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Input Power Requirements for High-Frequency Gravitational Wave Generators

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Abstract: An analysis is accomplished of the input power requirement of High-Frequency Gravitational Wave (HFGW) generators. Several techniques are explored using both off-the-shelf and advanced-nanotechnology generator elements. It is concluded that proof-of-concept test, involving *N* off-the-shelf array elements could be of meter to kilometer length and require 25 MW or less power if array elements are in a staggered arrangement. The power and size of an operational nanotechnology HFGW generator or transmitter device can be greatly reduced by the focusing effect of N^2 radiator pairs. Utilization of conventional piezoelectric Film Bulk Acoustic Resonators (FBARs), tailored and scaled for HFGW generation, could provide the initial commercial generation means. The use of the new infrared-energized ring concept of Woods and the use of a double helix array proposed by Baker may even further reduce the power and size requirements of the device to <<20 W and mm in length and width.

Keywords: High-Frequency Gravitational Waves, HFGW, gravitational wave generator, laboratory GW generation
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INTRODUCTION

It has been demonstrated theoretically that high frequency relic gravitational waves (HFRGWs) in the high-frequency band of 10 GHz exist having amplitudes on the order of 10^{-30} m/m and that may be detectable by the proposed ultra-high sensitivity Li-Baker Chinese HFGW detector (Li et al., 2008; Baker, Stephenson and Li , 2008). In particular, the recent papers by Leonard Grishchuk (1977a; 1977b; 2007 and Grishchuk and Soloklin, 1991), 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. If such a detector has been built and satisfactorily tested by sensing HFRGWs, then the laboratory generation of High-Frequency Gravitational Waves (HFGWs) can be considered. The figure of merit for such gravitational wave (GW) generation (Baker, Stephenson and Li, 2008) 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 number of in-phase element pairs, *N*, involved in the system squared. (Romero and Dehnen, 1981; Dehnen and Romero, 2003, page 6, Eq. (2.24)). As an example, of low-frequency GW generation, for PSR 1913+16, the distance between the GW radiators (binary neutron stars on orbit) is 4.1×10^9 m, the change in (centrifugal) force is 1.16×10^{33} N, the frequency is 7.2x10-5 s^{-1} or 7.2×10^{-5} Hz and, since there is but one element (one neutron-star pair), it is multiplied by unity. This yields a GW power of 10.1×10^{24} W (very close to the value as obtained using conventional relativistic analyses (Baker, 2000a)). 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 9.5×10^{15} m from the Earth, then the GW flux at the Earth is 2.26×10^{-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 proposed Laser Interferometer Space Antenna. (LISA). In the laboratory the aforementioned gravitational force change could not even approach those of the celestial sources so alternative means need to be investigated thus one must turn to other means of GW generation. Analyses have shown (Baker, 2006) that only electromagnetic, rather than gravitational forces can be utilized in the laboratory and that HFGWs can be generated there. Interferometer-based GW detectors as LIGO and LISA are not sensitive to GW frequencies above at most 2 kHz and, therefore, are inadequate for HFGW detection.

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 Halpren and Laurent (1964), some 40 years ago) discussed by Giorgio Fontana (2003); as well as an actual LASER generator of HFGWs as discussed by Baker, Li and Li (2006). A rather practical laboratory HFGW generator is one utilizing off-the-shelf components such as magnetron energized piezoelectric crystals or Film Bulk Acoustic Resonators or FBARs (Woods and Baker, 2005; Baker, Woods and Li, 2006). Another, more exotic HFGW generator involves the use of nuclear forces (Fontana and Baker, 2006; Fontana and Binder, 2009). The figure of merit is given explicitly by Baker, Stephenson and Li (2008). This figure of merit can be extended by considering other effects. Since in the laboratory the force change could not even approach those of the celestial sources. it would seem that the magnitude of any laboratory generated GWs could be best increased (1) by utilizing electromagnetic forces rather than gravitational, (2) by increasing the distance between the gravitational radiators, (3) by increasing the GW frequency and especially (4) 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 (Romero and Dehnen, 1981; Dehnen and Romero, 2003). Such N^2 dependence also may be the key to successful laboratory generation of GWs, especially High-Frequency Gravitational Waves (HFGWs). In that regard, recent proposal by Woods (Woods and Baker, 2009; Baker and Black, 2009)) propose the use of infrared-energized atomic nuclei, electrons and or molecules, which have a very large N, contained in a stack of waveguide rings (Patents Pending). In what follows we will briefly consider several aspects of laboratory HFGW generation.

The distance between GW radiators may be proportional to the GW wavelength in that it may have a useful GW-generation 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 un-sliced 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) of Baker, Stephenson and Li (2008a), and if there were 100 splits of an FBAR, then there would be one-hundredth the GW flux resulting from each, but 100 more of them so the net effect according to the N^2 rule would be $(100)^2/100$ or a one-hundred fold increase in HFGW flux 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 (Baker 2000b). 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. 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 by Baker, Stephenson and Li (2008). It will have a total HFGW power of 0.066 W and for a distance out from the last in-line, in-phase FBAR element of one HFGW wavelength (6.1 cm) it will have a flux of 3.53 Wm^{-2}, yielding a HFGW amplitude there of $A = 4.9\times10^{-28}$ m/m. This result differs from the result of Baker, Stephenson and Li

(2008), since they took the distance out as 1.5 HFGW wavelengths (9 cm) not one wavelength or 6.1 cm. Although the frequencies may be different one can extrapolate approximately from the results of Dehnen and Romero–Borja's (2003) analyses in which the angle of the needle-like radiation pattern is inversely proportional to the square root of the product of the distance between the radiators (the width between FBAR bands or tracks) and *N*. The distance for the system discussed here is 6.1 cm and for Dehnen and Romero–Borja's, 2003 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 and Romero (2003) (Eq. (4.51)) 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 the FBARs into two bands or tracks of 100 rows each or 110x100μm = 1.1 cm wide bands of FBARs placed a wavelength or 6.1 cm apart. We will stagger the rows, as shown schematically in Fig. 1, 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 power of each of these small slices will be 10^7 W (10,000 off-the-shelf kilowatt Magnetron energizers) with their power spread over $1.8x10^8$x100 FBAR slices or 0.56 mW for each slice. If we assume a 1 mA current, then the voltage across the 1 μm wide slices is 0.56 V for a 560,000 V/m field strength, which should not arc. 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 nanotechnology 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.

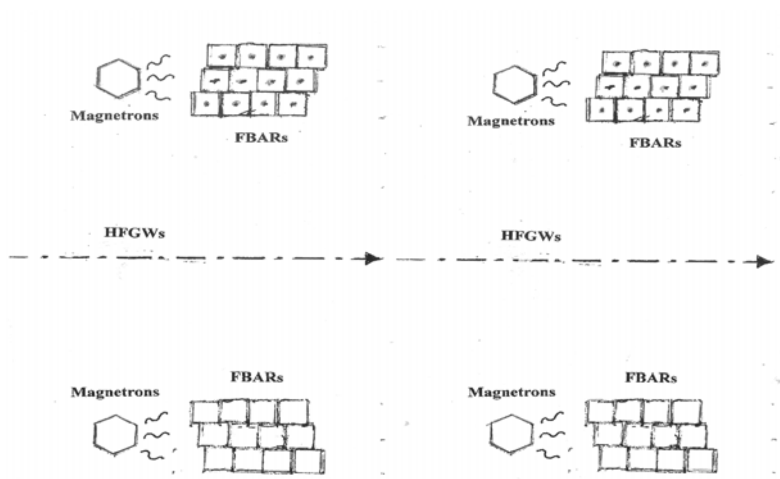

FIGURE 1. Illustration of the Parallel Staggered Tracks of FBARs

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 (Romero and Dehnen, 1981; Dehnen and Romero, 2003), agrees to within half a percent with the approach of Baker, Stephenson and Li (2008), as shown in Baker (2007). 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. Also staggered columns of split FBARs as discussed by Baker (2009) could be placed on double-helix ribbons (Baker and Black, 2009) with the Magnetron energizers conveniently situated on their axes. Another approach to element design is to utilize lasers whose targets are the force-generating elements. This HFGW generator means is initially presented in Baker, Li and Li (2006). Utilization of myriads of nano-scale lasers could generate high-frequency HFGW pulses.

The use of submicroscopic particles for HFGW generation was suggested by Baker (2000b) and was utilized as the basis of an infrared (IR) energized generator by Woods and Baker (2009). There is significant promise for the IR-generated HFGWs (Patents Pending). If you have a standing wave in a waveguide ring and excite it properly, then you have a GW source at its center. Please see Fig. 2 from Woods and Baker (2009). The easiest configuration to analyze requires that two counter-propagating traveling waves be excited inside this waveguide, thus producing a standing optical wave inside the guide. Regions of the guide separated by $\lambda/2$ will oscillate in anti-phase but the resultant HFGW will be in phase, since the produced GW is at doubled frequency. Therefore, this configuration is equivalent to the ring of discrete acoustic resonators (small masses) proposed previously by Woods and Baker (2005) for terrestrial HFGW production. Because the active material vibrates in phase and in opposite pairs and has circular symmetry, all the generated GW will combine in phase at the center of the torus. The GW flux produced at its center is proportional to the N submicroscopic particle pairs in the ring. There is no N^2 build up but there is a N build up. If you have a stack of n rings, which are excited in sequence at light speed as a generated, growing GW passes by, then you have a n^2 build up in GW flux. The IR wavelength is about 2.5×10^{-6}m and the IR waveguide has a cross-sectional area radius of $\lambda/4$ in order for it to be a monomode (lowest order mode) so that the phase doesn't change across the waveguide. Thus the cross-sectional area of each IR ring is $\pi\ (2.5\times10^{-6}\text{m}\ /4)^2 = 1.23\text{x}10^{-12}\text{m}^2$ and its diameter is 1.25×10^{-6} m. The volume of each 100-m radius toroidal ring is $2\pi\ (100)(\ 1.23\text{x}10^{-12}) = 7.7\text{x}10^{-12}\ \text{m}^3$. Woods and Baker (2009) divide the mass density of pentane by its molecular mass and that gives the density of jerkable masses = $6.3\times10^{28}\ \text{m}^{-3}$. Thus the number of masses in a 100-m radius circular wave guide $2N = (6.3\times10^{28})(\ 7.7\text{x}10^{-12}) = 4.85\text{x}10^{17}$ submicroscopic "particles" or potentially jerkable masses. According to Table 1 of Woods and Baker (2009) for pentane $P_i = 4.62\text{x}10^{-16}$ W. Thus the flux for all of the mass pairs in a single ring from Eq. (8) is $(1/2)(2N)(0.01146)\ P_i = 1.29\ \text{Wm}^{-2}$.

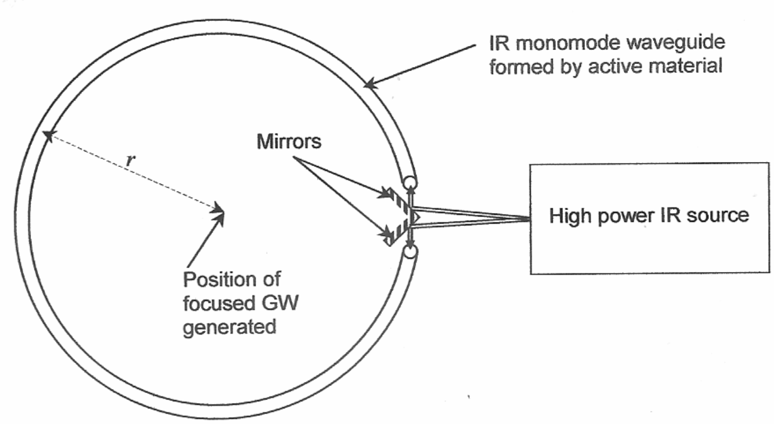

FIGURE 2. Circular Resonator Geometry Using Infra-Red Excitation.

Baker and Black (2009) reduce the ring radius to one meter, but set up 100 rings, concentrically (side by side in the same plane) with an average radius of the one meter. The reduced radius drops the P_i by $(100)^2$ to $4.62\text{x}10^{-20}$, but because of the 100 concentric rings the $N = 4.85\text{x}10^{17}/2$ remains the same. Thus the flux for a single "plate" of concentric rings is $1.29\text{x}10^{-4}\ \text{Wm}^{-2}$. We now stack some 10^6 of these plates on top of one another. Thus a 1.25-m high stack. In this case $n = 10^6$ and we can apply the n^2 law. Thus a HFGW total flux of $1.29\text{x}10^{8}\ \text{Wm}^{-2}$ will be generated by the stack. Of course (as R. C. Woods has pointed out, Woods and Baker (2009)) we need to be careful how much power is fed to each ring. One possible arrangement is to feed the output of one ring to the input of the next. The problem here is that the source won't have a long enough coherence length, even if the attenuation of the IR doesn't kill the power after a ring or two. To avoid this, from one source the available energizing power, on the order of a MW but possibly reducible to less than 20 W, could be divided equally between all the rings and fed to them up the stack at the speed of light. Thus there is some uncertainty in the IR-ring generator and the FBAR generators would be the best for the proof-of-concept tests and the first practical applications. As computed by Baker and Black (2009) for the stack of rings, the amplitude of the laboratory-generated HFGWs is $A = 1.21 \times 10^{-28}$. Clearly 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.

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CONCLUSION

After proving out the Li-Baker detector on relic HFGWs, proof-of-concept tests (involving only off-the-shelf HFGW-array elements) can be accomplished with lengths on the order of 2 km depending upon placement of Magnetrons, FBARs and power lines. The length could be greatly reduced by a factor of 10 to 1000 (due to the N^2 effect for HFGW generated flux) if each track consisted of several close (110μm) parallel -multiple, staggered rows of off-the-shelf FBARs as shown schematically in Fig. 1. (Power proportional to N elements and beam area inversely proportional to N since the pencil beam is narrowed as N increases as shown in Baker and Black (2009)). Such a design would also allow for the power of the Magnetron beam (properly focused) to be more completely absorbed by the FBARs. The power requirement for the 20,000 off-the-shelf Magnetrons on the two linear tracks (not staggered) for the proof-of-concept tests would be about 25 MW, so that a power substation of that size would be required. Power and size of an operational nanotechnology HFGW generator or transmitter utilizing advanced FBARs can be greatly reduced by the focusing effect of N^2 radiator pairs. The use of the IR-rings concept of Woods and Baker (2009) may even further reduce the power and size requirements of the device as a future development. The use of nanotechnology could conceivably result in power and HFGW-generator size of less than 20 watts and only millimeters in length and width.

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