PCB DESIGN AND CARD ASSEMBLY FOR AN ACTIVE RFID TAG IN CREDIT CARD FORM FACTOR

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ABSTRACT

An Active Radio Frequency Identification (RFID) transponder is used in conjunction with a customer relationship system to provide a variety of customer relationship management services within a retail establishment. The transponder includes a battery-powered integrated circuit and low-frequency antenna that detect a low-frequency activation signal from an activator when a customer enters a retail establishment. The transponder also includes a high frequency antenna and oscillating crystal for transmitting an identifier signal when activated. The battery, integrated circuit, high-frequency antenna, low-frequency antenna, and crystal are embodied in a card assembly substantially conforming to a form factor of a credit card or smaller that can be carried in, for example, a wallet, purse, or pocket of a customer.
Crystal embedded into PCB, reducing assembly thickness to that of the crystal itself.

PCB via cut through & crystal soldered on sides to via

Dimensions and strength of crystal corner metallization are critical.

Filling in void between crystal and PCB with an adhesive after soldering may increase strength.

FIG. 14
FIG. 15

Proposed crystal package

Narrow portion of proposed crystal package window in PCB cutout. Achieves assembly flatness goal with crystal package thickness of 0.38mm.
FIG. 18

Excessive L.F. Antenna (Coil) deformation during Card lamination
PCB DESIGN AND CARD ASSEMBLY FOR AN ACTIVE RFID TAG IN CREDIT CARD FORM FACTOR

RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 61/430,447 entitled “Reader Network System for Implementing Presence Management in a Physical Retail Environment” to Rolin, et al., filed Jan. 6, 2011, U.S. Provisional Application No. 61/430,450, entitled “PCB Design and Card Assembly for an Active RFID Tag in Credit Card Form Factor” to Rolin, et al., filed Jan. 6, 2011, and U.S. Provisional Application No. 61/430,451, entitled “Power Management for an Active RFID Tag in Credit Card Form Factor” to Rolin, et al., filed Jan. 6, 2011, the contents of which are all incorporated by reference herein.

BACKGROUND

[0002] 1. Field of Art
[0003] The invention generally relates to customer relationship management and more specifically to customer relationship management in a physical retail environment.
[0004] 2. Description of the Related Art
[0005] Modern society has created a plethora of ways to provide goods and services to customers. However, physical locations continue to be the predominant forums preferred by customers. Physical locations include brick and mortar establishments, i.e., those places a customer can physically go to purchase goods, receive services, etc. Whatever the type of business, be it retail stores, banks, restaurants, patio cafes, or any other type business, customers prefer to interact directly with the providers of the goods and services.
[0006] From a perspective of customer service at brick and mortar establishments, present systems lack a mechanism to effectively service the customer based on his profile, preferences, and transaction history, or at best these mechanisms are very ad-hoc and un-automated. Although basic incentive systems are commonly used, these incentives are very limited in their effectiveness because they are offered at the end of the transaction, which is too late. Furthermore, present brick and mortar locations lack the technology to track and service customers within the retail establishment.

SUMMARY

[0007] In a first embodiment, an Active Radio Frequency Identification (RFID) transponder is configured for use with a customer relationship management system. An integrated circuit stores an identifier of the transponder. The integrated circuit is further configured to detect a low-frequency activation signal and responsive to the detection, generate a high-frequency identifier signal representing the identifier of the transponder. A low-frequency antenna is coupled to the integrated circuit for receiving the low-frequency activation signal. A crystal is coupled to the integrated circuit for generating high-frequency oscillations for generating the high-frequency identifier signal. A high-frequency antenna is coupled to the integrated circuit for transmitting the high-frequency signal representing the identifier. A battery provides power to the integrated circuit. The integrated circuit, the low-frequency antenna, the high-frequency antenna, crystal, and the battery are all integrated in a card assembly substantially conforming to a form factor of a credit card or smaller.

[0008] In a second embodiment, a method is provided for manufacturing a Radio Frequency Identification (RFID) transponder. A Flexible Printed Circuit Board Assembly (FPCBA) is formed comprising an integrated circuit, a high-frequency antenna coupled to the integrated circuit, and a crystal coupled to the integrated circuit. The FPCBA is combined into a card assembly which further includes a low-frequency antenna coupled to the integrated circuit and a thin film battery for powering the integrated circuit. The card assembly substantially conforms to a form factor of 85.47 mm x 53.92 mm x 0.8382 mm or smaller.

[0009] The features and advantages described in the specification are not all inclusive and, in particular, many additional features and advantages will be apparent to one of ordinary skill in the art in view of the drawings, specification, and claims. Moreover, it should be noted that the language used in the specification has been principally selected for readability and instructional purposes, and may not have been selected to delineate or circumscribe the inventive subject matter.

BRIEF DESCRIPTION OF THE FIGURES

[0010] FIG. 1 is a block diagram of an In-Store Ad Network in accordance with one embodiment.
[0011] FIG. 2 is a block diagram of a store-corporate application communication system in accordance with one embodiment.
[0012] FIG. 3 is a timing diagram of a card life cycle in accordance with one embodiment.
[0013] FIG. 4 is a timing diagram of a card activation process in accordance with one embodiment.
[0014] FIG. 5 is a timing diagram of Normal Mode operation of a card in accordance with one embodiment.
[0015] FIG. 6 is a diagram illustrating an activator transmission data structure in accordance with one embodiment.
[0016] FIG. 7 is a diagram illustrating a card transmission data structure in a Beacon Mode, in accordance with one embodiment.
[0017] FIG. 8 is a block diagram of a card architecture in accordance with one embodiment.
[0018] FIG. 9 is a schematic diagram of a card in accordance with one embodiment.
[0019] FIG. 10 is a diagram illustrating an internal assembly of a card in accordance with one embodiment.
[0020] FIG. 11A is a layout diagram of a flex printed circuit board in accordance with one embodiment.
[0021] FIG. 11B is a layout diagram of a flex printed circuit board showing external connection points in accordance with one embodiment.
[0022] FIG. 12 is a side view construction diagram of a flex printed circuit assembly (FPCBA) in accordance with one embodiment.
[0023] FIG. 13 is a diagram illustrating an internal assembly of an IC package in accordance with one embodiment.
[0024] FIG. 14 is a diagram illustrating a crystal packaging option in accordance with one embodiment.
[0025] FIG. 15 is a diagram illustrating a second packaging option in accordance with one embodiment.
[0026] FIG. 16 is a diagram illustrating a flexible printed circuit board assembly in accordance with one embodiment.
[0027] FIG. 17 is a diagram of an LF antenna in accordance with one embodiment.
[0028] FIG. 18 is a diagram illustrating an LF coil deformation and detuning in accordance with one embodiment.
FIG. 19 is a diagram illustrating a thin battery in accordance with one embodiment.

FIG. 20 is a diagram illustrating effects of high battery source resistance in accordance with one embodiment.

The figures depict various embodiments of the present invention for purposes of illustration only. One skilled in the art will readily recognize from the following discussion that alternative embodiments of the structures and methods illustrated herein may be employed without departing from the principles of the invention described herein.

DETAILED DESCRIPTION

Overview

A Digital In-Store Ad Network system can be used in retail environments to detect the localized presence of customers in real time. The Digital In-Store Ad Network uses this presence knowledge of customers to deliver relevant and timely offers to those customers while they are in the retail environment. This optimizes the customer’s purchasing ability, increases store revenues, and increases customer loyalty. The Digital In-Store Ad Network collects and analyzes customer shopping pattern data and provides it to merchants and brand companies so they can easily optimize advertising effectiveness.

The digital in-store ad network comprises hardware and software platforms. The following description describes the hardware and operation of the reader network installed in a store implementing the digital in-store ad network system.

Terms & Descriptions Used herein

The following table (Table 1) provides example descriptions for terms used in the following sections. The table is intended to improve readability and clarity of the description of embodiments that follow. The terms below are not necessarily limited to the particular example definitions provided in Table 1, but rather should be interpreted in view of the entire description (which may vary in between different described embodiments) and in view of their usage in the claims.

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activation</td>
<td>Process of activating a Card (causes the Beacon State)</td>
</tr>
<tr>
<td>Activation Holdoff</td>
<td>Time period immediately following Beacon Mode expiration during which Card activation is disabled.</td>
</tr>
<tr>
<td>Activation Range</td>
<td>Maximum separation (distance) between an Activator and Card at which the Card will be successfully activated.</td>
</tr>
<tr>
<td>Activation Signal</td>
<td>RF transmission of an Activator used to turn on (activate) Cards. The activation signal contains data used by the Card to validate the activation signal and to set Card behavioral options.</td>
</tr>
<tr>
<td>Activation Zone</td>
<td>The physical volume within which a Card will be activated. Typically located at a Store or business entrance and/or exit.</td>
</tr>
<tr>
<td>Activator</td>
<td>Hardware device that wirelessly activates Cards upon arrival at an enabled retailer.</td>
</tr>
<tr>
<td>Active RFID Card</td>
<td>RFID card that uses an internal battery for enhanced performance</td>
</tr>
<tr>
<td>Anticollision</td>
<td>Method for avoiding or minimizing the collision of RF transmissions by more than one source occupying the same frequency and physical space so that each individual signal can be distinguished by a receiving device.</td>
</tr>
<tr>
<td>Base Station</td>
<td>Device that wirelessly receives Card read information from Readers and communicates this information to a host computer to facilitate the generation of offers to Cardholders through the Software Platform.</td>
</tr>
<tr>
<td>Beacon Mode</td>
<td>Operating state of a Card that commences upon activation. The Card periodically transmits a unique ID for detection by Reader hardware.</td>
</tr>
<tr>
<td>Brand Company Card</td>
<td>The branding manufacturer that sells products in stores (a.k.a. “Brand”).</td>
</tr>
<tr>
<td>Cardholder</td>
<td>Person (Consumer) who has opted into the Digital In-Store Ad Network and who possesses a Card.</td>
</tr>
<tr>
<td>Collision</td>
<td>Simultaneous RF transmissions by more than one source occupying the same frequency and physical space, which cause a receiving device to be unable to distinguish the individual signals. Also referred to as “data collision”.</td>
</tr>
<tr>
<td>Consumer</td>
<td>Individual that shops and/or purchases products in a store (becomes a Cardholder upon opting-in to carry a Card).</td>
</tr>
<tr>
<td>Deep Sleep</td>
<td>Normal operating state of a Card in which power consumption is very low and the Card does not transmit information to Readers.</td>
</tr>
<tr>
<td>Demodulation</td>
<td>Process of separating a modulated signal into component signals, such as an RF signal (“carrier”) and a data signal.</td>
</tr>
<tr>
<td>Digital In-Store Ad Network</td>
<td>Hardware/software system used that provides relevant offers to participating Consumers while they are physically at a participating retail environment.</td>
</tr>
<tr>
<td>Hotspot</td>
<td>Small area in a store containing Reader(s) that detect Cards within that area.</td>
</tr>
</tbody>
</table>
| ID                  | A numerical value assigned to and stored within each Card; the value being unique to each Cardholder. The ID Number is wirelessly transmitted by a Card when in the Beacon Mode for reception by Readers. Also referred to as “Card ID” or “ID number”.

Dec. 13, 2012
Listen
A state within the Sleep Mode during which the Card “listens” for activation signals. Cards can be activated only when in the Listen state. Generally applies to businesses which have implemented the Digital In-Store Ad Network. Also referred to as store, retailer, etc.

Modulation
Process of changing one signal as a function of another signal. Often used by transmitting devices to add information (data) onto an RF signal, thereby ‘carrying’ the data via electromagnetic wave to a remote receiving device for subsequent data extraction.

RF
Radio frequency.

RF Signal
Radio frequency energy. May be modulated to carry information (data) to a receiving device. May refer to an electromagnetic wave propagating in space in wireless communication systems.

RF Transmission
Generation of an RF signal. Often used to cause electromagnetic wave propagation from an antenna through space in wireless communication systems.

RFID
Radio Frequency Identification

Read
The process of wirelessly detecting and successfully decoding a Card ID.

Reader
Hardware device that wirelessly receives Card IDs and relays this information to the Base Station.

Read Range
Maximum separation (distance) between RF transmitting and receiving devices (e.g., Card and Reader, respectively) at which the transmitted RF signal can be successfully read.

Read Zone
The area within which a hotspot Reader can reliably read activated Cards.

Read Volume
General term referring to read range in 3-dimensional space. Read range may vary with direction, device orientation, and presence of physical objects, so read volume is not necessarily uniform or symmetrical.

Retailer
See merchant

Session Metrics
Data that describes a Cardholder’s shopping history within a participating retailer. This can include the time spent in the store, in each department, responses to ads, and purchases.

Store
See merchant

Wake-Up
The event of Card activation, which marks the transition from a low-power sleep state in the Card to a higher power activity state.

6LoWPAN
A wireless networking standard for low power wireless personal area networks.

INTRODUCTION

FIG. 1 provides a high-level illustration of an embodiment of a Digital In-Store Ad Network. The Digital In-Store Ad Network is a hardware-software system that provides an integrated direct marketing solution that benefits participating product manufacturers, merchants, and consumers alike. Consumers benefit because they can receive private, relevant, and timely offers from product manufacturers and merchants while physically in the retail environment. Product manufacturers benefit by having an opportunity to market directly to consumers based on interests they share when opting-in to the system and enhanced with the consumer’s shopping and purchasing history. Merchants benefit by better serving the needs of their customers, thereby improving customer loyalty and increasing sales. Revenue is collected from advertisers as a function of a) ads served, b) customer response to those ads, and c) offer redemption at the point of sale.

The hardware aspect of the Digital In-Store Ad Network is comprised of several distinct physical elements, each having specific functions. The hardware can be grouped into two general categories:

RFID-based loyalty/credit cards carried by participating consumers (Cardholders). Cards have the form factor of thin plastic credit cards, and can be left in the Cardholder’s wallet, purse, or pocket during use. Physical Card presentation or manipulation is not required. In FIG. 1, individual Cardholders 102 are differentiated from one another by letter. Other consumers (non-Cardholders) 104 have neither a letter nor a “card” symbol near their shoulder.

Hardware devices of several types are installed in the retail environment to wirelessly activate and read Novitaz RFID Cards; thereby detecting the presence of participating Cardholders. Furthermore, locations of Cardholders 102 within the store (e.g., department or product display) is determined by the spatial distribution of Readers 106 throughout the store. This hardware system delivers store presence of Cardholders 102 and activity data via the Internet 110 to secure servers that run the Software Platform 112. These hardware devices are known as Activators 108, Readers 106, and Base Stations 114; and are shown in FIG. 1.

The Software Platform 112 collects and analyzes store activity data of Cardholders 102 and then serves relevant offers to individual Cardholders 102 on their mobile phones while they are physically in a specific store 100. The Software Platform 112 is shown outside the store 100 in FIG. 1. The Software Platform 112 can match offers to the specific department or product display that the Cardholder 102 is visiting at the time. The Software Platform 112 contains many functions, which include:

A configurable marketing campaign tool for advertisers and merchants.
A Rules Engine to convert in-store shopping metrics into knowledge services, which are used by advertisers and merchants to analyze the effectiveness of offers so they can maximize revenues and customer loyalty.

A Cardholder portal for opting-in/out, entering or changing personal data, preferences, etc.

Hardware Building Blocks of Digital in-Store Ad Network System

Consumers that opt-in are issued active RFID Cards, and become Cardholders 102. The Card contains an electronic system with antennae for wireless communication with hardware devices within an enabled store ("Store") 100. The Card also contains an internal battery that extends the wireless communication distance to meet the requirements of the application. The circuitry within the Card is permanently encoded with an ID number that is unique to each Card (there is no ID duplication amongst the Card and Cardholder population). The ID is an abstract number and no personally-identifiable Cardholder data resides on the Card.

An important feature of the Card is its thin plastic credit card form factor, making it quite convenient and natural to carry. The Card can be produced with merchant-specific graphics so it can be offered as a loyalty card to its customers.

Another feature is that Cardholders 102 only bring their Card with them when they shop at a Store 100. Hardware is designed such that the Card can be left in the wallet, purse, pocket, etc. of a Cardholder 102—it does not have to be removed, manipulated, or presented in the store for the system function properly. No special effort is required on the part of the Cardholder 102—they simply walk into the Store 100 and shop in a normal manner.

When a Cardholder 102 opts-in to a sponsored program, their individual Card ID Number is associated with their account in the Software Platform 112. This information is known only to the Software Platform 112 and is used to facilitate the serving of offers to individual Cardholders 102 and for collecting shopping session metrics for participating brand companies and retailers. Other than their name and cellular telephone number, Cardholders 102 provide as much or as little additional information based upon the services they wish to receive and/or their individual disclosure preferences. Additional information, if provided, can include things such as product preferences, brand preferences, etc.; and can be used to provide even more relevant offers to Cardholders 102 while they are in a participating retail establishment.

The Software Platform 112 sends relevant offers are sent to a Cardholder’s mobile phone, either as a text or SMS message. Offers sent to a Cardholder’s mobile phone include product information and "coupon" codes that can be used for redemption at the point of sale.

The terms "store", "merchant", and "retailer" are used interchangeably in this description. These terms are not meant to limit the venue or business type in which the system can be used. Others include, but are not limited to, restaurants, entertainment, service businesses, etc.

An enabled Store 100 contains several distinct installed hardware devices, referred to as Activator 108, Reader 106, and Base Station 114. The basic function of each device and its role in the Digital In-Store Ad Network system is illustrated in FIG. 1 and described below. In general, the descriptions include the presence of at least one Card (i.e., Cardholder 102).

Activator

Activators 108 are typically located only at store entrances and/or egresses, so a Store 100 may have one or more Activators 108, depending upon the size and quantity of entrance and egress areas.

The Activator 108 wirelessly "turns on" (activates) a Cardholder's Card when they enter a Store 100, causing the Card to transmit its ID number via an RF (radio frequency) signal to receiving devices (Readers 106) distributed throughout the store.

The Activator 108 transmits a Card activation signal, which is a low frequency RF signal modulated with specific data represented by arrow waves 1 pointing away from the Activator 108 in FIG. 1. A Card that receives and decodes the Activator signal 1 is triggered, or "activated", and begins to transmit its unique ID, which is represented by a arrow wave 2 pointing away from activated Cards. Activators 108 repeatedly transmit the activation signal 1 in order to trigger Cards entering the Store throughout the day. Activation signals 1 are typically transmitted in multiple directions, or axes, to assure reliable Card activation independent of Card orientation as they enter the Store 100 (though single-axis transmission is also possible). Once activated, Cards periodically transmit their IDs 2 for a finite period of time, and can therefore be read multiple times during the Cardholder's visit to the Store 100 without requiring re-activation.

Specific Activator operating modes & parameters can be configured via an Ethernet (wired) interface (not shown). Some configuration settings can also be selected on a PC and sent to the Activator 108 by the Base Station 114 via a 6LoWPAN wireless communication network (wave arrows 3). Other wireless and/or wired communication methods/standards could be used if desired.
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Base Station

[0059] A single Base Station 114 is typically used in an enabled store. It wirelessly collects data (wave arrows 4) from all Readers 106 installed in the store. The Base Station 114 also sends configuration instructions 3 to Readers 106 and Activators.

[0060] Base Stations 114 wirelessly communicate with Readers 106 and Activators 108 within the Store 100 via a 6LoWPAN wireless communication network, as represented by the arrow waves 3 in FIG. 1. Other wireless and/or wired communication methods/standards could be used if desired. Base Stations are also capable of communication via an Ethernet (wired) interface (not shown).

[0061] The Base Station 114 does not communicate with Cards in one embodiment.

[0062] The Base Station 114 connects via Ethernet to a PC running software for local campaign management at the store level. The PC relays session metrics data via the Internet to the Software Platform 112, which in turn serves offers to Cardholders 102 and makes this data accessible to participating brand companies and merchants.

Store-Corporate Interface

[0063] An example of a Store-Corporate Interface is illustrated in FIG. 2. A Store Appliance 202 running a local software application connects to the Base Station 114, and is used to relay session metrics data to servers, which processes the data and makes it available to participating brand companies and merchants. The Store Appliance 202 is also used for Reader 106 and Activator 108 configuration, and provides an interface for store personnel.

[0064] The Store Appliance 202 runs the identification and store-engagement applications of the Digital In-Store Ad Network and communicates with the corporate appliance. The in-store session metrics are transferred from the store appliance to the corporate appliance; and then engagement plans and offers are disseminated from the corporate appliance.

Card

[0065] While not actually installed Store hardware, the Card is a hardware element of the System. It is a portable wireless identification device packaged in a credit card form factor that is carried by the Cardholder 102 to identify them upon entry to a participating Store 100.

[0066] The Card contains a sensitive antenna and receiver system designed to selectively detect low frequency RF transmissions from the Activator. When the Card is in the vicinity of the Activator 108 (Store entrance) and detects an activation signal 1, it turns on (activates) and begins transmitting its unique ID 2 at a high RF frequency through a different antenna. The Card periodically re-transmits its unique ID 2 for a finite period of time, which, for example, can approximate the typical time Cardholders 102 spend in the Store 100. Cardholder 102 presence within specific Store areas is detected by the hotspot Reader 106 in each area and then communicated to the Software Platform 112 via the Base Station 114 within the Store 100. The Software Platform 112 uses this information to serve timely and relevant offers to the Cardholder 102 and to collect Cardholder 102 shopping pattern data ("session metrics"). The Card may be re-activated upon the Cardholder’s next entry into a participating Store 100.

[0067] The Card contains a thin battery that powers the receiver and transmitter circuitry to achieve the activation range and read range needed for this application. Special methods are employed in the Card and the System to minimize battery drain, thereby maximizing Card life.

[0068] Card communication pathways are wireless only in one embodiment; there is no wired interface. In one embodiment, the Card receives information only from Activators 108, and sends information only to Readers 106. The Card utilizes one data structure and frequency (125 kHz) for the link with Activators, and a different data structure and frequency (433.92 MHz) for the link with Readers. The dual-frequency approach and choice of frequencies facilitate optimal performance for Card activation and for Card reading.

[0069] The Card does not communicate with Base Stations in one embodiment.

Operating Frequencies

[0070] The Activator 108 transmits a low RF frequency (125 kHz) magnetic field, which can be easily detected by the low-frequency (LF) receiving system of the Card. This frequency was chosen to maximize activation signal detection even when the Card is positioned against the Cardholder’s body or buried in the Cardholder’s purse surrounded by metal objects and fluids (which significantly impact performance at very high frequencies such as UHF (e.g., 900 MHz)).

[0071] Card reply transmissions, however, occur at 433.92 MHz—a much higher frequency than the activation signal. This high frequency will carry farther than a low frequency signal will. 433.92 MHz is less sensitive to the attenuating effects of metal or liquid objects positioned near the Card compared to 900 MHz. Furthermore, the battery-powered transmitter in the Card boosts the power of the Card ID transmission to overcome the attenuating effects of any objects that may be in close proximity to the Card, increasing read reliability in the reader network.

[0072] The large frequency separation enables performance optimization of receive and transmit functions within the Card without adverse interactions between the two subsystems. Finally, the large frequency separation between Activator 108 transmission and the Reader 106 receive band prevents interference between them—a Reader 106 positioned near an Activator 108 will not be overwhelmed by the Activator 108 transmissions, allowing it to clearly receive Card transmissions.

[0073] Reader data is sent to the Base Station 114 at a third carrier frequency of 2.4 GHz, making this communication link immune to Activator and Card transmissions. This same 2.4 GHz radio link is also used by the Base Station 114, Reader 106, and Activator 108 for configuration purposes.

System Operation

[0074] Unlike passive RFID cards, the Card contains a battery to facilitate long system communication distances. The battery powers detection circuitry to increase the sensitivity to Activator RF transmissions, enabling an activation range (distance) of several meters. The battery also powers circuitry that boosts Card transmission signal, which enables a read range of several meters (usually greater than activation...
range). The battery also powers circuitry that provides enhanced functionality not possible with passive RFID tag technology. The battery-powered Card technology, multi-frequency design, and overall system operation deliver the functionality and range required of the Digital In-Store Ad Network application.

[0075] Only a small and very thin battery will fit in a credit card form factor, significantly limiting battery energy storage capacity. Card longevity is an important characteristic that is a direct function of battery life, so the Card/Activators 108/Readers 106 are carefully designed to minimize power consumption and achieve a battery life of 2+ years.

[0076] FIG. 3 shows the different phases comprising the life cycle of a Card from its manufacture to its end of life (EOL) 314. Card life begins at time $T_0$ when the battery is connected 302 to the Card electronics assembly 306 during the manufacturing process 304. When this occurs, the Card automatically begins operations to guarantee proper initialization and allow testing to occur during the remainder of the manufacturing process (bootstrap 308 and Transition Modes 310). These processes are controlled by hardware and firmware that resides in the Card electronics assembly, and last for approximately 12 hours. The Card automatically transitions from each mode to the next, and the Card spends virtually its entire operational life in the Normal Mode 312. Card life ($T_{LIFE}$) ends when the battery is discharged to a voltage below the minimum operational threshold of the Card electronics (battery depleted 322).

[0077] There are two operational sub-modes of the Normal Mode 312 shown in FIG. 3: the Sleep Mode 316 (S) and the Beacon Mode 318 (B). The Card is naturally in the Sleep Mode 316, which is a very low power consumption state, and only leaves the Sleep Mode 316 when “woken up” by an Activator 320 (symbolized by the circled A with an arrow). The Card switches to the Beacon Mode 318 upon activation for a fixed period of time, during which the Card periodically transmits its ID for reception by Reader(s). At the end of this relatively short fixed period of time, the Card automatically reverts to the Sleep Mode 316 and remains there until it receives another activation signal during a future Store visit.

[0078] FIG. 4 illustrates the Card activation process. The physical Store 100 is shown at the top of the figure (side view). The Card is initially outside the Store 100 and is moving in a path through the entrance and into the Store 100. The Card is exposed to the signal transmitted by the Activator 108 while in the entrance area, or Activation Zone 402, defined by the intersection of the angled dashed lines from the Activator 108 and the movement path of the Card.

[0079] Electrical signals as a function of time are represented below the Store diagram. Activator transmission packets 404 are shown to illustrate the time-space nature of the activation signal in the Store entrance. The Activator 108 transmits a single activation data packet every 33 ms ($T_{ACT}$), with no signal transmission in between packets. The duration of each Activator transmission is approximately 20 ms ($T_{TD}$). The activation repetition rate is sufficiently high to provide several activation packets per Card as it passes through the entrance area of the Store 100, increasing activation reliability. This also ensures that all Cards entering the Store 100 throughout the day are reliably activated.

[0080] As the Card approaches the Store entrance, the Card begins to pick up the activation signal, as shown by the Activation Signal Strength 406 in Card waveform. The activation signal strength 406 received by the Card increases as the Card moves closer to the Activator 108. The received signal strength is greatest when the Card is well within the Activation Zone 402, and then begins to decrease as the Card moves out of the Activation Zone 402 and into the Store 100. The horizontal dashed line intersecting the received signal strength represents the minimum amplitude required by the Card to accurately receive and validate the activation signal. The received packets numbered 1, 2, 3, and 4 all have sufficient strength to be properly detected by the Card.

[0081] Packet number 1 is the first ‘valid’ activation packet received by the Card. The Card Mode 408 waveform illustrates the Card being activated at the end of Activator packet number 1, causing the Card to switch from the Sleep Mode 316 to the Beacon Mode 318. Activation triggers the random time delay $T_{RD}$, after which the Card transmits one ID packet for receipt by Reader(s) 106. At the end of the first Card ID transmission, the Card switches to a low power state and waits for a relatively long fixed time delay $T_{FW}$, followed by a shorter random time delay $T_{RD}$, and then transmits another ID packet. The line between each Card transmission is broken to indicate a different time scale—the magnitude of delay between Card transmissions is much greater than the duration of an individual Card ID transmission ($T_{PW}$). Card ID transmission takes about 14 ms, while the total delay between Card ID transmissions is on the order of 13 seconds. The Card continues to repeat ID transmissions with a different random delay $T_{RD}$ preceding each ID packet transmission, until the Beacon Mode duration expires (not shown). The Beacon Mode 318 duration is a fixed time, and can be set to a specific length by the Activator 108, thereby allowing customized behavior as a function of the type of store and typical Cardholder 102 shopping habits.

[0082] Greater detail of operation in the Normal Mode 312 is shown in FIG. 5. The Sleep Mode 316 is composed of constantly repeating Sleep Frames (SF), which last for a fixed period of time, $t_{SF}$ (227.5 ms). Cards do not transmit when in the Sleep Mode 316. Each Sleep Frame is composed of two states: the longest duration state being called Deep Sleep. The Deep Sleep state is the lowest power state, and lasts for the fixed duration $T_{DD}$ (182 ms). When the Deep Sleep timer expires, the Card switches to the Listen state, which lasts for the fixed duration $T_{L}$ (45.5 ms). During the Listen state, the Card power consumption increases slightly to “listen” for activation signals. At the end of the Listen state, the Card automatically reverts to the Deep Sleep state. The Deep Sleep/Listen cycle repeats continuously until the Card detects a valid activation signal during a Listen state period. When a valid activation signal is detected, the Card switches to the Beacon Mode 318.

[0083] Detail B of FIG. 5 illustrates Card reception of a valid activation signal during the Listen state by the circled A with an arrow. This truncates the Listen state and switches the Card to the Beacon Mode 318, beginning with the Pre-Tx (transmission) Delay, which has a randomly-generated duration. At the end of the Pre-Tx Delay, the Card transmits one ID packet (Tx), which lasts for duration $T_{DT}$. Card ID transmission is the highest power state of the Card, but fortunately is quite short in duration (~14 ms). At the end of the Card ID transmission, the Card switches to a much lower power, fixed-duration, quiet state (Beacon Sleep), $T_{SS}$. At the end of the Beacon Sleep period, a new random Pre-Tx Delay is generated, followed by the second Card ID transmission. Each full sequence composed of a Beacon Sleep period, Pre-Tx Delay, and Card ID transmission is referred to as a Beacon Frame.
This process repeats until the Beacon Mode duration expires ($t_{Bn}$). The Beacon Mode duration is a fixed period, but the number of Card transmissions that occur during that time are partially a function of the variable Pre-Tx Delay that occurs before each transmission. The Card cannot be re-activated while in the Beacon Mode, which is part of the low-power design of the invention.

At the end of the Beacon Mode, the Card returns to the Sleep Mode. The Activation Holdoff period, $t_{H}$, begins at this transition, and lasts for a fixed period of time. During the Activation Holdoff, the Card will not re-activate even if in an Activation Zone. This is useful to prevent re-activation if Cardholders linger at a Store entrance, or if they accidentally leave their Card in the Store near an activator (preserves battery life). The Activation Holdoff is a parameter transmitted by the Activator 108, allowing the Activator to set $t_{H}$ to suit the type of store and typical Cardholder shopping habits.

Anticollision in the Reader Network

The random Pre-Tx Delay is used as an anticollision mechanism to minimize the chance of simultaneous Card transmissions when two or more Cards enter the Store at the same time. Simultaneous Card transmissions within a hotspot cannot be accurately received by a Reader 106. If only the first Card ID transmission following activation was preceded by the Pre-Tx Delay and then a fixed time spacing was used thereafter to maintain temporal spacing between Cards, it would avoid data collision for only a brief period because those Cardholders 102 diverge from one another and move independently throughout the Store. Different combinations of Cardholders 102 will be present in different Hotspots over time, and this is unpredictable. By randomizing the delay before each Card ID transmission, the chance of simultaneous transmissions is minimized. If Card transmissions do overlap within a hotspot, the chances are high that an overlap will not occur in subsequent ID transmissions because each Card will chose a different delay time before transmitting. Variations to this method and other anticollision schemes can be used in the invention, but are not described in this document.

Content of Activator and Card Transmissions

FIG. 6 details the data contained in the Activator transmission. Each Activator 108 transmission packet begins with a Preamble 602, which is a continuous tone at 125 kHz for a fixed duration (2.56 ms in the present embodiment). The remainder of the Activator transmission is also at 125 kHz (LF carrier), but is ASK modulated with Manchester encoded data summarized by FIG. 6. The Preamble 602 is followed by fixed-content Start Gap 606 and Header fields 608. The Pre-amble 602, Start Gap 606, and Header fields 608 enable the Card to recognize and synchronize to the activation signal. The Wake-Up ID field 610 follows the Header 608, and is a specific code that must be validated by the Card to confirm it has received a valid activation signal. The Activator ID 612 is a variable data field used to set specific behavioral options in the Card for that activation event. The duration of the Activator transmission, $t_{AT}$, is 20.56 ms in the present embodiment.

The Card transmits a 433.92 MHz signal that is ASK modulated with Manchester encoded data as summarized in FIG. 7. Each ID packet begins with a fixed-data Preamble field 702 followed by a Start Bit 704, which enables the Reader 106 to recognize and synchronize to the Card transmission. Next, the unique Card ID field 706 is transmitted, followed by the Activator ID field 708. The Activator ID field 708 transmitted by the Card is identical the Activator ID received from the Activator 108. The Activator ID 708 can contain a parameter that identifies the specific Activator that activated the Card for use by the System.

The Card transmission packet ends with the CRC field 710, which is calculated based upon the preceding data transmitted, and is subsequently used by the Reader 106 to detect errors in the signal it receives. The duration of the Card transmission, $t_{C}$, is 14.125 ms in the present embodiment. The Card retransmits this packet on a variable time interval that is the sum of the random pre-transmission time delay (10 ms to 1000 ms) and a fixed time (11.6 s). The Card continues to transmit packets at this variable interval for a fixed period of time, $t_{AT}$, which can be set as a default value or in accordance with a parameter in the activation signal. The Beacon Mode duration ($t_{BM}$) can range from three packets to 2 hours in the present invention. The Card returns to the Sleep Mode when the Beacon Mode times out.

Optimization of Card Behavior for the Reader Network

Stores come in all shapes and sizes, and Cardholder shopping behavior can vary from store to store because of differences in products, services, or environment. For example, Cardholder visit duration in a large department store will likely be longer than a Cardholder visit to a very small store.

To accommodate these and other differences, Card behavior can be modified in a number of ways. Specific Card behavior can be established during the manufacturing process or at the time of Card issuance. Setting Card behavior upon activation, however, is ideal because it provides an adaptive, real-time method that can be tailored to the specific needs of each retail environment and typical Cardholder behavior within those environments. This optimizes performance for Cardholders, Retailers, and Brands alike without requiring the Cardholder to carry multiple Cards.

To accomplish this, a portion of the data encoded into the activation signal contains configuration information that is decoded by the Card to set its behavior following activation. Card configuration settings can be established via software on a host PC and an Ethernet connection to the Activator. Wireless configuration through the Base Station is also possible so settings can be easily modified after installation without having to connect cables to the Activator.

A few examples of Card configuration parameters are listed below, but do not represent the entire range of possibilities. Other parameters can be envisioned while remaining within the scope of the invention. The preferred embodiment allows predefined parameter sets to be selected from a limited list for data compactness. Other embodiments are envisioned that would allow adjustment of individual parameters with greater resolution, and remain within the scope of the invention. It is also envisioned that configurations could instruct Cards to alter their behavior as a function of time or other parameters.

Examples of Card behavioral configuration parameters:

- Beacon State time duration
- Can range from a few seconds to two hours
- Short duration useful in small stores with short Cardholder visits
Long duration useful in large stores with long Cardholder visits

Number of Card ID transmissions during Beacon State

Useful for very short Beacon duration

Useful in cases where repeated reading is undesired

Activation Holdoff time (default is zero)

Sets time after Beacon expiration during which Card activation is disabled

Reduces battery drain if a Card is accidentally left in the Store.

Minimizes unwanted re-activation when a departing Cardholder lingers in the entrance/egress area (i.e., within range of an Activator).

Activator ID (Card passes this value through to Readers as part of its ID)

Enables Store to know at which entrance a Card was activated.

Card behavior can be a function of the Activator ID

<table>
<thead>
<tr>
<th>Activator ID</th>
<th>Beacon Duration</th>
<th>Activator Holdoff</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1 ~30 seconds</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>2 ~60 seconds</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>3 ~300 seconds</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>4 ~45 minutes</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>5 ~60 minutes</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>6 ~90 minutes</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>7 ~120 minutes</td>
</tr>
</tbody>
</table>

Activation holdoff is defined as a period of time immediately following the expiration of the Beacon Mode, and during which the card cannot be activated.

Other behavioral options can be implemented in this way, but will require a larger Activator ID field or alteration of the above description (not described in this document). This basic capability provides a powerful yet flexible way to modify Card behavior, alter anticollision characteristics, etc. Care must be given, however, to maintain low power consumption.

Hardware Description of the Thin Active RFID Tag in Credit Card Form Factor

The block diagram of FIG. 8 shows electronic elements of the Card, which are a custom IC 814, a battery 812, a crystal 806, an LF antenna 808, an RF antenna 810, and several passive components (not shown). All components are mounted on a flexible printed circuit substrate except for the battery 812 and LF antenna 808.

The IC assembly 814 is comprised of two functional blocks, both of which are continuously powered by the battery. The LF Wake-Up & Control block 802 is microcontroller based, and cycles through firmware instructions stored in on-chip memory. The LF Wake-Up & Control block 802 is clocked by an internal RC oscillator while in the Sleep Mode to conserve battery life. The LF Wake-Up & Control block 802 also contains sensitive circuitry to detect Activator transmissions received from the LF Antenna 808. When a valid activation signal is received, demodulated, and processed by the LF Wake-Up & Control block 802, it enables the Modulator & RF Transmitter block 804, starting a crystal-based oscillator which provides an accurate and stable frequency reference for RF transmissions and Beacon Mode timing. The LF Wake-Up & Control block 802 then sends data consisting of the Card ID and other frames to the Modulator & RF Transmitter block 804; which in turn generates the modulated RF Card transmission signal that is received by Readers.

A schematic diagram of the Card electronics assembly is shown in FIG. 9. All components are mounted on a flexible printed circuit board (FPCB) except for the LF Antenna and the battery. The battery constantly supplies power to the Card electronics. The LF Antenna is a multi-turn wire coil whose inductance resonates with one or more capacitors on the FPCB (C2, C10, & C11). A small current is induced in the LF Antenna when the Card intercepts a 125 kHz magnetic field from an Activator (not shown), stimulating the LF resonant circuit. A properly-tuned resonant circuit increases the LF Antenna terminal voltage applied to receiving circuitry in U1, effectively extending the distance at which activation can be detected. Extraneous magnetic field signals outside the bandwidth of the LF tuned circuit are effectively removed by the resonant circuit, improving immunity to other systems. Because all components must be very thin, three resonating capacitors are used in the present embodiment to achieve sufficiently high resonating capacitance. Also, the use of multiple capacitors affords greater tuning flexibility through the combination of different values.

U1 is the functional heart of the Card. U1 contains a microcontroller that operates in accordance with firmware instructions stored in memory. Memory in U1 also contains the Card ID and other operating parameters described in previous sections. While in the Sleep state of the Sleep Mode, U1 detects and validates an activation signal, it triggers other functions within U1 and switches to the Beacon Mode. When a valid activation signal is received, U1 activates a circuit that oscillates at the resonant frequency set by crystal X1 (13.56 MHz in the present embodiment). The accurate and stable frequency of the crystal oscillator is multiplied up by a phase lock loop (PLL) within U1 to derive the RF carrier frequency used for Card transmissions (433.92 MHz). U1 ASK modulates the RF carrier with Manchester encoded Card data and then amplifies the modulated RF carrier. L1, C1, and C3 form a tuned impedance matching network that maximizes power transfer between the RF power amplifier in U1 and the RF (loop) Antenna to maximize read range.

C5 attenuates RF noise that may be present on the power supply terminals of U1 that might otherwise be present. Seven pads are available for temporary probing during Card manufacturing to load firmware and for subassembly test operations. No permanent external connections are made to these pads. In one embodiment, card electronics cannot be probed or physically accessed once the Card is laminated.

Design & Construction of the Thin Active RFID Tag in Credit Card Form Factor:

The physical design and construction of the Card, as well as the associated manufacturing processes, are all interrelated and important to achieving an active RFID Card that is small, very thin, and durable. First, the design may be miniaturized such that the combined assembly of all functional
components fit within an area smaller than 85.47 mm x 53.92 mm (ID-1 card dimensions specified by ISO/IEC Standard 7810, which is incorporated by reference herein). Second, the combined assembly of all functional components may be very thin so that the finished card thickness is not more than 0.84 mm (also per ISO/IEC 7810). Finally, the finished card product may be durable to provide reliable use by human beings without special care and handling. The card may furthermore be conditioned to meet bending and stiffness standards. For example, in one embodiment, the Card meets the standard described in ISO/IEC 10373-1 in which the deformation of the card when subjected to a test load is 35 mm (1.38 in) maximum and 13 mm (0.51 in) minimum. Furthermore, the card returns to within 1.5 mm (0.06 in) of its original flat condition within one minute after the load is removed, in one embodiment.

[0117] Meeting the maximum ISO card thickness specification is desirable for the Card to fit through normal credit card swipe readers. The Card may include a magnetic stripe on the back of the card, thereby allowing the Digital In-Store Ad Network functionality in a common platform as a loyalty or credit card. The Card can be slightly thicker if it will not carry a magnetic stripe on the back.

[0118] An example of an internal Card electronics assembly is shown in FIG. 10.

[0119] The electronics of the invention are highly integrated to minimize area. To achieve maximum density, the majority of the components are combined into a common assembly called a flexible printed circuit assembly, or FPCBA. The FPCBA consists of the following elements:

[0120] A flexible printed circuit board (FPCB) 1002—this is the FPCBA substrate onto which other electronic components are physically and electrically interconnected.

[0121] An integrated circuit (IC) 1004—this is the functional heart of the Card.

[0122] A crystal 1006—used in conjunction with circuitry in the IC 1004 to precisely generate the RF frequency at which the Card transmits its ID to Readers.

[0123] Several passive components 1008—capacitors, inductors, and resistors—used by the IC to support its functionality but which cannot be practically integrated into the IC.

[0124] An RF antenna 1010—converts the RF output of the IC that contains the Card ID to an electromagnetic wave for reception by Readers.

[0125] Two other components electrically connect to the FPCBA 1002, but are impractical to mount on top of the FPCBA 1002, and are physically located outside the boundary of the FPCBA 1002. Also, these two components cannot be physically mounted on top of the FPCBA 1002 like the other components because they are too thick and will cause the overall assembly to exceed the maximum allowable Card thickness. These two off-board components are:

[0126] A low-frequency antenna (LF coil) 1012—this converts electromagnetic Activator transmissions into an electrical signal for the IC so that the Card can be activated.

[0127] A thin film battery 1014, which provides a DC power source for the Card electronics.

Card Component Details

[0128] The FPCB is the substrate to which individual components comprising the Card electronics are physically mounted and electrically interconnected. Important requirements are thinness, flexibility, durability, and low cost. The FPCB may also be tolerant to high temperatures to withstand manufacturing processes such as surface mount component attach (soldering) and hot card lamination processes, and must maintain its physical and electrical properties after manufacturing.

[0129] Because the Card electronics assembly thickness is highly constrained, minimizing FPCB thickness is desirable. The FPCB design, FPCB fabrication, and FPCB were addressed together to achieve the requisite assembly thickness limit. In addition to excessive thickness, the Card electronics assembly area precludes the use of a rigid PCB because of the flexibility requirements of credit cards. Therefore, a flexible PCB construction is used. While these are routinely much thinner than their rigid counterparts, commonly available flexible PCBs may still be too thick for this application.

[0130] Electronic components can be mounted on both surfaces of the FPCB, but the finished assembly thickness would be too thick; so components are attached only to one side of the FPCB. The surface containing the components is referred to as the top side or component side of the FPCB.

[0131] One embodiment utilizes extremely thin film materials and coatings in the fabrication of the FPCB. The FPCB is comprised of a very thin dielectric (electrically non-conductive) core (e.g., 18 microns or less), typically polyimide (PI); which has good thermal, mechanical, and electrical properties. It will easily withstand the hot lamination temperatures and pressures without appreciable shifts in electrical characteristics.

[0132] FIGS. 11A-11B illustrate layout diagrams of a flex printed circuit board layout according to one embodiment. Very thin conductive traces are formed on each side of the PI core: these being used to interconnect the components used in the FPCB assembly. The conductive layers 1104, 1106 are typically composed of copper, and the pattern of each layer is etched from a uniform layer covering the entire FPCB area to form the circuit pattern of the printed circuit board. The FPCB silkscreen (labeling) layer 1102, which indicates where each component is located, is also shown in FIG. 11A.

[0133] Where desired, electrical connections between conductive circuit traces on each side of the PI core are formed by using one or more plated-through via holes (not shown). An array of larger-than-normal vias in the large pad under the IC become filled with solder during the FPCBA solder reflow process, providing several important functions. First, they allow air trapped in the solder paste under the IC to escape out the bottom side of the FPCB during the solder reflow assembly process to ensure the IC is parallel to the FPCB in the finished assembly. Second, the vias under the IC act as “solder wicks” to pull the IC as close to the FPCB surface as possible. Third, the center pad of the IC is the central ground node of the Card electronics, and solder-filled vias under the IC reduce the electrical resistance between the top and bottom copper layers at this critical circuit junction. The diameter and quantity of vias under the IC must be chosen carefully to achieve these goals while preventing without solder humps from forming on the bottom side of the FPCB increasing (which would increase assembly thickness).

[0134] A thin dielectric film covers the conductive layer on one or both sides of the PI core (see FIG. 11B), except where electrical connections to components are to be made during assembly. The dielectric film(s), also called soldermask layer
(s), block the flow of molten solder between adjacent conductive elements, thereby preventing unintended short circuits from forming when electronic components are soldered to the FPCB. Openings in the solder mask also provide access for electrical probing, such as that done during manufacturing test of the FPCB.

[0135] One embodiment utilizes a solder mask on both sides of the PCB, though the solder mask can be omitted on the bottom side if desired to reduce thickness ever further. The soldermask typically covers vias in the FPCB, so solder does not wick into them during reflow. A special bottom layer soldermask configuration is required in the area under the IC to enable the solder wicking described previously.

[0136] Top and bottom conductive layers may be globally or selectively plated with other metals, such as nickel and/or gold, to prevent corrosion. Plating occurs in all open areas of the soldermask layer(s), ensuring good physical interconnections between the FPCB and its components. FIG. 11B illustrates where external connections are made to the IC and the battery, as well as manufacturing test probe pads.

[0137] The large holes noted in FIG. 11B are larger than shown in one embodiment (approximately 3 mm diameter). The large holes prevent air from being trapped around the FPCB during the Card lamination process, thereby helping to smooth-out the surface finish of the Pre-lam (and ultimately the finished Card). The large holes also provide sites for “stitching” the top and bottom card plastic layers together in the region of the FPCB, reducing the chance of de-lamination because of repeated Card bending stresses.

[0138] Because the FPCB is small, it is fabricated in sheet (panel) form to minimize cost. Multiple FPCBs are fabricated onto one large sheet and then singulated before or after component assembly.

[0139] FIG. 12 shows the core elements comprising the FPCB, including the assembly stack-up with components. FPCB thickness can range from 56 to 85 μm, depending upon the exact composition of materials used. The thinnest construction is illustrated in FIG. 12. Even an FPCB thickness of 85 μm is challenging to achieve. The described embodiment utilizes very thin materials for each layer and advanced manufacturing processes. While a very thin FPCB is necessary to meet Card thickness requirements, it also provides greater flexibility (thicker FPCB constructions are inherently stiffer).

[0140] Integrated circuit (IC) [U1], of the present embodiment is a microelectronic subassembly that contains houses two individual integrated circuits 1302, 1304, or chips, to form the active functional electronics of the IC. The two chips 1302, 1304 perform different functions, as illustrated by the high-level block diagram of FIG. 13.

[0141] Assembling one IC atop of the other IC is attractive because it reduces the package area on the FPCB, but the resultant package would be too thick to fit within a credit card form factor. Therefore, a custom epoxy molded metal lead frame package was designed to allow the physical attachment of each chip side-by-side, resulting in a maximum package thickness of 0.40 mm (400 μm). Internal assembly of the IC package is illustrated in FIG. 13. The chips are adhered to the die attach pad of the lead frame using an adhesive such as epoxy. Electrical connections are made to each chip by very small wire bonds (usually gold); these wire bonds being from chip-to-package terminals and chip-to-chip. To reduce the number of wire bonds within the IC package, electrically conductive epoxy is used to mount the chips to the die attach pad of the lead frame; forming a “ground” connection from the substrate of each chip to the IC package to the FPCB. Non-electrically conductive adhesive could be used, but would require additional wire bonds to the chips. The chips could be attached via eutectic bonding, but this is more expensive and requires high process temperatures that may not be suited to the materials being used. This molded lead frame package is referred to as a 32-pin QFN package, and has dimensions of 7 mm x 7 mm in the lateral plane (parallel to the FPCB surface).

[0142] An advantage of the metal lead frame IC package described above is the durability it offers. The metal die attach pad combined with the epoxy molding provides strength and resistance to flex—an important feature for a system embedded within a plastic credit card.

[0143] Other embodiments, however, are not restricted to a molded lead frame IC package. Other package types and/or packaging methods can be utilized and remain within the spirit of the invention. Other packaging methods include, but are not limited to, various forms of chip on board (COB), direct flip-chip attachment on the FPCB, pre-packaged flip chip, and others.

[0144] In general, the IC package may contain one or more chips, the quantity being a matter of semiconductor integration, cost, and desired functionality. It is envisioned that the functions of each chip may eventually be integrated into one physical chip, further decreasing cost, enhancing miniaturization, and improving reliability (fewer wire bonds and solder joints on the FPCBA). Similarly, additional functionality can be accommodated by using two or more chips within a common IC package. In cases of increasing functionality and accommodation, assembly options for economical manufacture of a variety of products on the same FPCB, more than one IC package can be utilized.

[0145] Crystal [X1] operates with U1 circuitry to generate a precise frequency reference for RF Card transmissions. Crystal electrical characteristics determine the accuracy and stability of the RF frequency transmitted by the Card. The Crystal consists of precisely cut, sized and metalized quartz crystal mounted within a precision surface mount ceramic package.

[0146] An embodiment uses a crystal with an oscillation frequency of 13.560 MHz, which typically far exceeds the maximum allowable thickness for thin laminated card use; posing significant component sourcing challenges. One embodiment uses a 13.560 MHz crystal that just meets the thickness requirement. Crystals are available in thinner packages, but only with oscillation frequencies of at least 26 MHz. An advantage of thinner crystals is that the package area also decreases, reducing the potential for failure under mechanical stress. Future embodiments of the invention may use higher frequency crystals, with appropriate changes in U1.

[0147] The internal construction and mounting of the quartz element within the ceramic package are all beneficial in ensuring device performance, so the crystal is purchased as an assembly (i.e., a component). Mechanical stress, for example, can shift the crystal frequency, potentially causing Card performance issues. If the frequency shifts too much, the Reader may not receive Card signals effectively. Also, a shift may cause the Card to transmit at a frequency that is not allowed by regulatory authorities.

[0148] Although the ceramic package isolates the quartz element from the outside world, Card thickness constraints limit the amount of protection available. In most electronic assemblies, crystals are only contacted on one surface. In the
thin Card, however, the top of the crystal package is in contact with Card plastic. To minimize yield loss and parametric shift, special care must be taken to minimize thermal and mechanical stresses on the crystal package during the FPCB assembly and Card lamination processes. The Card design and manufacturing processes are controlled to prevent lamination plastic from contacting the edges of the crystal to enhance mechanical isolation on the sides of the crystal.

[0149] The crystal used in the present invention has dimensions of 2.50 mm × 2.00 mm × 0.45 mm (0.50 mm max.). The crystal is the thinnest individual component on the FPCBA, requiring that the FPCB and solder joint thickness used to attach the crystal be as thin as possible and tightly controlled.

[0150] Alternate crystal packaging schemes have been considered and can potentially be used:

[0151] Sink a portion of the crystal ceramic package into a hole in the FPCB as shown in FIG. 14. Electrical interconnections to the crystal package add complexity and potential reliability challenges, but may be worth considering.

[0152] Custom ‘stair-stepped’ ceramic package that partially embeds into the FPCB cross section as shown in FIG. 15. This offers the advantage of using standard surface mount assembly techniques. Ceramic package tooling NRE is quite high, however.

[0153] Purchase quartz crystal elements (known as “blanks”) and mount them directly to the FPCB, and design a cover to protect the quartz element. This can be complicated and may increase assembly cost, but might enable partial embedding in the FPCB cross section.

[0154] Card lamination process changes to accommodate a 500 µm crystal (low possibility).

[0155] Alternate frequency reference methods can potentially be used:

[0156] Utilize a higher frequency crystal and add oscillator circuitry to divide the output frequency down to 13.560 MHz required by U1 (e.g., 27.120 MHz+2). This could be implemented in one of several ways:

[0157] Develop a crystal & oscillator system in an appropriately thin surface mount package for subsequent FPCB assembly with the other components.

[0158] Develop an oscillator circuit in an appropriately thin surface mount package for use with a separate high-frequency surface mount crystal.

[0159] Develop an oscillator circuit that is assembled into the IC package along with the two chips. The oscillator circuit would operate with a higher-frequency surface mount crystal.

[0160] Use of “silicon clock” devices.

[0161] Use a ceramic resonator device (if a thin enough device can be found or developed).

[0162] Use of a precision RC oscillator system (accuracy and stability will be a challenge.)

[0163] Use of a precision RC oscillator & PLL that calibrates to Activator transmissions at each Card activation and then holds frequency steady for an entire Beacon period. (Requires new IC design and system signaling changes to facilitate calibration.)

[0164] Passive components not integrated into U1 may be assembled onto the FPCB, and consist of several capacitors, a resistor, and an inductor [R1, L1, C1, C2, C3, C5, C6, C10, C11]. Passive components must be thin and also small in area to reduce the chance of breakage when the Card is flexed. Passive components in the standard “0201” surface mount case size are used to meet the thickness spec and to reduce board area for durability. Smaller case sizes are also usable, provided the electrical specifications can be met. The 0201 case size satisfies both the packaging and electrical requirements. Larger case sizes, such as 0402, 0805, etc. are generally too thick; and their larger area increases the risk of damage during card flex.

[0165] Alternative embodiments may incorporate most of the capacitors and the inductor into the FPCB layout, eliminating the need to purchase and assemble them onto the FPCB. This will not only reduce cost in component procurement and FCPB assembly, but will also improve Card reliability by reducing the number of interconnections (solder joints). The very thin dielectric of the FPCB allows parallel plate capacitors to be formed by the top and bottom conductive layers of the FPCB without consuming excessive area.

[0166] The RF antenna converts the RF output of the IC that contains the Card ID to an electromagnetic wave for reception by Readers. This loop antenna is designed as an integral part of the FPCB conductive pattern (see FIGS. 11A-B), and does not require procurement and assembly like the other components. The precision of the FPCB fabrication process results in excellent repeatability of RF antenna electrical properties and control of parasitics; thereby optimizing production yield and Card performance. Implementation of the RF Antenna into the FPCB layout eliminates assembly yield concerns (no assembly required). The embedded RF antenna is impervious to Card lamination stresses as well as bending stresses encountered during Card use.

[0167] The RF antenna is designed for operation at 433 MHz in one embodiment, but can be redesigned using the same fabrication methods for operation at other RF frequencies if desired for variant embodiments. The RF antenna is built on the top (component) side of the FPCB. It is possible to form the loop antenna on the bottom side of the FPCB if desired.

[0168] It is also possible to form two loops, one on the top side and a second loop mirrored on the bottom side of the FPCB. Two loops electrically connected in parallel can reduce resistive antenna losses thereby increasing the radiated field strength; potentially increasing read range. One loop is generally sufficient in one embodiment, as the FPCB conductive layer is thicker than the skin depth at 433 MHz. Two loops may be useful if the FPCB conductive layer thickness is reduced, if the loop trace width is made narrower, if the effective loop length increases substantially, or if the RF frequency is reduced. Redundant conductive FPCB vias should be used in sufficient quantity to ensure that antenna circuit losses do not increase for loops fabricated on the bottom of the FPCB; thereby ensure sufficient current balance between top side and bottom side loops.

[0169] Read range will be improved with increasing the RF Antenna loop size/area. It can be seen in FIGS. 11A-B that the RF Antenna loop size fills the available space on the FPCB. Care must be taken in the design to minimize capacitive and inductive coupling between the RF Antenna and other subsystems on the FPCB, because such interactions can adversely impact read range and even battery life. Placing the RF Antenna at one narrow end of the Card helps to achieve this goal, as does maintaining sufficient spacing between the RF antenna traces and neighboring circuit traces. The RF Antenna location on the FPCB is also well-separated from the LF Antenna in the Card assembly to ensure that the two subsystems do not interact. To achieve even greater isolation,
the operating frequencies of the RF and LF subsystems are very widely separated; enabling each subsystem to be optimized independently of the other.

[0170] Top side-to-bottom side capacitors can be easily fabricated as part of the FPCB due to its very thin dielectric core, enabling the IC RF output to be capacitively coupled to an RF Antenna loop on the bottom of the FPCB if desired.

[0171] Similarly, alternative embodiments of the invention can embed RF Antenna impedance matching components C1, C3, and L1 (See FIG. 9) directly into the FPCB layout, eliminating the need to procure and attach surface mount devices for this function. This will reduce material and assembly cost, and increase reliability.

[0172] The FPCBA is the FPCB after the electrical components have been attached (excluding the LF Antenna and Battery) to form the functional subassembly of FIG. 16. The FPCB and components are assembled in a surface mount solder reflow process that physically places and permanently connects the electrical components to the FPCB. The FPCBA is a component of the Card electronics assembly.

[0173] The FPCBA may be electrically configured and tested before the LF Antenna and Battery are attached. This can be accomplished through a bed of nails test fixture, which physically holds the FPCBA while probing special test pads on the FPCBA. Test fixture probes are wired to an electronic system that executes the test. Probes on the test fixture also provide power and an activation signal to the battery and LF Antenna pads on the FPCBA. The test process generally involves programming the operating code and the individual Card ID into UI, followed by tests that validate the functional and/or parametric characteristics of the FPCBA prior to subsequent Card assembly steps. Individual FPCBAs that fail test can be more easily diagnosed and repaired prior to LF Antenna and Battery attachment, minimizing unnecessary loss and expense.

[0174] It should be understood that a variety of test methods and test options exist, and they can be in the form of contact electrical test as well as non-contact (wireless) testing. Indeed, final Card test and evaluation may occur wirelessly. Testing can be done at the component, subassembly, and final assembly levels, depending upon needs and constraints within the different production systems. Testing may occur at various levels, including but not limited to: IC test (wafer level and/or packaged IC), Device-level programming (wafer or packaged IC), PCB test (bare flex PCB), LF Antenna test, Battery test, FPCBA programming, FPCBA test, Pre-lam Card test (in sheet or singulated Card form), and End-lam Card test (in sheet or singulated Card form).

[0175] The LF Antenna is a coil of wire that transforms the electromagnetic field transmitted by the Activator into an electrical signal that is used by the IC to facilitate Card activation. More specifically, current is induced into the coil when the coil intercepts the magnetic field radiated by the Activator. The LF antenna is connected to one or more capacitors on the FPCBA to form a resonant circuit that is tuned to the same frequency of the Activator transmission. The amplitude of the induced Activator signal is increased by virtue of the energy storage properties of the tuned circuit, while rejecting (attenuating) magnetic fields at other frequencies (i.e. "noise"). So, the tuned circuit increases the sensitivity to Activator transmissions, thereby increasing activation range.

[0176] The LF coil consists of many turns of insulated wire (preferably copper) wound on top of each other to form a thin, flat air-core coil, as shown in FIG. 17. The turns of wire are typically bonded to each other so the coil is self-supporting and maintains its geometric properties (there is no bobbin or core to support the wires). Reference dimensions of the present embodiment are shown, but the LF Antenna can be designed in a variety of shapes and sizes if desired.

[0177] Multiple turns of wire increases magnetic flux linkage with the Activator magnetic field transmission, and therefore sensitivity. LF antenna inductance and LF tuning capacitance on the FPCBA determine the center frequency of this tuned circuit. To obtain high sensitivity, LF tuned circuit Q must be maximized; and this is partly achieved by minimizing LF Antenna resistance. Coil resistance increases with wire length (approximately linearly with the number of wire turns), while coil inductance increases proportionally to the square of the turns. Increasing turns increases magnetic flux linkage, but reduces Q because of increased resistance, and will require an appropriate reduction in tuning capacitance to remain resonant at the Activation frequency (125 kHz). If coil inductance increases too much, the requisite tuning capacitance may become too small to be practical. Also, overall tuned circuit Q decreases as tuning capacitance decreases and tuning inductance increases. Therefore, the proper balance between these factors must be reached to optimize performance. If the tuned circuit Q becomes too high, the circuit bandwidth can become so narrow that Activator data is attenuated or "stripped off" the LF carrier signal; reducing activation range or even preventing the card from activating. So, LF antenna parameters must be carefully balanced to achieve proper performance.

[0178] For reference, the LF Antenna used in the present embodiment has an inductance of 4.5 mH and a Q of 30. It should be understood that LF antenna designs having different values and characteristics can be made while maintaining the spirit of the invention.

[0179] The mean winding area of the LF antenna coil should be as large as possible and the winding width (outside "diameter" minus inside "diameter") should be as small as possible to maximize the magnitude of Activator flux "captured" by the coil. The size of the LF antenna is tightly constrained by the space available on the Card; which is bounded by the Card edges on two sides, the battery on a third side, and the FPCBA on a fourth side. At the same time, the LF antenna must be kept very thin to satisfy the Card thickness limit. These conflicting constraints generally mean that smaller diameter wire is required in the coil, which adversely affects coil Q and activation range. Extremely small diameter wire also increases the risk of wire breakage during manufacturing and mechanical stresses during Card use.

[0180] The LF coil is typically wound on a mandrel with flanges to establish the interior coil shape and coil thickness. The mandrel rotates and the wire is laid side by side and layered until the desired number of turns is achieved. Wire tension and feeding must be controlled to provide the desired turns density without stretching or breaking the wire. The mandrel and flanges and the entire process must be carefully controlled to ensure the coil is very uniform and flat (a warped coil will cause the laminated card to be warped or distorted). A method is employed to bond adjacent wires to each other (for example, by applying a chemical that seeps into crevices between turns and activates an adhesive film on the wire). At least one mandrel flange is removed so the flat coil can be removed.

[0181] Excess wire that exits the interior winding area and the outer winding area are cut to the desired length so elec-
Electrical connection to the FPCBA can occur in a subsequent assembly process. The insulation film must be removed from the ends of the LF coil lead wires prior to attachment to the FPCB to ensure a low electrical resistance and mechanically reliable connection. While wire insulation can be mechanically stripped from the wire, it is an inefficient process that can also cut or weaken the very fine wire. Special insulation formulations are often used that burn off during soldering, or can be chemically stripped from the wire. Coil connection to the FPCB is often done via soldering or thermocompression bonding. If the coil wire diameter is too small, the coil wire can become weakened at the FPCB termination points by mechanical damage or by copper leaching into the solder; so the wire diameter must be selected for mechanical reasons as well as electrical reasons.

The LF coil is not mounted on the FPCB not only because assembly thickness will be excessive, but also to physically space the LF coil away from conductive traces on the FPCB to avoid adverse inductive coupling between the two (which would otherwise detune and/or load the LF resonant circuit). One advantage of using a low frequency (125 kHz) magnetic field activation signal is that it can easily penetrate the human body without appreciable attenuation; enabling Card activation to occur independently of its position with respect to the Cardholder’s body. Also, the reactivity levels of the LF Antenna and resonant capacitor are high enough to make the Card insensitive to additional parasitic capacitance that can be caused by a person holding the Card over the coil. Finally, the physical location and center frequencies of the LF and RF antennae are so greatly separated that they do not interact with each other; meaning that each subsystem can be independently designed and optimized.

The high temperature and pressure applied during Card lamination can cause coil deformation, altering the inductive coupling between turns and therefore the inductance. This detunes the resonant circuit, shifting the center frequency away from that transmitted by the Activator, as shown in FIG. 18. A small frequency shift is acceptable, but too large a shift will rapidly reduce activation range. Coil deformation generally tends to shift the resonant frequency upwards. Coil deformation can also change interwinding capacitance of the coil, shifting LF tuned circuit resonance even further. In FIG. 18, the Card with little or no coil deformation is resonant at the Activator carrier frequency (the most efficient condition), causing voltage V1 to develop across the tuned circuit. For purposes of comparison, assume that V1 is the activation threshold of U1 within the Card. At the same distance from the Activator, the Card with excessive coil deformation suffers an upward shift in resonant frequency and possibly reduced Q; resulting in the much lower voltage V2 across the tuned circuit. To be activated, the Card with the deformed coil must be moved closer to the Activator to increase this voltage to the value of V1. Coil deformation can even lead to electrical short circuits between adjacent coil turns that are normally insulated from one another. Such severe coil damage can prevent the Card from activating at any distance.

All of these LF Antenna design and manufacturing factors are highly interactive and may be carefully evaluated to yield a high performance/high reliability Card.

The Battery is a thin film energy storage device that provides DC operating power for the Card electronics to yield the activation sensitivity and Card transmission ranges required with adequate margins to compensate for range-limiting real-world conditions.

In one embodiment, the Card does not have the physical space available for commonly available batteries because of their excessive thickness and area. This poses a challenge when attempting to maximize energy storage capacity. High battery energy storage capacity works hand-in-hand with low Card power consumption to maximize Card lifetime. The battery may have high energy density in a suitably thin and small package as shown in FIG. 19. One embodiment uses a thin film lithium metal battery to meet these criteria.

Card electronics desirably have sufficient battery voltage to function properly, so voltage sag during discharge is important. Battery types with relatively “flat” voltage profiles during discharge may yield longer Card life than will equally-rated battery types having more sloped voltage profiles. A battery that maintains its output voltage above the minimum Card operating voltage for the bulk of its storage capacity will deliver longer Card life. The Lithium battery used in one embodiment exhibits a fairly flat voltage profile for the bulk of its useful life.

Not all thin film batteries are equal in performance, and other attributes are also important in determining the appropriate battery for this application. Excessive battery source resistance, for example, can shorten Card life because it can appreciably reduce the voltage actually available to the Card electronics. This is most important when the Card is transmitting its ID (the highest current consumption state) because high battery source resistance will cause excessive voltage drop inside the battery (between the cells and the battery terminals); causing the Card to be non-functional even when sufficient energy is stored in the battery.

FIG. 20 is a diagram illustrating effects of high battery source resistance in accordance with one embodiment. If the external battery voltage drops below the minimum operating voltage, V_MIN, of the Card electronics when the Card begins to transmit, it will instantly shut the Card electronics off. Such an event occurs early in the sixth transmit current pulse of FIG. 20. The discharge rate of the battery is exaggerated to show how this problem can arise as battery voltage is naturally depleted through normal Card use. The event shown in FIG. 20 prematurely terminates the Beacon Mode and deactivates the Card. Battery source resistance should not only be kept low, but it should not increase appreciably with Card use.

The battery may be exposed to high temperature and pressure stresses during Card lamination. The battery selected may be designed with these factors in mind, ensuring that energy storage capacity, shelf life, and source resistance do not degrade unacceptably during lamination; thereby maximizing manufacturing yield and Card life.

Battery terminal metallurgy must be compatible with the bonding process and materials used during Card assembly. The battery has flat metal tabs that are sized and spaced to match the FPCBA pads and that do not increase battery thickness. The battery terminals are suitable for thermocompression bonding as well as soldering. Thermocompression bonding is preferred because it does not rely on excessive temperatures to make the electrical connection, thereby minimizing the risk of damage during Card assembly. Soldering requires significant heat and must be controlled to ensure that excessive solder does not cause the Card electronics assembly to be too thick. Finally, the bonding process
must provide mechanical strength that can tolerate the lamination process as well as Card usage (bending, twisting, compression, drop, etc.).

[0192] Card electronics subassembly occurs after FPCBA test is successfully completed. An example of the resulting assembly is shown in FIG. 10. The FPCBA, LF coil, and battery are accurately positioned on a card plastic substrate, and the LF coil and battery are electrically connected to the FPCBA via thermocompression bonding, soldering, or other suitable method. The bonding process must ensure that the finished assembly height including the bond sites do not exceed the card electronics assembly thickness limit. Card electronic assembly is usually performed in a batch process for production throughput and cost reasons. Multiple card electronic assemblies are precisely positioned next to one another on a common substrate, or sheet. The completed card electronics assembly may be tested again at this stage if required.

[0193] Multiple plastic sheets are stacked, or layered, on top of the substrate sheet containing the card electronics assemblies in order to result in a more uniform thickness profile. This stack of card electronics assemblies and plastic layers is then compressed, or laminated into a single element through the application of heat and pressure. This is not the final card, however, and is referred to as a “Pre-laminate” or “pre-lam.” Pre-lams may be tested before the final lamination steps if desired.

[0194] Pre-lams are sandwiched between additional plastic layers that typically contain colored sheets and/or custom graphics, which are often used to display card issuer/business information, logos, etc. Clear protective films cover the graphics layers, and this final stack-up is hot-laminated into a single element referred to as an “end-laminate” or “End-lam”. The outer graphics and coverfilm layers help to mask surface non-uniformities of the Pre-lam; providing a smooth, uniform, blemish-free surface finish. End-lam material types, thicknesses, and the lamination process are carefully controlled to ensure the final sheet thickness does not exceed the maximum allowable Card thickness. Individual Cards are singulated from the finished End-lam sheet. Finished Card testing may be performed in sheet form and/or individually after Cards are singulated from the sheet.

[0195] The FPCBA, LF coil, battery, and their interconnections may withstand the high temperature and pressure of the card lamination process. The card electronics may also withstand residual mechanical stresses that may be stored in the Card as a result of pressure and thermal cycles during lamination without functionality or performance degradation. After manufacturing, the Card will be exposed to additional stresses during normal handling and use. Therefore, Card design, component and material selection, manufacturing processes, and test processes may all be carefully considered to meet production yield and reliability requirements.

[0196] Various embodiments described above may be implemented using computer program modules, applications, or software for providing functionality described herein. In such implementations, computer program instructions and/or other logic are used to provide the specified functionality. Thus, a module or application can be implemented in hardware, firmware, and/or software. In one embodiment, program modules or applications formed of executable computer program instructions are stored in a non-transitory computer-readable storage medium, loaded into a memory, and executed by one or more processors to carry out the functions described herein.

[0197] The present invention has been described in particular detail with respect to a limited number of embodiments. Those of skill in the art will appreciate that the invention may additionally be practiced in other embodiments. The system may be implemented via a different combination of hardware and software from that described. Also, the particular division of functionality between the various system components described herein is merely exemplary, and not mandatory; functions performed by a single system component may instead be performed by multiple components, and functions performed by multiple components may instead be performed by a single component.

[0198] Finally, it should be noted that the language used in the specification has been principally selected for readability and instructional purposes, and may not have been selected to delineate or circumscribe the inventive subject matter. Accordingly, the disclosure of the present invention is intended to be illustrative, but not limiting, of the scope of the invention.

1. An Active Radio Frequency Identification (RFID) transponder for use in a customer relationship management system, the transponder comprising:
   a card assembly having a form factor of a credit card or smaller;
   an integrated circuit storing an identifier of the transponder, the integrated circuit configured to detect a low-frequency activation signal and responsive to the detection, generate a high-frequency identifier signal representing the identifier of the transponder;
   a low-frequency antenna coupled to the integrated circuit for receiving the low-frequency activation signal;
   a crystal coupled to the integrated circuit for generating high-frequency oscillations for generating the high-frequency identifier signal;
   a high-frequency antenna coupled to the integrated circuit for transmitting the high-frequency signal representing the identifier, and
   a battery for providing power to the integrated circuit;
   wherein the integrated circuit, the low-frequency antenna, the high-frequency antenna, crystal, the antenna, and the battery are integrated into the card assembly.

2. The transponder of claim 1, further comprising:
   passive components coupled to the integrated circuit and integrated in the card assembly.

3. The transponder of claim 1, wherein the card assembly has a form factor smaller than 85.47 mm×53.92 mm×0.8382 mm.

4. The transponder of claim 1, wherein the card assembly substantially conforms to bending stiffness standards specified in section 8.1 of ISO/IEC Standard 7810, Physical Characteristics of Identification Cards.

5. The transponder of claim 1, wherein the card assembly further comprises:
   a magnetic strip on a surface of the card assembly, the magnetic strip readable by a magnetic card reader.

6. The transponder of claim 1, wherein a plurality of components of the card assembly are mounted on an FPCBA (Flexible Printed Circuit Board) and combined into a FPCBA (Flexible Printed Circuit Board Assembly).

7. The transponder of claim 6, wherein the FPCBA includes the integrated circuit, the crystal, the high-frequency antenna and a plurality of passive components.
8. The transponder in claim 7, wherein the card assembly further comprises off-board components separate from the FPCBA, the off-board components including the low-frequency antenna and the battery embodied as a thin-film battery.

9. The transponder of claim 6, wherein the low-frequency antenna is positioned adjacent to the FPCBA in the card assembly.

10. The transponder of claim 6, wherein the low-frequency antenna is positioned away from conductive traces on the FPCBA to avoid adverse inductive coupling.

11. The transponder of claim 6, wherein the FPCBA comprises a material tolerant to manufacturing processes including surface mount component attach and hot card lamination.

12. The transponder of claim 6, wherein the FPCBA comprises an electrically non-conductive dielectric core having a thickness of 18 microns or less.

13. The transponder of claim 12, wherein the electrically non-conductive dielectric core comprises polyimide (PI).

14. The transponder of claim 12, wherein the FPCBA comprises very thin conductive traces formed on each side of the dielectric core, the thin conductive traces used to interconnect the components in the FPCBA.

15. The transponder of claim 14, wherein the FPCBA further comprises electrical connections between the conductive traces on each side of the FPCBA formed by using one or more plated-through via holes.

16. The transponder of claim 15, wherein at least one of the plated-through via holes is positioned to allow air trapped in solder paste under the integrated circuit to escape out a bottom side of the FPCBA opposite the integrated circuit during a solder reflow assembly process, the at least one of the plated-through via holes further positioned to ensure that the integrated circuit is mounted substantially parallel to the FPCBA, and the at least one of the plated-through via holes further positioned to act as a solder wick pulling the integrated circuit to the FPCBA surface and reduce electrical resistance between top and bottom copper layers of the FPCBA.

17. The transponder of claim 12, further comprising a solder mask covering a conductive layer on at least one side of the dielectric core for blocking flow of molten solder between adjacent conductive elements and preventing short circuits from forming when electronic components are soldered to the FPCBA, the solder mask comprising a thin dielectric film.

18. The transponder of claim 17, wherein the FPCBA further comprises openings in the solder mask to provide access for electrical probing.

19. The transponder of claim 17, wherein the FPCBA further comprises nickel or gold plating in open areas of the solder mask for physically connecting between solder on the FPCBA and electrical components.

20. The transponder of claim 6, wherein the FPCBA is configured to temperatures and pressures associated with a lamination process without appreciable shifts in electrical characteristics.

21. The transponder of claim 6, wherein the FPCBA further comprises holes of at least 3 millimeters in diameter, the holes configured to prevent air from being trapped during lamination of the card assembly.

22. The transponder of claim 21, wherein the large holes are further configured to stitch together top and bottom layers of plastic surfaces of the card assembly to prevent delamination of the card assembly.

23. The transponder of claim 6, wherein the FPCBA comprises a thickness in a range of approximately 56 to 85 microns.

24. The transponder of claim 1, wherein the integrated circuit comprises:

   a first chip for detecting the low-frequency activation signal; and
   a second chip for transmitting the high-frequency identifier signal.

25. The transponder of claim 24, wherein the first chip and the second chip are positioned in a side-by-side assembly having a thickness less than or equal to 400 microns.

26. The transponder of claim 25, wherein the first and second chips of the integrated circuit are adhered to a die-attach pad of a lead frame with an adhesive.

27. The transponder of claim 24, wherein the integrated circuit further comprises:

   wire bonds for electrically connecting the first and second chips to each other and to other components of the card assembly.

28. The transponder of claim 1, wherein the crystal comprises a cut, sized and metalized quartz crystal mounted within a precision surface mount ceramic package.

29. The transponder of claim 28, wherein the crystal has a thickness less than or equal to 500 microns.

30. The transponder of claim 28, wherein a portion of the crystal is sunk into a hole of the FPCBA.

31. The transponder of claim 28, wherein the crystal is partially embedded into the FPCBA using a stair-stepped ceramic package.

32. The transponder of claim 28, wherein the crystal is mounted directly to the FPCBA using blanks and wherein a cover protects the blanks.

33. The transponder of claim 1, wherein the high-frequency antenna is configured to operate at approximately 433 MHz.

34. The transponder of claim 1, wherein the high-frequency antenna comprises a loop antenna.

35. The transponder of claim 1, wherein the high-frequency antenna comprises:

   a first loop on a top portion of the card assembly; and
   a second loop on a bottom portion of the card assembly, the second loop mirrored relative to the first loop.

36. The transponder of claim 1, wherein the high-frequency antenna is configured to be resistant to card lamination stresses and bending stresses of the card assembly.

37. The transponder of claim 1, wherein the low-frequency antenna and the battery are attached to the card assembly using a bed of nails fixture.

38. The transponder of claim 1, wherein the low frequency antenna is coupled to one or more capacitors to form a resonant circuit tuned to a frequency of the received activation signal.

39. The transponder of claim 1, wherein the low-frequency antenna comprises a plurality of turns of insulated wire wound on top of each other to form a thin flat air-core coil, and wherein the plurality of turns are bonded to each other to form a self-supporting coil.

40. The transponder of claim 1, wherein the low-frequency antenna is configured to operate at a frequency of that can penetrate a human body without appreciable attenuation.

41. The transponder of claim 1, wherein the low-frequency antenna is configured to operate at approximately 125 kHz.
42. The transponder of claim 1, wherein the low-frequency antenna is tuned to maximize a Q factor of the low-frequency antenna.

43. The transponder of claim 1, wherein the battery comprises a thin film lithium metal battery meeting physical space limitations of the form factor of the transponder.

44. The transponder of claim 1, wherein the battery is configured to withstand temperature and pressure stresses associated with a card lamination process applied to the card assembly.

45. The transponder of claim 1, wherein the battery comprises battery terminals having metallurgy compatible with a bonding process and materials of the card assembly.

46. The transponder of claim 45, wherein the battery comprises battery terminals configured as flat metal tabs sized and spaced to match FPCBA pads.

47. The transponder of claim 45, wherein the battery terminals are suitable for thermo-compression bonding and soldering.

48. The transponder of claim 45, wherein the battery terminals are bonded to an FPCBA.

49. The transponder in claim 1, wherein the integrated circuit, the high-frequency antenna, the low-frequency antenna, the crystal, and the battery are embodied in a laminated plastic card substrate.

50. A method for manufacturing a Radio Frequency Identification (RFID) transponder, comprising:

forming a Flexible Printed Circuit Board Assembly (FPCBA), the FPCBA comprising an integrated circuit, a high-frequency antenna coupled to the integrated circuit, and a crystal coupled to the integrated circuit; and

combining the FPCBA into a card assembly which further includes a low-frequency antenna coupled to the integrated circuit and a thin film battery for powering the integrated circuit, the card assembly substantially conforming to a form factor of 85.47 mm x 53.92 mm x 0.8382 mm or smaller.

51. The method of claim 50, wherein forming the FPCBA comprises:

fabricating a plurality of FPCBAs in a panel; and

separating individual FPCBAs from the panel.

52. The method of claim 50, further comprising:

positioning the FPCBA, the low-frequency antenna, and the thin film battery on a plastic card substrate; and

laminating the plastic card substrate to form a pre-laminate.

53. The method of claim 52, wherein laminating comprises:

positioning multiple card assemblies in a sheet; and

laminating the sheet of card assemblies.

54. The method of claim 52, wherein the laminating comprises:

adding a shielding layer with cut-outs to surround and shield the FPCBA, the low-frequency antenna, and the battery from the laminating.

55. The method of claim 52, wherein the laminating comprises applying heat and pressure to the plastic card substrate.

56. The method of claim 52, further comprising:

sandwiching the pre-laminate between additional plastic layers including text or graphics and providing a protective film to create an end-laminate.

57. The method of claim 56, wherein creating the end-laminate comprises:

adding a magnetic stripe to the card assembly for encoding information relating to a cardholder.

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