A Prospective on High-Frequency Gravitational Waves

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High Frequency Gravitational Waves (HFGWs) are gravitational waves (which differ from hydrodynamic gravity waves) that have frequencies of 100 kHz to 100 MHz (Hawking and Israel 1979). As their frequency increases, very high-frequency gravitational waves (VHFGWs) and ultra high-frequency gravitational waves (UHFGWs) are generated. These have frequencies of 100 MHz to 100 GHz and 100+ GHz, respectively. The generic term HFGWs describes all three of these bands. These waves move through the "fabric" of space similar to the way an ocean wave moves through the water. This "fabric," as Einstein describes it, is called the "space-time continuum" and is four-dimensional. It contains the usual three dimensions of space: for example, (1) east-west (2) north-south) (3) up down, but also includes the dimension of (4) time. An example of a specific location inthis "fabric" would be 5th Street and 3rd Avenue on the forth floor at 9 AM. This "fabric" can not be seen, just like wind, sound, and gravity can not be seen. These waves in space-time evidence themselves by very small distortions. Like a meter-long rubber ruler in space-time stretches or contracts a very small fraction of a meter – possibly a billion, billion, billion, billionth of a meter. This extremely small change in length per meter is defined as the amplitude, *A,* of the HFGW.

The term "gravity waves," refers to water waves in which buoyancy acts as a restoring force, as opposed to relativistic "gravitational waves." Such gravity waves are hydrodynamic in nature and are, for example, found at the base of hurricanes. Please note that tidal change is not a "gravitational wave" in the spacetime continuum. Tidal influences have amplitudes on the order of meters at the Earth, whereas gravitational-wave disturbances are but fractions of a proton diameter in amplitude.

1. **History**

The history of gravitational waves (GWs) predates Einstein's 1916 paper where he first discussed them. In 1905, several weeks before Einstein presented his Special Theory of Relativity, Jules Henri Poincaré, the famous French mathematician and Celestial Mechanic, suggested that Newton's theories needed to be modified by including "Gravitational Waves" (Poincaré 1905).

The first mention of high-frequency gravitational waves or HFGWs was during a lecture in 1961 by Robert L. Forward, presented at the *Lockheed Astrodynamics Research Center* in Bel-Air, California, USA. The lecture was based upon a paper concerning the dynamics of gravity (Klemperer and Baker 1957) and Forward's work (1960) on the Weber Bar. The first actual publication concerning HFGWs was in mid 1962 when M. E. Gertsenshtein authored the pioneering paper entitled "Wave resonance of light and gravitational waves" (Gertsenshtein 1962). The next publication was in August of 1964 when L. Halpern and B. Laurent wrote a paper in *Il Nuovo Cimento* (Halpern and Laurent 1964). They suggested that "… at some earlier stage of development of the universe (the big bang) conditions were suitable to produce strong (relic) gravitational radiation." They then discuss "short wavelength" or HFGWs and even suggest a 'gaser' generator of HFGWs analogous to a laser for EM generation. In 1968 Richard A. Isaacson of the *University of Maryland* authored papers concerned with "Gravitational Radiation in the Limit of High Frequency" in the *Physical Review* (Isaacson 1968). L. P. Grishchuk and M. V. Sazhin in early 1974 published a paper on "Emission of gravitational waves by an electromagnetic cavity," which also involved HFGWs. In August of 1974 G. F. Chapline, J. Nuckolls and L. L. Woods suggested the generation of HFGWs by nuclear explosions and in 1978 V. B. Braginsky and Valentin N. Rudenko wrote about "Gravitational waves and the detection of gravitational radiation…" The Russians were most interested in HFGWs during the "Cold War" especially in the 1970's. Then in 1979 Steven W. Hawking and W. Israel presented an actual definition for HFGWs having frequencies in excess of 100 kHz.

The theme of relic or big-bang generated HFGW and its relationship to "String Cosmology" (roughly related to the popular string theories of today) was picked up by G. Veneziano at the First Conference on Particles, Strings and Cosmology, at *Northeastern University* in March of 1990 and later discussed by M. Gasperini and M. Giovannini in 1992. This work continues on today, especially the research of L. P. Grishchuk (2007), and is the motivation for HFGW detectors under development by *Birmingham University,* England, *INFN Genoa,* Italy, and *Chongqing University,* China. The Peoples Republic of China's HFGW research program was initiated by Professor Fangyu Li at *Chongqing University*, China in 1990. His first paper on the subject was published in ACTA Physsica Sisica in 1992 entitled "Interaction between Narrow Wave Beam-type High Frequency Gravitational Radiation and Electromagnetic Fields." In essence Professor Li recognized the value of the inverse of the Gertsenshtein effect (1962), to detect HFGWs. In this case gravitational waves in a strong static magnetic field interact with a beam of electromagnetic waves, having the same frequency as the HFGWs (synchro-resonance), to generate photons that result from the passage of the HFGWs and can be utilized as the theoretical basis for an ultra-sensitive HFGW detector. (The usual Gertsenshtein effect involves the generation of gravitational waves by the passage of electromagnetic waves through a static magnetic field.)

The first Patent Application for a GW generator (now granted as United States Patent 6,160,336) was made on November 19, 1999. (Joseph Weber had a patent on an "Electromagnetic Coupled Detection of Dynamic Gravitational Force Gradients," United States Patent 3,722,288, filed in 1969, but it was unrelated to

GWs, Puyuelo Jacques Emil Henri had a French Patent FR 2661295 A1 "Transmitter/receiver of gravitational waves" granted on October 25, 1991, but it was telepathy or thought transmission and Hideo Seki had a Japanese Patent JP 2001077766 A "Communication Method by Gravitational Wave of High Frequency" granted on March 23, 2001 to "… communicate with stars … and to examine diseases inside a human body …"). And then, Robert M L Baker, Jr. was awarded United States Patent Number 6,417,597, for a "Gravitational Wave Generator," filed July 14, 2000.

The first *High-Frequency Gravitational Wave Conference* (International High-Frequency Gravitational Wave Working Group) was organized in 2003 at the *MITRE Corporation* in Mclean, Virginia, USA. The Conference was dedicated to Robert Lull Forward who can be considered as the person who coined the term High-Frequency Gravitational Waves. The meeting attracted over 50 scientists from 14 countries and some 25 technical papers were presented. Several HFGW research pioneers were present including Leonid P. Grishchuk from Russia and the UK, Valentin N. Rudenko from Russia, Giorgio Fontana from Italy, Eric W. Davis, Senior Scientist at *The Institute for Advanced Studies at Austin*, USA; Gary V. Stephenson of *Boeing*, USA, and R. Clive Woods, Chairman of the Department of Electrical and Computer Engineering, *Louisiana State University*, USA and Robert M L Baker, Jr. and Paul Murad who were cochairman of the Conference. One of the authors at that *Gravitational Wave Conference* was Professor Fangyu Li. He is the leader of the Chinese HFGW research program and, as already mentioned, he and his Chinese colleagues have had a very active HFGW research program in operation from 1990 to date.

2. **Sources of HFGWs**

There exist several sources for HFGWs or means for their generation. The first generation means is the same for gravitational waves (GWs) of all frequencies and is based upon the quadrupole equation first derived by Einstein in 1918. A formulation of the quadrupole that is easily related to the orbital motion of binary stars or black holes, rotating rods, laboratory HFGW generation, etc. is based upon the jerk or shake of mass (time rate of change of acceleration) and is derived by Baker (2006) as

$$P = 1.76\text{x}10^{-52}\ (2r\Delta f/\Delta t)^2\ \text{W} \qquad (1)$$

where P is the power of the GWs, r is the distance between two masses, m, Δf is a change in force, N, over the time interval Δt, s, that is, the jerk or shake of the two masses, such as the change in centrifugal force with time as masses move around each other on a circular orbit. Please recognize, however, that Δf need NOT be a gravitational force (please see Einstein,1916; Infeld quoted by Weber 1964, p. 97; Grishchuk 1974). Electromagnetic forces are more than 10^{35} larger than gravitational forces and should be employed in laboratory GW generation. As Weber (1964, p. 97) points out: "The non-gravitational forces play a decisive role in methods for detection and generation of gravitational waves ..."

Equation (1) is also termed "quadrupole formalism" and holds in weak gravitational fields (well over 100 g's however), for speeds of the generator "components" less than the speed of light and for r less than the GW wavelength. This last restriction may not really apply. Certainly there would be GW for r greater than the GW wavelength, but the quadrupole formalism might not apply exactly. For very small Δt the GW wavelength, λ_{GW} = c Δt (where c ~ $3\text{x}10^8$ ms^{-1}, the speed of light) is very small and the GW frequency ν_{GW} is high. As a numerical example, we will choose r = 10 m (convenient laboratory size though usually greater than λ_{GW}), Δf = $4\text{x}10^8$ N (or 400,000,000 N; for example, the force produced by a large number of piezoelectric resonators) and $\Delta t = 2x10^{-10}$ s (or 0.000,000,000,2 s; equivalent to about a ν_{GW} = 5 GHz shake frequency) so that λ_{GW} = 6 cm and $P = 2.8x10^{-13}$ W (0.000,000,000,000,28 watts or 0.28 picowatts). Clearly a very small HFGW power generated.

Two other means of generating HFGWs are somewhat similar: the Gertsenshtein effect and the gaser. The Gertsenshtein effect manifests itself when an electromagnetic (EM) beam (for example, microwaves or light) passes through a strong, static magnetic field in a vacuum and generates GWs having the same frequency as the EM radiation (Gertsenshtein 1962). (The inverse of the Gertsenshtein effect, that is, the generation of EM in the presence of HFGWs and a strong static magnetic field, can be utilized as the theoretical basis for an ultra-sensitive HFGW detector.) Simply described (Halpern and Laurent, 1964), the gaser consists of a long rod of a material and microscopical parts of which can be excited by a means, such as EM radiation, to emit GWs.

High-frequency relic gravitational waves or HFRGWs are produced by the big bang in a fashion somewhat similar to the cosmic microwave background or CMB. They were discussed originally by Halpren and Juvet in 1968 and by Grishchuk in 1974 and in 2007 and since have been considered to be of significant astrophysical and cosmological importance. Their amplitudes are, however, quite small, that is, $A \sim 10^{-30} - 10^{-33}$, where as previously defined A is the amplitude of the strain or fractional deformation of the spacetime continuum. That is, it is a measure of the length change of a given length, cause by the passage of a GW, in meters divided by the given length in meters, so that it is dimensionless.

In the case of the laboratory HFGW generation it is important to relate the amplitude of a GW, A, with the power, P, or more exactly with the GW flux, F_{GW}, in Wm^{-2}. From Appendix A of Baker, Woods and Li (2006)

$$A = 1.28\text{x}10^{-18} \sqrt{F_{GW}/\nu_{GW}}. \quad (2)$$

Following the proceeding numerical example we will concentrate the HFGW on a diffraction-limited area of $4\text{x}10^{-3}$ m^2 or 0.004 m^2 for a HFGW flux of $2.8\text{x}10^{-13}/4\text{x}10^{-3} = 7\text{x}10^{-11}$ Wm^{-2}. Thus $A = 2\text{x}10^{-33}$. It is an extremely small HFGW amplitude, but possibly a detectable signal.

Relic and other HFGWs were the subjects discussed at the *Second International HFGW Workshop* (http://earthtech.org/hfgw2/) held at the *Institute for Advanced Studies at Austin (IASA)*, Texas in September of 2007. Scientists from the United States, China, Russia and Italy presented and discussed their HFGW research. Presentations included Ultra-High Sensitivity HFGW detectors (with sensitivities that might reach HFGW amplitudes as small as 10^{-34}), means of generating HFGWs in the laboratory using long arrays of piezoelectric crystals (similar to the earlier work of Dehnen and Romero-Borja presented at the first HFGW Conference and based upon rigorous general relativistic analyses) using off-the-shelf components producing HFGW amplitudes of 10^{-24} to 10^{-32} and studies by Rudenko and Grishchuk that proved the existence of HFGW relic gravitational radiation.

3. **Detectors**

In the past few years HFGW detectors have been fabricated at *Birmingham University*, England and *INFN Genoa*, Italy. These two types of detectors may be promising for the detection of the HFGWs in the GHz band in the future, but currently their sensitivities are orders of magnitude less than what is required for the detection of high-frequency relic gravitational waves (HFRGWs) from the big bang.

3.1 British and Italian detectors

The *Birmingham* HFGW detector measures changes in the polarization state of a microwave beam (caused by the presence of a gravitational wave or GW) circulating in a closed microwave loop about one meter across. It is currently expected to be sensitive to HFGWs having spacetime strains of h ~ 2 x 10^{-13} /√Hz, where Hz is the GW frequency in Hertz. The h is a measure of the time-variable strain or fractional deformation in the spacetime continuum having amplitude *A*.

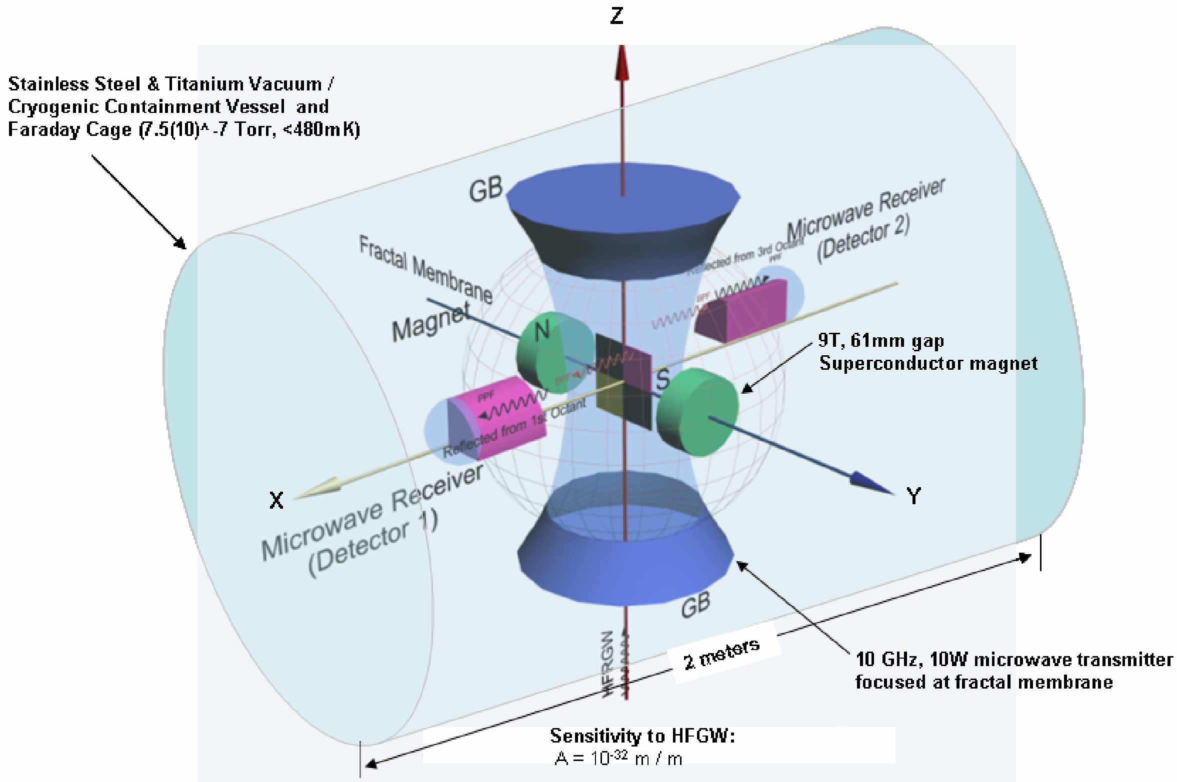
The *INFN Genoa* HFGW resonant antenna consists of two coupled, superconducting, spherical, harmonic oscillators a few centimeters in diameter. The oscillators are designed to have (when uncoupled) almost equal resonant frequencies. In theory, the system is expected to have a sensitivity to HFGWs with size (fractional deformations) of h ~ 2x10^{-17} /√Hz with an expectation to reach a sensitivity of h ~ 2x10^{-20} /√Hz. As of this date, however, there is no further development of the *INFN Genoa* HFGW detector.

3.2 Ultra-high sensitivity Chinese detector

Unlike the British and Italian detectors, the Ultra-high sensitivity Chinese detector depends on a different principle. It is based upon Gertsenshtein's GW theory published in 1962. The Chinese detector involves the selection and detection of HFRGWs with the predicted typical parameters ν_{GW} ~ 10^{10} Hz (10GHz) and h ~ 10^{-30} – 10^{-31} (Kogan and Rudenko (2004), Giovannini (1999), and Veneziano (2004)) and, is designed to also be able to detect the 4.9 GHz HFGW expected to be generated in the laboratory (Baker, Jr., Li, Woods, 2006). The usual Gertsenshtein effect (1962) involves the generation of GWs by electromagnetic (EM) waves under the influence of a strong static magnetic field.

In this case the GWs produced will have the same frequency as the EM waves producing them. The inverse Gertsenshtein effect, which is alluded to at the end of his paper (Gertsenshtein 1962, p.85) involves what is termed a synchro-resonance condition. Thus, using the Gertsenshtein effect, the Chinese detector has a strong EM beam (essentially a focused microwave beam, also called a “Gaussian beam”) at the expected frequency, phase and bandwidth of the HFRGWs (or HFGWs) passed through a strong static magnetic field. EM “detection” photons are produced due to the GWs. These detection photons **(**termed a “perturbative photon flux” or PPF) move off at right angles to the EM beam and to the direction of the magnetic field. According to theory they move off in both directions and are intercepted by two very sensitive microwave receivers or detectors. In order to concentrate the PPF at the detectors, paraboloid-shaped reflectors (made from “fractal membranes” discussed by Wenn (2002) and Zhou (2003)) are utilized. These reflectors focus the PPF in a diffraction-limited spot at the microwave receivers.

There does, of course, exist noise. The interior noise from thermal photon generation is eliminated by cooling the detection apparatus to below about 48 mK (0.048 Kelvin). In this case there are effectively no thermal photons at 10 GHz. The interior background photon flux (BPF) from the EM or Gaussian beam is reduced to a negligible level by moving the receivers out to the side about a meter away from the EM beam and by a series of superconductor or microwave absorbent baffles to “shade” the receivers. Stray EM resulting from scattering of particulate matter near the apparatus and possible dielectric dissipation can be effectively suppressed by evacuating the apparatus to about $7.5x10^{-7}$ Torr (a rather high vacuum). The exterior noise is eliminated by the use of a Faraday Cage composed of fractal membrane reflectors and a mosaic of superconducting chips attached to the interior of a containment vessel surrounding the low-temperature



detection apparatus exhibited in the following figure. This Faraday Cage effectively isolates the detector from the outside world.

It is found that for GWs having h ~ 10^{-32} to 10^{-34} the instantaneous values of the PPF may reach up to ~ 2.02x10 s^{-1} – 1.27x10^{3} s^{-1} through a surface having an area $10^{-2}m^{2}$ at the focus of the central EM "Gaussian" beam. It is possible to obtain very large signal-to-noise ratios at the one-meter distance of the detectors (or high-sensitivity microwave receivers) from the reflecting fractal membranes when focused into a diffraction-limited spot of area of about 3x10^{-3} m^{-2}. The size of the entire system can be limited to typical laboratory dimension (1 to 10m) and the system will have the capability to display directivity of the resonant components of the stochastic relic GW background and can provide a HFRGW map of the celestial sphere (similar to the map of the relic microwave background provided by the Wilkinson Microwave Anisotropic Probe or WMAP).

4. **Laboratory experiments**

There are several plans for the laboratory detection of high-frequency relic gravitational waves (HFRGWs). The ultra-high sensitivity Chinese detector seems to have the most promise; but the performance of these detectors is speculative at best. Even more speculative, but still promising, are plans for the laboratory generation and detection of HFGWs. There are a number of scientific papers dealing with such a prospect. Among them are: V. B. Braginsky and Valentin N. Rudenko (1978), F. Romero and H. Dehnen (1981), I. M. Pinto and G. Rotoli (1988), John Argyris and Corneliu Ciubotariu (1997), Robert M L Baker, Jr. (2000), and Leonid P. Grishchuk (2003). This last technical paper is the most prophetic, indicating that such a HFGW generation and detection laboratory experiment must await the advent of new technology. The following two approaches to the laboratory HFGW experiment do rely on such new technology.

4.1 *Piezoelectric*

Essentially the need for a large jerk or shake relies on an extremely large number of piezoelectric elements lined up and in phaseas first proposed by Romero and Dehnen (1981) and generates continuous HFGWs. In this case, however, use would be made of novel piezoelectric elements in the form of Film-Bulk-Acoustic Resonators (FBARs), found in cell phones, as energized by inexpensive magnetrons, found in microwave ovens. The concept (Woods and Baker 2005) is to separate two lines or tracks each composed of about 180 million FBARS (about 6,000 can be on a four-inch diameter silicon wafer) energized by ten thousand magnetrons (each FBAR when energized produces an internal jerk or shake of about 2 N). The separation distances of the lines or tracks (originally termed "clusters") can vary up to and including the lunar distance (the GW wavelength far less than the distance between clusters restriction is accepted). The resulting HFGW amplitudes are exhibited in the following table.

	Distance between clusters in meters	**Amplitude of the HFGWs**
Small Laboratory size	10	2×10^{-33}
Large Laboratory size	3×10^{2}	3×10^{-32}
30 km apart	3×10^{4}	3×10^{-30}
Lunar distance	4×10^{8}	4×10^{-25}

The radiation pattern at the focus of the HFGW generator, exactly midway between the two tracks, is computed in Landau and Lifshitz (1975, p. 349). It is in the shape of two symmetrical lobes of radiation directed in both directions (thus a figure "8") normal to the plane defined by the line connecting the two tracks and direction of the FBARs' impulsive force vector or jerk. There is a design-parameter relationship or "figure of merit" for a high-frequency gravitational wave laboratory generator comprising a number of vibrating masses or elements (e.g., piezoelectric crystals or FBAR pairs), which are lined up and in phase, that states:
The amplitude of the generated gravitational radiation is proportional to:

The distance between the individual vibrating masses (e.g., the width of the in-line, in-phase piezoelectric crystals or the distance between in-line, in-phase oppositely directed FBAR pairs).

The frequency of the generated gravitational radiation,

The change in force of the vibrating masses during each cycle and

The square of the number of in-line, in-phase vibrating masses or elements (piezoelectric crystals or FBAR pairs).

4.2 *LASER*

Ultra-high-intensity lasers are used to generate short-pulse HFGWs (Li, Baker and Li 2006). Like the FBAR clusters, two laser targets can be forcefully struck to produce a strong jerk or shake. The experimental approach involves new technology, that is high-intensity lasers causing $\geq 1.5\text{x}10^5$N-impulsive force on highly polished tungsten laser targets. The duration of the pulse is on the order of 70 picoseconds (0.000,000,000,07 s). The process underlying the generator's operation can be clarified by the following: Imagine a circle of light bulbs with the bulbs arbitrarily close to each other. Energize a pair of lights that are exactly opposite each other on the circle in sequence so that an observer perceives the two lights moving in a circle about each other. If the lights are very close together, then even though the lights are fixed, the observer has the illusion of orbiting lights whose emulated "angular-frequency" is determined by the rate of sequentially energizing the lights – similar to a string of "chasing" Christmas-tree lights. Next imagine that you have replaced the light bulbs by energizable, jerked masses, e.g., laser-targets. Again the perception is of orbiting masses even though the masses are overall fixed (except for very brief jerks). Since the masses are sequentially energized, an orbiting pair of masses and their change in centrifugal force (jerk) is emulated. As each pair of masses is energized or jerked the GW-radiation pattern (Landau and Lifshitz (1975) and Baker, Davis, and Woods (2005)) is, as already mentioned, approximately in the form of a figure "8" at the circle's center midway between the laser targets, directed both ways along the circle's center-line or axis. Each pair of laser pulses on targets, ten meters apart, produces about 22 watts of HFGW power and over a small diffraction limited infinitesimal spot has a GW flux of 10^{13} to 10^{14} Wm^{-2} during each pulse sequence. The resulting HFGW amplitude is about 4.5×10^{-23} or, if the distance between the targets was but one centimeter, then it is about 4.5×10^{-26} and both signals should be detectable.

5. **Applications**

Due to the extremely small amplitude of laboratory-generated HFGWs, their practical applications are very speculative. On the other hand, the potential applications of HFGWs (applied research) may well turn out to be the principal driving force for the pursuit of HFGW basic research even though the theoretical basis for the applications must await the successful completion of a HFGW generation and detection experiment. Unfortunately, the low-frequency GWs, having frequencies below 100 kHz and wavelengths that can exceed an astronomical unit, are not well suited to the practical applications that HFGWs may enjoy.

5.1 *Telecommunications*

As Thomas Prince (Chief Scientist, *NASA/JPL* and Professor of Physics at *Caltech*) commented (2002): “Of the applications (of HFGWs), communication would seem to be the most important. Gravitational waves have a very low cross section for absorption by normal matter and therefore high-frequency waves could, in principle, carry significant information content with effectively no absorption unlike any electromagnetic waves.” Multi-channel HFGW communications can be both point to point, for example to deeply submerged submarines, and point to multipoint, like cell phones. HFGWs pass through all ordinary material things without attenuation and represent the ultimate wireless system. One could communicate directly through the Earth from New York in the United States to Beijing in China, without the need for fiber optic cables, microwave relays, or satellite transponders – antennas, cables, and phone lines would be things of the past! Even the timing afforded by HFGW stations around the globe could result in at least a 51 billion dollar savings in conventional telecom systems over ten years according to a recent analysis of Harper and Stephenson (2007). Essentially, it would allow for greater telecommunications bandwidth usage efficiencies by synchronizing, through the use of HFGWs (which, unlike electromagnetic waves, move at constant speed through the Earth and atmosphere), all telecom transmitters and receivers. Thus no communication time would be needed for "waiting" for messages to appear – one message could follow right after another since you know precisely (to nanoseconds or better) when they will come in. Specifically, Harper and Stephenson find cost savings in communications message search-space and frequency-reference improvement and in phase-noise reduction of up to 150 billion dollars. Each savings is small, but their analyses show that that the sum of all the small improvements save billions of dollars in telecommunications costs annually.

5.2 *Optics*

According to a rather controversial theory a superconductor exhibits a large index of refraction for GWs (Li and Torr 1992). Thus optical devices, such as astronomical telescopes (both refracting and reflecting (Baker 2000 and 2004)), communication-link concentrators (Woods 2005), and variable-focus HFGW optical systems (Woods 2006 and 2007) can be designed and utilized in practice. In Baker (2004) the fabrication of a mosaic, high-temperature superconductor (HTSC) lens (a tight mosaic of individual HTSC chips) for a 100-meter diameter, f/0.5, precursor HFGW telescope is discussed. This experimental device would involve lens grinding/polishing considerations, telescope fabrication, and insuring the overall structural integrity. A grasp or gain of $3x10^4$ for the telescope is contemplated over a frequency range from 3 MHz to THz. The HFGW relic cosmic background or HFRGWs could be imaged by such a HFGW telescope and sensed by recently designed HFGW detectors already discussed in section 3.

5.3 *Surveillance*

The potential for through-earth, or through-water "X-rays" utilizing the extreme sensitivity of HFGW generation-detection systems to polarization angle changes (possibly sensitive to even less than 10^{-40} radians or one billion, billion, billion, billionth of a degree change) can be utilized in order to observe subterranean structures, geological formations (such as oil deposits), create a transparent ocean, view three-dimensional building interiors, buried devices, hidden missiles, weapons of mass destruction, achieve remote acoustical surveillance or eavesdropping, etc. – a full-body scan without radiation danger (Baker 2007). The Laser Interferometer Gravitational Observatory or LIGO and other long-wavelength GW interferometer detectors cannot detect HFGWs due to the HFGW's short wavelengths as discussed by Shawhan (2004). Long-wavelength gravitational waves having thousand and million meter wavelengths, which can be detected by LIGO, are of no practical surveillance value due to their diffraction and resulting poor resolution. It should also be noted that HFGW imaging could, in theory, defeat the recently proposed EM cloaking or stealth techniques (Leohart (2006), Pendry, Schung and Smith (2006) and Sanderson (2007)).

5.4 *Propulsion*

As discussed in the authoritative text by Landau and Lifshitz (1975), on page 349 of their fundamental (and internationally recognized authority on gravitational radiation) treatise, they state: "Since it has definite energy, the gravitational wave is itself the source of some additional gravitational field... its field is a second-order effect ... *But in the case of high-frequency gravitational waves the effect is significantly strengthened...*" Thus it is possible to change the gravitational field near an object by means of HFGWs and move or perturb it. In this way HFGWs might provide a remote means for causing perturbations to the motion of objects such as missiles (anything from bullets to ICBMs), spacecraft, rogue comets or minor planets that are destined to impact Earth, land or water vehicles or craft – a totally new propulsion system! (Fontana 2006)

5.5 *Nuclear Fusion*

If there is an ultra-high intensity HFGW flux impinging on a nucleus, then it is possible to initiate nuclear fusion at a remote location – mass disruption. Also it may be possible to create radioactive waste-free nuclear reactions and energy creation (Fontana, G. and Baker, R. M L, Jr. 2007). The fusion reactions active on stars are driven by gravity, therefore why not consider a similar process built at a much smaller scale? A heritage of thousands of theoretical results from the field of General Relativity are waiting for clever engineering applications, and among them some can be selected for demonstrating that fusion reactors can be constructed according to new principles. For instance non-linear effects related to HFGWs can be applied to "Gravity Induced Fusion" (GIF). Metric changes at the atomic scale can emulate the muonic fusion process without the need for muons, therefore the process can be described with known theories and supporting experiments. All the difficulty is then transferred to the technical difficulty of building a suitable generator of HFGWs.

6. **LIGO**

LIGO, which is the inspiration for HFGW research, advertises a detection frequency range for gravitational waves (GWs) of 40 Hz to 2000 Hz (Shawhan

2004, p. 356). The problem with higher frequencies is the inability of LIGO to "observe" the interference pattern between the LIGO legs caused by the passage of a GW. From the referenced article (Shawhan 2004, p. 356): "At higher frequencies, the quantum nature of the laser beam (made of discrete photons, albeit a large number of them) limits the precision of the measurement. Increased laser power would reduce the problem of quantum noise, but ultimately the LIGO (and other) interferometers (such as the Advanced LIGO, GEO600, Virgo and the proposed Laser Interferometer Space Antenna or LISA) are not suited to measuring gravitational waves that stretch or shrink the arms much more rapidly than the time a photon typically remains in the optical cavity, which is roughly a millisecond for these interferometers (thus a one kilocycle frequency upper limit)." That's why it is necessary to turn to the *Birmingham University*, England; the *INFN Genoa*, Italy; the *Chongqing University*, China, or other specifically HFGW detectors. There has been some research accomplished with LIGO in the 51 Hz to 150 Hz range, in search of the stochastic GW background (Abbott *et al.* 2007), but no published research at much higher frequencies.

7. **References**

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Sources of HFGWs

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