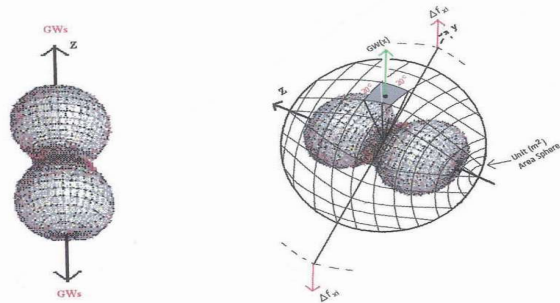


# Gravitational Waves

## The World Of Tomorrow, a Primer



Robert M L Baker, Jr.

This Book is dedicated to my Wife  
Bonnie Sue Baker, MBG



(June, 2016)

Who in the 1960s suggested to me "Why don't you work on gravitational waves? I have a feeling they may be important in the future!"



**Gravitational Waves: The World of Tomorrow**  
**a Primer**

**FOREWORD**

I have been a member of Dr. Robert Baker's Gravitational-Wave Team since 1999. However, our relationship goes back further to when I was preparing for my doctorate at the Massachusetts Institute of Technology. Many of us utilized Dr. Baker's textbooks in Astrodynamics. Many of his orbit-determination concepts progressively led to my selection as Eagle Pilot of Apollo XI and to the successful first Moon landing. Those

were exciting times and somewhat similar to today. With the launch of Sputnik and my journey to the Moon a new era in the world of tomorrow arrived: The Space Age!

Now, having actually detected gravitational waves, another new world of tomorrow has arrived: The Gravitational Wave Era! We are now on edge of learning more about the merger of black holes from low-frequency gravitational waves detected recently by LIGO. We can learn even more at the higher end of the gravitational-wave frequency spectrum, possibly about higher-order dimensions, multiple universes, how the universe started ... the Big Bang!

But now of even greater practical importance is the potential use of high-frequency gravitational waves for communication. Since, like gravity itself, these waves go through all matter unattenuated, not absorbed like microwaves. They propagate almost without absorption though interstellar space – and, for example, could convey messages from the star Antares to Earth or from Mars cyclers back to Earth. The high-frequency gravitational wave advantage would be that direct

communication can be maintained without relays even if Mars or the Moon is between the cyclers and Earth. Here on Earth, there would be no need for microwave or cell phone stations, cables or even relay satellites – the ultimate wireless system! However, that is not the main reason I recommend your reading this book. I believe what the world needs are not many more highly trained scientists and engineers, but a greater knowledge of those of you without advanced scientific university background, business people and others with only high school training in science and mathematics. All of us should achieve some fundamental understanding of the basics of science and engineering, now that understanding should include gravitational waves. That is the purpose of this very instructive book and I strongly urge you to read it.

Dr. Buzz Aldrin

ISBN 978-1-4958-1184-1

ISBN 978-1-1182-2 eBook

With Exercises Published December 2016

Amazon.com Gravitational Waves by Robert Baker

## **PREFACE**

This volume is a *primer* that presents the most basic elements of gravitational waves (GWs). It is meant to fill the gap between general news articles and technical treatments in order for the layperson as well as for those readers with considerable scientific background to understand better gravitational waves as well as the potential of gravitational waves in the *world of tomorrow*.

There is always difficulty in writing a book that is valuable reading for persons having different educational backgrounds. Freshly minted PhDs in the physical sciences may find this book too elementary or glossing over important science. Those who measure their last exposure to introductory science courses in decades, may find the book too challenging. In order to bridge this educational gap, five of the more technical sections of the book are optional reading. The reader who chooses to bypass these sections will also find that careful reading of chapters 1 through 4,7,10 and 12 and simply skimming the other chapters, will provide them valuable insights concerning gravitational waves. Equations and arithmetic involved in utilizing such equations are included in the book as being essential to the understanding of gravitational waves. In this regard, an extensive nomenclature of symbols and list of important equations provides a self-contained key to all of the physics and astronomical nomenclature utilized in the book and each equation definition includes a reference to the chapter in which the term or equation is used. A sufficient prerequisite for the book would be a high school course in astronomy, physics and/or engineering.

The prerequisite mathematic background would be algebra, solid geometry and trigonometry. Course or courses in calculus would be valuable, but not essential for the reader.

In general, this book presents compelling routes for individuals in order for them and their organizations to take advantage of the new technology of gravitational waves. Those gravitational waves at the high-end of the gravitational-wave frequency scale may have practical applications. Such high-frequency gravitational waves or HFGWs seem to be of little interest to much of the current research and news media. This neglect is unfortunate since HFGW research, like low-frequency gravitational wave research, is **not** speculative and should be brought to the attention of all parties interested in gravitational waves.

In the Literature Survey Appendix of this book *are in excess of 600 references*. The majority of these references are directly related to HFGW research. Many of them are peer-reviewed and published in recognized journals and conference proceedings dating back to the 1960s. The important points of this considerable HFGW research are spotlighted in this volume although gravitational waves of all frequencies are discussed.

The Literature Survey references also serve as a key to the literature for the purposes of self-study or research. They are in chronological order and are annotated and divided into categories of:

### **Gravitational Waves Basic References**

**Low Frequency (LF) GWs from Orbiting Objects and Black Hole coalescence (mHz – kHz)**

## **Interaction of Electromagnetic and Gravitational Waves (100 kHz – GHz)**

### **Terrestrial or Laboratory Generation of High-Frequency Gravitational Waves (HFGWs 100 kHz – PHz)**

#### **High-Frequency Gravitational Wave (HFGW) Detectors**

#### **HFGW Applications**

#### **HFGW Propulsion and Gravity Modification**

#### **Cosmology: Relic and Primordial Background (HFGW: kHz – THz)**

#### **Gravitational Collapse**

**(Some References are in more than one category.)**

The medium through which gravitational waves move, spacetime, is described in Chapter 1. Spacetime's most difficult to understand dimension, *time*, is analyzed by means of light cones in Chapter 2. Gravitational waves are destined to unlock the secrets of the beginning of our Universe, cosmology. In order to grasp cosmological concepts an understanding of entropy is essential and a simplified description of entropy is provided in Chapter 3. Chapter 4 involves the actual definition of gravitational waves and comparison with other waves. Chapter 5 provides a history of gravitational waves and introduces the basic quadrupole equation from general relativity. Chapter 6 discusses natural sources of low-frequency gravitational waves, or LFGWs, such as the merger of binary black holes, supermassive black holes and neutron stars. Such mergers will enhance our understanding of dark energy and the history and composition of the universe as a whole. The use of interferometers, such as the Laser Interferometer Gravitational Wave

Observatory or LIGO and the proposed Laser Interferometer Space Antenna (LISA) as well as its pre-deployment LISA-Pathfinder mission are discussed in this Chapter.

The reader is introduced to high-frequency gravitational waves, or HFGWs, in Chapter 7. The concepts of diffraction as well as a detailed analysis of the gravitational-wave generation radiation pattern are also presented in this chapter. In Chapter 8 cosmological natural sources of high-frequency gravitational waves from the early Universe are described. In Chapter 9 several possible laboratory sources of HFGWs are discussed.

These laboratory HFGW generators are still in the early development phase. Their possible practical application to communications awaits that development. The same could be said about radio waves before Marconi generated them in the laboratory 25 years after Maxwell published [“A Treatise on Electricity and Magnetism”](#) in 1873. Even though there was no successful radio-wave generator or crystal radio detector at that time, the Treatise stimulated many people to experiment with the concept of radio communication. In the literature survey, Appendix of this book can be found a rich collection of hundreds of HFGW references that may also serve to stimulate the development of HFGW communication as did Maxwell’s Treatise for radio communication. Eight designed or actually built high-frequency gravitational wave detectors or receivers are introduced in Chapter 10. Specifically, the Cruise-Ingley Birmingham University and the Li-Baker Chongqing University high-frequency gravitational wave detectors are described in more detail. Such high-frequency gravitational wave detectors may allow for the reception and analyses of primordial high-frequency waves from the early Universe. These waves could have



been produced in the period of inflation or “The Big Bang”. Unlike light photons, high-frequency gravitational waves would have traveled without attenuation through the newborn Universe. If primordial high-frequency gravitational waves and those from the so-called “brane world” were detected, then extra dimensions of space discussed in Chapters 1 and 11 might be sensed.

Although considerable theoretical work has been published since the 1960s, so far none of the HFGW astrophysical sources from the early Universe have produced signals that have been detectable by these eight different HFGW detector systems. There is a similar situation for the single interferometer detector system (including LIGO and the European Virgo) developed for the detection of LFGWs, whose future development was suggested in 1972 by Rainer Weisse of MIT, but formally announced in 1992. That system’s detection of the theoretically predicted black-hole merger LFGWs emissions was finally announced after 24 years of research and development and a total expenditure of over a half billion dollars of research funds. Eventually, following LIGO’s example, detection of early Universe HFGWs emissions may also be expected.

Chapter 11 discusses miscellaneous opportunities and concepts; a new approach to theoretical cosmology, entropy, parallel universes, or “realities,” and even presents a theory on time travel between universes that could be tested by the detection and analyses of gravitational waves. Chapter 12 considers the very practical applications of high-frequency gravitational waves, especially to global communications, *which is expected to change the world of tomorrow*. Applications of high-frequency gravitational waves to the Search for Extraterrestrial Intelligence or SETI and to interstellar travel, “starshot,” are also presented in this final chapter.

The proofreading by Pennee Conlee Hull, Robin Baker Fell and Diana Dunn Walker is very much appreciated. Ames Reed did an excellent job with many of the scientific drawings. Professor Fangyu Li was instrumental in developing the cosmology sections of Chapter 8. Professor R. Clive Woods provided me with important quotations and information, especially on gravitational-wave optics. Gary Stephenson and Thomas Lane contributed many scientific insights. Dr. Eric Davis provided much of the most up-to-date reference material for this Book and especially for the propulsion section of Chapter 12. Fred Noble, of Wintec Corporation in Palm Springs, California, backed all of the several gravitational-wave patents -- without his assistance, no such patents would have been granted. Transportation Sciences Corporation provided the financial support for the preparation of this Book. And, finally, thanks to my Economic Round Table of The California Club fellow Executives for putting up with yet another presentation of parts of this book on gravitational waves.

Robert M L Baker, Jr., PhD, November 15, 2016

### Postscript

On June 17, 2008, a research group called the JASONS, composed of very influential and respected university scientists, was given a briefing on the generation, detection and applications of high-frequency gravitational waves (HFGWs). The [JASON Report \(JSR-08-506\)](#) on that briefing was published in October 2008. The Report was widely distributed to the US scientific community and various press organizations reported it. The JASON Report stated that “Our main conclusions are that the proposed applications of the science of HFGW are fundamentally wrong; that there can

be no security threat; and that independent scientific and technical vetting of such hypothetical threats is generally necessary. We conclude that previous analysis of the Li-Baker detector concept is incorrect by many orders of magnitude ...” The author of the JASON Report’s basic premise for generating HFGWs was: “*A basic mechanism for generating a HFGW is the direct conversion of an electromagnetic wave into a gravitational one of the same frequency by a strong static magnetic field. This **Gertsenshtein process** is idealized in Figure 3.*” In addition the Report states: “Proposed HFGW detectors *have generally been based upon versions of the inverse **Gertsenshtein process.***” These statements are both incorrect. The *Gertsenshtein process* or effect was published in 1962: M. E. Gertsenshtein, “Wave resonance of light and gravitational waves,” *Soviet Physics JETP*, 14, Number 1, pp. 84-85. The effect is extremely weak and is **not** utilized in most of the modern HFGW generation, detection or applications. ***Specifically, the Gertsenshtein process is not involved in any of the analyses in this Book and the JASON Report does NOT apply to this text.***

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#### EXERCISE SOLUTIONS

1.1 The sports car will back down a spiral below the origin to -1 minute, -2 minute, -3 minute, etc. points.

1.2 The pendulum period will be increased, so at (a) it will be further up the time axis (greater time) and more to the right.

2.1 The trajectory would start out at the coordinate of -1 hour down (the time axis of the cones) and 100 miles out from the polling place or origin of both time cones. It would be a straight line ending at

the 0 hour (pole closes) point and 50 miles out from the polling place at the cone's axis. The voting was missed and not cast!

2.2 The starship Enterprise trajectory would start out at the origin of the upper cone (polling place at the time 0). After one hour it would have traveled' and spread the election results, to the 200-mile point out from the upper cone's axis. Its own light cone would be 100 miles broader at the one-hour point than the one hour point of those who obeyed the speed limit and the Enterprise would have informed more people of the election results.

3.1 There are 5,000 chips (locations) plus 5 individual ski locations multiplied by 2 skies plus a single trash can = 5,011 microstates. The skies stored in their specified locations is one microstate and the chips in the trash can is the second microstate. It should be recognized, however, that there may be several alternative answers! Just explain them.

3.2 The simplified model associates the escape velocity (or speed) with the speed of light. The mass of the black hole remains the same. Therefore, a higher escape speed would be the result of a higher mass density. Essentially, more gravitational attraction to be overcome, so greater escape speed if closer to the mass center. Therefore, a denser black hole of the same mass would be smaller.

4.1 From Figure 4-1 for a water (and other) waves, the frequency,  $\nu = v/\lambda$ . In this equation  $v$  is the speed of the wave and  $\lambda$  its wavelength. Therefore,  $\lambda = v/\nu$  and with  $v = 10$  m/s and frequency equals one wave striking every ten seconds or 0.1 strikes per second or Hz,  $\lambda = 10/0.1 = 100$  m long wavelength.

4.2 From Figure 4-1 for a gravitational wave the frequency,  $\nu$ , is also,  $\nu = v/\lambda$  and solving for the wavelength,  $\lambda$ , we again find  $\lambda = v/\nu$ . In this case  $v = 3 \times 10^8$  m/s and frequency,  $\nu = 10^8$  Hz, so that  $\lambda = 3 \times 10^8 / 10^8 = 3$  meters.

5.1 From Chapter 4, the wavelength,  $\lambda = v/\nu$ . For GWs moving at light speed  $v = 3 \times 10^8$  m/s, therefore, at the Weber Bar the wavelength =  $3 \times 10^8 / 1.66 \times 10^3 = 1.81 \times 10^5$  m or 181 kilometers.

5.2 From Figure 5-4 one can apply trigonometry, that is  $\tan(\Delta\theta) = \text{Opposite-Side}(\Delta f) / \text{Adjacent Side}(200N)$ . So that for  $\Delta\theta = 1^\circ$ , we have  $\tan(1^\circ) = 0.01745 = (\Delta f)_i / 200$  N. So that solving for  $\Delta f$  one finds  $\Delta f = 3.49$  N.

6.1 Since there are  $9.46 \times 10^{15}$  meters in a light year, at a distance of 4.4 light years for PSR1913 +16, its distance at the distance of the Alpha Centauri system, would be  $R = 4.16 \times 10^{16}$  meters. We again assume that its power of  $7.34 \times 10^{24}$  watts, is spread evenly over a sphere of radius  $R$  since low-

frequency gravitational waves (LFGWs) are completely diffracted away and have no preferred directivity (which makes LFGWs a very poor choice for GW applications). The sphere's area is about  $2.18 \times 10^{34} \text{ m}^2$  so that the GW's power flux at the Earth's distance would be about  $S = 3.37 \times 10^{-10}$  watts per square meter. By the way, if we applied the key equation from Chapter 9,

$$A = 1.28 \times 10^{-18} \sqrt{S} / v_{\text{GW}} \text{ m/m}, \quad (9-5)$$

with the GW frequency  $v_{\text{GW}} = 1/\text{period of PSR13 +16} = 1/1.395 \times 10^4 \text{ s} = 7.17 \times 10^{-5}$  per second or Hz, we find the maximum GW amplitude  $A = 2.8 \times 10^{-21}$  m/m, which might be detected by LIGO.

6.2 As in Exercise 5.1, from Chapter 4, the wavelength,  $\lambda = v/v$ . For GWs moving at light speed  $v = 3 \times 10^8 \text{ m/s}$ , therefore, at the low chirp frequency Hz of 35 Hz the wavelength =  $3 \times 10^8 / 35 = 8,570$  kilometers and at 250 Hz high chirp frequency, when the black holes are near to coalescence, the wavelength is about 1,200 kilometers.

7.1 From Equation 7-1

$$\sin(\theta_{\text{diff}}) = \lambda/w = c/v$$

Therefore, with  $c = 3 \times 10^8 \text{ m/s}$  and  $v_{\text{EM}} = 2.5 \times 10^9 \text{ Hz}$  (2.5 GHz),  $\sin(\theta_{\text{diff}}) = 0.12$  and  $\theta_{\text{diff}} = 6.9^\circ$ . The HFGW frequency is twice the EM frequency, so for the GW  $\sin \theta_{\text{diff}} = 0.06$  and  $\theta_{\text{diff}} = 3.4^\circ$ .

7.2 From Table 7-1 the fraction of radiation in the  $10^0$  segment is 0.3445 and contains about the 34 percent of the radiation.

8.1 Roughly ; an average or "root-mean-square" (rms) spacetime strain of  $h_{\text{rms}} = 10^{-10} \text{ m/m}$ .

8.2 The speed of increase of the radius to a point on the surface of the little universe is  $0.01 \text{ m} / 10^{-34} \text{ s} = 10^{36} \text{ ms}^{-1}$ . To make this to be the speed of light, the clock in the little universe would need to be slowed by  $10^{36} / 3 \times 10^8 = 3.33 \times 10^{28} \text{ s/s}$ . Note that during one second (one click of the second hand on the clock in our Universe), the time moves in the little universe  $3.33 \times 10^{28} \text{ s}$  or, since there are about  $3.15 \times 10^{16}$  seconds in a billion years, about  $3.33 \times 10^{28} \text{ s} / 3.15 \times 10^{16} = 1.06 \times 10^{12}$  billion years. Sounds like a lot of time, but in the little universe its first  $10^{-34}$  seconds is still only  $10^{-34} \text{ s} \times 3.33 \times 10^{29} \text{ s/s} = 3.33 \times 10^{-4}$  seconds. If the standard meter is shrunk by  $3 \times 10^8$ , then the time calculation would be unaffected since the given 1 cm radius and time of  $10^{-34}$  seconds in today's Universe remains unchanged.

9.1 The actual hypothesized force created by a miniaturized FBAR is proportional to the FBAR area so the square of the scale factors, that is for Case a)  $\Delta f_a = (2 \text{ Newtons}) \times (1/100)^2 = 2 \times 10^{-4} \text{ N}$  or Newtons. The inverse of the frequency of an FBAR,  $\Delta t$  in seconds is, as already noted, proportional to the thickness that is, the thinner the FBAR the higher its excitation frequency and the smaller the resulting  $\Delta t$ . For the non-miniaturized FBAR  $\Delta t = 4 \times 10^{-10} \text{ s}$  so Case a)  $\Delta t_a = 4 \times 10^{-12} \text{ s}$  and  $v_{EM} = 250 \text{ GHz} = 2.5 \times 10^{11} \text{ Hz}$ . The effective or average radius to the FBAR array  $= r_B = r_{rms} = \sqrt{[(r_1^2 + r_2^2)/2]} = 39.5 \text{ m}$ . The volume of the generator's FBAR array is  $V_B = L \times \pi(r_1^2 - r_2^2) = 1,178,000 \text{ m}^3$ . Therefore,  $N_{Aa} = V_B / V_a = 1,178 / 1.33 \times 10^{-19} = 8.86 \times 10^{21}$ . The main factor in the power equation Eq. (5-6) (or Eq. (5-12)),  $(2r_A \Delta f_a / \Delta t_a)^2_{Aa} = (2 \times 3.95 \times 2 \times 10^{-4} / 4 \times 10^{-12})^2 = 1.56 \times 10^{17}$  so  $P_{Aa} = 0.5 \times N_{Aa} \times 1.76 \times 10^{-52} (2r \Delta f / \Delta t)^2_{Aa} = 1.22 \times 10^{-13} \text{ W}$ .

9.2 The basic enhancement due to superradiance is according Eq. (9-4), for case A), a) at a meter distance is :

$$S(1)_{Aa} = (P_{Aa}/4)/(1.71/N_{Aa}') = (1.22 \times 10^{-13}/4) \times 10^{12}/1.71 = 0.18 \text{ W/m}^2 \text{ and } \sqrt{S_{Aa}} = 0.4242 \text{ and}$$

$v_{GW} = 500 \text{ GHz}$  (GW frequency is twice EM frequency) or  $5 \times 10^{11} \text{ Hz}$ . Therefore at one meter distance from the generator is  $A_{Aa}(1) = 1.08 \times 10^{-30}$ .

10.1 The National Astronomical Observatory of Japan HFGW Detector utilizes two recycling interferometers with arms about 75 cm long whereas the LIGO Interferometers are about 4 kilometers in length. The National Astronomical Observatory of Japan HFGW Detector is sensitive to about 100 MHz ( $10^8 \text{ Hz}$ ) whereas LIGO's LFGW detectors are sensitive to less than 2 kHz to a small fraction of a Hz.

10.2 The Gertsenshtein Effect was published in 1962 and considered the interaction of gravitational waves and electromagnetic waves, specifically light, under the influence of a magnetic field. The Effect is extremely weak and of little value in GW, especially HFGW, detection or generation. The Li Effect was developed by Fangyu Li of Chongqing University in China during the 1990s. Far different from the Gertsenshtein Effect, it relies on an Electromagnetic (EM) beam having the same frequency and direction as the HFGW to be detected. Its only similarity is that it utilizes a magnetic field perpendicular to both EM GW radiation direction and is roughly 30 orders of magnitude more effective than the Gertsenshtein Effect.

11.1 From Equation 11-7,  $L_2^2 = (1 - v^2/c^2) \times L_1^2$  so their ratio of  $(0.5)^2 = 0.25 = 1 - v^2/c^2$ . Therefore,  $v^2/c^2 = 1 - 0.25 = 0.75$  and  $v^2 = c^2 \times 0.75 = 9 \times 10^{16} \times 0.75 = 6.75 \times 10^{16}$  so the  $v = 2.6 \times 10^8 \text{ m/s}$ .



11.2 Since the event occurred at one *instant* of time, ALL the horses would be transferred back and forth at the same time from one osculating universe (“point” in the STU). Thus there would be no change from their Gaussian distributional along the track. Of course, the location of the “starting gate” and “finish line” have no relevance except to set the imaginary scene. It is only the distribution of the vacillating sub-nano particles (“horses”) that counts.

12.1 The propulsion thrust would be like that of EM-propulsion thrust. That is, similar to a Flashlight since both forms of radiation travel at the speed of light and carry very little momentum. Furthermore, only HFGWs (not LFGWs) could be focused in the aft StarCraft direction and the HFGW generation process, discussed in Chapter 9, would require more energy for a given thrust value than thrust created by chemical reaction. Conventional propulsion means, for example, burning hydrogen and oxygen, is far more efficient than either the on-board generation of EM or GW would be.

12.2 From Table 12-1, the time is 40 million years of ability to practice interstellar communication. From Table 12-2 it is  $N = 1.48 \times 10^{16}$  potential intercommunicating civilizations. From Table 12-3  $N_2^2 = 2.2 \times 10^{20}$  and the messages per year,  $f_2$ ,  $5.5 \times 10^{15}$ . Therefore, the messages per day is  $5.5 \times 10^{15} / 365 = 1.5 \times 10^{13}$  and per hour is  $6.3 \times 10^{11}$ . Essentially, the longer the lifetime of advanced civilizations the more chance there is to intercept their interstellar messaging.

## PRAISES DR BAKER'S NEW BOOK

"...I worked my way through your book on gravitational waves. I believe I understood the basics of it, though not all of the details. ... But I certainly learned far more about gravitational waves than I previously knew, and I am grateful for the experience. You have a wonderful gift for explaining the subject with clarity."

Joseph Schulman, MD

Founder and Chairman of the Board of the Genetics & IVF Institute

President of the "Committee of 25"

Palm Desert, California, USA

"Now, having actually detected gravitational waves, another new world of tomorrow has arrived: The Gravitational Wave Era! We are now on edge of learning more about the merger of black holes from low-frequency gravitational waves detected recently by LIGO. We can learn even more at the higher end of the gravitational-wave frequency spectrum, possibly about higher-order dimensions, multiple universes, how the universe started ... the Big Bang!... I recommend your reading this book. I believe what the world needs are not many more highly trained scientists and engineers, but a greater knowledge of those of you without advanced scientific university background, business people and others with only high school training in science and mathematics. All of us should achieve some fundamental understanding of the basics of science and engineering, now that understanding should include gravitational waves. That is the purpose of this very instructive book and I strongly urge you to read it."

Buzz Aldrin,

Pilot of the first manned spaceship to land on the Moon

Melbourne, Florida, USA

“Among other excellent discussions this book presents to me an entirely new concept in multiuniverses. Its Chapter 11 describes the osculation or ”kissing” of other universes with our Universe, not the largest scales of our Universe, at huge black holes or “worm holes,” but instead at the smallest scales where the so-called quantum-mechanical “frenzy” or “foam” exists.”

The Rev. Dr. Cynthia Forde

Association of Professional Genealogists

Hempstead, Texas, USA

“Fascinating explanation of how we will communicate and possibly travel through space upon harvesting the phenomenon of Gravitational Waves. Written for dummies (like me) and intellectuals alike by, UCLA Professor Robert Baker, the world’s foremost expert on the subject. Read the forward by astronaut Dr Buzz Aldrin. I personally am looking forward to experiencing this new "Wave".

“I am an Amazon Kindle Fanatic with around 500 books archived in my kindle library, I occasionally buy hard copies as I did with this marvelous book. I did a lot of back and forth reference and consider Gravitational Waves a must hard copy purchase not only for its Graphics and Photos but for its pending historical value.”

William B. Stevenson, Jr.

Palm Desert, California, USA

“Not familiar with the science of gravitational waves and yet we live in a world that is influenced by gravity, I thought to read this new book by Dr. Robert Baker. What a fascinating and well written read. Gravitational waves influence on time travel and communicating through the core of earth sans satellites was thoughtfully presented and fascinating to read. This book, unto its own, is a TIME TRAVELER for the curious inventor seeking create for the world of tomorrow.”

Robin Fell

Inventor

Santa Barbara, California, USA

Please visit [www.gravwave.com](http://www.gravwave.com)

## REVISIONS

TO: "Gravitational Waves: the World of Tomorrow, a Primer with Exercises," December 2, 2016.

By Robert M L Baker, Jr.

<u>Page</u>	<u>Line(s)</u>	<u>Modification</u>
	18	Copyright ©2017 Robert M L Baker, Jr.
	26	Third Printing, September 1, 2017

**89** last line under Figure 8-6 (2580 -2581) Replace by:

about  $10^{-34}$  seconds after the "Big Bang". Adapted from Cover, *Discover* **23**, No.4.

Stop for a moment! Take a breather before we start to discuss the laboratory generation of HFGWs in the next Chapter. It is very important that you are comfortable with the concept of **superscripts** especially if you are not actively involved with Science, Technology, Engineering and Mathematics or STEM. We introduced superscripts in Chapter 3 on entropy, but for non-STEM readers let's now look at superscripts in more detail. For numbers superscript are compact way to define numbers. For example,  $10^5 = 100,000$  and  $10^{-5} = 0.000,001$ . Sometimes the commas are not included, that is simply 100000 and 0.000001 are used. Also often we express numbers like 500,000 by  $5 \times 10^5$  and 0.000,005 by  $5 \times 10^{-5}$ . Using a calculator try some other examples such as  $(5 \times 10^5) \times (5 \times 10^{-5})$  yourself until you are comfortable with the process. Superscripts also come into equations. For example,  $\pi^2 = (3.14159...) \times (3.14159...) = 9.869,96 \dots$  and  $\pi^{1/2} = \pi^{0.5} = \sqrt{\pi} = 1.772,45 \dots$ , etc. In addition, superscripts come into play with units such as speed in meters per second or m/s or  $\text{ms}^{-1}$ .

**90** 8-11 (2587-2593). Replace these lines in Exercise 8.2 by:

Consider a point on the surface of an "assumed" spherical universe shown in Figure 8-6 pictured at time  $10^{-34}$  seconds, which using our current Universe's meter length is given to be 1 cm in radius in the picture. By about what factor must we speed up a clock while the little universe is inflating (or "maturing") after the "Big Bang" to allow for the travel between the origin of the little spherical universe and its surface utilizing today's current meter and an assumed constant, light speed of  $3 \times 10^8$  m/s? Suppose the meter were shrunk by  $3 \times 10^8$  in the little universe. What would be the effect on its clock?

**100** 7 Replace line 2829 by:

beam radiation pattern half-power vertex angle,  $\theta_{1/2}$ ) and the flux (watts  $\text{m}^{-2}$ ) thereby increased. Sometimes,  $N' = N$  so

**102** 3-5 Replace lines 2906 to 2903 by:

The analogous FBAR construction could be a  $110 \mu\text{m}$  by  $110 \mu\text{m}$  rectangular-section thread consisting of standard  $11.0 \mu\text{m}$  thick,  $110 \mu\text{m}$  by  $110 \mu\text{m}$  rectangular FBAR wafers as shown in Figure (9-7), but strung together rectangular side to side in the thread.

**103** 7-13 Replace lines 2935 to 2941 by the following:

more efficient FBARs]  $\Delta f = 2$  Newtons for a standard off-the-shelf 11  $\mu\text{m}$  thick FBAR wafers. (<http://www.gravwave.com/docs/Am%20Inst%20of%20Phys%20009.pdf> ) Therefore, the area of each of the FBARS laying on its edge on any parallel plane is  $110 \mu\text{m} \times 1.1 \mu\text{m} = 1.21 \times 10^{-9} \text{m}^2$  and the total number of the FBAR pairs per plane is  $0.5 \times 0.377 \text{m}^2 / 1.21 \times 10^{-9} \text{m}^2 = 1.56 \times 10^8$ . The number of parallel planes, hence the number of energized sources of HFGWs in the double-helix stack, is the length of the generator divided by the FBAR width (like the analogous mattresses, they are all on edge in any level) or  $20\text{m} / 1.1 \times 10^{-4} = 1.82 \times 10^5$ . Therefore, the total number of FBAR pairs,  $N$ , is  $(1.56 \times 10^8) \times (1.82 \times 10^5) = 2.84 \times 10^{13}$  and the number of energized sources  $N' = 1.82 \times 10^5$ . We assume for

15-20 Replace lines 2943 to 2948 by the following:

excited. They generate only one gravitational-wave and/or GW power source at the center, consisting of all  $1.82 \times 10^5$  FBARs being excited in a given plane simultaneously as EM energizing radiation moves plane to plane up the axis of the double helixes. The total number of energized GW sources  $N = 2.84 \times 10^{13}$ .  
For

32 Replace line 2960 by:

$$P = 1.3 \times 10^{13} \times 1.76 \times 10^{-52} (0.5 \times 2 / 4 \times 10^{-10})^2 = 1.43 \times 10^{-20} \text{ W}.$$

104 19-20 Replace lines 2982- 2983 by:

$$S(1\text{m}) = (P/4) / (1.71/N') =$$

$$(1.43 \times 10^{-20} / 4) / (1.71 / 1.82 \times 10^5) = 3.8 \times 10^{-16} \text{ W m}^{-2}. \quad (9-4)$$

104-105 25-28 Replace lines 2988 to 2996 by:

with  $v_{\text{GW}} = 2 \times v_{\text{EM}} = 5 \times 10^9 \text{ Hz}$ ,  $A = 1.28 \times 10^{-18} \times 1.95 \times 10^{-8} / 5 \times 10^9 = 5 \times 10^{-36}$ . So that at a one-meter distance from the double-helix generator  $A(1) = 5 \times 10^{-36} \text{ m/m}$ . (Unlikely, but possibly detectable by the Li-Baker HFGW detector to be discussed in the next Chapter 10, especially if closer than one meter to the generator.) If a detector were at a  $1.3 \times 10^7 \text{ m}$  (diameter of Earth) distance, then  $S(1.3 \times 10^7 \text{ m}) = 2.2 \times 10^{-30} \text{ Wm}^{-2}$  and the maximum amplitude  $A$  of the HFGW is given by  $A(1.3 \times 10^7 \text{ m}) = 3.8 \times 10^{-43}$ . Certainly, not useful for trans-global HFGW communication.

105 2&3` Between lines 2996 and 2997, insert:

Also of interest is the spread or, alternatively, the concentration of generated HFGWs. For  $N' > 1$ , the aforementioned half-power point angle,  $\theta_{\%}$ , of the radiation pattern for a multi-element generator, such as the double helix, is given by Eq. (4b) of Baker and Black (2009), "Radiation Pattern for a Multiple-Element HFGW Generator":

<http://www.drrobertbaker.com/docs/Analyses%20of%20HFGW%20Generators%20and%20Radiation%20Pattern.pdf>

$$\theta_{\%} = \sin^{-1}(0.737/\sqrt{N'}). \quad (9-6)$$

Above 5<sup>th</sup> line up, or above line 3013, insert the following paragraph:

We now embark on a very hypothetical, possibly imaginative task of estimating the effect of miniaturizing the FBARs or some excitable MEMS vibrator to nanometer sizes. Ultimately only

experiments will provide the actual specifications, but we will make some “educated guesses.” As determined from the work of Snil A. Behave and Roger T. Howe (U. S. Patent 7522019, April 21, 2009), the electrostatic force impulse or jerk for a parallel-plate electrostatic transducer, such as a FBAR, is proportional to its surface area. For a square, nominal FBAR wafer, with a 2 Newton  $\Delta f$ , having dimensions  $110 \mu\text{m} = 1.1 \times 10^{-4} \text{ m}$  on a side, its nominal area is  $1.21 \times 10^{-8} \text{ m}^2$  and the  $\Delta f$  of smaller FBARs can be approximately computed as ratios of this area.

Last line, Replace Line 3017 by the following:

can be separated precisely along the double-helix axis so that  $N'$  approaches  $N$ . The situation is a bit complicated at these small scales. Atoms of silicon are 0.078 nanometers or nm apart, water molecules are about 0.27 nm across. However, to control the location of a nano-FBAR much less than about 0.1 nm is difficult. For example, nanocar races “... typically jolt their molecular (cars) along 0.3 nm each time ...” (NATURE 544, p.279 and <http://scim.ag/nanocarrace> ). So in any given direction nano-FBARs could not be easily situated to locations to a precision much better than one-tenth nm by winding very thin nm-sized thread. As we have suggested a

106 Replace lines 3029 – 3048 by the following:

For another example, consider a ten times larger, 200-meter long generator (designated as case B), with an outside radius of  $r_{1B} = 50 \text{ m}$  and an inside radius of the FBAR array of  $r_{2B} = 25 \text{ m}$ . The effective or average radius to the FBARs in the array =  $r_B = r_{rms} = \sqrt{[(r_1^2 + r_2^2)/2]} = 39.5 \text{ m}$ . The volume of the FBAR array would be  $V_B = L \times \pi (r_1^2 - r_2^2) = 1,178,000 \text{ m}^3$ . The dimensions of the nano-FBARs are  $1/1000^{\text{th}}$  of the nominal FBAR (case b) or  $1.1 \times 10^{-8} \text{ m}$  thick and  $1.1 \times 10^{-7} \text{ m}$  on a side. The area is  $A_b = 1.21 \times 10^{-14} \text{ m}^2$  and the volume of an  $\text{FBAR}_b$  is  $V_b = 1.33 \times 10^{-22} \text{ m}^3$ . Since the force (jerk) is proportional to the nano-FBAR<sub>b</sub> area,  $\Delta f_b = (2 \text{ Newtons}) \times (1/1000)^2 = 2 \times 10^{-6} \text{ N}$  or Newtons. The inverse of the frequency of an FBAR,  $\Delta t$  in seconds is, as already noted, proportional to the thickness that is, the thinner the FBAR the higher its excitation frequency and the smaller the resulting  $\Delta t$ . The  $v_{GW}$  is twice  $v_{EM}$ . Therefore,  $\Delta t_b = 4 \times 10^{-13} \text{ s}$  and  $v_{EM} = 2.5 \text{ THz} = 2.5 \times 10^{12} \text{ Hz}$ . As far as the number of nano FBARs,  $N_{Bb} = V_B / V_b = 1,178,000 / 1.33 \times 10^{-22} = 8.86 \times 10^{27}$ . By the way, there are no connections, mountings and power feeds in the double-helix HFGW generator since it is the passing EM wave that excites the FBARs. As to structure, the fabrication means would be a nano 3D printer or assembler that are now (2017) in the advanced development stage. The idea here is that the “glue” that holds the nano MEMS/FBARs in the double-helix HFGW generator can be a fraction of a nanometer in thickness. Another way to consider the supporting of the nano-FBAR wafers is that they would be similar to nano-bricks with very thin mortar layers between them and one cylindrical wall “built” (by a 3D printer or fabrication machine) or “mortared in” closely behind another. Imagine the cylindrical structures in the mattress-storage facility one tightly built against another. The good thing about production-assembly “machines” is that they produce uniformly exact copies – every “widget” produced by a production machine is identical. Furthermore, exact copies of structural parts, like nano-helix arms, are a natural result of 3D printing or fabrication. The 3D printers or assemblers could produce items and locate them to a precision “exactness” of one tenth of a nanometer or perhaps better— especially since the production of the double-helix HFGW generator is that of a cylindrically symmetric device (see again the nano-racing cars discussion in NATURE 544, p.279 and <http://scim.ag/nanocarrace> for the state of the art in the nano world).

Since  $(2r \Delta f / \Delta t)^2_{Bb} = (2 \times 39.5 \times 2 \times 10^{-6} / 4 \times 10^{-13})^2 = 1.56 \times 10^{17}$ ,  $P_{Bb} = 0.5 \times N_{Bb} \times 1.76 \times 10^{-52} (2r \Delta f / \Delta t)^2_{Bb} = 1.22 \times 10^{-7} \text{ W}$ . The effect of superradiance is that the HFGW flux,  $S(1)$ , at a one-meter distance from the end of

larger 200-meter double-helix cylindrical array caused by  $N'$  is given by Eq. (9-4). Let us assume that there can be 1000 precise displacements defined by the 3D assembler of any of the FBAR's their long dimension along the generator's axis and fewer in the thin-width dimension, say 100 possible precise displacements of FBARs "laid," perpendicular to the generator's axis by the 3D assembler. Essentially we assume that there are  $1000 \times 100 = 10^5$  "degrees of freedom" or possible precise "locations" of any one FBAR resulting from the ability of locating any given nano FBAR better than 0.1 nm. The *number of levels* or the minimum value of  $N_{Bb'}$  for case B), b) will be  $0.5 \times 200 \text{m} / 1.1 \times 10^{-7} \text{m} = \sim 10^9$ . However, we assume 100,000 degrees of freedom so that  $N_{Bb'} = 10^9 \times 10^5 \sim 10^{14}$  and  $S(1)_{Bb} = (P_{Bb}/4)/(1.71/N_{Bb'}) = (1.22 \times 10^{-7}/4) \times 10^{14}/1.71 = 1.8 \times 10^7 \text{ W/m}^2$  (about 10,000 times the maximum solar flux on our Earth) and  $vS_{Aa} = 4,242$ . Finally,  $v_{GW} = 5 \text{ THz}$  (GW frequency is twice EM frequency) or  $5 \times 10^{12} \text{ Hz}$  and  $A_{Bb}(1) = 1.08 \times 10^{-27}$ . For a distance from the case B), b) generator of one Earth diameter of  $1.3 \times 10^7 \text{ m}$ ,  $S_{Bb}(1)$  is reduced by  $1/1.3 \times 10^7$  squared. So that  $vS_{Aa}$  is reduced by  $1.3 \times 10^7$  and also  $A_{Bb}$ . Therefore,  $A_{Bb}(1)/(1.3 \times 10^7) \sim 10^{-34} \text{ m/m[R1]}$  and may be possible to detect with an improved Li-Baker detector. From Eq. (9-6) the half-power radiation pattern for case B), b) is, with  $N_{Bb} \sim 10^{14}$ ,  $\theta_{1/2} = 7.4 \times 10^{-9}$  or  $4 \times 10^{-7}$  degrees. Note that for case B), b) the radius of the half power point radiation pattern cross section at one Earth diameter distance is  $1.3 \times 10^7 \times 7.4 \times 10^{-9} =$  about 10 cm – very small radiation pattern. However, at 5 light years ( $5 \times 9.46 \times 10^{15}$  meters), the average distance between stars in our galaxy, the HFGW radiation pattern is  $2 \times 5 \times 9.46 \times 10^{15} \times 10^{-9} = 3.5 \times 10^5 \text{ km}$  across. It may be possible to design a device to cause the FBAR array to be more random and thereby increase the HFGW beam width,  $\theta_{1/2}$ , and, of course, decrease the power,  $S$ , and HFGW amplitude,  $A$ . Please remember that these numerical examples are based upon educated guesses and are for only one type of HFGW generator.

Another concern is the amount of power required for the HFGW generation by the double-helix HFGW generators. The power for each FBAR is proportional to its volume or its area times its thickness. For example, a hundred times smaller FBAR of case A) a) has  $100^3$  times more FBARs BUT uses  $(1/100)^3$  less energy than the nominal off-the-shelf FBAR. Therefore, when we scale down the dimensions of the FBAR element we increase their number in exact proportion to the decrease in their required power and there is *no change* in the generator's overall power requirement. Let us digress here for an illustrative example. Suppose we have a 1,000 foot-long ocean liner that has 10 decks and has 10 passageways each having 10 luxurious cabins on each deck. The liner has  $10 \times 10 \times 10 = 1000$  luxurious cabins. If each cabin has a single 60 watt bulb, then there will be  $1000 \times 60 = 60,000$  watts of lighting power. Suppose a 100-foot long sailboat that is  $1/10^{\text{th}}$  the size of the ocean line, which is  $(1/10)^3$  the volume and has but only one luxurious cabin and one 60-watt bulb. Its power requirement of 60 watts and is proportional to its "volume" of  $1/1000^{\text{th}}$  that of the ocean liner's volume and, hence, number of cabins and bulbs. The estimates of the power required to generate a HFGW pulse (that is, to excite a pair of off-the-shelf FBARs) is between 20 and 40 microwatts ( M. Zang (2017), *Journ. of Micromechanics and Microelectronics* **27**, No. 4) or about  $2 \times 10^{-5}$  watts. For the standard, off-the shelf FBAR wafers we have computed that the total number of such FBAR pairs for the first analyzed HFGW generator, having  $2.84 \times 10^{13}$  off-the-shelf FBAR pairs, would be  $2.84 \times 10^{13} \times 2 \times 10^{-5} = 568$  megawatts (divided by 22,500 megawatts  $\times 100 = 2.5\%$  of the Chinese *Three Gorges Dam's* output). Such power is required for each HFGW output pulse of the HFGW generator. Thus it is per  $4 \times 10^{-10}$  second-duration pulse and if the FBARs are excited by a pulsed laser (say, one pulse per second), then  $568 \times 10^9 \times 4 \times 10^{-10} = 227$  watts average power per pulse. In fact, for the much higher frequency of cases A) a) and B) b), the most reasonable way to excite them would be by pulsed lasers. Of course, EM wave excitation of the FBARs would need a high-amplitude wave. Thus periodic *excitation wave packets* radiated by specially designed lasers might be desirable,



**107** 4-10 (3055-3063). Replace Exercises 9.1 and 9.2 by the following:

- 9.1 Consider the  $L_A = 20$  m long double-helix HFGW generator, but enhanced with the outside radius of the generator and hence of the FBAR array  $r_{1A} = 5$  m and the inside radius of the FBAR array  $r_{2A} = 2.5$  m. Term it Case A). Also assume that the FBAR dimensions are reduced by a factor of  $1/100$ . Term it Case a). Therefore, the FBARs are  $1.1 \times 10^{-7}$  m thick and  $1.1 \times 10^{-6}$  m on a side. Compute the force,  $\Delta f_a$  in N for the miniaturized FBARs and their  $\Delta t_a$  and  $v_{EM}$ . Next compute the number of FBAR pairs, their effective radius and the power of the generator in watts – no superradiance need be computed.
- 9.2 Continuing with the enhanced 20-meter HFGW generator of Exercise 9.1. Let  $N' = 10^{12}$  for the number of gravitational wave focus points or individual FBAR pairs lined up precisely along the axis of the enhanced 20 m generator to account for superradiance. What would be its power flux in watts per square meter at distances of one meter? What is the maximum space-time strain  $m/m, A$ , at one meter distance from the generator?

**127** 13 (3471) Replace line by:

to smaller and smaller scales. Time-based entropy change can be related the “SPEED” of a clock; slowed relative to another clock in the moving frames of special relativity of this Chapter or in the accelerated frames in general relativity. In an early universe the clocks could be *speeded up*, one of today’s seconds being billions of “years” as a universe matures. This concept was addressed in Chapter 8, specifically Exercise (8-2), where the main issue was the constancy of the speed of light. The osculation point of one universe with another could be based on not only setting the clocks to be in some sense “simultaneous,” but setting their speeds, slow or fast, appropriately.

**130** 6-8 UP (3603-3605) Replace by:

These include traveling through Archibald Wheeler’s “wormholes,” mentioned in Chapter 1, and the “time-traveling horses” of the SpaceTimeUniverse (STU) “imagined” in this Chapter. Passage or “bubbling out” from one universe to another need not necessarily be at the “large-scale part” of a universe such as Wheeler’s wormholes. It could well be at the very “small scale part” of a universe, where particles come into and go out of “existence” as in Brian Greene’s quantum foam, where there may exist an osculation point between or among universes.

**137** 7<sup>th</sup> line up (3777) replace by:

lasers, a very powerful HFGW beam, such the one produced by the hypothetical 200-meter HFGW generator or  $1.8 \times 10^7$  W/m<sup>2</sup> (at one meter about 10,000 times the maximum solar flux on our Earth), reflected by a possible HFGW

**142** Last line (3938) Add to the line at the bottom of the page:

Another concept here is “transhumanism,” that is, technologies that seek to transform humans and extend life forms indefinitely. As Mark O’Connell asks the question in his book *To Be a Machine* (2017, Doubleday, ISBN 9780385540414), “... whether or not we even need the bodies that we were born with for us to remain *human*?”

**143** 18 (3926) Add to the line:

Some original analyses in this vein was accomplished by V. M. Lipunov (1986).

157 8 up Replace line 4331 by:

$\Theta_{\text{dif}}$  = angular spread of waves caused by diffraction in radians or degrees

$\Theta_{\frac{1}{2}}$  = semi vertex angle of the half-power points of a HFGW generator's radiation pattern in radians or degrees

160 3 Add line after 4372:

$$\theta_{\frac{1}{2}} = \sin^{-1}(0.737/\sqrt{N})$$

Chapter 9

225 13-15 (6581-6583). Replace all of Solution 8.2 by:

The speed of increase of the radius to a point on the surface of the little universe is  $0.01 \text{ m} / 10^{-34} \text{ s} = 10^{36} \text{ ms}^{-1}$ . To make this to be the speed of light, the clock in the little universe would need to be slowed by  $10^{36} / 3 \times 10^8 = 3.33 \times 10^{28} \text{ s/s}$ . Note that during one second (one click of the second hand on the clock in our Universe), the time moves in the little universe  $3.33 \times 10^{28} \text{ s}$  or, since there are about  $3.15 \times 10^{16}$  seconds in a billion years, about  $3.33 \times 10^{28} \text{ s} / 3.15 \times 10^{16} = 1.06 \times 10^{12}$  billion years. Sounds like a lot of time, but in the little universe its first  $10^{-34}$  seconds is still only  $10^{-34} \text{ s} \times 3.33 \times 10^{29} \text{ s/s} = 3.33 \times 10^{-4}$  seconds. If the standard meter is shrunk by  $3 \times 10^8$ , then the time calculation would be unaffected since the given 1 cm radius and time of  $10^{-34}$  seconds in today's Universe remains unchanged.

16-27 (6594-6595). Replace both Solutions 9.1 and 9.2 by:

9.1 The actual hypothesized force created by a miniaturized FBAR is proportional to the FBAR area so the square of the scale factors, that is for Case a)  $\Delta f_a = (2 \text{ Newtons}) \times (1/100)^2 = 2 \times 10^{-4} \text{ N}$  or Newtons. The inverse of the frequency of an FBAR,  $\Delta t$  in seconds is, as already noted, proportional to the thickness that is, the thinner the FBAR the higher its excitation frequency and the smaller the resulting  $\Delta t$ . For the non-miniaturized FBAR  $\Delta t = 4 \times 10^{-10} \text{ s}$  so Case a)  $\Delta t_a = 4 \times 10^{-12} \text{ s}$  and  $v_{\text{EM}} = 250 \text{ GHz} = 2.5 \times 10^{11} \text{ Hz}$ . The effective or average radius to the FBAR array =  $r_B = r_{\text{rms}} = \sqrt{[(r_1^2 + r_2^2)/2]} = 39.5 \text{ m}$ . The volume of the generator's FBAR array is  $V_B = L \times \pi(r_1^2 - r_2^2) = 1,178,000 \text{ m}^3$ . Therefore,  $N_{Aa} = V_A / V_a = 1,178 / 1.33 \times 10^{-19} = 8.86 \times 10^{21}$ . The main factor in the power equation Eq. (5-6) (or Eq. (5-12)),  $(2r_A \Delta f_a / \Delta t_a)^2_{Aa} = (2 \times 3.95 \times 2 \times 10^{-4} / 4 \times 10^{-12})^2 = 1.56 \times 10^{17}$  so  $P_{Aa} = 0.5 \times N_{Aa} \times 1.76 \times 10^{-52} (2r \Delta f / \Delta t)^2_{Aa} = 1.22 \times 10^{-13} \text{ W}$ .

9.2 The basic enhancement due to superradiance is according Eq. (9-4), for case A), a) at a meter distance is :

$$S(1)_{Aa} = (P_{Aa}/4)/(1.71/N_{Aa}) = (1.22 \times 10^{-13}/4) \times 10^{12}/1.71 = 0.18 \text{ W/m}^2 \text{ and } vS_{Aa} = 0.4242 \text{ and}$$

$v_{\text{GW}} = 500 \text{ GHz}$  (GW frequency is twice EM frequency) or  $5 \times 10^{11} \text{ Hz}$ . Therefore at one meter distance from the generator is  $A_{Aa}(1) = 1.08 \times 10^{-30}$ .

227 Replace last (6651-6652) two lines by:

Coast University, an ABET accredited university for the adult learner. He won the UCLA Physics Prize, was the recipient of the AIAA's Dirk