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Multiple Smart Phones Inductive Charging Station System

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Abstract: In today's technology market, more and more devices are moving towards wireless charging. For example, one of the flagship companies, Apple, recently announced that they would begin to offer wireless charging in their devices. Besides Apple, many other companies such as Samsung, LG, HTC, and Sony already offer this feature to their customers. Many consumers have issues with the prices that come with replacing disfigured cables that result from daily use. In response to this, we would like to promote wireless charging through building an inductive charging station capable of detecting and charging multiple devices wirelessly at the same time. This would eliminate the need for charging cables, and the wear and tear that comes with them. This would also be more cost effective than buying multiple copies of the wireless chargers that are already on the market. The proposed design would be able to charge up to six devices simultaneously via a coil array and detection circuit. The design takes into consideration the dimensions of the current smart devices and moves to accommodate such devices. This device would also be cost effective so that acquiring would not be an issue, be it businesses, universities, or public spaces that take an interest. The designed wireless charging station cost approximately $173. It is designed to charge different smart phones with different dimensions. Practically, our station can fully charge smart phones approximately in same time as if using wired charging cables. The designed charging station is flexible and can be updated to charge bigger smart devices.

Keywords: Smart phones, Inductive charging station, Multiple phone charging

1. INTRODUCTION

Technology is always changing and adapting to its surroundings. As something becomes obsolete, it is replaced with something new, or more efficient. Recently, there are numerous devices on the market that are used in our everyday life such as smart phones, tablets, and other handheld devices. Smart phones have been used in many modern applications [1-5]. In commercial applications, smart phones are widely used to make banking transactions and money transfer. In [1], The authors add some security features smart phones to secure mobile browser for mobile banking. The added security features in [1] ensure security of mobile transactions based on the user location and prevent users from various attacks. Object detection application is widely used in many homeland security and transportation applications. In [2], object detection algorithm is performed from images collected from smart phone, tablet and wearable cameras. The light object algorithm in [2] depends on using depth sensors being integrated in a variety of embedded devices such as smart phones and wearables. Depth sensors are contact free and avoid some of the pitfalls caused by variations in lighting and background conditions that are typically associated with images from conventional cameras. In [3], a smart system has been proposed to help blind people avoiding obstacles while walking. A laser pointer and an android smart phone are used with an image processing algorithm to avoid obstacles. The used components of the algorithm in [3] are simple and cheap. There are many other applications that use smart phones such as controlling a robotic arm and kids games as seen in [4] and [5], respectively.

It is clear from aforementioned applications that smart phones, tablet and wearable cameras perform many smart algorithms. This will kill the battery of the smart phone in short time. As a result, all these devices have one major thing in common, that is, they must be plugged in and charged at some point. But what happens when you plug in your device and it does not respond or charge? The problem of using wired charging cables is that wired charging introduces wear and tear on the ports of these devices, maybe even to the point where charging is no longer possible. Or maybe the wire itself deteriorates to a point of no longer being functionable. These issues can be observed as being evident in Figure **1** and Figure **2**.

There are many online methods to decrease the frayed charging cable and/or damaged charging port of a cellular device[6]. However, all such solutions are temporary and could not give a permanent solution for frayed charging cable problem. One of the recent methods that can remedy the aforementioned charging cord problem is to use wireless chargers instead of using the conventional wired charging method [7, 8]. In recent years, companies such as Samsung, HTC, LG, Sony, and even Apple have developed devices capable of being charged wirelessly[9]. Wireless charging utilizes characteristics of magnetic

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fields to introduce a current to the device being charged via induction [10]. If mastered, this wireless power transfer, although not as efficient as cabled power transfer, could be used in many applications. Charging of electric vehicles, laptops, or even generators are examples of such applications.

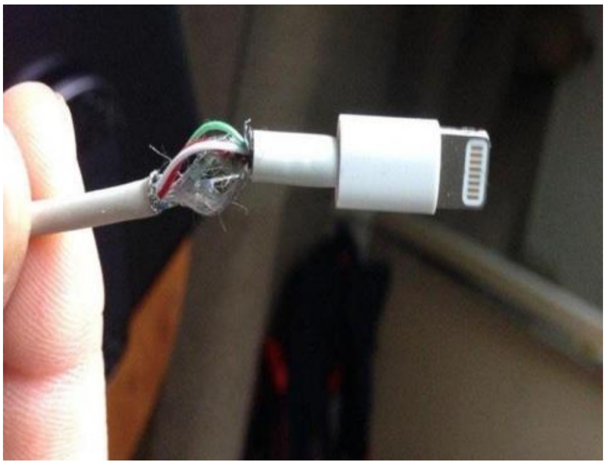

Figure 1. Frayed Charging Cable.

Figure 2. Damaged Charging Port of a Cellular Device.

Wireless charging stand is a new charger that is widely used nowadays for charging smart devices such as smart phones, iPads, and smart watches. Different kinds of these chargers are available online [11, 12]. In this paper a well-designed wireless charger stand is designed to wirelessly charge many types of smart devices. The design at hand would consist of an array of coils separated into several stations to charge multiple devices simultaneously. Our design would be suitable to alleviate these issues for the fact that it introduces a simple yet effective way to provide inductive charging [13, 14].

The paper is organized as follows, in section 2, the problem formulation is described. The proposed wireless charging station is fully described in section 3. Scientific Theories of the proposed wireless charging station is described in section 4. Device Constraints and controlling are described in sections 5 and 6. Implementation of the designed station is described in section 7. Conclusion and future is drawn in section 8.

2. PROBLEM FORMULATION

Wired charging method has its own downfalls. This includes wear and tear on the charging cables themselves, as well as damages to the charging ports of the devices. These complications bring many unwanted costs to the consumers. Additionally, Wired charging has long been the standard in power transfer. The reason for change is not because of an inefficiency, but that of the durability and ergonomic aspects of the charging process. Imagine reaching to plug and unplug your device every few hours. Not only does this wear out the device and wire, but it can also affect your body. The constant bending down and reaching movements could have a negative impact on the body in the long run. In this paper, we offer an effective solution to the aforementioned problem. An effective inductive wireless charging station, that could charge multiple devices simultaneously, is implemented and evaluated. The designed charging wireless station is considered as an initiative design for charging multiple devices. Most of the available inductive wireless charging stations are design for a single device charging at a time. However, our wireless charging station can fully charge multiple and different smart phones simultaneously in an appropriate time. The low cost and the multiple charger option gain our design superiority compared to the wireless chargers available online purchases [11, 12].

3. THE PROPOSED ARCHITECTURE

With the increase in wireless charging compatible devices, the need for effective charging methods also increase. A simple wireless inductive charging station implemented in this paper to charging multiple smart devices (Maximum of six devices at the same time) with a high efficiency. The high efficiency of the implemented station is due to three factors. First, the required time for fully charging the smart device compared to the wired charging method. Second, the power saving option of our charging station, it is achieved by disabling un-used coils while charging less than six smart phones. Third, the multiple and simultaneous charging devices capability of our charging station is another factor representing the high efficiency. Last, the flexibility of the designed station, at which, its dimensions can be easily modified to charge different types of smart devices rather that phones.

The designed station includes multiple coils in an array fashion, and a detection circuit that determines when a phone is within charging range. This allows savings in energy when no device is present on our charging station. Our design, as it stands, will cost approximately $172.88. This will include the coils themselves, miscellaneous components such as resistors, capacitors, timers, and an Elegoo Mega as will illustrated later in the implementation section.

The inductive charging station is designed to be mounted on a 40cm × 32cm table, to charge one or more mobile devices simultaneously whenever they are placed on the surface. This dimension was determined to be what was needed to comfortable fit six devices on the surface properly spaced for charging. The implemented wireless structure uses multiple small coils in a grid-like fashion on a flat surface, as seen in Figure. A detector circuit along with a detection program is used to detect disturbances in the frequency to turn on individual transmitter (primary) coils underneath the receiver (secondary) coil in the device(s) being charged [15, 16]. For the charging station, the elements needed are; a 555 Timer, to change the input voltage into a square wave, a Mosfet transistor to act as an oscillator, capacitors and coils configured for the resonant frequency, and a microcontroller to control whether the circuit is on or not. The circuit is broken into two major sections; i.e. the detection circuit and the charging circuit. Below is a conceptual model of our design.

4. Scientific Theories of the Proposed Wireless Charging Station

Wireless charging utilizes the properties of inductive coupling. Without these properties it would not be possible to charge cellular phones with our wireless charging station. Faraday's law shows that a change in a magnetic field induces a voltage into a system [10]. In our design, when the transmitter coil and the receiver coil come into proximity, current proceeds to flow to the receiver coil in the device, resulting in the device being charged. By running an electric current through the coiled copper wire, a magnetic field is produced. When a second coil is placed within this field, an alternating current will flow through it. The magnetic field transfers electric power from one coil to the other. The cell phone will then begin to charge since the receiver coil imbedded into it reacts with our transmitter coil in our device. When the coils are separated, the power transfer no longer occurs, and the phone stops charging. Figure 3 illustrates the fundamentals of inductive coupling.

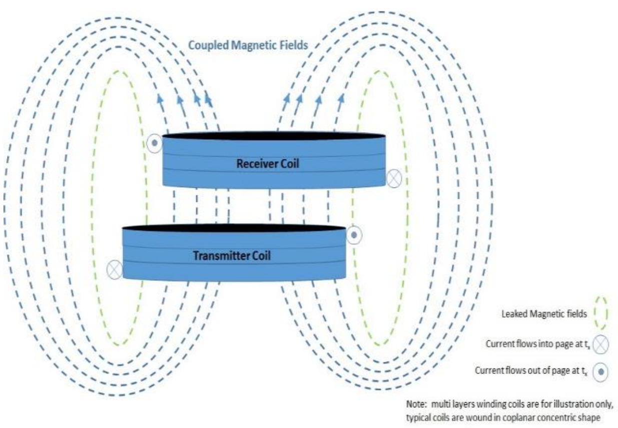

Figure 3. Coupled magnetic field between transmitter and receiver coils.

Our wireless charging station requires the use of a programmable microcontroller to conserve energy. Saving energy is very important in the designed station not to produce large amounts of heat that may damage the hardware components of both the charging station and the devices being charged. The Elegoo Mega is what we decided to use to meet this requirement [17]. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. It contains everything needed to support the microcontroller. The design currently uses 6 transmitter coils. The function of the detection circuit is to scan for a change in frequency and keep the coils off until a receiver coil is placed on or near the transmitter which will create a slight disturbance in the frequency. This detector circuit then sends the measurements to the Mega. As a result, the Mega determines the measurements and matches them to the predetermined code. For power efficiency and safety; the measurements are sent to the inputs of the Mega. The Mega will then determine the nearest transmitter coil and turn it on. If multiple devices are detected, then multiple coils will be activated. Figure 4 shows the microcontroller being utilized in the designed wireless charging station.

Figure 4. Elegoo Mega Microcontroller.

The transmitter coils of the charging station are arranged in array fashion which allows the users to get enough space in the station to charge their devices. The coils are embedded slightly underneath a Plexiglass or similar material, that will be mounted on the surface of the station. When a device with a receiver coil is placed anywhere on the charging surfaces, the device will charge. A magnetic field is generated which extends to the receiver coil. That magnetic field overlapping the receiver coil induces a current, which is used to charge the device. Each transmitter coil has its own driving circuit composed of a Mosfet Transistor and a 555 timer. The resonant frequency at which the coils operate at is determined by equation (1). Using this equation, the resonate frequency was determined to be 131.72 kHz. Figure 5 is an example of the transmitter coils used.

$$f_r = \frac{1}{2\pi\left(\sqrt{LC}\right)} \tag{1}$$

Figure 5. Transmitter Coil.

The 555 timers being used in wireless charging station are configured in the astable configuration. This means that the output voltage being supplied to the Mosfet transistors acts as a periodic pulse that alternates between the VCC value and zero volts. This allows the cellular device to receive the energy signal it needs to charge. The frequency for these timers were set to match that of the resonate frequencies from the transmitter coils. This frequency was determined by equation (2) and set to be within the QI range. Our frequency, using equation (2), was determined to be 133.87 kHz. Figure 6 indicates a 555 timer in the astable configuration.

$$f = \frac{1.44}{(R_1 + 2R_2)C} \quad (2)$$

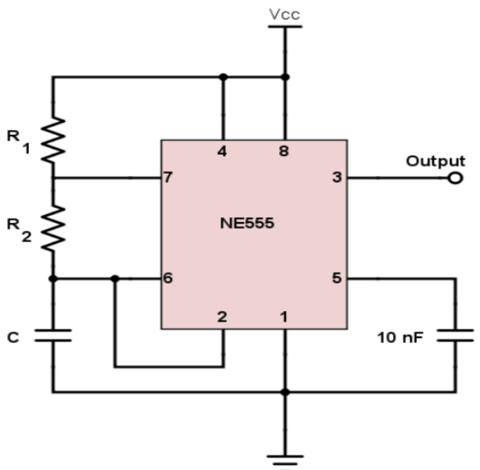

Figure 6. 555 Timer in the astable configuration.

5. DEVICE CONSTRAINTS

The inductive charging station would be limited to a 40cm x 32cm dimension of the table or nightstand it is mounted to. One constraint with inductive coupling, is that it only works over a short range, around 2 to 4 mm, meaning that the charging station and the device need to be in immediate contact with one another. The power capability of the device maxes out at around 5 Watts. Power constraint is also limited in the sense that induction-based wireless charging technology can only charge one device per coil. Device customization also plays a roll, as metal cases would interfere with the magnetic field. The device must remain stationary to charge. Lastly, smart phones should have an impeded receiver coil in order to be able to use our wireless charging station.

6. WIRELESS CHARGING STATION PROGRAMMING

For the wireless inductive charging station, a program was needed to detect disturbances in the magnetic fields around each transmitter coil. For our device, we used Arduino coding since it is compatible with the Elegoo Mega. When the device is turned on, each pin is initialized to store the default frequency of the transmitter coils. A continuous loop then checks for a disturbance in the frequency (placement of a phone with a receiver coil). When a disturbance is detected from a receiver coil coming into proximity of the transmitter coil, the device begins charging.

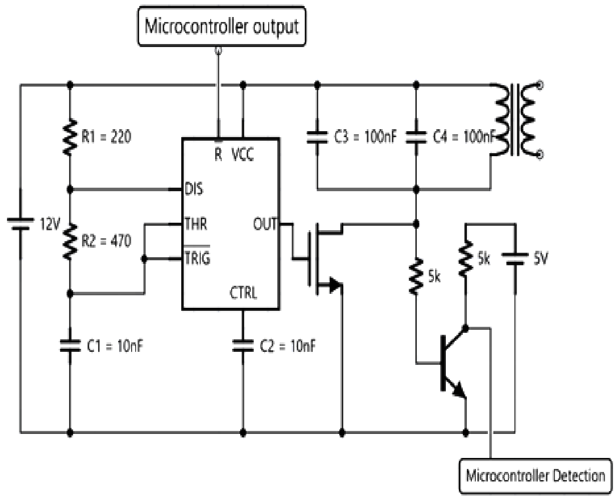

Figure 7. Charging circuit for one smart phone device**.**

7. IMPLEMENTATION AND DISCUSSION

The inductive charging station would be relatively easy to implement. The idea is to mount the system within common furniture, so that it would be easily accessible. The system, as described earlier, would make use of an array of coils so that charging the device or devices would be simplistic. The number of coils per station was experimentally chosen to minimize the power consumption represented in heating format.

The electric components would be connected as shown in Figure 7.The microcontroller detection circuit is used to measure and store the initial frequency for each coil. This circuit is included for each of the six coils. After this initial value is stored, it is compared every cycle to check for a change in frequency. This would occur from the presence of a receiver coil encountering the transmitter coil. The microcontroller would then send the VCC value of 12V to the reset pin of the 555 timer, resulting in the charging circuit operating at normal capabilities. This configuration allows for the device to conserve energy when a device is not present, while also allowing multiple devices to be charged simultaneously.

Figure **8** shows the final charging circuit for charging six smart phones, but, before the transmitter coils were added. Figure **9** shows the test circuit, in laboratory, charging three devices simultaneously. Figure **10** shows the device mounted inside of the prototype device. The prototype of our charging station shown in Figure **10**. It is worth mentioning that the implemented charging station system can be modified to charge any other smart device other than phones. This require changing the size of the flat area of prototype shown in Figure **10**.

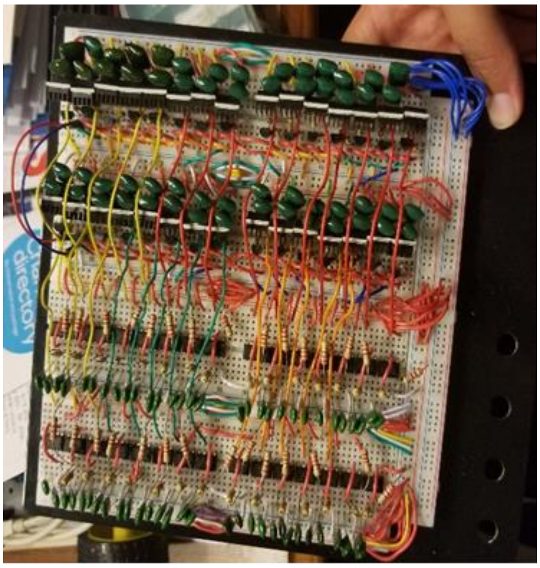

Figure 8. Final charging circuit.

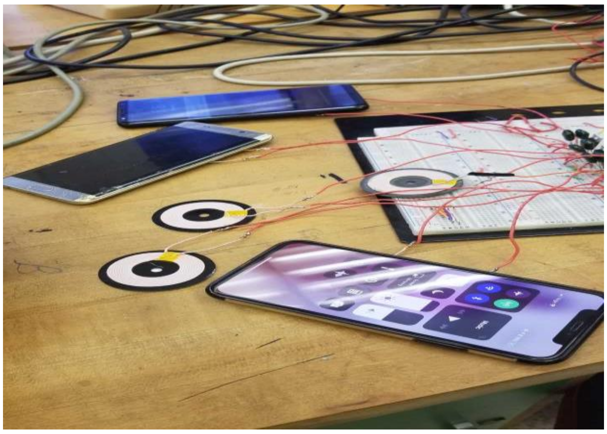

Figure 9. Test circuit in Laboratory charging three smart phone devices.

Figure 10. Prototype charging station.

The multiple device inductive charging station for smart phones utilizes the QI range to charge the devices. Qi comes from the Chinese word qi, meaning energy flow. This QI standard sets the resonate frequency that is utilized by all wireless charging compatible devices. This frequency range is from 110 and 205 kHz for the low power Qi chargers, and up to five watts and 80-300 kHz for the medium power Qi chargers. Table 1 shows the size and name of some of the common QI compatible smart devices that can be charged using our wireless charging station. These dimensions illustrate that the size of the proposed charging station is adequate to charge at least six devices simultaneously. The surface would be separated into six charging zones that are clearly labeled to indicated where a device can be charged. To make sure that no power is wasted, a detection program is needed to determine when a qi capable device meets the surface. When it comes to testing the system for efficiency, each individual coil will be tested to see how fast they charge a device, and how well that device holds the charge. These coils will then be tested in the array system, with one device, two devices, and so on connected to the system simultaneously. An effective method of providing power to this system will be required, especially when it comes to charging multiple devices.

The main advantages of the implemented wireless charging station are the simplicity of the design and the availability and the low cost of its components. Detailed budget for the final designed wireless charger is shown in Table 2. The individual components are very cheap and are available either online or in stores. The overall cost of the whole design is approximately $173 for a wireless charger that can charge six devices simultaneously.

Table 1. Dimensions of QI Compatible Devices.

Cellular Device	Length (mm)	Width (mm)	Thickness (mm)
Galaxy S6	143.4	70.5	6.8
Galaxy S6 Edge	142.1	70.1	7
Galaxy S7	142.4	69.6	7.9
Galaxy S7 Edge	150.9	72.6	7.7
Galaxy S8	148.9	68.1	8
Galaxy S8+	159.5	73.4	8.1
iPhone 8	138.4	67.3	7.3
iPhone 8+	158.4	78.1	7.5
iPhone X	143.6	70.9	7.7

Table 2. The overall cost of the implemented wireless charging station.

Material Needed	Cost	Quantity	Store	Part No.
555 Timer	$0.30	30	Mouser Electronics	NE555P
Adapter	$3.99	1	store.makeblock .com	14008
Transmitter Coils	$1.79	30	Aliexpress.com	N/A
Elegoo Mega	$14.99	1	Amazon.com	El-CB-003
Building Supplies	$30.0	1	Home Depot	N/A
Mosfet Transistor	$0.79	30	Mouser Electronics	IRF549 NPBF
Bipolar Transistor	$0.25	30	Mouser Electronics	BC547B
Miscellaneous Resistors	$0.10	120	Mouser Electronics	N/A
Miscellaneous Capacitors	$.15	120	Mouser Electronics	N/A
Total Cost	**$172.88**			

During the construction of the charging and the detection circuits, there were many complications that arose. The most critical problem that had to be solved was the heating issues we had. When we first began to construct the circuit, the Mosfet transistors were overheating at rapid speeds. To alleviate this issue heat sinks were applied to the transistors. Another issue we faced was that the circuit was drawing too much current, causing the insulation on the wires to give out. Therefore, the detection circuit was crucial in preventing unnecessary current from being drawn.

Depending on the battery being charged, the charging time of each device alters from one another. The Samsung Galaxy S8 takes approximately two hours and thirty-five minutes to fully charge, while the Samsung Galaxy S8+ takes approximately three hours to fully charge. The iPhone X had similar charging times to that of the Galaxy S8. Table 3 illustrate the overall fully charging time for different smart phone devices using wired charging and our wireless charging station. It is clear from the table that our station almost consumes the same time for fully charging different types of smart phone. However, our wireless charging station has two main advantages over the wired charging methods. First, it can charge multiple devices simultaneously. Second, the aforementioned problems of wired charging method are totally disappear. The only drawback of using our charging station is a slightly increase in the fully charging time which is acceptable if compared with the previous two advantages.

Table 3. Comparison of Charge Times Between Devices.

Cellular Device	Approximate Wired Charge Time (Hrs.)	Approximate Time to Charge with our Station (Hrs.)
Galaxy S6	1.48	2.0
Galaxy S6 Edge	1.51	2.1
Galaxy S7	1.65	2.5
Galaxy S7 Edge	1.85	3.0
Galaxy S8	1.66	2.5
Galaxy S8+	1.95	3.0
iPhone 8	1.5	2.1
iPhone 8+	2..0	2.5
iPhone X	2.0	2.5

8. CONCLUSION AND FUTURE WORK

The design of the Inductive charging stations aims to make charging portable devices more convenient and aesthetically pleasing. It encompasses a simple yet effective design that will allow consumers to easily take advantage of inductive charging. The way the coils are aligned, one does not have to worry about the placement of their devices to charge them. They also do not have to worry about the wear and tear that occurs from constantly plugging and unplugging a cord into their device(s). The design successfully charges multiple devices simultaneously. The device's surface allows for easy placement and charging of individual phones. Overall the design makes charging multiple devices easier than the traditional method of plugging in each individual device. If successful, this design could be used in many settings ranging from homes, work places, universities, and public spaces. Looking forward, the use of inductive charging can move even further than just charging cellular devices. Research and testing of charging electrical vehicles this way is already being done. The applications that can be achieved through inductive coupling are almost endless.

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