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The Physics of Cell Phones

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Introduction

Cell phones represent a type of technology that has been around for little over fifty years. However, it has only been recently that many people began to use cell phones as a major part of their everyday life. In the past, cell phones were used by business people to conduct their business. In today's society, one member of every residence of the United States owns a cell phone. Cell phones are interesting, useful and play a major role in our lives by bringing people closer together and keeping in constant touch with one another. However, most people do not understand the physics of a cell phone.

The purpose of this unit of "The Physics of Cell Phones" is designed to provide students in grades 5-8 the opportunity to explore and to solve problems about the physics of how cell phones work. This unit is divided into four sections. The first section of the unit establishes a definition of cell phones; the second section gives the history and some background information on how the cell phone evolved; the third section talks about how the cell phones work; the fourth section discusses turning speech into electrical impulses, and the fifth and final section of this unit talks about the pros and cons of cell phones.

Lesson plans are structured, so that students can become highly engaged in hands-on assignments to learn concepts taught. The use of technology by way of computer "How Stuff Works" www.howstuffworks.com is used to help explain and to assimilate concepts taught. The concepts are strongly linked to the scientific method and goals and objectives which are framed around standards in science. Curriculum standards are introduced in this unit with lesson plans. In addition, the unit consists of a teacher reading list, a student reading list and a bibliography.

Definition of a Cell Phone

This section answers the question: what is a cell phone? Cell phones are defined as sophisticated radios. They are a type of wireless communication device that uses many small cells with a base station and a cell phone tower at the center of each cell. These cells have extensive frequencies that allow thousands of people to use

cell phones at the same time. In this process, cellular calls are transferred from base station to base station as a user travels from cell to cell. For example, if you were traveling from New Haven to Rhode Island, your call would be transferred from several based stations along the way. Cellular phones use a short-wave analog or digital telecommunication in which a subscriber has a wireless connection from a mobile telephone to a relatively nearby transmitter and receiver in the base station. [1]

The History of the Cell Phone

The basic concept of cellular phones began in 1947. Bell Laboratories introduced the idea of cellular communications in 1947 with the police car technology and Motorola was the first to incorporate the technology into portable device that was designed for use outside of an automobile. During that same year, AT&Tproposed that the Federal Communications Commission (FCC) allocate a large number of radio-spectrum frequencies so that widespread mobile telephone service would become feasible and AT&T would have an incentive to research the new technology. However, broadcasting and sending a radio or television message out over the airwaves would come under (FCC) regulation. [2]

In 1968, the FCC changed its position by increasing, the frequencies allocation, freeing the airwaves for more mobile phones. AT&T and Bell Labs proposed a cellular system to the FCC of many small, low-powered, broadcast towers, each covering a 'cell' a few miles in radius and collectively covering a larger area. Each tower was supposed to use only a few of the total frequencies allocated to the system. As the phones traveled across the area, calls would be passed from tower to tower. [3]

Dr Martin Cooper, a former general manager for the systems division at Motorola, is considered the inventor of the first modern portable handset and made the first call on a portable cell phone in April 1973 to his rival, Joel Engel, Bell Labs head of research. In 1977, AT&T and Bell Labs constructed a prototype cellular system and a year later, public trials of the new system were started in Chicago with over 2000 trial customers. Two years later in 1979 a different undertaking, the first commercial cellular telephone system began operation in Tokyo. The seventies held great promise for cell phones. [4]

In 1981, Motorola and American Radio Telephone started a second U.S. cellular radio-telephone system test in the Washington/Baltimore area. By 1982, the slow-moving FCC finally authorized commercial cellular service for the USA. Despite the incredible demand, it took cellular phone service 37 years to become commercially available in the United States. Consumer demand quickly outstripped the 1982 system standards and by 1987, cellular telephone subscribers exceeded one million and the airways were crowded. To stimulate the growth of new technology, the FCC declared during that year that cellular licensees could employ alternative cellular technologies in the 800 MHz band. In 1988, another group, the Cellular Technology Industry Association (CTIA) was established to work with the cellular service operators and researchers to identify new technology requirements and set goals to introduce a new product by 1991. Shortly after, the Telecommunications Industry Association (TIA) created a standard specification based on the requirements the CTIA had recommended. The result was that wireless network divided them into time slots with each phone user having access to one time slot at regular intervals. These time slots will be discussed later in this unit. [5]

How Cell Phones Work

The major component of the cell phone system is the cell. The cell phone system divides an area of service into a set of cells on what might look like a hexagonal grid. A phone tower or base station in the center of the cell covers an area of 2 or 3 square miles around the tower. Cell phones transmit to towers, which then connects you to the normal land based telephone system to route the call. In other words, a handoff has to happen when you move from one cell to another. A typical large city has hundreds of towers and each carrier in each city runs what is called a central office, known as the mobile telephone switching office (MTSO). For example, as you drive from one city to another every couple of miles, the system hands off to another cell. You don't realize that is happening because it is not noticeable. Let us look at what happens when someone calls you. [6]

First, when you power up the phone, it listens for special frequencies (control channel) that the phone and tower use to talk to one another. If there are no control channels, the phone displays a message –no service, because it knows it is out of range. Second, the phone transmits a registration request, so that the MTSO keeps track of your phone location in the data base. It is important for the MTSO to know which cell you are in when it wants to ring your phone. Third, the MTSO gets the call, and it tries to find you by looking into the database to see which cell you are in. Fourth, the MTSO chooses a frequency pair that your phone will use in that cell to take the call. Fifth, the MTSO communicates with your phone over the control channel to tell it what frequencies to use and when your phone and the tower switch on those frequencies, you are connected and talking. And sixth, as you move toward the edge of the cell, the cell tower notes a diminishing signal. The diminishing signal indicates that it is time for the control channel to hands off you to the next cell. [7]

Analog and Digital Signals

An analog signal has a base carrier's radio frequency signal, which is modified in some way to amplify the strength of the signal or vary the frequency to add information to the signal. An analog signal can be represented as a series signal to a signal carrier known as sine waves because carrier waves are analogous to the fluctuations of the human voice or other sound that is being transmitted. Advanced Mobile Phone System (AMPS), the first common cell phone system in the U.S., uses a range of frequencies between 824MHz and 894 MHz for analog cell phones. A Hertz (Hz) is equal to cycles per second, while a MegeHertz (MHz) is equal to one million cycles per second. The frequencies chosen to be used in analog voice channels are 30 kHz wide, because it gives voice quality that is comparable to a wired telephone. The transmitter and receiver frequencies of each voice channel are separated by 45 MHZ, to keep them from interfering with each other. Each carrier has 395 voice channels and 21 control channels for activities of registration and paging. Each cell only uses about one-seventh of its frequencies. This helps a hexagonal cell and the six cells in the grid to all use the frequencies. Digital cell phones use the same radio technology in a different way. For example, digital phones change voice into binary information (1 and 0) and then compress it. This compression allows ten digital phones to occupy the same frequency space as one analog cell phone. [8]

Cell Access Technology

Cell phone networks use three common technologies: 1) Frequency-Division Multiple Access (FDMA); 2) Time-Division Multiple Access (TDMA) and Code-Division Multiple Access (CDMA). [9]

Frequency-Division Multiple Access (FDMA)

First the FDMA puts each call on a separate frequency. It separates the spectrum into distinct voice channels by splitting it into equal pieces of bandwith and sending it out. This is used mainly for analog and not considered to be effective. [10]

Next, TDMA assigns each cell a certain portion of time on a designated frequency. TDMA is a 30 MHz wide analog channel broken down into 6.7 millisecond time slices with each split into three time slots. Voice data is compressed to digital information with less transmission space than analog. TDMA is the access technology for the global communication system for mobile communication (GSM) and operates at 1.9 GHz in the U.S. It is used in digital cellular. [11]

CDMA gives a unique code to each call and spreads it over the available frequencies by using spreading technology. Each phone will transmit on all the allotted frequencies. Each phone uses a different random number to decide which frequency. It will assign a code and will time stamp each signal. It uses the global positioning system (GPS) to get information. [12]

The Parts of a Cell Phone

If you take a cell phone apart, you find that it contains just a few individual parts, such as, an antenna, a liquid crystal display (LCD), a keyboard, a microphone, a speaker, and a battery. Inside the phone there is a circuit board. The circuit board is the heart of the system. Your journey through the computer chips on the circuit board would consist of three rooms. First you would enter in room analog-to-digital and digital-to-analog conversion chips which translate the outgoing audio signal from analog to digital and the incoming signal from digital back to analog. It can process millions of calculations per second in order to compress and decompress the voice stream. Then you would enter into the second room where the digital signal processor (DSP) is located. Here in this room you would soon discover that the DSP is a highly customized processor designed to perform signal manipulation calculations at high speed. Next, you would enter the third room with the microprocessor. The microprocessor handles all the main functions for the keyboard and display, deals with command and control signaling with the base station (cell tower) and also coordinates the rest of the functions on the board. The read only memory (ROM) and Flash memory chips provide storage for the phone's operating system and customizable features, such as the phone directory. The radio frequency (RF) and power section handles power management and recharging, and also deals with the hundreds of FM channel. Finally, the RF amplifiers handle signals traveling to and from the antenna. [13]

Turning Speech Into Digital

Speech is sound in motion, but talking produces acoustic pressure. A telephone reproduces sound by electrical means. However, in wireless technology, a coder inside the mobile telephone converts sound to digital impulses on the transmitting side and on the receiving side it converts these impulses back to analog sounds. A coder or vocoder is a speech analyzer and synthesizer all in one. A vocoder is found in every digital wireless telephone and is part of a larger chip set called a digital signal processor. In this process, sound gets modeled and transmitted on one end of the vocoder and on the receiving end, the speech synthesizer part, interprets the signal and produces a close match of the original. [14]

These sounds can vary because of telephone circuit's resistance, while electrically representing speech with a continuous (analog) electromagnetic wave; however, digital signals remain stable for the length of their travel because digital signals are a mathematical or numerical representation of sound, with each sonic nuance captured as a binary number. [15]

When you hear sound, your ears are responding to tiny, rapid changes in the pressure of the air. These changes are called sound waves. They can have a single frequency and constant amplitude. Hearing is a complex mixture of waves with different frequencies and amplitudes. Sound waves range from pure sine waves to complex combinations of waves. The normal human ear can perceive sound ranging in frequency from 20 to 20,000 Hz. [16]

The Advantages and Disadvantages of Cell Phones

Advantages of Cell Phones

The cell phone is a wonderful invention and there are several advantages to cell phones. Cell phones have changed the way society thinks, operates and communicates. One advantage of cell phones is that it allows its users the advantage of a wider opportunity to communicate by a principle call frequency reuse. Through this principle the same frequency can be used by different cells without creating interference from other cells. Frequency can be used over and over. Cell phones operate within cells and can switch cells as the user moves around. Someone using a cell phone can drive hundreds of miles and maintain a conversation during the entire journey. In any cell, as many as fifty-six people can be talking on their cell phone at one time. This seems to be a more efficient and effective way to communicate. A second advantage of cell phones is that they are small and easy to carry around.

Modern digital cell phones can process millions of calculations per second in order to compress and decompress the voice stream. Cell phones have full duplex. This means that you can use one frequency for talking and a second frequency, separate frequency for listening. Both people on a cell phone can talk at once. The cell phone can communicate on 1,664 channels or more. In addition, cell phones (TDMA) use a dual band. This means that it can operate in both 800 MHz and 1900 MHz bands. [17]

Other advantages of us cell phones are that it gives you a wide variety of functions, for example, you can

store information, make task or to-do lists, keep track of appointments and set reminders. Cell phones have a built-in calculator for math, you can send, receive calls, get information for a variety of sources, such as, news, entertainment, stock quotes, play simple games.

Cell phones have great influence in our everyday life and are convenient to have around. Cell phones are a faster and more effective way to transfer information. Some parents use cell phones to keep in contact with their children. Other uses it for business and to keep in contact with loved ones. Cell phones have played a vital role in bringing the world closer together. Indeed, it is an added resource that gives it user's great advantages.

Disadvantages of Cell Phones

There are some disadvantages of owning a cell phone. As mentioned earlier in this unit, cell phones are those in which information is sent to one or more receiver by means of a modulated electromagnetic wave. Electromagnetic radiation can occur as a result of electromagnetic waves. The wavelength of electromagnetic wave determines its propertiesX-rays, infrared microwaves, radio waves and light waves (See Appendix B). The frequency of an electromagnetic wave is the number of cycle that occurs in one second. [18]

There are concerns about cell phones like many other electronic devices. First, the cell phone physically has non-repairable internal parts that can corrode. For example if a cell phone gets wet, you may damage internal parts. Also, extreme heat in a car can damage the battery or the cell-phone electronics and extreme cold may cause a momentary loss of the screen display. Second, analog cell phones may have problems of cloning. Cloning means someone has stolen its ID numbers and makes long distance calls on the owner's account. Third, another disadvantage of cell phones is that it does not have the ability to provide the callers location like a land line telephone. If you do not know where you are, you can not be found, if in trouble, on a cell phone. The tower can be located, but the caller can not because cells use base stations and towers to hand off calls as the user moves from one location to another. Fourth, like all electromagnetic waves, radio waves contain vibrating, electric and magnetic fields. In free space, these electric and magnetic fields are constrained to be perpendicular to each other, and to the direction of propagation. The waves can also be polarized. For example, if the electric field vibrates only in the vertical direction, the wave is vertically polarized. This polarization will not change as the wave travels through free space. In urban areas, radio waves are usually scattered by buildings and other large objects. This type of scattering effectively creates extra polarization states in all three spatial directions at a receiving antenna.

Sometimes cell phone calls in an area of tall buildings have a great deal of interference and dropped signals. The reason is because radio signals from the cell phones and towers all reflect back and forth between buildings around us. There echoes almost overlap at the antennas, but vary on points on the wave form from each reflection caused by the differing lengths the waves travel and the effect of reflection of various surfaces. This cause a great drop in signal strength and clarity and the signal may be dropped.

Other disadvantages of the cell phone exist that are noteworthy, but do not relate to physics. I mentioned only a few of these, because of its important to teachers, parents, students and other educators that may teach social skills and other social interactions as a means of integrating the two disciplines.

There are reasons to suspect that cell phone may cause cancer of the ear or brain tumors. The more individuals use cell phones and the greater the number of years used by them, the greater the risk of brain tumors. However, the mobile phone industry has long resisted any suggestion of a link to cancer, though it

accepts that mobile phone radiation does affect the electrical activity in the brain. [19] According to the Federal Drug Administration (FDA), who requires the manufactures of wireless phones to notify users of health hazards, there is not available evidence that show that any health problems are associated with using wireless phones. There is no proof, however, that wireless phones are absolutely safe. [20]

Second, the extensive growth in the wireless communications industry over the past ten years has been accompanied by growing concern for the potential hazards of drivers using wireless communication devices from moving vehicles. There has been increasing concern over the safety of using communications devices while driving, particularly within the public sector. Based on the information collected, many accidents have occurred as a result of the inattention and distraction created by the use of a cellular telephone while driving. Americans spend substantial amounts of time commuting and members of the public place high importance on keeping up with their tasks and activities. It is fair to assume that individuals will attempt to optimize their time in the automobile by doing other things at the same time.

Third, schools seem to be getting sick of cell phones interrupting the education of students. Many school districts are banning student's use of cell phones in school. School districts and law enforcement agencies say those electronic devices are used more often than not for drug related and gang related activities. Students bringing cell phones to school have place an awesome responsibility on teachers and other educator to provide a safe and orderly environment for students because of student's access to calls in schools and especially in classrooms. Students bringing cell phones to school can be faced with too many temptations that interfere with their schooling.

Fourth, many restaurant owners are telling cell phone users not to use their cell phones in their place of business. Some business establishments and restaurants owners in the United States are getting sick of cell phones and people evading the privacy of others during lunch or dinner. People find some of these cell phone users to be annoying and sometimes disruptive.

Lesson Plans

The following lesson plans are used to enhance students understanding of standards taught. Lesson plans are framed around New Haven Public School Performance Standards: Science 5-8. The specific Standard addressed is Performance 5.1. Students will develop understanding of technological designs, which solve problems and improve the quality of life. These standards can be found in New Haven Curriculum Framework Document, which is located in classrooms and the media center in every school. In addition, these standards can be found on the New Haven Public School web page, webmasternhps.net.

Lesson Plan I

Communication has evolved over the years (i.e., smoke signals, telegraph, radio telephone and now cell phones to increase our ability and desire to communicate afar.

Objective: Students will use a variety of strategies to demonstrate ways communication has evolved over the years.

Activity 1: Make a Phone Using Aluminum Cans and String

Make a phone using two aluminum cans (plastic cups also work) and some string, 10 to 25 feet long. Put a small hole in the bottom of each can or cup, and string the line from one cup to the other. Have students take turns holding the cups or cans. Try several different volumes, and pitches by adjusting the string. See if students can find an explanation for how the aluminum can phone work. Have each pair of students discuss responses with the rest of the class.

Activity 2: Demonstrating Frequencies of Sound Waves

Discuss with the class how your ears respond to sound through the rapid osculating changes in the pressure of the air. These changes are sound waves that have a single pitch (frequency and constant loudness (amplitude). The range of human hearing can perceive a sounds ranging in frequency from 20 to 20,000 Hz. Sound waves range from pure sine waves to complex combinations of waves of 1 cycle per second (1 Hertz or 1 Hz). Use a rope or a wave spring to demonstrate various waves. Let students try to form different wavelengths. Then have them pluck a rubber band to demonstrate different frequencies of sound waves.

Activity 3: The Electromagnetic Spectrum

Using Appendix B, have students discuss what they know about th *e* Electromagnetic Spectrum. Ask them where radio waves fall within the spectrum. And are these waves hazardous to your health. If not, why? if so, why?

Lesson Plan II: Using the International Morse Code

Objective: To discuss another way people communicated from long distances in the past.

Strategies: Using the book: *Science and Communication Circuits and Projects. Forrest M. Mines III,* P 102. Use the international Morse Code to discuss a different way of communicating.

Discussion: In 1836, Samuel E.B. Morse built the first working telegraph. He also devised a code that permitted telegraph operators to exchange information. His code is still used by telegraph, radio and signal light operators. Listed below is The International Morse Code.

A .-	B-...	C-.-.	D-..	E.	F..-.	G--.
H....	I..	J.---	K-.-	L.-..	M--	N-.
O---	P.--.	Q--.-	R.-.	S...	T-	U..-
V...-	W.--	X-..-				
1.----	2..---	3...--	4....-	5.....	6-....	7--...
8---..	9----.	0----	. .-.-.-	? ..--..	- ....-	

Think of the code as sound, not dots and dashes. Have students say "dit" for dot and "dash" for dash. Thus A is "ditdah" or "didah", B is Dahdididit, etc. Use the International Morse Code and have students create messages to send to each other.

Lesson Plan III

Objective ***:*** To have students recognize that the cell phone is a device used to communicate in our everyday lives.

Strategies: Divide students up into small groups of fours or fives. Have each group to brainstorm what they know about cell phones

Activity 1:

Each group will:

- Define what is a cell phone?

- How does a cell phone work?

- What are the advantages and disadvantages of having a cell phone?

Activity 2 : *Whole Group Discussion*

Each group will share their information gained in the small groups in the whole group. Then each person will be given a two-way radio to communicate. A two radio is the best way to demonstrate how cell phones work. Then, teacher will use the cell phone using the Website wwwhowstuffworks.com to explain how cell phones work and the parts of the cell phone.

Lesson Plan IV: Critical Thinking

Objective: Students will do some critical thinking about how cell phones affect their lives and people around them.

Activity 1: Writing Prompt:

. What would you do if some in your class interrupt the class by taking out a cell phone and start talking to friend?

Activity 2:

- Write an essay on how do you think messages are sent and received on a cell phone.

Activity 3:

- Write an essay on the following question. Do cell phones cause accidents and why?

Lesson Plan V: Explain How A Cell Phone Works

Objective: To have students do a project that demonstrate how cell phones work.

Strategies : Teacher will present a whole group discussion and use speakers to teach the concepts on cell phones. Next, small group discussions will be done by individual groups on the information presented. Then, students will do on-line research, use books, and other research tools to help them complete their projects. Finally, each student will make a presentation explaining how their project works.

Lesson Plan VI: How Much Would You Pay To Have A Cell Phone

Objective: Students will choose the best payment plan for cell phones monthly rate.

Strategies: Have students use this chart and choose a payment plan to answer the two situations below.

Plan	Monthly Access Charge	Peak Time	Off Peak Time
A	$ 10.00	$0.28	$0.28
B	$ 20.00	$0.28	Free
C	$ 20.00	125 min. included	$0.28

Which plan would you purchase based on your monthly airtime?

- *Situation 1* : You spend 50 minutes on the phone during peak air time, 25 minutes during off peak time. What plan would be better? Show why.

- Situation 2: Most of your calls occur during off peak time. You spend 20 minutes a month during peak time and 100 minutes during off peak time. What plan should you purchase? Why?

Assessment: All lesson plans will be assessed through portfolios, projects, class work, homework and journals.

Appendices

APPENDIX A: A Brief History of Cellular Phones

1947-The basic concept of cellular phones began. Bell Laboratories introduced the idea of cellular communications in with the police car technology.

1968-The FCC reconsidered its position in 1968, stating "if the technology to build a better mobile service works, we will increase the frequencies allocation, freeing the airwaves for more mobile phones

1973-Dr Martin Cooper, a former general manager for the systems division at Motorola, is considered the inventor of the first modern portable handset. He made the call to his rival, Joel Engel, Bell Labs head of research.

1977-AT&T and Bell Labs had constructed a prototype cellular system.

1979 -The first commercial cellular telephone system began operation in Tokyo.

1981- Motorola and American Radio telephone started a second U.S. cellular radio-telephone system test in the Washington/Baltimore area.

1982- The slow-moving FCC finally authorized commercial cellular service for the USA.

1987- Cellular telephone subscribers exceeded one million and the airways were crowded. During that time, three ways of improving services existed: 1) increase frequencies allocation; 2) split existing cells and 3)

improve thetechnology.

1988- The Cellular Technology Industry Association (CTIA) was established to work with the cellular service operators and researchers to identify new technology requirements and set goals.

1991-The Telecommunications Industry Association (TIA) created a standard specification based on the requirements the CTIA had recommended. The TDMA Interim Standard 54 or TDMA IS-54 was released.

1994- TDMA IS-136 uses the frequency bands available to the wireless network and divides them into time slots with each phone user having access to one time slot at regular intervals

Source: Adapted from ATT Cellular Telephone Equipment Installation Course-CL. 3403, CA. 1985. Updated 1995.

APPENDIX B: The Electromagnetic Spectrum

nm = nanometer (1nm= .000 000 001 meter

m = micrometer (1m = .000 001 meter)

mm = millimeter (1mm = .001 meter)

m = meter (1m = 39.37 inches)

km = kilometer (1km = 1000 meters)

Violet Yellow Red Near Infared
Blue Green and Orange
400nm – 500nm 600nm – 700nm 800nm
Visible Light
X-Rays Ultraviolet Infared
1nm - 10nm 100nm – 400nm 100m - 1mn

Wavelength: This is a chart of the electromagnetic spectrum that will assist teachers with the teaching of electromagnetic waves.

Source: Forrest M. Mines, III. Science and Communication Circuits and Projects . "Sound". Radio Shack. 2000.

Some of these books are available from-on-line bookstores, such as "Amazon"

Teacher Resource List:

Amazon.com:Books: Marshall Brain's *How Stuff Works* by Marshall Brain (Arthur) Tom Farley. Basic Wireless Principles: How it works. http://inventors.about.com/library/inventors/blcell.htm

History of Cellular and Mobile Phones-PCS-Digital Cell Phones. "How the FCC slowed the progress of a cellular phone system", http://inventors.about.com/library/inventors/blcell.htm

Forrest M. Mines, III. Science and Communication Circuits and Projects . "Sound". Radio Shack. 2000.

Amazon.com: Books: Janice VanCleave's Physics for Every Kid by Janice101 Easy Experiments in Motion, Heat, Light, Machines, and Sounds. March, 1991.

Barnes & Noble.com: Books: "The Way Things Work Kit" by David Macaulay, Neil Ardley.

Amazon.com: Books: *The Cell Phone Handbook: Everything You Wanted To Know About Wireless Telphony But Didn't Know What To Ask.* By Penelope Stez, June, 1999.

Endnotes

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2. Cellular Telephone Basics:AMPS & Beyond. Tom Farley KD6NSP. http://www.privateline.com/Cellbasics/Cellbaics.html

3. Tom Farley. TelecomWriting.com's Telephone History Series.http//www.TelecomWriting.com/pcshistory.htm. P 7-11

4. Ibid., pp. 7-10

5. Ibid., p. 11

6. "How Cell Phones Work". HowStuffWorks (http://www.howstuffworks.com), by Marshall Brain. HowStuffWorks, Inc. 2002

7. Marshall Brain. *How Stuff Works. Cell Phones.* New York. NY, Hungry Minds, Inc. 2001, p.205.

8. Ibid., p. 205

9. Ibid., p. 206

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13. "How Cell Phones Work". HowStuffWorks (http://www.howstuffworks.com), by Marshall Brain. HowStuffWorks, Inc. 2002

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19. John D. MacArthur, "Cell Phones and the Brain, Townsend Letter for Doctors & Patients, 2000, p.1

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