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"Gravitational wave generator apparatus"

By Robert M L Baker, Jr. and Bonnie Sue Baker

Peer-review: First Referee's Comments:

The talk represents an innovative advancement over the papers by Dehnen and Romero-Borja. Dehnen and his student proposed the use of crystal oscillators for GW generation over 30 years ago utilizing a purely general-relativity approach. But the oscillators available then were many orders of magnitude larger than the Microelectromechanical systems or MEMS of today that have the same performance. Therefore the door is open now for a fresh approach and their double-helix design is ingenious.

The presenters should, however, address the problem of manufacturing irregularities. The basic equation they utilize is a variant of the quadrupole. It has been indirectly validated by observing the effect of energy loss due to GW radiation in the case of orbiting binaries. Assumed two-body orbits such as these are NOT exactly two body since there will always be perturbations (caused by various other masses around the binary system). Thus there exist irregularities in their motion and the orbiting pair is not EXACTLY across from one another. Thus irregularities do not invalidate the concept of GW generated by the third derivative motion of two opposed masses in their MEMS. But such irregularities should be considered or at least mentioned by the presenters.

My review is most positive, however, and the presentation should be accepted.

Peer-review: Second Referee's Comments:

First comment is that in the Proceedings of the presentation the font type seems to shift around. I would "select all" and then pick one, for instance Times New Roman. Also check punctuation.

Second comment is that the author hit on a very important point with the superradiance aspect of the

EM needed to generate GW. You need a changing acceleration in the mass-energy distribution to make a GW, so IF you are dealing with EM alone it has to be at least superradiant EM almost by definition. But this does not imply "superradiant GW" to me. I would ask "Is there really any other kind?" Because since it is a wave and therefore by definition an oscillation in space time, it is also simply an acceleration field, a changing acceleration field, and that's all it is. So you can't really say its "superradiant GW" because that might imply that there is GW out there somewhere that is not superradiant - that there are GWs that might not involve accelerated frames.

Third comment is that superradiance even for EM seem vague to me. I guess it is OK as a description of a class of radiation effects tied to acceleration that is how Wikipedia describes it. But there are members of this class that would generate GW, and potentially members that would not. Let's take them one by one:

Zel'dovich radiation - this is superradiance EM emitted by rotating (Kerr) black holes. However if the black hole is rotating uniformly there is no change in acceleration. Therefore there is no GW generated, as it is the change in acceleration that is important. Alternatively, one can consider the case of an accretion powered pulsar, in which the pulsar acceleration is changing as matter is falling in. In this case there is a 3rd derivative of motion, so there should be both superradiant EM and GW would be emitted.

Unruh radiation - this is the still theoretical argued radiation that would be black body radiation an accelerated observer sees. So instead of moving the source, you are moving the observer. The effective blackbody radiation observed due to 1 G in acceleration is something like 10^-20 K thermal blackbody radiation. So it is a very small effect. Once again, if the acceleration is a uniform rotation, even in the observer, then no GW is observed.

Cherenkov radiation - the radiation emitted when charged particles go through a dielectric at a phase velocity greater than light speed, like in the case of beta decay particles going through heavy water, i.e. the blue glow in a nuclear reactor. One can easily imagine a pulse of Chrenkov radiation causing a "jerk" in the spacetime frame, and therefore a GW. But one can also imagine a very uniform emission of Chrenkov radiation that never increases or decreases, and therefore has no 3rd derivative. In this case no GW would be emitted. So is superradiant EM a necessary condition for GW? No, you can do it with spinning dumbbells. Is superradiant EM sufficient to generate GW? No, you can have superradiant EM emitted from a uniformly rotating black hole and it will never create GW. Therefore superradiance is neither a necessary nor a sufficient condition to creating GW.

BUT, that said, superradiance could be advantageously used to create GW if conditioned properly in a way that has a 3rd derivative as the authors have done. And if you want to make a gravitational wave with pure EM, then by definition it will be superradiant, since it is creating a ST frame with a 3rd derivative, therefore the also the second derivative. That is why what the authors propose is extremely fascinating. I would recommend the presentation; however additional reviewers may be in order (more than the usual two for these STAIF papers) since the concept is so novel.

Peer-review: Third Referee's Comments:

I believe that I have reviewed this HFGW generation concept previously for a PowerPoint presentation, but my comments are again as follows:

1) I understand that a proper electromagnetic excitation for the double helix must be a **circularly polarized** http://en.wikipedia.org/wiki/Circular_polarization EM wave, produced by a http://en.wikipedia.org/wiki/Helical_antenna or phased and crossed dipoles http://sv1bsx.50webs.com/antenna-pol/polarization.html . Please tell something about that in the paper.

2a) Most important: If the authors are considering couples composed of far away masses. In this case in order to be able to move in reciprocal synchronization, each element of the couple could be electrically charged; it is not necessary to use MEMS, I understand that those particles could be ions in a plasma. Maybe I can understand the double helix system (far away masses) if the MEMS are piezo-rods connecting the two "ideal" helixes. The center of mass and center of inertia is the axis of the two helixes. In this case the rods need **not** be electrically charged and the size of the elementary emitting system is the distance between the two helixes **exactly like** the author discusses. Each rod must change shape from I to S under em excitation. For instance: Fig 4 "MEMS pair, one on each ribbon " change to something like "MEMS axis connecting the two ribbons"

2b) Alternatively the authors can keep the description of the system **as is**, in this case I understand that the size of the emitting system is the size of the MEMS, that is "much smaller" than the distance between the two ribbons. We do not need to have far distant masses. This is **not** a limitation of the quadrupole, in fact to operate at 2.5GHz the MEMS must be very small, and the general rule is that the maximum GW output power per kg of material is proportional to frequency squared provided that a suitable arrangement of many discrete sources is made. The **double helix** certainly is one of them (I think that **it is the optimal arrangement!**). I believe that if these two points should be clarified, this will be an improvement in the talk and, in any event, the talk should be published in the Forum Proceedings.

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The Space Technology & Applications International Forum

Gravitational wave generator apparatus

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Abstract

An apparatus or structure is proposed for generating high-frequency gravitational waves (HFGWs) between pairs of force-producing elements by means of the simultaneous production of a third time derivative of mass motion of the pair of force-producing elements. The elements are configured as a cylindrical array in the proposed structure and are activated by a radiation wavefront moving along the axis of symmetry of the array. The force-producing elements can be micro-electromechanical systems or MEMS resonators such as nanometer piezoelectric-crystal on silicon film-bulk acoustic resonators or FBARs. A preferred cylindrical array is in the form of a double helix and the activating radiation can be electromagnetic as generated by microwave transmitters such as Magnetrons. As the activating radiation wavefront moves along the axis of the structure it simultaneously activates force elements on opposite sides of the structure and thereby generates a gravitational wave between the pair of force elements. It is also indicated that the Earth is transparent to the HFGWs. Thus a sensitive HFGW detector, such as the Li-Baker under development by the Chinese, can sense the generated HFGW at an Earth-diameter distance and could, in theory, be a means for implementing transglobal HFGW communications.

PACS: 04.30Db, 41.90+e, 95.55Ym

Keywords: Gravitational waves, high-frequency gravitational wave generator, HFGW, communication, MEMS, FBARS

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1. 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[i] 1918. A formulation of the quadrupole that is easily related to the orbital motion of binary stars or black holes, rotating rods, laboratory HFGW generation, etc. is based upon the jerk or shake of mass (time rate of change of acceleration), such as the change in centrifugal force vector with time; for example as masses move around each other on a circular orbit. Figure 1 describes that situation. Recognize, however, that change in force Δf need NOT be a gravitational force (see Einstein; Infeld quoted by Weber[ii]. Grishchuk and Sazhin[iii]). Electromagnetic forces are more than 10^{35} times larger than gravitational forces and should be employed in laboratory GW generation. As Weber[ii] points out: “The non-gravitational forces play a decisive role in methods for detection and generation of gravitational waves ...” The quadrupole equation is also termed “quadrupole formalism” and holds in weak gravitational fields (but well over 100 g’s), 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. For very small time change Δt the GW wavelength, $\lambda_{GW} = c\ \Delta t$ (where $c \sim 3\times10^8$ m s^{-1}, the speed of light) is very small and the GW frequency ν_{GW} is 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. For very small time change Δt the GW wavelength, $\lambda_{GW} = c\ \Delta t$ (where $c \sim 3\times10^8$ m s^{-1}, the speed of light) 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 2*r* apart. This situation is completely analogous to binary stars or black holes on orbit as shown in Figs. 1 and 2.

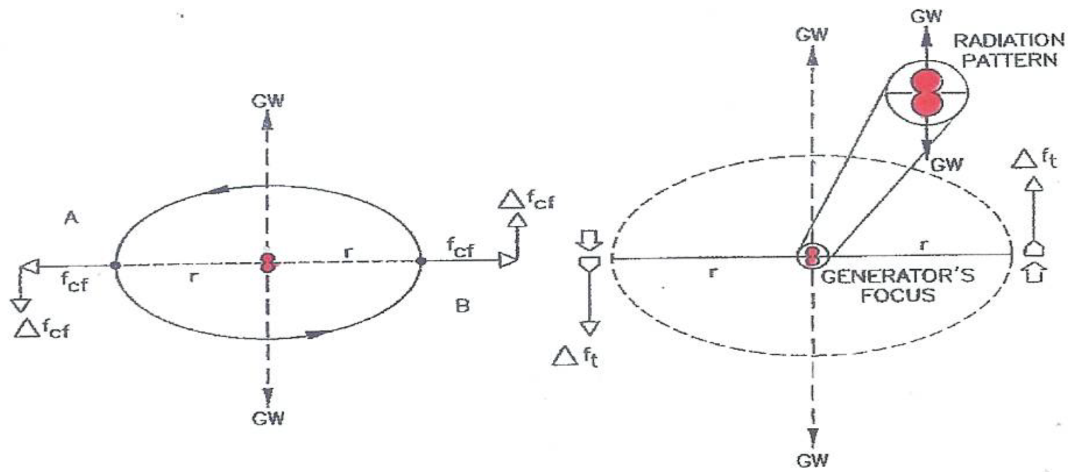

Figure 1. Change in centrifugal force of orbiting masses, Δf_{cf}, that produces GW radiation.

2. 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, $60 \times 60 \times 3 \times 10^8 = 1.08 \times 10^{12}$ 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 $1/10 \times 60 \times 60 = 2.8 \times 10^{-5}$ Hz.

According Landau and Lifshitz [iv] 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[4]) 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 or individual resonators. In any event they would 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 wavefront 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 binaries.

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. 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[v] and Scully and Svidzinsky[vi] .

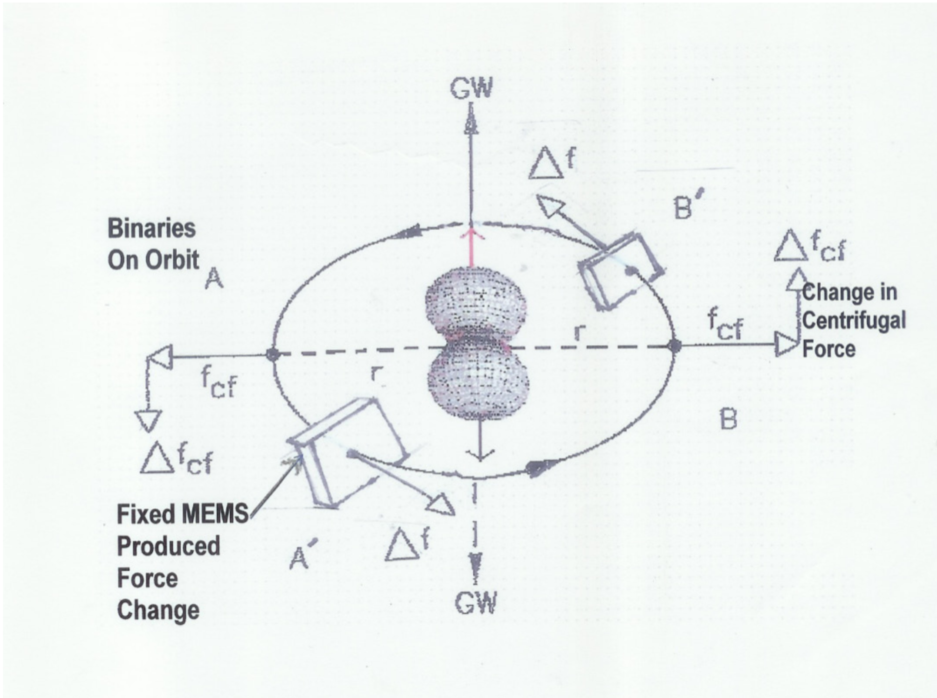

Figure 2. Radiation pattern calculated by Landau and Lifshitz [IV], Section 110 Page 356.

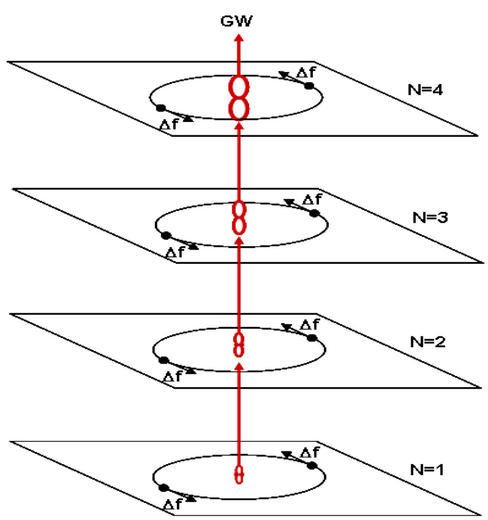

Figure 3. GW flux growth analogous to stack of *N* orbital planes.

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 [vii], computed a superradiance build up of "… needle-like radiation …" HFGWs beam from a closely packed but very long linear array of crystal oscillators. 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)[viii] 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. The force change, Δf, produced by energizing one off-the-shelf FBAR is 2 N according to Woods and Baker[ix]

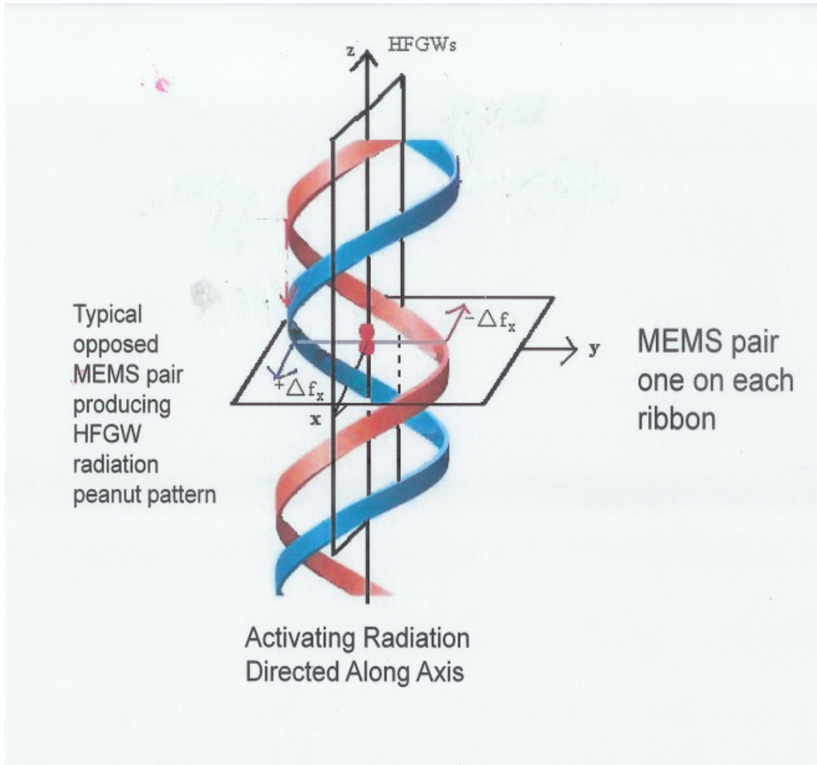

Figure 4. Double-Helix HFGW generator FBAR array (Patent Pending).

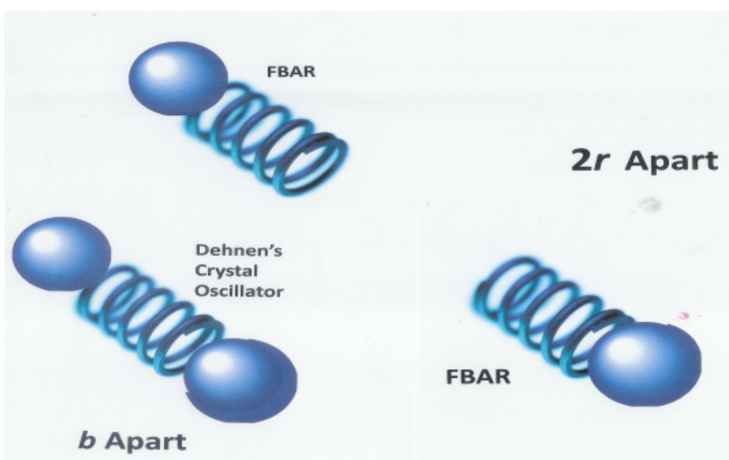

Figure 5. Comparison of Dehnen and Romero-Borja [VII]] crystal oscillator and FBAR-pair system.

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 **wavefront 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. Thus **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 wavefront irregularities would however be mitigated or eliminated by a properly designed waveguide.

3. Results

As a numerical example of a double-helix FBAR array, we will choose the median radius of the overall array as r = 20 cm (convenient laboratory size though usually somewhat greater than λ_{GW}), Δf = 2 N for an off-the-shelf FBAR and $\Delta t = 4\times10^{-10}$ s (equivalent to about a v_{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 [x], found by hyperlink at http://www.gravwave.com/docs/Astronomische%20Nachrichten%202006.pdf))

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

MEMS resonator shown there is about 50 μm square by 2 μm thick for a volume of about 10^{-14} m^3). In Section 5 we will discuss even smaller MEMS.

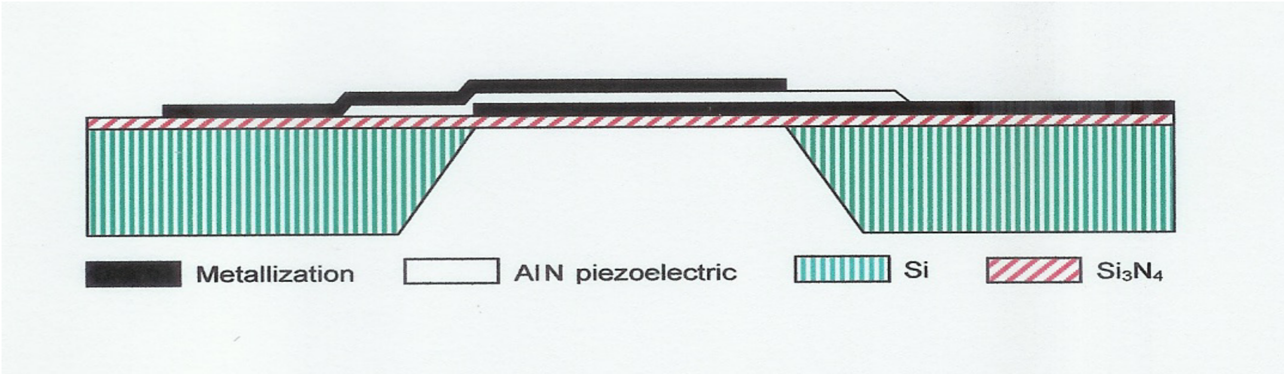

Figure 6. Basic FBAR construction (cross-section side view, not to scale).

Thus the total number of FBARs in the double-helix cylindrical array is 3.1×10^{13} and the number of pairs is half of that. Thus there will be N = 1.55×10^{13} FBAR pairs in the double-helix cylindrical array. Since each FBAR exhibits a jerking force of 2 N the combined Δf of all the jerking FBAR pairs is 3.1×1013 N if the jerking pairs (or "orbits") were collapsed and moved in concert analogous to the orbit plane with the synchronized mass motion. A more conservative approach would be that there are *N* individual GW power sources each with aΔf = 2 N . 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 $P = 1.55\times10^{13} \times 1.76\times10^{-52}(0.5\times2/4\times10^{-10})^2 = 1.69\times10^{-20}$ 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[6]. Thus the HFGW flux, in W m^{-2}, becomes much larger at the cap of the peanut shaped radiation pattern. According to the analyses of Baker and Black [xi] 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:

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

From Baker, et al. [XII] , Eq. (6A) of the Appendix, the amplitude of the dimensionless strain in the fabric of spacetime is:

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

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, $\Delta f = (2\ N)(1.55\times10^{13} / 333)$. Thus the changes in Eq. (1) cancel out and there is no change in HFGW flux. From Woods, et al.,[XIV] 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 [XIV], 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 [XV]) by introducing superconductor resonance chambers into the interaction volume (which also improves the Standard Quantum Limit; Stephenson [XVI]) 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 [XVII] that could concentrate very high frequency gravitational waves at the detector or receiver.

The HFGW beam is very narrow. From Eq. (4b) of Baker and Black (2009) [XII], for N = 1.55×10^{13} the angle would be $\sin^{-1}(0.737)/\sqrt{1.55\times10^{13}} = 1.87\times10^{-7}$ radians. For N = 333 the angle is 0.0022 radians. This is still narrow, but the double helix configuration certainly reduces the width of the HFGW beam. 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.

4 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 printing equipment might be employed if nanotechnology techniques for them are sufficiently developed for such a precise fabrication.[xx] 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 FBAR pairs are slightly out of alignment and their lines intersect when energized, then the total power of the created GW would effectively be due to $\Delta f =$ $2N\times1.55\times10^{13}\times10 = 3.1\times10^{14}$ N force change, but the number of such levels (of 10 common, undifferentiated FBAR pairs) would be N-10 $= 1.55\times10^{12}$. The resulting beam would be much 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 nanotechnology assembly techniques 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 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 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 nano-technology, three-dimensional printing, and to carefully control their environment, e. g., isothermal, after fabrication during the double-helix HFGW generator operation.

5. Influence of the size of a MEMS

Let us next examine 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 they cancel out and the focusing effect of the more numerous (larger N) increases the flux! Thus the smaller 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 [XVIIi] 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) 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!

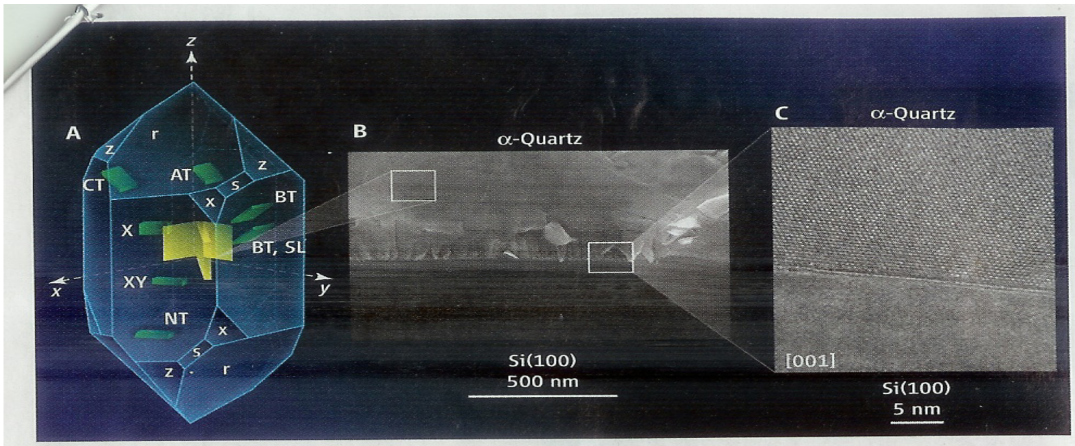

Figure 7 quartz deposited on silicon

Due to new piezoelectric crystal on silicon technology, the dimensions of a typical MEMS, for example an FBAR, went 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

$$S = (1.76\times10^{-52}\,(2\times0.2\times1.55\times10^{18}\times2\times10^{-6}/4\times10^{-10})^2))/4)(\,1.55\times10^{18}/1.71) = 3.83\times10^{8}\ \mathrm{Wm^{-2}} \qquad (3a)$$

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 $\nu_{GW} \approx 1/4\times10^{-10}\ s^{-1} = 2.5\times10^{9}$ Hz or 2.5 GHz into Eq. (4), and $S = 3.83\times10^{8}\ Wm^{-2}$, we find from Eq. (4) $A = 1\text{x}10^{-23}$ m/m one-meter from the end of the double-helix HFGW generator or transmitter. At a greater distance from the double-helix HFGW generator than one meter the A is 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:

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

Therefore the calculated HFGW amplitude is:

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

Thus with Chinese Li-Baker HFGW detector program successful, the quartz deposited on silicon MEMS practical and 3D Nanoscale printing available[XX], **the Li-Baker detector will exhibit sufficient sensitivity to receive the generated HFGW signal globally.**

6. Conclusions

The overall concept is shown in Fig. 8 in very simplified form. In theory the preferred and patented [XIX] 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[XX] and HFGW lenses to concentrate the HFGW signal at the receivers.

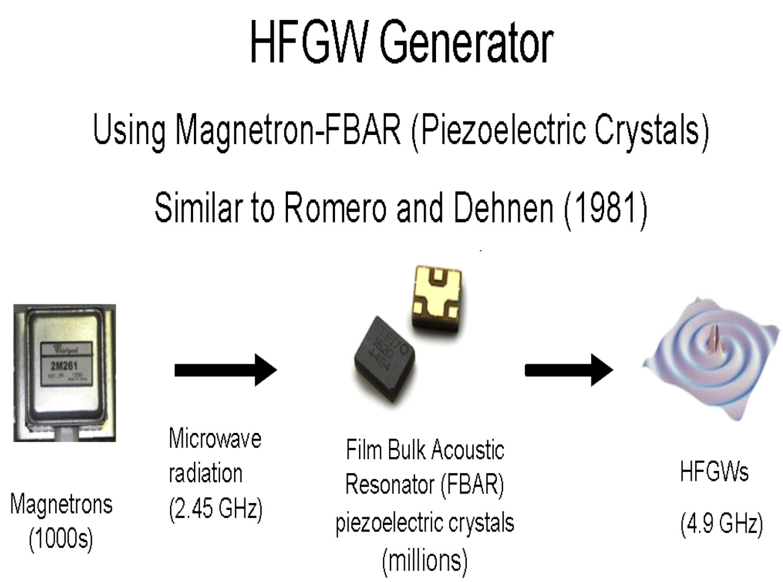

Figure 8. Simplified concept of the HFGW generator.

A HFGW amplitude of the time-varying strain of the fabric of spacetime, A = 3.8×10^{-30} 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 transglobal 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 crystal oscillator study by Dehnen [VII] is probably the most important up to now, but its reliance on old-style 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 transglobal communication. All the relevant literature has been cited that supports the theory and fabrication of the proposed HFGW generator.

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