Double-Helix, High-Frequency Gravitational Wave Generator Utilizing Nano Piezoelectric Crystals

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ABSTRACT **The Double-Helix, High-Frequency Gravitational Wave (HFGW) Generator is described that makes use of a newly developed nano/quartz-deposited-on-silicon fabrication technique. This new technique suggests that the integration of quartz with silicon may provide a route to fabricate advanced (and much smaller) piezoelectric devices. Gravitational waves or GWs can be generated by a pair of masses acted upon by equal and opposite force changes or sudden movements or "jerks". Centrifugal force changes of orbiting neutron-star pairs produce jerks and GWs, as observed by Hulse and Taylor, and was the basis for the indirect confirmation of the existence of GWs. The laboratory HFGW generator concept is to produce the two equal and opposite jerks at two masses by micro-electromechanical systems (MEMS) under the influence of a high-frequency microwave beam. The MEMS could be film-bulk acoustic resonators (FBARs). An FBAR is a rather standard oscillator found in almost every cell phone and manufactured by the billions! They involve an oscillating mass that undergoes repeated jerks (force changes as it oscillates) and would be placed in pairs on opposite ribbons of the HFGW generator's Double Helix windings. Using the new technique a conventional FBAR could have each dimension reduced by a factor of one thousand and the approximate 50 μm piezoelectric size of conventional FBARs reduced to 5nm for an overall 10^{12} reduction in FBAR size! The number of FBARs is proportional to the inverse cube of a dimension of an FBAR (the smaller the FBAR, the more you can pack in the apparatus). The generated HFGW flux, Wm^{-2}, is proportional to the square of the number of FBARs due to the focusing effect of a string of HFGW sources called "Superradiance" and can be relatively large. The best fabrication means for such a generator would be 3D printing of the nano-quartz-crystal FBARs and associated circuits. Estimates of the improvement in Double-Helix flux generation using the new technique are discussed as is its application to global HFGW communication.**

Key Words: Gravitational waves, nano-quartz, FBARS, micro-electromechanical systems, high-frequency gravitational waves, 3D printing.

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I. INTRODUCTION

As will be discussed there exist several sources for high-frequency gravitational waves (HFGWs) or means for their generation. Historically the first generation means, which is the same for gravitational waves (GWs) of all frequencies, is based upon the quadrupole equation first derived by Einstein [1] in 1918. A formulation of the quadrupole that is easily related to the orbital motion of binary stars or black holes, rotating rods, laboratory GW generation, etc. is based upon the jerk or shake of mass (time rate of change of acceleration), such as the change in a centrifugal force vector with time; for example as masses move around each other on a circular orbit. Centrifugal force changes of orbiting neutron-star pairs produce jerks and GWs as observed by Hulse and Taylor [2] and was the basis for the indirect confirmation of the existence of GWs**.** The determination that the energy loss from the Nobel-Prize winning Hulse and Taylor was in agreement with Einstein's theory for gravitational wave emissions was due to the analyses of Taylor and Weisberg [3]. Figure 1 describes that situation. The jerks can also be associated with merger of binary black holes [4] and the detection of that rare event led to the construction of the of the Laser Interferometer Gravitational Observatory or LIGO , which is now encountering parametric instability [5]. But LIGO is incapable of sensing high-frequency gravitational waves (HFGWs) [6] even if it is operational. Six HFGW detectors have been assembled by researchers at Birmingham University, England by Cruise [7], [8], INFN Genoa, Italy [9] and the Astronomical Observatory of Japan [10]. Other HFGW detectors or receivers, are also under development at Stanford University in the United States [11], Chongqing University in China, such as the Li-Baker HFGW Detector [12], [13], [14], [15] and in Australia [16]. All of these detectors are completely different from the detection techniques found deficient by a well-publicized JASON study in the United States. Please review the following: http://www.gravwave.com/docs/Q%20&%20A.pdf.

It is to be recognized that the change in force Δf need NOT be a gravitational force (see Infeld quoted by Weber [17] and Grishchuk and Sazhin [18] . Electromagnetic forces are more than 10^{35} times larger than gravitational forces and should be employed in laboratory GW generation. As Weber [17] points out: "The non-gravitational forces play a decisive role in methods for detection and generation of gravitational waves ..." Furthermore, electromagnetic waves can be of high frequency and lead to high-frequency gravitational waves or HFGWs. Einstein's quadrupole equation is also termed "quadrupole formalism" and holds in weak gravitational fields (but well over 100 g's [19]), for speeds of the generator "components" less than the speed of light and for the distance between two masses r less than the GW wavelength. Certainly there would be GW generated for r greater than the GW wavelength, but the quadrupole "formalism" or equation might not apply exactly. According to a remark made by the well-known theoretical physicist Leonid P. Grishchuk [20] at The MITRE Corporation Gravitational Wave Conference, this third requirement may not be a stringent or even necessary condition. For very small time change Δt the GW wavelength, $\lambda_{GW} = c\ \Delta t$ (where the speed of light $c \sim 3\times10^{8}$ m s^{-1}) is very small and the GW frequency ν_{GW} is high. The concept is to produce two equal and opposite jerks or Δf's at two masses, such as are involved in micro-electromechanical systems (MEMS), for example film-bulk acoustic resonators (FBARs), a distance $2r$ apart. This situation is completely analogous to binary stars or black holes on orbit as shown in Figs. 1 and 2.

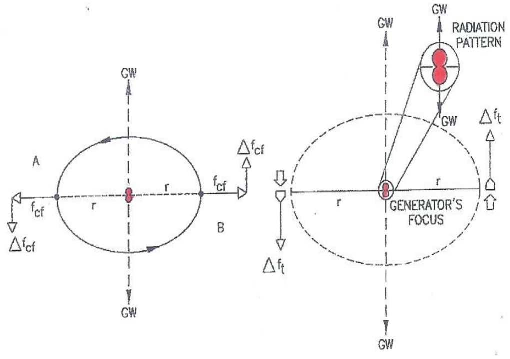

Fig. 1, Change in centrifugal force of orbiting masses, Δf_{cf}, that produces GW radiation.

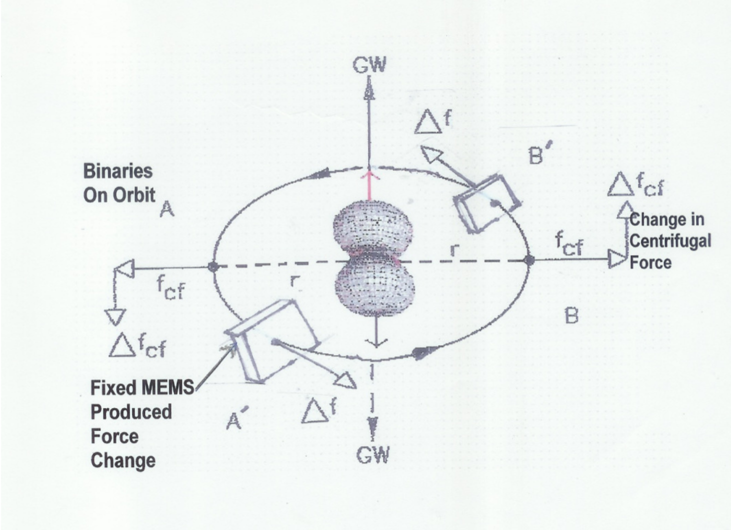

Fig. 2, Radiation pattern calculated by Landau and Lifshitz [21], Section 110, Page 356.

II. DISCUSSION

Next we consider an array of GW sources. Consider a stack of binary-star orbit planes, each one involving a pair of masses circling each other on opposite sides of a circular orbit as shown in Fig. 3.

Let the planes be stacked one light hour apart (that is, GWs moving at the speed of light ≈ 3×10^8 ms^{-1} , 60 × 60 × 3 × 10^8 = 1.08×10^{12} meters apart) and each orbit exactly on top of another (coaxial circles). Let us also suppose that the periods of the orbits were 10 hours. The orbital "frequency" would then be 1/10×60×60 = 2.8×10^{-5} Hz.

According to Landau and Lifshitz [21] on each plane a GW will be generated that radiates from the center of each circular orbit. The details of that generation process are that as the masses orbit a radiation pattern is generated. In simplified terms (from the equations shown in an exercise on page 356 of Landau and Lifshitz [21]) an elliptically shaped polarized arc of radiation is formed on each side of the orbit plane (mirror images). As the two masses orbit each other 180^0 the arcs sweep out a figure of revolution and the resulting integrated GW radiation is circularly polarized. Together these figures of revolution become shaped like a peanut as shown in Fig. 2. This situation occurs when the orbiting masses move half an orbital period 180^0 or 5 hours on their orbit. Thus the frequency of the GW generated is twice the orbital frequency or 5.6×10^{-5} Hz.

The general concept of the present HFGW generator is to utilize an array of force-producing elements arranged in pairs in a cylindrical formation. They could be piezo-rods connecting the two masses, as designed and analyzed utilizing General Relativity, Dehnen and Romero-Borja in 1981 [22], [23] or individual resonators. Their concept is in complete accord with the "jerk" concept (jerks internal to piezoelectric crystals) of Baker [19]. In any event they would also be analogous to the binary arrays of Fig. 3 in which an imaginary cylinder could be formed or constructed from the collection of circular orbits. As a wave front of energizing radiation proceeds along the cylindrical axis of symmetry of such a cylindrical array, the force-producing element pairs (such as pairs of FBARs) are energized simultaneously and jerk, that is they exhibit a third time derivative of mass motion, in concert. The jerking generates gravitational waves focused midway between the jerking pairs exactly analogous to centrifugal force jerks of the orbiting binary stars or Einstein's rotating dumbbells [1].

2.1 Double helix

A convenient cylindrical array is a double helix exhibited in Fig. 4. In this case the MEMS or FBARs are placed along the opposing ribbons of the helixes [24], [25]. As activating radiation (e.g., magnetron-generated microwaves) moves along the axis of symmetry of the helixes, the opposing FBARs are energized and jerk thereby producing a HFGW. It is important that the activating radiation be phase-coherent. In order to understand this concept better let us return to the orbit-plane stack of Fig. 3. A GW generated by the first binary (at the base of the stack) should reach the second member of the stack just as the GW arc is formed with the correct polarization and phase. We imagined the polarization plane as the plane of an elliptical arc. Since the orbit planes are one light hour apart the orbiting binaries must be synchronized one hour of motion further along on their orbit from the initial locations, when they were exactly aligned, in order to reinforce the GW moving along the axis of the imaginary orbit-plane cylinder. Analogously the activating radiation of the double-helix cylindrical array must energize each FBAR pair as the GW passes. Thus if the energizing radiation is produced by microwave transmitters along the GW path (axis of symmetry of the helixes) they must be phase coherent. As will be discussed in more detail in the next following sub-section 2.2, the phase coherent HFGW flux or signal increases in proportion to the **square** of the number of MEMS (e.g., FBARs) HFGW-generation elements, N according to Dicke [26] and Scully and Svidzinsky [27].

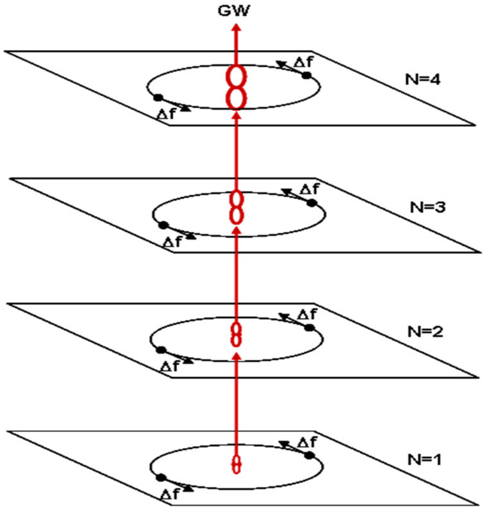

Fig. 3, GW flux growth analogous to stack of N orbital planes.

2.2 Superradiance

The N^2 build up, termed “Superradiance,” 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 (W m^{-2}) thereby increased. Utilizing General Relativity, Dehnen and Romero-Borja [22], [23] computed a superradiance buildup of “… needle-like radiation …” HFGWs beam from a closely packed but very long linear array of the very large crystal oscillators available at the time (1979). Their oscillators were essentially two vibrating masses that were a distance b apart whereas a pair of vibrating FBAR masses is a distance $2r$ apart as shown in Fig. 5. However, the FBAR operates in an analogous fashion as piezoelectric crystals. Superradiance also occurs when emitting sources such as atoms “…are close together compared to the wavelength of the radiation …” Note that it is not necessary to have the MEMS or FBAR elements 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 MEMS or FBARs as in Baker, Woods and Li [28]) reaches a couple of nearly opposite FBARs at the same time so that a coherent radiation source or focus is produced between the two FBARs. The energizing transmitters, such as Magnetrons, can be placed along the helixes’ array axes between separate segments of the array or, more efficiently, at the base of the double helixes so that a Superradiance microwave beam is projected up the axis of the helixes [25]. The force change, Δf, produced by energizing one off-the-shelf FBAR is 2 N according to Woods and Baker [29].

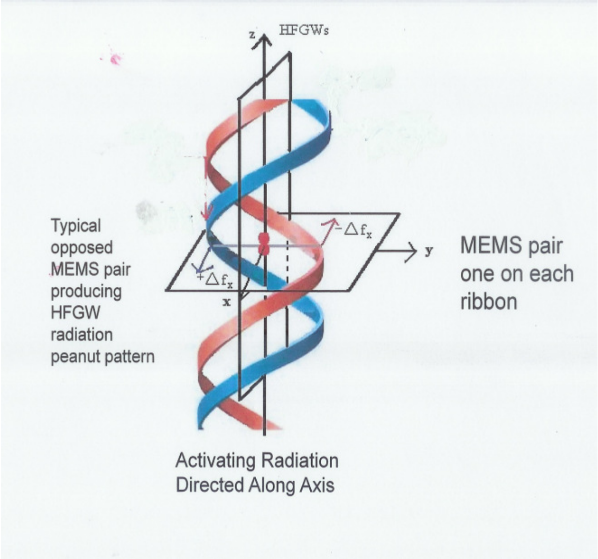

Fig. 4. Double-Helix HFGW generator FBAR array (Patent Pending [25]).

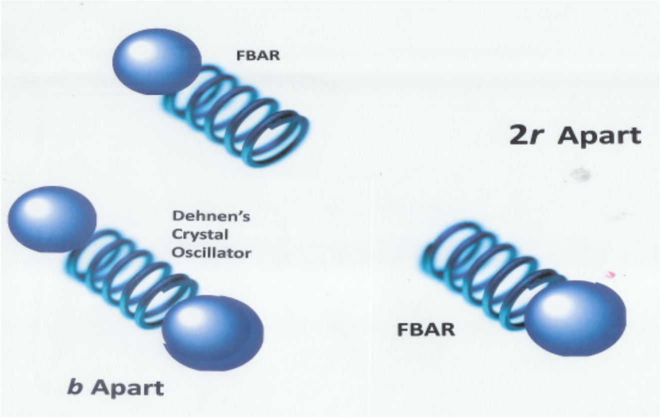

Fig. 5. Comparison of Dehnen and Romero-Borja [22], [28] crystal oscillator and FBAR-pair system.

2.3 Analogy and fabrication technique

In order to clarify the double-helix concept and its fabrication, let us consider a totally different yet analogous situation. It is a storage facility for mattresses. Each mattress is, say, 7 feet by 6 feet and one foot thick (analogous to a **gigantic MEMS or FBAR**). The storage-facility is composed of many coaxial cylindrical structures that are analogous to the cylindrical array of MEMS. The cylindrical structures consist of 7-foot wide compartments between the cylinders’ inside and outside walls and each of these compartments is 6-feet high. Thus one can store one mattress on its side in each compartment. In order to reach a given compartment, imagine that two escalators are installed on the inside wall of each cylindrical structure. They are in the form of spiral escalators "stairways" and are constructed on exactly opposite sides of each cylindrical storage structure (essentially the ribbons of a **double helix** of MEMS). As an example, let us consider one of the cylindrical structures that happen to have a diameter of 100 feet. The circumference of the inside wall of the cylinder is about 314 feet so that the foot of the opposite escalator is about 157 feet distant from its opposite. We take the tread of each escalator step as one foot wide (enough room to slide a mattress in or out of its compartment when the escalator is periodically halted). We want to be able to reach each mattress so the escalators must rise 6 feet in 157 feet in the first 6-foot- high floor of the storage structure. Thus the height of each escalator step when it is moving is 6/157 of a foot or about 1/32 of an inch. Two people start up on each escalator simultaneously, which is analogous to a **wave front from a Magnetron** moving up a double helix of FBARs. They proceed up from compartment to compartment. At each of the 157 "levels" (***N***) they reach opposite pairs of mattresses. In the analogous manner the wave front reaches opposite FBARs and excites them and produces a jerk and, therefore, HFGW radiation pattern focused between the FBARs. But what about the other coaxial cylindrical mattress storage cylinder structures? In order to transport the mattresses the tread width needs to be kept constant that is, more levels on cylinder structures having inside diameters of more than 100 feet and fewer levels on cylinder structures having diameters less than 100 feet. Thus each level is distinct and every mattress pair is on a uniquely *different* level (there are *N such different levels and, hence, mattress pairs).* Also the escalators for each cylinder could be located at different starting points on the circumference of a given cylinder structure. For example, if there were ten structures, then one could place them on different azimuths such as 0, 18, 36, 54, 72, 90, 108, 126, 144 and 162 degrees or at random. Such options may be considered in the fabrication or building process of the imaginary mattress–storage cylinders' construction or, analogously, **the FBAR array fabrication**. In order to develop the double helix winding, a column could be fabricated with the mattress joined that is, glue the mattresses back to back. This would create a 6-foot by 7–foot cross-section tube or, for the analogous FBARs, a 110 μm by 110 μm thread (or whatever the dimensions of the trimmed FBAR MEMS are). Then place one tube on top of the other *after* 157 feet. Thus the composite tube exhibits a 7-foot by 2×6 = 12-foot rectangular cross-section. The analogous FBAR construction would be a 110 μm by 220 μm rectangular cross-section thread. The FBAR fabrication would continue by tightly-winding the composite threads around a microwave-transparent cylinder or spool, layer after layer. This fabrication means, although simple in theory, might be quite difficult in practice since the "threads" are so small and delicate. A more practical fabrication means would the utilization of Nanoscale 3D printers [30]; such as Lee and Ho-Young Kim [31] proposed for Electrospin Nanofibers. The resulting double-helix structure could be inserted in the microwave guide. Returning to the mattress analogy, it is recognized that each escalator passenger may take off at slightly different time, analogous to slightly **irregular wave front.** They all, however, will ascend at the same speed: the speed of light in the structure. Such wave-front irregularities would however be mitigated or eliminated by a properly designed waveguide.

III. RESULTS

As a numerical example of a double-helix FBAR array, 20 meters long with 30-cm thick "walls." We will choose the median radius of the overall array as r = 20 cm (convenient laboratory size though usually somewhat greater than λ_{GW}). Thus the volume of the array is $\pi\ (r_1^2 - r_2^2)^2 \times 20\ m^3$, where r_1 is the outside radius = 0.35 m and r_2 is the inside radius = 0.05 m,so the volume = 7.5 m^3. Δf = 2 Newtons for an off-the-shelf FBAR [29] and $\Delta t = 4\times10^{-10}$ s (equivalent to about a ν_{EM} = 2.5 GHz frequency or pulse of the jerk or energizing radiation frequency) so that λ_{EM} =12 cm and λ_{GW} = 6 cm (the frequency of the GW is twice that of the frequency of the energizing EM wave) and the power, *P* from the basic GW equation (its derivation can be found in, for example, Baker [19], found by hyperlink at http://www.gravwave.com/docs/Astronomische%20Nachrichten%202006.pdf))

$$P=1.76\times10^{-52}\ (2r\ \Delta f/\Delta t)^2\ W. \qquad (1)$$

MEMS resonator shown there is about 50 μm square by 2 μm thick for a volume of about 10^{-14} m^3). In Section V we will discuss even smaller MEMS.

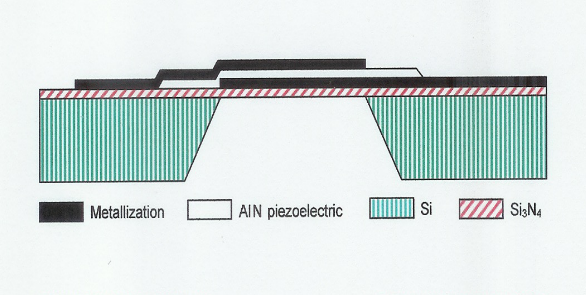

Fig.6. Basic FBAR construction (cross-section side view, not to scale).

The volume of the double-helix array, which comprises many coaxial cylindrical arrays, was calculated to be 7.5 m ^{3}. Thus the total number of FBARs in the double-helix cylindrical array when this volume is divided by the volume of the FBAR MEMS is 3.1×10^{13} and the number of pairs is half of that. Thus there will be $N = 1.55\times10^{13}$ FBAR pairs in the double-helix cylindrical array. Since each FBAR exhibits a jerking force of 2 Newtons [29] the combined Δf of all the jerking FBAR pairs is 3.1×10^{13} Newtons if the jerking pairs (or "orbits") were collapsed and moved in concert analogous to the orbit planes in Fig. 3. Thus from Eq. (1), with $2r_{rms} = 2\sqrt{[(r_1^2 + r_2^2)/2]} = 0.5$ m, the total power produced by the double-helix array is $P = 1.55\times10^{13} \times1.76\times10^{-52}(0.5\times2/4\times10^{-10})^2 = 1.69\times10^{-20}$ W. But due to the N levels, each one of which represents an individual GW focus, there exists a "Superradiance" condition in which the HFGW beam becomes very narrow as shown schematically in Fig. B of Scully and Svidzinsky [27]. Thus the HFGW flux, S in W m^{-2}, becomes much larger at the cap of the peanut shaped radiation pattern. According to the analyses of Baker and Black [32] the area of the *half-power cap* is given by:

$$A_{cap} = A_{1/2(N=1)} / N \quad m^2, \tag{2}$$

where $A_{1/2(N=1)} = 0.1358$ m^2 for a single level (N =1) at a distance of 0.282 m (radius of a one square meter area sphere) or $(1m/0.282m)^2(0.1358) = 1.71$ m^2 at a distance of one meter. Thus Eq. (2) becomes $A_{cap} = 1.71/N$ m^2 (actually one fourth of the HFGW power reaches the cap since half goes to the other side of the peanut-shaped radiation pattern in the vertical or z direction in Figs. 2 and 3). Thus the HFGW flux at a one-meter distance from the end of the double-helix cylindrical array is:

$$S(1) = (P/4)/(1.71/N) = (1.69\times10^{-20}/4)/(1.71/1.55\times10^{13}) = 3.8\times10^{-8} \text{ W m}^{-2} . \tag{3}$$

From Baker, Stevenson and Li [28], Eq. (6A) of the Appendix, the amplitude of the dimensionless strain in the fabric of spacetime is:

$$A = 1.28\times10^{-18}\sqrt{S}/\nu_{GW} \text{ m/m}. \tag{4}$$

So that at a one-meter distance $A = 5\times10^{-32}$ m/m. If the FBARs in all of the helix levels are not activated as individual pairs, then the situation changes. For example, let all of the FBARs in a 6-cm wide level (½ λ_{EM}) be energized in concert. The number of levels would be reduced to N = 20 m/0.06 m = 333. But, because the FBAR-pairs in each level act together, Δf = (2 Newtons) (1.55×10^{13} / 333). Thus the changes in Eq. (1) cancel out and there is no change in HFGW flux. From Woods, et al. [13] the current estimated sensitivity of the Chinese Li-Baker HFGW Detector is $A = 1.0\times10^{-30}$ m/m to 1.0×10^{-32} m/m with a signal to noise ratio of over 1500 (Woods, et al [13], p. 511) or if we were at a 1.3×10^7 m (diameter of Earth) distance, then $S = 1.33\times10^{-20}$ Wm^{-2} and the amplitude A of the HFGW is given by $A = 3.8\times10^{-39}$ m/m. Although the best theoretical sensitivity of the Li-Baker HFGW detector is on the order of 10^{-32} m/m, its sensitivity might be increased (Li and Baker [12]) by introducing superconductor resonance chambers into the interaction volume (which also improves the Standard Quantum Limit; Stephenson [14]) and two others between the interaction volume and the two microwave receivers. Together they provide an increase in sensitivity of five orders of magnitude and result in a theoretical sensitivity of the Li-Baker detector to HFGWs approaching amplitudes of 10^{-37} m/m. There also could be a HFGW superconductor lens, as described by Woods [33] that could concentrate very high frequency gravitational waves at the detector or receiver. At this point it should be noted that although the HFGW *amplitude*, *A,* has a square root of the HFGW power flux, S, shown in Eq. (4), so that is proportional to N, the actual HFGW power flux S is proportional to N^2 and it is S rather than A that falls off with the inverse square power law.

The HFGW beam is very narrow. From Eq. (4b) of Baker and Black [32], for $N = 1.55\times10^{13}$ the angle would be $\sin^{-1} (0.737)/ \sqrt{1.55\times10^{13}} = 1.87\times10^{-7}$ radians or about 10^{-5} degrees. On the opposite side of the Earth the beam is 2 to 4 meters across. For N = 333 the angle is 0.0022 radians or about a tenth of a degree. This is still narrow, but the double helix configuration reduces the width of the HFGW beam much more. Additionally multiple HFGW carrier frequencies can be used, so the signal is very difficult to intercept, and is therefore useful as a low-probability-of-intercept (LPI) signal, even with widespread adoption of the HFGW technology.

IV. IRREGULARITIES

There are at least three irregularities that affect the performance of the present double-helix generator design utilizing current MEMS or FBAR sizes. First is the ability to separate or differentiate the $N = 1.55\times10^{13}$ FBAR pairs due to irregularities in the fabrication of the helix ribbons. Second is the irregularity in the wave front of the energizing microwave radiation produced by the Magnetrons. Third are irregularities in the delay time between the incidence of the energizing or activating microwave radiation and the FBAR mechanical force change. At first glance the required positioning accuracy for MEMS, specifically FBARs, of about 0.155 pedometers would seem to be impossible to achieve using conventional assembly techniques. On the other hand, the tight machine winding of the 110 μm by 220 μm rectangular cross-section FBAR threads in a dust-free environment, might have a tolerance of less than a small fraction of a nanometer. Alternatively, three-dimensional (3D) printing equipment should be employed if nanotechnology techniques for them are sufficiently developed for such a precise fabrication [30]. It is to be recognized that the simultaneous energizing of two FBARs produces GW radiation at the midpoint of a line exactly between them. If, for example, *every* ten FBABs don't intersect exactly when energized, then the total power of the created GW would effectively be reduced to $\Delta f = 2$ Newtons$\times1.55\times10^{13}\times10 = 3.1\times10^{14}$ Newton force change, but the number of such levels (of 10 common, undifferentiated FBAR pairs) would be $N\text{-}10 = 1.55\times10^{12}$. The resulting beam would be broader and hence the flux would be less. However the power at each GW generation site, e.g., MEMS, would be greater. Thus there would be compensatory effects and the influence on the HFGW flux would not be as much as one might at first believe. Other scenarios could be imagined in which pairs of FBARs were simultaneously energized at sites not directly across from each other, but hopefully 3D printer nanotechnology assembly techniques, which involve exact positioning of the "printed" components, will obviate the problem. Furthermore the focal spot between them is not an exact point, but has extent as does the jerked masses in the FBARs (a similar situation arises with orbital masses, e.g., neutron stars not being exactly equal or point masses, but having, extent). The irregularity in the wave front of the energizing microwave radiation produced by the Magnetrons is a more vexing design problem. If the irregularities in the wave front has cylindrical symmetry, then several superimposed GW beams will be generated in which the total power remains the same, but as in the prior situation, the beam is broadened and the HFGW flux reduced. Proper microwave-guide design, e.g., coaxial cable-like construction, of the manifold of multiple Magnetron radiation input will be essential in any event. There will be a delay between the incidence of the energizing or activating microwave radiation and the FBAR mechanical force change or jerk of their internal masses and if the delay is exactly the same for all FBARs, then there is no problem. If the delay has cylindrical symmetry about the axis of the helixes (e.g., due to some thermal effect) then the effect is as previously found, an increase in beam width and a resulting decrease in HFGW flux. Efforts will need to be made to manufacture and assemble the FBARs in a very uniform manner, either by tight machine winding or by 3D printer nano-technology and to carefully control their environment, e. g., isothermal, after fabrication during the double-helix HFGW generator operation.

V. INFLUENCE OF THE SIZE OF A MEMS

Let us next examine in more detail the potential positive influence of the reduction of size of a MEMS or FBAR on the flux, S. The number of FBARs is proportional to the inverse cube of a dimension of an FBAR (the smaller the FBAR, the more you can pack in the apparatus). The Δf is directly proportional to the cube of such a dimension (the bigger the FBAR the more the Δf). Thus the size effect cancel out but the focusing effect of the more numerous (larger N) still increases the flux! Of course the flux is now proportional to N not N^2.)Thus the smaller is still the better! On the other hand, in any practical system we would probably want to drive the resonators at their maximum allowable amplitude. If we start by doing that with 110μm (one millionth of a meter or 10^{-6}) resonators then as we reduce the FBAR dimensions the physical amplitude of vibration stays the same, and at some point will exceed the material strength as we reduce the FBAR dimensions. Nevertheless, new research reported by C. Jettrey Brinker and Paul G.

Clem [34] concerning quartz deposited on silicon, as shown in Fig. 7, suggest that the integration of quartz with silicon may provide a route to fabricate advanced (and much smaller and stronger) piezoelectric devices. Note that in the following figure a nm or nanometer is one billionth of a meter or 10^{-9} meter so that an FBAR could have each dimension reduced by a factor of one thousand and, the approximate 110 μm piezoelectric reduced to 5nm (another factor of 110/5 = 22 cubed or 10^{4}) for an overall 10^{13} reduction in FBAR or MEMS size!\

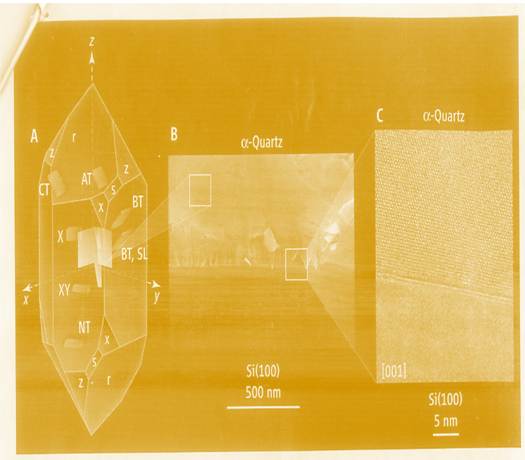

Fig.7 Quartz deposited on silicon

Due to new nano-piezoelectric crystal on silicon technology and 3D printing, the dimensions of a typical MEMS, for example an FBAR, can go from 110 μm (micrometer or millionth of a meter or 10^{-6} m) to 5 nm (nanometer or one billionth of a meter or 10^{-9} m) size and one might have a 10^{13} reduction in FBAR size except for considerations of exceeding the material strength of an FBAR. We will assume a conservative reduction in dimension of an FBAR to 1% of its 110μm resonators size or 10^{6} reduction in FBAR size (not 10^{13}) so that the volume of a current state-of-the-art resonator pair, 4.84×10^{-12} m^3 will be decreased by a factor of $(0.01)^3 = 1\times10^{-6}$ so that the total volume of the pair now would be 4.84×10^{-18} m^3 and $N = 7.5/4.84\times10^{-18} = 1.55\times10^{18}$. The Δf for the miniaturized FBARS is reduced from 2 Newtons to $\Delta f = 2\times10^{-6}$ Newtons. Again the $\Delta t = 4\times10^{-10}$ s and r = 0.2 m Thus Eq. (3) for the HFGW flux one meter distant from the double-helix HFGW generator (with the superradiance narrowing of the beam) becomes

$$S = (1.76 \times10^{-52} (2\times0.2\times1.55\times10^{18}\times2\times10^{-6}/4\times10^{-10})^2))/4)(.55\times10^{18}/1.71)= 3.83\times10^{8}\,\mathrm{Wm}^{-2} \qquad (3a)$$

which seems really large (383 thousand times more than the solar flux at the Earth's surface!), but what about the resulting strain amplitude of spacetime?

Introducing $\nu_{GW} \approx 1/4\times10^{-10}\,\mathrm{s}^{-1} = 2.5\times10^{9}$ Hz or 2.5 GHz into Eq. (4), and $S = 3.83\times10^{8}$ Wm^{-2}, we find from Eq. (4) $A = 1\mathrm{x}10^{-23}$ m/m one-meter from the end of the double-helix HFGW generator or transmitter and probably detectable by one or more of the half dozen HFGW detectors, already discussed, built or under development. [8], [9], [10], [11], [12], [16]. At a greater distance from the double-helix HFGW generator than one meter the A is much smaller. In fact for a distance away of the diameter of the Earth, 1.27×10^{7} m,, according to the inverse square law the HFGW flux would be reduced by a factor of 6.2×10^{-15}. We will first compute the HFGW flux one Earth diameter away:

$$S = (1.76 \times 10^{-52} (2\mathrm{x}0.2\times1.55\mathrm{x}10^{18}\times2\times10^{-6}/4\times10^{-10})^2))/4)(1.55\times10^{18}/1.71)(6.2\times10^{-15}) = 2.37\times10^{-6}\mathrm{Wm}^{-2}. \qquad (3b)$$

Therefore the calculated HFGW amplitude is:

$$A = 1.28\times10^{-18}\sqrt{S} / (\nu_{GW}) = 1.28\times10^{-18}\sqrt{2.37\times10^{-6}} / 2.5\times10^{-9} = 7.89\times10^{-31}\ \mathrm{m/m} \approx 10^{-30}\ \mathrm{m/m}. \qquad (4a)$$

In general, we find according to the figure of merit in [35], Eq. (10), the amplitude of the generated HFGW, A, is proportional to $r\nu_{GW}\,\Delta f\, n^{2}$, Δf is proportional to l^3 and n is proportional to $1/l^3$. Thus A is proportional to $r\,\nu_{GW} / l^3$. From [34] l could be reduced from 110 μm to less than 11 μm for a 1000 fold increase in HFGW amplitude to

$$A \approx 10^{-30}\ \mathrm{m/m}\ \mathrm{x}\ 10^{3} = 10^{-27}\ \mathrm{m/m} \qquad (4b)$$

or a reduction in HFGW generator to one tenth or less the size – material strength of the piezoelectric elements may be the only limit. The 3D printing [30] would probably need to be additive manufacturing in order to form more than 10^{18} nano-FBARs less than 1.1 μm in size. It would require very narrow laser or electron beams; a fraction of a μm in diameter. Since the double-helix HFGW generator exhibits cylindrical symmetry a cylindrical "powder bed" will probably need to be rapidly rotated, and its axis gradually moved a μm or so at a time and utilize multiple narrow laser or electron beams in order to reduce fabrication time. Alternatively a FBAR "blanket" could be 3D printed composed of μm layers of FBARs constructed layer by layer using electron beams of HDTV type refreshing pixel matrices. The “blanket” then rolled up to form the barrel of the Double-Helix HFGW generator. As already mentioned there could be segments along the axis of the generator each energized by a separate microwave source [25].

Thus with HFGW detector programs successful, the quartz deposited on silicon MEMS practical and 3D Nanoscale printing available [30] **a HFGW detector will exhibit sufficient sensitivity to receive the double-helix generated HFGW signal globally!**

VI. APPLICATIONS

In addition to global communications there are other potential applications of HFGWs. In the Search for Extra-Terrestrial Intelligence or SETI, thus far only possible electromagnetic propagations have been monitored. However according to Baker and Baker [36] an extra-terrestrial civilization, possibly intercommunicating from some **one hundred sextillion** Exoplanets, would probably utilize HFGWs since, unlike electromagnetic radiation, it is not easily absorbed by matter especially interstellar matter. There are also other possible applications of HFGW to surveillance of underground facilities and the remote movement of masses. These are discussed with respect to the global war on terror by Baker [37].

VII. CONCLUSIONS

The overall concept is shown in Fig. 8 in very simplified form. In theory the preferred and patented [25] double-helix array of force-producing FBARs can generate significant superradiant HFGW radiation. A numerical example of a 20-meter long array is presented. Activation-energy radiators or transmitters (such as off-the-shelf Magnetrons) can be utilized to energize MEMS such as off-the-shelf FBARs found in cell phones. Thus point-to-point communication, even at a distance greater than the diameter of the Earth, might be realized using very sensitive HFGW Chinese detectors or receivers, quartz deposited on silicon MEMS with Nanoscale 3D printing [30] and HFGW lenses [33] to concentrate the HFGW signal at the receivers.

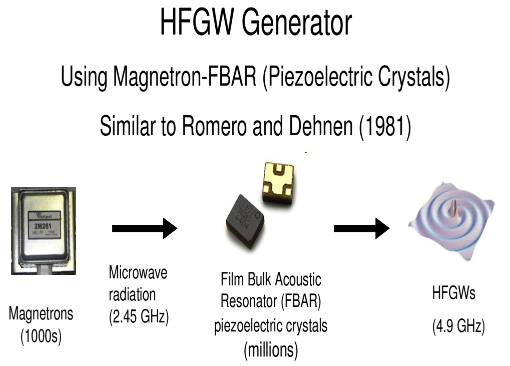

Fig. 8. Simplified concept of the HFGW generator.

A HFGW amplitude of the time-varying strain of the fabric of spacetime, $A = 3.8\times10^{-30}$ m/m to 10^{-27} m/m is created at a distance of one Earth diameter from the generator. It is also indicated that the Earth is transparent to the HFGWs. Thus with a sensitive HFGW detector, such as the Li-Baker successfully developed by the Chinese and the quartz deposited on silicon technology practical, one could sense the generated HFGW at an Earth-diameter distance and could, in theory, be a means for trans-global communications.

The approach to the laboratory or manmade terrestrial generation of HFGWs is innovative and unique. There have been few other advances in the HFGW generation field. The General Relativity based crystal oscillator study by Dehnen [22] is probably the most important up to now, but its reliance on old-style, 1970s, crystals (not modern MEMS technology) and a linear rather than a cylindrically symmetric array resulted in a very inefficient HFGW generator. The methods discussed herein are the most appropriate to the science and engineering of terrestrial HFGW generation and trans-global communication. All the relevant literature has been cited that supports the theory and fabrication of the proposed HFGW generator.

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