Brief Overview of the Generation of Gravitational Waves

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GENERAL OVERVIEW

It has been demonstrated theoretically that gravitational waves in the high-frequency band of GHz exist having amplitudes on the order of 10^{-30} m/m, which may be detectable by the proposed ultra-high sensitivity Chinese HFGW detector (discussion of it to be found on this Website in RECENT PUBLICATIONS, item 10; together with American Institute of Physics or AIP peer reviews). In particular, the recent papers by Leonard Grishchuk and Valentine Rudenko at the 2007 2nd High-Frequency Gravitational Wave Workshop (HFGW2), confirm that relic high-frequency gravitational waves or HFGWs certainly exist and that the origin of these HFGWs is the cosmic background associated with the big bang. The interested reader is invited to visit the site for the 2007 Invitational 2nd HFGW Workshop at: www.earthtech.org/hfgw2/ in order to view these papers.

The figure of merit for gravitational wave (GW) generation is that the amplitude of the GW is proportional to the distance between gravitational-wave radiators (e. g., the orbital major axis of a binary black hole pair), the force change (e. g., the orbital centrifugal-force change), the GW frequency and the square of the number of in-phase element pairs, N, involved in the system squared. The N square enters only in this relativistic-based relationship since there is a square in the Quadrupole equation. Each different N has a unique relativistic system associated with it in spacetime (a reference here is Dehnen and Romero-Borja's paper, page 26, item 7 of RECENT PUBLICATIONS in the www.gravwave.com website or page 6 of their actual paper, Eq. (2.24)). As an example, for PSR 1913+16, the distance between the GW radiators (binary neutron stars on orbit) is $4.1\text{x}10^{9}$ m, the change in (centrifugal) force is $1.16\text{x}10^{33}$ N, the frequency is $7.2\text{x}10^{-5}$ s^{-1} or $7.2\text{x}10^{-5}$ Hz and, since there is but one element (one neutron-star pair), it is multiplied by unity. This yields a GW power of $10.1\text{x}10^{24}$ W (very close to the value as obtained using conventional relativistic analyses as shown in this Website as item 3 of RECENT PUBLICATIONS). If we assume that the orbital plane of the star pair is normal to the direction to the Earth and that PSR 1913+16 is $9.5\text{x}10^{15}$ m from the Earth, then the GW flux at the Earth is $2.26\text{x}10^{-8}$ Wm^{-2}. The coalescing binary black holes are much closer to each other of course; however their force changes are billions of times greater and their frequencies momentarily higher than PSR 1913+16. This yields larger GW fluxes that may be detected by the advanced Laser Interferometer Gravitational Observatory (LIGO) and by the Laser Interferometer Space Antenna. (LISA). By the way, such interferometer-based GW detectors are not sensitive for GW frequencies above at most 2 kHz and, therefore, are inadequate for HFGW detection. In the laboratory the aforementioned gravitational force change could not even approach those of the celestial sources so alternative means need to be investigated.

LABORATORY GENERATION OF HFGWs OVERVIEW

A number of devices for the laboratory generation of HFGWs have been proposed including the GASER (a gravitational-wave LASER first proposed by B. Laurent some 40 years ago) discussed by Giorgio Fontana on http://earthtech.org/hfgw2/papers/Talk%203%20The%20HTSC%20GASER.pdf. As well as an actual LASER generator of HFGWs as discussed by Robert Baker, Fangyu Li and Ruxin Li on http://www.drrobertbaker.com/docs/AIP;%20HFGW%20Laser%20Generator.pdf. In order to be specific and for computational purposes, we will utilize the laboratory HFGW generator utilizing magnetron-energized piezoelectric crystals or FBARs (discussion of it to be found on this Website in RECENT PUBLICATIONS, item 7; together with American Institute of Physics or AIP peer reviews). The figure of merit already described is given by relationship (10) in this same reference. This figure of merit can be extended by considering other effects. In the laboratory the force change could not even approach those of the celestial sources. Thus it would seem, at first glance, that the magnitude of any laboratory generated GWs could be best increased by utilizing electromagnetic forces rather than gravitational, by increasing the distance between the gravitational radiators, by increasing the GW frequency and especially by developing a large number of in-phase system elements. This last effect enters as the square of the number of elements, n , as proved using General Relativity analyses by Dehnen and Romero–Borja's analyses, page 26 of item 7 to be found on this Website in RECENT PUBLICATIONS. Such an n^2 dependence also may be the key to successful laboratory generation of GWs, especially High-Frequency Gravitational Waves (HFGWs). In what follows we will briefly consider these aspects of laboratory HFGW generation. The distance between GW radiators may be proportional to the GW wavelength in that it may have a limit that is less than or equal to a GW wavelength. The wavelength is inversely proportional to the GW frequency. Thus given some value for the proportional constant, say unity or the distance between radiators equal to one GW wavelength, the GW frequency cancels out. As already noted it is important to take advantage of square of the number of in phase elements for useful laboratory HFGW generation. If we slice the elements in one dimension (the dimension along the axis of HFGW generation) in order to increase the number of elements, then the change in force per element will be inversely proportional to the number of elements. For example, if the elements are sliced into one hundred separate pieces, then each piece will have one hundredth of the force of the unsliced element. Essentially, f = ma and it is assumed that the acceleration of the element was the same after the split as before. This result also follows Eq. (8), page 17 of item 7, and if there were 100 splits of an FBAR, then the power to an individual slice, P and its mass, m would be both one hundredth of their un-split value and the square root of their product would again be one hundredth. The frequency of the split elements may be a higher value -- but the attendant increase in GW power (proportional to the square of the higher frequency) and the decrease in power due to a smaller distance between tracks (assuming that the distance between tracks is one GW wavelength, which would be smaller) would cancel and there would be no net effect on HFGW amplitude.

It is concluded, therefore, that the amplitude of the generated HFGWs is proportional to the number of in phase elements, N (not the square). A large number of elements for a given HFGW-generator length can be best realized by reducing the size of the individual elements to submicroscopic size (as discussed in U. S. Patent Number 6,784,591 to be found on this Website in RECENT PUBLICATIONS, item 12).

Let us consider the 1.8×10^{8} cell-phone film bulk acoustic resonators or FBARs, 10,000 Microwave-Magnetron, proof-of-concept laboratory HFGW generator discussed on this Website in RECENT PUBLICATIONS, item 7 (together with AIP peer reviews). Assuming a 10 μm distance or margin between the 100 μm on a side conventional FBARs, the overall length of the laboratory generator will be 110×10^{-6} m x 1.8×10^{8} elements = 19.8 km. The same result, of course, as that found on p. 18 of item 7. It will have a total HFGW power of 0.066 W and for a distance out from the last in-line, in-phase FBAR element of one HFGW wavelength (6.1 cm) it will have a flux of 3.53 Wm^{-2}, yielding a HFGW amplitude there of A = 4.9×10^{-28} m/m. This result differs from the result on p. 19 of item 7, since there we took the distance out as 1.5 HFGW wavelengths (9 cm). By the way, the inline set of FBAR elements also produces a more needle-like radiation pattern of HFGWs so that the flux and resulting A may even be larger. Although the frequencies may be different one can extrapolate approximately from the results of Dehnen and Romero–

Borja's analyses, page 26 of item 7 in which the angle of the needle-like radiation pattern is inversely proportional to the square root of the product of the distance between the radiators (the width between FBAR bands or tracks) and N. The distance for the system discussed here is 6.1 cm and for Dehnen's system 0.00001 m, for a factor of 6,100 and N differs by $1.8x10^8/5x10^7 = 3.6$ for a product of $2.2x10^4$ and the inverse of the square root is $6.7x10^{-3.}$ Using the result from Dehnen's paper (Eq. (4.51), page 12) of a needle half angle of 1.7 degrees we would extrapolate to 0.0115 degrees or very approximately $2x10^{-4}$ radians.

Since we are no longer constrained to the use of rudimentary off-the-shelf components as we were for the proof-of-concept apparatus, we can manipulate the submicroscopic elements. First, we will stagger them into two bands or tracks of 100 rows each or 110x100μm = 1.1 cm wide bands of FBARs a wavelength or 6.1 cm apart. We will stagger the rows, as shown schematically in Fig. 2, p. 19 of item 7, by displacing adjacent rows in the bands by 1.1 μm. Thus the overall length will be reduced to 198 m. Second, we can slice the 100 μm length of each FBAR element, along the direction of travel of the HFGW build up, into one-hundred 1 μm wide slices (exhibiting 0.1 μm margins). The staggered row displacements are now reduced to 11 nm. The overall length will be reduced to about 198 cm. Concentrating the 10 MW power to each of these 1.1 cm wide bands may prove to be difficult. Thus, as an example, we will replace the continuous-wave Magnetrons by a pulsed microwave source having one-microsecond-long pulses one second apart. The required average power for each FBAR band will now be 10 W. As a practical nano-technology limit, we could reduce the slice width by two orders of magnitude to 10 nm. This would also require that the row displacements would be 110 pm (we are now into atomic if not sub-atomic dimensional changes). The overall length could be reduced to about 2 cm or the amplitude of the HFGWs could be increased to $A = 4.9x10^{-26}$. In this latter case the average energizing microwave power applied to each band would need to be increased to 1 kW. A preferred compromise in this apparent nano-technology limit might be to reduce the HFGWs generator's length to about 20 cm and increase the HFGW amplitude A to $4x10^{-27}$ m/m.

LABORATORY-GENERATION HFGW ELEMENT OVERVIEW

The complimentary approach to optimizing a practical HFGW generator is to increase the force produced by each element without increasing the required power, i.e., increasing element efficiency. This was initially done using the modern light-weight piezoelectric FBARs rather than the heavy 10-gram crystals considered by Dehnen and Romero-Borja that were of 1981 vintage. Their paper on HFGW generation, utilizing conventional general-relativity analyses of a piezoelectric-crystal HFGW generator, which agrees to within half a percent with our approach, can be viewed on this website at the end of item 7. Special designs of FBAR-like elements for optimum force-generation efficiency will improve the HFGW generator performance beyond that for the usual cell-phone FBAR designs.

Another approach to element design is to utilize lasers whose targets are the force-generating elements. This HFGW generator means is initially presented in the www.DrRobertBaker.com Website under PUBLICATIONS AND COMMUNICATIONS, AIP; HFGW Laser Generator (Baker, Li and Li paper http://www.drrobertbaker.com/docs/AIP;%20HFGW%20Laser%20Generator.pdf). Utilization of myriads of nano-scale lasers would generate high-frequency HFGW pulses as analyzed on this Website in RECENT PUBLICATIONS, item 7 (together with AIP peer reviews).

Several other possible HFGW force-generation elements are noted in U. S. Patent Number 6,784,591 to be found on this Website in RECENT PUBLICATIONS, item 12. Thus there are a number of opportunities to enhance HFGW generation performance, utilizing special element designs, either by reducing the generator size or increasing the generated HFGW amplitude or both.