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UTILIZATION OF HIGH-FREQUENCY GRAVITATIONAL WAVES FOR AEROSPACE SYSTEMS AND TECHNOLOGY*

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by

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The predictions in this document of benefits of high-frequency gravitational wave-based Aerospace applications are theoretical at this time. Evidence of their success is contingent upon laboratory experiments in their generation and detection. Nonetheless, given their potential vital aerospace, strategic military and economic importance, I believe that these possible applications are important motivations for research and development.— Robert M L Baker, Jr.

Abstract

High-Frequency Gravitational Wave (HFGW) technology has been reported in well over one-hundred peer-reviewed scientific journal articles over the past five decades. For several years the Peoples Republic of China has funded HFGW research programs involving dozens of their scientists and well-known Russian scientists have been involved in HFGW research for over four decades. Theoretical aerospace, military and civilian applications are communications, surveillance, remote initiation of nuclear events and propulsion, including “moving” space objects and missiles in flight and frustrating anti-missile and anti-satellite systems. This paper presents the historical and theoretical background for the utilization of High-Frequency Gravitational Waves (HFGWs) as an enabling technology for aerospace systems and presents analytical techniques and theoretical quantitative results for the generation, detection and application of HFGWs.

EXECUTIVE SUMMARY

● High-Frequency Gravitational Wave (HFGW) technology has been reported in well over one-hundred peer-reviewed scientific journal articles over the past five decades and is a space-related enabling technology.

● For several years the Peoples Republic of China has funded HFGW research programs involving dozens of their scientists (please see http://www.gravwave.com/docs/Chinese%20Detector%20Research%20Team.pdf) and well-known Russian scientists have been involved in HFGW research for over four decades.

● Technology developed by GravWave® LLC, Transportation Sciences Corporation and other institutions overseas can lead to devices, some already constructed overseas, that can generate and detect HFGWs in the laboratory.

● Low-Frequency Gravitational Waves (LFGWs), having wavelengths many kilometers in length, have none of the practical applications that HFGWs have due to their long wavelengths and, furthermore, interferometric detectors of LFGWs, such as LIGO, Virgo, GEO600 and the proposed LISA, cannot detect HFGWs as discussed in http://www.drrobertbaker.com/docs/Why%20LIGO%20can%27t%20detect%20HFGWs.pdf .

● Gravitational waves have a very low cross section for absorption by normal matter, so HFGWs could, in principle, carry significant information content with effectively no absorption, unlike electromagnetic (EM) waves.

● Because of their unique characteristics, HFGWs could be utilized for uninterruptible, very low-probability-of-intercept (LPI) communications.

● Other potential very theoretical military and commercial aerospace applications are propulsion, including "moving" space objects and missiles in flight, frustrating anti-missile and anti-satellite systems, surveillance through buildings and the Earth itself, and remote initiation of nuclear events.

● The important potential military and commercial aerospace applications of this enabling technology are motivations for research and development and such an R&D program in the United States is recommended for immediate initiation.

Preface:

The following Paper is divided into four parts: Benefits to the Aerospace Technology, Threats to National Security, Physics and Plan for Developing a Working Prototype. It is important to recognize from the outset that, possibly aside from communications, the applications are theoretical. These applications can only be evaluated *after* the Proof-of-Concept Experiment, since prior to that there are many unanswerable questions. The physics, discussed in Section 3, however is sound and all applications have reasonable expectations. It should also be recognized that there have been some five decades of research concerning high-frequency gravitational waves (HFGWs)—most of them in the form of peer-reviewed publications in the open scientific literature. Much of the prior research is described in the section concerning Physics and several dozen references are cited at the conclusion of this paper. Although most of the theoretical applications are stunning, the field of HFGW research is far from being science fiction. The plausibility of the theoretical applications cannot be adequately determined until after the recommended proof-of-concept test is successfully completed.

What are high-frequency gravitational waves or HFGWs?

Visualize the luffing of a sail as a sailboat comes about or tacks. The waves in the sail's fabric are similar in many ways to gravitational waves, but instead of sailcloth fabric, gravitational waves move through a "fabric" of space. Einstein called this fabric the "space-time continuum" in his 1915 work known as General Relativity (GR). Although his theory is very sophisticated, the concept is relatively simple. This fabric is four-dimensional: it has the three usual dimensions of space—east-west, north-south, and up-down—plus the fourth dimension of time. Here is an example: we define a location on this "fabric" as 5th Street and Third Avenue on the forth floor at 9 AM. We can't see this "fabric," just as we can't see wind, sound, or gravity for that matter. Nevertheless, those elements are real, and so is this "fabric." If we could generate ripples in this space-time fabric as Einstein predicted (1916), then many practical applications of HFGWs would become available to us. Much like radio waves can be used to transmit information through space, we could use gravitational waves to perform analogous functions. A more complete layperson's description of gravitational waves can be found at http://www.gravwave.com/docs/Layperson'%20s%20Discription%20of%20HFGWs%20Plus%20A.pdf . Gravitational waves are the subject of extensive current research, which so far has focused on low frequencies. High-frequency gravitational waves, as defined by physicists Douglass and Braginsky (1979), are gravitational waves having frequencies higher than 100 kHz. Although Gravitational Waves (GWs) are ordinarily very weak, theoretically they can be generated and detected in the laboratory and that possibility is the motivation for this analysis of their possible aerospace application.

1.0 Benefits to Aerospace Technology

1.1 Communications

1.1.1 Executive Level

Of the applications of high-frequency gravitational waves (HFGWs), communication appears to be the most important and most immediate. Although detectable, gravitational waves have a very low cross section for absorption by normal matter, so high-frequency waves could, in principle, carry significant information content with effectively no absorption, unlike electromagnetic (EM) 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 Moscow in Russia to Caracas in Venezuela—without the need for fiber optic cables, microwave relays, or satellite transponders, as noted in Fig. 1.1.1. Antennas, cables, and phone lines would be things of the past. A timing standard alone, provided by satellite HFGW stations around the globe, could result in a multi-billion dollar savings in conventional telecom systems over ten years, according to the analysis of Harper and Stephenson (2007). The communication and navigation needs of future magnetohydrodynamic (MHD) aerospace vehicles, such as the MHD aerodyne (www.mhdprospects.com), which is high in electromagnetic interference, similar to plasma interference seen at reentry, would be another possible applications area for HFGW communications.

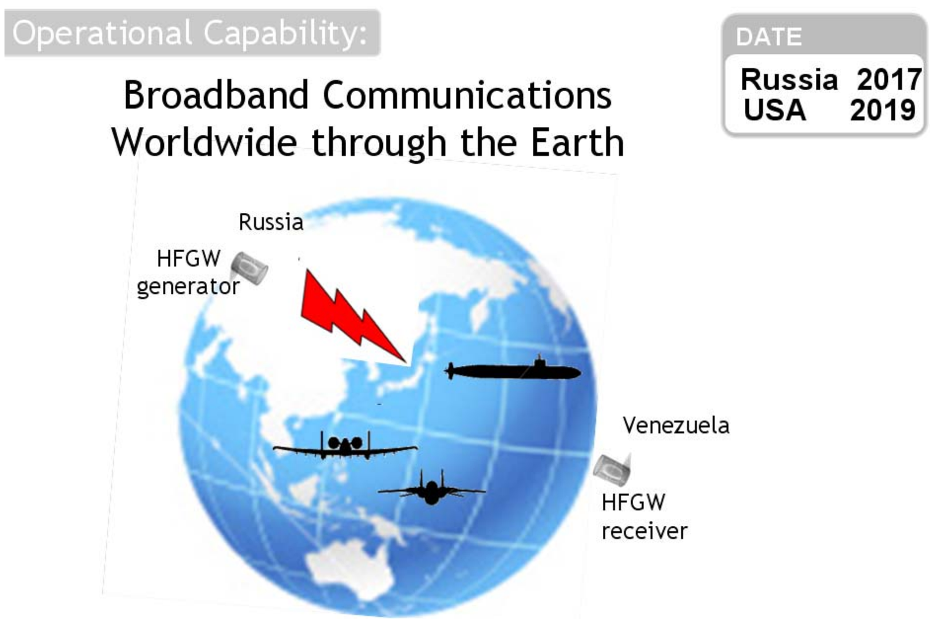


Figure 1.1.1. Broadband Global HFGW Communication
[*Operational capability predictions are based on very rough estimates by the author from conversations and impressions gained during four international HFGW Workshops (MITRE2003, Austin 2007, Huntsville 2009 and Johns Hopkins 2010) and trips to China in 2004, 2006 and 2008 and to Europe (2002 and 2009) and the Middle East in 2009.*]

1.1.2 More Detail

A detailed discussion of high-frequency gravitational wave communications can be found at http://www.gravwave.com/docs/com%20study%20composite%20.pdf. As far as receivers for the communications system are concerned, as discussed in he subsections of Section 3.0, three such detectors have been built outside the United States. In England the HFGWs are detected by the change in polarization they produce in a microwave-guide loop and this effect is utilized in the *Birmingham University* HFGW Detector (Cruise and Ingley, 2005); in Italy by a pair of coupled harmonic oscillators is utilized for HFGW detection (Chincarini and Gemme, 2003) and at the *National Astronomical Observatory of Japan* HFGW detection is achieved by synchronous interferometers (Nishizawa et al. 2008). A theoretically more sensitive HFGW detector utilizes detection photons generated from electromagnetic beams having the same frequency, direction and phase as the HFGWs in a superimposed magnetic field, the Li-Baker HFGW Detector (Baker, Stephenson and Li, 2008; Li et al., 2008; Li et al. 2009). The Li-Baker HFGW Detector will be selected for analysis of the communications system because of its theoretically greater sensitivity. There are a number of alternative devices theorized to generate HFGWs in the laboratory (HFGW transmitters) such as: the Russians: Grishchuk and Sazhin (1974), Braginsky and Rudenko (1978), Rudenko (2003), Kolosnitsyn and Rudenko (2007); the Germans: Romero and Dehnen (1981) and Dehnen and Romero (2003); the Italians: Pinto and Rotoli (1988), Fontana (2004); Fontana and Baker (2006); the Chinese: Baker, Li and Li (2006). The HFGW generation device or transmitter alternative selected is based upon bands of piezoelectric-crystal, film-bulk acoustic resonators or FBARs (Baker, Woods and Li, 2006) since they are readily available "off the shelf."

Gertsenshtein (1962) established theoretically that an electromagnetic (EM) wave in the presence of a magnetic field would generate a gravitational wave (GW) and also hypothesized an "inverse Gertsenshtein effect," in which GWs generate EM photons. Such photons are a second-order effect and according to Eq. (7) of Li, et al. (2009) the number of EM photons are "…proportional to the amplitude squared of the relic HFGWs …" and that it would be necessary to accumulate such EM photons for at least 1.4×10^{16} seconds in order to achieve relic HFGW, from the Big Bang, detection (Li et al., 2009). A **different effect** was suggested theoretically by Li, Tang and Zhao (1992) in which EM photons having the same frequency and direction as the GWs and suitable phase matching as the GWs, interact directly with GWs in a magnetic field and produce "detection" EM photons that signal the presence of relic HFGWs. In the case of this Li theory the number of EM photons is proportional to the amplitude of the relic HFGWs, $A \approx 10^{-30}$, not the square, so that it would be necessary to accumulate such EM photons for only about 1000 seconds in order to achieve relic HFGW detection (Li et al., 2008). Based on the Li theory, as validated by eight journal articles independently peer reviewed by scientists well versed in general relativity (Li, Tang and Zhao 1992; Li and Tang 1997, Li, Tang, Luo 2000; Li, Tang and Shi 2003; Li, Wu and Zhang 2003, Li and Yang 2004; 2009; Li and Baker 2007) including capstone papers: Li et al. (2008) and Li et al. (2009), Baker developed a detection device (2001), the Li-Baker HFGW detector (Baker, 2006; Baker, Stephenson and Li, 2008). **The JASON report (Eardley, 2008) confuses the two effects and erroneously suggests that the Li-Baker HFGW Detector utilizes the inverse Gertsenshtein effect. It does not and does have a sensitivity that is about $A/A^2 = 10^{30}$ greater than that incorrectly assumed in the JASON report.**

An estimate of the range that a HFGW transglobal communication system might achieve, after a laboratory proof-of-concept test is successfully completed, based on a technical paper by Baker and Black (2009):
http://www.drrobertbaker.com/docs/Analyses%20of%20HFGW%20Generators%20and%20Radiation%20Pattern.pdf), is as follows:

The generation of HFGWs in the laboratory or the HFGW transmitter is based upon the well-known astrodynamic gravitational-wave generation process (Landau and Lifshitz (1975)). In Fig.1.1.2 is shown the gravitational wave (GW) radiation pattern for orbiting masses in a single orbit plane where $\mathbf{f}_{cf}$ is the centrifugal force and $\Delta \mathbf{f}_{cf}$ is the change in centrifugal force, acting in opposite directions, at masses **A** and **B**.. Next consider a number *N* of such orbit planes stacked one on top of another again with the gravitational-wave (GW) radiation flux (Wm^{-2}) growing as the GW moves up the axis of the *N* orbit planes as in Fig. 1.1.3 . We now replace the stack of orbital planes by a stack of *N* HFGW-generation elements.

These elements could be pairs of laser targets (Baker, Li and Li, 2006), gas molecules (Woods and Baker, 2009), piezoelectric crystal pairs (Romero-Borja and Dehnen, 1981; Dehnen and Romero-Borja, 2003) or film-bulk acoustic resonator (FBAR) pairs, which also are composed of piezoelectric crystals (Woods and Baker, 2005). Since they can be obtained "off the shelf" we select the FBAR alternative. Thus we now have a HFGW wave moving up the centerline of the FBAR-pair tracks, as shown in Fig. 1 of Baker (2009). Note that FBARs are ubiquitous and are utilized in cell phones, radios and other commonly used electronic devices and that they can be energized by conventional Magnetrons found in Microwave Ovens.

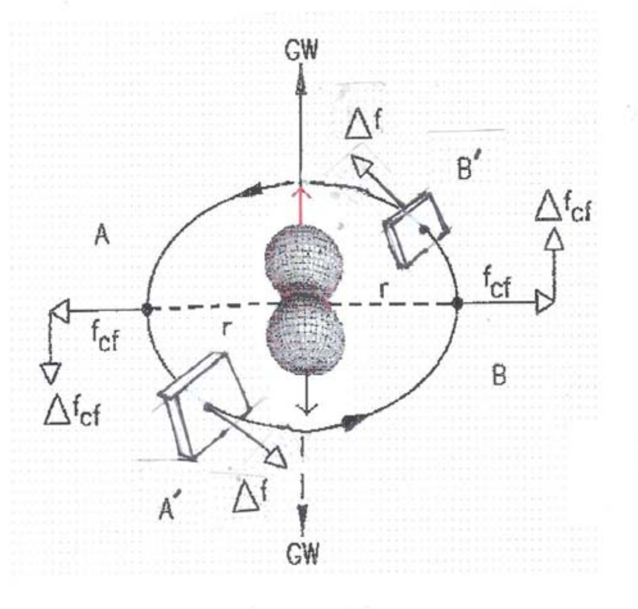


Figure 1.1.2. Radiation pattern calculated by Landau and Lifshitz (1975) Section 110, Page 356.

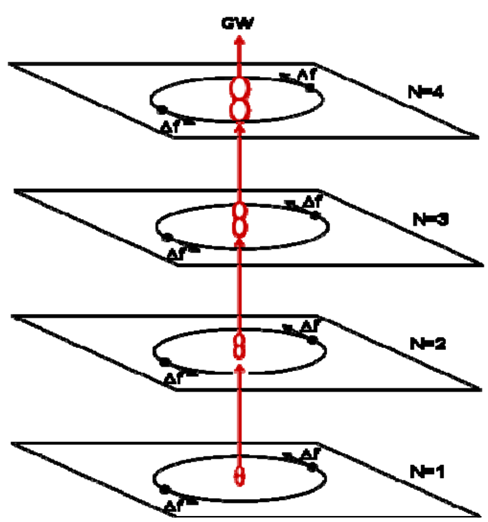


Figure 1.1.3. GW Flux Growth Analogous to Stack of *N* Orbital Planes

The HFGW flux, Wm^{-2}, or signal increases in proportion to the square of the number HFGW-generation elements, N that is "Superradiance" (Scully and Svidzinsky, 2009). The N^2 build up is attributed to two effects: one N from there being N HFGW power sources or generation elements and the other N from the narrowing of the beam so that the HFGW is more concentrated and the flux (Wm^{-2}) thereby increased (Romero-Borja and Dehnen, 1981; Dehnen and Romero-Borja*,* 2003). Note that it is not necessary to have the FBAR tracks perfectly aligned (that is the FBARs *exactly* across from each other) since it is only necessary that the energizing wave front (from Magnetrons in the case of the FBARs as in Baker, Woods and Li (2006)) reaches a couple of nearly opposite FBARs at the same time. The HFGW beam is very narrow, usually less than 10^{-4} radians (Baker and Black, 2009) and increasing N narrows the beam. Additionally multiple HFGW carrier frequencies can be used, so the signal is very difficult to intercept by US military adversaries, and is therefore useful as a low-probability-of-intercept (LPI) signal, even with widespread adoption of the technology.

The force change, $\mathbf{\Delta f}$, produced by a single off-the-shelf FBAR is 2 N (for $1.8x10^8$ FBARS the force change is $4x10^8$ N or about 2 N per FBAR according to Woods and Baker (2005) and proportional to $\sqrt{Q}$). The basic equation for the GW power produced by a change in force pair such as FBARs, P, as derived in Baker (2006), and discussed in the Section 3.3.1 on Physics, is:

$$P = 1.76x10^{-52}\,(2r\,\Delta f/\Delta t)^2 \quad W, \tag{1.1.1}$$

where 2 r is the distance between the FBAR pair, m, $\Delta f = |\mathbf{\Delta f}|$ is the force change, N and Δt is the time over which the force change occurs, s or the inverse of the HFGW frequency, $1/\nu_{GW}$. As can be seen from Fig. 1.1.2 the fixed (not orbiting) FBARs are faced (i.e., the normal to their flat surface in the $\mathbf{\Delta f}$ direction) tangent to the circle at **A'** and **B'**. From p.1282 of Baker, Woods and Li (2006) in plan form the flat FBAR surface is 100μm x100μm and they are about 1 μm thick. To allow for margins we will take the FBAR dimensions overall as $110x110x2\ \mu m^3$. Let nFBARs be spread out radially like a vane on ribbons of a double helix section of Fig. 1.1.4. Thus $\Delta f = 2nxN$. If n = 1000, then the radial extent of the FBARs vane would be 11 cm. For r = 1m, Δf = 2000 N and ν_{GW} = 4.9 GHz, the HFGW power generated by the i^{th} FBAR vane pair is $P_i = 6.76x10^{-26}$ W. Note that $2r$ = 2 m is greater than the HFGW wavelength λ_{GW} = 6.1 cm. Nevertheless, according to page 1283 of Baker, Woods and Li (2006) Eq. (1.1.1) is still valid. From Eq. (6) and Table 2 (for 10^0 half angle at N =1) of Baker and Black (2009) we have for the signal, $S(1.0)$, or flux, F(1.0), at one meter from the end of an array of N FBAR vane pairs

$$S(1.0) = F(1.0) = N^2 F(1.0)_{N=1} = N^2\,(0.336)\,P_i \quad . \tag{1.1.2}$$

Let us place the FBAR vane pairs adjacent to each other so there will be $2\pi r/2\mu = 3.14x10^6$ vane pairs on each 110 μm thick level leading up a cylindrical double-helix FBAR array (US Patents 6,417,597 and 6,784,591 and Patents Pending). We "stack" these 110 μ thick levels one on top of the other in a *double helix configuration* (Baker and Black, 2009; Patent Pending) as shown in Fig. 1.1.4 in order to increase N and narrow the beam. There will be 10m/110 μm = $9.1x10^4$ levels so that $N = 2.9x10^{11}$. Thus, from Eqs. (1.1.1) and (1.1.2), we have $S = 1.9x10^{-3}\ Wm^{-2}$ at a one meter distance or if we were at a $1.3x10^7$ m (diameter of Earth) distance, then $S = 1.12x10^{-17}\ Wm^{-2}$. From Eq. (1.1.1), derived in the Appendix of Baker, Stephenson and Li (2008), the amplitude A of the HFGW is given by:

$$A = 1.28x10^{-18}\,\sqrt{S}/\nu_{GW} \quad m/m, \tag{1.1.3}$$

so that $A = 0.88x10^{-36}$ m/m. The sensitivity of the Li-Baker HFGW detector is on the order of 10^{-32} m/m, but its sensitivity can be increased dramatically (Li and Baker, 2007) by introducing superconductor resonance chambers into the interaction volume (which also improves the Standard Quantum Limit; Stephenson, 2009) and two others between the interaction volume and the two microwave receivers (see section 3.6.2 on the Li-effect). Together they provide an increase in sensitivity of five orders of magnitude and result in a sensitivity of the Li-Baker detector to HFGWs having amplitudes of 10^{-37} m/m. Since the exact frequency and phase of the HFGW signal is known (unlike big-bang relic HFGWs, for which the Li-

Baker detector was designed (as shown in Slide #6 from Grishchuk (2007) that exhibits the 10 GHz peak in relic HFGW energy density), a much more sensitive, optimized HFGW detector will likely be developed. Such a sensitive detector will still not be quantum limited (Stephenson, 2009). The power required at 2x56 mW per FBAR pair (Woods and Baker, 2005) would be about $2 x n x N x 56 x 10^{-3} = 3.2 x 10^{13}$ W. There are two approaches to reduce the average power to, say 32 MW for a conventional commercial substation: first, one could utilize nanotechnology and increase the output flux of the generator by "slicing" each FBAR into a thousand parts. As discussed in Baker (2009) the total power would remain the same, but the output flux would be increased by N^2. Thus one could maintain the same flux of $1.12x10^{-3}$ Wm^{-2} but with $1/N^2$ or 10^{-6} of the required power or 32 MW. Second, one could communicate with one microsecond bursts every second (roughly a 4.9 kHz information bandwidth). One would still need about 32 thousand off-the-shelf Microwave-Oven-type, in-phase, one kW Magnetrons distributed along the double-helix cylinder walls. The Magnetron would be angled up along the direction of the HFGW beam in the double helix and produce about a kilowatt of average power, but for the second, burst case, with MW burst capability. The frequency-standard optimized FBARs would be replaced by Δf-optimized ones. In fact, since according to Eq. (8) of Woods and Baker (2005) the FBAR force is proportional to the square root of the quality factor, Q, and the 2 N force was based upon a $Q = 100$ and according to Nguyen (2007) the Q can be raised to $\approx 10^7$, the force would increase 300 fold, the HFGW flux 100,000 fold and the HFGW amplitude A, would also increase 300 fold. The very speculative use of superconductor GW lenses (US Patent 6,784,591) and mirrors (such mirrors suggested by Baker (2003; 2004), Woods (2006a; 2006b), Chiao, et al. (2009) and Minter, et al. (2009), *but in a concave parabolic mosaic form* (Baker, 2003 and 2005)) would serve to further concentrate the HFGWs and increase their amplitude A at the detector/receiver and greatly improve the information bandwidth. For more details on HFGW Communication, please visit http://www.gravwave.com/docs/com%20study%20composite%20.pdf

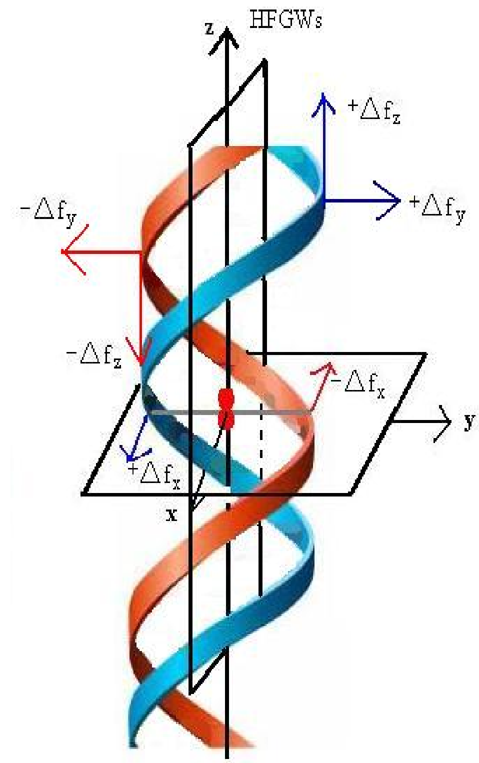


Figure 1.1.4. Double Helix Configuration of FBAR Pairs (Patent Pending)

1.2 Advanced Applications and Benefits (very theoretical; most answers must await a "Bell-Watson" proof-of-concept experiment)

1.2.1 "Bell-Watson" Proof-of-Concept Experiment
(March 10, 1876, on the occasion of their first successful telephone experiment: Alexander Graham Bell to Thomas A. Watson: "Mr. Watson -- come here!")

1.2.1.1 Executive Level

The Aerospace applications of HFGWs, especially the theoretical ones to be described next, depend on data obtained from a successful proof-of-concept test. This test will involve an HFGW generator (for this initial test, it will be the Magnetron/FBAR design utilizing parallel tracks of FBARs) sending a message to a Li-Baker HFGW Detector or receiver, to be described later. The approach is the same as that used by Alexander Graham Bell in sending a message to Thomas A. Watson. Thus we call it the *Bell-Watson Proof-of-Concept Experiment* (March 10, 1876, on the occasion of their first successful telephone experiment. Alexander Graham Bell to Thomas A. Watson: "Mr. Watson -- come here!"). Such a piezoelectric HFGW generation means was first suggested by Romero and Dehnen (1981) based upon General Relativity or GR theory.

1.2.1.2 More Detail

Section 4.0 is devoted to the plan for developing working prototypes of the HFGW detector and generator, but some of the highlights of the plan will be mentioned here for the proof-of-concept test. The Magnetron/FBAR HFGW generator will be selected for fabrication because it can be constructed from off-the-shelf components. This generator is described in Sections 4.4 and 4.5. To successfully test the HFGW generator, there must be a device available to detect its signal. So the first device to be constructed will be the Li-Baker HFGW Detector (three other candidates for the HFGW detector/receiver have been built by other countries, England, Italy and Japan, and are described in Section 3.6.3 ; but the Li-Baker Detector should be far more sensitive). Since relic HFGWs exist in the frequency range of the Li-Baker detector (5 to 10 GHz; as noted in Fig. 4 of Grishchuk 2008), proof of its ability to detect HFGWs will be based on its ability to detect these naturally occurring relic HFGWs from the Big Bang. The Li-Baker Detector is described in Section 3.6.

1.2.2 Surveillance

1.2.2.1 Executive Level

The potential for through-earth or through-water "X-ray like" surveillance utilizing the extreme sensitivity of HFGW generation-detection systems to polarization angle *changes* (possibly sensitive to even less than 10^{-4} radians) might allow for observing subterranean structures and geological formations (such as oil deposits), creating a transparent ocean; viewing three-dimensional building interiors, buried devices, hidden missiles and weapons of mass destruction, achieving remote acoustical surveillance or eavesdropping, etc., or even a full-body scan without radiation danger (Baker 2007a). Please see Fig. 1.2.2.1. Note that it is *not* necessary to *measure* the polarization, as assumed in Eardley (2008), only to *sense a difference.* Thus, 10^{80} gravitons, as stated by Eardley (2008), would never be required*.* Either way, an experiment will lend more light on the subject than speculations. The Laser Interferometer Gravitational Observatory (LIGO) and other long-wavelength GW interferometer detectors (such as GEO 600, Virgo, TAMA, Advanced LIGO and the planned Laser Interferometer Space Antenna, or LISA) cannot detect HFGWs due to the HFGW's short wavelengths, as discussed by Shawhan (2004). Long-wavelength gravitational waves have thousand- to million-meter wavelengths, which can be detected by LIGO (LIGO is frequency limited to signals below 2,000 Hz and wavelengths longer than 150 km), but these are of no practical surveillance (or communications) value, due to their diffraction and resulting poor resolution. Furthermore the LIGO technology is completely different from the detection method and noise suppression suggested here. (An analogy is that microwave engineers do not generally work closely with extra-low-frequency and audio engineers because the technologies and methodologies are too widely divergent.) 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) if these techniques are ever practically applied. It will not be possible to prove or absolutely disprove the potential for this very theoretical HFGW surveillance application until after the "Bell-Watson" experimental results are analyzed, with various material placed between the HFGW generator and detector.

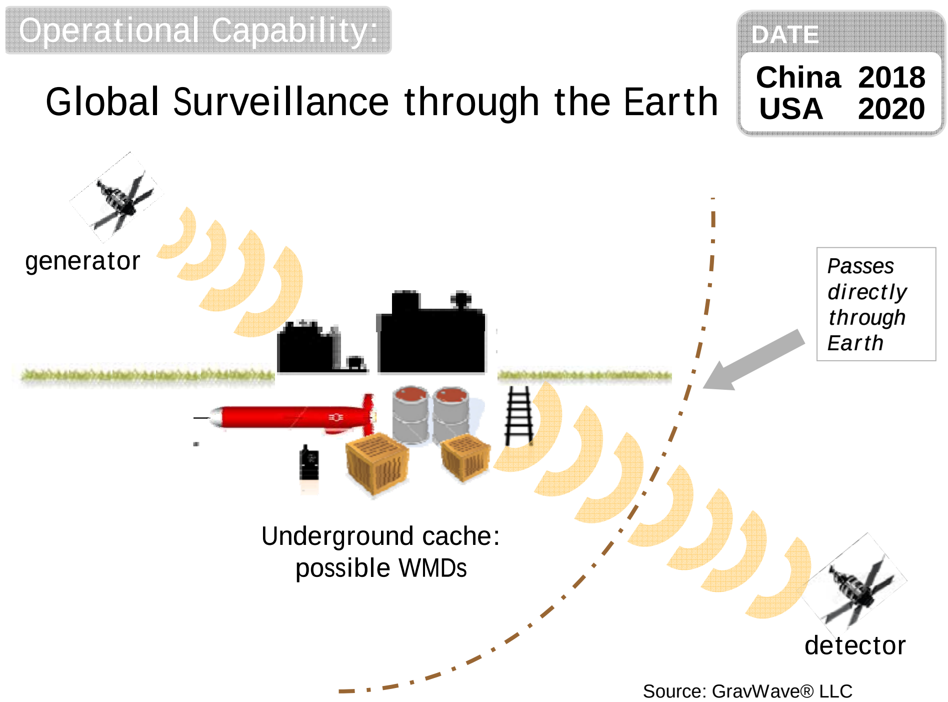


Figure 1.2.2.1. HFGW Surveillance
[*Operational capability predictions are based on very rough estimates by the author from conversations and impressions gained during four international HFGW Workshops (MITRE2003, Austin 2007, Huntsville 2009 and Johns Hopkins 2010) and trips to China in 2004, 2006 and 2008 and to Europe (2002 and 2009) and the Middle East in 2009.*]

1.2.2.2 More Detail

As previously stated gravitational waves, including HFGWs, pass through most material with little or no attenuation; but although they are not absorbed, their polarization, phase, velocity (causing refraction or bending of gravitational rays), backscatter, and/or other characteristics can be modified by a material object's texture and internal structure. For example, the change in polarization of a GW passing through a material object is discussed in Misner, Thorne and Wheeler (1973): "In the real universe there are spacetime curvatures due not only to the energy of gravitational waves, but also more importantly to the material [objects and structures] content of the universe ... its wavelength changes [based on gravitational red shift] and [the gravitational wave] backscatters off the curvature to some extent. If the wave is a pulse, then the backscatter will (change) its shape and polarization...." It is extremely difficult to theoretically establish the actual magnitude of the changes, especially at very high frequencies (10^9 Hz and higher) and to quantify them prior to the proof-of-concept HFGW generation/detection laboratory experiments.

1.2.3 Remote HFGW-Induced Nuclear Fusion

1.2.3.1 Executive Level

If an ultra-high-intensity HFGW flux impinges on a nucleus, it is possible that it could initiate nuclear fusion at a remote location, or "mass disruption." Also it may be possible to create radioactive waste-free nuclear reactions and energy reactions (Fontana. and Baker, 2007). The fusion reactions active on stars are driven by gravity, so why not consider a similar process built at a much smaller scale? 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-catalyzed fusion process without the need for muons (the muon is basically a heavy electron, about 200 times the mass of an electron, and, like an electron, is also a fundamental, point-like particle, as far as present day experimental measurements can tell, and has an electric charge identical to that of an electron). So an HFGW-based GIF process can be described with known theories and supporting experiments. The technical difficulty here reduces to that of building a suitable HFGW generator having an exceedingly high flux – a flux that might be concentrated by the very theoretical, but still possible, superconductivity-based HFGW optics (Woods, 2005; Woods, 2006a; Woods, 2006b). As with the other very theoretical applications of HFGWs, experimental data must be collected, especially at high frequencies of more than 10^9 Hz. Theory, no matter how carefully conceived, will not be able to either prove or completely disprove the remote nuclear event application.

1.2.3.2 More Detail

Nuclear fusion is a process in which separate nuclei with a total initial mass combine to produce a single nucleus with a final mass less than the total initial mass. Below a given atomic number, the process is exothermic; that is, since the final mass is less than the combined initial mass, the mass deficit is converted into energy by the nuclear fusion. On Earth, nuclear fusion does not happen spontaneously because electrostatic barriers prevent the phenomenon. To induce controlled, industrial-scale nuclear fusion, only a few methods have been discovered that look promising, but net positive energy production is not yet possible because of low overall efficiency of the systems.

In Fontana and Baker (2007), it is proposed that an intense burst of HFGWs could be focused or beamed to a target mass composed of appropriate fuel or target material to efficiently rearrange the atomic or nuclear structure of the target material, with consequent nuclear fusion. Provided that efficient generation of HFGW can be technically achieved, the proposed fusion reactor might ultimately become a viable solution for the energy needs of mankind and alternatively, a process for beaming HFGW energy to produce a source of fusion energy remotely, even inside solid materials. The goal of the proposed technology is simple: to reduce the distance between the nucleus and the associated electron of a suitable hydrogen isotope (typically deuterium) by a factor of 200. With such a squeezed hydrogen nucleus, experiments by Cohen (1989) with muonic hydrogen molecules show that fusion can take place on a picosecond time scale.

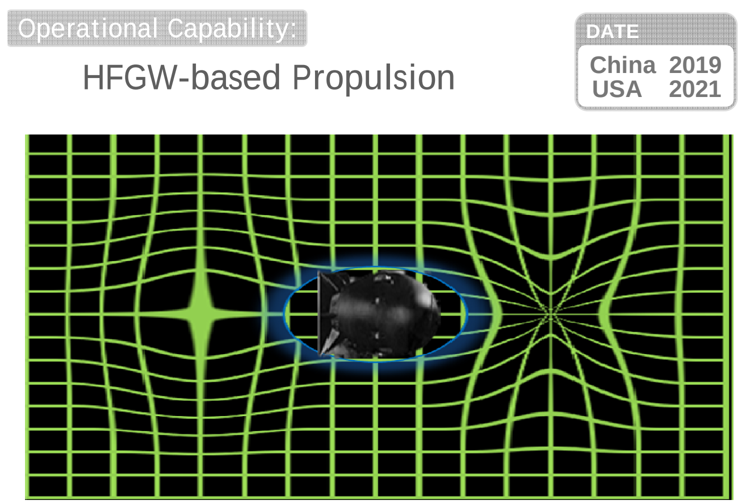
As pointed out by Fontana and Baker (2007) "At high amplitudes, gravitational radiation is nonlinear, thus we might expect a departure from geometric optics. Fortunately, the problem has been already theoretically examined and the resulting effects are found to be advantageous. Nonlinearity improves the focusing process and the GW amplitude, *A,* goes to one in finite time, producing a singularity "regardless" of the starting, non-focused amplitude of the impinging gravitational wave (Corkill and Stewart, 1983; Ferrari, 1988a; Ferrari 1988b; Ferrari, Pendenza and Veneziano, 1988; Veneziano, 1987; Szekeres, 1992). The effect of a $\Delta A = 0.995$ pulse of HFGWs on the couple formed by a deuterium nucleus and its electron is the reduction of their relative distance by a factor of 200. If this distance reduction is effective for a few picoseconds, then the two nuclei of a deuterium molecule can fuse and give a He atom plus energy, which is the usual nuclear-fusion process in a star."

This concept should be considered after a successful "Bell-Watson" experiment and after subsequent very-high-frequency experiments with a very-high-flux HFGW generator are successfully accomplished. Until such an experiment such an HFGW application must be viewed with great skepticism.

1.2.4 Propulsion or Remote Displacement of Masses

1.2.4.1 Executive Level

HFGWs could theoretically be used for the remote displacement of masses or propulsion (Patent Applied for, Baker, 2007b) and control of the motion of objects such as missiles, missile warheads (please see Fig. 1.2.4.1), anti-ballistic missile and anti-satellite payloads, spacecraft and asteroids, and remote control of clouds of hazardous vapors. Gravitational field changes, suggested originally by two famous Russian GR experts (Landau and Lifshitz, 1975), caused by one or more HFGW generators could urge a spacecraft in a given direction, causing a lower static gravitational field in front of a vehicle (it "falls" forward) and a higher one behind (providing a "push"). The concept is that the mass essentially "rolls" down a "hill" produced by the static g-field; that is, potential energy increase of a mass is provided by the energetic HFGWs. In the 1970s and 1980s the Russians reported research on the generation of such HFGWs (e.g., Grishchuk and Sazhin, 1974; Grishchuk, 1977; Braginsky and Rudenko, 1978), but their efforts were terminated at the end of the Cold War. The magnitude of the static g-field is proportional to the square of the HFGW frequency (according to Landau and Lifshitz, 1975) and is described in Baker (2007b). Tests with 10^9 Hz or higher gravitational waves must be accomplished before the application is either discarded or accepted.



Source: GravWave® LLC

Figure 1.2.4.1 Missile warhead moved by HFGWs (Landau and Lifshitz (1975)) . [*Operational capability predictions are based on very rough estimates by the author from conversations and impressions gained during four international HFGW Workshops (MITRE2003, Austin 2007, Huntsville 2009 and Johns Hopkins 2010) and trips to China in 2004, 2006 and 2008 and to Europe (2002 and 2009) and the Middle East in 2009.*]

1.2.4.2 More Detail

Quote from section 108, page 349 of the authoritative Landau and Lifshitz (1975) textbook:

"Since it has definite energy, the gravitational wave is itself is the source of some additional gravitational field (static g-field). Like the energy producing it, this field is a second-order effect in the h_{ik}. **But in the case of high-frequency gravitational waves the effect is significantly strengthened**: the fact that the pseudotensor t^{ik} is quadratic in the derivatives of the h_{ik} introduces the large factor λ^{-2}. In such a case we may say that the wave itself produces the background field (static g-field) on which it propagates. This [static g] field is conveniently treated by carrying out the averaging described above over regions of four-space with dimensions large compared to λ. Such an averaging smooths out the short-wave "ripple" and leaves the slowly varying background metric (static g-field)." (Brackets and boldface type added for clarity and emphasis.) Landau and Lifshitz (1975) offer no elaboration of the physics and mathematics that they based their assertion on, but their textbook discussion is certainly developed from their specific analyses or could be derived. In any event, the concept is clear. A judgment on this effect should await experiment.

Quote from Fontana (2004):

"A large literature exists on colliding gravitational waves (Szekeres, 1992; Ferrari, 1988a and 1988b), it has been found that the collision or focusing of gravitational waves produce curvature singularities. These singularities have properties very similar to those of a black hole, an essential and fundamentally simple object, which produces a gravitational field. Gravitational wave propulsion is the application of these theories to space travel. Generators of GWs could be installed directly onboard or remotely to a spacecraft to induce curvature singularities near the spacecraft. As was already mentioned the use of HFGW "… as a source of some additional gravitational field…" at a distance was suggested by L. D. Landau and E. M. Lifshitz (1975). According to GR, spacecraft mass interacts with spacetime curvature, therefore the spacecraft will move towards the singularity. In the Newtonian picture, because of the non-linearity of space, the wave at the focus is converted to a Coulomb-like gravitational field."

Until an experiment provides actual data, we only know theoretically that **the static g-field increases with the square of the HFGW frequency**. Its persistence may be related to the amplitude of the HFGW and its extent is dependent on the extent of HFGW beams. So we would utilize HFGW frequencies equal to or higher than those utilized for HFGW communications, e.g., $\nu_{GW} = 5 \times 10^9\ s^{-1}$ even up to frequencies of $10^{15}\ s^{-1}$ or higher. According to p. 175 of Baker and Makemson (1960) a perturbative derivative of the *vis-viva* equation from celestial mechanics yields

$$2s^{\cdot}s^{\cdot\prime} = \mu a'/a^2 \quad , \qquad (1.2.4.2.1)$$

where $s^{\cdot}$ is the missile's speed, $s^{\cdot\prime}$ is the perturbation in speed or perturbative acceleration, $\mu = 1$ in characteristic units and a' is the perturbation in the trajectory's semi-major axis a. Thus the perturbative change in a due to the g-field change is

$$a' = 2s^{\cdot}s^{\cdot\prime}a^2 \quad . \qquad (1.2.4.2.2)$$

The actual perturbative acceleration would be a result of GR analyses; but a MKS dimensional analysis yields an equation of the form:

$$s^{\cdot\prime} = l_0\, \nu_{GW}^{\,2} \qquad ms^{-2} \qquad (1.2.4.2.3)$$

where l_0 is a parametric length dependent on environmental factors such as local gravity, local gravitational gradient, local density of particulate matter, etc. and would probably be best determined experimentally after the development of an efficient HFGW generator. Dividing $s^{\cdot\prime}$ ms^{-2} by the local gravity g_0, equal to 9.8 ms^{-2} for geocentric orbits and trajectories, yields $s^{\cdot\prime}$ in characteristic astrodynamic units. Of course l_0 may be exceedingly small.

Using the standard astrodynamics equations found, for example, on pages 90 and 91 of Herrick (1971), a computer program (to be found below), yields from a 26.8 to a 2.7 mile perturbative g-field change in missile entry location for 6,200 mile ICBM trajectories (*with 50 to 100 length, 0.1 to 0.01 g-field perturbations* or *perturbative acceleration*). For short-range 1,400 mile trajectories, it yields from a 2.0 to a 0.41 mile perturbative g-field change in missile entry location (*with 25 to 50 mile length, 0.1 to 0.01 g-field perturbations*). Such modest changes would not greatly reduce the damage caused by an enemy's ICBM nuclear strikes, but would frustrate anti-missile systems or defend against, for example, surgical strikes against submerged submarine assets. The computer program, which is meant to be a tool for order-of-magnitude calculation, the parameters of which would come from HFGW experiments, in *True BASIC* follows.

```
Print "This program computes the change in Missile entry location caused by a "
Print "  HFGW-produced g-field change for minimum-velocity trajectories."
REM Refer to pp. 91 and 92 of Herrick (1971)

Print "What is the geocentric angle between launch and entry in degrees?"
Input  delta_v                                                          ! degrees
Let range = 2*PI*3963* delta_v/360                                      ! range in miles
Print "Range in miles =",range
Print "What is the length of the trajectory segment of the g-field change in miles?"
Input g_field_length                                                    ! miles
Print "What is the magnitude of the g-field change at launch in g's ?"
Input g_field                                                           ! g's
Let s_dot_grav = g_field                                                ! perturbative accel.
OPTION ANGLE degrees
Let gamma_sub_zero =  45 – delta_v/4                                    ! degrees
Let e =TAN(gamma_sub_zero)                                              ! eccentricity
Let a = 1/(1+e^2)                                                       ! semi-major axis
Let sdot =  SQR(1-e^2)                                                  ! characteristic units
Let initial_speed = sdot*4.912                                          ! launch speed in mps
Let RA = a*(1+e)
Let HA = 3963*(RA – 1)                                                  ! height in miles
Print "Height in miles at apogee ",HA
OPTION ANGLE radians
Let cos_E_0 =  -e                                                       !  E_0 in radians
Let sine_E_0 = SQR(1-e^2)
Let E_0 = ACOS(cos_E_0)
Let M_0 = E_0 – e*sine_E_0                                              ! mean anomaly
Let n = 0.074367/(a^1.5)                                                ! mean motion
Let travel_time = (2*PI-2*M_0)/n                                        ! minutes
Print "The trajectory travel time in minutes from launch to entry/impact =",  travel_time
Let perturbative_derivative_a = 2*a^2*sdot* s_dot_grav                  ! characteristic units
Let pertubatve_time_interval = g_field_length/ initial_speed            ! seconds
Print "The time the perturbation at launch acts in seconds =", pertubatve_time_interval
Let pertubatve_time_interval = pertubatve_time_interval/(13.447*60)     ! secs per radian
Let delta_a = perturbative_derivative_a *pertubatve_time_interval
Print " delta a change due to launch g-field perturbation =", delta_a   ! earth radii
Let percent_orbit_scale_change = delta_a/a
Let range_change = range* percent_orbit_scale_change
Print "Perturbative g-field change in Missile entry location in miles =", range_change

end
```

With regard to more *conventional* HFGW propulsion, a very well known example of the rocket propulsion effect that can be produced by gravitational waves is that of a star undergoing asymmetric octupole collapse, which achieves a net velocity change of 100 to 300 km/s via the anisotropic emission of gravitational waves (Bekenstein, 1997). Bonnor and Piper (1997) performed a rigorous analysis for their study of gravitational wave rockets. They obtained the gravitational wave rocket equations of motion directly by solving the Einstein general relativistic field equation in a vacuum using the spacetime metric of a photon rocket as a model. The photon fluid stress-energy tensor for the photon rocket model must be cancelled out so that one actually solves the Einstein vacuum field equation $R_{mn} = 0$, because the gravitational waves that propel the rocket are not a physical fluid. Instead, they are ripples in the shape of spacetime that move through the surrounding background spacetime. So Bonner and Piper added new terms within the resulting vacuum field GR equation that cancel out the photon fluid stress-energy tensor in order to arrive at the equations of motion. To carry out their program, they found that a gravitational source looses mass by the emission of quadrupole waves and gains momentum from recoil, when it emits quadrupole and octupole waves. Thus, the terms that they added to the photon rocket metric are those representing quadrupole and octupole gravitational waves. A gravitational wave rocket will perform exactly like a photon rocket (Davis, 2009b). It will have the maximum possible specific impulse with light-speed exhaust velocity because gravitational waves propagate through space at the speed of light. But such rockets also have extremely low thrust, and so would be more applicable for interstellar missions rather than interplanetary missions within our solar system and still probably impractical.

2.0 Threats to National Security

2.1 HFGW Global HFGW Communications

2.1.1 They have, we don't

Any nation that possesses a communication system that is totally secure, high-bandwidth and can propagate directly through the Earth has an economic advantage over nations who do not posses that capability. From a national security viewpoint, they would be able to communicate with little or no possibility of interception. Surprise attacks by enemies of the United States could be planned and executed utilizing such a communications system with impunity.

2.1.2 We have, they don't

The United States would not only have an economic advantage over all other countries, due to less expensive communications (no fiber optic cables, microwave relay stations or satellite transponders required), but would also possess the most secure communications system in the world. Because of our ability to communicate with deeply submerged submarines, an improved very secure undersea anti-ballistic-missile system could be developed to thwart would-be rogue-nation attacks.

2.1.3 We both have

All nations would be on an equal par, but due to their ingenuity, U. S. researchers could exploit the new communications system more rapidly than other countries and perhaps devise a message interception means.

2.2 Very Theoretical Advanced Applications

2.2.1 Surveillance

2.2.1.1 They have, we don't

The advantage of terrorists and other adversaries of the United States would be great. They could completely observe all of our military and commercial assets and, if they mean to physically harm the U.S., they could plan and execute successful attacks on the U.S. and its allies with great confidence.

2.2.1.2 We have, they don't

The United States would be able to observe, identify and accurately locate catches of weapons including weapons of mass destruction anywhere on or under the Earth. Enemy plots could be foiled and any military efforts that the United States made greatly enhanced – the "fog of war" could be lifted! In addition the United States would have a commercial advantage in its ability to remotely observe and locate valuable geological resources such as oil and minerals.

2.2.1.3 We both have

The world would be an "open book" and the possibility of surprise attack greatly reduced, if not eliminated. The world would be a far safer place to live. Even the fight against crime would be greatly enhanced.

2.2.2 Remote HFGW-Induced Nuclear Fusion

2.2.2.1 They have, we don't

The advantage of terrorists and other adversaries of the United States would be enormous! They could employ blackmail and extortion. The means to achieve a suitable defense against HFGW weapons, since they can pass through all materials, would be nearly impossible.

2.2.2.2 We have, they don't

The United States has a history of benevolence and does not start conflicts. Thus, other world powers would not fear the U.S. unless it acted in self defense against those who would harm it. The world would, therefore, be more stable.

2.2.2.3 We both have

Essentially the situation of the "Cold War." Peace would be based on "mutually assured destruction." Use of the technology for a cheap source of energy without radioactive waste would be useful to all nations and improve the global environment.

2.2.3 Propulsion or Remote Displacement of Masses

2.2.3.1 They have, we don't

HFGW propulsion would be useful science and technology no matter what nation possessed the capability. Its application to anti-ballistic-missile defense would, however, limit our ability to retaliate against an aggressor equipped with long-range missiles since our antiballistic missile trajectories could be perturbed and the anti-missile systems rendered ineffective..
.

2.2.3.2 We have, they don't

A missile defense system could be developed to perturb the trajectories of short-range tactical, medium-range, and intercontinental ballistic missiles.

2.2.3.3 We both have

There would be a balance among those nations having the capability. The scientific and technical applications would be enhanced because more talent could be applied worldwide. All nations of the world could participate in exploring the use of HFGW propulsion systems, especially as applied to space travel.

3.0 Physics

3.1 Gravitational Waves

3.1.1 Executive Level

From the Preface of this Paper we repeat: "What are gravitational waves or GWs? Visualize the luffing of a sail as a sailboat comes about or tacks. The waves in the sail's fabric are similar in many ways to gravitational waves, but instead of sailcloth fabric, gravitational waves move through a "fabric" of space. Einstein called this fabric the 'space-time continuum' in his 1916 work known as General Relativity (or GR). Although his theory is very sophisticated, the concept is relatively simple. This fabric is four-dimensional: it has the three usual dimensions of space: (1) east-west, (2) north-south, (3) up-down, plus the dimension of (4) time. Here is an example: we define a location on this 'fabric' as 5th Street and Third Avenue on the forth floor at 9 AM. We can't see this "fabric" just as we can't see the wind, sound, or gravity for that matter. Nevertheless, those elements are real, and so is this 'fabric' If we could generate ripples in this space-time fabric, then many applications become available to us. Much like radio waves can be used to transmit information through space, we could use gravitational waves to perform analogous functions." A more complete layperson's description of gravitational waves can be found at http://www.gravwave.com/docs/Layperson'%20s%20Discription%20of%20HFGWs%20Plus%20A.pdf .

3.1.2 More Detail

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). Einstein (1918) derived the Quadrupole Equation, which is utilized to determine the strength of gravitational waves. A few scientists worked on methods to detect GWs, such as Joseph Weber, but at the time, it was believed by most of the scientific community that these "gravitational waves" were just artifacts of Einstein's GR theory and probably didn't exist in a meaningful form. Then in 1974, two astronomers, Russell Hulse and Joseph Taylor, were studying a radio star pair designated PSR1913+16 at the huge Arecibo radio observatory in Puerto Rico. They observed that the star pair was coalescing (the pulses were received a little sooner than expected) and the energy it was losing during this coalescence was *exactly* as predicted by Einstein. They received the Nobel Prize in 1993 for this discovery, and from then on, the skepticism evaporated and scientists accepted that, due to this indirect evidence, gravitational waves did indeed exist. However, the gravitational waves generated by these star pairs are of very low frequency, only a fraction of a cycle per second to a few cycles per second. So if the stars orbit very tightly around each other with a period of, say, one second (for comparison, the period of our motion around the Sun is one year), the gravitational-wave frequency is 2 Hz. (The gravitational-wave frequency is twice the orbital frequency, based on theoretical analyses.) If black holes spun around each other during the final phase of their coalescence (or "death spiral") in say one fortieth of a second, their frequency would be ($40\ s^{-1}$) x 2 = 80 Hz. The possibility of detecting these low-frequency gravitational waves generated by black hole coalescence motivated the construction of LIGO, Virgo, GEO600 and other such interferometer-based low-frequency gravitational wave (LFGW) detectors

3.2 High-Frequency Gravitational Waves (HFGWs)

3.2.1 Executive Level

HFGWs are gravitational waves with frequencies greater than 100kHz, following the definition of Douglass and Braginsky (1979). The first mention of high-frequency gravitational waves or HFGWs was during a lecture by Forward and Baker (1961), based on a paper concerning the dynamics of gravity (Klemperer and Baker, 1957) and Forward's prior work on the Weber Bar. The first publication concerning HFGWs was in 1962, the Russian theorist M. E. Gertsenshtein's (1962) pioneering paper, "Wave resonance of light and gravitational waves" -- a paper already mentioned in Subsection 1.1.2 to be discussed in Subsection 3.6.1.1 of this Paper.

3.2.2 More Detail (Russian and Chinese HFGW Research)

Halpern and Laurent (1964) 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 discussed "short wavelength" or HFGWs. These gravitational waves are termed High-Frequency Relic Gravitational waves or HFRGWs. In 1968, Richard A. Isaacson of the University of Maryland authored papers concerned with gravitational radiation in the limit of high frequency (Isaacson, 1968). The well-known Russian HFGW researchers L.P. Grishchuk and M.V. Sazhin (1973) published a paper on emission of gravitational waves by an electromagnetic cavity and fellow Russians V.B. Braginsky and Valentin N. Rudenko (1978) wrote about high-frequency gravitational waves and the detection of gravitational radiation. (By the way, both Grishchuk and Rudenko participated in the 2003 MITRE and the 2007 Austin International HFGW Workshops.) Also discussed in the literature are possible mechanisms for generating cosmological or relic HFGWs, including relativistic oscillations of cosmic strings (Vilenkin, 1981), standard inflation (Linde, 1990), and relativistic collisions of newly expanding vacuum bubble walls during phase transitions (Kosowsky and Turner, 1993). The theme of relic or big bang-generated HFGWs (HFRGWs) and its relationship to “String Cosmology” (roughly related to the well-known contemporary string theory) was suggested by G. Veneziano (1990), and later discussed by M. Gasperini and M. Giovannini (1992). HFRGWs were qualitatively analyzed originally by Halpern and Jouvet (1968) and later by Grishchuk (1977, 2007), and since then have emerged as having significant astrophysical and cosmological importance (Beckwith 2008a and 2008b).

This work continues today, especially the research of Leonid Grishchuk and Valentin Rudenko in Russia, Fangyu Li and his HFGW research team in China and is the motivation for HFGW detectors built at *INFN Genoa* (Italy), at *Birmingham University* (England) and at the *National Astronomical Observatory of Japan* (a 100MHz detector) and under development at *Chongqing University* (China). As has been mentioned HFGWs are characterized by an amplitude *A,* which is the relative strain or fractional deformation of the space-time continuum calculated as the length change in meters (caused by the passage of a GW), divided by the original length in meters, so that *A* is dimensionless. As has been emphasized their amplitudes are, however, quite small. Typically for HFRGWs, $A \sim 10^{-32}$ to 10^{-30} (dimensionless units or m/m) for naturally occurring relic HFGW from the Big Bang.

3.3 The Quadrupole

3.3.1 Executive Level

One way we can generate wind waves is by the motion of fan blades. Likewise, gravitational waves (GWs) can theoretically be generated by the motion of masses. The Quadrupole Equation was derived by Einstein in 1918 to determine the power of a generated gravitational wave (GW) due to the motion of masses. Because of symmetry, the quadrupole moment (of Einstein’s quadrupole-approximation equation) can be related to a principal moment of inertia, I, of a mass system and can be approximated by

$$P = -dE/dt \approx -G/5c^5\ (d^3I/dt^3)^2 = 5.5\text{x}10^{-54}\ (d^3I/dt^3)^2 \quad \text{watts.} \tag{3.3.1}$$

In which -dE/dt is the generated power output of the GW source, *P* is in watts, c is the speed of light, G is the universal constant of gravitation, and d^3I/dt^3 is the third time derivative of the moment of inertia of the mass system. The GW power is usually quite small because of the small coefficient multiplier.

3.3.2 More Detail

Alternately, from Eq. (1), p. 90 of Joseph Weber (1964), 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] (please also see, for example, pp. 979 and 980 of Misner, Thorne, and Wheeler (1973), in which I in the kernel of the quadrupole equation and also takes on its classical-physics meaning of an ordinary moment of inertia):

$$P = 32GI^2\,\omega^6\,/5c^5 = G(I\omega^3)^2/5(c/2)^5 \ \text{watts}$$

or

$$P = 1.76\text{x}10^{-52}(I\omega^3)^2 = 1.76\text{x}10^{-52}(r[rm\omega^2]\omega)^2 \ \text{watts} \tag{3.3.2}$$

where $[rm\omega^2]^2$ can be associated with the square of the magnitude of the rod’s centrifugal-force vector, $\mathbf{f_{cf}}$,. for a rod of mass, *m*, and radius of gyration, r. This vector reverses every half period at twice the angular rate of the rod (and a component’s magnitude squared completes one complete period in half the rod’s period). Thus the GW frequency is 2ω. Following Weber’s numerical example (1964) for a one-meter long rod spun so fast as to nearly break apart due to centrifugal force, the radiated GW power is only 10^{-37} watts. *This result often convinces a reader that it is impossible to generate GWs in the laboratory.* **Such is not the case.**

3.4 "Jerk" or "shake"

3.4.1 Executive Level

Let us consider two masses a distance *2r* (in meters) apart that undergo a "jerk" or a "shake," that is, a change in force, $\Delta f = |\mathbf{\Delta f}|$ (in Newtons) over a short time interval, Δt (in seconds). In this case, the Quadrupole Equation is of the form given by Eq. (1.1.1) of this Paper and, originally, by Eq. (4.4) of Baker (2000b) and in the first HFGW Patent (Baker, 2000a):

$$P = 1.76\text{x}10^{-52}\,(2r\,\Delta f\,/\,\Delta t)^2\ \text{watts.} \tag{3.4.1}$$

There are two important conclusions to be drawn from this equation: first, there is a very small multiplier (10^{-52}), so simply moving two masses will result in a very-low-power laboratory-generated gravitational wave. Second, the quantity in the parenthesis is the distance between the two masses, $2r$, multiplied by the jerk or shake, $\Delta f / \Delta t$, and it is squared, so these factors are very significant in determining the generated gravitational-wave power. This formulation of the quadrupole equation (as derived in Baker (2000b) and (2006)) is at the heart of many approaches to laboratory HFGW generation, since the faster the jerks (the smaller the Δt), the *higher* the GW frequency and the greater the GW power. A large force change, Δf is also most valuable and can be achieved by utilizing a very large number, *n*, of HFGW generation elements.

However, the trick is that we ***don't require gravitational force to generate gravitational waves!*** It's really the motion of the mass that counts, not the kind of force that produces that motion. How do we obtain a large force change? To make it practical, we need a force that is much larger than the force of gravitational attraction. Let's do a thought experiment and think of two horseshoe magnets facing each other (north poles facing south poles). They will attract each other strongly. If we reverse the magnets, put them down back-to-back with their poles facing outwards, then primarily their gravitational force acts due to their masses and we sense little or no attractive pull. As a matter of fact, magnetic, electrical, nuclear and other non-gravitational forces are about 10,000,000,000,000,000,000,000,000,000,000,000 (10^{34}) times larger than the gravitational force! So, if we have our choice, we want to use "electromagnetic force" as our force, not weak gravity.

3.4.2 More Detail

As a validation of the forgoing form of the Quadrupole Equation, 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 PSR1913+16 (the neutron star pair observed by Hulse and Taylor to prove indirectly the presence of GWs). We computed that each of the components of change of force, $\Delta f\,(f_{x},_{y}) = 5.77\text{x}10^{32}$ [N] (multiplied by two since the centrifugal force reverses its direction each half period) and Δt = (1/2)(7.75hrx60minx60sec) = $1.395\text{x}10^4$ [s] for PSR1913+16 . Thus, using the jerk approach and Eq. (1.1.1) of this Paper:

$$P=1.76\text{x}10^{-52}\{(2r\Delta f_c f_x/\Delta t)^2+(2r\Delta f_c f_y/\Delta t)^2\}$$

$$=1.76\text{x}10^{-52}(2\text{x}2.05\text{x}10^9\text{x}5.77\text{x}10^{32}/1.395\text{x}10^4)^2\text{x}2 = 10.1\text{x}10^{24}\ \text{watts} \tag{3.4.2}$$

compared to the result of $9.296\text{x}10^{24}$ watts using Landau and Lifshitz's (1975) more exact two-body-orbit formulation. The most stunning closeness of the agreement is of course fortuitous, since due to orbital eccentricity, there is not complete symmetry among the Δf_c components around the orbit.

3.5 Laboratory HFGW Generation

3.5.1 Executive Level

How could we make use of this analysis and generate GWs in the laboratory? Instead of the change in "centrifugal force" of the two orbiting neutron stars or black holes, let us replace that force change with a change of non-gravitational force: the much more powerful one of electromagnetism. Please see Fig. 3.5.1. One way to do this is to strike two laser targets with two oppositely directed laser pulses (a laser pulse is an electromagnetic wave; Baker, Li and Li, 2006). The two targets could be small masses, possibly highly polished tungsten. Each laser-pulse strike imparts a force on the target mass acting over a very brief time, commonly defined as a "jerk" or shake or impulse. Einstein says, according to his broad concept of "quadrupole formalism," that each time a mass undergoes a change or buildup in force over a very brief time; gravitational waves are generated—*in the laboratory!*

There are a number of alternative devices theorized to generate HFGWs in the laboratory such as those proposed by: the Russians: Grishchuk and Sazhin (1974), Braginsky and Rudenko (1978), Rudenko (2003), Kolosnitsyn and Rudenko (2007); the Germans: Romero and Dehnen (1981) and Dehnen and Romero-Borja (2003); the Italians: Pinto and Rotoli (1988), Fontana (2004); Fontana and Baker (2006); and Baker (2000a) and (2000b); and the Chinese: Baker, Li and Li (2006). The HFGW generation device or transmitter alternative selected is based upon bands of piezoelectric-crystal (first suggested by the Germans), film-bulk acoustic resonators or FBARs (Baker, Woods and Li, 2006) since they are readily available "off the shelf."

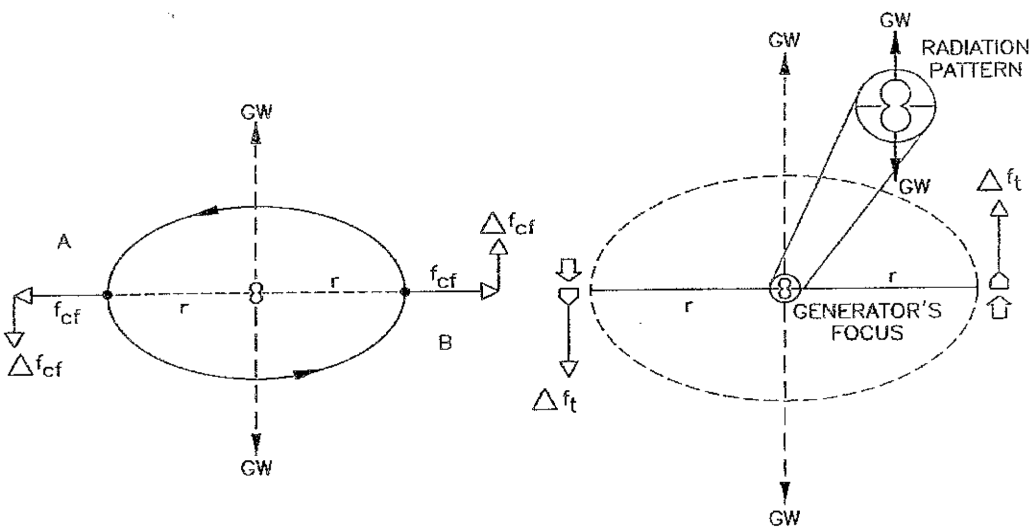


Figure 3.5.1. Change in Centrifugal Force of Orbiting Masses, Δf_{cf}, Replaced by Change in Force, Δf_t, to Achieve HFGW Generator's Radiation

With regard to the laser-pulse approach to HFGW generation (Baker, Li and Li, 2006), the duration of these pulses is very short—a very small fraction of a second, perhaps only one thousand billionth; but that short duration leads to or is represented by an extremely high frequency, on the order of billions cycles per second (say, 1,000,000,000,000 Hz or a Terahertz, or THz) for this pulse duration, Δt, which essentially is the inverse of the frequency, that is 1/1,000,000,000,000 s^{-1} = 0.000,000,000,000,1 second. There are several theories for potential laboratory HFGW generators. For example, as mentioned in Section 1.1.2 piezoelectric crystals (Romero-Borja and Dehnen, 1981 and Dehnen and Romero-Borja, 2003 similar to the FBAR acoustic resonators discussed in Woods and Baker, 2005), microscopic systems (Halpern and Laurent, 1964), infrared-excited stacks of gas-filled rings (Woods and Baker, 2009), electromagnetic cavities (Grishchuk and Sazhin, 1973), a nuclear-energy source (Chapline, Nuckolls and Woods, 1974; Fontana, 2004), high-intensity lasers (Baker, Li and Li, 2006), and several others. All of these candidate HFGW generators should be analyzed for possible Aerospace applications.

3.5.2 More Detail

A recommended embodiment of the laboratory proof-of-concept HFGW generation concept is to replace the just discussed laser targets by two parallel tracks of millions of very inexpensive little piezoelectric crystals, which are ubiquitous and found in cell phones, and energize them by thousands of inexpensive magnetrons found in microwave ovens. Please see Fig. 3.5.2. According to the analyses of Section 1.1.2 the little crystals each produce a small force change, but millions or billions of them operating in concert can produce a huge force change and generate significant HFGWs. As has been mentioned this generator concept has been analyzed in Romero-Borja and Dehnen (1981), Dehnen and Romero-Borja (2003) and Woods and Baker (2005). As suggested in Section 1.1.2 a large number of elements for a given HFGW-generator length can be best realized by reducing the size of the individual elements to submicroscopic size, as discussed in U. S. Patent Number 6,784,591 (Baker 2000a).

Let us consider a proof-of-concept HFGW generator, using 1.8×10^{8} cell-phone film bulk acoustic resonators or FBARs (each of which involves piezoelectric crystals) and 10,000 microwave-magnetrons for a proof-of-concept laboratory HFGW generator. Assuming a 10 µm distance or margin between the FBARs (110 µm on a side with conventional FBARs), the overall length of the laboratory generator will be 110×10^{-6}m x 1.8×10^{8} elements = 19.8 km, which is the same result as that found by Baker, Stephenson and Li (2008). It will have a total HFGW power of 0.066 W and for a distance out from the last in-line, in-phase FBAR element of one HFGW wavelength (6.1 cm at 4.9 GHz), it will have a flux of 3.53 Wm^{-2}, yielding a HFGW amplitude, $A = 4.9 \times 10^{-28}$ m/m. This result differs slightly from the result of Baker, Stephenson and Li (2008), since they took the distance out as 1.5 HFGW wavelengths (9 cm) not one wavelength, or 6.1 cm. Use of 100 staggered rows on each side will reduce the length of the parallel-track array to 190 m (Baker, 2009).

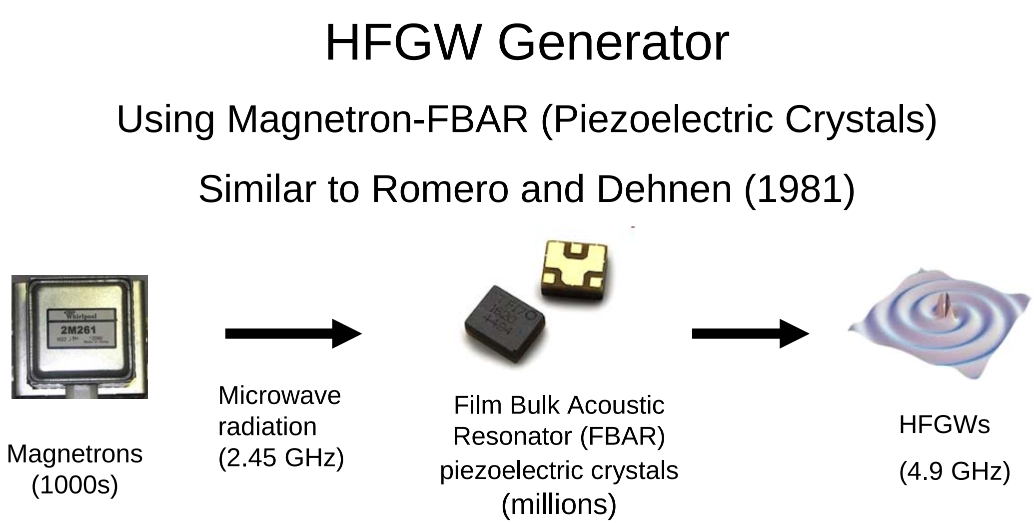


Figure 3.5.2. Magnetron FBAR (Piezoelectric Crystal) HFGW Generator.

3.6 Laboratory HFGW Detection

3.6.1 The Gertsenshtein Effect

3.6.1.1 Executive Level

If high-frequency electromagnetic (EM) microwaves propagate in a static magnetic field, then the interaction of the EM photons with the static magnetic field can generate HFGWs. This is the Gertsenshtein Effect (G-effect) that was discussed in Subsection 1.1.2. The HFGW generated by this G-effect is a second-order perturbation proportional to the square of the very small GW amplitude, A^2, and has **not** shown to be effective for detection or generation of HFGW signals.

3.6.1.2 More Detail

At the outset, it should be emphasized that ***neither the HFGW detector nor the HFGW generators discussed in this paper utilize the Gertsenshtein effect****.* The purpose in mentioning it is to show that gravitational waves and electromagnet (EM) waves actually interact. Gertsenshtein (1962) analyzed the energy of gravitational waves that is excited during the propagation of electromagnetic (EM) radiation (e.g., light) in a constant magnetic or electric field. He found it is possible to excite gravitational waves by light (or other EM energy). He also states at the conclusion of his two-page article that it is possible to do the inverse: generate EM radiation *from* GWs, but exceedingly little such EM radiation is produced.

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3.6.2 The Fangyu Li Effect

3.6.2.1 Executive Level

The **Fangyu Li effect**, a recent breakthrough in HFGW detection, was first published in 1992. As already mentioned, this "Li effect" was validated by eight journal articles, independently peer reviewed by scientists well versed in general relativity, (Li, Tang and Zhao, 1992; Li and Tang, 1997; Li, Tang, Luo, 2000; Li, Tang and Shi, 2003; Li and Yang, 2004; Li and Baker, 2007; Li, et al., 2008; Li, et al., 2009). The reader is especially encouraged to review the key results and formulas found in Li et al., 2008. The Fangyu Li effect is *very different* from the classical *(inverse)* Gertsenshtein effect or G-effect. With the Fangyu Li effect, a gravitational wave transfers energy to a separately generated electromagnetic (EM) wave in the presence of a static magnetic field as discussed in detail in Li et al., 2009. That EM wave has the same frequency as the GW (ripple in the spacetime continuum) and moves in the same direction. This is the "*synchro-resonance condition*," in which the EM and GW waves are synchronized (move in the same direction and have the same frequency and similar phase). The result of the intersection of the parallel and superimposed EM and GW beams, according to the Fangyu effect, is that *new EM photons move off in direction perpendicular to the beams and the magnetic field direction*. Thus, these new photons occupy a separate region of space (see Fig. 3.6.1) that can be made essentially noise-free and the synchro-resonance EM beam itself (in this case a Gaussian beam) is not sensed there, so it does not interfere with detection of the photons. The existence of the transverse movement of new EM photons is a **fundamental physical requirement**; otherwise the EM fields will not satisfy the Helmholtz equation, the electrodynamics equation in curved spacetime, the non-divergence condition in free space, the boundary and will violate the laws of energy and total radiation power flux conservation. This Fangyu Li effect was utilized by Baker (2001) in the design of and Peoples Republic of China Patent (for claims please see (http://www.gravwave.com/docs/Chinese%20Detector%20Patent%2020081027.pdf) of a device to detect HFGWs, the innovative Li-Baker HFGW Detector. An advantage of the Li-Baker HFGW Detector is that with the magnetic field off only the noise (all of it) is present. If one turns on the magnet, then the noise *plus the HFGW signal* is present. A subtraction of the two then can provide for a nearly noise-free signal. Randomness in the signal and the noise prevents a "pure" signal however; but the detector does still exhibit a great sensitivity. Noise sources such as scattering, diffraction, "spillover" from the synchro-resonant EM beam, "shot noise," thermal or black-body noise, etc. have been examined in detail and found to be suppressible (for example by utilizing an off-the-shelf microwave absorbing material to be described in the next subsection) low temperature and high vacuum) and exhibit little influence on the detector's sensitivity.

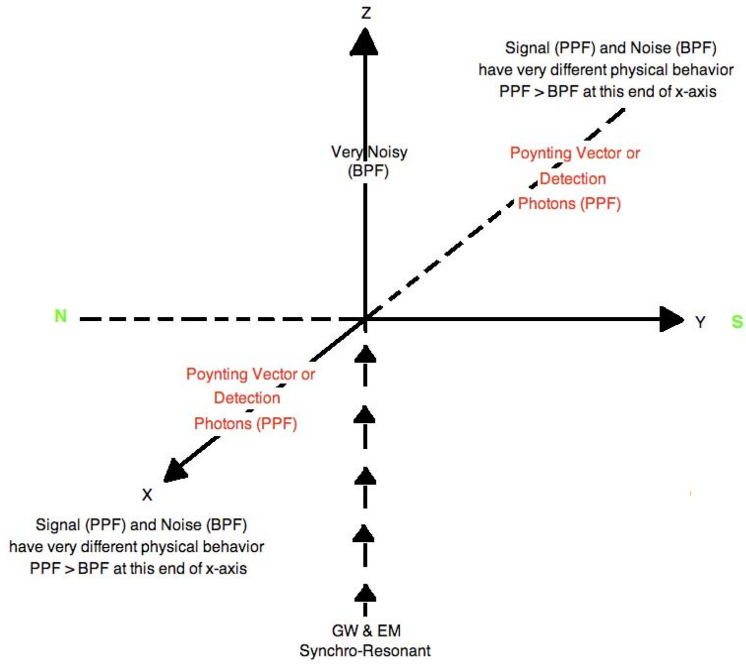


Figure 3.6.1. Detection Photons Sent to Locations that are Less Affected by Noise

3.6.2.2 More Detail

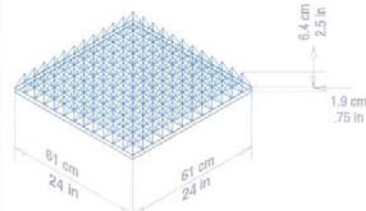
In connection with HFGW detection it should be recognized that *unlike the Gertsenshtein effect,* a *first-order* perturbative photon flux (PPF), proportional to A not A^2, comprising the detection photons or PPF, will be generated in the *x*-direction as in Fig. 3.6.1. Since there is a 90 degree shift in direction, there is little crosstalk between the PPF and the superimposed EM wave (Gaussian beam), furthermore only the noise (not the PPF) is present when the magnetic field is turned off, so the noise can be "labeled," therefore the PPF signal can be isolated and distinguished from the effects of the Gaussian beam, enabling better detection of the HFGW. A major noise-reduction concept for the HFGW detector involves microwave absorbers. Such absorbers are of two types: metamaterial or MM absorbers (Landy, et al., 2008) and the usual commercially available absorbers. In theory multiple layers of metamaterials could result a "perfect" absorber (two layers absorb noise to -45 db according to p.3 of Landy, et al., 2008), but in practice that might not be possible so a combination of **MM**s (sketched as dashed **blue lines** in Figs. 3.6.3 and 6.6.5) backed up by the commercially available microwave absorbers would be desirable. As Landy, et al. (2008) state: "In this study, we are interested in achieving (absorption) in a single unit cell in the propagation direction. Thus, our MM structure was optimized to maximize the (absorbance) with the restriction of minimizing the thickness. If this constraint is relaxed, impedance matching is possible, and with multiple layers, a perfect (absorbance) can be achieved." As to the commercially available microwave absorbers, there are several available that offer the required low reflectivity. For example ARC Technologies, Cummings Microwave, the ETS Lindgren Rantec Microwave Absorbers to mention only a few. The ETS Lindgren EHP-5PCL absorbing pyramids seem like a good choice. At normal incidence the typical reflectivity is down -45 db (guarantied -40 db). The power for one 10 GHz photon per second is $6.626\text{x}10^{-24}$ W and if one can tolerate one thousandth of a photon per second for a series of back and forth reflections off the microwave absorbent walls of the detector as the stray radiation (BPF) ricochet in a zigzag path to the detector (shown in **red** in Figs. (3.6.3) and (6.6.4), then if the **stray radiation were 1000 watts** (the **entire** power of the EM GB), then the total required db drop should be:

$$\text{Power db} = 10 \log_{10} (\text{power out/power in}) = 10\log_{10} (6.626 \times 10^{-27}/1000) = -290 \text{ db} \qquad (3.6.2.1)$$

so there should be no problem if there were 290/40 ≈ 7 reflections of the noise (BPF) off the pyramids without any other absorption required. Note that Eq. (3.6.2.1) provides the needed absorption of the BPF noise before reaching the detector(s) for a **full** 1000 watts of stray radiation. A possible better approach would be to remove the restriction of minimizing the **MM** thickness and incorporate them in the absorption process. Let us consider an absorption "mat" consisting of three **MM** layers, each layer a quarter wavelength from the next (in order to cancel any possible surface reflection) and provide a - 45 db -45 db -45 db = -135 db absorption (Patent Pending). Behind these **MM** layers would be a sheet of 10 GHz microwave pyramid absorbers providing a -40 db absorption before reflection back into the threer MM layers. Thus the total absorption would be -135 db -40 db –135db = -310 db. The absorption mat (Patent Pending) would cover the containment vessel's walls as in Figs. (3.6.3) and (3.6.5) and produce an efficient anechoic chamber. These walls are configured to have a concave curvature facing the corners at **B**, **B'**, **C** and **C'** such that any off-axis waves from the Gaussian beam or GB (stray waves or rays of BPF that may not have been eliminated by the absorbers in the transmitter enclosure) would be absorbed. The lower, bulbous section of the transmitter enclosure would only have a layer of microwave pyramid absorbers that would absorb most of the side-lobe radiation. In this case heat conductors would transfer the heat produced by the GB side lobe's absorption to a cooling system outside the main detector enclosure. The neck of the transmitter enclosure shown in Fig. (3.6.6) would be covered with the absorption mat in order to effectively absorb any remaining side-lobe stray radiation before entering the interaction volume in the main detector enclosure or anechoic chamber. The data sheets concerning the10 GHz microwave pyramid absorbers are as follows:

EHP-3PCL Microwave Absorber

PYRAMIDAL, HI-PERFORMANCE



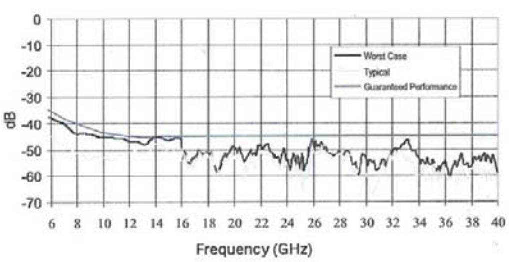
Features

- **Numerically Optimized Design**
- **200 V/m Power Handling Capability**
- **Fire Retardant**

Physical Specifications

MODEL		EHP-3 PCL
Absorber Footprint		61 cm x 61 cm (24 in x 24 in)
Absorber Height	Overall	8.25 cm (3.25 in)
	Base	1.9 cm (.75 in)
	Pyramid	6.4 cm (2.5 in)
Pyramid Base Dimension		3.8 cm x 3.8 cm (1.5 in x 1.5 in)
Pyramids per Absorber		256
Weight (1 piece)		1 kg (2 lb)
Absorbers per Carton		22
Carton Dim. L x W x H		63.5 cm x 63.5 cm x 132 cm (25 in x 25 in x 52 in)

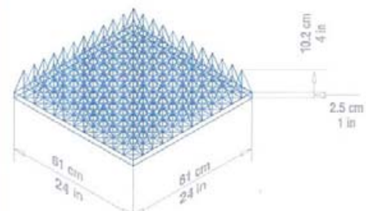
Measured Reflections at Normal Incidence



FREQUENCY/BAND	TYPICAL REFLECTIVITY	GUARANTEED REFLECTIVITY
4-8 GHz C-Band	-35 dB	-30 dB
8-12 GHz X-Band	-45 dB	-40 dB
12-18 GHz Ku-Band	<-45 dB	-45 dB
18-40 GHz K-Band	<-45 dB	-45 dB

EHP-5PCL Microwave Absorber

PYRAMIDAL, HI-PERFORMANCE



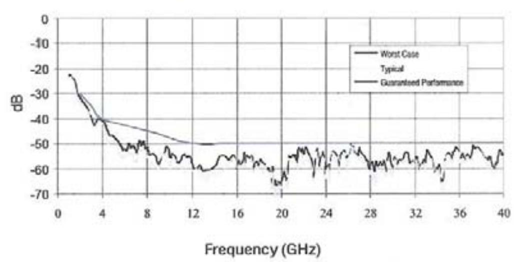
Features

- **Numerically Optimized Design**
- **200 V/m Power Handling Capability**
- **Fire Retardant**

Physical Specifications

MODEL		EHP-5 PCL
Absorber Footprint		61 cm x 61 cm (24 in x 24 in)
Absorber Height	Overall	12.7 cm (5 in)
	Base	2.5 cm (1 in)
	Pyramid	10.2 cm (4 in)
Pyramid Base Dimension		5.1 cm x 5.1 cm (2 in x 2 in)
Pyramids per Absorber		144
Weight (1 piece)		1.6 kg (3.6 lb)
Absorbers per Carton		14
Carton Dim. L x W x H		63.5 cm x 63.5 cm x 132 cm (25 in x 25 in x 52 in)

Measured Reflections at Normal Incidence



FREQUENCY/BAND	TYPICAL REFLECTIVITY	GUARANTEED REFLECTIVITY
2-4 GHz S-Band	-32 dB	-30 dB
4-8 GHz C-Band	-42 dB	-40 dB
8-12 GHz X-Band	<-50 dB	-45 dB
12-18 GHz Ku-Band	<-55 dB	-50 dB
18-40 GHz K-Band	<-50 dB	-50 dB

The Li-Baker HFGW detector operates as follows:

1. The perturbative photon flux (PPF), which signals the detection of a passing gravitational wave (GW), is generated when the two waves (EM and GW) have the same frequency, direction and suitable phase. This situation is termed "synchro-resonance." These PPF detection photons are generated (in the presence of a magnetic field) as the EM wave propagates along its *z*-axis path, which is also the path of the GWs, as shown in Figs. 3.6.1, 3.6.2, 3.6.3 and 3.6.6.

2 The magnetic field **B** is in the y-direction. According to the Li effect, the PPF detection photon flux (also called the "Poynting vector") moves out along the x-axis in both directions as exhibited in Fig. 3.6.1.

3 Unlike the plane EM wave, the BPF from the GB is mainly concentrated in the z-direction, but it also contains some transverse BPF, although the later is often much smaller than the former. The signal (the PPF) and the background photon flux (BPF) from the GB, a component of the noise, have very different physical behaviors. The transverse BPF vanishes at the longitudinal symmetrical surface of the GB where the PPF moving out in the x-direction has a maximum and the PPF reflected by the semi-paraboloid reflector exhibits a very small decay compared with the very large decay of the BPF especially since the BPF is essentially totally absorbed by the detector walls (please see 4 and 5 below). Moreover the PPF only occur when the magnet is on, thereby reducing cross-coupling.

4 The noise (the PBF) is to be intercepted by a microwave-absorbent shield (Figs. 3.6.3, 3.6.5 and 3.6.6) before reaching the microwave receivers located on the *x*-axis (therefore isolated from the synchro-resonance Gaussian EM field, which is along the *z*-axis).

5. The absorption is by means of off-the-shelf -40 dB microwave pyramid 1reflectors/absorbers and by layers of metamaterial (MM) absorbers (tuned to the frequency of the detection photons) shown in Fig. 3.6.4 (Patent Pending). ***The incident ray can have almost any inclination.*** As Service (2010) writes, "… Sandia Laboratories in Albuquerque, New Mexico are developing a technique to produce metamaterials that work with [electromagnetic radiation] coming from virtually any direction." In addition, isolation from background noise is further improved by cooling the microwave receiver apparatus to reduce thermal noise background to a negligible amount. In order to achieve a larger field of view (the detector would be very sensitive to the physical orientation of the instrument) and account for any curvature in the magnetic field, an array of microwave receivers having, for example, 6 cm by 6 cm horns (two microwave wavelengths, or $2\lambda_e$ on a side) could be installed at x = ± 100 cm (arrayed in planes parallel to the y-z plane).

The resultant efficiency of detection of HFGWs is very much greater by 10^{30} than from the inverse Gertsenshtein effect, which has been exploited in some previously proposed HFGW detectors. The proposed novel Li-Baker detection system is shown in Fig. 3.6.2. The detector is sensitive to HFGWs directed along the +*z*-axis, and the geometrical arrangement of the major components around this axis and the use of destructive-interference layers (at the 10 GHz single frequency of the incoming HFGWs), composed of microwave transparent material exhibiting different indices of refraction, is the key to its operation.

The detector, shown schematically in Fig. 3.6.2, has six major components and several noise sources that are discussed in the following:

1. A Gaussian microwave beam or GB (focused, with minimal side lobes and off-the-shelf microwave absorbers for effectively eliminating diffracted waves at the transmitter horn's edges, shown in yellow and blue in Fig. 3.6.6) is aimed along the +*z*-axis at the same frequency as the intended HFGW signal to be detected (Yariv 1975). The frequency is typically in the GHz band, exhibiting a single ("monochromatic") value such as 10 GHz (in the case of HFRGW or Big-Bang detection), and also approximately aligned in the same direction and suitable phase as the HFRGWs to be detected. The microwave transmitter's horn antenna is located on the –z axis and a microwave absorbing device at the other end of the z-axis (Fig. 3.6.2, covered by Peoples Republic of China Patent No. 0510055882.2; see

http://www.gravwave.com/docs/Chinese%20Detector%20Patent%2020081027.pdf.). The microwave generation and microwave absorbing equipment are in separate enclosures or chambers sealed off by microwave transparent walls from the main detector chamber and shielded and thermally isolated. The absorption of the actual GB in the isolated GB-absorption enclosure only requires conducting the heat away from the array of absorbing material to a cooler that is external to the main detector enclosure or chamber, to be located at some distance away from the main detector compartment, thereby reducing the thermal load on the main detector's cooling system (please see item 6 below).

2. A static magnetic field ***B*** (generated typically using superconductor magnets such as those found in a conventional MRI medical body scanner) and installed linearly along the z-axis, is directed (N to S) along the *y*-axis, as shown schematically in Fig. 3.6.2. The intersection of the magnetic field and the GB defines the "interaction volume" where the detection photons or PPF are produced. The interaction volume for the present design is roughly cylindrical in shape, about 30 cm in length and 9 cm across. In order to compute the ***sensitivity***, that is the number of detection photons (PPF) produced per second for a given amplitude HFGW, we will utilize equation (7) of the analyses in Baker, Woods and Li (2006), which is a simplification of equation (67) in Li, et al. (2008),

$$N_x^{(1)} = (1/\mu_0\, \hbar\, \omega_e)\, AB_y\psi_0\delta s \qquad \mathrm{s}^{-1} \qquad (3.6.2.2)$$

where $N_x^{(1)}$ is the number of *x*-directed detection photons per second produced in the interaction volume (defined by the intersection of the Gaussian beam and the magnetic field) , $\hbar$ = Planck's reduced constant, ω_e = angular frequency of the EM (= $2\pi\nu_e$), ν_e = frequency of the EM, A = the amplitude of the HFGW (dimensionless strain of spacetime variation with time), B_y = y-component of the magnetic field, ψ_0 = electrical field of the EM Gaussian beam or GB and δs is the cross-sectional area of the EM Gaussian beam and magnetic field interaction volume. For a proof-of-concept experiment, the neck of the GB is 20 cm out along the z-axis from the transmitter; the radius of the GB at its waist, W, is $(\lambda_e z/\pi)^{1/2} = (3 \times 20/\pi)^{1/2} = 4.3$ cm; the diameter is 8.6 cm (approximately the width of the interaction volume); and the length of the interaction volume is l = 30 cm, so $\delta s = 2Wl = 2.58 \times 10^{-2}$ m^2, i. e., the areas of the GB and B_y overlap. From the analysis presented in Li, Baker and Fang (2007), the electrical field of the EM GB, ψ, is proportional to the square root of EM GB transmitter power, which in the case of a 10^3 Watt transmitter is 1.26×10^4 Vm^{-1}. For the present case, $\nu_e = 10^{10}$ s^{-1}, $\omega_e = 6.28 \times 10^{10}$ rad/s, $A = 10^{-30}$, and B_y = 16 T. Thus Eq. (3.6.2.2) gives $N_x^{(1)}$ = 99.2 PPF detection photons per second. For a 10^3 second observation accumulation time interval or exposure time, there would be 9.92×10^5 detection photons created, with about one-fourth of them focused at each receiver, since half would be directed in +x and half directed in the –x-directions respectively, and only about half of these would be focused on the detectors by paraboloid reflectors. For an advanced detector (Li and Baker 2007), there would be a amplifying resonance chamber (10^3 amplification) in the interaction volume, then the sensitivity would be further improved. We will consider such issues elsewhere.

3. Semi-paraboloid reflectors are situated back-to-back in the y-z plane, as shown in Figs. 3.6.3 and 3.6.5, to reflect the +x and –x moving PPF detection photons (on both sides of the y-z plane in the interaction volume) to the microwave receivers. The sagitta of such a reflector (60 cm effective aperture) is about 2.26 cm. Since this is greater than a tenth of a wavelength of the detection photons, $\lambda_e/10$ = 0.3 cm, such a paraboloid reflector is required, rather than a plane mirror (also, for enhanced noise elimination, the reflector's focus is below the x axis and "out of sight" of the GB's entrance opening). Thus the paraboloid mirrors are slightly tilted, which allows the focus to be slightly off-axis (similar to a Herschelian telescope) so that the microwave receivers cannot "see" the orifice of the Gaussian beam (GB) and, therefore, encounter less GB spillover noise. Since such a reflector would extend out 2.26 cm into the GB (on both sides of y-z plane or 4.5 cm in total), a half or semi-paraboloid mirror is used instead in order not to block the Gaussian beam significantly. The reflectors are about 30 cm high (along the z-axis) and 9 cm wide (along the y-axis) and extend from z = 0 cm to z = +30 cm as shown in Figs. 3.6.3 and 3.6.5. The reflectors are installed to reflect ± x-directed photons to the two or more microwave receivers on the x-axis at x = ± 100 cm from the y-z plane (there could be several microwave receivers stacked at each end of the x-axis to in increase the field of view and account for any variations in the magnetic field from uniform straight lines). The semi-paraboloid reflector extends from a sharp edge at point *A* in Fig. 3.6.3 at the center of the

Gaussian beam (GB). Thus there will be almost no blockage of the GB. The reflectors can be constructed of almost any material that is non-magnetic (to avoid being affected by the intense magnetic field), reflects microwaves well and will not outgas in a high vacuum.

4. High-sensitivity, shielded microwave receivers are located at each end of the x-axis. Possible microwave receivers include an off-the-shelf microwave horn plus HEMT (High Electron Mobility Transistor) receiver; Rydberg Atom Cavity Detector (Yamamoto, et al. 2001); quantum electronics device (QED) microwave receiver, such as the Yale detector invented by Schoelkopf and Girvin (Schuster, et al. 2006), and single-photon detectors (Buller and Collins 2010). Of these, the HEMT receiver is recommended because of its off-the-shelf availability.

5. A high-vacuum system able to evacuate the chamber from 10^{-6} to 10^{-11} Torr (nominally about 7.5×10^{-7} Torr) is utilized. This is well within the state of the art, utilizing multi-stage pumping, and is a convenient choice.

6. A cooling system is selected so that the temperature T satisfies $k_B T << \hbar\omega$, where k_B is Boltzmann's constant and $T << \hbar\omega/k_B \approx 3\text{K}$ for detection at 10 GHz. This condition is satisfied by the target temperature for the detector enclosure $T < 480\text{mK}$, which can be conveniently obtained using a common helium-dilution refrigerator so that negligible thermal photons will be radiated at 10 GHz.

Ideally the Gaussian beam is a culminated beam having distinct edges. In actuality it is not, but falls off exponentially. In the prototype under analysis, which has peak sensitivity at 10 GHz, , the energy per detection photon is $h\nu_e = 6.626\text{x}10^{-34}$ (Js)x10^{10} (s^{-1}) = $6.626\text{x}10^{-24}$ (J), so for a 1,000 W GB, the total photons per second for the entire beam is 1.51 x 10^{26} photons per second. At the 100-cm-distant microwave receivers, the theoretical GB intensity is reduced to [exp (- $2\text{x}100^2/4.3^2$)](1.51 x 10^{26}), **which is essentially zero**.

With regard to the background photon flux (BPF) or noise BPF from the scattering in the Gaussian beam, we introduce hydrogen or helium into the detector enclosure prior to evacuating it to reduce the molecular cross-section and, therefore, increase the mean free path. The photon mean free path, *l,* for helium gas molecules at a high-vacuum pressure of $7.5\text{x}10^{-7}$ Torr ($9.86\text{x}10^{-10}$ atmospheres) and temperature of 480mK, is given by (diameter d of a He molecule is $1\text{x}10^{-8}$ cm):

$$l = 1/(n\sigma) = 1/([\,N_m P_l/T][\pi d^2/4]) = 1/([1.51\text{x}10^{13}][7.85\text{x}10^{-17}]) = 844 \text{ cm}, \qquad (3.6.2.3)$$

where N_m = number of molecules in a cm^3 at standard temperature and pressure (STP) = $2.7\text{x}10^{19}$, P is the pressure in atmospheres and T is temperature in degrees Kelvin or the ratio of the temperature at STP to that in the detector. Since 844 cm is far longer than the 30 cm long interaction volume, there will be negligible degradation of the EM-GB interaction due to intervening mass. With regard to scattering, λ_e =3 cm = $3\text{x}10^8$ Å (wavelength of the GB's EM radiation) is very much greater than the diameter of the He molecule ($1\text{x}10^{-8}$ cm), so there would be Ralyeigh scattering (caused by particles much smaller than the wavelength of the EM radiation). The average scattering cross section (σ_{ray}) per H_2 molecule (about the same as per He_2 molecule) is given by $\sigma_{ray}(H_2) = (8.48\text{x}10^{-13}/\lambda_e^4 + 1.28\text{x}10^{-6}/\lambda_e^6 + 1.61/\lambda_e^8)\ \text{cm}^2$ (with λ_e in Å) = $1.047\text{x}10^{-46}$ cm^2. Thus the Rayleigh scattering mean free path is

$$l_{ray} \approx 1/(n\sigma_{ray}) = 1/([\,N_m P_l/T][\,\sigma_{ray}(H_2)] = 1/([1.51\text{x}10^{13}][1.047\text{x}10^{-46}]) = 6\text{x}10^{32} \text{ cm}. \qquad (3.6.2.4)$$

Utilizing the exponential change in scattering along the Gaussian beam

$$I = I_0\, e^{-z/ray}, \qquad (3.6.2.5)$$

where I is the intensity of the scattering in photons per second at a distance z from the GB transmitter and I_0 is the initial intensity of the GB = $1.51\text{x}10^{26}$ s^{-1} . The interaction volume, where the EM, HFGWs and the magnetic field interact to produce the PPF, extends from z = 10 cm to z = 40 cm, so that the intensity difference between these two points (the scattering from the interaction volume) is $I(10) - I(40) = I_0$ ($e^{-10/ray}$

$- e^{-40/ray}) \approx (1.51x10^{26})(-1 + 10/6x10^{32} + 1 – 40/6X10^{32}) = 3x10^{-7}$ photons per second scattered in the 30 cm long interaction volume, **which is negligible**.

Diffraction elimination: The corners at **B, B', C** and **C'**, of Figs. 3.6.3 and 3.6.5 will exhibit radii of curvature in excess of two wavelengths and no diffraction of the GB should occur. At the relatively long wavelengths of the microwaves in the GB, small obstructions and corners could, however, be sources of diffraction. Because of that and in order to facilitate the installation (attachment) of the absorbing pyramids, and layers of metamaterials (**MM**s as in Fig. 3.6.4, the radiuses of the corners are over three wavelengths (9 cm) in length.

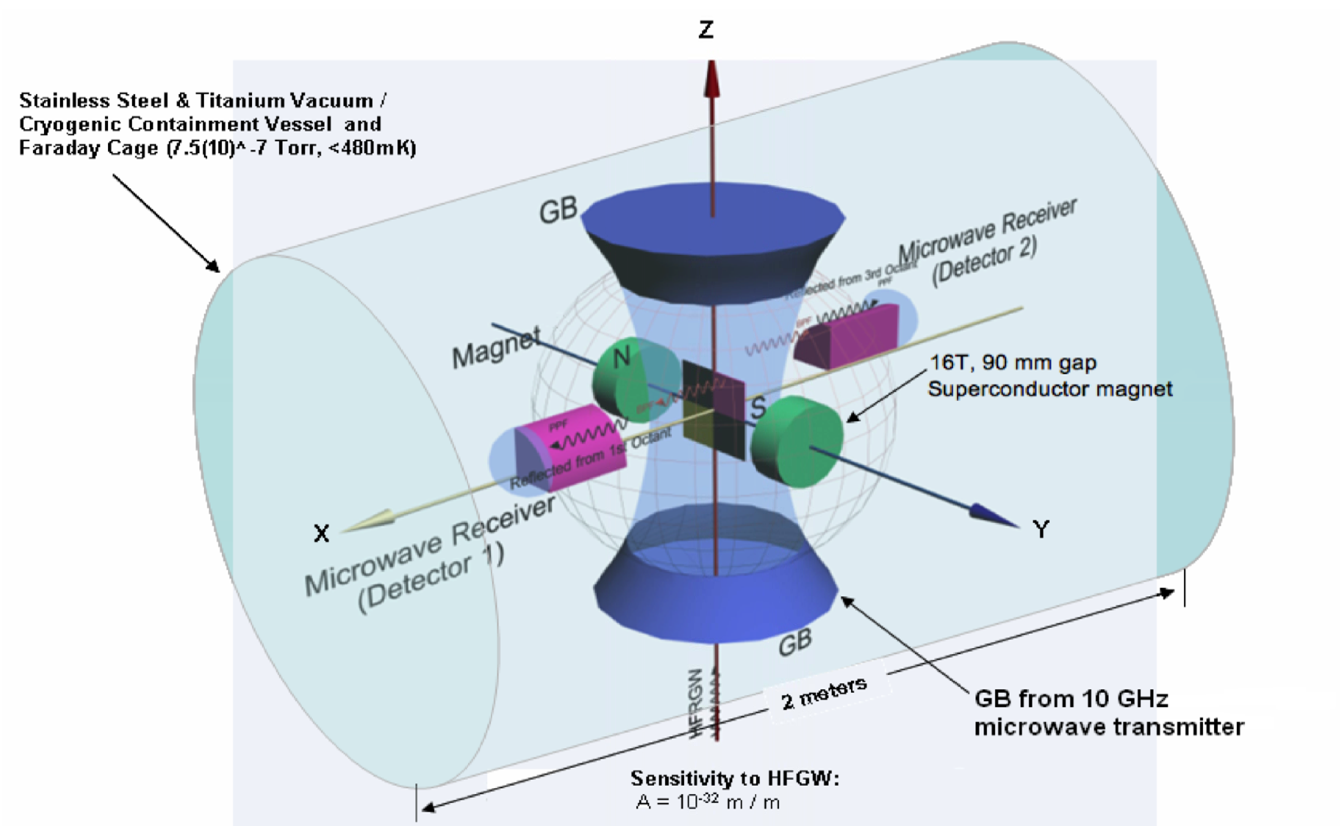


Figure 3.6.2 Schematic of the Proof-of-Concept Li-Baker HFGW Detector (Peoples Republic of China Patent Number 0510055882.2) For claims see http://www.gravwave.com/docs/Chinese%20Detector%20Patent%2020081027.pdf

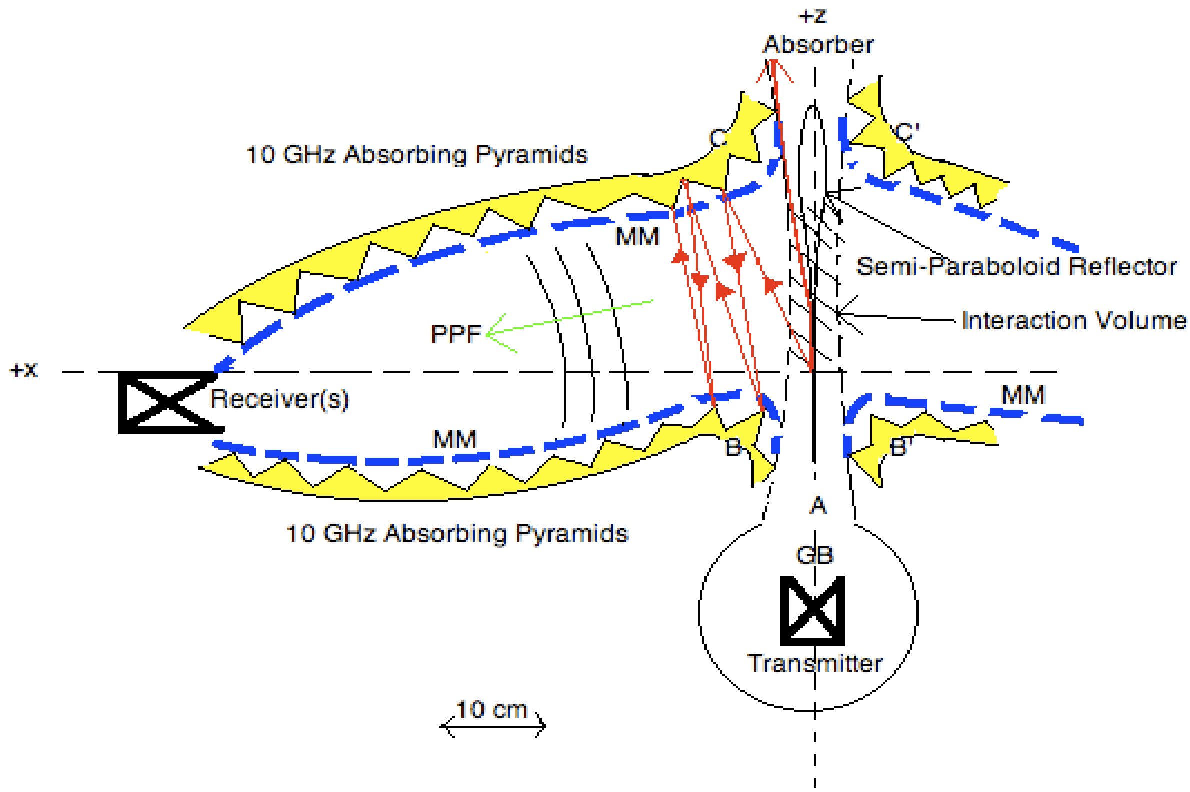


Figure 3.6,3. Side-view schematic of the Li-Baker HFGW detector exhibiting microwave- absorbent walls in the anechoic chamber.

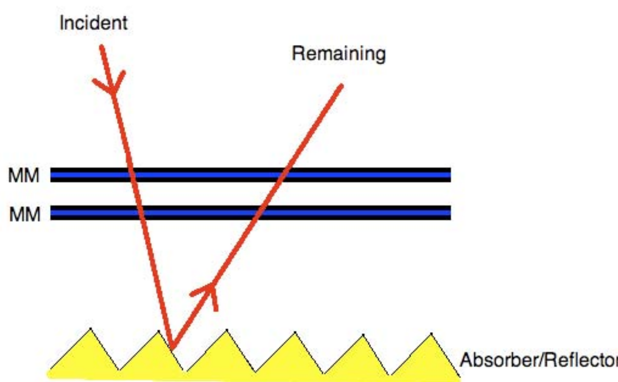


Figure 3.6.4. Schematic of the multilayer metamaterial or MM absorbers and pyramid absorber/reflector. Patent Pending.

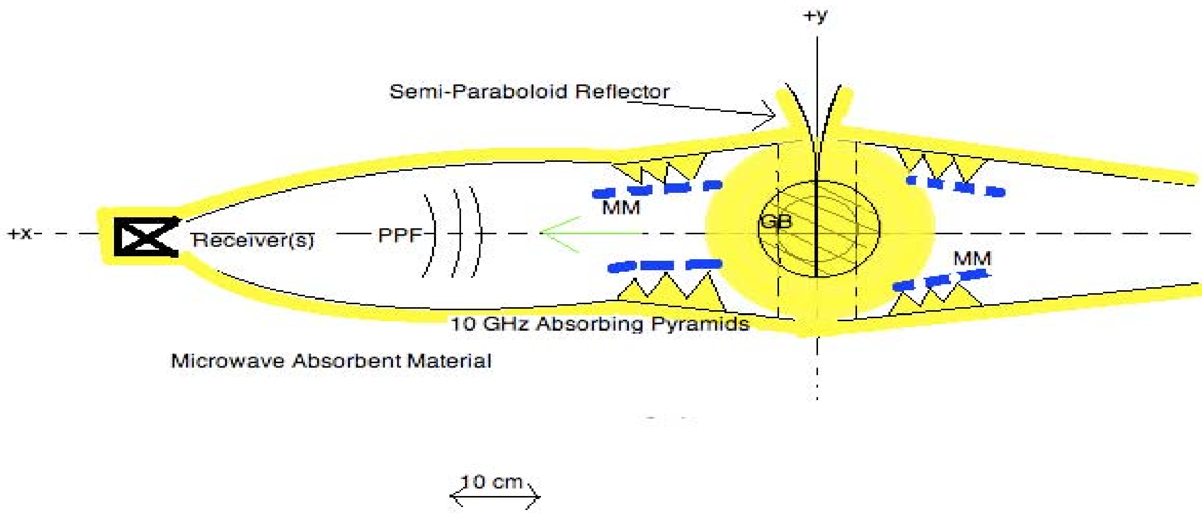


Figure 3.6.5 Plan-view schematic of the Li-Baker HFGW detector exhibiting microwave- absorbent walls in the anechoic chamber.

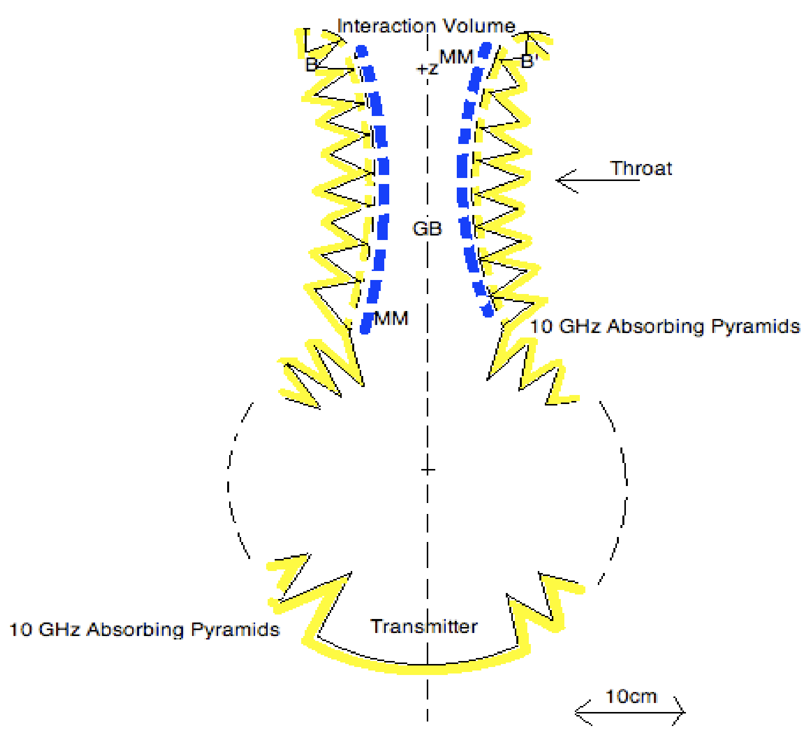


Figure 3.6.6. Gaussian-beam transmitter compartment (Patents Pending).

As already noted the identification of this synchro-resonance, which the Li-Baker HFGW detector is based on, has been extensively covered in the literature. At least ten peer-reviewed research publications concerning its theory of operation have appeared following Li, Tang and Zhao (1992), including those by Li and Tang (1997), Li *et al.* (2000), Li, Tang and Shi (2004), Li and Yang (2004), Baker and Li (2005), Baker, Li and Li (2006), Baker, Woods and Li (2006), Li and Baker (2007), Li, Baker and Fang (2007), Baker, Stephenson and Li (2008), Li *et al.* (2008) and Li *et al.*, (2009)..

Unlike the existing British, Italian and Japanese detectors, the proposed ultra-high-sensitivity Li-Baker Chinese detector depends on a different principle: it does not use the resonance of the British and Italian detectors or the interferometers of the Japanese detectors (the LIGO, Advanced LIGO, GEO600, TAMA and Virgo low-frequency GW detectors also utilize interferometers). As previously discussed, the theory upon which the Li-Baker detector is based on is very different from Gertsenshtein's GW theory.

3.6.3 Other HFGW Detectors

3.6.3.1 Executive Level

In the past few years, HFGW detectors have been fabricated at Birmingham University, England, INFN Genoa, Italy and in Japan. These types of detectors may be promising for the detection of the HFGWs in the GHz band (MHz band for the Japanese) 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. Such a detection capability is to be expected utilizing the Li-Baker detector. Nevertheless, **all four candidate detectors** (plus, possibly, the use of superconductors to greatly enhance sensitivity (Li and Baker, 2007)) should be analyzed for possible Aerospace applications.

3.6.2 More Detail

The Birmingham HFGW detector measures changes in the polarization state of a microwave beam (indicating the presence of a GW) moving in a waveguide about one meter across. Please see Fig.3.6.7. It is expected to be sensitive to HFGWs having spacetime strains of $A \sim 2 \times 10^{-13}$ /√Hz, where Hz is the GW frequency, and as usual A is a measure of the strain or fractional deformation in the spacetime continuum (dimensionless m/m).

Figure 3.6.7. Birmingham University HFGW Detector

The *INFN Genoa* HFGW resonant antenna consists of two coupled, superconducting, spherical, harmonic oscillators a few centimeters in diameter. Please see Fig. 3.6.8. 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 about ~ 2x10-17 /√Hz with an expectation to reach a sensitivity of ~ 2x10^{-20} /√Hz. As of this date, however, there is no further development of the *INFN Genoa* HFGW detector.

Figure 3.6.8. INFN Genoa HFGW Detector

The Kawamura 100 MHz HFGW detector has been built by the National Astronomical Observatory of Japan. It consists of two synchronous interferometers exhibiting an arms length of 75 cm. Please see Fig. 3.6.9. Its sensitivity is now about 10^{-16}/√Hz. According to Mike Cruise of Birmingham University its frequency is limited to 100 MHz and at higher frequencies its sensitivity diminishes.

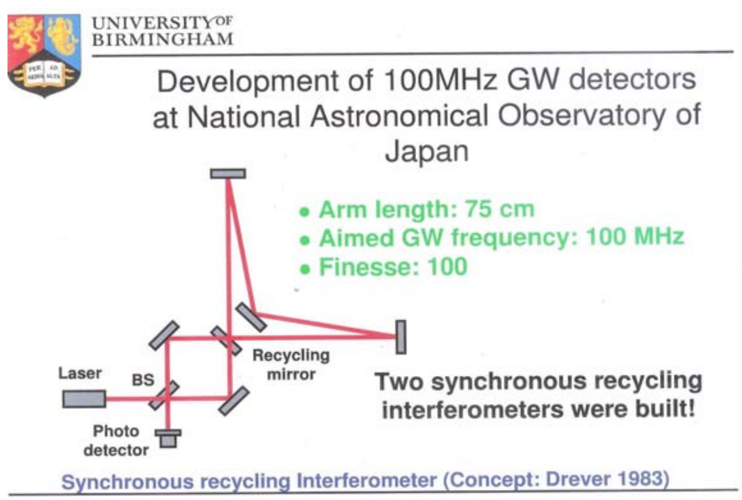


Figure 3.6.9. The National Astronomical Observatory of Japan 100MHz Detector.

4.0 Outline of Plans for Developing Working Prototype

4.1 Plans & Specifications preparation for Li-Baker Detector. Please see Appendix A of http://www.gravwave.com/docs/com%20study%20composite%20.pdf

4.2 Fabrication of Prototype HFGW Generator from Off-the-Shelf Components

The details of this 4.2 effort necessarily depend upon the plans and specifications developed in the initial 4.1 effort.

4.3 Proof-of-Concept Test: Detection of Relic HFGWs by Li-Baker Detector

Testing of the Li-Baker detector will commence after final assembly, cool-down, and confirmation of high vacuum. Please see subsection 4.5. First, noise rejection will be estimated by turning on and off the static magnetic field and measuring the output of the two microwave detectors. The field will then be turned on and the Gaussian beam turned off and again, and the output of the microwave detectors measured. After analyzing the results of these noise tests, the detector will search for relic HFGW signals in 5 to 10 GHz region, this frequency based on Grishchuk (2008) analyses of HFRGWs. Successful detection, and replication by other researchers will then provide proof of the efficacy of the detector.

4.4 Plans & Specifications for Magnetron/FBAR HFGW Generator

A large jerk or shake is required to generate a significant HFGW signal. GravWave® proposes to use an extremely large number of piezoelectric elements lined up and in phase, as proposed by Romero-Borja and Dehnen (1981 and Dehnen and Romero-Borja (2003) to generate HFGWs for detection and study in the laboratory. This will employ Film Bulk Acoustic Resonators (FBARs), found in cell phones, energized by inexpensive magnetrons, found in microwave ovens. The concept (Woods and Baker 2005) is to create two lines or tracks 600m apart (Baker, Stevenson and Li, 2008), each composed of about 180 million FBARS (about 6,000 can be on a four-inch diameter silicon wafer), energized by 10,000 magnetrons (each FBAR, when energized, produces an internal jerk or shake of about 2 N).

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 (a figure "8" of revolution as shown in Fig. 1.1.2) 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).

Let us consider a proof-of-concept laboratory HFGW generator, using 1.8×10^{8} cell-phone film bulk acoustic resonators or FBARs and 10,000 microwave magnetrons, as discussed. Assuming a 10 μm distance or margin between the 100 μm on a side for conventional FBARs, the overall length of the laboratory generator will be 110×10^{-6} m x 1.8×10^{8} elements = 19.8 km. For a separation of the tracks of 2r = 600m it will have a total radiated HFGW power of 0.066 W and for a distance out from the last in-line, in-phase FBAR element of one HFGW wavelength (6.1 cm), it will have a flux of 3.53 W m^{-2}, yielding an HFGW amplitude there of about A = 4.9×10^{-28} m/m. This amplitude can be easily detected at a distance of 1 meter by the Li-Baker HFGW Detector. The length of the parallel-track array of magnetron/FBARs can be reduced to 198 m by staggering the rows of FBARs.

The inline set of FBAR elements also produces a more needlelike radiation pattern of HFGWs (Superradiance), so the flux and resulting signal amplitude may even be larger. Although the frequencies may be different, one can extrapolate approximately from the results of Dehnen and Romero-Borja's analyses, in which the angle of the needle-like radiation pattern is inversely proportional to the square root of the product of the distance between the radiators (the width between FBAR bands or tracks) and N. The distance for the system discussed here is 6.1 cm and for Dehnen's system, 0.00001 m, for a factor of 6,100 and N differs by 1.8x108/5x10^7 = 3.6 for a product of 2.2x10^4 and the inverse of the square root is 6.7x10^{-3}. Using the result from Dehnen's paper (Eq. (4.51), page 12) of a needle half angle of 1.7 degrees, we would extrapolate to 0.0115 degrees or approximately 2x10^{-4} radians, which agrees Baker and Black (2009) who utilize Eq. (1.1.1) and their resulting equation (4b).

4.5 Proof-of-Concept Test of the Li-Baker Detector and HFGW Generator

The magnetron-FBAR HFGW generator will be tested with the Li-Baker HFGW Detector. The Magnetrons will be energized (requiring about 20 MW) and the detector will be employed to receive the signal –like the "Bell-Watson" experiment. The acceptance tests for the Li-Baker HFGW Detector is as follows:

4.5.1. Magnet Off and GB Off

The Li-Baker detector microwave receivers will receive noise resulting from lack of a tight Faraday Cage and/or thermal effects. A 10 GHz source would be moved to search for Faraday Cage "leaks." If they existed, such leaks once located would be corrected. The temperature of the detector enclosure would be measured to be what is calculated to be sufficient to remove all thermal or blackbody noise, 480 mK. If not negligible, then the enclosure will be cooled to a lower temperature until the noise is eliminated. As noted, a unique feature of the Li-Baker HFGW detector is that some of the noise sources are present when the magnetic field is "off" and there is no signal or detection photons present. With the magnetic field "on" there is noise plus the signal. Thus, one can distinguish between HFGW generated photons and the background generated photons from the GB. In principle one could use coincidence gating to subtract the noise (with the magnet "off") from the signal plus "noise" with the magnet "on" and obtain the signal alone. However, there will still be stochastic noise sources that form a noise spectrum that can be reduced by filtering but cannot be completely removed. Consider a simplified case of a uniform, low-frequency (compared with the 10 GHz signal) square-wave chopper frequency energizing the magnet, with the magnet alternatively "off" and "on." It could be utilized to remove some of the background photons from the GB. However, the dark-background shot noise and the signal shot noise could not be separated out since both would be switched off when switching the magnet off.

A standard sensor design method, already mentioned, for aggregating noise sources is to translate all noise terms through the system, or "refer them" from the location at which they occur to the equivalent noise at the detection photon microwave receiver(s) (Boyd 1983). Such an expression of noise is equivalent to the amount of power that this amount of noise would represent at the detector, and is known as the *noise-equivalent power* or NEP. All the uncorrelated noise components can be root-sum-squared together, so that:

$$\mathrm{NEP} = \sqrt{[\ (P_{nd})^2 + (P_{ns})^2 + (P_{nj})^2 + (P_{npa})^2 + (P_{nqa})^2]}\ \ \mathrm{W} \quad , \qquad (4.5.1.1)$$

where the equivalent-power noise components are defined as follows:

The *dark-background shot noise is* $P_{nd} = h\nu\sqrt{(N_d)}/\Delta t$ and N_d is the dark-background- photon count. Shot noise is proportional to the square root of the number of photons present in a sample and is mitigated by using the absorption mat and wall geometry to keep the detection photon (PPF) detectors on a different axis (x-axis) than the BPF background photons (z-axis). Stray BPF spillover and diffraction that still manages to get reflected onto the detectors will create the shot noise, but such noise can be filtered out by pulse-modulating the magnetic field.

The *signal shot noise is* $P_{ns} = h\nu\sqrt{(N_s)}/\Delta t$ where N_s is the signal-photon coun*t*, and Δt is the sample or accumulation time. There is of course no way to mitigate signal photon noise because the creation and propagation of HFRGW photons is constrained by stochastic processes, the maximum signal-to-noise ratio (SNR) will be limited to the square root of the number of HFRGW-created photons.

The *Johnson noise* (due to the thermal agitation of electrons when they are acting as charge carriers in a power amplifier) is $P_{nj} = 4k_BTR_L\mathrm{B_W}$, where R_L is the equivalent resistance of the front-end amplifier and $\mathrm{B_W}$ is the bandwidth. Mitigation of this noise source is accomplished by reducing bandwidth or reducing load resistance. However, in practice the bandwidth is often fixed by the application, in this case by the detection bandwidth. And the load resistance is required to generate a large voltage from a very small current. Hence there is in practice an optimum selection of load resistance that will optimize the signal to noise output, and the selection of this load resistance is the essence of impedance matching in its most basic form. Johnson noise is generally reduced also by refrigeration.

The *preamplifier noise* is $P_{npa} = \mathrm{BW}/\, f_l$, which is essentially 1/f noise, where the crossover frequency f is related to stray capacitance and load resistance; in which $f_l = 1/(2\pi\, R_L C_{jn})$, where C_{jn} = detection capacitance plus FET (field effect transistor) input capacitance plus stray capacitance. This noise source is mitigated by reducing bandwidth, reducing load resistance, or reducing stray capacitance.

The *quantization noise* is $P_{nq\mathrm{a}} = \mathrm{QSE}/\sqrt{12}$, where QSE is the quantization step equivalent or the value of one LSB (Least Significant Bit , the smallest value that is quantized by an ADC, or Analog to Digital Converter). This noise source is easily mitigated by increasing the number of bits used in an ADC so that the LSB is a smaller portion of the overall signal. In practice the QSE is selected so that it does not cause lower SNR.

The *mechanical thermal noise* is caused by the Brownian motion of sensor components. Mitigation is to refrigerate the sensing apparatus to reduce thermal inputs. As already pointed out the 0.48 K cooling should be sufficient, but if not an even lower temperature can be achieved.

The *cosmic ray noise* is caused by cosmic rays, which could be separated from a GW event based on lack of interactions with the magnetic field, and would not be sensed by the shielded 10 GHz microwave receivers.

The *phase* or *frequency noise* (of the EM-GB) is due to the fluctuations in the frequency of the microwave source for the GB. Steps will need to be taken to keep the GB source tuned precisely to the interaction volume resonance, thus reducing phase noise and maximizing the resonant magnification effect required from the interaction volume cavity. A cavity-lock loop or alternatively a phase-compensating feedback loop will be selected during post-fabrication trials to mitigate this noise source

The noise or noise equivalent power at the receiver(s) or NEP, is not a constant, but exhibits a stochastic or random component. In order to obtain the best estimate of the detection photons one would need to utilize a filter, possibly a Kalman filter (pp. 376-387 in Baker 1967).

4.5.2. Only the Magnet On

The magnet is not expected to produce noise at 10 GHz, but if noise is detected, then the superconducting magnet design will be improved using absorbing pyramid baffles or changing components location until the magnet noise is found and eliminated.

4.5,3. Magnet Off and GB On

This is the more challenging situation and it will be divided into GB spillover noise and GB system noise. The initial acceptance test will be to slightly vary the frequency of the GB and look for a minimum of noise (with the magnet off ONLY noise will be present at the receivers).

CONCLUSIONS

High-frequency gravitational wave (HFGW) generators have been proposed theoretically by the Russians, Germans, Italians and Chinese. HFGW detectors are a reality and three have been actually constructed outside the United States by the British, Italians and Japanese. A theoretically more sensitive detector than these, the Li-Baker, utilizing metamaterial and off-the-shelf microwave absorbers to eliminate noise, together with a theoretical, multi-FBAR HFGW generator in a double-helix configuration that are discussed, could be utilized for transglobal, low-probability of intercept (PPI) communications. The multi-elements of the transmitter (HFGW generator) are off-the-shelf piezoelectric film-bulk acoustic resonators or FBARs energized by off-the-shelf' modified Magnetrons. In theory a large number of these FBAR elements could lead to HFGW generator-detector communications for a laboratory proof-of-concept experiment. Pending the recommended proof-of-concept HFGW experiment other HFGW applications could be of value. These theoretical applications, yet to be quantified, but discussed herein, include surveillance and remote displacement of masses such as missiles and anti-missiles and remote HFGW-induced nuclear fusion.

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