Application of High-Frequency Gravitational Waves to Imaging

(Paper HFGW-03-120, Gravitational Wave Conference, The MITRE Corporation,
McLean, Virginia, USA, May 6-9, 2003)
by

Robert M. L. Baker, Jr.†

ABSTRACT

According to some pioneering analyses of Ning Li and David Torr, the speed of a gravitational wave is reduced in a superconductor. This revelation lays the theoretical ground work for utilizing a superconductor, especially a high-temperature superconductor (HTSC), as a refractive medium. Lenses for High-Frequency Gravitational Wave (HFGW) telescopes can similarly be fabricated for gathering and focusing speculative celestial HFGW sources or relic HFGW from an anisotropic cosmic background. Other lenses can be fabricated for concentrating HFGW in a communications system, for imaging through material like an "X-ray," etc. Some specific designs of a HFGW Telescope, a HFGW communications optical train for three different communications systems (including a list of advantages for a transglobal HFGW communications system), and a "through-Earth" imagining systems (potentially capable of generating three-dimensional views of subterranean structures, such as geological formations, oil deposits, etc.) although very speculative, are examined and evaluated.

1. INTRODUCTION

According to some pioneering analyses of Ning Li and David Torr [1], the speed of a gravitational wave is reduced in a superconductor. Their result is **not** controversial. Their article was peer reviewed; examined by C. A. Lundqist, C. M. Will, and Jeeva Anandan; and has had no opposing articles published since it appeared over a decade ago. Clearly, the revelation of a reduction in GW phase velocity lays the theoretical ground work for utilizing a superconductor, especially a high-temperature superconductor (HTSC), as a refractive medium. One then can fabricate a lens from such a refractive medium. The use of this type of lens is especially promising for High-Frequency Gravitational Waves (HFGW) since the shorter the wavelength, the less is the diffraction and the greater the resolution. At a one GHz frequency the GW wavelength is 30 [cm] and at one THz it is 0.3[mm]. The diffraction of HFGW causes a fanning out of the HFGW from any aperture; for example, a spreading out from the aperture at the "end" of a HFGW generator or from the aperture of a HFGW lens. Because of diffraction the image of a point source, such as a distant stellar source of HFGW, is not a point, but spreads out into what is termed a spurious disk surrounded by alternate concentric rings of the presence or absence (interspace) of HFGW. The angular measure of the effect of diffraction is the angle, $\alpha_{d,}$ subtended by the first interspace when viewed from the center of the aperture. In radians it is given by

---

† Senior Consultant, GRAVWAVE® LLC and Transportation Sciences Corporation. 8123 Tuscany Avenue, Playa del Rey, California 90293, USA. Telephone: (310) 823-4143. E-mail: bakerjr@attbi.com.
.

$$\alpha_d = 1.22\lambda_{GW}/d \qquad (1)$$

where λ_{GW} is the wavelength of the HFGW and d is the diameter of the aperture measured in meters. The resolving power of a telescope, which is the angle between two point sources when they can be resolved as seperate points, is also about α_d .

Dr. Ning Li stated to me (telephone conversation on January 14, 2002) that the uncertainty in the GW speed in a superconductor, v_p (phase velocity) is about 50% or $v_p = (1 \pm 0.5)x10^6$ [m/s]. The classical index of refraction, N, is given by

$$N = (\text{velocity in a vacuum})/(\text{velocity in the medium}) = c/v_p = 3x10^8/(1\pm 0.5)x10^6 = 400 \pm 200, \qquad (2)$$

where, as Einstein stipulated, the speed of gravitational waves in a vacuum is the speed of light, $c = 3x10^8$ [m/s]. One of the objectives of the proposed gravitational-wave experiment is to reduce the uncertainty in v_p by measuring the intensity of HFGW in front of a HFGW lens to establish its focal length and/or the diameter of the spurious disk. One would utilize one of the HFGW generators and one of the HFGW detectors described at this Conference for such an experiment.

Another device, the GASER HFGW generator, described at this Conference (paper HFGW-03-107), exhibits a focus that can be dynamically adjusted by a mechanical bending of its elements. Such focusing can also be utilized in a HFGW optical system, but will not be dealt with here.

In spite of the refractive index uncertainty, I will present designs of HFGW telescopes, lenses for communications systems, and the very speculative through-material imaging systems. I will treat each of these subjects of HFGW imaging separately in what follows.

2. HFGW TELESCOPE

A HFGW Telescope has two major components and a third component is required to test it. The first component is a one to one-hundred-meter diameter multifaceted lens composed of a mosaic of several high-temperature superconductors (tiles) or other media that will refract and focus HFGW. Such a medium is state of the art or near to it. For example, a ten-inch diameter, half-inch thick superconducting disk was reported built in March 1997 at the *University of Alabama* and *Superconductor Components, Inc.* in Columbus, Ohio has fabricated an approximately 6-inch diameter Yttrium-Barium-Copper-Oxide ($YB_2C_3O_{7-\delta}$) or YBCO HTSC disk for *NASA* to test the results of Podkletnov. For large-diameter HFGW Telescope objective **lenses composed of many separate tiles (there is no need to have them physically tied or fused together)** one can utilize far less expensive (though somewhat lower temperature, that is lower than the temperature of liquid Helium that allows YBCO to superconduct) HTSC such as steel-clad MgB_2. Note that since GW can pass through any material without attenuation, such as the detectors on the focal plane themselves, the slope of the marginal ray through the lens at the image can exceed 90 [deg] and can be incident on the "wrong side" of the detector array. Thus focal ratios less than one half might be achieved.

The second component is a HFGW detector (or matrix of detector elements under computer control) placed on the focal plane (or focal surface) of the HFGW lens. Unlike the Low-Frequency Gravitational (LFGW) detectors such as *Caltech*'s Laser Interferometric Gravitational Observatory or LIGO (having interferometric-arm dimensions of hundreds or thousands of meters), the HFGW detectors will make use of nanoscale, sophisticated elements, possibly HTSCs, already discussed during this Conference, but will require considerable new-technology development – albeit much of the applicable ultra-fast science, nanomachine technology, and high-temperature superconductor technology is currently under rapidly expanding development at hundreds of laboratories both here and abroad. The third component, needed for optical-bench testing of the HFGW Telescope, is the HFGW generator device itself.

2.1 *Numerical Example*

As a numerical example, for a 100 [m] objective-lens-diameter, d, Earth-based HFGW

Telescope, and a micrometer (10^{-6}[m]) GW wavelength, λ_{GW}, and (approximately) also the spurious disk diameter (for a point source) at the focal plane, the **HFGW frequency, $\nu = c/\lambda_{GW} = 3x10^8/10^{-6} = 3x10^{14}$ [Hz} = 300 THz.** The GW grasp, or GW gathering power, or **amplification is $\{d/1.22\lambda_{GW}\}^2 = \{100[m]/(1.22x10^{-6})\}^2 = 7x10^{15}$** for point sources observed by the 100-meter HFGW Telescope.

Such HFGW celestial point sources might include the very speculative ultra-small, nearer, relic black holes – a candidate for *Dark Matter*; sequences of super-nova shell material jerked from rest to a large fraction of the speed of light over a few centimeters of distance in, say, a picosecond, (... the "... extremely strong compressional shocks in matter...," suggested by Pinto and Rotoli [2], p.568) and Halpern and Laurent [3], p.745, even suggest HFGW radiation from the interior of a star (Sun). The *Big Crunch/Big Bang* theories developed in Conference paper HFGW-03-115 could be tested. As Professor John Miller of *Oxford* and *Trieste* said to me (May 4, 2002): **"It has been the fashion to look for celestial sources of rather low-frequency GW, now my eyes are opening to the possibility of celestial sources of your high-frequency GW."** In this same regard, Pankaj S. Joshi's paper, delivered at this Conference (HFGW-03-105) is most relevant in that it suggests the possibility of other very energetic celestial events as generating HFGW.

2.2 *Lens Optics*

In order to tackle HFGW optics I will rely on an old, rather standard, textbook on optics by Warren J. Smith [4]. The standard lens equation (for example, Eq. (2.30), page 35 of Smith [4]) is

$$1/f = (N - 1)(1/R_1 - 1/R_2). \qquad (3)$$

For a plane convex lens, one spherical-lens-surface radius, $R_2 \rightarrow \infty$ and with N » 1 with the HFGW passing through a HTSC, I have for the other spherical-lens-surface,

$$R_1 = Nf, \qquad (4)$$

where for a **f/1 lens**, and an example of a **10-meter diameter lens**, f = 10 [m], so that $R_1 = (400)(10) = 4000$ [m], $f = R_1/N$ and f = 4000/200 = 20 [m] to 4000/600 = 6.7 [m] or f/2 to f/0.67. The uncertainty in f being the uncertainty of the speed of GW in a superconductor as reflected in the uncertainty of the index of refraction.

2.3 *Polishing the HTSC Lens*

The superconductor's spherical lens surface is $4000 - \sqrt{((4000)^2 - (10/2)^2)} = 3.125$ [mm] thicker at the center than at the edge. A high-temperature superconductor tile, such as YBCO, is brittle and must be treated gently, especially during grinding. A fine soft abrasive (softer than that used for glass lenses) is required and soft brass grinding tools should be used in place of the standard cast-iron. Note that a spherical surface is readily generated by random grinding and polishing (because any line through the center is an axis). An ordinary spherical optical surface for light wavelengths is a true sphere to a few millions of an inch, whereas for, say, one-centimeter GW wavelengths (30 GHz HFGW), 1/10th of a mm or 100 micrometers will do. As far as a quality of the surface finish of the surfaces is concerned, a surface specification of 100-50 permits a scratch of 100 micrometers apparent width and a pit or depression depth of 0.5 mm. One should probably avoid a thickness-to-diameter ratio < 50 (less than 20 cm thickness for a 10-meter diameter lens) so that the lens will not spring and warp up in the grinding process. However a strong steel backing can be utilized to support the multiple-tile, mosaic lens both during grinding and when it is operating in the HFGW telescope and a much thinner lens can be utilized. As discussed on page 417 of Smith [4], a variation in focal length, Δf, due to a lens-surface radius variation, ΔR_1, (say, one tenth of a mm or 0.0001 [m]), is given by

$$\Delta f = f^2 (N - 1)\Delta R_1/R_1^2 = (10)^2(399)(0.0001)/(4000)^2 = 2.5x10^{-7} \text{ [m]} = 0.25 \text{ [micrometers]}, \qquad (5)$$

which is very satisfactory.

2.4 *Focal-Plane Detector*

As to the detection elements in the focal plane, let's determine the effective f number, f/#, of the objective lens system from Eq. (9.20), page 231 of Smith [4] where the diameter of the detector array, D, is taken to be 0.1 [m] (10 centimeters or 10 wavelengths for 30 GHz HFGW), for this example I again make the lens diameter d = 10 [m], and the half-field of view of the system, α, is given by

$\alpha = D/2f = 0.1/(2)(10) = 0.005$ [radians]} or about 0.3 [degrees], (6)

so as a check I find that,

$f/\# = D/(2d\alpha) = 0.1/(2x10x0.005) = 1$ (7)

as designed.

Let's suppose that there are about 80 one-cm-on-a-side detection elements on the circular focal plane of the telescope. Note that one might utilize a hemispherical immersion lens (composed of a superconductor) that reduces the linear size of the image by a factor of its index of refraction, for example, 400 times. One can also cover a larger field of view by means of a field lens located near the image plane (see page 233 of Smith [4]). One can combine the field lens and immersion lens. Thus there are all kinds of suitable design alternatives here including, especially, the *Topoga* Lens (U S Patent No. 2,031,792) that covers a field of view of 90 degrees to 100 degrees at a speed of f/8 (see p. 369 of Smith [4]). The detectors could be sandwiched in between two oppositely directed co-located lens systems in order to view most of the celestial sphere simultaneously. Initially at least, a pair of oppositely directed HFGW telescopes constructed at one site with a focal plane in common, could be utilized in order to achieve coincident observations for signal verification and noise reduction by comparing the GW-image signals. The co-located telescopes would be fixed but, if set at an angle to a circle of latitude, they could scan the entire celestial sphere as they are carried around by the Earth's diurnal motion.

2.5 *Focal Ratio f/0.5 lens*

Let us next consider an example of a "fast" f/0.5 lens. For an extended celestial source, such as ripples or other anisotropic features of limited angular extent in the relic or primordial cosmic background, by *Ockham's Razor* the intensity or power at the focus, P, for an objective lens diameter, d, and a focal length, f, and GWflux in [watts/m^2] is

$$P[\text{watts}] \approx (\text{GWflux})(\text{ObjectiveLensArea})(1/\{\text{focal ratio}\}^2)$$

$$\approx \text{GWflux}\,[\text{watts/m}^2]\ \pi(d/2)^2[\text{m}^2]\ (1/0.5\ )^2\,[\text{watts}]\ . \quad (8)$$

Thus the "gain" for such an extended source with f/# = 0.5, d = 100 [m] and f = 50 [m] is $3x10^4$ for an intensity or power at the focus is about **$3x10^4$**GWflux [watts].

Let us consider the lens system for this configuration. The classical index of refraction, N, is given by Eq. (2) and, as we have seen, is 400 ±200. For a plane convex lens, $R_2 \rightarrow \infty$ and with N » 1 I have from Eq. (4)

$R_1 = Nf = (400 \pm 200)f$ (9)

so that $R_1 = (200)(50) = 10{,}000$ [m] to $(600)(50) = 30{,}000$ [m]. Again the uncertainty in the lens surface radii being the uncertainty of the speed of GW in a superconductor as reflected in the uncertainty of the index of refraction. If a superconductor field lens or immersion lens encloses the detectors on the focal plane, then since λ_{GW} is greatly reduced, resolution of the extended anisotropic source is enhanced due to less diffraction and smaller detection elements.

3. HFGW COMMUNICATION SYSTEM

I will very briefly discuss three examples of HFGW communications enhanced by HFGW lenses: interstellar-spacecraft, transglobal, and miniaturized–transceiver local communication. I will also emphasize the advantages of HFGW communications over electromagnetic (EM) for transglobal communications systems enhanced by HFGW lenses. Complete discussions of the application of HFGW to communications are given in Conference papers HFGW-03-104 and HFGW-03-109.

3.1 *Interstellar-Spacecraft Communication*

Let us consider the case of communications with an interstellar spacecraft at a distance of ten light years and an onboard HFGW generator or transmitter having a frequency of **300 THz** ($\lambda_{GW} = 10^{-6}$ [m]) and a 100-meter diameter telescope receiver on Earth. For a three-meter-diameter transmitter on board the spacecraft the HFGW beam widening due to diffraction will be like a cone with a $1.22\lambda_{GW}$

/width-of-source = $1.22x10^{-6}$ [m]/3[m] = $4x10^{-7}$ [radian] apex angle, α_d,. Thus over a distance of 10 light years (*lyr*) or $9.5x10^{16}$ [m], the signal at the focal plane of the receiving HFGW Telescope will be reduced by a factor of

{Gathering Power}{Area of Transmitter Beam}/{Area of Beam Spread by Diffraction} =

$\{7x10^{15}\}\{\pi(3[m]/2)^2\}/\{\pi(9.5x10^{16}[m]x\ 4x10^{-7}[radians]/2)^2\} = 5x10^{16}/1.14x10^{21} = \mathbf{4.4x10^{-5}}$. (10)

By the way, recall (Section 2.1) that the GW gathering power or amplification was calculated to be $7x10^{15}$ for a 100-meter diameter telescope objective lens and a 300THz frequency.

From Shannon's classical equation (reference [5], page 623), the maximum information rate, C, is given by

$C = B\log_2(1+S/N)$ (11)

where B is the band width, say 300 THz or $B = 3x10^{14}$ [Hz] and GW flux at the transmitter (or HFGW generator) of 10^{10} [watts/m^2] (from Eq. (35) p. 35 of Baker [6]) so that $S = (3x10^{10})(4.4x10^{-5}) = 1.32x10^6$ [watts/m^2], and with hypothesized noise (to be discussed in the next section), $N = 10^{-8}$ [watts/m^2], I have

$C = 3x10^{14}\log_2\{1 + (1.32x10^6/10^{-8}\} = 3x10^{14}\{\log_2(1.32x10^{14})\} \approx 1.4x10^{16}$ [bps] (12)

or 14 Qbps (Quadra bits per second) maximum information transfer rate. Quite good for a ten-light-year-distant spacecraft.

3.2 *Transglobal Communication*

An approximate estimate of what information transfer rate a HFGW transglobal communication system, based upon more modest system requirements, might achieve is obtained as follows:

3.2.1 *Configuration*

Suppose that the distance between the HFGW generating or transmitting device and the receiver or detector is about one Earth's radius, 7,000 [km], that is, the HFGW beam cuts a grazing path through the Earth. For the preferred *stack of jerking rims* situation (Baker [6] pp. 28-30 and U. S. Patent No. 6,417,597) with a picosecond (10^{-12} [s]) pulse duration or $\nu = 10^{12}$ [1/s] or one THz, I will calculate the signal strength, S. In this device the coherent GW emanates from one end of a 3 [m] diameter HFGW generator and spreads out like a cone (having an apex angle, $\alpha_d = 1.22\ c\Delta t/3 = (3.66x10^8)(10^{-12})/3 \approx 1x10^{-4}$ [radians]) resulting in an area of $\pi(1x10^{-4}x7x10^6/2)^2 = 3.8x10^5$ [m^2] some 7000 [km] away with average power from page 29 of Baker [6] of 0.1[watt/m^2] for a 300-meter long device I have,

$S = (0.1)/(3.8x10^5) = 2.5x10^{-7}$ [watts/m^2]. (13)

One would, of course, utilize an optical system at the 7,000 [km] distant receiver. If it were the same as a 100-meter telescope designed in the preceding subsection 2.1 but operating at one THz rather than at 300 THz, then one would have a gain or amplification of $1.75x10^6/(300)^2 = \mathbf{8x10^{10}}$ so that the signal (HFGW flux) at the receiver would be $(\ 2.5x10^{-7}\ )(8x10^{10}) = \mathbf{2x10^4}$ **[watts/m^2].**

3.2.2 *Bandwidth*

Let us estimate that the **detector's "noise" is $N \approx 10^{-8}$ [watts/m^2] in the THz band** (probably not many GW sources there except for relic or primeval background and possibly HFGW generated by HFEM as suggested by Brustein, *et al* [7] or additional celestial noise suggested by Joshi in Conference paper HFGW-03-105). But Brownian motion, thermal and quantum fluctuations, etc. may result in much more noise than these sources as discussed by Stephenson in Conference paper HFGW-03-104. Also I have hypothesized that the GW detector exhibits sensitivity on this same order.

Of course the bandwidth of the long-base-line, interferometric or resonance GW detectors, such as LIGO, are at most about a few KHz and they are **not** designed for THz detection. Thus it is difficult to make comparisons of HFGW detectors (receivers) with the sensitivity of LFGW interferometric detectors. Nevertheless I can use such an analysis as a bench mark (although admittedly, it's like comparing "grapefruits and goats"). The "signal" or GW flux from an osculating circular orbit of a binary black hole or BBH system having between a 6 and a 100-BH-radii semimajor axis is between $5\text{x}10^{-5}$ and $4\text{x}10^{-11}$ [watts/m^2] (please see [6], pp. 19 and 27). A ten-watt isotropically radiating radio transmitter at a distance of 7 [km] produces a signal of $10/4\pi(7000)^2 = 1.6\text{x}10^{-8}$ [watts/m^2]. Note that the sensitivity of the single-crystal detectors considered by Joseph Weber 42 years ago were on the order of about 10^{-10} [watts] as given on p. 313 of Weber [8]. In fact, Weber [9] has speculated optimistically (p. 30) that there is "… no limit to the theoretical sensitivity of a (elastic solid) gravitational radiation antenna, and perhaps no limit to the number of novel methods for improving the sensitivity of existing antennas." More recently in an article by Bernard *et al* (10) they suggest that superconducting coupled microwave cavities could detect fractional HFGW deformations or strain amplitudes having a sensitivity of $\Delta l/l = 10^{-20}/\sqrt{\nu_{GW}} = 10^{-26}$ for THz GW. Also, as previously noted, A. M. Cruise [11)] and R. M. J. Ingley [12], [13], Chincarini and Gemme [14]as well as Li, Tang, and Shi [14] have proposed detectors for HFGW. All this work is somewhat similar to that found in Weber's 1973 U. S. Patent No. 3,722,288.

The bandwidth, B, of Eq. (11) is taken to be the switch on-off or "chop" rate or reciprocating "hammer blows" or jerks that could be well over 10^{12} per second (that is, well over a THz).

Returning to the calculation of information rate, C, Eq. (11) yields

$$\begin{aligned} C &= 1\text{x}10^{12}\log_2(1+ 2\text{x}10^4/1\text{x}10^{-8}) \\ &= 10^{12}(40) = 4\text{x}10^{13} \end{aligned}$$

or about 40 Tbps (Terabits per second) maximum information transfer rate.

Multiple HFGW generators or "transmitters" could increase the bandwidth further as could increasing the carrier frequency above one THz. Note also that here I am talking about a single "carrier" chopping frequency whereas in actuality one can spread the information over an entire band of GW frequencies! Thus HFGW is **the ultimate wireless system**, even reaching submerged submarines and it offers the potential of greater than QHz point-to-multipoint communication (10^{15} Hz, the term Quadrahertz, QHz, is preferred over the term Petahertz or PHz).

3.2.3 *Advantages*

There are several advantages to a HFGW transglobal communication system enhanced by HFGW lenses:

Reduced cost due to avoidance of interconnecting network elements, such as satellite relays, fiber-optic cable, microwave transponders, etc. expenses could be reduced or eliminated. On the other hand, since I do not yet know the difference between the HFGW and the conventional EM transceivers cost, the savings may be somewhat less than or more than the current costs. With regard to Internet communication costs, it should be noted that most of the telecom expense arises from the purchase, installation, maintenance and operation of routers, switches, transceiver-relays, etc. and general overhead. These costs should not change significantly in the transition to HFGW telecommunications.

Increased bandwidth is due to the Quadrahertz or Qbps capability of HFGW. The higher the frequency is, the more efficient GW generation is. The GW spectrum is not only abundant and virgin, but in a sense it is quite limitless — "bandwidth wasting circuits become ideal again..." ([15], p. 207) — every inhabitant of planet Earth can have his or her own bandwidth — ten or so MHz each and ample bandwidth for encryption to satisfy privacy issues. Of particular importance, however, is the fact that current telecom companies have already expended considerable capital on their interconnecting networks and would not want to abandon them. In the case of intercontinental submarine, fiber-optic cable networks they are designed to operate without failure for 20 years and have "ample excess bandwidth" capacity available. (The specifications demanded by the equipment providers have required that the only buried pieces are the fiber itself and amplifiers and the regenerating pieces are either no longer buried or are able to be kept on land.) Apparently then, only if they had catastrophic cable failure and the cost of repair exceeded the cost of replacement by an HFGW system would it seem to be advantageous to shift to HFGW. On the other hand, "ample excess bandwidth" does not mean that there is a capacity for a one-hundred fold or one-thousand-fold increase in bandwidth as afforded by HFGW, for example Quadrahertz (QHz or Qbps) capability. If such an ultra-wide-bandwidth were available, then it is expected, if not *guaranteed,* that applications will be developed to utilize it and **render current telecom networks such as submarine cable and EM wireless devices obsolete!**

There will be less interference; that is, there is expected to be less interfering noise in HFGW than is the case with EM radio communication, e.g., no car-ignition noise, no solar-activity noise, no overhead-power-line noise, no multiple-path ghosts. In this regard, buildings, metal-skinned aircraft, mountains, or barriers of any type do not adversely affect HFGW since all matter is transparent to it. Thus one can anticipate "Dolby ® like" clear, high-fidelity transmission.

HFGW will reduce transmission time delay. GW transmits directly through the Earth without circuitous fiber-optic, satellite, or microwave interconnecting networks. The intercontinental one-way time delay will usually be less than the ratio of the diameter of the Earth divided by the speed of light or $12.8\text{x}10^6/3\text{x}10^8 = 0.043$ [sec] or **43 milliseconds**. For comparison an equatorial geosynchronous satellite communication system will involve a delay at least twelve times longer.

Expansion of a HF GW network is inexpensive, since there is no need for an interconnecting network. The upgrade cost savings is also gained because the transmission-reception equipment is easily accessible and upgradeable at fixed Earth-based sites (unlike satellites on orbit or submarine cables, and remote equipment locations, etc.).

3.3 *Local Communication (Utilizing a miniaturized HFGW Transceiver)*

Let us consider potential advances in the capabilities of a HFGW communications system and consider a miniaturized HFGW transceiver. Here I will concentrate on the HFGW generator or transmitter design of the transceiver as already described in Conference paper HFGW-03-117 (pp. 15 and 16, Eqs. (26) and (27)). For the purpose of having a specific numerical example let us suppose that the dimensions of the transmitter or GW-generation device involve an energizing-element sheath (e.g., microscopic coils) that is 6 [mm] thick surrounding a 3 [mm] radius energizable-element core (e.g., microscopic magnets) and that the device is 18 [mm] in length. The effective length or radius of gyration, r, is **6 [mm]**. The volume would be $\{\pi(3\text{mm} + 6\text{mm})^2 - \pi(3\text{mm})^2\}$ in cubic mm. At the receiver, which I assume to be 7 [km] away, I will introduce a 18 [mm] diameter superconducting lens to gather and focus the HFGW in order to concentrate or amplify the signal at the receiver. I will again consider that $\Delta f_l/\Delta V$ can be increased 100 fold by increased magnetic efficiencies due, for example, by the use of superconducting electromagnets (rather than rather weak permanent magnets) to $3\text{x}10^9$ [N/m^3]. I will also consider a reduction in pulse time to one femtosecond or $\Delta t = 10^{-15}$ [s] (QHz frequency). The longitudinal-force pulse,

$$\Delta f_l = (\text{Volume})(\Delta f_l/\Delta V) = (\pi[(9\text{x}10^{-3})^2 - (3\text{x}10^{-3})^2]\,[0.018]\,)(3\text{x}10^9) = (4.07\text{x}10^{-6})(3\text{x}10^9) = 1.22\text{x}10^4 \text{ [N]}. \qquad (14)$$

$$P = \tfrac{1}{2}\text{x}1.76\text{x}10^{-52}\,\{(2)(0.006)(1.22\text{x}10^4)/10^{-15}\}^2 = \mathbf{1.89x10^{-18}} \text{ [watts]}. \qquad (15)$$

This power from the forward, "coherent-radiation" end of the device is distributed over an area defined by the diffraction pattern at a distance of R = 7 [km]. The diffraction angle, α_d , at the apex of a cone of HFGW is, similar to Eq. (1), given by

$$\alpha_d = 1.22\ \lambda_{GW}/\text{core-diameter} = 1.22c\Delta t/(0.018) = 1.22\ (3\text{x}10^{-8})(10^{-15})/(0.018) \approx 1.7\text{x}10^{-5} \text{ [radians]}. \qquad (16)$$

The area of the conical spread of the HFGW is

$$A = \pi(\alpha_d R/2)^2 = \pi(1.7\text{x}10^{-5}\text{x}7\text{x}10^3/2)^2 = \mathbf{1.07x10^{-2}} \text{ [m}^2\text{]}. \qquad (17)$$

The lens, which concentrates the HFGW at the receiver, has a grasp, GW gathering power, or concentration of $(d/\lambda_{GW})^2 = \{(0.018)/(3\text{x}10^8)(10^{-15})\}^2 = \mathbf{3.6x10^9}$. Putting it all together the signal at the receiver is

$\{(1.89\text{x}10^{-18})/(1.07\text{x}10^{-2})\}\{3.6\text{x}10^{9}\}$ = $\mathbf{6.3x10^{-7}}$ **[watts/m^2].**

Note that *the HFGW signal at the receiver is inversely proportional to the* ***sixth power*** *of the system's pulse length, Δt,* (including the lens at the receiver or *directly proportional to the* ***sixth power*** *of the HFGW frequency*. The foregoing is a bit of a simplification since, like the discussion of the linear-motor design in Baker [6], pp. 28-30, one would turn to a concentric, cylindrical-layer construction – not to a simple sheath and core. Thus the energizing elements (e.g., coils) and energizable elements (e.g., magnetic sites) would be close enough for the GW waves (of wavelength $\lambda_{gw} = c\Delta t = (3\text{x}10^{8})(10^{-15}) = 3\text{x}10^{-7}$ [m] or 300 nanometers – probably much smaller{N is 400, so 400 times smaller} in a superconductor) marching down the cylinder coherently, to build up with an electron migration distance of only (electron migration speed)(Δt) = $(2.38\text{x}10^{8})(10^{-15})$ = 238 nanometers.

By the way, and like the *spacetime* continuum through which it propagates, gravitational-wave frequencies should not be subjected to governmental regulation. Paraphrasing George Gilder [15] p. 162: not only can numerous HFGW transmitters and receivers operate in the same frequency band, they can also "see" other user's HFGW signals and avoid them.

4. THROUGH-MATERIAL IMAGING SYSTEM

The general concept is to image the texture and/or internal structure of a material object that is interposed between a source or sources of gravitational waves and a detector or detectors of gravitational waves. Thus the detectors can reveal the texture and internal structure of the material object in much the same way as X-rays do in the electromagnetic wave spectrum. In the case of X-rays the electromagnetic radiation is far less penetrating than the gravitational radiation. As we know gravitational waves can, in fact, propagate directly through the Earth. In FIG. (1) the HFGW generator, 1, transmits HFGW, 3 , through a material object, 2, and passes through some structure, 4, that modifies the HFGW and projects against a detector, 5, which produces an image of the structure on a display, 7. The source of the gravitational waves can be one or more of the gravitational wave generators described in papers presented at this Conference or it can be the primordial or relic cosmic background or other source or sources, 16, shown in FIG. (6). The gravitational wave detector or detectors can be those also described in this Conference. Multiple gravitational wave generators, 10, shown in FIG. (4) and/or detectors, 12, shown in FIG. (5), which can be in motion relative to the material object, 13, can be utilized to provide a **stereoscopic** or three-dimensional view of the material object's texture and/or internal structure and/or suppress or screen out unwanted features of the material object's texture or internal structure. The gravitational-wave generators and/or detectors can also be in motion, 13, relative to the material object as, for example, being Earth-satellite based.

Clearly it might be a significant computational task to suppress the various features of the Earth's interior from near-surface features at or near the lithosphere. As noted this task might, however, be simplified by dynamically shifting HFGW frequencies and scanning between HFGW generators distributed around say, the United States and satellite-borne HFGW detector arrays sweeping up data from the opposite side of the Earth (scanning). It would be similar to the system utilized for "full-body" medical scans. In more detail:

(i) Different HFGW frequencies may be scattered, refracted, polarization shifted, etc. by interior features of the Earth differently than from certain interesting features relatively near the Earth's surface or in the ocean - thereby allowing for a "filtering" process.

(ii) By having different paths between say, HFGW generated in the United States and the receiving satellite (or satellites) detector arrays one could "triangulate" and differentiate between "deep" and "superficial" features in or near the lithosphere.

Lenses for concentrating and focusing the HFGW could be positioned directly in front of the HFGW generator as, 8, in FIG. 2 or near the detection device as, 9, in FIG. 3. The volume of data to be analyzed in order to image interesting structures to (possibly) sub-millimeter accuracy would, of course, be significant. On the other hand, there are some valuable patternrecognition techniques and super-parallel computer architectures that might be employed. Nevertheless, the computer power required could be of the same magnitude (or greater) than that required for weather prediction.

5. CONCLUSIONS

As an essential part of the experiment to generate and detect HFGW in the laboratory a test of the refractive power of an HTSC should be accomplished. In particular the index of refraction (perhaps different for different HTSCs) should be established by means of measuring HTSC-lens focal length and/or the diffraction pattern of an HFGW beam. Subsequent experiments should define the elements involved in a HFGW optical system for use in a HFGW communications system or telescope. Finally, changes in phase, speed (index of refraction), frequency (dispersion), amplitude (possibly caused by scattering), and other HFGW features that might change during HFGW transmission through various material objects should be experimentally examined.

REFERENCES

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

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

[3] L. Halpern and B. Laurent (1964), “On the Gravitational Radiation of a Microscopic System,” *IL NUOVO CIMENTO,* Volume XXXIII, Number 3, pp. 728ff.

[4] Warren J. Smith (1966), *Modern Optical Engineering,* McGraw-Hill.

[5] C. B. Shannon (1948), *Bell Systems Technical Journal*, Volume 27, Number 379, p. 623.

[6] Robert M. L. Baker, Jr. (2000), “Preliminary Tests of Fundamental Concepts Associated with Gravitational-Wave Spacecraft Propulsion,” *American Institute of Aeronautics and Astronautics: Space 2000 Conference and Exposition,* Paper Number 2000-5250, September 20, August 21, 2001, Revision. (Please see Internet site at: http://drrobertbaker.com/RevisedAIAAPaper.htm .)

[7] R. Brustein, M. Gasperini, M. Giovannini, and G. Veneziano (1995), “Relic gravitational waves from string cosmology,” *Physics Letters B,* Volume 361 pp. 45-51.

[8] Joseph Weber, (1960), “Detection and Generation of Gravitational Waves,” *Physics Review*, Volume 117, Number 1, pp. 306-313.

[9] Joseph Weber and T. M. Karade (1986), *Gravitational Radiation and Relativity*, World Scientific Publishing Co., Singapore.

[10] Phillippe Bernard, Gianluca Gemme, R. Parodi, and E. Picasso (2001), “A Detector of Small Harmonic Displacements Based on Two Coupled Microwave Cavities,” *Review of Scientific Instruments,* Volume 72, Number 5, May, pp. 2428-2437.

[11] A. M. Cruise (2000), “An electromagnetic detector for very-high-frequency gravitational waves,” *Class. Quantum Gravity,* Volume 17, pp. 2525-2530.

[12] R. M. J. Ingley and A. M. Cruise (2001), “An Electromagnetic Detector for High Frequency Gravitational Waves,” *4th Edoardo Amaldi Conference on Gravitational Waves*, Perth, Australia, July.

[13] Andrea Chincarini and Gianluca Gemme (2003), “Microwave-based, high-frequency gravitational wave detector,” *PaperHFGW-03-103 Gravitational-Wave Conference, The MITRE Corporation,* May 6-9.

[14] Fang-Yu Li, Meng-Xi Tang, and Dong-Ping Shi (2003), “Electromagnetic response for a high-frequency gravitational wave in the GHz to THz band,” *Paper HFGW-03-108 Gravitational-Wave Conference, The MITRE Corporation,* May 6-9.

[15] George Gilder (2000), *Telecosm,* Simon and Schuster, p. 162.