NFC ANTENNAS FOR SMART PHONES

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Abstract - Antenna design plays a vital role for an NFC enabled smartphone. Inductively coupled near-field communication link is a short-range wireless skill allowing the devices to interconnect with each other through the coupling of magnetic field. These antenna designs for NFC tags/devices/systems offer a variety of rewards including low cost, high efficiency, better ability to penetrate through non-magnetic materials and also other antenna design effecting factors such as resistance to eavesdropping, no multipath fading, low propagation delay and low probability to interfere with other RF systems operating outside the operational range of the near-field system including highly secured data transfer standards. The current paper discusses briefly the fundamentals of antenna design, factors effecting the performance and leading to the antenna's best suitable for NFC smartphones.

Keywords - ***Near Field Communication, Smartphone, NFC tags, Antenna, Inductance, NFC Mobile, Data transfer speed, Tag Memory, Security***

I. INTRODUCTION

NFC on a Smart phone is the technology, defined as a set of communication protocols that enable two electronic devices, one of them being a smartphone, to establish communication between in near field. In communication terms a Transmitter and a Receiver, transmitting information between for transactions processing or data transfer.

NFC defines the intended link budget between the two NFC designed antennas as being able to communicate up to a distance of 4" (100mm) specifically operating at the unlicensed frequency of HF range 13.56MHz. [3] Radio Frequency Identification (RFID) tags are products or items using advanced barcode labels allows quick liability of objects. In order to understand and propose a suitable working antenna design for the NFC enabled smartphones, in the following sections a brief discussion of fundamentals such as what RFID tags meant to be, types, how they communicate and standards is presented before actually getting into the actual NFC antenna concepts for reader's knowledge.

II. TAGS

The tags or NFC tags or RFID tags used during the modes of communication in the smartphones, are of different types. These tags are passive tags of no power of its own, embedded into the devices itself such as posters where a small amount of data is stored and can be used to communicate with active NFC devices of reader/writer. While designing every single NFC tag, the factors such as read speed, die size, and unit price while making them very low cost and still maintaining the high-performance properties.

So far as defined by the NFC Forum and standards, 5 different tags based on the operating mode, memory range and data transfer speed rate. [7]

Type-1 tag: This tag is capable of read-write and may be user-configurable to read-only mode. The memory size - 93 bytes to 2 Kbytes, communication speed - 106 kbit/s. This tag is cost effective and widely used for NFC applications.

Type-2 tag: This tag is capable of read-write-capable and may be user-configurable to read-only mode. The memory size - 48 bytes to 2 Kbytes, communication speed - 106 kbit/s.

Type-3 tag: This tag is capable of read-write-capable and may be user-configurable to read-only mode and also can be enabled for re-writing. The memory size – 2 Kbytes, communication speed - 212 kbit/s or 424 kbit/s. This is a very complex structure applicable to complicated applications when compared to other types and also its highly expensive due to its supportability.

Type-4 tag: This tag is factory-set to read-only mode and precise infrastructure will be required for changing its mode. The memory size - 32 Kbytes, communication speed - 106 kbit/s, 212 kbit/s and 424 kbit/s. These tags are pre-configured tags by the manufacturer.

Type-5 tag: This tag type is a recent development to allow NDEF messages to be stored and read on tags using the NFC-V technology. The memory size - 64 Kbyte, communication speed - 26.48 kbit/s.

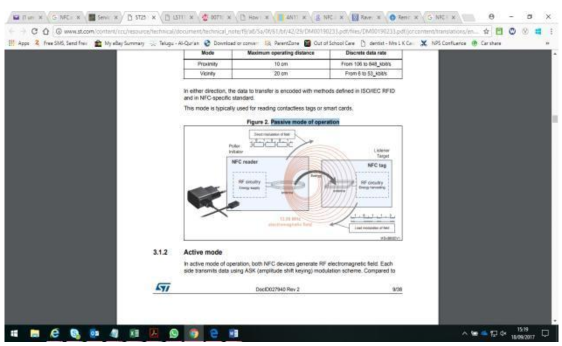
Of all 5 types of tags, only Type-1 tags doesn't support anit-collision mechanism while all others do.

III. MODES OF OPERATION

NFC tags/devices works in two modes. a) Active Mode of Operation b) Passive Mode of Operation.

- *Passive mode:* In passive mode of operation, only one of the devices generates a Radio Frequency field playing the role of initiator known as NFC initiator while the second device doesn't generate any RF filed staying passive, playing the role of target known as NFC target. The active NFC device handovers data by controlling the channel of the RF field when it generated. The generated modulation is sensed by the passive NFC device and translated into data. On the other hand, the passive NFC device sends data to the active NFC device by load-modulating the field intensity. The method used during the card readings or contactless tags is called passive mode of operation, as only one NFC device will be active once during data transformation. [5][6]

- *Active mode:* In active mode of operation, instead of one NFC device, both devices generate Radio Frequency Electromagnetic field. Each side transmits data using ASK (amplitude shift keying) modulation scheme.



Mode	Maximum operating distance	Discrete data rate
Proximity	10 cm	From 106 to 848_kbit/s
Vicinity	20 cm	From 6 to 53_kbit/s

In either direction, the data to transfer is encoded with methods defined in ISO/IEC RFID and in NFC-specific standard.

This mode is typically used for reading contactless tags or smart cards.

Figure 2. Passive mode of operation

3.1.2 Active mode

In active mode of operation, both NFC devices generate RF electromagnetic field. Each side transmits data using ASK (amplitude shift keying) modulation scheme. Compared to

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Figure 1: NFC Reader and Listener interaction in NFC electromagnetic field @13.56MHz

IV. MODES OF COMMUNICATION

There are three different interaction modes predictable, those include a) read / write mode, b) card emulation mode and c) peer-to-peer mode.

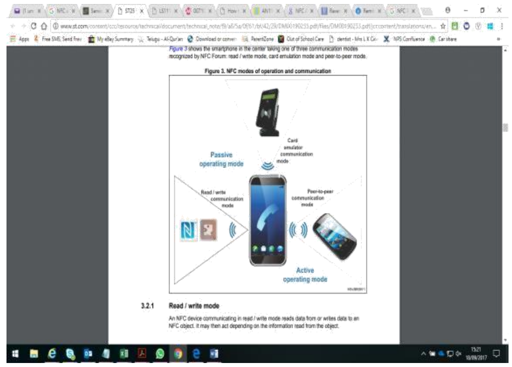

Figure 2: NFC Tags/Devices Operating Modes

- *Read / write mode*: In this mode an NFC device reads data from or writes data to an NFC object. To detail with an example, an NFC smartphone in its near field of an NFC tag will be able to extract the tag info such as a URL and then redirect it to the relevant website followed by sending an update while the security of data received and transferred is low.

- *Card emulation mode*: In this mode, the NFC device operate in passive mode, and acts as as a typical contactless smart card, allowing few operations including access control, contactless payments, firmware exchange or data transfer while the securing the data transferring to high end.

- *Peer-to-peer mode (P2P)*: In this mode, the NFC devices operate in active mode, means both the NFC devices will be communicating in a rotation mode of allowing each device to interconnect and interchange the information. One of the devices initiates and establishes a communication link with the rule of listen-before-talk, allowing each other to exchange information making it possible to exchange huge amounts of data on a secured platform when compared to other two modes.

V. ANTENNA

Antenna design carries an important role in radio wave propagation. The latest development in the areas of wireless telegraphy, radio, and television has improved the antenna design to great extent. Input parameters are very key factors in designing an antenna. In Antenna Designs, there are two main fields: far and near. The near field is close to the antenna and far field is about or more 10 wavelengths from transmitting antenna. The radio wave propagation also depends on the angle of the Transmitting & Receiving antenna placed Vertical/Horizontal/Circular. This is known as Polarisation.

Another key parameter in antenna design greatly influences is gain factor / power gain. Antenna gain is defined as the ratio of the antenna's power to hypothetical lossless isotropic antenna power from a far-field source. The receiving antenna gain is equal to its transmitting antenna gain in ideal circumstances such as LOS & Free Space Loss where there is no loss but in practical scenario it changes. Due to this gain factor, now it has become common practice, antennas are referred by their gains.

G = (power radiated by an antenna)/(power radiated by referenced antenna)

The effective length characterizes the efficiency of the antennas in transmitting and receiving radio waves. Transmitter effective length is defined as the length of the free space in conductor. Receiver effective length is the ratio of EMF at the receiver input to the intensity of the electric field. i.e., A doublet is the simplest and most widely used antenna for most purposes also known as dipole antenna. The dipole antennas produce a radiation pattern resembling that of an elementary electric dipole with a radiating structure supporting a line current so energized that the current has only one node at each end consisting of two identical conductive elements such as wires or rods. The length of the rods is chosen in such a way that they have quarter length of the wavelength at operational frequencies.

The dipole antenna structure consists of two metallic rods through which current and frequency flow. This current and voltage flow makes an electromagnetic wave and the radio signals gets emitted. The antenna contains a radiating element which splits the rods and make current flow through the centre with the help of a feeder. [8] The dipole antenna is a particularly important form of RF antenna which is very widely used for radio transmitting and receiving applications. The different types of dipole antennas are (a) Half wave dipole antenna – it is a half a wavelength long (b) Multiple half waves dipole antenna **-** is an odd multiple of half wavelengths long (c) Folded dipole antenna **-** dipole antenna is folded back on self while still maintaining the length between the ends of half a wavelength while an additional length of conductor effectively connects the two ends together (d) Short dipole **-** is one where the length is much shorter than that of half a wavelength (e) Non-resonant dipole **-** antenna can be operated away from its resonant frequency and fed with a high impedance feeder. This enables it to operate over a much wider bandwidth.

So, in designing the factors such as the antennas gain levels, antenna feeder losses, path losses, radio transmitter power levels, and receiver sensitivity to be determined. In addition to the antenna design factors, there are number of factors such as ground conductivity, permittivity, permeability, reflectance, distortion, signal fading, shadowing, ISI, scattering, refraction and diffraction etc. The accounting of all these factors is known as Link Budget. Using the link budget, a feasible solution can be designed which meets the requirements and as well as work accurately without being over designed spending additional expenditure.

VI. FACTORS TO BE EVALUATED FOR NFC ANTENNA DESIGN

When designing an NFC/HF RFID antenna, carefully consider the placement of the coil within the final mechanical encasement and ensure that the antenna coil is kept away from metal. Because NFC/HF RFID is based on magnetic fields, any metal within close proximity to the antenna coil has a dampening effect on the antenna. When the antenna coil is dampened, the inductance changes, and this change negatively affects the tuning of the antenna by causing the center frequency to drift away from 13.56 MHz. Furthermore, the metal may also create eddy currents that affect the received RF signals. Both issues reduce range performance for the antenna and could even potentially make RFID tags unreadable. However, if it is not possible to avoid placing an antenna coil near the metal case of an enclosure, then a ferrite sheet could be used between the coil and the metal to reduce the effects of the detuning and increase performance of the NFC/HF RFID antenna. If this is the situation, then the antenna must be measured for inductance and tuned when placed within the final enclosure including the ferrite sheet, so that the tuning circuit can account for the changes to the coil inductance caused by the metal and the ferrite sheet. Recommended spacing for both vertically stacked and side-by-side geometries between metal surfaces and the NFC/HF RFID antenna coil is 10 mm. At that distance, it is likely that metal still has an effect on the antenna coil, such as reducing the Q factor and lowering performance compared to being in free space, but the magnitude of those effects should be reduced to a manageable level.

Antenna Types

While applying the above concepts during the antenna design specifically to the antennas used in smartphones is practically more complicated compared with other types antennas used such as in broadcasting. These antennas can be categorised as 1. primary cellular antenna, 2. diversity cellular antenna, 3. GPS antenna, 4. WIFI antenna, 5. NFC Antenna etc.

Antenna Design for NFC Mobile

The primary cellular antenna on a smartphone is an extremely important one as it acts as both transmitter and receiver for communication. Diversity cellular antenna works only as a receiver, which in general can be found along with the primary cellular antenna in modern smart mobiles. Each and every single mobile will have a GPS antenna, acts as a receiver only with fairly using a very small bandwidth. On the other hand, WIFI antenna is the smallest antenna as it operates at the highest frequency range which works as both receiver and transmitter and is connected to a chip enabling both Wi-Fi and Bluetooth. NFC antennas function at low frequency on a smartphone or on small devices which means that the radiation efficiency of an NFC antenna will be very low.

While setting up the laboratory for designing the antenna to work on a smart phone in NFC tag, there are number of concepts to be accounted for such as (a) Antenna size i.e., to determine the acceptable size of the antenna in synchronise to NFC tag specifications of NFC tag applications (b) Antenna type i.e., communication distance from our NFC tag and antenna requirements such as number of turns, track width, spacing etc. (c) Antenna board and (d) Resonant capacitor value. A radio frequency signal can be radiated effectively at the specific wavelength of the frequency. For NFC tags to perform as expected, it is estimated the wavelength at 13.56 MHz is 22.12 meters. Therefore, it is practically not possible to form a true antenna for most NFC tag applications. Instead, antenna circuit with a small loop at the frequency is studied.

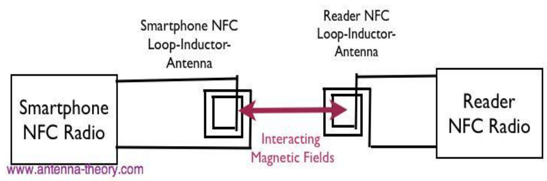

Figure 3: NFC loop inductor antenna

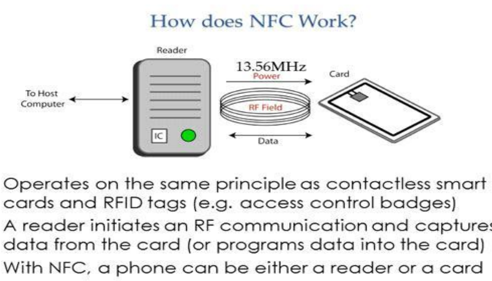

Figure 4: NFC enabled device reading card @13.56MHz in RF field

NFC tags/card acts as information sources only as they have no power source while NFC enabled device or NFC reader sends power and commands to the tag/card, which in turn responds with data.

Antenna Size

In view of the design, the primary concern raises here is the size of an antenna which can be fitted very well on a smartphone of small size to max size available of current day smartphones of 6 inches (or less). Already existing technologies such as GPS antenna, Wi-Fi antenna proved to be nearly right size on the mobiles, hence in turn providing a map for NFC antenna size as well. So, a detailed analysis of present and past technologies widely been used, a conclusion of nearly antenna size to be limited to around 3inches i.e., around 2.5cm around to be max. as detailed above, effective length will be the factor in deciding efficiency of antenna's, the smaller the size the higher the wavelength. However, as NFC works only at 13.56MHz frequency in HF spectrum, wavelength ???? which also confirms in turn that the radiation from such an antenna of size is totally nullable.

It can be almost explored, that the antenna on a smart phone is not actually an antenna as widely used during TV broadcasting for an example. To design an antenna for NFC mobile of required size, is kind of actually a loop circuit i.e., NFC loop inductor antenna as shown in above picture.

Antenna Circuit design

Inductive coupling NFC uses electromagnetic induction between two loop antennas located within each other's near field. The inductive coupling is the NFC wireless diffusion of electric energy between magnetically coupled coils. Inductive coupling uses magnetic fields that are a natural part of current's movement through wire. When electrical current passes through a wire, creates a circular magnetic field around the wire, while bending the wire into a coil intensifies the magnetic field and as the more number of loops the coil makes, the bigger will be the field. Modulation is a process of integrating a signal with a sinusoid while producing a new signal having more benefits over the unmodulated signal. Hence a loop antenna is a tuned LC circuit operating at a particular frequency, and antenna will be at resonance when both the capacitive impedance and inductive impedance are equal. [1][4]

The inductive coupling allows the coupled proximity and vicinity devices to exchange information and allows to do power transfer. [2] The RF field mean energy decreases during the data transfers when a coupling device signals data to card. These decrease levels depend on the different methods and techniques of modulation and data encoding. While the coupling device signals data to the listening device by direct modulating, the listening device signals data to the coupling device by load-modulating. The variations created during the direct and indirect modulation produced by the coupling device and listener are interpreted as data. While performing the data transfer between the reader and listener i.e., between the NFC passive tags and NFC active devices, passive devices draw energy from the RF field generated by active device eliminating the need of power supply or a battery.

In order to design an NFC antenna loop, the main factors to be evaluated are read distance, speed of data transfer, loop inductance, capacitance, resistance etc. Read range is described as a maximum communication distance between the reader and tag. However, the read range of passive RFID tags/devices differs based on system configuration. The Impedance analyser can measure the Capacitance (C), Resistance (R) and Inductance (L -Loop inductance) of the antenna when properly tuned for desired frequency, such as the inductance for the reader antenna coil for 13.56 MHz is typically in the range of a few microhenries (μH). The antenna can be moulded with air-core or ferrite core inductors or metallic or conductive trace on board or on flexible substrate. The reader antenna can be made of either a single coil or a double coil. The factor Q defines the quality and performance of the antenna where it operates. The loop circuit must be adjusted to the required frequency to make the most of power used efficiently. The Q of the circuit is related to both read range and bandwidth of the circuit. The resonant circuits can be either series or parallel. The series resonant circuit results in minimum impedance at the resonance frequency and so because of its simplicity and the availability of the high current into the antenna element, the series resonant circuit is often used for a simple proximity reader, while, a parallel resonant circuit results in maximum impedance at the resonance frequency. In general, the parallel resonant circuit is used in both the tag and the high-power reader antenna circuits. The coir circuit must be tuned to the resonance frequency for a maximum achievable performance of the device.

VII. CONCLUSION

An NFC enabled Smartphone and NFC or RFID tags/systems to be supported with appropriately tuned antennas to safeguard the data transfer, high performance and optimal read ranges. The NFC Antenna's or Loop coil tuning process and achieving high and optimised performance at near field operating frequency of 13.56 MHz is technical. The above case study and lab tests, recommends that the ability of a wireless link is determined by the two factors, both the power received and the bandwidth of the system. In the above discussed design of a conventional setup of an inductively coupled coil, the compromise of power and bandwidth can be observed, but modulation techniques application will mitigate this concern. Increase in reception of the high-speed modulation information while securely transferring data in peer-to-peer mode with active devices considering the important factors inductance, capacitance, resistance and quality factors and tuning these in synchronisation of each other, a greater performance of a NFC antenna can be attained.

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