws, which govern the physical process of planetary motion. The effect of that motion can be computed using, for example, the two-body approximation, or it could be determined directly from the equations of motion described by Newton's Laws, using a computer- implemented numerical integration.

The two-body approximation itself is **not** the physical law at all, but only one means of describing the resultant motion – a "lowest-order solution." In the case of a nuclear-reaction-generated gravitational wave, in which a nuclear particle is ejected from a nucleus, it is like a small rocket, or in the case of electrons shaken in a resonance cavity, plasma beam, superconductor, etc., there is a third time derivative of the motion of the nucleus in the first case or electron mass in the second case, or a jerk, which produces gravitational waves whose power can be estimated, for example, by the quadrupole approximation. Thus when I mention a "quadrupole-produced gravitational wave" I'm really implying the fundamental physical concept of the jerk and not the computational means for establishing the power of the gravitational wave.

3.2 *Harmonic Motion.*

As far as a harmonic motion of a mass or a pair of masses is concerned (harmonic oscillator), gravitational waves are generated. Just as in the case of a pendulum, the usual descriptor of harmonic motion, there exists a third time derivative of the pendulum bob. It is the jerk of that bob that produces the gravitational wave, which can be estimated using a quadrupole approximation or computed exactly by means of a rather complicated solution of the equations of special and general relativity.

4. LABORATORY MICRO- AND NANO-SCALE HFGW GENERATION DEVICES

In this section I will describe an Individual Independently Programmable Coil System or ***IIPCS*** (U. S. Patent No. 6,160,336), miniature integrated circuits, which provide for the emulation of a device that is much more extensive than the individual energizable elements (e.g., the small permanent magnets), and I will summarize what all of the HFGW-generation devices accomplish.

4.1 *Individual Independently Programmable Coil System*

I will now discuss HFGW generation devices that utilize, for example, microchip and nanotechnology in order to generate HFGW in the laboratory. For the very large number of ultra-small, sub-millimeter coil elements utilized in some of the devices discussed, a miniaturized integrated circuit can be utilized (please see, for example, the coil turn of *Al* utilized by Y. Acremann, *et al* [13]). They will be embedded in or imprinted on a silicon chip, organic material, or in connection with polymer-based or superconductor devices. They will consist of multiple layers with appropriate sequencing time delays to ensure near simultaneity of the magnetic fields interaction as the direct-current train of approximately one-picosecond or shorter pulses simultaneously traverse each coil set on the chip levels. The timing sequence could be integrated in the chip with the ultra-fast switches or transistors or through other semi-conductor devices. The myriad of these small coils in a three-dimensional array (please see FIG. (1)) act on the field of a small magnet to produce the jerk.

Since the jerk is generated by an electromagnetic process, there could be significant EM radiation generated that could reduce the efficiency of the device. It should, however, be emphasized that **it is <u>not</u> the magnetic field that generates the HFGW**, but rather the mass of the magnets (or other energizable elements) that are jerked that generates the GW. The magnetic material exhibits magnetic sites (perhaps on a molecular level or ferromagnetic atoms) that, of course, include electrons; but in this case (as opposed to a superconductor HFGW generator) it is not the electron mass being jerked that produce the GW, but rather the actual magnet's mass.

4.2 *Miniaturized Integrated Circuits*

A preferred design (U. S. Patent No. 6,417,597) utilizes conventional computer chips or wafers of a computer logic system, containing IIPCS circuit elements (U. S. Patent No. 6,160,336). These circuits are about 18 micrometers or less apart and include a synchronizing clock, input/output ports, and sub-millimeter coils on 50 to 100 micrometer centers. The chips are about 6 mm to 9 mm square and are obtained from silicon wafers. These chips are sewn into a circuit-board roll with an approximately 25-micrometer-diameter gold thread. Several layers of this roll (for example, 25) are connected in a fixed location or band adjacent to the moving or non-moving (jerking or non-jerking) spindle's rim and they form the IIPCS in the spindle rim's magnetic field. (The rolls of chips just mentioned are routinely fabricated by French-owned *Oberthur Card Systems* {a plant exists at Rancho Dominguez, California}, French-based *Gemplus, Schlumberger* {Paris and New York}, and California-based *Frost & Sullivan*.)

4.2.1 *Coil Sets*

In the proposed miniaturized integrated circuit devices, as exhibited in FIG. (1), there will be a very large number of ultra-small, sub-millimeter or microscopic coil sets or elements, 56, embedded in or imprinted upon a silicon chip, 57, in multiple layers. Ultra-fast micro-switches or transistors of the IIPCS, 58, will launch a long a series of current pulses, 59, of approximately nanosecond to picosecond or less duration moving at the electron's mobility speed (approximately light speed, c) that will be timed to reach the individual coil sets or elements almost simultaneously (with the same rise time as discussed in Y. Acremann *et al* [13]). These pulses can travel along several individual conductors, as in FIG. (1), or along one single conductor per line, as in FIG. (2), and thereby interact with the magnetic field of a nearby magnet on the rim, 60, in concert.

This interaction will result in a third-time-derivative motion or jerk of the uncharged magnetic masses on the rim to generate a train of gravitational waves. **The effect is exactly the same as a rotating or ratcheting rim with the change in centrifugal force (jerks) replaced by the reciprocating jerks of the magnets attached to the rim.** The ultra-fast switches are preferably semiconductor-based, such as the semiconductor optical amplifier (SOA), a semiconductor nonlinear interferometer such as a nonlinear *Sagnac* interferometer on a phosphide semiconductor chip, etc. (please see, for example, D. Cotter, *et al* [14], pp. 1523-1528).

4.2.2 *Pulse Duration*

The pulse duration will be such as to completely energize any given coil set as it passes through it in order to produce a magnetic field interaction. As has been emphasized, the interaction will result in a third-time-derivative circumferential motion or jerk of a cylindrical stack of rims, 63, shown in FIG. (3A) (figure 2 of US Patent 6,417,597) and generate a long GW train of successive GW pulses having axis, 29. This stack or barrel is surrounded by and immediately adjacent to a sheath of IIPCS-controlled coil sets, 64. The cross–section of the barrel or an individual rim of the stack is shown in FIG. (3B) (figure 8A of US Patent 6,160,336). The coils (myriads of them represented by a single coil) 26, interact with the tiny rim magnets, 24; produce jerks along axes, 27, which emulate a ratcheting rim, 15. In the case of a design with the current-pulse train on a single conductor interconnecting a line of coil sets, FIG. (2), there will be a build up of impulses to full value as the current-impulse train progresses down the line of coil sets. Use of a single conductor wire for each line of coil sets reduces the resistive power loss. In each line of coils set in series 61 there will be time delays, 62, between coil sets to ensure simultaneity of the current pulses reaching any given coil set. The myriad of miniature coil sets (incased in layers of chips) will energize (jerk) each tiny rim magnet.

4.2.3 *Parallel-Conductor Stacks*

In FIG. (4), ultra-fast switches or transistors of the IIPCS, 58, will launch a long series of direct-current pulses acting in either direction, 59, of approximately nanosecond or picosecond or less duration moving at the electron's mobility speed along individual conductors or single interconnecting computer wires in order to produce current pulses, 59, acting in concert to generate modulated jerks and resulting HFGW (GHz to THz and higher frequencies) with axis, 29 (or perpendicular to that axis). The current pulses will be timed to reach parallel-plate conductors, 66, which may have different masses or may have ballast, 67, attached and/or carry different current, and/or have different modulus of elasticity and/or are constructed differently in their mountings for the purpose of exhibiting asymmetrical mass displacements, jerks or "hammer blows." The asymmetry is required in order to avoid the null situation to be discussed in Section 9. (Such a concept of utilizing the force between parallel current-carrying conductors is similar to the nanowire or nanoplate devices to be described in Section 8.)

4.3 *Emulation of a Much More Extensive Body*

As a GW front passes by the energizable, e. g., in the case of parallel-plate, elements (schematically shown in FIGS. (5A) and (5B) as 80, 84, 86, and 88) or individual members of a stack of (jerking) rims as shown in FIG. (3A), they are energized in sequence thereby increasing the wave's amplitude. In FIG. (5B) such an effect is schematically illustrated as GW 83 ,85, 87, and 89 build up to accumulate the GW, 82, wave front shown also in FIG. (5A).

Thus a linear device having a much longer effective length (or radius of gyration), r, or a cylindrical stack of rims having a much larger mass than any single rim is emulated. Again, this is all subject to experimental verification. It is to be emphasized that **any unwanted EM radiation can be screened out.**

In FIG. (6), ultra-fast switches or transistors of the IIPCS, 58, will launch a long series of current pulses, of approximately picosecond duration along individual conductors or single, interconnecting conductor wires that will be timed to reach individual, sub-millimeter micro- or nano-electromechanical elements, or piezoelectric crystals, etc. 56. This will be in sequence to reinforce and cause a *build up* of the amplitude of a **coherent** GW beam (as in FIG. (5B)) having axis, 29. The ensemble of electromechanical elements (including other kinds of energizable elements such as nanomachines) will also be embedded in or imprinted on a silicon chip in multiple layers. FIGS. (7A) and (7B) (figures 7A and 7B of US Patent 6,160,336) exhibit the ultra-fast, micro-switches (1.1d,u to 1.4 d,u and 1.5 *l*,r to 1.8 *l*,r) set so no current flows through the coils and ultra-fast, micro-switches (2.1 d,u to 2.4 d,u and 2.5 *l*,r to 2.8 *l*,r) set so that the current flows through the coils right to left. Other switch setting can reverse this current direction.

4.4 *Summary*

The problem, which all of the devices discussed in this paper solve, is to cause a system of masses, which could be mini-magnets, micro-devices (e.g., small plates), nano-devices (e.g., nanowires), individual molecules, submicroscopic particles, or individual electrons (as in a superconductor) to move in concert with a jerk in order to *build up* (generate) HFGW with either planar or cylindrical wave propagation. Such jerking masses produce a very long sequence of HFGW pulses having significant average power without generating incapacitating heat, causing disruptive g loads, or producing overpowering EM radiation.

As I have emphasized, the problem is solved in several alternative ways by utilizing an array of energizable elements (e. g., rim-magnets, coils, parallel plates, piezoelectric crystals, dielectrics, capacitors, nanomachines, high-temperature superconductors, electrons, nuclear particles, laser beams, etc.) to be activated by energizing elements (e.g., coils, submicroscopic particles, laser beams, etc.) under computer-logic-system control.

As already noted, these energizable elements are activated or energized in the correct sequence with correct timing by the IIPCS computer (computer-controlled logic system) to accumulate a GW (moving at local GW speed in the energizable mass, which may or may not be near to the vacuum light speed) as the GW front moves in the mass or collection of masses. Essentially, the IIPCS causes the entire mass or collection of masses, or rims, or molecules to jerk effectively in unison or in step with the GW wave front and generate coherent HFGW. That is, the jerk will progress in step with the GW front and build the GW amplitude up – somewhat similar to a cyclotron pulsing a charged particle as it circles around in its magnetic field, or, possibly, like a traveling-wave amplifier and similar to the coherent GW generation suggested by Romero and Dehnen [12]. Energizable elements (that jerk when energized) are energized in sequence as the GW front passes. As has been seen, these elements taken together emulate a much larger, more extensive mass. **That is, the entire mass "appears" to the GW (as it passes) to be a single larger mass (e.g., a solid massive cylindrical flywheel) being jerked cohesively.** Experiments suggested at this Conference would not only shed light on such HFGW characteristics, but also, as suggested by Y. Acremann, *et al* [13] in their discussion of the processional motion of the magnetization vector "… forms the basis for realistic models of magnetization dynamics in a largely unexplored but technologically increasingly relevant (picosecond) time scale."

5. MAGNETIC FIELD BUILD UP AND HEAT LOSS

I will commence the analysis using the theoretical example of the ratcheting or jerking rim and then evolve the device into both a stack of rims and into a linear form. It should be recognized again that a rotating rim could generate GW, but in order to generate significant and continuous GW its rotational rate would need to be so large that the rim would be torn apart! Thus a rotating rim has been replaced by a ratcheting or jerking rim and that rim will be replaced by a stack of rims composed of individual jerking rim elements and finally by a linear motor.

5.1 *Magnetic Field Build Up*

Although of little concern in most applications, the length of time to "build-up" the magnetic field of the coils is important here as it is in the experimental work of Y. Acremann [13]. The electrons must complete sufficient coil turns (moving at the current pulse speed – about $2.3 x 10^8$ [m/s] or 77% of light speed) in approximately a picosecond to "launch" most of the magnetic field that produces the impulsive force (like a "hammer blow") or jerk when it interacts with the static magnetic field of permanent or electromagnets as effectively "carried around" by the ratcheting rim. Thus, they must be very tightly wound with each coil "set" having a total length of less than 0.3 mm (0.0003[m] or 300 micrometers). The coils are tightly wound in order to react rapidly enough as the current pulses move through the coils at electron migration (for the ultra fast switch semiconductors) or current pulse speed, about 0.77c according to some experiments by Spring [19] who found current speeds from 0.66c to 0.9c. Note the electrons themselves, like water molecules in an ocean wave, do not move with the wave and have drift speeds on the order of only one m/s. If each of the ultra-small, sub-millimeter coil sets consist of two coils or turns, as exhibited in FIGS. (7A) and (7B), then their diameters are on the order of $d = 0.3/2 \pi = 0.05$[mm] = 50 [μm] or less. (Note that the single-turn coil of *Al*, utilized by Y. Acremann, *et al* [13] was about 6 [μm] in diameter.) The coil wire could be made of gold having about a 0.015-mm or 15-micrometer diameter. The resistance for such wire at room temperature is about 135 [ohms/m] -- high-temperature superconducting (HTSC) material would be useful here. As will be seen from Section 5.4.2, in the spin-up jerk mode the IIPCS will need to build up **0.26 [Tesla]** flux density, at the appropriate polarity and interval, e. g., every 0.044 [m] for magnets of that rim spacing (the requirements for the spin-down jerk mode are essentially the same, but reversed). The magnetic flux density, B, is given by

$$B = \mu_o n i / l \text{ [Tesla]} \qquad (16)$$

where $\mu_o = 4\pi x 10^{-7}$ (permeability of free space), n is the number of coil turns, i is the current through the coils [amps], and l is the length of the coil conductors [m]. The double coil sets will be placed on 50 to 100 [micrometer] centers, so that there will be about $2x100x100 = 2x10^4$ coil turns on each square-centimeter level of the stack of 25 coil levels or layers. With $l = 0.044$ [m], $n = 25x2x10^4 = 5x10^5$, $i = 9.1x10^3/5x10^5 = 0.018$ [amps] or 18 milliamperes, , $n i = 9.1x10^3$ [amp turns], so that Eq. (6) yields **B = 0.26 [Tesla].**

5.2 *Heat Loss*

The total length of 15-micrometer-diameter gold wire across any given layer or level is 100(rows) x100 (coil and jumper/time-delays)x(600 micrometers) = 6 [m]. For the 25 layers or levels there will 150 [m] of wire with a resistance of 150[m] x135[ohms/m] = $2.025x10^4$ [ohms]. Since on average every other pulse interval across a conductor wire will carry no current (resulting of course, in a lower average GW power), the heat loss per centimeter of chip stack or semi-conductor layers is

$$(1/2)i^2R = \mathbf{3.28\ [watts]}. \qquad (17)$$

This heat loss can be reduced by 32% by using 25-micrometer-diameter wires for the time-delay jumpers, but high-temperature superconductors (HTSCs) for this purpose are contemplated. In addition there may be some energy loss or resistance occasioned by EM radiation generated during the GW-generation process **– reduced or eliminated since the jerked masses are uncharged**. Such an EM energy loss can be reduced by the design of the energizing coil elements and controlling the direction of current pulses by the IIPCS. Concerns of the influence of magneto resistance (MR) of both the conductors and the semiconductor circuits and the dynamics of the impulsive magnetic field buildup should be addressed during experiments as would be the aforementioned EM radiation, which could significantly reduce the efficiency of the HFGW generator. Note that alternating currents are **not** utilized (only direct-current, positive pulses) in order not to drive the electrons to the conductor's skin and thereby increase resistance. This is probably not a problem if superconductors are utilized and their utilization is contemplated in most of the HFGW devices described in this paper.

5.3 *Direction of the Generated HFGW*

The HFGW is expected to progress both ways along the axis of the rims (or cylindrical stack of independent rims) since there is a square associated with the kernel of the quadrupole equation—so there is no preferred direction along the axis of the cylinder. Such a concept will be subject to experimental verification and the propagation direction may be dependent upon whether or not there is circular polarization or cross "+" polarization or a combination. Between the rims HTSC lenses can be inserted to concentrate the HFGW along the axis of the rings. As has been emphasized a large number of ultra-fast switches, preferably semiconductor based (exhibited in FIGS. (7A) and 7(B)), would be activated simultaneously along the progressing gravitational wave front in one of the two directions by the coil-control computer, with communication lines of nearly equal length to all switches. The coil-control computer logic system of the IIPCS could also activate coil sets inside and outside the rim, not just outside as shown in FIGS.(3A) and (3B) and concentric "layers" of rims and coils could be utilized.

The coils, which are closely adjacent to magnets or magnetic sites in the rim or rims, are to be sequentially activated in order to generate coherent HFGW in one direction (non-coherent HFGW will propagate in the other direction). Depending upon the proximity of the coils and the duration of the current pulses, there may be currents induced in one coil juxtaposed to another. *Any induced currents will produce deterministic reverberations for which the computer logic system of the IIPCS that can be programmed to account for.* In any event, the reverberations would subside as the current-produced magnetic pulses either collapse or clear the ensemble of chip layers at light speed.

5.4 *Linear-Motor, Linear-Jerk GW*

The foregoing discussion of a ratcheting rim is included first in order to bridge the gap between the rather conventional celestial GW mechanisms involving circular motion and the terrestrial laboratory cylindrical stack of "rotating" or jerking rims. Another laboratory device is similar to that proposed by Romero and Dehnen [12] and involves a linear motor device involving linear motion. (Yet another variant of the ratcheting rim is a ratcheting rod shown in FIG. (8), which could be oriented at various angles.) In the following subsections I discuss the linear-motor concept, estimate the coil-magnet force (utilized for all the devices discussed in this paper), and by means of a numerical example, determine the material acceleration.

5.4.1 *Concept*

The linear-motor design of the HFGW-generation device, sometimes referred to as a *linear induction motor* or LIM, is visualized to involve a single sector of the ratcheting rim with the impulsive forces, ?f, being longitudinal and tangential to the ring of energizable elements, Δf_l, rather than radial. If the rim magnets and adjacent coils were peeled off from the rim and laid out flat, then the result would be a linear motor. Please see FIGS. (9A) – (9D) for a schematic of the progression of such a "peeling." In a very hypothetical case , a 2000-meter-radius exemplar device once peeled would be 2pr = 2px2000 = 6283 [m] in length and, since for this linear mass distribution $I = (1/3)mr^2$ and $d^3I/dt^3 \cong (2/3)r\,\Delta f_l\,/\Delta t$, the effective radius or radius of gyration is 6283/3 = 2094 [m] ˜ 2000 [m] (a measure of the mass distribution) and I assume that it is a tube 3 [m] in diameter. One-centimeter-wide chip rolls would be placed longitudinally along the sides of central, cylindrical, permanent- (or electro-) magnetic tube, core, piston, or barrel, 63, consisting of an array of magnetic energizable element sites, 57, as shown in FIG. (3A) if one replaces the stack of jerking rims by a solid cylinder of magnets surrounded by a sheath of coils. The thin (approximately one cm thick) band of Alnico 5 permanent magnets could be replaced by far stronger electromagnets that face outward as in FIG. (3B).

5.4.2 *Estimate of Force*

In general, permanent magnets exhibit irregular magnetic fields and associated forces. As a rule of thumb a band of juxtaposed 1.75-inch-long (0.044[m]) magnets will lift a weight in excess of 30 pounds per 1.75 inches or {30x12"/1.75" = 206 pounds)/(2.2 pounds per kilogram)} {3.28 feet per meter} = 307 [kg/m] x{ 9.8 Newtons per kilogram weight}or produce about **3000 [N/m]** of longitudinal force, f, per meter. Each 1.75-inch permanent magnet has a flux density, B, of about 2,600 gauss or **0.26 [Tesla]** developed every 4.4 [cm]. This matches the magnetic flux density of the juxtaposed coils from Eq. (16). Thus since each meter-long, square-centimeter segment of the roll would produce about **3000 [N/m]** of longitudinal force, f_l, per meter and all together they form a sheath of sub-millimeter coils (energizing elements) surrounding this central magnetic core, tube, piston, or barrel of a stack of rings of juxtaposed magnets. I will be extrapolating these numbers to micro- or nano-magnets so it is important to establish a specific magnetic force per unit volume, which of course would be much larger if electromagnets replace the permanent magnets and HTSCs were introduced. The impulsive force per unit volume for the meter long square-centimeter cross-section magnet and closely adjacent coil combination, is ?f_l/?V = 3000[N/m]/(0.01[m])^2 = **3x10^7 [N/m^3]**. As mentioned already, rings of such uncharged elements, whose planes are parallel to the passing GW crest, will be energized or jerked tangentially to the rings as the GW crest passes and add to its amplitude so as to generate coherent HFGW. Note that in this case the motion of the magnetic mass is asymmetrical (either "in" or "out") so that there is a quadrupole moment without GW cancellation. (In this regard, please see Section 9.) Pinto and Rotoli [15] (p. 567) indicate that "... the quadrupole formula is only valid provided a suitable surface integral (vanishes), which is the case for a series of point sources" such as the energizable elements of the subject device and that of Romero and Dehnen [12].

5.4.3 *Numerical Example*

As a numerical example for the linear-motor design, there would be about one roll or 25-layer strip of chips spaced around and adjacent to the cylindrical barrel of the linear motor (64, shown in FIG. (3A)) in a longitudinal direction (parallel to the barrel axis) every two centimeters forming the sheath. There would be πx3[m]x100[cm/m]/2[cm] = 471 strips around the barrel's circumference, each one having a length of 2px1000 = 6283 [m] so that

Δf_l=(471)(6283[m])(3000[N/m]) =**9x10^9 [N]** (18)

and with κ_{mr3dot} = 32 (the theoretical quadrupole-approximation value to be established experimentally since r may not be less than λ_{GW}),

P= 1.76x10^{-52} (? x6283x9x10^9/10^{-12})^2 = 0.25 [watts]. (19)

Thus, with the reference area being the two 3 [m] diameter "barrels" or "pipes" or "tubes" or cylindrical ends (GW propagating in both directions so the area is doubled) with a thickness of one centimeter, area = 2 (3p) (0.01) = 0.19 [m^2], the generated HFGW flux is about 0.25/0.19 = 1.3 [watts/m^2] near the hypothetical device. The average HFGW flux or signal would be about 1 [watt/m^2]. As a point of reference I again compare our terrestrial HFGW generator to celestial Low-Frequency Gravitational Wave or LFGW generation. Thus, for the sake of argument (although admittedly, it is like comparing "apples to oranges") the 1 [watt/m^2] is compared to **4x10^{-16} [watts/m^2]** maximum signal from a 500 mega parsec [Mpc] distant, 1000 black-hole (BH) radius semimajor-axis binary black hole (BBH) osculating orbit and **5x10^{-5} [watts/m^2]** from a 6-BH radius osculating orbit ([10], pp. 19 and 27) – or over **ten-thousand times stronger** than the LFGW signal from a 6 BH-radii BBH osculating orbit just before merger**!**

For cylindrical GW, in case the barrel magnets participated in harmonic oscillation (each end's uncharged magnetic sites moved in and out harmonically relative to the other), the reference area would be (6283)(3π) = 6x10^4 [m^2] and the GW flux would be 0.25/6x10^4 = 4x10^{-6} [watts/m^2]. Although the jerked masses are uncharged, the high-frequency electromagnetic fields may generate significant EM radiation that will be studied in any experimental effort.

5.4.4 *Material Accelerations*

The acceleration, *a*, caused by the jerk is obtained by multiplying the activation time, dt, by the time rate of change of acceleration. The time rate of change of acceleration is d*a*/dt ˜ ?*a*/?t and by Newton's second law ?f = m?*a* so ?*a* = ?f/m and

$$da/dt \approx \Delta f/m\Delta t. \quad (20)$$

From Eq. (18) ?f = 9x10^9 [N], m (mass) per meter for the cylinder of magnets is equal to (3.8[kg/m] of magnet strips)(471 strips per meter of cylinder)(6283 [m] cylinder length) = 1.12 x 10^7 [kg], and ?t = 10^{-12} [s]. Thus

$$da/dt = 9x10^9/(1.12x10^7)(10^{-12}) = 8x10^{14} [m/s^3] \quad (21)$$

Let us suppose that the total activation time for jerking a magnet in one direction, dt, is three picosecond pulse lengths or $3x10^{-12}$ [s]. Therefore, a = (d*a*/dt)dt = $(8x10^{14})(3x10^{-12})$ ~ $2.4x10^3$ [m/s^2] or 245 g's and far less than, say, the acceleration experienced by a bullet in the barrel of a gun. Thus the magnet would not disintegrate. The acceleration is also probably within the weak-field limit of Einstein's equations since for PSR 1913 + 16 the acceleration at periastron is over 100 g's (Section 2.3.4) and probably much grater acceleration is encountered for a spinning neutron star for which the Einstein equations presumably hold.

In the *extreme case* of 100 picoseconds of continuous jerk (in the same direction), dt = 10^{-10} [s], the speed would build up to

$$ds/dt = (da/dt)\delta t^2/2 = (8x10^{16})x10^{-20}/2 = 0.0004 [m/s] \quad (22)$$

and the displacement of the magnetic mass (composed of many magnetic surface sites, 57, of the linear motor, piston, or barrel shown in FIG. (3A)) is

$$s = (da/dt)\delta t^3/6 = (8x10^{16}/6)x10^{-30} = 1.3x10^{-16} [m]. \quad (23)$$

Again there could be considerable "motion" of the magnetic mass, but even in the most unlikely case of an extremely long series of jerks in the same direction (100 pulses), it goes a very small distance before the IIPCS reverses the built-up acceleration, speed, and displacement and *the stresses in the material of the device would be minimal.*

In general, for permanent-magnet and coil combinations of all of the devices discussed in this paper, which exhibit an N-pulse long activation time, the acceleration is

$$da/dt = \{(?f \text{ per meter})/(\text{mass per meter})\}N \quad (24)$$

with dt = N ?t. We have calculated that ?f per meter = 3000 [N/m}, that mass per meter = 3.8 [kg/m], and with N = 3 (the ?t's cancel out), d*a*/dt = (3000/3.8)x3 = 2368 [m/s^2] or 245 g's as before. **Since the ?t (and, therefore, the frequency) cancel out, the material (magnet) acceleration is only dependent upon the ratio of force to mass of the magnets and the number of current pulses, N, in the total time that the magnet is activated (jerked) in one direction before the IIPCS reverses the jerk.**

6. HIGH-INTENSITY HFGW GENERATOR

A high-intensity HFGW-generation would necessarily involve a much shorter pulse duration, e.g., ten attoseconds or 10^{-17} [s] (100 PHz or QHz frequencies). In this regard, Raymond Lewis told us during this Conference (5/7/03) that "... quantum jump might greatly reduce ?t to, say, 10^{-18} [s]...." I will configure the generator as before as a barrel composed of a stack of individual and separate rims whose edges are again covered with a juxtaposed array of ultra-small micromagnets (energizable elements) surrounded by a sheath of ultra-small microcoils (energizing elements). The device is again represented by the schematic drawn in FIG. (3A) whose cross section or individual separate rims are shown in FIG. (3B) except that there are multiple concentric rims or rings around the cylinder axis. If the HFGW spreads out from one rim to the next, then a thin HTSC lens (please see paper HFGW-03-120) can be inserted between the rims in order to concentrate the HFGW down the axis of the stack as its intensity is built up. At the end of the stack of rims or rings there is a final HTSC lens that concentrates the HFGW on a focal plane.

The power of the device is given by a variant of Eq. (6). Each rim or ring has magnets on its periphery that are energized by an adjacent shell of coils (using the IIPCS for timing). As already noted there are many concentric rims or rings at, say, two-centimeter intervals along the axis of the rim or ring stacks to allow for a one-centimeter thick (maximum thickness) HTSC lens to be sandwiched in between the one-centimeter thick, d*l*, ring sets. I will set the overall length of the generator to be l = 500 [m] so that there are n = (l/dl)/2 = 25,000 rims (or sets of concentric rings) along the axis of the cylinder (FIG. (3A)). I utilize the force per meter that has been calculated for the (rather weak) permanent magnets of F = 3000 [N/m] and set the radius of the outermost rim to be r_0 = 10 [m], so that the rims or rings in any cross section number n = (r_0/dl)/2 = 500. The power of the HFGW generator is given by (half goes the opposite way)

$$P = ½x1.76x10^{-52} ? \sum_{k=1, step2}^{k=500} \{2r_k\, Fnn(2pr_k)/?t\}^2 \text{ [watts]} \quad (25)$$

where r_k = 2k dl [m] and ?t = 10^{-17} [s]. The numerical result is about **380 kW**.

At the focus of the last or end lens, the size of the diffraction pattern on the focal plane defines the maximum HFGW flux. The diameter of the diffraction pattern is 1.22?$_{GW}$, where ?$_{GW}$ = c ?t and for the ten-attosecond (100Qz), ?$_{GW}$ = $3x10^{-9}$ [m]. Ideally all of the HFGW power is concentrated in this diffraction pattern, which has an area of p$(1.22x3x10^{-9}/2)^2$ = $1.05x10^{-17}$ [m^2]. So the flux is **$3.7x10^{22}$ [watts/m^2]**. Such a hypothetical and ideal flux density compares favorably with the ultra-intense laser pulses of 10^{23} [watts/m^2], which produce proton energies of "... up to 58 MeV..." [18].

7. MINITURIZED HFGW GENERATOR

For the purpose of having a specific numerical example of a miniaturized HFGW generator, suppose that the dimensions of the transmitter or miniaturized device involve an energizable-element stack of tiny rims (e.g., rings or circles of microscopic magnets) that is 6 [mm] thick surrounding a 3 [mm] radius energizing-element core (e.g., microscopic coils). The diameter of the device is 2(3+6) = 18 [mm]. The radius of gyration would be 6 [mm]. Let us also suppose that the device is 18 [mm] in length. At the receiver, which I assume to be 7 [km] away, I will introduce a d = 18 [mm] diameter superconducting lens to gather and focus the HFGW in order to concentrate or amplify the signal at the receiver. I will consider that ?f_l /?V can be increased ten fold by increased magnetic efficiencies due to the use of superconducting electromagnets (rather than rather weak permanent magnets) to $3x10^8$ [N/m^3]. I will also consider a reduction in pulse time to one 100 attoseconds or ?t = 10^{-16} [s]. The longitudinal-force pulse, ?f_l = (Volume) x(?f_l /?V) = (p[$(9x10^{-3})^2$ – $(3x10^{-3})^2$] [0.018]) x($3x10^8$) = ($4.07x10^{-6}$)($3x10^8$) = $1.22x10^3$[N]. Thus from Eq. (6) I find (with half the GW, the non-coherent half, going in the opposite direction)

$$P = ½x\ 1.76x10^{-52}\{(2)(0.006)(1.22x10^3)/10^{-16}\}^2 = \mathbf{1.89x10^{-18}} \text{ [watts]}. \quad (26)$$

This power from the forward, "coherent-radiation" end is distributed over an area defined by the diffraction pattern at a distance of 7 [km] or range, R = $7x10^3$ [m]. The diffraction angle, a_d , at the apex of a cone of HF GW is given by (please see Conference paper HFGW-03-120)a_d ˜ ?$_{GW}$ /device-diameter = c?t/(0.018) = ($3x10^8$)(10^{-16})/(0.018) = $1.67x10^{-5}$ [radians].

The area of the conical spread of the HF GW is

$$a = p(a_d\ R/2)^2 = p(1.67x10^{-5}x7x10^3/2)^2 = \mathbf{1.07x10^{-2}} \text{ [m}^2\text{]}. \quad (27)$$

The 18 [mm] diameter lens, which concentrates the HF GW at the receiver, has a grasp or GW gathering power, or amplification of $(d/?_{GW})^2$ = $\{(0.018)/(3x10^8)(10^{-16})\}^2$ = **$3.6x10^9$** . Putting it all together the signal at the receiver is {($1.89x10^{-18}$)/($1.07x10^{-2}$)}{$3.6x10^9$} = **$6.3x10^{-7}$ [watts/m^2]**, which is about an order of magnitude larger than a ten-watt isotropic EM transmitter at a 7 [km] distance ($1.6x10^{-8}$ [watts/m^2], p.42 of [10]).

Note that *the HFGW signal at the receiver is inversely proportional to the* ***sixth power*** *of the system's pulse length, ?t,* (including the lens at the receiver). The foregoing is a bit of a simplification since, like the discussion of the high-intensity design in Section 6, one would turn to a concentric, cylindrical-layer construction – not to a simple sheath and single rim configuration. Thus the energizing elements (e.g., coils) and energizable elements (e.g., magnetic sites on the rims) would be close enough for the GW waves (of wavelength c?t = ($3x10^8$) (10^{-16}) = $3x10^{-8}$ [m] or 30 nanometers – probably much smaller in a superconductor) marching down the cylinder coherently, to build up with an electron migration distance of only ($2.38x10^8$)(10^{-16}) = 23.8 nanometers [nm].

8. NANOMECHANICAL RESONATOR

A recent paper by Melosh, *et al* [17] raises the possibility of utilizing high-frequency nanomechanical resonators for generating HFGW. They indicate some 10^{11} junctions (presumably where resonators could be located) per square centimeter of wafer or chip. The resonance frequency of the wires is "... expected to range from tens of MHz to GHz." At the GHz frequency, ?t ˜ 10^{-9} [s]. The ?f is more difficult to estimate. Let us assume that the force applied to the resonators is like the force between two parallel current-carrying conductors mentioned in Section 4.2.3 and exhibited schematically in FIG. (4). In this case the classical equation for the force (impulse) is

$$?f = \mu_0 \, l i_a i_b / 2pd, \qquad (28)$$

where μ_0 = 4px10^{-7} , *l* is the length of the wire section, d is the distance between wires, and i_a and i_b are the currents flowing through any adjacent pair of wires. The wires can be as small as 20 [nm] in diameter for a wire cross section of about 3x10^{-16}[m^2]. If one were able to conduct a TAmp/m^2 or 10^{12} Amps/m^2 (a most difficult problem especially if superconductors are contemplated), then the current in the two wires would be three tenths of a milliamp or 3x10^{-4} [A]. I will assume that at the resonator the wire section, *l*, subject to the force and the distance, d, between wires are about equal. Thus Eq. (28) yields

$$?f = (4p\text{x}10^{-7})\,(3\text{x}10^{-4})^2/(2p) = 3.6\text{x}10^{-21}[\text{N}] \qquad (29)$$

and if I had about a three-meter stack of these (assumed 1 [mm] thick) wafers or chips (so that the radius of gyration for a computer-logic system control to build up a coherent GW along the stack, would be r = 1 [m]), and with 10^{11} resonators per wafer, Eq. (6) yields

$$P= 3\text{x}10^3\text{x}1.76\text{x}10^{-52}\text{x}\{2(3.6\text{x}10^{-21})(10^{11})/10^{-9}\}^2$$

$$= 6.8\text{x}10^{-50} \quad [\text{watts}]. \qquad (30)$$

Clearly this is **not** a viable HFGW generator. Even if one could impress a QHz frequency on the nanowires one could only expect a 10^{12} improvement – not enough.

A better way to implement a system like this would be to utilize an array of parallel plates that are, for example, one centimeter on a side and one millimeter thick. A two-meter square plate would hold about ten thousand of them plus associated circuitry and, again, there could be a three-meter stack for a one-meter radius of gyration for the build up of a coherent beam. In this case the area of the "wire" would be (0.01) (0.1) = 10^{-3} [m^2]. Assuming only 10^5 [A/m^2], a 100 [A] current would pass through each pair (probably superconducting to avoid heat). Let us suppose that I can separate the plates by 100 [nm] or 10^{-7} [m] and that for the centimeter plates *l* = 0.01 [m]. Thus evaluation of Eq. (28) yields

$$?f = (4p\text{x}10^{-7})(0.01)(100)^2/2p\text{x}10^{-7}=200\ [\text{N}] \qquad (31)$$

with QHz current pulses ?t = 10^{-15} [s]. There are 10^4 of the energizable elements on each plate as the GW wave passes by and if the plates are one-half centimeter apart (therefore 3[m]/0.05 = 600 of them in the stack) , so that Eq. (6) yields

$$P= 600\text{x}1.76\text{x}10^{-52}\{2\text{x}10^4\text{x}200/10^{-15}\}^2 = 1.7\text{x}10^{-6}\ [\text{watts}]. \qquad (32)$$

All of this is very hypothetical, but much closer to a realistic HFGW generator.

9. SYMMETRY AND NULL GW GENERATION

There exist some situations in which a jerk exists in a system of masses, but there is no attendant GW generation. One often refers to these as *symmetrical situations*. A situation in which a system is so symmetrical that one can think of the GW as canceling out and becoming null. Of course there are reactive jerks when a star collides with a black hole resulting in some acceleration of both bodies, or one neutron star orbits another with action and reaction on both bodies and in both cases GW is generated. Also GW would be expected to be generated with the reactive jerks of coils and magnets, motion of resonate cavity walls, Cooper pairs in a superconductor, electrons in a dielectric, etc. But there are situations, such as an isotropic explosion of a star, in which there is a jerk due to an expanding shell of gas and **no** GW is generated.

This situation warrants some attention. Consider FIG. (10A) in which there is shown the cross section of an exploding shell of gas having diameter, d. I consider two opposite small incremental masses of the shell, $?m_1$ and $?m_2$, which are jerked to the top and bottom of the figure. Let us suppose that they are jerked so that each mass generates two oppositely moving GWs, normal to the direction of the jerk in a plane perpendicular to the plane of the figure. I show as $?_{GW}$. The usual assumption for the efficacy of the quadrupole approximation for estimating GW power is that $?_{GW}$ »d, which is the case for most celestial LFGW generators. Thus I have the situation shown in FIG. (10B) and the GW cancel out and become null.

10. CONCLUSIONS

The jerk formulation of the quadrupole approximation was derived in two alternative ways for the HFGW power of a laboratory HFGW generation device. The formulation was numerically validated by analysis of a well-known GW-generating binary pulsar, PSR 1913+16. By means of numerical examples, it was shown that the resistive heat loss and device component acceleration are well within tolerable limits.

Micro- and nano-scale HFGW generator components have been described in connection with a computer logic system to facilitate the generation of coherent HFGW. A device consisting of a cylindrical stack or jerking rims was also described in connection with two specific designs: a high-intensity HFGW generator and a miniaturized HFGW generator. Moreover, the outputs of HFGW fluxfrom these devices range from 6.3×10^{-7} [watts/m^2] to 3.7×10^{22} [watts/m^2]. In either case the fluxes are greatly increased by increasing the frequency of the jerks to the QHz or higher and by including a HTSC lens to concentrate the HFGW. Linear motor HFGW-generator designs were configured and studied. The situation in which component symmetry prohibits the generation of GW due to destructive GW interference was examined. A nanomechanical resonator concept is analyzed, but not found to be especially efficient. And finally, the major conclusion is that **laboratory HFGW generation devices are feasible, practical, and warrant experimental investigation**.

REFERENCES

[1] Joseph Weber (1964), "Gravitational Waves," in *Gravitation and Relativity*, Chapter 5, pp. 90-105, W. A. Benjamin, Inc., New York.

[2] Charles W. Misner, Kip Thorne, and John Archibald Wheeler (1973), *Gravitation*, W. H. Freeman and Company, New York.

[3] Abraham Pais (1982), *Subtle is the Lord … The Science and the Life of Albert Einstein*, Oxford University Press, pp. 38, 242, 280, and 384.

[4] K. S. Thorne (1987), "Gravitational radiation," Chapter 9 of *300 Years of Gravitation*, Cambridge Press.

[5] L. D. Landau and E. M. Lifshitz (1975), *The Classical Theory of Fields*, Fourth Revised English Edition, Pergamon Press, pp. 348, 349, 355-357.

[6] H. Taylor, Jr. (1994), "Binary pulsars and relativistic gravity," *Reviews of Modern Physics*, Volume 66, Number 3, July, 1994 pp. 711-719.

[7] P. C. Peters and J. Mathews (1963), "Gravitational Radiation from Point Masses in a Keplerian Orbit," *Physical Review*, Volume 131, pp. 435-440.

[8] Samuel Herrick (1971), *Astrodynamics Volume 1*, Van Nostrand Reinhold, pp. 60 and 61.

[9] Robert M. L. Baker, Jr. (1967), *Astrodynamics, Application and Advanced Topics*, Academic Press, New York.

[10] Robert M. L. Baker, Jr. (2000), "Preliminary tests of fundamental concepts associated with gravitational-wave spacecraft propulsion," *American Institute of Aeronautics and Astronautics: Space 2000 Conference and Exposition,* Paper Number 2000-5250, September 20, August 21, 2001, Revision. (Please see Internet site at: http://drrobertbaker.com/RevisedAIAAPaper.htm .)

[11] F. Ashby, Ian Foster, James M. Lattimer, Norman, Manish Parashar, Paul Saylor, Schutz, Edward Seidel, Wai-Mo Suen, F.

D. Swesty, and Clifford M. Will (2000), "A Multipurpose code for 3-D relativistic astrophysics and gravitational wave astronomy: application to coalescing neutron star binaries," *Final Report for NASA CAN NCCS5-153*, October 15, 30 pages

[12] F. Romero B. and H. Dehnen (1981), "Generation of gravitational radiation in the laboratory," *Z. Naturforsch,* Volume 36a, pp.948-955. And: Heinz Dehnen and Fernando Romero-Borja (2003), "Generation of GHz - THz band, high-frequency gravitational waves in the laboratory," *Paper HFGW-03-102 Gravitational-Wave Conference, The MITRE Corporation,* May 6-9.

[13] Y. Acremann, *et al*, (2000), "Imaging processional mf otion of the magnetization vf ector," *Science*, Volume 290, October 20, pp. 492-495.

[14] D. Cotter, *et al* (1999), "Non-linear optics for high-speed digital information processing," *Science*, Volume 286, November 19, pp. 1523-1528.

[15] I. M. Pinto and G. Rotoli (1988), "Laboratory generation of gravitational waves," *Proceedings of the 8th Italian Conference on General Relativity and Gravitational Physics*, Cavlese (Trento), August 30 – September 3, World Scientific-Singapore, pp. 560-573.

[16] Ning Li and Douglas G. Torr (1992), "Gravitational effects on the magnetic attenuation of super conductors," *Physical Review B*, Volume 46, Number 9, p. 5491. (HFGW refraction).

[17] Nicholas A. Melosh, Akram Boukai, Frederic Diana, Brian Gerardot, Antonio Badolato, Pierre M. Petroff, and James R. Heath (2003), "Ultrahigh-density nanowire lattices and circuits," *Science,* Volume 300, April 4, pp.112-115.

[18] K. W. D. Ledingham, P. McKenna, and R. P. Singhal (2003), "Applications for nuclear phenomena generated by ultra-intense lasers," *Science*, Volume 300, May 16, p.1107.

[19] Spring, L. (1954), "Discoveries and Observations," item number 68., http://www.teslatech.info/ttstore/articles/spring/discover.htm, accessed October 9, 2002.