ANALYZING THE PROPAGATION OF RADIOFREQUENCY ELECTROMAGNETIC RADIATION EMITTED BY CELL PHONES AND POSSIBLE EXPOSURE-REDUCING SOLUTIONS

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Abstract

Within the last two decades, cell phones have become ubiquitous among users of all ages around the world, prompting concern over the possible health effects of the non-ionizing electromagnetic radiation used by these devices. While multiple studies have been mainly inconclusive and inconsistent on this matter, a clearer understanding of how cell phone radiation is emitted during usage is needed, along with a possible solution to limit the amount of energy to which users are exposed. In this study, the radiofrequency emission from numerous common cell phones was measured by a Signal Hound BB60C spectrum analyzer attached to a broadband antenna as each phone performed various functions such as calling and texting. For the phone found to have the highest emission levels, cell phone cases were analyzed as possible exposure-reducing solutions. The study examined cell phone cases composed of simple and complex materials, including two cases constructed by the researcher. A relatively inverse relationship was observed between the amplitude of a phone's emission and the distance from the phone. A substantial difference in the amplitude of emission was identified among the various functions examined, with the function of calling emitting the highest and charging and idle the lowest. Among the cell phone cases evaluated, all cases produced an effect on the radiofrequency emission, but only specially designed cases such as the self-constructed cases were effective at limiting or redirecting the emission away from a user. Overall, the radiofrequency emission from cell phones was found to be primarily dependent on which function they were performing, but varied among phone types and changed relative to the phone's position.

Keywords

Radiofrequency Emission, Electromagnetic Radiation, Spectrum Analyzer, Electromagnetic Interference Shielding, Cell Phones

Introduction

Over the past twenty years, cell phones have become an integral part of everyday life for billions of people worldwide. According to the Pew Research Center, 90 percent of American adults own a cell phone as of January 2014 [1]. Cell phone users utilize their devices for several purposes including making calls, sending and receiving text messages, accessing third-party applications, and connecting to the Internet. Cell phones communicate and perform these functions by emitting nonionizing electromagnetic radiation in the radiofrequency range, commonly referred to as cell phone radiation. However, this type of radiation is different than the ionizing radiation found in X-rays and gamma rays, and it cannot break bonds nor cause ionization in the body [2]. Nevertheless, there has been public concern over the health effects of cell phone radiation, particularly because of the frequency and length of time of current cell phone use.

Currently, the vast majority of research and studies on this matter has been inconclusive and has not been reliable enough to prove that cell phone radiation can or cannot lead to adverse health effects. The Centers for Disease Control and Prevention states that more research is needed and that it is not known whether cell phone radiation can lead to negative health effects after many years of use [3]. Although a large number of studies have been focused on whether cell phone use is carcinogenic, other health effects have also been researched. For example, a decade-long, international study named INTERPHONE yielded contradictory results, concluding that cell phone users in the lowest use categories had lower tumor rates than those who do not use cell phones. However, it did find that those who used cell phones most heavily, at least thirty minutes a day for ten years or more, had a substantially elevated risk of brain tumors compared to those who did not use cell phones [4]. The seemingly protective effects at low usage and potentially concerning effects at heavy usage have made the aforementioned study controversial and unreliable. Similarly, the National Cancer Institute observed no increase in brain cancers from 1987 to 2007, the time during which cell phone use became widespread. The study assumed that if cell phones were carcinogenic, then tumors would increase as cell phone use did, but the study failed to account for the differences in cell phone use between those who did and did not develop brain cancers [5]. On the other hand, a study that examined the effect of cell phone use on the brain showed that continuous cell phone exposure for fifty minutes was associated with increased brain glucose metabolism in the area nearest to the cell phone. However, the significance of this elevated metabolic function is unknown [6]. A 2007 Swedish analysis of sixteen case-controlled studies found that a decade of heavy cell phone use created almost twice the risk for acoustic neuroma, and that it is more likely to grow on the side of the head where the cell phone is used more frequently [7]. Other studies have also found adverse health effects, including one from Israel that discovered a relationship between persistent cell phone use and parotid (salivary) gland tumors [8]. In addition, electromagnetic fields from cell phones have been shown to greatly decrease sperm motility in males, along with decreased sperm linear velocity, linearity index, and acrosin activity while increasing sperm DNA fragmentation percent [9]. Furthermore, the International Agency for Research on Cancer has classified the radiofrequency electromagnetic fields used by cell phones as possibly carcinogenic to humans, meaning that an association is possible; however, other complicating factors exist that cause uncertainty [2]. Overall though, no study has been able to definitively establish a causal link between cell phones and cancer or other illnesses [10].

Other factors also have prompted users to take precautions concerning cell phone use. For example, the disproportionate effects of radiofrequency radiation on children compared to adults and the FCC's standards for regulating cell phone radiation that many claim are unreliable [11]. Numerous scientists agree that since the tissue surrounding children's skulls is much thinner than that of adults, children absorb far more electromagnetic radiation emitted by cell phones [12]. Therefore, it is likely that any potential adverse effects from cell phone use would have a greater impact on younger users. Moreover, most studies have not studied health effects in children, despite the fact that children are using cell phones at much younger ages and will be exposed to cell phone radiation for most of their lifetime.

Currently, the relatively brief period of time in which cell phones have become popular has prevented researchers from studying the long term effects of cell phones for usage periods of more than fifteen years. While no substantial evidence has been able to give a definitive answer on how cell phones affect us in the short term, many uncertainties exist that warrant reasonable concern. Over the next several decades, longer term studies will provide greater insight as to the health effects of cell phone use, but in the meantime it is crucial that users are aware of the patterns of cell phone electromagnetic radiation emission and of any possible solutions to reduce exposure to the body. Therefore, unlike previous studies that are focused on the potential health effects of cell phone use, this study evaluates how cell phone radiation emission is affected by factors such as different usage functions of a cell phone, distance from the phone, and differences between the front and back of the phone. It is important to know more about how and to what extent cell phone radiation emission is affected by how we use our phones, because doing so will allow us to understand what behaviors we can change to limit our exposure.

This study was divided into two separate stages based on the two objectives of the project. First, to discover the differences in cell phone radiofrequency radiation when subjected to different conditions, a variety of common cell phones was gathered and used to measure emission levels at different distances and sides while the devices were calling, texting, streaming data, charging and being idle for the control. Then, to analyze potential solutions to reduce a user's exposure was conducted by measuring the same factors while the phone that emitted the most overall cell phone radiation was enclosed in various types of cell phone cases, including two cases constructed by the researcher. Cell phone cases were chosen as potential solutions based upon the claims of several cell phone case manufacturers that their cases reduce a user's exposure to electromagnetic radiation. Previously, no studies have analyzed the specific patterns of cell phone radiation when subjected to different conditions. Also, there is no scientific research that shows any solution is effective at reducing a user's exposure to cell phone radiation.

For the first stage of the study, the hypothesis was that the distance from a cell phone would inversely affect the amplitude of cell phone radiation emission. Several predictions were also made; including that older cell phones would emit a higher amount of radiation than newer cell phones. In addition, it was predicted that of all the tested functions, sending a cellular call would increase a cell phone's radiation the most. For the second stage of the study, the hypothesis was that more complex cell phone cases made of metal and other similar materials would have a measurable effect on the amount of radiation emitted or the direction of emission. One prediction was that plastic cell phone cases would not have any noticeable effect on radiation emission. It was also predicted that without a cell phone case, a similar amount of radiation would be emitted from both the front and back of a phone.

Methods

Stage One

In order to measure the radiofrequency radiation emission, a conventional room was used to simulate a realistic environment in which most users use their cell phones. The equipment used for gathering data was a Signal Hound BB60C spectrum analyzer attached to an Antenna Factor ANT-DB1-LP-RM-01-N broadband antenna. These devices were attached using cables to an HP Pavilion g7 laptop PC, where the spectrum analyzer software was run, and data was collected and stored. The testing apparatus was an elevated cell phone stand, which held each cell phone being tested directly facing the testing equipment at a specific distance, measured and marked on the floor as shown in **Figure 1**. A variety of common cell phones was tested in the experiment, including the iPhone 4, iPhone 5, iPhone 5C, iPhone 6, Samsung Intensity II, Samsung Galaxy S4 Mini, and Samsung Galaxy S5. Each phone was tested individually as it performed the functions of calling, texting, streaming data, and charging. To test calling, each phone made an outgoing call to a landline phone for the lengths of thirty seconds and two minutes. To test texting, each phone received an incoming text message from an independent cell phone. To test the function of streaming data, each phone accessed the same video over a cellular network. To test charging, each phone was connected to its charger. The control for this stage was each cell phone being idle, or inactive, for at least fifteen seconds. Every phone was tested on the front and back sides during each function. All cell phones were tested at the three distances of fifteen centimeters, forty centimeters, and fifty-five centimeters from the antenna. By mimicking the distances of holding a cell phone away from the body while on speakerphone mode, this data can be used to predict trends for emission at closer distances. The phones were not measured at closer distances from zero to fifteen centimeters because at least a full wavelength of radiofrequency emission is needed to obtain accurate measurements, which cannot be gathered at distances closer than those tested.

For every function, each cell phone was secured upright on the cell phone stand platform, and the platform was adjusted to the specified distance away from the antenna. The bandwidth in MHz in which each specific function operates was identified using the software, and measurements were taken in that precise range. The software recorded each individual trial and measured the emission both quantitatively and qualitatively during a function, as displayed in **Figure 2**. The channel power gave the average amount of power for each emission in Decibel-milliwatts (dBm) over the entire emission and was used for collecting data. This procedure was repeated for each function on every phone until there were multiple trials recorded.

For the function of calling, the cell phone called a landline phone to avoid any possible interference that could be caused by an additional cell phone. The time of the trial began when the landline picked up the phone, and when the time for each specific call elapsed, five consecutive measurements of the channel power were taken and recorded. The call was terminated by the landline and the software stopped recording the trial. This occurred for calls lasting both thirty seconds and two minutes – two times chosen for being common cell call lengths.

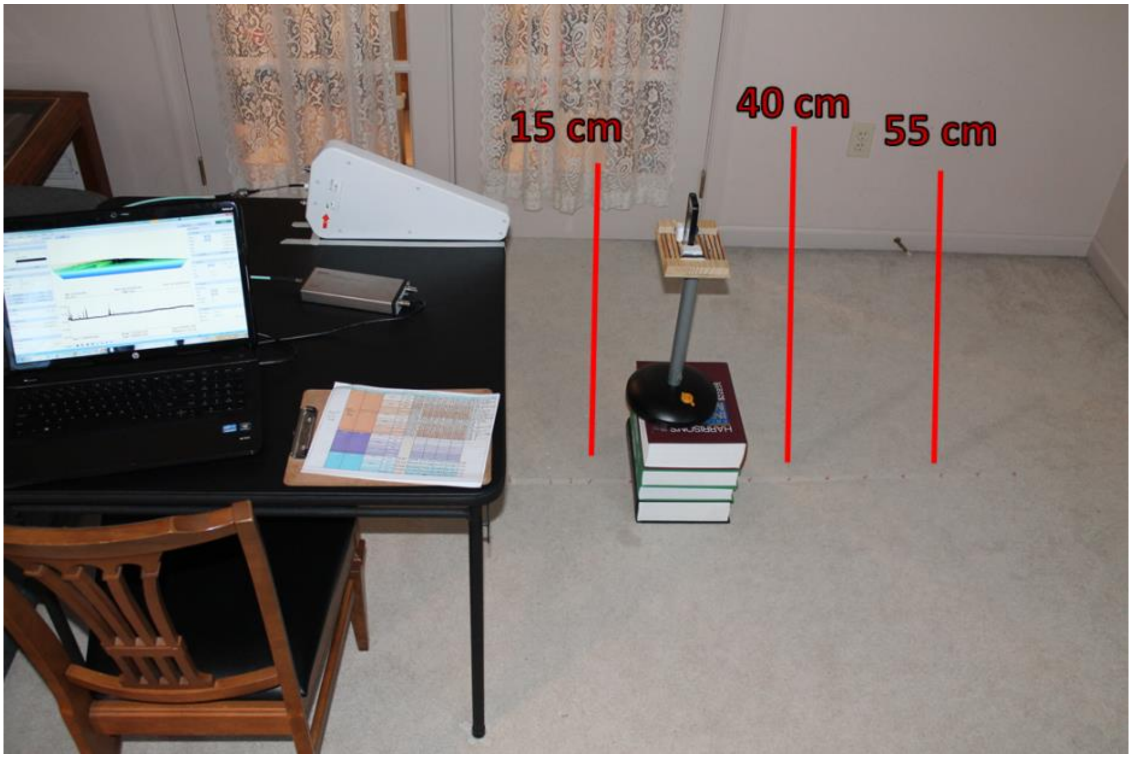

Figure 1. The testing apparatus used for measuring cell phone radiation emission. The table on the left held the antenna, spectrum analyzer, data sheets, and laptop operating the data-collecting software. The elevated cell phone stand secured each phone directly at the three distances during testing.

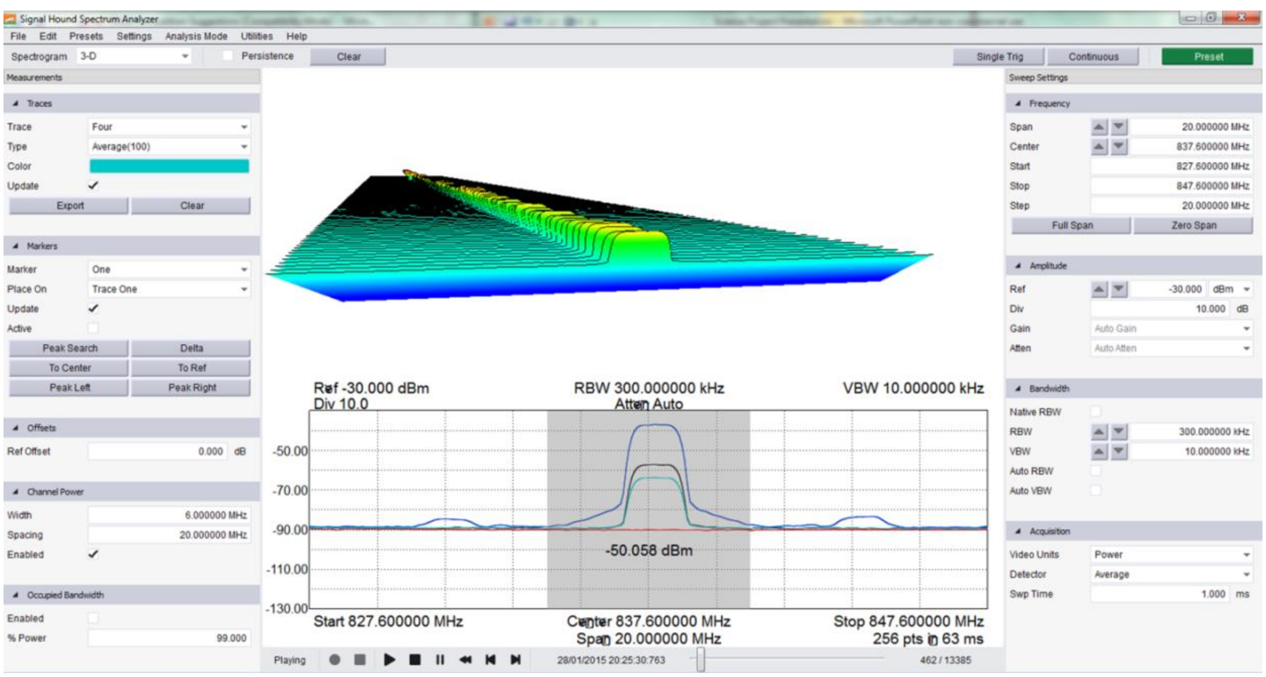

Figure 2. A screenshot of the spectrum analyzer software used for visualizing and collecting data. The chart in the lower center provided real-time feedback of the emission being analyzed. On the y-axis is the amplitude in dBm and on the x-axis is the span of the signal in MHz. The channel power measured the emission in the dark grey area and gave a numerical value underneath. The blue line showed peak emission, the black showed current emission, and the teal showed average emission. The middle top was a 3D representation of the emission.

For the function of texting, the cell phone received a text message from another cell phone that was far enough from the antenna to avoid interference. As the cell phone received the text message and emitted a radiofrequency signal, one measurement was taken of the channel power and recorded.

For the function of streaming data, the cell phone accessed a video on YouTube using 3G or LTE cellular data, depending on each phone's capabilities. The time of the trial began when the video started, and every twenty seconds one measurement of the channel power was taken and recorded, with the first being at 0:20 and the last being 1:40. These multiple measurements were chosen to study the radiofrequency emission over numerous points while streaming data.

For the function of charging, the cell phone was connected to its specific charger that was plugged into an outlet. As the charger was connected to the phone, one measurement was taken of the channel power and recorded.

For the control of the phone being idle, the phone was measured during a fifteen second period of inactivity where the phone was on but the screen was off. After at least fifteen seconds of the phone remaining idle, one measurement of the channel power was taken and recorded.

This stage of experimentation was controlled across several aspects. All cell phones had Verizon as their cellular carrier to prevent any differences in emission based on the carrier. Before every individual test occurred, each phone was straightened and lined up to be directly in front of the antenna measuring its emission and perpendicular to the cell phone stand holding it. There were no other signals or electronic devices emitting a signal besides the phone being tested, as the testing environment and its surroundings were cleared of any possible interference. For every test conducted on a function at a specific distance and on a single side, at least five or more identical trials were conducted, and then an average value was calculated to ensure accurate data was collected.

Once all data was collected for the first stage, all information was organized into spreadsheets. Multiple channel powers for each side were averaged into a single value, which was then used for analyzing the data. The data collected was examined for trends between amplitude of emission and distance from phone, year of phone, and function. All values taken in Decibel-milliwatts were negative, so they were converted to milliwatts for ease of interpretation.

Stage Two

Once stage one was complete, the phone that emitted the most overall radiation, the iPhone 4, was used for exploring potential solutions to limit radiofrequency emission and therefore reduce a user's exposure. Many potential solutions were investigated, but cell phone cases were ultimately chosen to be examined because they do not alter the experience of using the device. Also, several current existing cell phone cases claim to limit a user's exposure to cell phone radiation, chiefly one manufactured by Pong. Several cell phone cases were tested on the iPhone 4 while performing the same tests conducted in stage one to study their effect on electromagnetic radiation emission. The cases tested were a black iPhone 4 Pong Radiation Case, a black plastic iPhone 4 Speck Case, a self-constructed iPhone 4 Case with Plastic Hinge shown in **Figure 3**, and a self-constructed iPhone 4 Case with Paper Hinge shown in **Figure 4**. The control for this stage was the iPhone 4 without any case. The

Figure 3. The self-constructed iPhone 4 Case with Plastic Hinge. This case secured with a Velcro fastener features an electromagnetic shielding flap that folds over the screen, redirects the signal along the hinge, grounds it to the phone's metal, and feeds it towards the back.

Figure 4. The self-constructed iPhone 4 Case with Paper Hinge. This case features the same shielding method as the other self-constructed case, but with a flexible flap that can be shifted to protect the back of the phone as well.

two self-constructed cases were created using multiple materials to limit the amount of radiation emitted towards the head and body of the phone's user. The design of both of the self-constructed cases began with a plastic bumper shell that surrounded the outer edges of the iPhone 4 and a paper or plastic hinge that attached that shell to a foldable flap that blocked the radiation emitted from the screen. To create the flap, a piece of firm cardboard was cut to the size of the phone's screen and black poster board was glued onto its back. A special electromagnetic interference shielding film, called Chomerics EMI Shielding Tech Film, was secured to the front of the cardboard using Chomerics Conductive Copper Foil Tape, which was attached from the Tech Film along the hinge to the inside of the bumper case, towards the back of the case. The film was covered with a piece of black poster board to enclose all sensitive materials. The flap was then glued to the paper or plastic hinge which was glued to the outside of the bumper case. A Velcro fastener was constructed to hold the flap securely in place, and a hole for the phone's speaker was cut to allow for use of the flap during calls. Each case was designed so the Tech Film would block the radiation emission from the front of the phone, and the Conductive Copper Foil Tape would reroute the signal along the hinge to the inside of the case's frame and would ground the signal to the outer metal part of the iPhone 4 and out towards the back of the phone. This stage was controlled using the same procedures and precautions for stage one, with the only variable being the case on the iPhone 4 during testing. Use of the iPhone 4 as a control allowed any change caused by a cell phone case to be measured. The same process for analyzing collected data in stage one was used in this stage.

Results and Discussion

STAGE ONE

Multiple qualitative observations allowed a thorough analysis of each cell phone function to be completed. For the function of calling, the emission produced by all of the calls had a specific signature that was visible on the software. This transmission created a signal that was constant but continually fluctuated vertically, eventually dropping completely off as the call was terminated. The highest peak of emission occurred immediately as the call began and the phone initiated signal with the cellular tower. For the function of texting, the signature signal was more difficult to identify than a call and varied in shape and bandwidth between ranges. A majority of the phones emitted a signal in several elongated bursts that were relatively low in amplitude and that appeared immediately before the incoming text message was displayed on the phone. Older phones such as the iPhone 4 and the Samsung Intensity II emitted a long, narrow burst that increased as the phone received the message and ceased once the phone displayed the message. For the function of streaming data, the visible signal shape was inconsistent and of low amplitude. The shape was similar to that emitted during a text message and in the same bandwidth, but it occurred more frequently. For the function of charging, occasionally very small signal bursts were observed as the phone was plugged into its charger, but charging emitted almost no radiofrequency energy as shown in **Figure 5**. The control of the phone being idle yielded no visible emission of radiofrequency energy and remained unchanged throughout all distances.

The hypothesis for the first stage was accepted because it was demonstrated that the closer a cell phone is located, the more radiofrequency energy it emits. This was shown through the relatively inverse relationship between amplitude of emission and distance, confirming many claims that increasing a user's distance from their phone will reduce exposure. The relationship was established based on the pattern closely resembling the Inverse Square Law. However, it can be identified in **Figure 6** and **Figure 7** that emission levels do not diminish completely after 40 centimeters and that emission levels tend to be higher at 55 centimeters than 40 centimeters. This seemingly contradictory result is likely due to the physical patterns and wavelengths of radiofrequency energy, which do not behave in a predictable manner and therefore can create deviations from expected trends.

Next, it was found that cell phones emit the most radiation during the function of calling, exposing users to a high amount of energy for a long period of time. This is because calling requires a large amount of energy and it is a continuous transmission of data. A user should also know that the peak emission occurs as a burst when the phone firsts initiates a cellular call.

It was also shown that texting and streaming data using 3G capabilities emits a higher amount of radiation than newer phones that operate on LTE technology. The differences between how 3G and LTE networks transmit information explain the slow speed and higher emission of operating an older, inefficient cell phone. Also, it was concluded that a cell phone emits a negligible amount of radiofrequency energy when it is charging or remaining idle. This stage primarily showed that radiofrequency emission levels are primarily based on function, but are affected greatly by increased proximity to the device and other factors relative to the user's environment.

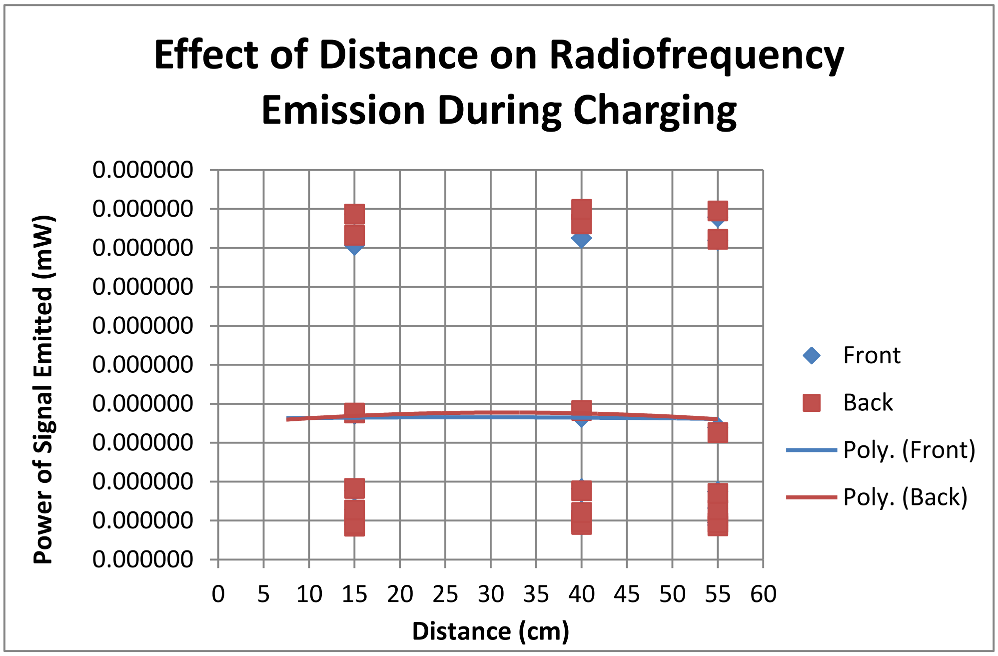

Figure 5. The effect of distance on the radiofrequency emission during the function of charging. The power of the emission is shown on the y-axis and the distance from the phone is on the x-axis. All red points are data taken from the back of the phone and blue points are taken from the front. Polynomial trendlines were used to highlight patterns in the data.

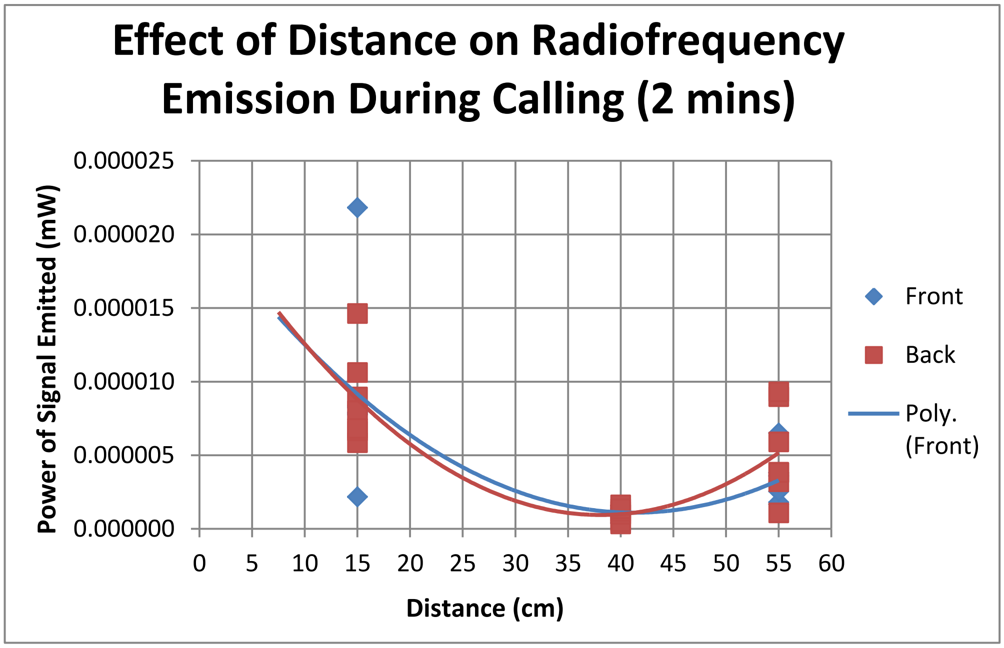

Figure 6. The effect of distance on the radiofrequency emission during the function of calling for 2 minutes. The power of the emission is shown on the y-axis and the distance from the phone is on the x-axis. All red points are data taken from the back of the phone and blue points are taken from the front. Polynomial trendlines were used to highlight patterns in the data and predict emission at closer distances.

STAGE TWO

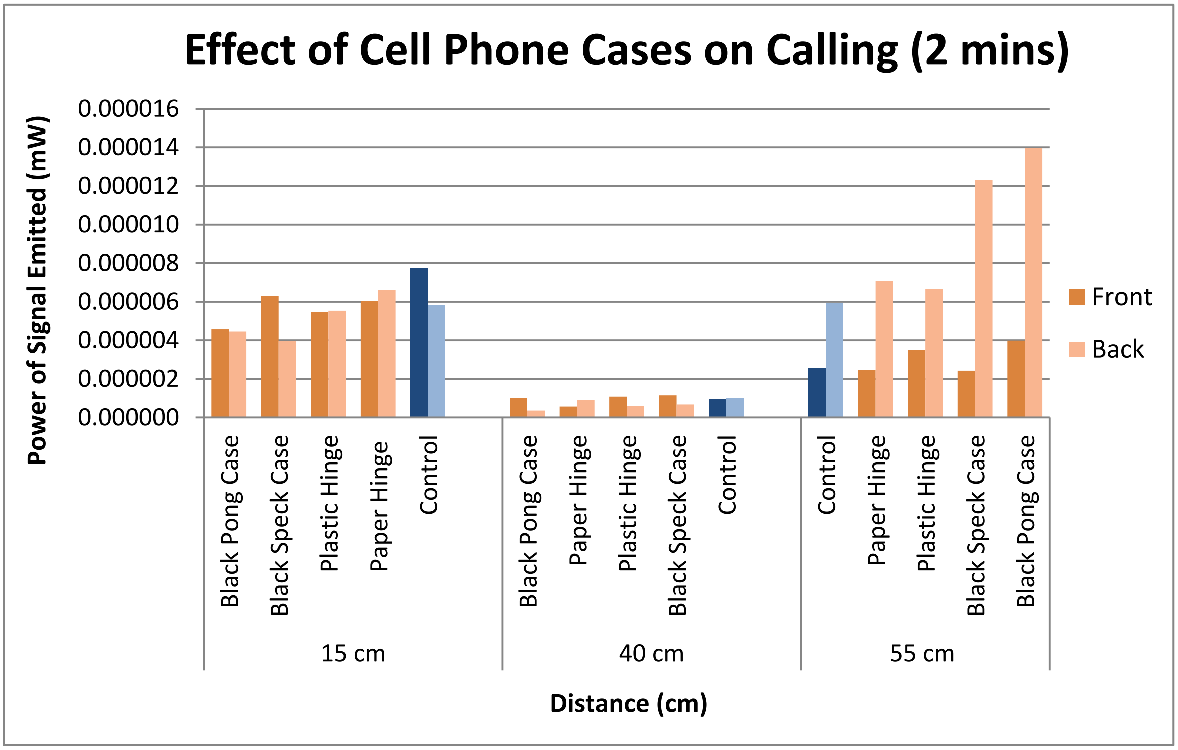

Figure 7. The performance of cell phone cases during the function of calling for 2 minutes at three distances. The power of the emission is shown on the y-axis and the three distances are grouped along the x-axis. Dark orange represents levels from the front of the phone and light orange from the back. Cases are grouped from lowest to highest emission along with the control, highlighting each case's performance.

Throughout the second stage, all cell phone cases were analyzed for how they affected radiation emission, limited emission amplitude, redirected amplitude towards the back of the phone, and performed compared to the control of no cell phone case. For the function of calling at 15 centimeters, the two self-constructed paper and plastic hinge cases were the only cases that redirected the emission more towards the back than the front of the phone, as shown in **Figure 7**. At that distance, all cases were more effective than the control of having no case. At 55 centimeters, all cases redirected more emission to the back of the phone but the paper and plastic hinge cases reduced the emission more than the other cases. For other functions the emissions at 40 centimeters were lower than at the other two distances.

The self-constructed iPhone 4 Case with Plastic Hinge was very effective at limiting emission during calling, but did not do as well at redirecting radiofrequency away from the front of the phone. The self-constructed iPhone 4 Case with Paper Hinge was noticeably effective at redirecting emission during most functions, yet it performed only slightly better than the control at limiting emission. The plastic iPhone 4 Speck Case performed similar to the control, and did not demonstrate an ability to consistently limit or redirect emission. The iPhone 4 Pong Radiation Case performed similar to the control in regards to reducing a user's exposure, but was not effective at redirecting radiation away from the user as claimed.

The hypothesis for the second stage was accepted because cases that included complex materials such as metal did have a measurable effect on the radiation emission and demonstrated a variance from the control. Overall, it was concluded that all cell phone cases affect the radiofrequency energy emitted by a cell phone, but only cases specifically designed and deliberately engineered to limit or redirect radiation in a certain direction are effective at reducing a user's exposure. The significant differences between the control and the experimental groups of cases are evidence of the direct effects caused by using a cell phone case. Next, it was shown that standard plastic cases such as the Speck iPhone 4 Case tested are not effective at limiting or redirecting radiofrequency energy and offer no protection to the user. The Pong iPhone 4 Radiation Case performed similar to a phone without a cell phone case, but its claims of redirecting radiation away from the user were not substantiated and therefore it does not protect a user. However, the two self-constructed cases using a unique flap design were relatively successful at limiting a user's exposure. The paper hinge case was the most effective at consistently redirecting and limiting radiofrequency emission. The plastic hinge case was also effective in these areas. Also, throughout this stage, all cases were observed for potential attenuation of cellular signal, but no cases demonstrated any attenuation of signal strength or battery strain. This stage showed that cell phone cases must be engineered specifically to limit or redirect radiofrequency in order to protect the user and that the two self-constructed cases were the most effective of those tested.

Conclusions

In the first stage of the study, the electromagnetic radiation emission from various cell phones was measured as they performed common functions. A relatively inverse relationship between the amplitude of emission and distance from the phone was discovered, highlighting that a user receives less radiofrequency radiation exposure with increased distance from the device. Also, a significant difference in emission amplitude and behavior was found among the various functions examined. Functions such as calling emitted higher amounts of radiation due to the large transmission of data, while the functions of charging and idle emitted almost no radiation. This stage also revealed that cell phones using older, more inefficient networks like 3G require more energy and emit more radiation.

The second stage of the study examined the effect of several cell phone cases when placed on the phone that emitted the most radiation in the first stage. It was concluded that all cell phone cases affect the amplitude and direction of radiofrequency emission. However, only cases that used methods of electromagnetic interference shielding were effective at redirecting radiofrequency radiation away from the user. Because no signal or battery attenuation was observed as a result of redirecting the emission, this method could be utilized as a screen protector or directly into the front of a phone to reduce a user's exposure. Cell phone cases made out of plastic or cases that claim to limit cell phone radiation are not effective at reducing a user's exposure.

This experiment has been an enriching and rewarding experience, but it would not have been possible without the help of those who supported me in various capacities along the way. First, I would like to thank Signal Hound, for generously allowing me to use specialized equipment to collect data and whose belief in advancing science is reassuring and hopeful. I would like to thank the various companies who donated materials to my project, including Parker Chomerics, Speck, and Pong. I would also like to recognize the many people who supported and assisted me throughout, especially my parents, Mr. Sibbach, Mr. Ambler, Nancy and Erica Wang, and all who donated phones.

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Awards

Capital Area Science and Engineering Fair (CASEF)

Capital Area Science and Engineering Fair
March 2015

- First Place Score
- First Place Overall Category Winner in Physics and Astronomy Category

Pennsylvania Junior Academy of Science (PJAS)

Pennsylvania Junior Academy of Science Region 4 Competition
February 2015

- First Place Award
- PJAS State Competition Qualifier

Pennsylvania Junior Academy of Science State Competition
May 2015

- First Place Award