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WATERPROOF CELLULAR PHONE DESIGN

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Final Report
EE15N: The Life of an Engineering Project

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[1] With Block Diagrams
Cover image from gallery.hd.org

Waterproof Cellular Phone Design

Abstract

The design will waterproof a custom, candy bar cell phone model. The goal is to implement waterproofing techniques with minimum cost, while maintaining durability, aesthetics, and normal cell phone capabilities. The main features of the new cell phone design are touch screen keyboard, parylene-c coated main board, and a sealed cell phone body. Furthermore, the cell phone includes a battery charger that comes with a software application that detects shortage, another application that adjusts for pressure differences and other cell phone components waterproofed by PlastiDip, thermal epoxy and other cost-effective materials.

Executive Summary

With the explosion of the cell phone market in the last few years, there has been an increasing demand for a waterproof cell phone. Recent research suggests that liquid related accidents or activities are responsible for more than 20 % of the cell phone damages. Such frequent occurrence of fluid related accidents of cell phones raises the demand for a waterproof cell phone that is cost-effective and has normal cell phone capabilities. Therefore, the market prospects of waterproof cell phones are positive. The ultimate goal of this engineering project is to introduce a new, innovative, waterproof cell phone to the market that was both affordable and appealing to consumers. Survivability without compromising the popular functions of current cell phone designs is essential to the success of this project and is kept in mind throughout the entire process. By creating a phone that is both aesthetically pleasing and capable of surviving the hazards of an everyday environment, consumers are afforded a luxury that is not currently available in the cell phone industry today, establishing a niche in the market for our product. The approach undertaken focused on decomposing the cell phone into its main components and waterproofing them. For instance, the cell phone was subdivided into the main board, screen, antenna, battery etc. The second step was to prioritize each component in regards to their functional importance. Although cost efficient methods of waterproofing were looked into, the different parts are waterproofed through different methods that varied in cost. The choice of the waterproofing method depended on the cost and the relevant functional importance of the component. After waterproofing each component with relatively cost-efficient methods, the pieces are put together into a complete cell phone design. Generally, the design approach emphasized cost efficiency, aesthetics, and functional importance of each component and the marginal benefits of waterproofing a particular component. Overall, the project was a major success. After a quarter of researching a waterproof cell phone, we discovered that it is very feasible to fabricate such a device. Also, this is possible with a relatively small investment. We estimate that a waterproof phone will cost (not retail) approximately $30 - $60 more than a non-waterproof version. The extra costs for the waterproofing parts and materials is fairly low however the extra testing and quality control required is a large part of the price increase. Therefore, with the proper equipment and testing, this project could be a major success in the field. The approximate cost of this waterproof cell phone is about $180. Compared to the cell phone upon which our product is designed, this is an increase in about $30. The demand for a

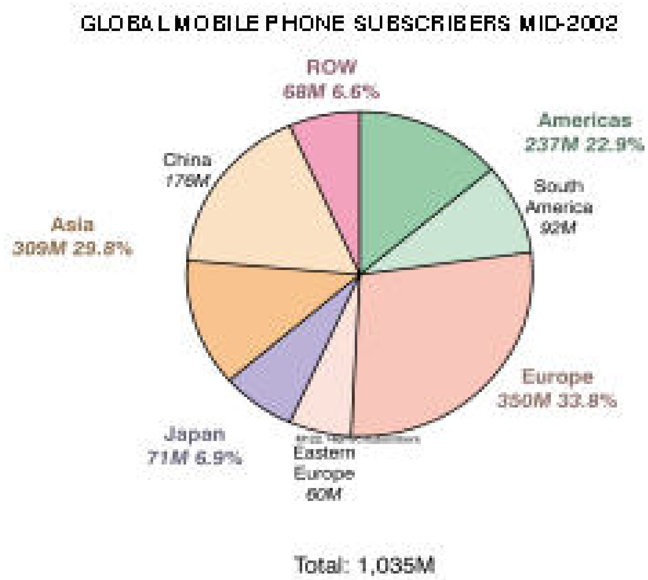
waterproof cell phone outweighs this relatively small increase in cost. If all goes according to plan, the launch date for this phone is October 2006.

I. Introduction

A. Booming Cell Phone Industry

The cell phone market has demonstrated a remarkable growth over a very short period of time and has undergone three generations of mobile phones. Not only is its ubiquity felt in the corporate and business arena, but also in the personal arena where in kids playing around a pool are also seen with their Nokia or Motorola cell phone. Its multi-features, including the ability to take pictures, email, and watch videos, have virtually made the cell phone a mini-PC. Within nearly twenty years, cell phones have transformed from an expensive luxury item, to a basic necessity, especially among developed countries.

When AT&T serviced the first 2000 cell phone customers in 1977, the growth of the cell phone industry to today's level was unforeseen. Globally, the number of cell phones has skyrocketed to1.8 billion. Cell phones have come to outnumber the number of PCs 3 to 1. Just in the US, more than 175 million people own cell phones compared to 4.3 million in 1990.



There are no signs of slowing in the market opportunity the cell phone industry encompasses. For instance, according to a research by Gartner Inc., a major market research firm, "About 812 million mobile terminals--such as cell phones and smart phones--were sold in 2005." Gartner also expects that by 2008, companies will be shipping a billion cell phones worldwide. Users are also constantly looking for new features, accessories, and even decorations that would further the trendyness of cell phones. Particularly, one sector of interest that had not been explored by many major cell phone companies is the issue of waterproofing a cell phone.

B. Why Waterproofing?

A study done by a cell phone insurance company shows that more than 20% of damages result from liquid related accidents or activities. An article by Stanley A. Miller II in *Milwaukee Journal* provides multiple anecdotes, including one in which an information technology manager flushed his cell phone. When he retrieved it after an hour, the cell phone would not turn on. Michael Powers, an executive of the Cellular Telecommunications & Internet Association, estimates that about 54 million cell phones are insured. Considering the level of fluid related accidents of cell phones and the growing market opportunity, a demand for a new waterproof cell phone arises.

C. Problem Statement

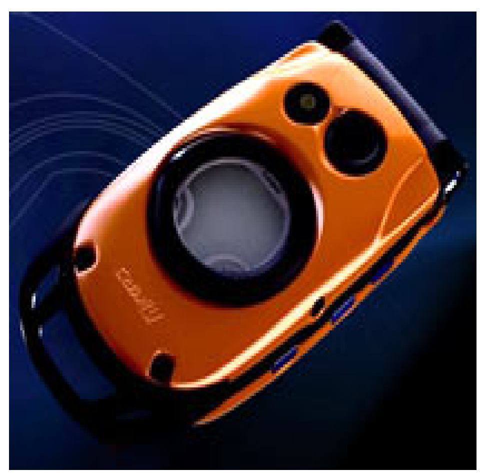
A major problem with cell phone designs is their susceptibility to water damage. With this design we will determine a way to waterproof the individual components of a cell phone and allow for its use in liquid involving activities such as surfing, snorkeling, diving, scuba diving, and even talking in the rain. Current waterproof cell phones are extremely expensive and limited to a single design. We will explore technology and ideas allowing any cell phone to be easily converted into a waterproof model and/or redesigning a new cell phone. Existing circuit boards could be reused but coated with special waterproofing technology and specific parts could be replaced for their hydrophobic counterparts. The transportability of our design to other cell phones would allow it to gain a competitive edge over other products while keeping costs at a minimum.

II. Analysis of the Problem

A. Existing products and background

Waterproof or water-resistant cell phones already exist and are currently available in the market in Korea and Japan. The recent products include G'zOne TYPE-R and Can U 5025 by Casio and LG telecom. Since Can U 5025 is a copied version of G'zOne TYPE-R, their design specifications are the same, with the exception of the network part. These cell phones are suitable for tough environments.

B. Product Specifications



Casio’s cell phone is ideally suited for outdoor use. According to its chief of product planning, *“We’ve worked really hard to come up with something similar that is also durable and water-proof.*”[3] In order to meet such demand, G'zOne TYPE-R is designed to be water-proof, shock resistant, and has a 1.3MP digital camera and electronic compass. These features facilitate outdoor activities such as fishing, camping, and hiking that are likely to expose the cell phone to water, pressure, and shock. Other features include a 2.2 inch QVGA screen, illuminated clock, a stop watch, and USB port. However, there are some limitations that might negatively affect its performance in the market.

3 http://www.idiottoys.com/2005/05/casio-g-shock-phone.html

Pros

- It has a good water-proof capability. It is waterproof up to one meter for a 30 minute duration.
- Its waterproofing technology is to fill its seams with rubber packing. Such design prevents the flooding of water inside the substance and thus sustains all its functional capabilities.
- For its outdoor use, it is also dust-proof. The speaker and the ear piece are designed in a way that prevents the influx of the dust and the water.
- In addition, it has excellent shock-proof features such as magnesium alloy on the main body that makes the phone more shock-resistant.
- It can take video camcorder-quality pictures under water.

Cons

- Despite such excellent features, some of its product reviews available are not positive. To quote one of the reviews, it is "chunky, ugly, plasticky and pretty nasty."[4] The crux of the problem lies in its "chunky" appearance. We live in a time where aesthetic is one of the top priorities in designing technical products.
- Another problem is the cost. It costs about US$500. There is a lack of consensus among customers whether the product is worth the cost.
- Also, because of its added features that enhance its water and shock resistant capabilities, it is relatively heavy.

C. Challenges and Design Constraints

These products are only available in Korea and Japan and are tailored for a very specific part of the population. Considering that a cell phone is a device you use every day, a bulky and rugged cell phone is not likely to have a great appeal to general customers. In other words, sacrificing its slick and cool appearance in order to ensure ruggedness and durability is not the best approach to promote its sales in the general market. In essence, these existing products are narrowly tailored for outdoor activities and therefore, its ruggedness at the expense of aesthetics significantly reduces its appeal to general users.

Our water proof cell-phone will address these problems with the existing products in order to enhance customer appeal and profitability. The challenge is to design a cell phone that is as tough as G'zOne TYPE-R, but less expensive, less heavy, and aesthetically pleasing.

Another challenge is to make sure to waterproof each component, instead of waterproofing the entire case. The existing product's approach is to waterproof the case so that water cannot flood inside by sealing its crevices with rubber packing. Our new water-proof cell phone will waterproof the individual components.

In addition, our cell phone should be deigned to appear aesthetically superior. We will need to make it compact and stylish in order to differentiate our phone from the Casio product and perform well in the general market.

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[4] http://www.idiottoys.com/2005/05/casio-g-shock-phone.html

In sum, our waterproof cell phone should be designed in ways that complement G'zOne Type-R's weaknesses while ensuring high durability and waterproof capability.

i. Objective Tree—Waterproof Cell Phone

An objective tree is constructed "in order to clarify and better understand a client's project statement. Objective trees are hierarchical lists that branch out into tree-like structures and in which the objectives that designs must serve are clustered by sub-objectives and then ordered by degrees of further detail. The highest level of abstraction of an objective tree is the top-level design goal, derived from the client's project statement."[5]

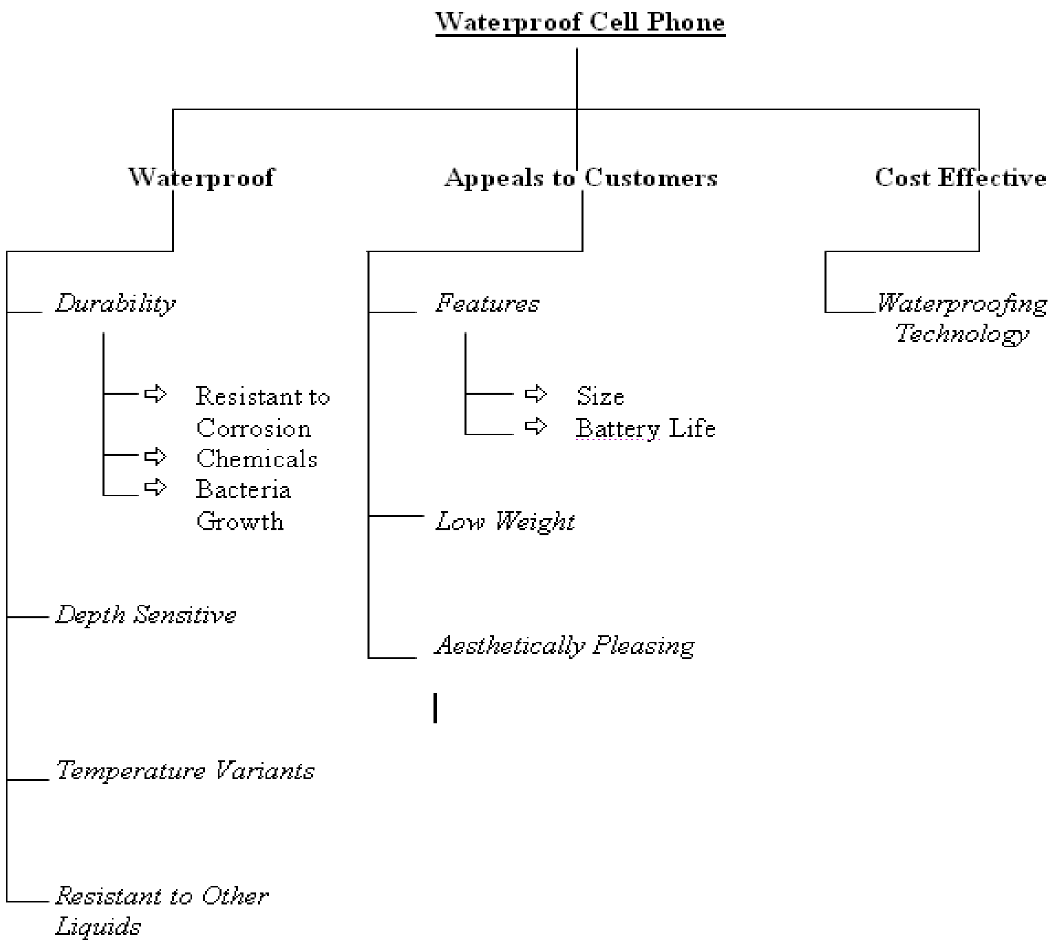


Figure 2.2 The objective tree displaying the objectives and sub-objectives for the waterproof cell phone.

III. Design Alternatives (Trey and Sarah)

A. External Design

The morphological chart was constructed in order to identify the ways or means that can be employed to make the required function(s) occur. This chart is used to provide a framework for

[5] Engineering Design pg 28

visualizing a design space which generates, collects, identifies, stores, and explores all of the potential design alternatives that might solve the design problems.[6]

i. Morphological Chart—Waterproof Cell Phone

Function	**Possible Means**				
Type of Phone	Flip	Slide	Bar	--	--
Antenna	Internal	External	Both	--	--
User Interface	Standard	Touch screen	"Qwerty"	--	--
Waterproofing	Outer Casing	Individual Components	--	--	--
Screen	Color	Black/White	--	--	--
Casing	Metallic	Plastic	--	--	--
Digital Transmission	CDMA	TDMA	GSM	--	--
Battery	Removable	Non-removable	Nickel Cadmium	Lithium Polymer	Lithium Ion

Figure 3.1 Our morphological chart for the waterproof cell phone depicts the functions and the corresponding implementations for each function.

ii. Analysis/Description of Morphological Chart

Most of the morph chart for our waterproof cell phone was constructed by looking at current industry standards and analyzing what comprised them. Unlike other engineering projects that can automatically rule out many combinations by default, our morph chart is somewhat unique in the fact that potentially all of the combinations are distinct possibilities. The goal, then, is to find

[6] Engineering Design pgs 28-9

the arrangement that is most appealing to the consumer, based on criteria such as aesthetics, cost, and weight. The compilation of the best groupings and the metrics to evaluate these are discussed in later sections.

B. Waterproofing Techniques

There are several waterproofing methods associated with each individual component of the cell phone. By establishing which options adequately fulfilled the performance specifications in the most cost effective manner, we were able to determine which technique would be applied. The various options in the design space are detailed below.

i. Battery

The techniques related to waterproofing a battery are dependent on whether or not the battery is a removable component. In the scenario where the battery is not removable, the waterproofing is fairly simple. The battery compartment would remain sealed and interlock with the waterproofing substance used to coat the main board. Alternatively, if the battery were designed to be removable, it would become increasingly difficult to waterproof the component. It would become necessary to design a process that tests whether or not there is moisture present before allowing the compartment to open. This new design would have to implement a feature that ensures the battery's survivability even after constantly being removed and replaced in the compartment as well.

ii. Speaker

Waterproof speakers already exist as a ubiquitous part of the aquatic industry. However, the standard size for existing speakers does not fall below approximately four inches—much too large for our purpose. The two options presented to us were therefore (1) construct a much smaller version of an already existing waterproof speaker, or (2) coat a corresponding cell phone speaker with a waterproof sealant that would protect the component without compromising sound quality.

After researching the possible sealants that could be employed, the field was narrowed to three main choices: polypropylene, mylar, or plastidip. The first option, polypropylene (polypropene) (PP), is a thermoplastic polymer, used in a wide variety of applications, including food packaging, textiles, laboratory equipment, automotive components, and polymer banknotes. An addition polymer made from the monomer propylene, it is unusually resistant to many chemical solvents, bases and acids. The second option, mylar, is a trade name for biaxially-oriented polyethylene terephthalate (BOPET) polyester film used for its high tensile strength, chemical and dimensional stability, transparency, and electrical insulation.[7] It is important to note that mylar is considerably more costly than its polypropylene counterpart, but is subsequently

[7] Courtesy of Wikipedia™

stronger and more resistant to a wider array of chemicals and temperature variants. The final waterproofing technique is PlastiDip, "a flexible, synthetic, multi-purpose rubber coating that exhibits excellent moisture, acid, alkaline, and abrasion resistance."[8] PlastiDip is cheaper than both polypropylene and mylar but still provides a measure of flexibility and insulation intrinsic to its more expensive counterparts.

iii. Microphone

When creating the design space for the microphone, it was of principal importance that the waterproofing technique did not interfere with the sound quality of the cell phone. It soon became apparent, however, that the method was of little importance. If water reaches the microphone element, it will be damaged and the microphone will produce a static noise, but the ability for sound waves to travel through solid and liquid mediums allows for an external coating that does not affect the transmission of sound. Essentially, this implies that the design space for waterproofing the microphone is limitless. A microphone can be covered with anything from PlastiDip to saran wrap and still serve the same function. The main disadvantage of the "coating" waterproofing technique is the inefficient acoustic coupling of the mic element to the water. For our intents and purposes, this disadvantage becomes virtually irrelevant. Survivability is the most important criterion in the design; it is not practical or realistic to expect consumers to answer calls underwater and experience perfect sound transmission.

iv. Main Board

The sole waterproofing technique corresponding with the main board of the cell phone utilizes parylene, a polymer that enjoys a variety of positive attributes including moisture resistance. When applied, parylene has a uniform thickness on all surfaces and is transparent in thin quantities. It is lightweight compared to other possible coatings and withstand temperatures from -200 C◦ to +200 C◦. Concurrently, parylene is insoluble in common solvents and has extremely high dielectric strength.[9]

v. Screen

The cell phone screen often enjoys a preexisting level of water resistance. Thus, the specific challenge associated with this component was finding a sealant that would not alter the amount of pressure the screen could take. The design space included three primary options. The first alternative was to coat an LCD screen or a plasma screen with a transparent, hard coating such as epoxy. Epoxy, or polyepoxide, is a thermosetting epoxide polymer that cures (polymerizes and crosslinks) when mixed with a catalyzing agent or "hardener". Most common epoxy resins are produced from a reaction between epichlorohydrin and bisphenol-A.[10] The second alternative was coating the screen with parylene, a polymer which acts like epoxy, but functions even in high temperatures (mentioned previously). Finally, the third alternative was the employment of a touch screen. The resistive technology of the panel "is coated with a thin metallic electrically conductive and resistive layer that causes a change in the electrical current which is registered as

[8] Courtesy of http://www.plastidip.com/consumer/index.html
[9] http://www.vp-scientific.com/parylene_properties.htm
[10] Courtesy of Wikipedia™

a touch event and sent to the controller for processing. Resistive touch screen panels are generally more affordable [than surface wave or capacitive technology] but offer only 75% clarity and the layer can be damaged by sharp objects. Resistive touch screen panels are not affected by outside elements such as dust or water."[11]

vi. Antenna

For sake of completeness, the waterproofing techniques of the antenna will be mentioned briefly. The main options were to incorporate an internal antenna, external antenna, or a combination of both. Ultimately, it was decided that an internal antenna would be the most effective in our design selection for aesthetic and reception purposes. With this implementation, an internal antenna interconnects with a waterproof sealant to ensure that the signal and component itself remains unaffected by exposure to water.

IV. Evaluations and Results of Design

A. Metrics

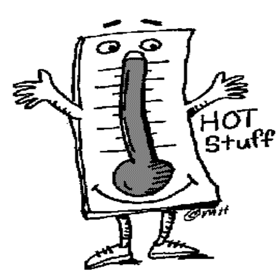
i. Cost (Josh)

One of the most important metrics for this design is the actual cost of creating, developing, and testing this phone. Since a waterproof design is completely new, it will take a lot more time to develop this design. Also, it will require a lot more components to be manufactured in order to make this phone truly waterproof. Therefore, the cost of the phone will be more expensive than those that are lacking the waterproof feature. Finally, testing to make sure that all phones are actually waterproof will add even more expenses to the overall design.

The design is therefore a success if the cost can be held at a level that will not destroy the demand for this phone. The goal is to make sure that this phone is cheaper than some of the more expensive PDA style phones and only slightly more expensive than a non-waterproof version of a similar phone.

ii. Temperature Tolerance: (Josh)

The phone's tolerance to variations in temperature is another metric for this design. While it is a secondary concern, it is still important for the proper functioning of this phone. The goal is to create a phone that can withstand variations in temperature between -20˚C and 50˚C. The phone needs the ability to place calls through this temperature range. Also, the phone needs to maintain its waterproof properties at all of these temperatures. The phone is a success if it fulfills these requirements during testing and consumer use.



iii. Distortion of signal and sound: (Josh)

[11] http://en.wikipedia.org/wiki/Touchscreen#Touchscreen_technology

While the cost of a waterproof phone is perhaps the most important metric for this design, it is encountered very rarely. Once the phone is purchased, the cost of the phone is not a constant concern in the mind of the user. Instead, the quality of phone calls and the sound received is analyzed every day. Therefore, it is very important to insure that this phone does not drop too many calls. It needs to maintain an average number of dropped calls that is on par or better than current phones on the market. Also, the quality of the sound from the phone needs to equate or surpass the quality of phones on the market. Any distortion in the voice from a person should originate from their cell phone and not this waterproof cell phone.

iv. Aesthetics (Berhane)

Aesthetics is quite a challenging item to quantify systematically. However, since one of our core objectives is customer appeal, aesthetics require particular attention. How does an engineering design team measure a customer's preference for certain items? The metrics for aesthetics that was ultimately used was the use of market research analysis from firms like Gartner and Dow that specialize in surveying customers and trends in the market. For instance, this metric of aesthetics was utilized in choosing between metallic encasing vs. polymer encasing. The repeatability of this metrics relies on current trends.

v. Sound and call quality (Josh)

While the cost of a waterproof phone is perhaps the most important metric for this design, it is encountered very rarely. Once the phone is purchased, the cost of the phone is not a constant concern in the mind of the user. Instead, the quality of phone calls and the sound received is analyzed every day. Therefore, it is very important to insure that this phone does not drop too many calls. It needs to maintain an average number of dropped calls that is on par or better than current phones on the market. Also, the quality of the sound from the phone needs to equate or surpass the quality of phones on the market. Any distortion in the voice from a person should originate from their cell phone and not this waterproof cell phone.

vi. Moisture transmission (Berhane)

In evaluating how well the waterproofed cell phone works, it is important to measure the amount of moisture that ingresses into the cell phone. Although internal components of the cell phone including the motherboard are waterproofed, this metrics would be very significant as accumulation of more moisture inside the cell phone can slowly lead to corrosion of metallic body or even affect certain bodies such as the antenna, which have been waterproofed with cheaper methods.

Another important factor with using moisture transmission is its role in evaluating the type of material to use. For instance parylene c has a much lower moisture transmission than epoxy, although both are waterproof coatings. As a result, parylene is a premium coating that will be applied on the motherboard, which is more sensitive to water contact than other parts such as the encasing.

A procedure in which different materials and design bodies are used to compare the results of how much moisture passes through the encasing and materials will be utilized.

vii. Pressure (Berhane)

a. Depth Level

One of the most important metrics that will be used is the response of cell phone product towards different levels of depth. With increasing depth underwater, the pressure will increase. After a certain amount of depth, the cell phone may dismember. Different classifications utilizing depth level exist. For example, one that will be used is class division. Here is an adopted version of a waterproofing metric with regards to depth:

Class 1 – Water resistant for light rain or light splash applications; cell phone can be submerged underwater vertically.

Class 2 – Waterproof underwater pressure, and different pressure variations, while in submersion from various angles

Class 3 – Submersion of cell phone in water or liquid greater than 3 feet in depth

Class 4 – Waterproof and submersible up to 15 feet; suitable for underwater sports such as swimming and snorkeling, where great depths are not common.

These four classes (adopted from http://www.thewaterproofstore.com/wara.html) will provide a basis of analysis for comparing alternatives and testing the cell phone product.

b. Pressure differential

Pressure difference between the internal body and the outside will be measured. An extreme pressure difference can put an undue burden on the exterior body frame and also the inside/outside parts of the screen. As waterproofing usually entails the caulking of junctions between the parts of the cell phone, air inside the cell phone body will be more compressed. The design, through relief valve, will attempt to reduce the pressure difference between inside of the cell phone body and the outside environment.

V. Detailed Design Description and Evaluation

A. Motherboard (Josh)

The motherboard is the most important part of the phone and also the most difficult to waterproof. All communications must pass through this part and the majority of components are located on the motherboard. Therefore, careful consideration was taken in order to properly design a waterproofed motherboard.

The motherboard must be able to send and receive data while submersed in water. However, the components are so tightly packed and dissipate so much heat that they must receive adequate cooling. The processor/DSP and graphics chip dissipate an enormous amount of energy per square inch therefore cooling around these surfaces is even more delicate. Thus, the need to enclose these components for waterproofing directly conflicts with the need to openly ventilate these components in order to remove heat.

The cheapest idea was to simply enclose the board in a sealed compartment; however, it is very difficult to cool the parts. Every single part would need some sort of heat sink attached outside of the compartment. Also, any parts passively cooled inside of this compartment would rapidly heat up and could reach their thermal limits after hours of continuous heating.

The most effective solution is to use a parylene coating on the motherboard. This coating is a thin layer of a clear plastic material. However, this coating can be laid in a very thin layer while still allowing for complete protection against water. This thin layer will then allow for heat to radiate and the motherboard can also be in an open compartment so air or water can be used to passively cool the board. For the extremely hot components like the processor/DSP and graphics chip, heatsinks would be attached to the components and then treated with the parylene coating. This will ensure that even with a slightly decreased cooling efficiency, the heatsinks will compensate for this temperature increase and keep the motherboard at its original level.

Other advantages of the parylene coating are that it has an extremely high dielectric constant. Even though the layer will be extremely small, it will be almost impossible for current to jump between water on the surface of the layer and the components below. Also, the parylene coating is able to withstand very large variations in temperature. Therefore, even if a part is heating up very quickly, the part will destroy itself before it breaks down the coating and exposes itself to water. Finally, the parylene is also resistant to fungus and bacteria. This was a concern because if water managed to hit the motherboard it might stay inside of the phone for a very long time. It is possible then that bacteria or fungus could start to grow on some components. However, with this coating, the motherboard will be unaffected by water or bacteria.

B. Battery Charger / Connector (Josh)

The battery charger and connector were easily overlooked components and therefore they were barely noticed. However, their design is vital to the proper functioning of the phone. The goal for the charger is to charge the phone whenever the charger is plugged in and the battery is not 100%

full. However, this is extremely difficult to implement with waterproofing technologies. How would the phone handle charging when it was underwater? How would the phone create a removal waterproof seal with the charger? As for the connector, its design is to send data back and forth between computers. However, like the charger, this is difficult in the presence of water. What happens when one of the contacts is shorted by water while it is connected to a computer?

Ultimately, it was decided to only charge the phone and allow its connection to a computer in the absence of water. This will dramatically save time with the design, limit the testing for the phone, and lower the liability in case the waterproof fails and the phone electrocutes someone. In order to charge the phone and connect it to a computer only when it is dry, the voltage between the charger contacts and the connector contacts is constantly measured. If the hardware or software ever detects a short between these two points, it immediately disconnects the battery and phone from the charger and disables the connector pins. Therefore, if the phone is submersed in a conductive material like ionized water, the charger and connector will be deactivated and the phone will be safe from the external power connection. However, given this solution it is possible to charge the phone in a non-conductive material, like cooking oil. While this point is absolutely useless to the common user, it might actually be implemented by some people in the field, since this same case was tried on a computer only a month ago. This random case is worth noting and should be included in the disclaimer for this phone.

i. Batteries (Berhane)

The battery is the power source and is, in essence, the backbone of cell phones. Because it is of such importance it deserves special consideration. Two items are of special significance: battery life and compactness. The battery type that will be used is lithium ion. It is the cost friendly and more efficient option. Although the NiMH batteries are one third the LiIon batteries, the LiIon is much smaller and provides a longer duration of talking time. The Lithium Polymer Cellular Phone Battery is a more advanced technology is less cost efficient, less stable and very dangerous. For this reason, it was not chosen. Overall, the LiIon presents the best energy-to-weight ratios, no memory effect, and a slow loss of charge when not in use. Waterproofing the battery is not an extra cost due to the water resistant encasing of most batteries. However, to ensure there is less moisture permeating through the water resistant membrane and cracks, it will be hermetically sealed with sealants such as silicone.

C. Sim Card (Josh)

A major problem with this design would be dealing with a removable sim card. If this phone operated on GSM networks, it would require sim card to properly operate. Even though most users of GSM phones do not frequently practice the removal of their sim cards, designing a waterproof compartment that could be opened and closed frequently would be necessary and extremely difficult. If the compartment ever failed or the user didn't close it properly, then the entire phone could be destroyed by any water seeping into the failed compartment.

Therefore, this phone is solely designed for CDMA markets. This removes the need for a removable sim card and all ESN programming would thus be accomplished through the network or connector.

D. Microphone (Josh)

The goal for the microphone is to be able to properly pick up the users voice at all times. This proves extremely difficult when dealing with a waterproof phone since sound waves are distorted underwater. If the phone were able to detect sound underwater, it would need to have extensive software that modified the detected sound based on its surrounding material. However, due to the fact that most people will not even attempt to talk underwater and that it is extremely difficult to talk underwater, the microphone will not be optimized for underwater sound detection.

The microphone does need to operate when a small amount of water is poured over its surface. Therefore, the microphone is covered with a thin layer of parylene. This will protect the microphone from water while maintaining a thin enough layer so the sound has very little distortion. Also, in order to compensate for this tiny layer covering the microphone, each phone will be calibrated in the software. This will ensure that the sound is not affected by the parylene coating. It is worth noting that this adjustment will not be continuously changing. It will be calibrated once in the factory and left in the phone.

E. Speaker (Josh)

The goal for the speaker is to output sound at any time. However, during underwater operation the sound may be slightly distorted due to the water. Therefore, the speaker will have two main modes of operation. When it is on land and not completely surrounded by water, it will output sound normally. It will have a small parylene coating covering it and will be calibrated, much like the microphone, in order to adjust for the extra layer. When the phone is underwater the user can turn the phone to underwater mode. This extra mode will adjust the sound outputted to compensate for the effects of water. Therefore, a person underwater with the phone in underwater mode should be able to listen to music or hear a person with mild distortion.

F. Screen/Keyboard (Berhane)

i. LCD

The type of screen chosen and the waterproofing of the screen emphasized low cost, appeal to customer, and adaptability to waterproof technology. The LCD will be coated with thermal epoxy to fulfill the durability as well as the cost efficient waterproofing techniques portion of the objectives of the design project.

The LCD screen is normally water resistant due to its outer coating, but to allow it to withstand liquids with temperature variations, the screen will be coated with a very thin layer of transparent coating. For example, a coating under consideration was parylene-c, which is optically clear, and can withstand temperatures up to 125 degrees Celsius. Despite its great benefit, its price tag discourages its use. However, since the motherboard is very essential to the functionality of the cell phone, parylene-c is used to coat it. As a result, thermal epoxy, which has about 1/3 of the price tag than parylene-c will be applied on the LCD to compensate for temperature variation of different liquids that may be spilled on it.

ii. Keyboard

One of the most unique features of the cell phone design is that the keyboard will be touch screen. The touch screen presented a flat layer in which one can avoid the caulking of cracks of a normal cell phone keyboard. Furthermore, touch screen technologies already embed great functionality under high pressures and are resistant to water and dust. Its ability to work with high pressure makes it ideal as an underwater technology wherein the cell phone will be exposed to higher-pressure levels.

Although a less numerically measured item, the touch screens presented an alternative that is new and unique, and would have a better customer appeal. Also, when looking at cost difference, the difference in building keyboards from touch screens and common plates did not exceed more than $10.

A major problem with using touch screen is the accommodation of increasing pressure with increasing depth underwater. The level of pressure exerted on the touch screen by the environment, particularly water, will have a different value. The solution for the pressure increase and the changing sensitivity of the LCD will be resolved through use of a software application for the cell phone. The software application will compensate for pressure difference across the screen created due to the submergence of water and adjust it with the normal environment. In essence, the software application will differentiate between a hand pushing on the keys or water applying pressure on it.

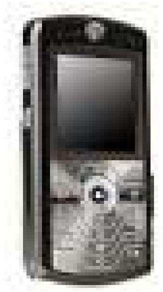
G. Antenna (Berhane)

The first decision was to decide between the use of internal antennas, external antennas, or both. Current technologies for internal antennas provided the same receptive ability as any other external antennas. As a result of aesthetics and good reception, internal antennas will be utilized in the design.

Antennas are tuned and shaped specifically for certain wavelengths. If too much water is in contact with the internal antenna, the antenna's shape can be slightly deformed. Deformation of the antenna will result in bad reception as a result of tuning to different, unintended wavelengths. Although there is a need to waterproof the antenna, the fact that the antenna is not external avoids the need for a transparent coating that would increase the cost. As a result, the antenna, which does not need any special waterproofing, will be waterproofed with parylene, which is a cost efficient material.

H. Encasing/Cell Phone Body (Berhane)

Two of the alternatives for the cell phone case considered were plastic polymer and metal. A parallel decision had to be made also on the type of cell phone- candy bar, flip, etc. The cell phone design will be a metallic (aluminum), bar cell phone. The candy bar model was chosen to easily integrate a touch screen cell phone and for aesthetic purpose.



Furthermore, the decision between the use of metallic or polymers rested on assessment of the consumer market. According to the Dow Product and Business News, published in 2006, nearly 80% of consumers would be more likely to purchase mobile phones if they were made of items like real wood and real metal. Even further, the article stated, "Consumers confess that they would spend $62.00 more for a cell phone and $169.30 more for a laptop with a luxury material, such as real woods, real metals, and designer fabrics on them." Using the cost effectiveness objective of the design, the metallic aluminum casing was chosen, which is estimated to cost less than $20.

O-ring sealants, a loop of elastomer used as a mechanical seal, will be utilized to caulk the different junctions of the components of the cell phone. Sometimes pressure differentials may exist when the outside pressure is much higher than the inside. In that case, a relief valve can exhaust gas from the inside to compensate for the pressure difference.

G. Block Diagrams

i. Main Board

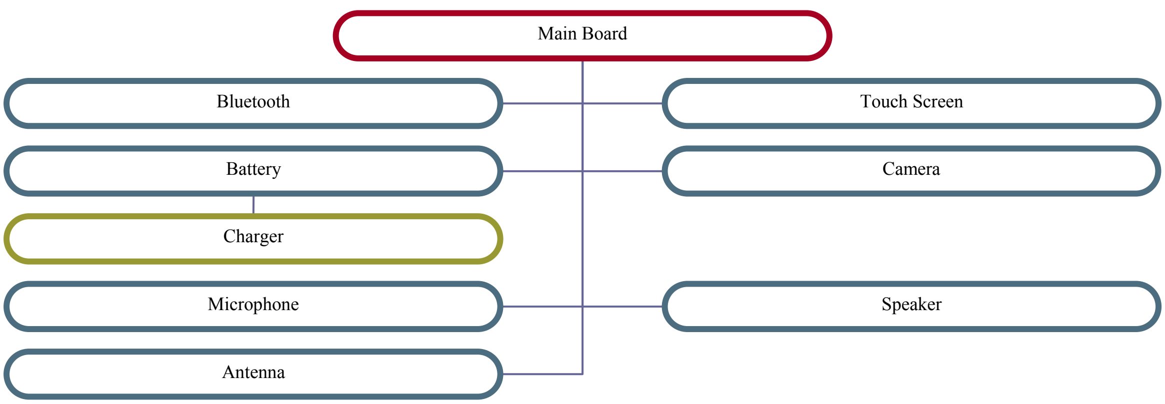


Figure 5.4

ii. Touch Screen

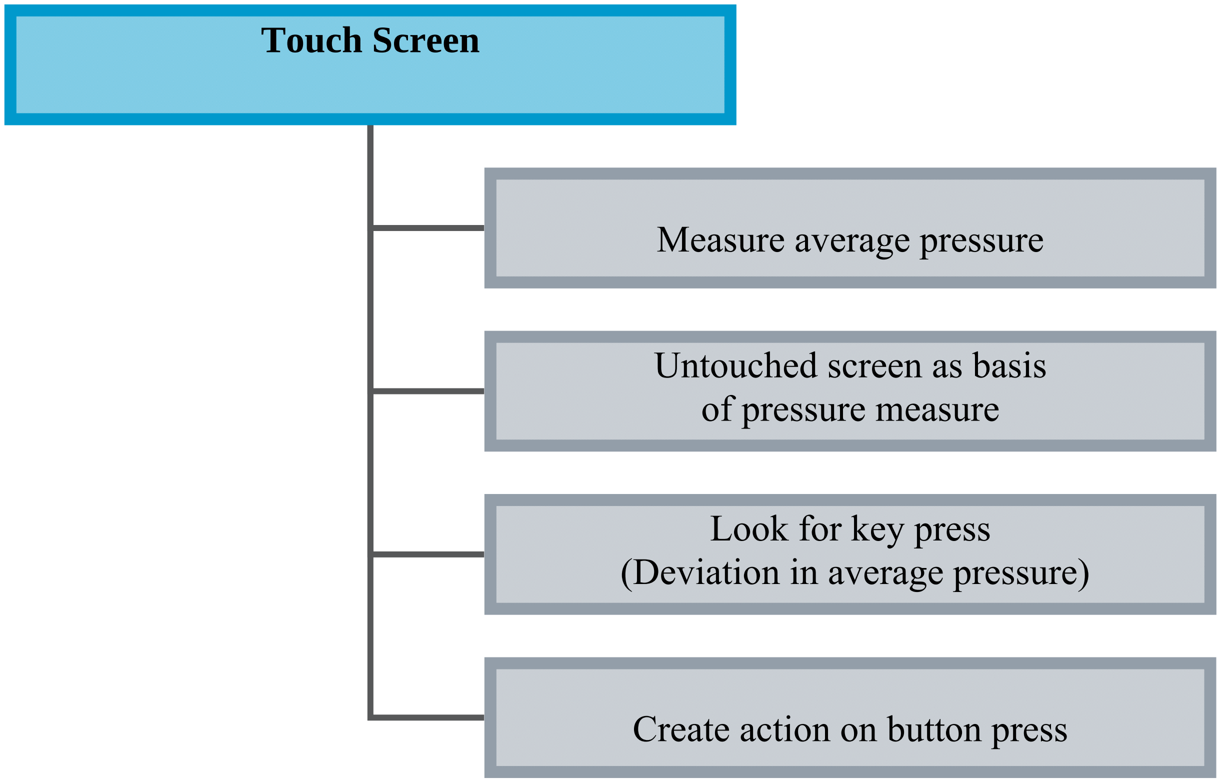


Figure 5.5

iii. Charger

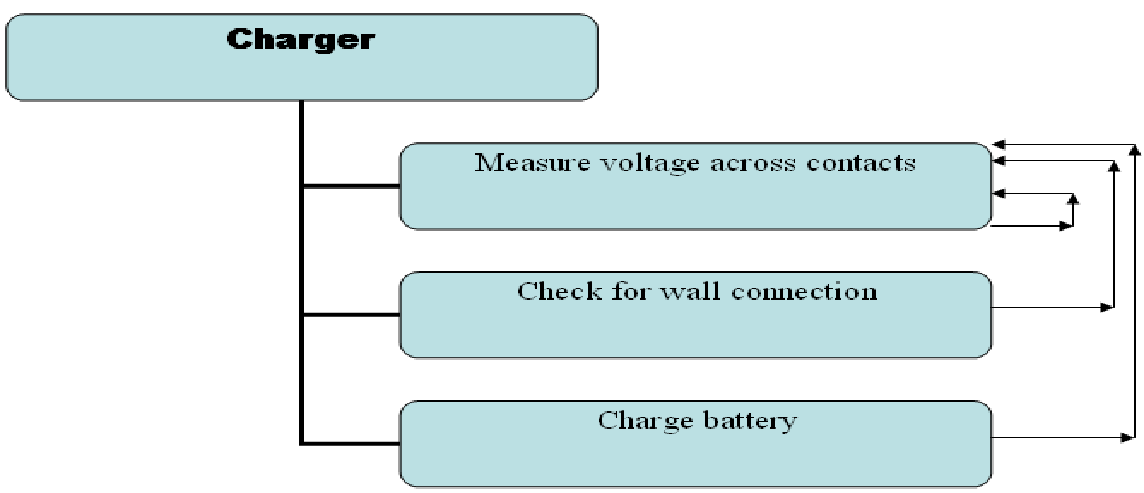


Figure 5.6

VI. Future of Waterproof Cellular Phone Design

A. Cost

The cell phone upon which the design is based costs approximately $150. With the addition of waterproofing features, the product would cost only about $30 more, making the total cost $180.

i. Table of Cost per Waterproofed Component

Waterproofed items	*Marginal cost*
Main board waterproofing	$20
Antenna	$0
Speaker (PlastiDip coating)	$1
Microphone (PlastiDip coating)	$1
Battery Case	$0.50-$1.00
Camera	$0
Touch screen software (in addition to hardware)	$1
Charger software/hardware	$1
Extra testing	$5
Labor Cost of manufacturing	$3
TOTAL*	~ $33 + base phone

Figure 6.1 This is an overestimate of the cost of waterproofing techniques such as the covering of the microphone and speaker

B. Schedule

Tasks	**Deadline**
Completion of Design	March 8, 2006
Final Documentation	March 20, 2006
Presentation to Class	March 25, 2006
Building Prototype of cell phone	April 20, 2006

a. Ordering of parts
b. Assembling
c. Testing compatibility

Testing I	April 30, 2006

d. Pressure levels
e. Temperature variation
f. Signal strength
g. Etc.

Revision of Design	May 5, 2006

h. Developing alternatives if needed
i. Re-analysis of Budgeting

Specification for Fabrication and Production May 12, 2006

Sample Manufacturing June 15, 2006

(Note: length of time is due to outsourcing to China and India)

Evaluation July 25, 2006

j. Focus groups
    i. Survey on customer satisfaction

Solutions to customer requests July 30, 2006

Marketing August 9, 2006

k. Research potential customers
l. Contract with cell phone providers

Release of Product October 10, 2006

Monitoring and Customer Support Ongoing

The approximate cost of this waterproof cell phone is about $180. Compared to the cell phone upon which our product is designed, this is an increase in about $30. The demand for a waterproof cell phone outweighs this relatively small increase in cost. If all goes according to plan, the launch date for this phone is October 2006.