

Voice-Magstripe [V-M]*: A Novel Prototype of A Graphene-based Multifunctional 'IoT' Device

Vijay A. Kanade

Research Associate, Evalueserve SEZ (Gurgaon) Private Limited,
Sector-48, Gurgaon-122002,
Haryana, India.

Abstract

Internet of Things (IoT) is connecting the world, and things are becoming dynamically interactive. The future of the interactive world is being carved by the advancement in the field of Internet of Things. Graphene-based technologies, a new paradigm in miniaturization of IoT devices, plays a lead role in carrying the future of IoT ahead, as it can handle interactivity by controlling physical devices at nano-scale level. The paper illustrates a novel prototype of a Graphene-based IoT device (i.e. a skinny mobile phone) that folds, flexes. The IoT device "Voice-Magstripe" is a razor thin handset powered by flexible battery units (micro-supercapacitors) or see-through solar panels built directly into a colorful screen. The proposed inventive model is an 'all-in-one' multifunction flexible device which augments the operations of a smartphone and a smartcard in a systematic way. "Voice-Magstripe" is a two layered 'graphene' architecture that encompasses a novel concept of embedding a dynamic rewritable/reconfigurable magnetic stripe onto a flexible graphene sheet by utilizing nano-sized graphene solenoid(s). The invention paves a way for future of IoT devices that are cheaper and easier to handle thus avoiding the hustle of carrying bulky IoT gadgets.

Keywords: Voice-Magstripe (V-M), Internet of Things (IoT), Graphene, Solenoid, Magnetic stripe.

Introduction

Internet of Things (IoT) enables seamless connectivity in an unparalleled range of settings, from smart homes to localization of environmental dangerous chemicals. Wireless communications today, share a plethora of forms - such as smartphones utilizing 4G / 5G connectivity, GPS gadgets, and electronic equipments connected via NFC to transportable sensors - operating in different frequency bands. To effectively drive these devices across multiple platforms, connected entities have to be mutually compatible with an entire range of frequencies without being bogged down by excessive physical hardware. Most compact & handy, wireless sub-systems currently command reconfigurable / reprogrammable circuitry that can calibrate an antenna to transmit and receive data simultaneously across various frequency spectrum. The only worry with the present technologies is that they utilize silicon or metal hardware, which does not complement well with higher frequencies. In order to regulate the speed of data travel, the above issue must be addressed. Apart from operation at higher frequencies, these devices are facing issues due to their rigid, fragile

structure and power-hungry characteristics.

Along with the increased usage and dependency on smartphones, smartcards play an equally significant role in our lives. Right from payments done in malls, grocery stores, parking outlets to general stores – smartcards have become an ingredient for our survival today. These smartcards are in fact plastic cards that store user specific information in an encoded format on the magnetic stripes. The rapid growth in the use of plastic cards with magnetic stripes in recent years has made things difficult to manage for people. For example, a wallet carrying multiple plastic cards with magnetic stripes can become quite thick and unmanageable. If a person places their wallet in their lower back-pocket, sitting with an unwieldy wallet filled with magnetic stripe cards may raise back issues. Furthermore, when a person needs to use a magnetic stripe card that person may have to shuffle through a pile of plastic cards in order to identify and pick the proper magnetic stripe card required for the current situation. Due to these prevalent problems associated with the exponentially growing magnetic stripe cards, it is desirable to implement newer technically advanced systems to cut-down on these problems.

The existing systems fail to address the burning issues of rigid phones and bulky wallets. A novel solution to the prevailing problems is addressed by utilizing a single 'All-In-One' device made out of 'graphene' – the 'wonder material'. Graphene enables circuits to operate at both low and high frequencies with unmatched optimal efficiency. Graphene is a single-atom-thick sheet of carbon that can replace every tangible matter and their sub-components used in modern day smartphones, making it lighter, faster and easier to direct. The said graphene device further supports the operational functionalities of smartcards by providing a simple solution of employing graphene solenoids onto the device for emulating the role of conventional magnetic-stripe cards (i.e. credit/debit/ATM cards).

Concept

The proposed concept reveals a rational design for an "all-in-one" IoT device that integrates the functionality of a mobile phone and a smartcard. The IoT device "Voice-Magstripe" is energy-efficient electronic equipment which avails the free sources of energy by utilizing a thin layer of graphene based solar cell and a thin layer of graphene-based thermoelectric device. The solar cell harnesses energy from the sun, whilst the thermoelectric layer utilizes the heat energy given off by human body or any other heat source. These layers are embedded on the lower panel of the phone along with the

Graphene-based “Integrated circuit” unit which includes the entire phone circuitry (e.g. Nano sized Antenna Circuitry, NFC unit, Microphone unit, Speaker circuit, Memory chips, etc.) necessary for the normal operation of a phone.

“Voice-Magstripe” interpolates a “Dynamic Rewritable Magnetic Stripe” on the upper layer of the phone. The magnetic stripe is made out of Graphene-based nano-coils that act as miniature solenoids and are operative replacements of conventional magnetic materials present in a magnetic stripe of a smartcard/credit card, etc. Graphene nano-coils have been recently discovered & studied for their electromagnetic properties by the Researchers at Rice University [1]. The graphene-based nano-coils have a smaller diameter of about 70 nm that allow the coils to be placed on the tracks of the magnetic stripe. The dimensions of the magnetic stripe comply with the International Organization for Standardization (ISO) standards (total vertical length of combined 3 tracks on magnetic stripe of a card = 0.400”, horizontal length = 3.375”). The nano-coils in the stripe are supported by an effective solenoid circuitry for managing the electrical changes that trigger the stripe during a swipe event. Furthermore, the processor IC is linked to the very solenoid circuit that acts as a brain of the stripe for simulating the activity of the stripe on detection of the swipe episode of “Voice Magstripe”. The processor IC has a storage unit which acts as a memory module to store the activity details (i.e. current generated at the coils) for the magnetic stripe during a swipe operation. The storage unit includes nano-sized memory chips to store the current values for specific card configured on the ‘V-M’ device. The IC is further connected to the touch display unit which assists a user to interact with the ‘V-M’ device and configure / select cards for usage as per choice. When the card for usage is selected by the user, the switch in the processor IC unit triggers the memory module to retrieve (i.e. current values) data saved for a particular card. As the data is retrieved, the solenoid circuitry drives the A.C current corresponding to the saved values in the storage. The A.C current passing through the coils creates the required magnetic field around it. This magnetic field in turn mirrors the activity of its counterpart magnetic materials present in the conventional magnetic stripe cards. In this manner, data is rewritten on the dynamic magnetic stripe for every disparate card.

The dimensions (length, width) used for the design of a “Voice-Magstripe” are the standard dimension of an Iphone-6 [7], keeping in mind the dimensional requirement of the magnetic stripe in accordance with the ISO standards. The thickness of the ‘V-M’ device is rested at about 0.76mm, thus making the unit compatible for the swipe operation achieved by the magnetic card reader at malls, shops, etc. The length of the magnetic stripe is about 3.375”, width about 0.400” and thickness of about 0.030” (0.76mm) – all the dimensions adhere to the ISO standards [8].

Furthermore, “Voice-Magstripe” is provided with a SIM card slot for inserting a SIM (Standard thickness of Micro / Mini SIM - 0.76mm or less) into the phone operative device. The multi-utility IoT device is also provided with a headphone

jack slot for two primary objectives:

1. For connecting the headphones
2. Connecting the card reader for reading and configuring the magnetic stripe cards onto the ‘V-M’ device.

(Note: The design of newer headphone jack slot and the subsequent headphones with different dimensions as compared to the traditional TRS connector standards is an additional point-of-focus for the ‘V-M’ device.)

Architecture

The fundamental architecture of the “Voice-Magstripe” involves two modules (Layers):

Module I (Lower-layer)

The lower layer of the ‘V-M’ device lays a stack of four important nanostructured components onto the graphene film. The layers include the following:

Ultrathin-film Graphene based Flexible Solar Cell

Graphene is a two-dimensional material having a hexagonal structure. Its unique mechanical, electrical and optical properties make it an essential element for commercial industries. Graphene has a capacity of converting a single photon of light into multiple electrons that can drive electric current, which practically means an inevitable increase in the efficiency of solar panels. This ability makes graphene extremely desirable for any opto-electric technology driven entity that requires the conversion of light into electricity, and should lead to solar cells that are able to capture light energy from the entire solar spectrum with minimal loss [12]. In addition to opto-electrical properties, graphene has a low coefficient of light absorption (2.3%) which makes the material almost completely transparent. In a way, it gives a clear hint that solar cells based on graphene can notably amplify the absorbed spectrum of electromagnetic radiation (i.e. in terms of wavelength). Furthermore, Graphene material has a very high tensile strength making it significant component for usage with flexible organic substrates [11].

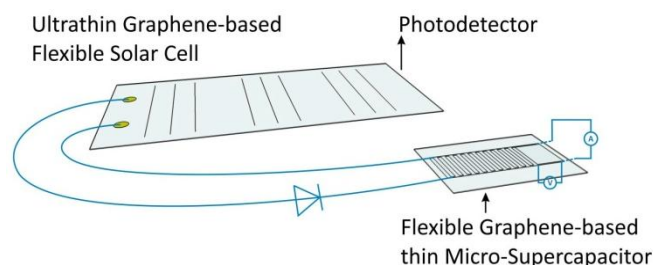


Figure 1: Solar cell with a Micro-Supercapacitor

Graphene-based Thermoelectric Generator (TEGs):

The basic conversion unit of ‘Thermoelectric’ energy is

known as Thermo-Electric Generator (TEG) [3]. The elemental building block of a traditional TEG unit is termed as a thermocouple which is composed of two n-type and p-type materials bonded together. Consequently, a typical TEG is constructed from multiple such thermocouples which are electrically connected in series and thermally connected in parallel. When a temperature gradient is applied between the top and bottom layers of the module, electrons (in the n-type material) and holes (in the p-type material) spread away from the hotter side towards the colder side - resulting in a potential difference across the material that is used to generate power. [2]

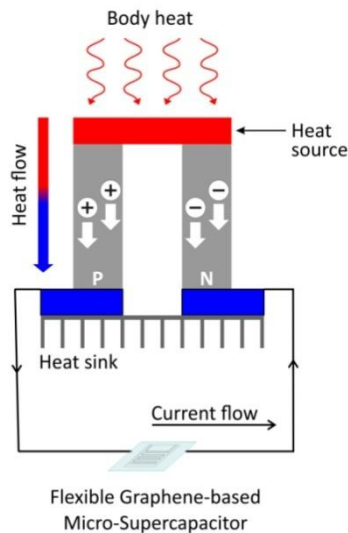


Figure 2: Functional mechanism of Thermoelectric Generator (TEG)

(Note: When heat is applied to one of the two conductors or semiconductors, heated electrons flow toward the cooler one. In the above diagram - when the pair is connected through an electrical circuit, direct current (DC) flows through that circuit. A thermoelectric circuit is composed of matter with different Seebeck coefficient [p-doped and n doped semiconductors], and is further configured as a thermoelectric generator)

Flexible Graphene based Micro-Supercapacitor(s)

Supercapacitors or ultracapacitors are the electrical storage units, having a high energy storage density along with a high power density. Supercapacitors are preferable devices to use in microelectronics since they can store a greater amount of energy in comparison to the nanoscaled size they possess - they can be charged and discharged briskly. In addition to this, the lifespan that supercapacitors hold is almost limitless. Micro-supercapacitors are structurally flexible and act as micro-batteries at the nano-scale degree [13].

Graphene-based Thin film Integrated Circuit

Integrated circuits are ubiquitous integrants present in

everything, from tea-makers to electronic computers and are shaped from perfectly crystalline substance like silicon. These IC's are quite thin—but Graphene-based Thin film Integrated Circuits have pushed thin-film boundaries to the single-atom level.

Photolithography is a well-known method for fabricating integrated circuits by laying materials, layer by layer, on flat silicon sheet.

The targeted materials of choice include graphene (single atom-thick sheets of repeating carbon atoms), hexagonal shaped boron nitride. In addition to these materials, thin sheets of repeating boron and nitrogen atoms are considered as well.

The technique, called patterned regrowth, leads to atomically thin circuits that are substrate free - the structure developed is so thin that it can float on water or through air, without compromising tensile strength and electrical performance.

In patterned regrowth, the basic photolithography technology is harnessed usually used for processing of silicon wafer - thereby allowing graphene and boron nitride to grow in extremely flat smooth films—no grooves, ridges or bumps—which, when combined with the final semiconductor material, leads to the first atomically thin integrated circuit [3].

The circuit thus developed exploits the high speed of electrons in graphene material, thereby making graphene ideally suitable to handle the high frequencies of mobile phone transmissions - both in the receiver and in generating the signal to send out to the base station.

IC includes nano-electronics for speakers in a 'V-M' device. Conventional speakers drive sound vibrations by compressing the air. But graphene can achieve the same output by using heat—similar to the lightning that generates thunder by heating the air. The advantage with graphene is that—being thin, it takes negligible current to heat up, but on the contrary it cools in an instant. Driving audio-frequency currents through a graphene sheet (ultrasound) - generates sound waves without the requirement for any moving parts. In theory this makes devices simpler and cheaper and further opens up the possibility of newer applications [4].

Similarly, the IC unit includes various other important components developed using graphene that play a pivotal role in the functioning of a phone - like Nano-sized Antenna circuitry [10], Speaker circuit, Microphone & NFC unit, Memory chips, etc. All these components are placed on the graphene sheet that works in synchronization for effective running of a phone module within a 'V-M' device.

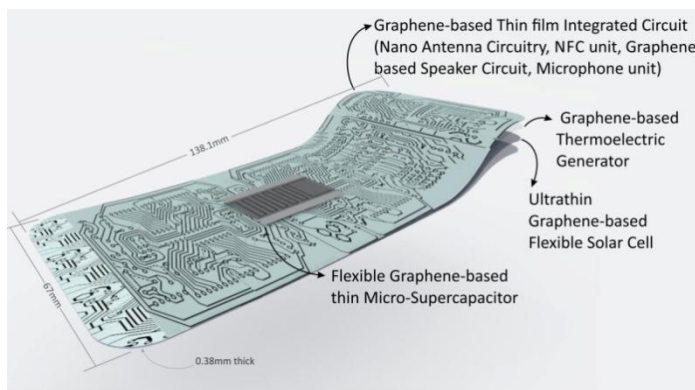


Figure 3: Lower-layer architecture of 'V-M' IoT device

Module II (Upper-layer)

Graphene-based Transparent Electrodes for Highly Efficient Flexible OLEDs

Flexible organic light-emitting diodes (OLEDs), placed upon a plastic substrate, are in use for next-generation displays that can be stretched or rolled during their natural operation.

The display panel used in the second module of 'V-M' device is a flexible OLED wherein graphene is used as a transparent electrode (TE). OLEDs are stacked in distinct ultra-thin layers on plastic substrates, in which various layers of organic compounds are squeezed between two chief electrodes (cathode and anode). When voltage is applied between the two electrodes (i.e. by turning the button 'ON' for the phone display in this case), electrons from the cathode and holes (positive charges) from the anode are pulled towards each other to eventually meet in the emissive layer. OLEDs effuse light as an electron merges with a positive hole, emanating energy in the form of a photon. The top electrode of the OLED is transparent for the 'V-M' device, and thus OLEDs emit light from the top [5].

On similar lines, the 'V-M' device has another touch display for handling different magnetic stripe cards. When the button for card is turned "ON", the "Voice-Magstripe" prepares itself for card operation. The card display obeys the same principle as that of the phone display unit.

Fabrication of Dynamic Rewritable Magnetic stripe

Typical magnetic stripe cards are encoded with standard magnetic arrangements. The rewritable dynamic magnetic stripe encodes data for various magnetic stripe cards onto one card. The rewritable dynamic magnetic stripe card includes a graphene solenoid coil for generating a magnetic field and solenoid circuitry for driving the solenoid coil to generate a magnetic field.

The magnetic stripe in "Voice-Magstripe" is fabricated on the graphene sheet of about 0.38mm. The fabrication of magnetic stripe is accomplished by embedding the graphene-based nano-coils onto the display surface of "Voice-Magstripe". The dimensions (length, width) for depositing these graphene-

based coils obey the compliance rules for magnetic stripe cards set by ISO. As per ISO standards, length of magnetic stripe is about 3.375", width about 0.400", distance from the top of the card to the top & bottom of magnetic stripe is about 0.218" and 0.618" respectively. The magnetic stripe is composed of three tracks with each track having the vertical length of about 0.110". These tracks encode user information like PAN, Name, CVV* etc. accessed during a swipe operation. The graphene-based coils are layered over graphene sheets adhering to the above mentioned guidelines of ISO.

The proposed magnetic stripe card discloses a unique magnetic stripe configuration which allows a single card to imitate the details of all the available cards – such configuration is therefore termed as "rewritable". The 'V-M' device is provided with a touch display in order to assist the user in selecting the card for usage at malls, shops, etc. Furthermore, the magnetic stripe encapsulates graphene-based nano-coils in a silver colored film for protection. As the solenoid coils are graphene-based, the coils transmit light through them, thus making the stripe fade-away/invisible when light is projected on the graphene display. Thereby, allowing the normal operation of the phone with no hindrance from the immersed magnetic strip. The magnetic stripe film chosen is silver colored for the same illuminating reason. The fading away functionality is similar to the 'Assistive-touch' icon property availed by the iPhone users [9].

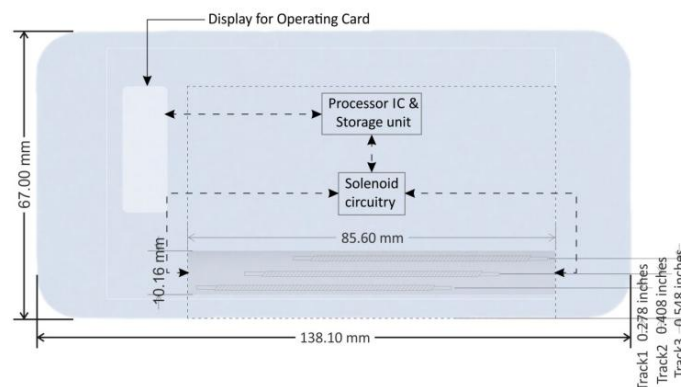


Figure 4: Block diagram of a 'Dynamic Rewritable Magnetic Stripe' with dimensions

Configuring Magnetic Stripe Cards onto "Voice-Magstripe"

The "Voice-Magstripe" is provided with specially designed magnetic stripe reader. This stripe reader is used to configure and write data onto the 'solenoid-coil' supported magnetic stripe of the phone.

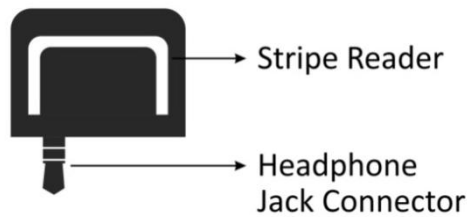


Figure 5: Magnetic Stripe Reader

To configure the magnetic stripe onto the 'V-M', following steps are followed:

1. The stripe reader is inserted into audio/connector jack
2. The physical/original magnetic stripe card is swiped on the stripe reader.
3. The read head in the reader reads the orientation of the magnetic dipoles during swipe
4. The change in the magnetic dipole orientations manifests as a magnetic flux reversal in a coil present in the read-head of the reader
5. These magnetic flux reversals in the coil induce a small electrical current that are relayed/transmitted to the solenoid coils through the solenoid circuitry.
6. The potential difference between the ends of the solenoid coil is amplified and demodulated to extract the underlying encoded digital information of the magnetic stripe.
7. The extracted information/data (i.e. A.C current generated for a particular card) is remembered and stored in the storage unit of the 'V-M' device for future swipe operations of the respective card.
8. The user enters details through the provided display on the 'V-M' after a swipe operation. The data entered by the user is processed by the processor IC circuit & gets stored in the storage unit block. Later on when the user selects a particular card for usage, user inputs are processed at the processor IC & the respective data (i.e. A.C current for the card) is retrieved from the storage. The retrieved data is used by the solenoid circuitry to drive A.C current through the solenoid coils that evenly mimic the original magnetic stripe.

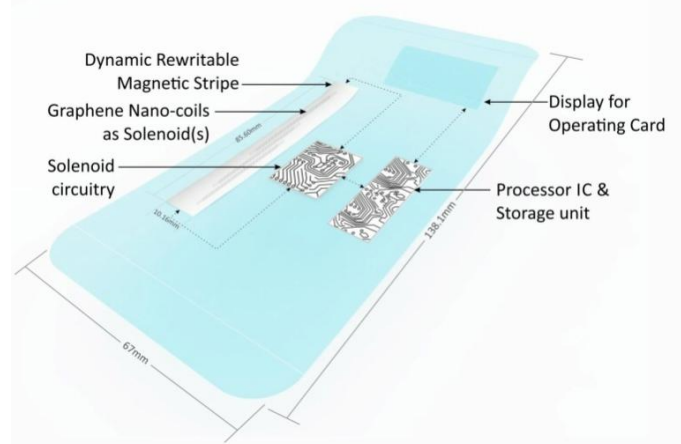


Figure 6: Circuitry for the Magnetic Stripe

Dynamic Rewritable Magnetic Stripe: Operation

Traditional magnetic stripe cards use magnetic media to store the userspecific information on the magnetic stripe. The information to be stored onto the magnetic stripe card is converted to binary format i.e. binary ones and zeros. The binary data is encoded as per the adaptive orientation of magnetic dipoles onto the magnetic stripe of the 'V-M' device. To read & access the digitally stored data off the magnetic stripe, the magnetic stripe of the 'V-M' device is swiped across a magnetic card reader with an appropriate read-head. The read-head recognizes the dynamic changes in the orientation of the magnetic dipoles during a swipe across the read-head of the card reader. The change in the magnetic dipole orientations is apparent as reversal of magnetic flux in a coil of the read-head. These magnetic flux reversals in the coil induce a small electrical current that generates a potential difference between the two ends of the coil in synchronization with the magnetic flux changes. The potential difference between the ends of the coil is reinforced, amplified and harmonized to extract the underlying encoded digitized data.

Just as magnetic flux reversals induce an electrical current in a coil, driving an electrical current in a solenoid coil creates a relative magnetic field as per Ampere's law. Hence, by driving an alternating current, magnetic field reversals may be achieved. Thus, by appropriately driving an alternative electrical current through the solenoid coils, the coils emulate the magnetic stripe of a typical magnetic stripe card. The solenoid coil used in the invention is a recently discovered nano-sized graphene solenoid coil [1] driven by solenoid circuitry. By utilizing the solenoid circuitry to drive an alternating current in the graphene solenoid coil while the 'V-M' device is being swiped in a card reader, the rewritable dynamic magnetic card echoes a traditional magnetic stripe card. Specifically, the solenoid circuitry modulates the alternating current through the graphene solenoid coil in time to mimic the magnetic flux changes that a read-head measures during the swipe of a conventional magnetic stripe card [6].

Use-case

The rewritable dynamic magnetic stripe card detects user input from a user input system (i.e. display unit). When the user input is received, the rewritable dynamic magnetic stripe card processes the user input. The user input signal causes the dynamic rewritable magnetic stripe card to reconfigure the magnetic stripe. The user input can be the user selecting magnetic stripe card to be used for the swipe such as a specific credit/debit card. If any specific card is selected then the rewritable dynamic magnetic stripe card triggers a respective A.C current through the solenoid coils that in turn generates a magnetic field around it. The magnetic field generated then performs the function of the conventional magnetic stripe card that encases magnetic materials in their magnetic stripe. Once the user input is taken by the 'V-M' device, the solenoid circuitry retrieves the remembered data i.e. A.C current recorded at the time of configuration of the original smartcard onto the 'V-M' device. And further, based on the remembered information the solenoid circuitry rewrites/reprograms the magnetic stripe and prepares the corresponding card for operation.

A single 'swipe operation' involves data-flow through various components of the 'V-M' device. The data-flow is depicted in the below flowchart.

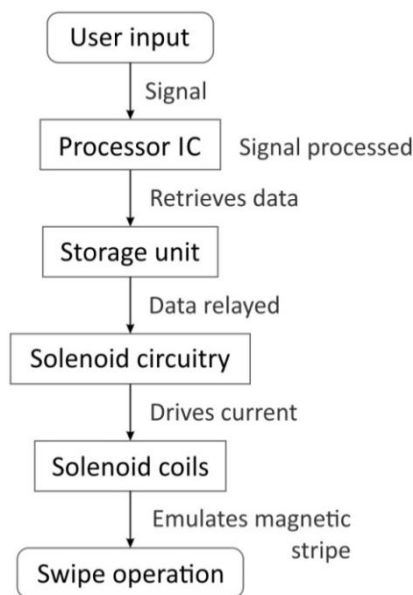


Figure7: Flowchart for a swipe operation of a 'Dynamic Rewritable Magnetic Stripe'

Optimizing Output of "Voice-Magstripe"

The total thickness of the solenoid coil (i.e., the core diameter plus silver colored encasing structure, packaging or the like) is less than the total thickness of the physical rewritable dynamic magnetic stripe card. The International Organization for Standardization ("ISO") specifies the maximum thickness of payment cards as 0.84 millimeters (0.033 inches). The solenoid coil core diameter is approximately 70nm.

A dynamic rewritable magnetic stripe card may be constructed with a single solenoid coil in a magnetic stripe track for creating a magnetic field. However, with the single coil magnetic stripe card design, there is substantial change in the measure/magnitude of the external magnetic field created between the ends of the solenoid coil and the center of the solenoid coil. Since the magnetic field output by the solenoid coil is much greater at the ends compared to center of the solenoid coil, a magnetic stripe reader may have issues while reading the information output generated by the solenoid coil.

The issue of a weak magnetic field can be addressed by utilizing multiple parallel solenoid coils arranged in an overlapping manner in order to create a more even magnetic field.

The individual solenoid coil(s) may be individually or collectively driven through a common solenoid circuitry.

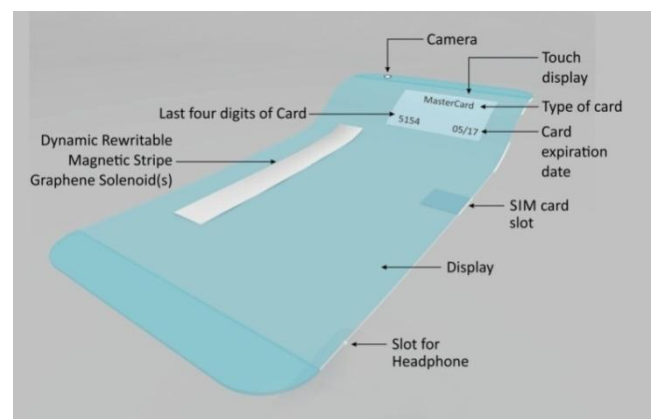


Figure 8: Magnetic stripe under operation - Upper layer of "Voice-Magstripe"

Table 1: Physical characteristics of the "Voice-Magstripe" (Implementation/Observation)

Physical characteristics	Geometric Measurements / Dimensions (mm/inches)
1. Length of 'V-M'	138.10
2. Width of 'V-M'	67.00
3. Thickness of 'V-M'	0.76
4. Length of Magnetic-stripe	85.60 (3.375")
5. Width of Magnetic-stripe (top) from the edge of 'V-M'	0.218" (approx.)
6. Width of Magnetic-stripe (bottom) from the edge of 'V-M'	0.618" (approx.)
7. Total width of Magnetic-stripe (top-bottom – includes 3 tracks containing the encoded data)	0.400" (min)
8. Width of each track on the Magnetic-stripe containing the encoded information	0.110"

(Note: Dimensions of the Magnetic-stripe comply with the ISO standards)

Advantages:

1. Thin, strong, transparent&flexible device
2. Energy-efficient Device – Harnessing free sources of energy.
3. Versatile Graphene – Exploit as many properties (electrical, optical, mechanical, etc.)
4. ‘All-In-One’ Device
5. Single ‘Dynamic Rewritable Magnetic Stripe’ replaces large collection of standard ‘Magnetic Stripe Cards’.

Conclusion

The material used for developing the ‘V-M’ device is cheap, transparent and is electrically conductive at the same time. The above properties of Graphene stand out among its competitor materials making it ideal for the flat-screen displays used on smart phones that require electricity to power the optical components, and to respond to the touch senses of the user.

Furthermore, arewritable dynamic magnetic stripe card employed on ‘V-M’ can be utilized to overshadowthe drawbacks of any conventional or static magnetic stripe card. Thus, a single rewritable dynamic magnetic stripe card can be used to emulate many different conventional magnetic stripe cards (credit/debit/ATM). Therefore, the user only needs to carry a single rewritable dynamic magnetic stripe card instead of a voluminous collection of conventional magnetic stripe cards. In addition to the above advantage,the user need not search through a stack of magnetic stripe cards to realize the specific magnetic stripe card for the present scenario.

Thus,the “Voice-Magstripe”forms a composite device providing the functionality of a phone as well as a smartcard.



Figure 9: “Voice-Magstripe”

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