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INTRODUCTION

Radio Frequency Identification (RFID) systems use radio frequency to identify, locate and track people, assets and animals. Passive RFID systems are composed of three components – a reader (interrogator), passive tag and host computer. The tag is composed of an antenna coil and a silicon chip that includes basic modulation circuitry and non-volatile memory. The tag is energized by a time-varying electromagnetic radio frequency (RF) wave that is transmitted by the reader. This RF signal is called a carrier signal. When the RF field passes through an antenna coil, there is an AC voltage generated across the coil. This voltage is rectified to result in a DC voltage for the device operation. The device becomes functional when the DC voltage reaches a certain level. The information stored in the device is transmitted back to the reader. This is often called backscattering. By detecting the backscattering signal, the information stored in the device can be fully identified.

There are two classes of RFID device depending on type of memory cell: (a) read only device and (b) read and write device. The memory cell can be made of EEPROM or FRAM. EEPROM is based on CMOS silicon and FRAM is based on ferroelectric memory. Since CMOS process technology has been matured, the EEPROM can be produced relatively at lower cost than the FRAM device. However, FRAM based RFID device consumes less power which is desirable for low power device. Therefore, it is known as a good candidate for the future RFID device, if its manufacturing cost becomes compatible to that of the CMOS technology.

Because of its simplicity for use, the passive RFID system has been used for many years in various RF remote sensing applications. Specifically in access control and animal tracking applications.

In recent years, there have been dramatic increases in application demands. In most cases, each applications uses a unique packaging form factor, communication protocol, frequency, etc. Because the passive tag is remotely powered by reader’s RF signal, it deals with very small power (~µW). Thus, the read range (communication distance between reader and tag) is typically limited within a proximity distance. The read range varies with design parameters such as frequency, RF power level, reader’s receiving sensitivity, size of antenna, data rate, communication protocol, current consumptions of the silicon device, etc.

Low frequency bands (125 kHz – 400 kHz) were traditionally used in RFID applications. This was because of the availability of silicon devices. Typical carrier frequency (reader’s transmitting frequency) in today’s applications range from 125 kHz – 2.4 GHz.

In recent years, the applications with high frequency (4 – 20 MHz) and microwave (2.45 GHz) bands have risen with the advent of new silicon devices. Each frequency band has advantages and disadvantages. Therefore, this frequency band becomes the most dominant frequency band in passive RFID applications.

DEFINITIONS

READER, INTERROGATOR

RFID reader is used to activate passive tag with RF energy and to extract information from the tag.

For this function, the reader includes RF transmission, receiving and data decoding sections. In addition, the reader includes a serial communication (RS-232) capability to communicate with the host computer. Depend-
ing on the complexity and purpose of applications, the reader’s price range can vary from ten dollars to a few thousand dollar worth of components and packaging.

The RF transmission section includes an RF carrier generator, antenna and a tuning circuit. The antenna and its tuning circuit must be properly designed and tuned for the best performance. See Application Note AN710 (DS00710) for the antenna circuit design.

Data decoding for the received signal is accomplished using a microcontroller. The firmware algorithm in the microcontroller is written in such a way to transmit the RF signal, decode the incoming data and communicate with the host computer.

Typically, reader is a read only device, while the reader for read and write device is often called interrogator. Unlike the reader for read only device, the interrogator uses command pulses to communicate with tag for reading and writing data.

**TAG**

Tag consists of a silicon device and antenna circuit.

The purpose of the antenna circuit is to induce an energizing signal and to send a modulated RF signal. The read range of tag largely depends upon the antenna circuit and size.

The antenna circuit of tag is made of LC resonant circuit or E-field dipole antenna, depending on the carrier frequency. The LC resonant circuit is used for the frequency of less than 100 MHz. In this frequency band, the communication between the reader and tag takes place with magnetic coupling between the two antennas through the magnetic field. The antenna utilizing the inductive coupling is often called magnetic dipole antenna.

The antenna circuit must be designed such a way to maximize the magnetic coupling between them. This can be achieved with the following parameters:

- a) LC circuit must be tuned to the carrier frequency of the reader
- b) Maximize Q of the tuned circuit
- c) Maximize antenna size within physical limit of application requirement.

See Application Note AN710 for more details.

When the frequency goes above 100 MHz, the requirement of LC values for its resonant frequency becomes too small to realize with discrete L and C components. As frequency increases, the wavelength is getting shorter. In this case, a true E-field antenna can be made of a simple conductor that has linear dimension less than or equivalent to half (½) the wavelength of the signal. The antenna that is made of a simple conductor is called electric dipole antenna. The electric dipole antenna utilizes surface current that is generated by an electric field (E-Field). The surface current on the conductor produces voltage at load. This voltage is used to energize the silicon device. Relatively simple antenna structure is formed for the higher frequency compared to the lower frequency.

**READ ONLY DEVICE, READ/WRITE DEVICE:**

For the read only device, the information that is in the memory can’t be changed by RF command once it has been written.

Read only devices are programmed as follows: (a) in the factory as a part of manufacturing process, (b) contactlessly programmed one time after the manufacturing (MCRF200 and MCRF250) or (c) can be programmed and also reprogrammed in contact mode (MCRF355 and MCRF360).

A device with memory cells that can be reprogrammed by RF commands is called read/write device. The information in the memory can be reprogrammed by interrogator command.

Memory in today’s RFID device is made of (a) CMOS or (b) FRAM array. The CMOS memory cell needs higher voltage for writing than reading. In the passive read/write device, the programming voltage is generated by multiplying the rectified voltage. The voltage multiplier circuit is often called a charge pumper. In addition to the programming voltage, the read/write device needs command decoder and other controller logics. As a result, the read/write device needs more circuit building blocks than that of the read only device. Therefore, the device size is larger and cost more than a read only device. The FRAM device needs the same voltage for reading and writing. However, its manufacturing cost is much higher than CMOS technology. Most of RFID device available today’s market place are CMOS based device.

**READ/WRITE RANGE**

Read/write range is a communication distance between the reader (Interrogator) and tag. Specifically, the read range is a maximum distance to read data out from the tag and write range is a maximum distance to write data from interrogator to tag.

The read/write range is related to:

1. Electromagnetic coupling of the reader (interrogator) and tag antennas, (2) RF Output power level of reader (interrogator), (3) Carrier frequency bands, (4) Power consumption of device, etc.

The electromagnetic coupling of reader and tag antennas increases using similar size of antenna with higher Q in both sides. The read range is improved by increasing the carrier frequency. This is due to the gain in the radiation efficiency of the antenna as the frequency increases. However, the disadvantage of high frequency (900 MHz - 2.4 GHz) application are shallow skin depth and narrower antenna beam width. These cause less penetration and more directional problem,
respectively. Low frequency application, on the other hand, has advantage in the penetration and directional, but a disadvantage in the antenna performance.

The read range increases by reducing the current consumptions in the silicon device. This is because additional radiating power is available by reducing the power dissipation in the silicon device.

**MODULATION PROTOCOL**

The passive RFID tag uses backscattering of the carrier frequency for sending data from the tag to reader. The amplitude of backscattering signal is modulated with modulation data of the tag device. The modulation data can be encoded in the form of ASK (NRZ or Manchester), FSK or PSK. Therefore, the modulation signal from the tag is Amplitude-Amplitude, Amplitude-FSK and Amplitude-PSK. See MicroID 125 kHz Design Guide for Amplitude, Amplitude-FSK and Amplitude-PSK reader.

**CARRIER**

Carrier is the transmitting radio frequency of reader (interrogator). This RF carrier provides energy to the tag device, and is used to detect modulation data from the tag using backscattering. In read/write device, the carrier is also used to deliver interrogator’s command and data to the tag.

Typical passive RFID carrier frequencies are:

a) 125 kHz - 400 kHz
b) 4 MHz - 24 MHz
c) 900 MHz - 2.45 GHz.

The frequency bands must be selected carefully for applications because each one has its own advantages and disadvantages. Table 1 shows the characteristic of each frequency bands.

**TABLE 1:**

<table>
<thead>
<tr>
<th>Frequency Bands</th>
<th>Antenna Components</th>
<th>Read Range (typical)</th>
<th>Penetration (skin depth)</th>
<th>Orientation (Directionality)</th>
<th>Usability in metal or humid environment</th>
<th>Applications (typical)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Frequency (125 - 400 kHz)</td>
<td>Coil (&gt; 100 turns) and capacitor</td>
<td>Proximity (8&quot;)</td>
<td>Best</td>
<td>Least</td>
<td>Possible</td>
<td>Proximity</td>
</tr>
<tr>
<td>Medium Frequency (4 MHz - 24 MHz)</td>
<td>Coil (&lt; 10 turns) and capacitor</td>
<td>Medium (15&quot;)</td>
<td>Good</td>
<td>Not much</td>
<td>Possible</td>
<td>Low cost and high volume</td>
</tr>
<tr>
<td>High Frequency (&gt;900 MHz)</td>
<td>E-field dipole (a piece of conductor)</td>
<td>Long (&gt; 1 m)</td>
<td>Poor</td>
<td>Very high</td>
<td>Difficult</td>
<td>Line of sight with long range</td>
</tr>
</tbody>
</table>
SYSTEM HANDSHAKE

Typical handshake of a tag and reader (interrogator) is as follows:

A. Read Only Tag
   1. The reader continuously transmits an RF signal and watches always for modulated backscattering signal.
   2. Once the tag has received sufficient energy to operate correctly, it begins clocking its data to a modulation transistor, which is connected across the antenna circuit.
   3. The tag’s modulation transistor shorts the antenna circuit, sequentially corresponding to the data which is being clocked out of the memory array.
   4. Shorting and releasing the antenna circuit accordingly to the modulation data causes amplitude fluctuation of antenna voltage across the antenna circuit.
   5. The reader detects the amplitude variation of the tag and uses a peak-detector to extract the modulation data.

B. Read and Write Tag
   (Example: MCRF45X devices with FRR and Reader Talks First mode)
   1. The interrogator sends a command to initiate communication with tags in the fields. This command signal is also used for energizing the passive device.
   2. Once the tag has received sufficient energy and command, it responds back with its ID for acknowledgment.
   3. The interrogator now knows which tag is in the field. The interrogator sends a command to the identified tag for what to do next: processing (read or write) or sleep.
   4. If the tag receive processing and reading commands, it transmits a specified block data and waits for the next command.
   5. If the tag receives processing and writing commands along with block data, it writes the block data into the specified memory block, and transmits the written block data for verification.
   6. After the processing, the interrogator sends an “end” command to send the tag into the sleep (“silent”) mode.
   7. If the device receives “end” command after processing, it sends an acknowledgement (8-bit preamble) and stays in sleep mode. During the sleep mode, the device remains in non-modulating (detuned) condition as long as it remains in the power-up. This time the handshake is over.
   8. The interrogator is now looking for the next tag for processing, establishes an handshake and repeats the processing.

9. See Figure 4-1 in MCRF45X data sheet for more details.

BACKSCATTER MODULATION

This terminology refers to the communication method used by a passive RFID tag to send data to the reader using the same reader’s carrier signal. The incoming RF carrier signal to the tag is transmitted back to the reader with tag’s data.

The RF voltage induced in the tag’s antenna is amplitude-modulated by the modulation signal (data) of tag device. This amplitude-modulation can be achieved by using a modulation transistor across the LC resonant circuit or partially across the resonant circuit.

The changes in the voltage amplitude of tag’s antenna can affect on the voltage of the reader antenna. By monitoring the changes in the reader antenna voltage (due to the tag’s modulation data), the data in the tag can be reconstructed.

The RF voltage link between reader and tag antennas are often compared to a weakly coupled transformer coils; as the secondary winding (tag coil) is momentarily shunted, the primary winding (reader coil) experiences a momentary voltage drop.

DATA ENCODING

Data encoding refers to processing or altering the data bitstream in-between the time it is retrieved from the RFID chip’s data array and its transmission back to the reader. The various encoding algorithms affect error recovery, cost of implementation, bandwidth, synchronization capability and other aspects of the system design. Entire textbooks are written on the subject, but there are several popular methods used in RFID tagging today:

1. **NRZ (Non-Return to Zero) Direct.** In this method no data encoding is done at all; the 1’s and 0’s are clocked from the data array directly to the output transistor. A low in the peak-detected modulation is a ‘0’ and a high is a ‘1’.

2. **Differential Biphase.** Several different forms of differential biphase are used, but in general the bitstream being clocked out of the data array is modified so that a transition always occurs on every clock edge, and 1’s and 0’s are distinguished by the transitions within the middle of the clock period. This method is used to embed clocking information to help synchronize the reader to the bitstream. Because it always has a transition at a clock edge, it inherently provides some error correction capability. Any clock edge that does not contain a transition in the data stream is in error and can be used to reconstruct the data.
3. **Biphase_L (Manchester).** This is a variation of biphase encoding in which there is not always a transition at the clock edge. The MCRF355/360 and MCRF45X devices use this encoding method.

**FIGURE 2: VARIOUS DATA CODING WAVEFORMS**

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<th>WAVEFORM</th>
<th>DESCRIPTION</th>
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<tbody>
<tr>
<td>Data</td>
<td>1 0 1 1 0 0 1 1 0 0 1 1 0 1 0</td>
<td>Digital Data</td>
</tr>
<tr>
<td>Bit Rate CLK</td>
<td></td>
<td>Clock Signal</td>
</tr>
<tr>
<td>NRZ_L (Direct)</td>
<td></td>
<td>Non-Return to Zero – Level</td>
</tr>
<tr>
<td></td>
<td></td>
<td>‘1’ is represented by logic high level.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>‘0’ is represented by logic low level.</td>
</tr>
<tr>
<td>Biphase_L (Manchester)</td>
<td></td>
<td>Biphase – Level (Split Phase)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A level change occurs at middle of every bit clock period.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>‘1’ is represented by a high to low level change at midclock.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>‘0’ is represented by a low to high level change at midclock.</td>
</tr>
<tr>
<td>Differential Biphase_S</td>
<td></td>
<td>Differential Biphase – Space</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A level change occurs at middle of every bit clock period.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>‘1’ is represented by a change in level at start of clock.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>‘0’ is represented by no change in level at start of clock.</td>
</tr>
</tbody>
</table>

**Note:** Manchester coding is used for the MCRF355/360 and MCRF45X
DATA MODULATION FOR 125 kHz DEVICES (MCRF2XX)

Although all the data is transferred to the host by amplitude-modulating the carrier (backscatter modulation), the actual modulation of 1’s and 0’s is accomplished with three additional modulation methods:

1. **Direct.** In direct modulation, the Amplitude Modulation of the backscatter approach is the only modulation used. A high in the envelope is a ‘1’ and a low is a ‘0’. Direct modulation can provide a high data rate but low noise immunity.

2. **FSK (Frequency Shift Keying).** This form of modulation uses two different frequencies for data transfer; the most common FSK mode is FC/8/10. In other words, a ‘0’ is transmitted as an amplitude-modulated clock cycle with period corresponding to the carrier frequency divided by 8, and a ‘1’ is transmitted as an amplitude-modulated clock cycle period corresponding to the carrier frequency divided by 10. The amplitude modulation of the carrier thus switches from FC/8 to FC/10 corresponding to 0’s and 1’s in the bitstream, and the reader has only to count cycles between the peak-detected clock edges to decode the data. FSK allows for a simple reader design, provides very strong noise immunity, but suffers from a lower data rate than some other forms of data modulation. In Figure 3, FSK data modulation is used with NRZ encoding.

3. **PSK (Phase Shift Keying).** This method of data modulation is similar to FSK, except only one frequency is used, and the shift between 1’s and 0’s is accomplished by shifting the phase of the backscatter clock by 180 degrees. Two common types of PSK are:
   - Change phase at any ‘0’, or
   - Change phase at any data change (0 to 1 or 1 to 0).

PSK provides fairly good noise immunity, a moderately simple reader design, and a faster data rate than FSK. Typical applications utilize a backscatter clock of FC/2, as shown in Figure 4.

**FIGURE 3:** FSK MODULATED SIGNAL, FC/8 = 0, FC/10 = 1
FIGURE 4: PSK MODULATED SIGNAL

ANTI-COLLISION

In many existing applications, a single-read RFID tag is sufficient and even necessary: animal tagging and access control are examples. However, in a growing number of new applications, the simultaneous reading of several tags in the same RF field is absolutely critical: library books, airline baggage, garment and retail applications are a few.

In order to read multiple tags simultaneously, the tag and reader must be designed to detect the condition that more than one tag is active. Otherwise, the tags will all backscatter the carrier at the same time and the amplitude-modulated waveforms shown in Figure 3 and Figure 4 would be garbled. This is referred to as a collision. No data would be transferred to the reader. The tag/reader interface is similar to a serial bus, even though the “bus” travels through the air. In a wired serial bus application, arbitration is necessary to prevent bus contention. The RFID interface also requires arbitration so that only one tag transmits data over the “bus” at one time.

A number of different methods are in use and in development today for preventing collisions; most are patented or patent pending. Yet, all are related to making sure that only one tag “talks” (backscatters) at any one time. See the MCRF250 (DS21267), MCRF355/360 (DS21287) and MCRF45X (DS40232) data sheets for various anti-collision algorithms.
FEATURES

- Carrier frequency: 13.56 MHz
- Data modulation frequency: 70 kHz
- Manchester coding protocol
- 154 bits of user-reprogrammable memory
- On-board 100 ms sleep timer
- Built-in anti-collision algorithm for reading up to 50 tags in the same RF field
- “Cloaking” feature minimizes the detuning effects of adjacent tags
- Internal 100 pF resonant capacitor (MCRF360)
- Read-only device in RF field
- Rewritable with contact programmer or factory-programmed options
- Very low power CMOS design
- Die, wafer, PDIP or SOIC package options

APPLICATION

The MCRF355 and MCRF360 are Microchip’s 13.56 MHz microID™ family of RFID tagging devices. They are uniquely designed read-only passive Radio Frequency Identification (RFID) devices with an advanced anti-collision feature. The device is powered remotely by rectifying RF magnetic fields that are transmitted from the reader.

The device has a total of six pads (see Figure 1-1). Three (ant. A, B, VSS) are used to connect the external resonant circuit elements. The additional three pads (VPRG, CLK, VDD) are used for programming and testing of the device.

The device needs an external resonant circuit between antenna A, B, and VSS pads. The resonant frequency of the circuit is determined by the circuit elements between the antenna A and VSS pads. The resonant circuit must be tuned to the carrier frequency of the reader for maximum performance. The circuit element between the antenna A and VSS pads is used for data modulation. See Application Note AN707 (DS00707) for further operational details.

The MCRF360 includes a 100 pF internal resonant capacitor (100 pF). By utilizing this internal resonant capacitor, the device needs external coils only for the resonant circuit. Examples of the resonant circuit configuration for both the MCRF355 and MCRF360 are shown in Section 3.

When a tag (device with the external LC resonant circuit) is brought to the reader’s RF field, it induces an RF voltage across the LC resonant circuit. The device rectifies the RF voltage and develops a DC voltage. The device becomes functional as soon as VDD reaches the operating voltage level.

The device includes a modulation transistor that is located between antenna B and VSS pads. The transistor has high turn-off (a few MΩ) and low turn-on (3 Ω) resistance. The turn-on resistance is called modulation resistance (RM). When the transistor turns off, the resonant circuit is tuned to the carrier frequency of the reader. This condition is called uncloaking. When the modulation transistor turns on, its low turn-on resistance shorts the external circuit element between the antenna B and VSS. As a result, the resonant circuit no longer resonates at the carrier frequency. This is called cloaking.
The induced voltage amplitude (on the resonant circuit) changes with the modulation data: higher amplitude during uncloaking (tuned), and lower amplitude during cloaking (detuned). This is called "amplitude modulation" signal. The receiver channel in the reader detects this amplitude modulation signal and reconstructs the modulation data.

The occurrence of the cloaking and uncloaking of the device is controlled by the modulation signal that turns the modulation transistor on and off, resulting in communication from the device to the reader.

The data stream consists of 154 bits of Manchester-encoded data at a 70 KHz rate. The Manchester code waveform is shown in Figure 2-2. After completion of the data transmission, the device goes into sleep mode for about 100 ms. The device repeats the transmitting and sleep cycles as long as it is energized. During the sleep time the device remains in an uncloaked state.

Sleep time is determined by a built-in low-current timer. There is a wide variation of the sleep time between each device. This wide variation of sleep time results in a randomness of the time slot. Each device wakes up and transmits its data in a different time slot with respect to each other. Based on this scenario, the reader is able to read many tags that are in the same RF field.

The device has a total of 154 bits of reprogrammable memory. All bits are reprogrammable by a contact programmer. A contact programmer (part number PG103003) is available from Microchip Technology Inc. Factory programming prior to shipment, known as Serialized Quick Turn ProgrammingSM (SQTPSM), is also available. The device is available in die form or packaged in SOIC or PDIP.

Note: Information provided herein is preliminary and subject to change without notice.
# 1.0 ELECTRICAL CHARACTERISTICS

## TABLE 1-1: ABSOLUTE MAXIMUM/MINIMUM RATINGS

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Symbol</th>
<th>Min.</th>
<th>Max.</th>
<th>Units</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coil Current</td>
<td>IPP_AC</td>
<td>—</td>
<td>40</td>
<td>mA</td>
<td>Peak-to-Peak coil current</td>
</tr>
<tr>
<td>Assembly temperature</td>
<td>TASM</td>
<td>—</td>
<td>300</td>
<td>°C</td>
<td>&lt; 10 sec</td>
</tr>
<tr>
<td>Storage temperature</td>
<td>TSTORE</td>
<td>-65</td>
<td>150</td>
<td>°C</td>
<td>—</td>
</tr>
</tbody>
</table>

## TABLE 1-2: DC CHARACTERISTICS

All parameters apply across the specified operating ranges, unless otherwise noted.

### Commercial (C): TAMB = -20°C to 70°C

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Symbol</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Units</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading voltage</td>
<td>VDDR</td>
<td>2.4</td>
<td>—</td>
<td>—</td>
<td>V</td>
<td>VDD voltage for reading</td>
</tr>
<tr>
<td>Hysteresis voltage</td>
<td>VHYST</td>
<td>—</td>
<td>TBD</td>
<td>—</td>
<td>TBD</td>
<td>—</td>
</tr>
<tr>
<td>Operating current</td>
<td>IDD</td>
<td>—</td>
<td>7</td>
<td>10</td>
<td>µA</td>
<td>VDD = 2.4V during reading at 25°C</td>
</tr>
<tr>
<td>Testing voltage</td>
<td>VDDT</td>
<td>—</td>
<td>4</td>
<td>—</td>
<td>V</td>
<td>—</td>
</tr>
<tr>
<td>Programming voltage:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High level input voltage</td>
<td>VIH</td>
<td>0.7 * VDD</td>
<td>—</td>
<td>—</td>
<td>V</td>
<td>External DC voltage for programming and testing</td>
</tr>
<tr>
<td>Low level input voltage</td>
<td>VIL</td>
<td>—</td>
<td>—</td>
<td>0.3 * VDD</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>High voltage</td>
<td>VHH</td>
<td>—</td>
<td>20</td>
<td>—</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Current leakage during sleep</td>
<td>IDD_OFF</td>
<td>—</td>
<td>10</td>
<td>—</td>
<td>nA</td>
<td>(Note 1)</td>
</tr>
<tr>
<td>Modulation resistance</td>
<td>RM</td>
<td>—</td>
<td>3</td>
<td>4</td>
<td>Ω</td>
<td>DC resistance between Drain and Source gates of the modulation transistor (when it is turned on)</td>
</tr>
<tr>
<td>Pull-Down resistor</td>
<td>RPDW</td>
<td>5</td>
<td>8</td>
<td>—</td>
<td>KΩ</td>
<td>CLK and VPRG internal pull-down resistor</td>
</tr>
</tbody>
</table>

**Note 1:** This parameter is not tested in production.
## TABLE 1-3: AC CHARACTERISTICS

All parameters apply across the specified operating ranges, unless otherwise noted.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Symbol</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Units</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier frequency</td>
<td>FC</td>
<td>13.56</td>
<td></td>
<td>MHz</td>
<td></td>
<td>Reader’s transmitting frequency</td>
</tr>
<tr>
<td>Modulation frequency</td>
<td>FM</td>
<td>58</td>
<td>70</td>
<td>82</td>
<td>kHz</td>
<td>Manchester coding</td>
</tr>
<tr>
<td>Coil voltage during reading</td>
<td>VPP_AC</td>
<td>4</td>
<td>—</td>
<td>82</td>
<td>VPP</td>
<td>Peak-to-Peak AC voltage across the coil during reading</td>
</tr>
<tr>
<td>Coil clamp voltage</td>
<td>VCLMP_AC</td>
<td>—</td>
<td>32</td>
<td>—</td>
<td>VPP</td>
<td>Peak-to-Peak coil clamp voltage</td>
</tr>
<tr>
<td>Test mode clock frequency</td>
<td>FCLK</td>
<td>115</td>
<td>500</td>
<td>150</td>
<td>kHz</td>
<td>25°C</td>
</tr>
<tr>
<td>Sleep time</td>
<td>TOFF</td>
<td>50</td>
<td>100</td>
<td>150</td>
<td>ms</td>
<td>Off time for anti-collision feature, at 25°C</td>
</tr>
<tr>
<td>Internal resonant capacitor</td>
<td>CRES</td>
<td>85</td>
<td>100</td>
<td>115</td>
<td>pF</td>
<td>Internal resonant capacitor between Antenna A and Vss, at 13.56 MHz</td>
</tr>
<tr>
<td>Resonant frequency (MCRF360)</td>
<td>FR</td>
<td>12.65</td>
<td>13.56</td>
<td>14.711</td>
<td>MHz</td>
<td>with L = 1.377 µH</td>
</tr>
<tr>
<td>Write/Erase pulse width</td>
<td>TWC</td>
<td>—</td>
<td>2</td>
<td>10</td>
<td>ms</td>
<td>Time to program bit, at 25°C</td>
</tr>
<tr>
<td>Clock high time</td>
<td>THIGH</td>
<td>—</td>
<td>4.4</td>
<td>—</td>
<td>µs</td>
<td>25°C</td>
</tr>
<tr>
<td>Clock low time</td>
<td>TLOW</td>
<td>—</td>
<td>4.4</td>
<td>—</td>
<td>µs</td>
<td>25°C</td>
</tr>
<tr>
<td>Stop condition pulse width</td>
<td>TPW:STO</td>
<td>—</td>
<td>1000</td>
<td>—</td>
<td>ns</td>
<td>25°C</td>
</tr>
<tr>
<td>Stop condition setup time</td>
<td>TSU:STO</td>
<td>—</td>
<td>200</td>
<td>—</td>
<td>ns</td>
<td>25°C</td>
</tr>
<tr>
<td>Setup time for high voltage</td>
<td>TSU:HH</td>
<td>—</td>
<td>800</td>
<td>—</td>
<td>ns</td>
<td>25°C</td>
</tr>
<tr>
<td>High voltage delay time</td>
<td>TDL:HH</td>
<td>—</td>
<td>800</td>
<td>—</td>
<td>ns</td>
<td>Delay time before the next clock, at 25°C</td>
</tr>
<tr>
<td>Data input setup time</td>
<td>TSU:DAT</td>
<td>—</td>
<td>450</td>
<td>—</td>
<td>ns</td>
<td>25°C</td>
</tr>
<tr>
<td>Data input hold time</td>
<td>THD:DAT</td>
<td>—</td>
<td>1.2</td>
<td>—</td>
<td>µs</td>
<td>25°C</td>
</tr>
<tr>
<td>Output valid from clock</td>
<td>TAA</td>
<td>—</td>
<td>200</td>
<td>—</td>
<td>ns</td>
<td>25°C</td>
</tr>
<tr>
<td>Data retention</td>
<td></td>
<td>—</td>
<td>200</td>
<td>—</td>
<td>Years</td>
<td>For T &lt; 120°C</td>
</tr>
</tbody>
</table>
### TABLE 1-4: PAD COORDINATES (MICRONS)

<table>
<thead>
<tr>
<th>Pad Name</th>
<th>Lower Left X</th>
<th>Lower Left Y</th>
<th>Upper Right X</th>
<th>Upper Right Y</th>
<th>Passivation Openings</th>
<th>Pad Center X</th>
<th>Pad Center Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ant. A</td>
<td>-610.0</td>
<td>489.2</td>
<td>-521.0</td>
<td>578.2</td>
<td>89 89</td>
<td>-565.5</td>
<td>533.7</td>
</tr>
<tr>
<td>Ant. B</td>
<td>-605.0</td>
<td>-579.8</td>
<td>-516.0</td>
<td>-490.8</td>
<td>89 89</td>
<td>-560.5</td>
<td>-535.3</td>
</tr>
<tr>
<td>VSS</td>
<td>-605.0</td>
<td>-58.2</td>
<td>-516.0</td>
<td>30.8</td>
<td>89 89</td>
<td>-560.5</td>
<td>-13.7</td>
</tr>
<tr>
<td>VDD</td>
<td>463.4</td>
<td>-181.4</td>
<td>552.4</td>
<td>-92.4</td>
<td>89 89</td>
<td>507.9</td>
<td>-136.9</td>
</tr>
<tr>
<td>CLK</td>
<td>463.4</td>
<td>496.8</td>
<td>552.4</td>
<td>585.8</td>
<td>89 89</td>
<td>507.9</td>
<td>541.3</td>
</tr>
<tr>
<td>VPRG</td>
<td>463.4</td>
<td>157.6</td>
<td>552.4</td>
<td>246.6</td>
<td>89 89</td>
<td>507.9</td>
<td>202.1</td>
</tr>
</tbody>
</table>

**Note 1:** All coordinates are referenced from the center of the die. The minimum distance between pads (edge to edge) is 10 mil.

**Note 2:** Die Size = 1.417 mm x 1.513 mm = 1417 µm x 1513 µm = 55.79 mil x 59.57 mil

---

### FIGURE 1-1: MCRF355/360 DIE LAYOUT

All units in the layout are µm.

Die Size before Saw: 1.417 mm x 1.513 mm = 1417 µm x 1513 µm = 55.79 mil x 59.57 mil

Bond Pad Size: 89 µm x 89 µm = 0.089 mm x 0.089 mm = 3.5 mil x 3.5 mil
### TABLE 1-5: DIE MECHANICAL DIMENSIONS

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Unit</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bond pad opening</td>
<td>—</td>
<td>3.5 x 3.5</td>
<td>89 x 89</td>
<td>mil</td>
<td>(Note 1, Note 2)</td>
</tr>
<tr>
<td>Die backgrind thickness</td>
<td>—</td>
<td>8</td>
<td>—</td>
<td>mil</td>
<td>Sawed 8” wafer on frame (option = WF)</td>
</tr>
<tr>
<td></td>
<td>—</td>
<td>177.8</td>
<td>—</td>
<td>µm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>—</td>
<td>11</td>
<td>—</td>
<td>mil</td>
<td>• Bumped, sawed 8” wafer on frame (option = WFB)</td>
</tr>
<tr>
<td></td>
<td>—</td>
<td>279.4</td>
<td>—</td>
<td>µm</td>
<td>• Unsawed wafer (option = W)</td>
</tr>
<tr>
<td></td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>mil</td>
<td>• Unsawed 8” bumped wafer (option = WB)</td>
</tr>
<tr>
<td>Die backgrind thickness tolerance</td>
<td>—</td>
<td>—</td>
<td>±1</td>
<td>±25.4 µm</td>
<td>(Note 3)</td>
</tr>
<tr>
<td>Die passivation thickness (multilayer)</td>
<td>—</td>
<td>0.9050</td>
<td>—</td>
<td>µm</td>
<td>(Note 5)</td>
</tr>
<tr>
<td>Die Size:</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>mil</td>
<td>—</td>
</tr>
<tr>
<td>Die size X*Y before saw (step size)</td>
<td>—</td>
<td>55.79 x 59.57</td>
<td>—</td>
<td>mil</td>
<td>—</td>
</tr>
<tr>
<td>Die size X*Y after saw</td>
<td>—</td>
<td>54.22 x 58</td>
<td>—</td>
<td>mil</td>
<td>—</td>
</tr>
</tbody>
</table>

**Note:**
1. The bond pad size is that of the passivation opening. The metal overlaps the bond pad passivation by at least 0.1 mil.
2. Metal Pad Composition is 98.5% Aluminum with 1% Si and 0.5% Cu.
3. As the die thickness decreases, susceptibility to cracking increases. It is recommended that the die be as thick as the application will allow.
4. This specification is not tested. For design guidance only.
5. The Die Passivation thickness can vary by device depending on the mask set used.
6. The conversion rate is 25.4 µm/mil.

**Notice:** Extreme care is urged in the handling and assembly of die products since they are susceptible to mechanical and electrostatic damage.

### TABLE 1-6: PAD FUNCTION TABLE

<table>
<thead>
<tr>
<th>Name</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ant. A</td>
<td>Connected to external resonant circuit, (Note)</td>
</tr>
<tr>
<td>Ant. B</td>
<td>Connected to external resonant circuit, (Note)</td>
</tr>
<tr>
<td>Vss</td>
<td>Connected to external resonant circuit. Device ground during test mode, (Note)</td>
</tr>
<tr>
<td>VDD</td>
<td>DC voltage supply for programming</td>
</tr>
<tr>
<td>CLK</td>
<td>Main clock pulse for device</td>
</tr>
<tr>
<td>VPRG</td>
<td>Input/Output for programming and read test</td>
</tr>
</tbody>
</table>

**Note:** See Figure 3-1 for the connection with external resonant circuit.
2.0 FUNCTIONAL DESCRIPTION

The device contains three major sections: (1) Analog Front-End, (2) Controller Logic and (3) Memory. Figure 2-1 shows the block diagram of the device.

2.1 Analog Front-End Section

This section includes power supply, power-on-reset, and data modulation circuits.

2.1.1 POWER SUPPLY

The power supply circuit generates DC voltage (VDD) by rectifying induced RF coil voltage. The power supply circuit includes high-voltage clamping diodes to prevent excessive voltage development across the antenna coil.

2.1.2 POWER-ON-RESET (POR)

This circuit generates a power-on-reset when the tag first enters the reader field. The reset releases when sufficient power has developed on the VDD regulator to allow for correct operation.

2.1.3 DATA MODULATION

The data modulation circuit consists of a modulation transistor and an external LC resonant circuit. The external circuit must be tuned to the carrier frequency of the reader (i.e., 13.56 MHz) for maximum performance.

The modulation transistor is placed between antenna B and Vss pads and has small turn-on resistance (RM). This small turn-on resistance shorts the external circuit between the antenna B and Vss pads as it turns on. The transistor turns on during the “High” period of the modulation data and turns off during the “Low” period.

When the transistor is turned off, the resonant circuit resonates at the carrier frequency. Therefore, the external circuit develops maximum voltage across it. This condition is called uncoaking (tuned). When the transistor is turned on, its low turn-on resistance shorts the external circuit, and therefore the circuit no longer resonates at the carrier frequency. The voltage across the external circuit is minimized. This condition is called cloaking (detuned).

The device transmits data by cloaking and uncoaking based on the on/off condition of the modulation transistor. Therefore, with the 70 kHz - Manchester format, the data bit “0” will be sent by cloaking (detuned) and uncoaking (tuned) the device for 7 ms each. Similarly, the data bit “1” will be sent by uncoaking (tuned) and cloaking (tuned) the device for 7 ms each. See Figure 2-2 for the Manchester waveform.

FIGURE 2-1: BLOCK DIAGRAM
2.2 Controller Logic Section

2.2.1 CLOCK PULSE GENERATOR

This circuit generates a clock pulse (CLK). The clock pulse is generated by an on-board time-base oscillator. The clock pulse is used for baud rate timing, data modulation rate, etc.

2.2.2 MODULATION LOGIC

This logic acts upon the serial data (154 bits) being read from the memory array. The data is then encoded into Manchester format. The encoded data is then fed to the modulation transistor in the Analog Front-End section. The Manchester code waveform is shown in Figure 2-2.

2.2.3 SLEEP TIMER

This circuit generates a sleep time (100 ms ± 50%) for the anti-collision feature. During this sleep time (TOFF), the modulation transistor remains in a turned-on condition (cloaked) which detunes the LC resonant circuit.

2.2.4 READ/WRITE LOGIC

This logic controls the reading and programming of the memory array.

---

**FIGURE 2-2: CODE WAVEFORMS**

<table>
<thead>
<tr>
<th>SIGNAL</th>
<th>WAVEFORM</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>1 0 1 1 0 0 1 1 0 1 0</td>
<td>Digital Data</td>
</tr>
<tr>
<td>CLK</td>
<td></td>
<td>Internal Clock Signal</td>
</tr>
<tr>
<td>BIPHASE-L (Manchester)</td>
<td></td>
<td>Biphase – Level (Split Phase)</td>
</tr>
<tr>
<td>NRZ-L (Reference only)</td>
<td></td>
<td>Non-Return to Zero – Level</td>
</tr>
</tbody>
</table>

**Note:** The CLK and NRZ-L signals are shown for reference only. BIPHASE-L (Manchester) is the device output.
3.0 RESONANT CIRCUIT

The MCRF355 requires external coils and capacitor in order to resonate at the carrier frequency of the reader. About one-fourth ($\frac{1}{4}$) of the turns of the coil should be connected between antenna B and Vss; remaining turns should be connected between antenna A and B pads. The MCRF360 includes a 100 pF internal resonant capacitor. Therefore, the device needs only external coils for the resonant circuit. For example, the device needs 1.377 $\mu$H of inductance for the carrier frequency = 13.56 MHz.

Figures 3-1 (a) and (b) show possible configurations of the external circuits for the MCRF355. In Figure 3-1 (a), two external antenna coils (L1 and L2) in series and a capacitor that is connected across the two inductors form a parallel resonant circuit to pick up incoming RF signals and also to send modulated signals to the reader. The first coil (L1) is connected between antenna A and B pads. The second coil (L2) is connected between antenna B and Vss pads. The capacitor is connected between antenna A and Vss pads. Figure 3-1 (b) shows the resonant circuit formed by two capacitors (C1 and C2) and one inductor.

Figure 3-1(c) shows a configuration of an external circuit for the MCRF360. By utilizing the 100 pF internal resonant capacitor, only L1 and L2 are needed for the external circuit.

**FIGURE 3-1: CONFIGURATION OF EXTERNAL RESONANT CIRCUITS**

![Diagram of MCRF355 resonant circuit](image)

![Diagram of MCRF355 resonant circuit](image)

![Diagram of MCRF360 resonant circuit](image)
4.0 DEVICE PROGRAMMING

MCRF355/360 is a reprogrammable device in contact mode. The device has 154 bits of reprogrammable memory. It can be programmed in the following procedure. (A programmer, part number PG103003, is also available from Microchip.)

4.1 Programming Logic

Programming logic is enabled by applying power to the device and clocking the device via the CLK pad while loading the mode code via the VPRG pad (See Examples 4-1 through 4-4 for test definitions). Both the CLK and the VPRG pads have internal pull-down resistors.

4.2 Pin Configuration

Connect antenna A, B, and Vss pads to ground.

4.3 Pin Timing

1. Apply VDDT voltage to VDD. Leave VSS, CLK, and VPRG at ground.
2. Load mode code into the VPRG pad. The VPRG is sampled at CLK low to high edge.
3. The above mode function (3.2.2) will be executed when the last bit of code is entered.
4. Power the device off (VDD = VSS) to exit programming mode.
5. An alternative method to exit the programming mode is to bring CLK logic “High” before VPRG to VHH (high voltage).
6. Any programming mode can be entered after exiting the current function.

4.4 Programming Mode

1. Erase EE Code: 0111010100
2. Program EE Code: 0111010010
3. Read EE Code: 0111010110

Note: ‘0’ means logic “Low” (VIL) and ‘1’ means logic “High” (VIH).

4.5 Signal Timing

Examples 4-1 through 4-4 show the timing sequence for programming and reading of the device.

EXAMPLE 4-1: PROGRAMMING MODE 1: ERASE EE

<table>
<thead>
<tr>
<th>CLK Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLK</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VPRG</td>
<td>VHH...</td>
<td>VIH...</td>
<td>VIH...</td>
<td>TWC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Erases entire array to a ‘1’ state between CLK and Number 11 and 12.
EXAMPLE 4-2: PROGRAMMING MODE 2: PROGRAM EE

| CLK Number | 1 | 2 | ... | 5 | 6 | 7 | 8 | 9 | 10 | 11 | ... | 165 |
|------------|---|---|-----|---|---|---|---|---|---|----|-----|-----|-----|

CLK

VPRG

VIL

VIL

VIH...

VHH...

Pulse high to program bit to “0”

Leave low to leave bit at “1”

TWC

TWC

Program bit #0 … Program bit #153

Note: Pulsing VPRG to VHH for the bit programming time while holding the CLK low programs the bit to a ‘0’.

EXAMPLE 4-3: PROGRAMMING MODE 3: READ EE

CLK Number

CLK

VPRG

VIL

VIL

VIH...

bit #0 data

bit #1 data

bit #153 data

Turn off programmer drive during CLK high

MCRF355 can drive VPRG.

EXAMPLE 4-4: TIMING DATA

CLK

VPRG

VHH

VIH...

VIL

THIGH

TLOW

THD:DAT

VHH

VIH

VIL

TAA

TSU:DAT

TSU:HH

TDL:HH

TPW:STO

TSU:STO

TWC
MCRF355/360 GUIDE PRODUCT IDENTIFICATION SYSTEM

To order or obtain information, (e.g., on pricing or delivery), please refer to the factory or the listed sales office.

| Package: | WF = Sawed wafer on frame (8 mil backgrind) |
|          | WFB = Bumped, sawed wafer on frame (8 mil backgrind) |
|          | W = Wafer (11 mil backgrind) |
|          | WB = Bumped wafer (11 mil backgrind) |
|          | S = Dice in wafer pack |
|          | SB = Bumped die in wafer pack |
|          | SN = 150 mil SOIC |
|          | P = PDIP |

| Temperature Range: | -20°C to +70°C |

| Part Number: | MCRF355 = 13.56 MHz Anti-Collision device |
|             | MCRF360 = 13.56 MHz Anti-Collision device with 100 pF of on-chip resonance capacitance |

Sales and Support

Data Sheets
Products supported by a preliminary Data Sheet may have an errata sheet describing minor operational differences and recommended workarounds. To determine if an errata sheet exists for a particular device, please contact one of the following:

1. Your local Microchip sales office
2. The Microchip Corporate Literature Center U.S. FAX: (480) 792-7277
3. The Microchip Worldwide Site (www.microchip.com)

Please specify which device, revision of silicon and Data Sheet (include Literature #) you are using.

New Customer Notification System
Register on our web site (www.microchip.com/cn) to receive the most current information on our products.
**Microchip Development Kit Sample Format for the MCRF355/360 Devices**

<table>
<thead>
<tr>
<th>Header</th>
<th>13 Bytes of User Data</th>
<th>16-Bit Checksum</th>
</tr>
</thead>
<tbody>
<tr>
<td>11111111 0</td>
<td>Customer Number 0</td>
<td>Byte 13 0</td>
</tr>
</tbody>
</table>

- 9 bit header
- 8 bit customer number
- 104 bits (13 x 8) of user data
- 17 bits of zeros between each byte, header, and checksum
- 16 bits of checksum

**Total:** 154 bits

**Notes:**

- Users can program all 154 bits of the MCRF355/360. The array can be programmed in any custom format and with any combination of bits.
- The format presented here is used for Microchip microID™ Development System (DV103003) and can be ordered as production material with a unique customer number.
- See TB032 for information on ordering custom programmed production material.
- The Microchip Development System (DV103003) uses nine 1’s (111111111) as header.
- The preprogrammed tag samples in the development kit have hex 11 (= 0001 0001) as the customer number.
- For the development system, users can program the customer number (1 byte) plus the 13 bytes of user data, or they can deselect the “Microchip Format” option in the MicroID™ RFLAB and program all 154 bits in any format.
- When users program the samples using the MicroID™ RFLAB, the RFLAB calculates the checksum (2 bytes) automatically by adding up all 14 bytes (customer number + 13 bytes of user data), and put into the checksum field in the device memory. See Example 1 for details.
- When the programmed tag is energized by the reader field, the tag outputs all 154 bits of data.
- When the demo reader detects data from the tag, it reports the 14 bytes of the data (customer number plus 13 bytes of user data) to the host computer if the header and checksum are correct. The reader does not send the header and checksum to the host computer.
- The “MicroID™ RFLab” or a simple terminal program such as “terminal.exe” can be used to read the reader’s output (28 hex digits) on the host computer.
- When the demo reader is used in the terminal mode (terminal.exe), the tag’s data appear after the first two dummy ASCII characters (GG). See Example 2 for details.

**EXAMPLE-2: CHECKSUM**

| Checksum (XXXXXXXX XXXXXXXXXX) = Byte 1 + Byte 2 + ......+ Byte 13 + Customer Number (1 byte) |

**EXAMPLE-3: READER’S OUTPUT IN TERMINAL MODE (“TERMINAL.EXE”)**

The demo reader outputs GG+28 hex digits, i.e., GG 12345678901234567890ABCDEFGF.
The first two ASCII characters (GG) are dummy characters.
The tag’s data are the next 28 hex digits (112 bits) after the first two ASCII characters (GG).
INTRODUCTION

The MCRF355 and MCRF360 are 13.56 MHz RF tags which can be contact programmed. The contact programming of the device can be performed by the user or factory-programmed by Microchip Technology, Inc. upon customer request. All 154 bits of data may be programmed in any format or pattern defined by the customer.

For factory programming, ID codes and series numbers must be supplied by the customer or an algorithm may be specified by the customer. This technical brief describes only the case in which identification codes (ID) and series numbers are supplied. The customer may supply the ID codes and series numbers on floppy disk or via email. The codes must conform to the Serialized Quick Turn Programming (SQTPSM) format below:

FILE SPECIFICATION

SQTP codes supplied to Microchip must comply with the following format:

The ID code file is a plain ASCII text file from floppy disk or email (no headers).

If code files are compressed, they should be self-extracting files.

The code files are used in alphabetical order of their file names (including letters and numbers).

Used (i.e., programmed) code files are discarded by Microchip after use.

Each line of the code file must contain one ID code for one IC.

The code is in hexadecimal format.

The code line is exactly 154 bits (39 hex characters, where the last 2 bits of the last character are don’t cares).

Each line must end with a carriage return.

Each hexadecimal ID code must be preceded by a decimal series number.

The series number must be unique and ascending to avoid double programming.

The series numbers of two consecutive files must also count up for proper linking.

FIGURE 1: EXAMPLE OF TWO SEQUENTIAL CODE FILES

<table>
<thead>
<tr>
<th>Filename</th>
<th>Code File</th>
</tr>
</thead>
<tbody>
<tr>
<td>FILE0000.TXT</td>
<td>00001 A14953D88C0A01F261234567890ABCDEF0123457</td>
</tr>
<tr>
<td></td>
<td>00002 C1F5308B492A781234567890ABCDEF012345B</td>
</tr>
<tr>
<td></td>
<td>00003 81FAC59981200B71234567890ABCDEF012345F</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Last Code</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Series Number</th>
<th>ID Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>12345</td>
<td>92782566DCAFE87561234567890ABCDEF987654B</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Filename</th>
<th>Code File</th>
</tr>
</thead>
<tbody>
<tr>
<td>FILE0001.TXT</td>
<td>12346 EA43786937DCFB871234567890ABCDEF987654B</td>
</tr>
<tr>
<td></td>
<td>12347 459724FC4A87ED241234567890ABCDEF9876547</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Last Code
Carriage Return
Space Necessary

If code files are compressed, they should be self-extracting files.
FEATURES

- Contactless read and write
- 1024 bits (32 blocks) of total memory
- 928 bits of user programmable memory
- User controlled write-protection of each block
- Manchester coding protocol with CRC for reading
- 70 kHz data rate
- RF field gaps and 1-of-16 PPM with CRC for writing
- High speed deterministic anti-collision algorithm for reading and writing virtually any number of tags in the same RF field
- Three pads for external antenna circuit (MCRF450, 451, 455)
- Two pads for external antenna (MCRF452)
- Internal resonance capacitors (MCRF451, 452, 455)
- Factory programmed unique 32-bit tag ID
- Interrogator talks first (ITF) or tag talks first (TTF) operation
- Fast and normal modes for data transmission
- Anti-tearing feature for secure write transactions
- Full 32-bit EAS support
- Very low power CMOS design
- Die, wafer, bumped wafer, PDIP or SOIC package options
- Asynchronous operation for low power/extended read range

PACKAGE TYPES

<table>
<thead>
<tr>
<th>PDIP/SOIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANT. A 1</td>
</tr>
<tr>
<td>NC 2</td>
</tr>
<tr>
<td>ANT. B 3</td>
</tr>
<tr>
<td>CLK 4</td>
</tr>
<tr>
<td>8 Vdd</td>
</tr>
<tr>
<td>7 Fclk</td>
</tr>
<tr>
<td>6 NC</td>
</tr>
<tr>
<td>5 Vss</td>
</tr>
</tbody>
</table>

DESCRIPTION

The MCRF45X is a contactless read/write passive RFID device that is optimized for 13.56 MHz RF carrier signal. The device needs an external LC resonant circuit to communicate with interrogator wirelessly. The device is powered remotely by rectifying an RF signal that is transmitted from the interrogator, and transmits or updates its contents of memory based on commands from the interrogator.

The device is engineered to be used effectively for item level tagging applications such as retail and inventory management, where a large volume of tags are read and written in the same interrogator field.

APPLICATION

The device contains 32 blocks of EEPROM memory. Each block consists of 32 bits. The first three blocks (B0 - B2: 96 bits) are allocated for device operation, the remaining 29 blocks (B3 - B29: 928 bits) are for user data. The 928 (B3 - B31) user bits are contactlessly writable block-wise by interrogator commands. All blocks except bits 30 and 31 in block 0 are write-protectable.
The device has two operational modes depending on the conditions of talk first (TF) and fast read (FR) bits. These modes are: "tag talks first" (TTF) and "interrogator talks first" (ITF) modes. The device operates in TTF mode if both TF and FR bits are set. In this mode, the device transmits its fast read response data (96 bits in default) as soon as it is energized, and waits for the next commands. The device operates in the "interrogator talks first" mode, if the TF bit is cleared. In this mode, the device requires an interrogator command before it sends any data.

The device uses an internal oscillator for data timing of the read operation. The data rate for reading is 70 kHz and uses Manchester format. The communication between the interrogator and the device takes place asynchronously.

The interrogator sends commands to the device by amplitude modulating its RF carrier signal. 1-of-16 Pulse Position Modulation (PPM) and specially timed gap pulses are used for the modulation of the carrier signal. The device includes a detection circuit to detect these interrogator commands.

To enhance the detection accuracy in the device, the interrogator sends a time reference signal (time calibration pulse) to the device followed by the command and programming data. The time reference signal is used to calibrate timing of the internal decoder of the device.

Depending on the metal mask options, the device includes internal resonant capacitor between antenna A and Vss pads: (a) no internal resonant capacitor for the MCRF450, (b) 100 pF for the MCRF451, (c) two 50 pF in series (25 pF in total) for the MCRF452 and (d) 50 pF for the MCRF455. The internal resonant capacitor for each metal mask option is shown in Figures 1-2 through 1-5.

The MCRF450 needs an external LC resonant circuit that is connected between antenna A, antenna B, and Vss pads. See Figure 1-2 for the external circuit configuration. The MCRF452 needs a single external antenna coil only between antenna A and Vss pads as shown in Figure 1-4.

This external circuit along with the internal resonant capacitor must be tuned to the carrier frequency of the interrogator for maximum performance.

When a tag (device with the external LC resonant circuit) is brought to the interrogator’s RF field, it develops an RF voltage across the external circuit. The device rectifies the RF voltage and develops a DC voltage (Vdd). The device becomes functional as soon as Vdd reaches the operating voltage level.

The device sends data to the interrogator by turning on/off the internal modulation transistor. This internal modulation transistor is located between antenna B and Vss. The modulation transistor has very small turn-on resistance between Drain (antenna B) and Source (Vss) terminals during its turn-on time.

When the modulation transistor turns-on, the resonant circuit component between antenna B and Vss, that is in parallel with the modulation transistor, is shorted due to the low turn-on resistance. This results in a change of the LC value of the circuit. As a result, the circuit no longer resonates at the carrier frequency of the interrogator. Therefore, the voltage across the circuit is minimized. This condition is called cloaking.

When the modulation transistor turns-off, the circuit resonates at the carrier frequency of the interrogator, and develops maximum voltage. This condition is called uncloaking. Therefore, the data is sent to the interrogator by turning-on (cloaking) and off (uncloaking) the modulation transistor.

Therefore, the voltage amplitude of the carrier signal across the LC resonant circuit changes depending on the amplitude of modulation data (cloaking for logic "High" level and uncloaking for logic "Low" level). This is called amplitude modulation signal. The receiver channel in the Interrogator detects this amplitude modulation signal and reconstructs the modulation data for decoding.

The device includes a unique anti-collision algorithm to be read or written effectively in multiple tag environments. To minimize data collision, the algorithm utilizes time division multiplexing of the device response. Therefore, each device can communicate with the interrogator in a different time slot. The devices in the interrogator’s RF field remain in a non-modulating condition if they are not in the given time slot. This enables the interrogator to communicate with the multiple devices one at a time without data collision. The details of the algorithm are described in Section 4.0.

To enhance data integrity for writing, the device includes an anti-tearing feature. This anti-tearing feature provides verification of data integrity for incomplete write cycles due to failed communication from the interrogator to the device during the write sequences.
1.0 ELECTRICAL CHARACTERISTICS

TABLE 1-1: ABSOLUTE RATINGS

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Symbol</th>
<th>Min.</th>
<th>Max.</th>
<th>Units</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coil current into coil pad</td>
<td>IPP_AC</td>
<td>—</td>
<td>40</td>
<td>mA</td>
<td>Peak-to-Peak coil current</td>
</tr>
<tr>
<td>Maximum power dissipation</td>
<td>PMPD</td>
<td>—</td>
<td>0.5</td>
<td>W</td>
<td>—</td>
</tr>
<tr>
<td>Ambient temperature with power applied</td>
<td>TAMBD</td>
<td>-40</td>
<td>125</td>
<td>°C</td>
<td>—</td>
</tr>
<tr>
<td>Assembly temperature</td>
<td>TAMAD</td>
<td>—</td>
<td>300</td>
<td>°C</td>
<td>&lt; 10 Sec</td>
</tr>
<tr>
<td>Storage temperature</td>
<td>TSTORE</td>
<td>-65</td>
<td>150</td>
<td>°C</td>
<td>—</td>
</tr>
</tbody>
</table>

**Note:** Stresses above those listed under “Maximum ratings” may cause permanent damage to the device. This is a stress rating only and functional operation of the device at those or any other conditions above those indicated in the operational listings of this specification is not implied. Exposure to maximum rating conditions for extended periods may affect device reliability.

TABLE 1-2: DC CHARACTERISTICS

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Symbol</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Units</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>All parameters apply across the specified operating ranges, unless otherwise noted.</td>
<td>Commercial (C): TAMBD = -20°C to 70°C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading voltage</td>
<td>VDDR</td>
<td>2.8</td>
<td>—</td>
<td>—</td>
<td>V</td>
<td>VDD voltage for reading at 25°C</td>
</tr>
<tr>
<td>Operating current in normal mode</td>
<td>IOPER_N</td>
<td>—</td>
<td>20</td>
<td>—</td>
<td>µA</td>
<td>VDD = 2.8V during reading at 25°C</td>
</tr>
<tr>
<td>Operating current in fast mode</td>
<td>IOPER_F</td>
<td>—</td>
<td>45</td>
<td>—</td>
<td>µA</td>
<td>VDD = 2.8V during reading at 25°C</td>
</tr>
<tr>
<td>Writing current</td>
<td>IWRITE</td>
<td>—</td>
<td>130</td>
<td>—</td>
<td>µA</td>
<td>At 25°C, VDD = 2.8V</td>
</tr>
<tr>
<td>Writing voltage</td>
<td>VWRITE</td>
<td>2.8</td>
<td>—</td>
<td>—</td>
<td>VDC</td>
<td>At 25 °C</td>
</tr>
<tr>
<td>Modulation resistance</td>
<td>RM</td>
<td>—</td>
<td>3</td>
<td>5</td>
<td>Ω</td>
<td>DC turn-on resistance between Drain and Source terminals of the modulation transistor at VDD = 2.8V</td>
</tr>
</tbody>
</table>
### TABLE 1-3: AC CHARACTERISTICS

All parameters apply across the specified operating ranges, unless otherwise noted.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Commercial (C): ( T_{\text{AMB}} = -20^\circ\text{C} ) to ( 70^\circ\text{C} )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parameters</strong></td>
<td><strong>Symbol</strong></td>
</tr>
<tr>
<td>Carrier frequency</td>
<td>( F_C )</td>
</tr>
<tr>
<td>Coil voltage during reading</td>
<td>( V_{PP_AC} )</td>
</tr>
<tr>
<td>Internal Resonant Capacitor</td>
<td>( C_{RES_100} )</td>
</tr>
<tr>
<td>Internal Resonant Capacitor</td>
<td>( C_{RES_2_50A} )</td>
</tr>
<tr>
<td>Internal Resonant Capacitor</td>
<td>( C_{RES_2_50B} )</td>
</tr>
<tr>
<td>Internal Resonant Capacitor</td>
<td>( C_{RES_50} )</td>
</tr>
<tr>
<td>Coil detuning voltage</td>
<td>( V_{DETUNE} )</td>
</tr>
<tr>
<td>Interrogator data (ITD) rate_normal</td>
<td>( \text{FITD_NORM} )</td>
</tr>
<tr>
<td>Interrogator data (ITD) rate_fast</td>
<td>( \text{FITD_FAST} )</td>
</tr>
<tr>
<td>Device data rate</td>
<td>( F_{DVD} )</td>
</tr>
<tr>
<td>Modulation depth of 1-of-16 PPM</td>
<td>( M_{DEPTH_PPM} )</td>
</tr>
<tr>
<td>Pulse width of 1-of-16 PPM for normal mode</td>
<td>( P_{WPPM_N} )</td>
</tr>
<tr>
<td>Pulse width of 1-of-16 PPM for fast mode</td>
<td>( P_{WPPM_F} )</td>
</tr>
<tr>
<td>Symbol width of 1-of-16 PPM for normal mode</td>
<td>( S_{WPPM_N} )</td>
</tr>
<tr>
<td>Symbol width of 1-of-16 PPM for fast mode</td>
<td>( S_{WPPM_F} )</td>
</tr>
<tr>
<td>Gap pulse width of Fast Read command</td>
<td>( G_{PW_FR} )</td>
</tr>
<tr>
<td>EEPROM (Memory) Writing Time</td>
<td>( T_{WRITE} )</td>
</tr>
<tr>
<td>Command Decode Time</td>
<td>( T_{\text{DECODE}} )</td>
</tr>
<tr>
<td>Time slot</td>
<td>( T_{\text{SLOT}} )</td>
</tr>
<tr>
<td>Listening Window</td>
<td>( T_{\text{LW}} )</td>
</tr>
<tr>
<td>Modulation depth of Fast Read command</td>
<td>( M_{DEPTH_FRR} )</td>
</tr>
<tr>
<td>Command Duration of Fast Read command (FRR and FRB)</td>
<td>( T_{\text{CMD_FRR}} )</td>
</tr>
</tbody>
</table>

**Note 1:** Not tested in production.
TABLE 1-3: AC CHARACTERISTICS

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Symbol</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Units</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input impedance A</td>
<td>Zin_A</td>
<td>—</td>
<td>TBD</td>
<td>—</td>
<td>Ω</td>
<td>Input impedance between antenna pad A and Vss, at 13.56 MHz with modulation transistor off (no external coils)</td>
</tr>
<tr>
<td>Input impedance B</td>
<td>Zin_B</td>
<td>—</td>
<td>TBD</td>
<td>—</td>
<td>Ω</td>
<td>Input impedance between antenna pad B and Vss, at 13.56 MHz with modulation transistor off (no external coils)</td>
</tr>
<tr>
<td>Data retention</td>
<td></td>
<td>200</td>
<td>—</td>
<td>—</td>
<td>Years</td>
<td>For T &lt; 120°C</td>
</tr>
<tr>
<td>Endurance</td>
<td></td>
<td>1</td>
<td>—</td>
<td>—</td>
<td>Million Cycles</td>
<td>At 25°C</td>
</tr>
</tbody>
</table>

Note 1: Not tested in production

TABLE 1-4: PAD COORDINATES (MICRONS)

<table>
<thead>
<tr>
<th>Pad Name</th>
<th>Lower Left X</th>
<th>Lower Left Y</th>
<th>Upper Right X</th>
<th>Upper Right Y</th>
<th>Passivation Openings</th>
<th>Pad Center X</th>
<th>Pad Center Y</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pad Width</td>
<td>Pad Height</td>
<td></td>
</tr>
<tr>
<td>Ant. Pad A</td>
<td>-853.50</td>
<td>-953.90</td>
<td>-764.50</td>
<td>-864.90</td>
<td>89.00</td>
<td>89.00</td>
<td>-809.00</td>
</tr>
<tr>
<td>Ant. Pad B</td>
<td>759.50</td>
<td>-955.50</td>
<td>848.50</td>
<td>-866.50</td>
<td>89.00</td>
<td>89.00</td>
<td>804.00</td>
</tr>
<tr>
<td>Vss</td>
<td>769.10</td>
<td>939.70</td>
<td>858.10</td>
<td>1028.70</td>
<td>89.00</td>
<td>89.00</td>
<td>813.60</td>
</tr>
<tr>
<td>Vdd</td>
<td>-839.50</td>
<td>83.70</td>
<td>-750.50</td>
<td>172.70</td>
<td>89.00</td>
<td>89.00</td>
<td>-795.00</td>
</tr>
<tr>
<td>CLK</td>
<td>721.10</td>
<td>116.00</td>
<td>810.10</td>
<td>205.00</td>
<td>89.00</td>
<td>89.00</td>
<td>765.60</td>
</tr>
<tr>
<td>FCLK</td>
<td>-821.50</td>
<td>872.50</td>
<td>-732.50</td>
<td>961.50</td>
<td>89.00</td>
<td>89.00</td>
<td>-777.00</td>
</tr>
</tbody>
</table>

Note 1: All coordinates are referenced from the center of the die. The minimum distance between pads (edge to edge) is 10 mil.

2: Unsawed die size = 74.96 mil x 89.15 mil.
### TABLE 1-5: DIE MECHANICAL DIMENSIONS

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Unit</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bond pad opening</td>
<td>—</td>
<td>3.5 x 3.5</td>
<td>—</td>
<td>mil</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>—</td>
<td>89 x 89</td>
<td>—</td>
<td>µm</td>
<td>—</td>
</tr>
<tr>
<td>Die backgrind thickness</td>
<td>—</td>
<td>8</td>
<td>—</td>
<td>mil</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>—</td>
<td>177.8</td>
<td>—</td>
<td>µm</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>—</td>
<td>11</td>
<td>—</td>
<td>mil</td>
<td>• Bumped, sawed 8” wafer on frame (option = WF) (Note 3)</td>
</tr>
<tr>
<td></td>
<td>—</td>
<td>279.4</td>
<td>—</td>
<td>µm</td>
<td>• Unsawed wafer (option = W)</td>
</tr>
<tr>
<td></td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>• Unsawed 8” bumped wafer (option = WB), (Note 3)</td>
</tr>
<tr>
<td>Die backgrind thickness tolerance</td>
<td>—</td>
<td>—</td>
<td>±1</td>
<td>mil</td>
<td>±25.4 mil</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>µm</td>
<td>Note 4</td>
</tr>
<tr>
<td>Die passivation thickness (multilayer)</td>
<td>—</td>
<td>0.9050</td>
<td>—</td>
<td>µm</td>
<td>Note 5</td>
</tr>
<tr>
<td>Die size X*Y before saw (step size)</td>
<td>—</td>
<td>74.96 x 89.15</td>
<td>—</td>
<td>mil</td>
<td>—</td>
</tr>
<tr>
<td>Die size X*Y after saw</td>
<td>—</td>
<td>73.39 x 87.58</td>
<td>—</td>
<td>mil</td>
<td>—</td>
</tr>
</tbody>
</table>

**Note 1:** The bond pad size is that of the passivation opening. The metal overlaps the bond pad passivation by at least 0.1 mil.

**Note 2:** Metal Pad Composition is 98.5% Aluminum with 1% Si and 0.5% Cu.

**Note 3:** As the die thickness decreases, susceptibility to cracking increases. It is recommended that the die be as thick as the application will allow.

**Note 4:** This specification is not tested. For design guidance only.

**Note 5:** The Die Passivation thickness can vary by device depending on the mask set used.

**Note 6:** The conversion rate is 25.4 µm/mil.

**Notice:** Extreme care is urged in the handling and assembly of die products since they are susceptible to mechanical and electrostatic damage.
Die Size before Saw: 1904.00 µm x 2264.4 µm = 1.904 mm x 2.2644 mm
= 74.96 mil x 89.15 mil

Bond Pad Size: 89 µm x 89 µm = 0.089 mm x 0.089 mm
= 3.5 mil x 3.5 mil

Note: Units in the coordinate are in µm.
See Table 1.5 for Die Mechanical Dimension.
TABLE 1-6: PAD FUNCTION TABLE

<table>
<thead>
<tr>
<th>Name</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ant. Pad A</td>
<td>Connected to antenna coil L1</td>
</tr>
<tr>
<td>Ant. Pad B</td>
<td>Connected to antenna coils L1 and L2 (450/451/455), NC for 452</td>
</tr>
<tr>
<td>Vss</td>
<td>Connected to antenna coil L2</td>
</tr>
<tr>
<td></td>
<td>Device ground during test mode, (Note 1)</td>
</tr>
<tr>
<td>NC</td>
<td>Not connected, (Note 2)</td>
</tr>
</tbody>
</table>

Note 1: Substrate = Vss

2: Leave floating or connect to Vss

Figure 1-2: MCRF450

- Ant. A
- NC
- NC
- L1
- C
- L2
- Ant. B
- NC
- Vss

L1: External Antenna Coil A
L2: External Antenna Coil B
C: External Capacitor
NC: Not connected
Note: Substrate = Vss

Figure 1-3: MCRF451

- Ant. A
- NC
- NC
- L1
- L2
- Ant. B
- NC
- Vss

Internal Resonant Capacitor (CRES_100) = 100 pF
L1: External Antenna Coil A
L2: External Antenna Coil B
NC: Not connected
Note: Substrate = Vss

Figure 1-4: MCRF452

- Ant. A
- NC
- NC
- L
- MCRF452
- Ant. B
- NC
- Vss

L1: External Antenna Coil A
L2: External Antenna Coil B
NC: Not connected
Note: Substrate = Vss

Internal Resonant Capacitor between Ant. A and Ant. B pads (CRES_2_50A) = 50 pF
Internal Resonant Capacitor between Ant. B and Vss pads (CRES_2_50B) = 50 pF
NC: Not connected
L: External Antenna Coil

Total Internal Resonant Capacitance = 25pF

Figure 1-5: MCRF455

- Ant. A
- NC
- NC
- L1
- L2
- MCRF455
- Ant. B
- NC
- Vss

L1: External Antenna Coil A
L2: External Antenna Coil B
NC: Not connected
Note: Substrate = Vss

Internal Resonant Capacitor (CRES_50) = 50 pF
L1: External Antenna Coil A
L2: External Antenna Coil B
NC: Not connected
Note: Substrate = Vss
2.0 BLOCK DIAGRAM

The device contains four major sections. They are: Analog Front-End, Detection/Encoding, Read/Write Anti-collision, and Memory sections. Figure 2-1 shows the block diagram of the device.

2.1 Analog Front-End Section

This section includes high and low voltage regulators, power-on-reset, 70 kHz clock generator, and modulation circuits.

2.1.1 HIGH AND LOW VOLTAGE REGULATOR

The high voltage circuit generates the programming voltage for the memory section. The low voltage circuit generates DC voltage (VDD) to operate the device.

2.1.2 POWER ON RESET (POR)

This circuit generates a power-on-reset voltage. The reset releases when sufficient power has been developed by the voltage regulator to allow for correct operation.

2.1.3 CLOCK GENERATOR

This circuit generates a clock (CLK). The main clock is generated by an on-board 70 kHz time base oscillator. This clock is used for all timing in the device except for the fast mode PPM decoding.

2.1.4 DATA MODULATION

The data modulation circuit consists of a modulation transistor and an resonant LC resonant circuit. The resonant circuit must be tuned to the carrier frequency of the interrogator (i.e., 13.56 MHz) for maximum performance.

The modulation transistor is placed between antenna B and Vss pads, and is designed to result in the turn-on resistance of less than four ohms (Rm). This small turn-on resistance shorts the resonant circuit component between the antenna B and Vss pads as it turns on. This results in a change of the resonant frequency of the resonant circuit. As a result, the resonant circuit becomes detuned to the carrier frequency of the interrogator. The voltage across the resonant circuit is minimized during this time. This condition is called “cloaking”.

The transistor, however releases the resonant circuit as it turns off. Therefore, the resonant circuit tunes to the carrier frequency of the interrogator again, and develops maximum voltage. This condition is called “uncloaking”.

The device transmits data by cloaking and uncloaking based on the on/off condition of the modulation transistor. Therefore, with the 70 kHz - Manchester format, the data bit “0” will be sent by cloaking and uncloaking the device for 7 μs each. Similarly, the data bit “1” will be sent by uncloaking and cloaking the device for 7 μs each. See Figure 4-1 for the Manchester waveform.

2.1.5 DETUNING CIRCUIT

The purpose of this circuit is to prevent excessive RF voltage across the resonant circuit.

This circuit monitors VDD and detunes the resonant circuit if the RF coil voltage exceeds the threshold limit (VDDETUNE) which is above the operating voltage of the device.
FIGURE 2-1:  BLOCK DIAGRAM

ANALOG FRONT-END SECTION  DETECTION/ENCODING SECTION  MEMORY SECTION

External Antenna Circuit

High/Low Voltage Regulator

To Memory (High Voltage)

Demodulator (Detector)

Memory Array

From High Voltage Regulator

Clock Generator

Fast Mode Oscillator

PPM Decoder

Registers

Power on Reset (POR)

To Anti-collision Command Controller (VDD)

CRC/Parity Generator and Checker

VDD

Main Clock

Data Encoder

Memory Array

High Voltage (HV)

Modulation

Registers

READ/WRITE ANTI-COLLISION SECTION

From HIGH Voltage (HV)

External Antenna Circuit

Anti-Collision Command Controller

To Anti-collision Command Controller

CRC/Parity Generator and Checker

Data Encoder

Time Slot Generator

(TC, TSMAX, Tag ID)

From High Voltage (HV)

Regulator

Demodulator (Detector)

From High Voltage (HV)

Anti-Collision Command Controller

To Memory (High Voltage)

FIGURE 2-2:  DATA WAVEFORM OF DEVICE

<table>
<thead>
<tr>
<th>SIGNAL</th>
<th>WAVEFORM</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>1 0 1 1 0 0 1 1 0 0</td>
<td>Digital Data</td>
</tr>
<tr>
<td>CLK</td>
<td></td>
<td>Internal Clock Signal</td>
</tr>
<tr>
<td>NRZ - L (Reference only)</td>
<td></td>
<td>Non-Return to Zero - Level</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“1” is represented by logic high level.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“0” is represented by logic low level.</td>
</tr>
<tr>
<td>BIPHASE - L (Manchester)</td>
<td></td>
<td>Biphas - Level (Split Phase)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A level change occurs at middle of every bit clock period.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“1” is represented by a high to low level change at midclock.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“0” is represented by a low to high level change at midclock.</td>
</tr>
</tbody>
</table>
3.0 DETECTION AND ENCODING SECTION

This section encodes data with the Manchester format and also detects commands from the interrogator.

3.1 Demodulator (Detector)

This circuit demodulates the interrogator commands, and sends them to the Pulse Position Modulation (PPM) decoder.

3.2 Fast Mode Oscillator

This oscillator generates a clock that is used for decoding fast mode commands.

3.3 PPM Signal Decoder

This section decodes the PPM signals, and sends the results to both the command decoder and CRC/parity checker.

3.4 Command Decoder

This section decodes the interrogator commands and sends the results to the anti-collision/command controller.

3.5 CRC/Parity Generator and Checker

This section generates CRC and parity bits for transmitting and receiving data. The device utilizes a 16-bit cyclic redundancy code (CRC) for error detection. Its polynomial and initial values are:

CRC Polynomial: $X^{16} + X^{12} + X^{5} + X^0$

Initial Value: $FFFF$

This polynomial is also known as CRC CCITT (Consultative Committee for International Telegraph and Telephone). The interrogator also uses the same CRC for data processing. The device uses the CRC in the following ways:

1. **Normal case:** The interrogator will send a write command with CRC. When the device receives the command, it checks the CRC prior to any processing. If it is a correct CRC, the device programs the block data and also stores the CRC in the EEPROM. As soon as the data is written in the memory, both the programmed data and stored CRC (SCRC) are sent back to the interrogator as a verification. The device also sends both the programmed data and stored CRC (SCRC) when as a response to the read command.

   If the CRC is incorrect, the device ignores the incoming message (does not respond to the interrogator) and waits for the next command with a correct CRC.

2. **Special Case 1:** When reading block 0 or 2, a calculated CRC (CCRC) is sent. This is because both the TF and FR bits in the block 0 are non-write-protectable while the rest of the bits in the block are write-protectable. This means the stored CRC (SCRC) in the block no longer represents the CRC of the block data if only the TF or the FR bit is reprogrammed. This is also true for block 2 which is a write-protection block. The write-protected bit cannot be reprogrammed once it has been written. Therefore, the stored CRC in these blocks (0 and 2) are not used. Instead, the device calculates the current CRC of the block and sends it to the interrogator.

3. **Special Case 2:** For the Fast Read (FR) response (this is the device response to an FRR command), bits 0-15 (FRR_CRC) in block 0 are sent as the CRC of the fast read field (FRF: blocks 3-5). See Table 4-3 for device responses.

3.6 Data Encoder

This section multiplexes serial data, encodes it into Manchester format, and sends it to the modulation circuit. See Figure 2-2 for the Manchester waveform.
4.0 READ/WRITE ANTI-COLLISION LOGIC

This section includes the anti-collision algorithm of the device, and consists of the anti-collision/command controller, the time slot counter, and the time slot generator.

4.1 Description of Algorithm

The read and write anti-collision algorithm is based on time division multiplexing of tag responses. Each device is allowed to communicate with the interrogator in its time slot only. When not in its assigned time slot, the device remains in a non-modulating condition. This enables the interrogator to communicate with other devices in the same interrogator field with fewer chances of data collision.

Figure 4-1 shows the anti-collision algorithm flowchart, which consists of four control loops. They are: Detection, Processing, Sleeping, and Reactivation loops. All devices in the interrogator’s RF field are controlled by five different commands and internal control flags.

The interrogator commands are:

1. Fast Read Request (FRR): If the TF bit of the device is cleared, then it will respond to only this command from the interrogator. This command consists of five specially timed gap pulses. See Figs. 4-3 to 4-8. The position of the five gap pulses in the given time span (1.575 ms) determines the parameters of the command. The command has three parameters: TCMAX, TSMAX, and Data transmission speed. The details of these parameters will be discussed in the following sections. If the device receives the FRR command, it sends the fast read (FR) response (96 bits in default) and then listens for 1 ms (TLW) for a matching code from the interrogator.

2. Fast Read Bypass (FRB): This command is used in the Reactivation loop. This command is only applicable to a device with the fast read bit (FR: bit 31 in block 0) cleared. The device responds with 64 bits of data which includes block 1 data (32-bit Tag ID), and then listens for 1 ms (TLW) for a matching code from the interrogator. The command structure is the same as the FRR command: Five specially timed gap pulses (1.575 ms). The command parameter (see Figure 4-8) determines the data rate (normal speed or fast speed) of subsequent interrogator commands.

3. Matching Code 1 (MC1): This command consists of time calibration pulses (TCP) followed by 1-of-16 PPM signals. It is used when the device does not need any further processing. This MC1 command causes a device which is in the Detection loop to enter the Sleeping loop.

4. Matching Code 2 (MC2): The command structure is the same as MC1: TCP followed by 1-of-16 PPM signals. The command is used when the device needs further processing (read/write). The device enters the Processing Loop if it receives this command in the Detection Loop.

The matching code (MC1 and MC2) command consists of 12 bits (or 3 symbols). The first 8 bits (or the first two symbols) are selected from the 32-bit Tag ID. The next 4 bits (or the 3rd symbol) determine the matching code type (3 bits) and a parity bit (see Section 4.2.3.6). The command lasts for about 11.2 ms including the time calibration pulses.

5. End Process (EP): This command consists of the time reference pulses followed by 1-of-16 PPM signals. The EP command causes a device to exit the Processing loop and enter the Sleeping loop.

4.1.1 DETECTION LOOP

The device can enter this loop in two ways if the fast read (FR: bit 31 of block 0) bit is set. The two ways depend on the condition of the talk-first (TF: bit 30 of block 0) bit. They are: (1) If the TF bit is cleared, the device enters this loop and waits for a fast read request (FRR) command. This is called "interrogator talks first" (ITF) mode. (2) If the TF bit is set, the device enters this loop by transmitting the fast read (FR) response without waiting for an FRR command. This case (2) is called "tag talks first" (TTF) mode.

For case (1) above, the parameters of the FRR are:

(a). Maximum number of time slots (TSMAX=1, 16, or 64),

(b). Maximum transmission counter (TCMAX = 1, 2, or 4), and

(c). Data transmission speed (normal or fast mode).

The purpose of the TCMAX and TSMAX parameters is to acknowledge the device in the Detection loop as fast as possible. TSMAX represents the maximum number of time slots between the end of the FR command and the beginning of the fast read (FR) response. One time slot (TSLOT) represents 2.5 ms. For example, TSMAX = 64 represents a maximum of 160 ms of time delay before sending the FR response. See Section 4.2.4 for the calculation of actual time delay. TCMAX represents the maximum number of fast read (FR) responses a device can send after an FRR command. For example, TCMAX = 4 means the device can send its FR response four times (after the FRR command) for acknowledgment (matching code).

The TSMAX and TCMAX values are determined by the interrogator's decision on how many tags are in the field. The interrogator may assign TSMAX = 1 and TCMAX = 1 assuming there is only one tag in the field. The efficiency of the detection will increase in multiple
tag environments by assigning a higher number to both the TSMAX and TCMAX. If the device receives the FRR, it clears the Position 1 flag, waits for its time slot and replies with the fast read (FR) response and then listens for 1 ms. The FR response consists of a maximum of 160 manchester data bits (default: 96 bits, see Table 4-3 and Example 7-1) which includes the 32-bit Tag ID and the fast read field data (blocks 3-5).

To acknowledge the FR response, the interrogator can start to send a matching code (MC) during the device’s 1 ms listening window (TLW). The MC is encoded with 1-of-16 PPM signal. See Figure 4-9 for the 1-of-16 PPM signal. The MC1 is given to the device if the device does not need any further processing. If the device receives the MC1, it enters the Sleeping loop and stays in the loop in a non-modulating condition. The MC2 command is given to the device if further processing (read/write) is required. If the device receives the MC2 command, it enters the Processing loop.

If the device misses the MC within the listening window, it sends the FR response again after its time slot if two conditions are met: (1) Position 1 flag is cleared and (2) TCMAX has not elapsed. The device checks the condition (elapsed or not elapsed) of TCMAX using an internal transmission counter (TC). The transmission counter (TC) consists of 3 bits. If the Position 1 flag is cleared, the device increments the TC by 1 each time it does not receive a MC during its listening window. See the flow chart in Figure 4-1 for the conditional increment of the transmission counter. Table 4-1 shows an example of detecting the elapsed TCMAX using a rolling modulo-8 transmission counter.

For the TTF case, the device repeats its FR response according to the TCMAX and TSMAX parameters as specified in Table 5-5. Even though the device is operating in TTF mode, it will respond to its correct MC during its listening window. If TCMAX = 1, 2 or 4, it will also respond to FRR commands just as in the ITF case (see Section 4.1.1.1).

**4.1.1.1 Matching Code Queuing**

Once the device receives the FRR command, it sends the FR response and waits for a matching code (MC) during its listening window. If the device does not receive its correct MC code before its TCMAX has elapsed (see Table 4-1), it goes back to the beginning of the Detection loop (position 1 in the loop), and waits for either a new FRR command or matching code (MC1 or MC2). This is called “matching code queuing”. In this queuing, the device stays in the Detection loop waiting for an interrogator command (FRR or MC). This queuing takes place within the Detection loop and is controlled by the conditions of Set Position 1 Flag and TCMAX.

This queuing allows the interrogator to communicate with a device outside its listening window. The result is enhanced and accelerated processing of individual devices in a multiple tag environment.

**TABLE 4-1: CONDITIONS FOR TCMAX = ELAPSED FOR ITF MODE**

<table>
<thead>
<tr>
<th>Rolling Modulo-8 TC</th>
<th>TCMAX = 1</th>
<th>TCMAX = 2</th>
<th>TCMAX = 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 0 1</td>
<td>elapsed</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>0 1 0</td>
<td>elapsed</td>
<td>elapsed</td>
<td>—</td>
</tr>
<tr>
<td>0 1 1</td>
<td>elapsed</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>1 0 0</td>
<td>elapsed</td>
<td>elapsed</td>
<td>elapsed</td>
</tr>
<tr>
<td>1 0 1</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>1 1 0</td>
<td>elapsed</td>
<td>elapsed</td>
<td>—</td>
</tr>
<tr>
<td>1 1 1</td>
<td>elapsed</td>
<td>—</td>
<td>elapsed</td>
</tr>
<tr>
<td>0 0 0</td>
<td>elapsed</td>
<td>elapsed</td>
<td>—</td>
</tr>
</tbody>
</table>

**4.1.2 PROCESSING LOOP**

The reading and writing processes take place in this loop. Devices in this loop are waiting for commands for processing. In order to read from or write to the device, its “Processing Flag” (PF) must be set. Any device entering this loop with its PF cleared is called a follow-along tag. This follow-along tag in the loop is not processed for reading or writing.

If the device with PF set receives the End process (EP) command, it exits this loop and enters the Sleeping loop. However, the same EP command sends the follow-along tag back to the Detection loop.

If the device receives the FRR or FRB command in this loop, it sees the command as invalid, resets itself, and goes back to the initial power up state.

**4.1.3 SLEEPING LOOP**

This loop is used to keep all processed devices in a “silent” condition. The devices stay in this loop in a non-modulating condition as long as they remain in the field.

**4.1.4 REACTIVATION LOOP**

This loop is used to process a device with its fast read (FR) bit cleared. A device in this loop waits for the fast read bypass (FRB) command. If a device receives the FRB, it transmits the contents of block 1 (Tag ID) in its memory and waits for matching code 2 (MC2) in its listening window. If the device in this loop receives matching code 2 (MC2), it leaves this loop and enters the Processing loop. This reactivation loop has no anti-collision capability; it is designed for reactivation of single devices. This loop can be effectively used in retail store applications to process returning items from customers.
FIGURE 4-1: ANTI-COLLISION FLOW CHART

1. Power Up in Tuned State. SleepID=TagID, TC=0. Set Processing Flag.
2. Listen for FRBypass.
   - FRB Received?
     - Yes: Read Back Block 1
     - No: Talk-First Bit Set?
6. Yes: FR Bit Set?
5. No: FRR?
4. Yes: Clear Position Flag
3. No: PPM Symbol?
2. Yes: TC > 0?
1. No: TCMAX ELAPSED?
0. Yes: Increment Transmission Counter
- No: Position Flag Set?
- Yes: Set Processing Flag

0. Clear Processing Flag
1. Correct Matching Code?
2. Yes: Set Processing Flag
3. No: Maintain Logic State

0. Correct Matching Code?
1. Yes: Set Processing Flag
2. No: End Command?
3. Yes: No Processing Flag Set?
4. Yes: Execute Command
5. No: Read or Write Command?
6. Yes: Valid Command?
7. Yes: Increment Transmission Counter
8. No: Process flag set?
9. Yes: Maintain Logic State
10. No: Start Command?
4.2 Anti-Collision Command Controller

This section manages the anti-collision algorithm and establishes the communications between the interrogator and device.

4.2.1 STRUCTURE OF READ/ WRITE COMMAND SIGNALS

The interrogator’s read/write commands have the following structure:

Read/Write command = Command + Address + Data + Parity (or CRC)

The commands are summarized in the table below:

**TABLE 4-2: READ/WRITE COMMANDS FROM INTERROGATOR TO DEVICE**

<table>
<thead>
<tr>
<th>Interrogator Command</th>
<th>Command Code</th>
<th>Address</th>
<th>Data</th>
<th>Parity or CRC</th>
<th>Symbol Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unused</td>
<td>00x</td>
<td>xxxxx</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Read 32-bit block</td>
<td>110</td>
<td>aaaaa</td>
<td>—</td>
<td>Parity</td>
<td>3 symbols</td>
</tr>
<tr>
<td>Unused</td>
<td>111</td>
<td>00xxx</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Unused</td>
<td>111</td>
<td>0100x</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>End Process</td>
<td>111</td>
<td>01010</td>
<td>—</td>
<td>Parity</td>
<td>3 symbols</td>
</tr>
<tr>
<td>Unused</td>
<td>111</td>
<td>01011</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Unused</td>
<td>111</td>
<td>011xx</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Unused</td>
<td>111</td>
<td>1000x</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Set Talk First Bit</td>
<td>111</td>
<td>10010</td>
<td>—</td>
<td>Parity</td>
<td>3 symbols</td>
</tr>
<tr>
<td>Set FR Bit</td>
<td>111</td>
<td>10011</td>
<td>—</td>
<td>Parity</td>
<td>3 symbols</td>
</tr>
<tr>
<td>Clear Talk First Bit</td>
<td>111</td>
<td>10100</td>
<td>—</td>
<td>Parity</td>
<td>3 symbols</td>
</tr>
<tr>
<td>Clear FR Bit</td>
<td>111</td>
<td>10101</td>
<td>—</td>
<td>Parity</td>
<td>3 symbols</td>
</tr>
<tr>
<td>Unused</td>
<td>111</td>
<td>1011x</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Unused</td>
<td>111</td>
<td>11xxx</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Unused</td>
<td>100</td>
<td>xxxxx</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Write 32-bit block</td>
<td>101</td>
<td>aaaaa</td>
<td>32 bits</td>
<td>CRC-16</td>
<td>14 symbols</td>
</tr>
<tr>
<td>Unused</td>
<td>01x</td>
<td>xxxxx</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Legend: aaaaa = Block address
x = don’t care
Command and address are sent MSN (most significant nibble) first
Data and parity/CRC are sent LSN (least significant nibble) first.
4.2.2 STRUCTURE OF DEVICE RESPONSE

When the device receives the interrogator command, it responds with 70 kHz -Manchester encoded data having the following structures:

**For blocks 0 and 2:**

Device Response = Preamble (8 bits) + Block Number (5 bits) + "000" + Block Data (32 bits) + Calculated CRC (CCRC: 16 bits)

**For all other blocks:**

Device Response = Preamble (8 bits) + Block Number (5 bits) + "000" + Block Data (32 bits) + Stored CRC (SCRC: 16 bits)

### TABLE 4-3: INTERROGATOR COMMANDS AND DEVICE RESPONSES

<table>
<thead>
<tr>
<th>Interrogator Command</th>
<th>Delay</th>
<th>Device Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read 32-bit block for block 0 and block 2</td>
<td>TDECODE</td>
<td>Preamble, block #, &quot;000&quot;, block data, CCRC</td>
</tr>
<tr>
<td>Read 32-bit block except for block 0 and block 2</td>
<td>TDECODE</td>
<td>Preamble, block #,&quot;000&quot;, block data, SCRC</td>
</tr>
<tr>
<td>Write 32-bit block</td>
<td>TWRITE</td>
<td>For blocks 0 and 2: Preamble, block #, &quot;000&quot;,block data, CCRC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>For all others: Preamble, block #,&quot;000&quot;, block data, SCRC</td>
</tr>
<tr>
<td>Set Fast Read (FR) bit</td>
<td>TWRITE</td>
<td>Preamble, 1 byte 0's, block 0 data, CCRC</td>
</tr>
<tr>
<td>Clear Fast Read (FR) bit</td>
<td>TWRITE</td>
<td>Preamble, 1 byte 0's, block 0 data, CCRC</td>
</tr>
<tr>
<td>Set Talk First (TF) bit</td>
<td>TWRITE</td>
<td>Preamble, 1 byte 0's, block 0 data, CCRC</td>
</tr>
<tr>
<td>Clear Talk First (TF) bit</td>
<td>TWRITE</td>
<td>Preamble, 1 byte 0's, block 0 data, CCRC</td>
</tr>
<tr>
<td>End Process (EP)</td>
<td>TDECODE</td>
<td>Preamble</td>
</tr>
<tr>
<td>FRR</td>
<td>f(TSMAX, TCMAX, 8-bit Tag ID)</td>
<td>Preamble,TC, TP, &quot;0&quot;, Tag ID, FRF, FRR_CRC (bits 0-15 in block 0) (maximum of 160 data bits)</td>
</tr>
<tr>
<td>FRB</td>
<td>TDECODE</td>
<td>Preamble, address of block #1(00001),&quot;000&quot;, Tag ID (32 bits), SCRC (64 data bits)</td>
</tr>
</tbody>
</table>

References used in this table. Examples are given in Section 7.0.

- **Preamble** = 11111110 (8 bits), "0" is transmitted last.
- **Block #** = 5 bit addressed block, transmits LSB (least significant bit) first.
- **Block data** = 32-bit data of the addressed block, transmits LSB first.
- **CCRC** = Calculated CRC of the preceding block number and block data. Transmits LSB first.
- **SCRC** = Stored CRC. This SCRC is the CRC of the write command, address, and data from the interrogator, LSB first. The device stores the CRC of the command for each block. See Section 5.2 for details.
- **TP** = Tag parameters (4 bits: "0", DF0, DF1, parity), where DF0 and DF1 determine the FR field length (see Table 5-6).
- **TC** = Transmission counter (3 bits), transmits LSB first.
- **Parity** = Even parity bit of TC and TP.
- **Tag ID** = 32 bits of unique identification code of the device, transmits LSB first. This Tag ID is pre-programmed in the factory prior to shipping.
- **8-bit Tag ID** = 8 bits of Tag ID selected from the 32 bits of the unique tag identification code. Transmits LSB first (see Section 4.2.3.6 for selecting the 8 bits from the Tag ID).
- **FRF** = Fast Read Field (blocks 3-5), transmits LSB first (see Section 5.0).
- **f(TSMAX, TCMAX, 8-bit Tag ID)** = Delay is a function of the TSMAX, TCMAX and 8-bit Tag ID.
- **TWRITE** = Writing time for EEPROM (see Table 1-3).
- **FRR_CRC** = CRC of 32-bit Tag ID first followed by fast read field (FRF) data.
- **TDECODE** = Time requirement for command decoding (see Table 1-3).
4.2.3 DETECTION OF INTERROGATOR COMMANDS

The interrogator sends commands to the device by amplitude modulating the carrier signal (gap pulse). The interrogator uses two classes of encoding signals for modulation. They are (a) 1-of-16 PPM for data transmission, and (b) specially timed gap pulse sequence for the fast read commands (FRR and FRB).

The fast read commands consist of five gap pulses within nine possible gap pulse positions (1.575 ms). The combination of the possible gap positions determines the command type and parameters of the fast read command.

The interrogator also sends time calibration pulses (TCP) prior to the 1-of-16 PPM. The TCP is used to calibrate the time base of the decoder in the device. The specifics of the two encoding methods and the TCP are described in the following sections.

4.2.3.1 FAST READ COMMANDS

The fast read commands are composed of five 175 µs-wide gap pulses (see Figure 4-2) whose spacing within 1.575 ms determines the command type and its parameters. Table 4-4 shows the specification of the gap signal for the fast read commands. Two commands are used for the fast read. They are: (1) Fast Read Request (FRR) in the Detection loop, and (2) Fast Read Bypass (FRB) in the Reactivation loop. See Tables 4-5 and 4-6 for the FRR gap pulse positions and also Figures 4-3 to 4-8 for the gap modulation patterns.

The parameters of FRR are (1) number of time slots (TSMAX = 1, 16, or 64), (2) max transmission counter (TCMAX), and (3) data transmission speed. The FRB has only a data transmission speed parameter (normal or fast speed mode). The device extracts these parameters based on the positions of the five gap pulses within the 1.575 ms time span as shown in Figures 4-3 to 4-8.

TSMAX=1 is given if there is only one device in the field. This is called “conveyor mode” or “single tag environment”. In this mode, the device responds with the FR response signal in every time slot until it receives a correct matching code, or until TCMAX is expired.

4.2.3.2 DATA TRANSMISSION SPEED

The interrogator can send data with two different data rates: (1) Normal and (2) Fast speed modes. The normal speed uses 2.8 ms/symbol, and the fast speed uses 160 µs/symbol. One symbol represents one 4-bit data packet (see Section 4.2.3.4 for 1-of-16 PPM). The data transmission speed is a parameter of the fast read commands (FRR and FRB). This parameter indicates the data speed of subsequent interrogator commands. The data rate of the device output (70 kHz) is not affected by this parameter.

<table>
<thead>
<tr>
<th>TABLE 4-4: SPECIFICATION OF GAP SIGNAL FOR FAST READ COMMANDS (FRR AND FRB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of gaps for one command</td>
</tr>
<tr>
<td>Total available number of gap positions within the command time span</td>
</tr>
<tr>
<td>Command time span</td>
</tr>
<tr>
<td>Gap pulse width</td>
</tr>
</tbody>
</table>
### TABLE 4-5: SPECIFICATION OF MODULATION SEQUENCE FOR FAST READ REQUEST (FRR)

<table>
<thead>
<tr>
<th>Maximum Time Slot (TSMAX)</th>
<th>TCMAX</th>
<th>Gap Pulse Position</th>
<th>Data Transmission Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>(1,2,3,4,6)</td>
<td>Normal Speed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1,3,5,6,8)</td>
<td>Fast Speed</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>(1,2,3,4,5)</td>
<td>Normal Speed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1,3,5,6,7)</td>
<td>Fast Speed</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>(1,2,3,5,6)</td>
<td>Normal Speed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1,3,5,7,8)</td>
<td>Fast Speed</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>(1,2,4,6,8)</td>
<td>Normal Speed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1,3,4,6,8)</td>
<td>Fast Speed</td>
</tr>
<tr>
<td></td>
<td>64</td>
<td>(1,2,4,5,7)</td>
<td>Normal Speed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1,3,4,5,7)</td>
<td>Fast Speed</td>
</tr>
</tbody>
</table>

### TABLE 4-6: SPECIFICATION OF MODULATION SEQUENCE FOR FRB COMMAND

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Gap Pulse Position</th>
<th>Data Transmission Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRB_N</td>
<td>(1,2,3,5,7)</td>
<td>Normal Speed</td>
</tr>
<tr>
<td>FRB_F</td>
<td>(1,3,5,7,9)</td>
<td>Fast Speed</td>
</tr>
</tbody>
</table>
FIGURE 4-2: PULSE WAVEFORM OF GAP AND 1-OF-16 PPM SIGNALS

TABLE 4-7: WAVEFORM CHARACTERISTICS OF GAP AND 1-OF-16 PPM SIGNALS

<table>
<thead>
<tr>
<th>Signal</th>
<th>Symbol</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Unit</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gap signal and 1-of-16 PPM for normal mode</td>
<td>td1</td>
<td>—</td>
<td>25</td>
<td>—</td>
<td>μs</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>td2</td>
<td>—</td>
<td>25</td>
<td>—</td>
<td>μs</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>t1</td>
<td>0</td>
<td>12.5</td>
<td>—</td>
<td>μs</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>t2</td>
<td>0</td>
<td>12.5</td>
<td>—</td>
<td>μs</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>t3</td>
<td>—</td>
<td>75</td>
<td>—</td>
<td>μs</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>t4</td>
<td>0</td>
<td>12.5</td>
<td>—</td>
<td>μs</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>t5</td>
<td>0</td>
<td>12.5</td>
<td>—</td>
<td>μs</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>t6</td>
<td>—</td>
<td>100</td>
<td>—</td>
<td>μs</td>
<td>PWPPM_N</td>
</tr>
<tr>
<td></td>
<td>t7</td>
<td>—</td>
<td>125</td>
<td>—</td>
<td>μs</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>t8</td>
<td>—</td>
<td>175</td>
<td>—</td>
<td>μs</td>
<td>—</td>
</tr>
<tr>
<td>1-of-16 PPM for fast mode</td>
<td>td1</td>
<td>—</td>
<td>1.25</td>
<td>—</td>
<td>μs</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>td2</td>
<td>—</td>
<td>1.25</td>
<td>—</td>
<td>μs</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>t1</td>
<td>0</td>
<td>0.75</td>
<td>—</td>
<td>μs</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>t2</td>
<td>0</td>
<td>0.75</td>
<td>—</td>
<td>μs</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>t3</td>
<td>—</td>
<td>4.5</td>
<td>—</td>
<td>μs</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>t4</td>
<td>0</td>
<td>0.75</td>
<td>—</td>
<td>μs</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>t5</td>
<td>0</td>
<td>0.75</td>
<td>—</td>
<td>μs</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>t6</td>
<td>—</td>
<td>6</td>
<td>—</td>
<td>μs</td>
<td>PWPPM_F</td>
</tr>
<tr>
<td></td>
<td>t7</td>
<td>—</td>
<td>7.5</td>
<td>—</td>
<td>μs</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>t8</td>
<td>—</td>
<td>10</td>
<td>—</td>
<td>μs</td>
<td>—</td>
</tr>
</tbody>
</table>
The following figures show the various modulation patterns of the fast read commands (FRR and FRB). Each command consists of a combination of five gap pulses within nine possible gap positions. The pulse width of each gap is 175 µs and the total time span of each command for the nine possible positions is 1.575 ms (175 µs x 9 = 1.575 ms).

In the figures, \( P_{mn} \) represents \( m \)th gap pulse at \( n \)th gap position in the given data packet (symbol).

**FIGURE 4-3: GAP MODULATION PATTERNS FOR FRR, NORMAL SPEED, TSMAX = 1**

![Diagram](image1)

**FIGURE 4-4: GAP MODULATION PATTERNS FOR FRR, FAST SPEED, TSMAX = 1**

![Diagram](image2)
FIGURE 4-5: GAP MODULATION PATTERNS FOR FRR, NORMAL SPEED, TSMAX = 16

(A) TCMAX = 1

(B) TCMAX = 2

(C) TCMAX = 4

FIGURE 4-6: GAP MODULATION PATTERNS FOR FRR, FAST SPEED, TSMAX = 16

(A) TCMAX = 1

(B) TCMAX = 2

(C) TCMAX = 4

FIGURE 4-7: GAP MODULATION PATTERNS FOR FRR, TSMAX = 64, TCMAX = 1

(A) NORMAL SPEED

(B) FAST SPEED
FIGURE 4-8: GAP MODULATION PATTERNS FOR FRB (FAST REQUEST BYPASS)

(A) NORMAL SPEED

(B) FAST SPEED

4.2.3.3 USAGE OF TSMAX AND TCMAX

The parameters of the TSMAX and TCMAX are determined by an expected number of tags in the Detection Loop. The following table shows the recommended FRR command repeat time for each of the 7 possible combinations of TSMAX and TCMAX. The command repeat time in Table 4-8 is calculated by:

\[
\text{Command Repeat Time} = \text{TSMAX} \times \text{TCMAX} \times 2.5\text{ms} \times 1.17
\]

where:

- 1.17 is related to the tolerance of the baud rate.

**TABLE 4-8: FRR COMMAND REPEAT TIME VS. (TSMAX, TCMAX)**

<table>
<thead>
<tr>
<th>(TSMAX,TCMAX)</th>
<th>(1,1)</th>
<th>(1,2)</th>
<th>(1,4)</th>
<th>(16,1)</th>
<th>(16,2)</th>
<th>(16,4)</th>
<th>(64,1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Command Repeat Time</td>
<td>2.925 ms</td>
<td>5.85 ms</td>
<td>11.7 ms</td>
<td>46.8 ms</td>
<td>93.6 ms</td>
<td>187.2 ms</td>
<td>187.2 ms</td>
</tr>
</tbody>
</table>

4.2.3.4 1-OF-16 PPM

The interrogator uses 1-of-16 Pulse Position Modulation (PPM) for matching codes (MC1 and MC2), End Process (EP), and also commands in Table 4-2. 1-of-16 PPM uses only one gap pulse in one of sixteen possible pulse positions for sending 4-bit symbols \(2^4=16\). This means one symbol (one data packet) represents 4 bits of binary data. One symbol lasts for 2.8 ms and 160 \(\mu\)s for normal speed and fast speed mode, respectively. All communications begin with time calibration pulses (TCP) composed of three pulses in positions zero, six and fourteen of a 1-of-16 PPM symbol as shown in Figure 4-10.

**TABLE 4-9: 1-OF-16 PPM PULSE SPECIFICATIONS**

<table>
<thead>
<tr>
<th></th>
<th>Normal Mode</th>
<th>Fast Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulation depth</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Pulse width</td>
<td>175 (\mu)s</td>
<td>10 (\mu)s</td>
</tr>
<tr>
<td>Gap width</td>
<td>100 (\mu)s</td>
<td>6 (\mu)s</td>
</tr>
<tr>
<td>Pulse positions per symbol</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Symbol width</td>
<td>2.8 ms</td>
<td>160 (\mu)s</td>
</tr>
<tr>
<td>Calibration sequence</td>
<td>Pulses in positions 0,6,14</td>
<td>Pulses in positions 0,6,14</td>
</tr>
</tbody>
</table>
FIGURE 4-9: 1-OF-16 PPM REPRESENTATION FOR HEX VALUES FOR NORMAL SPEED MODE

<table>
<thead>
<tr>
<th>Hex Value</th>
<th>0</th>
<th>175</th>
<th>350</th>
<th>525</th>
<th>700</th>
<th>875</th>
<th>1050</th>
<th>1225</th>
<th>1400</th>
<th>1575</th>
<th>1750</th>
<th>1925</th>
<th>2100</th>
<th>2275</th>
<th>2450</th>
<th>2675</th>
<th>2800</th>
</tr>
</thead>
<tbody>
<tr>
<td>PWPPM_N</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;0&quot;</td>
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<tr>
<td>&quot;1&quot;</td>
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<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;2&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;3&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;4&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;5&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>&quot;6&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;7&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;8&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;9&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;A&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;B&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;C&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;D&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;E&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;F&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Gap Position Order: 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
4.2.3.5 CALIBRATION OF TIME REFERENCE FOR DECODING

The device uses time calibration pulses (TCP) to match its internal decoder timing to the interrogator timing. The interrogator transmits the timing pulses at the start of all commands and at least every 17 symbols. The TCP uses a code violation of the 1-of-16 PPM signal consisting of three gap pulses within one symbol. The first gap pulse is located at position 0, the second gap pulse at position 6, and the third at position 14 of the symbol. The time period between the last two gap pulses is used to calibrate the device’s timing for decoding. Figure 4-10 shows the calibration pulses for normal speed mode. The waveform of the gap pulses is the same as the 1-of-16 PPM signal as shown in Figure 4-2. For the fast speed mode, the gap positions are the same. PWPPM_F is the gap pulse width and SWPPM_F is the symbol width of the fast mode.

FIGURE 4-10: CALIBRATION PULSES FOR NORMAL SPEED MODE
4.2.3.6 CALCULATION OF MATCHING CODE

When the interrogator receives the FR response from a device, it sends a matching code (MC) to select the device. The MC is sent during the device's listening window. There are two different types of matching codes. They are MC1 and MC2. Both MC1 and MC2 are used in the Detection loop and MC2 is used in the Reactivation loop as detailed in Figure 4-1. The MC1 command is used to send the device to the Sleeping loop, and MC2 is used to send the device to the Processing loop.

The MC is an 8-bit “match” of tag ID followed by 4-bit matching code type and parity bit such that:

- Matching code (12 bits) = "match (8 bits of tag ID)" + matching code type (3 bits) + parity (1 bit)

The matching code type and parity bit is bit-wise structured as follows:

- MC1: 010P
- MC2: 100P

where P represents the parity bit of all match bits (8 bits) plus the MC type (3 bits).

The “match” part of the MC is eight bits of the 32-bit Tag ID. The interrogator selects the 8 bits from the 32-bit Tag ID by calculating the bit range of the Tag ID. Equation 4-1 shows the equation for selecting the bit range using the transmission counter (TC). Both the 32-bit Tag ID and TC are included in the FR response. An example for the calculation of the matching code is given in Section 7-2.

**EQUATION 4-1: BIT-WISE EQUATION FOR “MATCH”**

\[
\text{"Match"} = \text{Tag ID bit range } a: b = \{4 \times TC\} \mod 32: \{4 \times (TC + 1) + 3\} \mod 32
\]

where \(\{\} \mod 32\) means the remainder of \(\{\}\) divided by 32. For example, \((28) \mod 32\) and \((35) \mod 32\) are 28 and 3, respectively.

4.2.4 TIME SLOT GENERATOR

This block generates time slots for the device. The time slot represents the time delay between the end of the FRR command and the beginning of the FR response. The available time slots are 1, 16 or 64. One time slot represents 2.5 ms. The device calculates the actual time slot based on the TSMAX, TC and Tag ID. The maximum time slot (TSMAX) is assigned to the device by the FRR command (see Figs. 4-3 to 4-7), or set to 16 if the talk first (TF) bit is set.

Four or six bits of the Tag ID are used at a time to calculate the time slot, with TC being the shift parameter to choose which portion of the 32-bit Tag ID is used as shown in Equation 4-2.

**EQUATION 4-2: EQUATION FOR TIME SLOT CALCULATION**

<table>
<thead>
<tr>
<th>TSMAX</th>
<th>Time Slot = Tag ID bit range a:b</th>
</tr>
</thead>
<tbody>
<tr>
<td>64</td>
<td>([4\times(TC+1)+1] \mod 32: [4 \times TC \mod 32] XOR TC LSB</td>
</tr>
<tr>
<td>16</td>
<td>([4\times(TC+1)-1] \mod 32: [4 \times TC \mod 32] XOR TC LSB</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

**Note:** The exclusive-or (XOR) in the above equation in Equation 4-2. This is called “semi-inverting” that randomizes worst case tag IDs, e.g. a Tag ID of ‘77777777’ or ‘00000000’. Table 4-10 shows examples of the calculation.
In Table 4-10, \( \text{h'}x..x' \) represents hexadecimal number, \( \text{d'}x..x' \) represents decimal number, and \( b'x..x' \) represents binary number.

Table 4-10 shows the calculated time slot (TS) is 5 for \( TC = 1 \) and \( TSMAX = 16 \) with Tag ID = \( \text{h'}825FE1A0' \). This means the device waits for 12.5 ms (5 x 2.5 ms = 12.5 ms) in a non-modulating condition between the end of FRR and the start of the FR response.

Also the TS is 37 for \( TC = 1 \) and \( TSMAX = 64 \). This means the device waits for 92.5 ms (37 x 2.5 ms = 92.5 ms) between the end of FRR and the start of the FR response in a non-modulating condition.

### TABLE 4-10: EXAMPLE: TAG ID = \( \text{h'}825FE1A0' \)

<table>
<thead>
<tr>
<th>TC</th>
<th>Relevant Tag ID</th>
<th>Selected Tag ID before XOR with LSB of TC</th>
<th>Calculated Time Slot (TS) (after XOR with LSB of TC)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hexadecimal</td>
<td>Binary</td>
<td>TSMAX=16</td>
</tr>
<tr>
<td>0</td>
<td>h'825FE1(A0)'</td>
<td>b'1010 0000'</td>
<td>h'0'</td>
</tr>
<tr>
<td>1</td>
<td>h'825FE1(A1)'</td>
<td>b'0001 1010'</td>
<td>h'A'</td>
</tr>
<tr>
<td>2</td>
<td>h'825FE1(A2)'</td>
<td>b'1110 0001'</td>
<td>h'1'</td>
</tr>
<tr>
<td>3</td>
<td>h'825FE1(A3)'</td>
<td>b'1111 1110'</td>
<td>h'E'</td>
</tr>
<tr>
<td>4</td>
<td>h'825FE1(A4)'</td>
<td>b'0101 1111'</td>
<td>h'F'</td>
</tr>
<tr>
<td>5</td>
<td>h'825FE1(A5)'</td>
<td>b'0010 0101'</td>
<td>h'5'</td>
</tr>
<tr>
<td>6</td>
<td>h'825FE1(A6)'</td>
<td>b'1000 0100'</td>
<td>h'2'</td>
</tr>
<tr>
<td>7</td>
<td>h'825FE1(A7)'</td>
<td>b'0000 1000'</td>
<td>h'8'</td>
</tr>
</tbody>
</table>

4.2.5 TIME SLOT COUNTER

This section generates the sleep time (2.5 ms x TS) of the device. During the sleep time, the device remains in a non-modulating condition.
5.0 MEMORY SECTION

The memory section is organized into two groups: (1) Main Memory Section and (2) Stored CRC Memory Section.

5.1 Main Memory Section

The main section is organized into 32 blocks as shown in Table 5-1. Each block has 32 bits. The first 3 blocks (0 - 2) are used for predefined parameters and device operation. The next three blocks (3 - 5) are used as the fast read fields. The blocks from 6 to 31 (26 blocks) are used for user data memory. The memory is read or written in 32-bit selectable units, with the exception of the fast read (FR) bit and the talk first (TF) bit, which are individually selectable.

TABLE 5-1: MEMORY ORGANIZATION

<table>
<thead>
<tr>
<th></th>
<th>Main Memory Section (32 blocks x 32 bits)</th>
<th>Stored CRC (SCRC) Section (32 blocks x 16 bits)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M S B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F R</td>
<td>TF</td>
<td>FR Response CRC</td>
<td>Block 0</td>
</tr>
<tr>
<td></td>
<td>Tag Parameters</td>
<td></td>
<td>(Tag Parameters/FR)</td>
</tr>
<tr>
<td></td>
<td>SNR 3</td>
<td></td>
<td>Block 1</td>
</tr>
<tr>
<td></td>
<td>SNR 2</td>
<td></td>
<td>(Tag ID = Serial Number)</td>
</tr>
<tr>
<td></td>
<td>SNR 1</td>
<td></td>
<td>Block 2</td>
</tr>
<tr>
<td></td>
<td>SNR 0</td>
<td></td>
<td>(Write-Protect 1st kb)</td>
</tr>
<tr>
<td></td>
<td>Fast</td>
<td>Read Field</td>
<td>Block 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(LS Block)</td>
<td>(FR Field Least Significant Block)</td>
</tr>
<tr>
<td></td>
<td>Fast</td>
<td>Read Field</td>
<td>Block 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(MS Block)</td>
<td>(FR Field)</td>
</tr>
<tr>
<td></td>
<td>Block 5</td>
<td></td>
<td>Block 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(FR Field Most Significant Block)</td>
</tr>
<tr>
<td></td>
<td>Block 6</td>
<td></td>
<td>Block 6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(User Data)</td>
</tr>
<tr>
<td></td>
<td>Block 7</td>
<td></td>
<td>Block 7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(User Data)</td>
</tr>
<tr>
<td></td>
<td>Block 8</td>
<td></td>
<td>Block 8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(User Data)</td>
</tr>
<tr>
<td></td>
<td>Block 9</td>
<td></td>
<td>Block 9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(User Data)</td>
</tr>
<tr>
<td></td>
<td>Block 10</td>
<td></td>
<td>Block 10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(User Data)</td>
</tr>
<tr>
<td></td>
<td>Block 11</td>
<td></td>
<td>Block 11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(User Data)</td>
</tr>
<tr>
<td></td>
<td>Block 29</td>
<td></td>
<td>Block 29</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(User Data)</td>
</tr>
<tr>
<td></td>
<td>Block 30</td>
<td></td>
<td>Block 30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(User Data)</td>
</tr>
<tr>
<td></td>
<td>Block 31</td>
<td></td>
<td>Block 31</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(User Data)</td>
</tr>
</tbody>
</table>
5.3 BIT LAYOUT

5.3.1 BLOCK 0

The bit layout in block 0 is given in the following table. FR and TF bits are not write-protectable.

<table>
<thead>
<tr>
<th>TABLE 5-2: BIT LAYOUT OF BLOCK 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>B0:31</td>
</tr>
<tr>
<td>FR</td>
</tr>
<tr>
<td>B0:23</td>
</tr>
<tr>
<td>TM2*</td>
</tr>
<tr>
<td>FRR CRC 15</td>
</tr>
<tr>
<td>B0:7</td>
</tr>
<tr>
<td>FRR CRC 7</td>
</tr>
</tbody>
</table>

Note: * These are ‘hardwired’ bits, not EEPROM bits.

5.3.1.1 DESCRIPTION OF BITS

<table>
<thead>
<tr>
<th>TABLE 5-3: FR BIT (B0:31)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

Note: FR bit is not write-protectable.

<table>
<thead>
<tr>
<th>TABLE 5-4: TF BIT (B0:30)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TF</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>1</td>
</tr>
</tbody>
</table>

Note: TF bit is not write-protectable.

<table>
<thead>
<tr>
<th>TABLE 5-5: TFT BITS (B0:29 - B0:28)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TFT1</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>1</td>
</tr>
</tbody>
</table>

Note 1: Only applicable in tag talks first (TTF) mode. If FRR, TCMA in command applies. Maximum time slot (TSMAX) parameter is set to 64 for TTF mode.

Note 2: The device continuously sends its FR response until it receives its correct matching code. On average, the device will send its FR response every 80 ms.

<table>
<thead>
<tr>
<th>TABLE 5-6: DF BITS (B0:27 - B0:26)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DF1</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TABLE 5-7: MT BITS (B0:25 - B0:24)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MT1</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>1</td>
</tr>
</tbody>
</table>

Note: The MT bits are “hardwired”.

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5.3.2 BLOCK 1: UNIQUE 32-BIT TAG ID
Block 1 contains 32 bits of unique Tag ID with stored CRC (SCRC). The ID is uniquely serialized.

5.3.3 BLOCK 2: WRITE-PROTECT FOR THE FIRST KBITS
Each bit corresponds to a 32-bit block, i.e. bit 0 to block 0, bit 1 to block 1, etc. Write-protection is a one way process, i.e. once a block is write-protected, it cannot be modified. It should be noted that the write-protect block itself can be write-protected. TF and FR bits in block 0 are not write-protectable even if the write-protection bit in the block is set.

5.3.4 BLOCKS 3-5: FAST READ FIELDS
These blocks contain data bits for the FR response. The state of the DF bits (see Table 5-6) in block 0 determines the actual number of bits to be sent. This block can be used as a customer ID or also as additional tag ID numbers.

6.0 DEVICE TESTING
The device will be shipped to customers with the Fast Read (FR) bit set, and with block 1 write-protected.
The following bits are factory programmed prior to shipping:
1. DF0(B0:26) and DF1(B0:27) are set to “0”.
2. TFT0(B0:28) and TFT1(B0:29) bits are set to “1”.
3. All bits in the FR field (blocks 3-5) are programmed to “1”s.
4. The FRR_CRC(B0:0 - B0:15) bits are also programmed according to the Tag ID and item (3) above.

---

**TABLE 5-8: TM BITS (B0:23 - B0:21)**

<table>
<thead>
<tr>
<th>TM2</th>
<th>TM1</th>
<th>TM0</th>
<th>Total memory size</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>512 bits</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1 Kbit (Default)</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>TBD</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>TBD</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>TBD</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>TBD</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>TBD</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>TBD</td>
</tr>
</tbody>
</table>

**Note:** The TM bits are “hardwired”.

**TABLE 5-9: B0: (20-16) AND B0: (15-0)**

| B0:(20-16) | Available for user |
| B0:(15-0)  | CRC for the Fast Read Response |

**TABLE 5-10: WRITE-PROTECT**

<table>
<thead>
<tr>
<th>Block X Write Status</th>
<th>Bit X of Write-Protect Block</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block X writable</td>
<td>1</td>
</tr>
<tr>
<td>Block X write-protected</td>
<td>0</td>
</tr>
</tbody>
</table>
7.0 EXAMPLES

EXAMPLE 7-1: READ/WRITE PULSE SEQUENCE

To write 1 block (32 bits) in normal mode with TS = 1: ~ 78.014 ms
To read 1 block (32 bits) in normal mode with TS = 1: ~ 42.214 ms

TDECODE (2.8 ms)

Listening window (Tlw) for 1 ms

For FR Response:
(Preamble (8 bits) + Tc (3 bits) + Tp (4 bits) + "0" + 32 bits of Tag ID + FRF (32-96 bits) + bits 0-15 in Block #0 = 160 bits max = 2.286 ms)

For FRB Response:
(Preamble (8 bits) + "00001" + "000" + 32-bit Tag ID (block 1 data) + SCRC (16 bits) = 64 bits = 0.914 ms)

Device Outputs:
After a completion of write cycle:
Preamble (8 bits) + written block # (5 bits) + "00000" + written block data (32 bits) + CCRC/SCRC (16 bits) = 64 bits = 0.914 ms
After read command:
Preamble (8 bits) + block # (5 bits) + "00000" + block data (32 bits) + CCRC/SCRC (16 bits) = 64 bits = 0.914 ms

End Process Command:
Cal. pulse + End Process Command (111) + Address (01010) + Parity (1) = Cal. Pulse + 3 symbols = 11.2 ms

Device Response: 8-bit preamble (11111110) (0.114 ms)
EXAMPLE 7-2: CALCULATION OF MATCHING CODE FOR TAG ID = 825FE1A0 (HEX, MSB FIRST)

The “match” part of the matching code is calculated by the Bit-Wise Equation in Equation 4-1:

“Match (8 bits)" = Tag ID bit range a:b = {4(TC)}modulo 32: {4(TC + 1) + 3}modulo 32

For TC = 2, the above equation gives a = 8, and b = 15.

The “Match (8 bits)” is chosen from (8th 9th 10th 11th) and (12th 13th 14th 15th) bits of the Tag ID.

Therefore, for the Tag ID = 825FE1A0 (hex) = b/1000 0010 0101 1111 1110 0001 1010 0000/,

“Match (8 bits)” = b/1110 0001/ = 1E (hex).

Using this “Match” part, a complete set of matching code is assembled as:

1E5   for MC1, and
1E9   for MC2

where: 5 in the MC1 was from b/0101/ (010 for MC1 and the last “1” is a parity bit),
and 9 in the MC2 was from b/1001/ (100 for MC2 and the last “1” is a parity bit).

Gap position in the 1-of-16 PPM signal for the calculated MC codes:

The gap position numbers in the 1-of-16 PPM for the calculated MC codes are (see Figure 4-9 for 1-of-16 PPM):

Positions 1, 14, and 5 for 1E5 for MC1 code
Positions 1, 14, and 9 for 1E9 for MC2 code.

The “Match” part of the matching code for various TCs are given in Table 7-1.

<table>
<thead>
<tr>
<th>TC</th>
<th>“Match (8 bits) in hex”</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0A</td>
</tr>
<tr>
<td>1</td>
<td>A1</td>
</tr>
<tr>
<td>2</td>
<td>1E</td>
</tr>
<tr>
<td>3</td>
<td>EF</td>
</tr>
<tr>
<td>4</td>
<td>F5</td>
</tr>
<tr>
<td>5</td>
<td>52</td>
</tr>
<tr>
<td>6</td>
<td>28</td>
</tr>
<tr>
<td>7</td>
<td>80</td>
</tr>
</tbody>
</table>
EXAMPLE 7-3: TO WRITE DATA INTO THE DEVICE

The interrogator command structure for writing (see Section 4.2.1) is:
Calibration pulse + Writing Command (MSN first) + Address (MSN first) + Data (LSN first) + Parity/CRC (LSN first)

If the interrogator wants to write data "0123cdef (Hex, MSB to LSB)" to block 5, the following message will be sent:
Calibration pulse + Write Command (MSN first) + Address (MSN first) + Data (LSN first) + Parity/CRC (LSN first)
= 101 (write command) + 00101 (address) + f e d c 3 2 1 0 (data, hex) + CRC
= Calibration pulse + a f e d c 3 2 1 0 6 0 2 e (hex string)

The hex string above is encoded with the 1-of-16 PPM signals. See Figure 4-10 for the 1-of-16 PPM representation of hex values.

Referring to Figure 4-10, the gap positions in the 1-of-16 PPM for the above hex string are:
Positions 10 (a), 5 (5), 14 (e), 13 (d), 12 (c), 3 (3), 2 (2), 1 (1), 0 (0), 6 (6), 0 (0), 2 (2), e (14).

EXAMPLE 7-4: TO READ DATA FROM THE DEVICE

To read the content of block 5 that has been programmed in the previous example, the interrogator sends the following command:
Calibration pulse + Read Command (110) + Address (00101) + Parity (0)
= Calibration pulse + C50 (hex)

The gap positions in the 1-of-16 PPM signal for the above hex string are:
12 (C), 5 (5), 0 (0).

Device Response:
When the device receives the above interrogator command, the device outputs the following 70 kHz Manchester encoded data string (see Section 4.2.2 for the structure of device response):
Preamble (8 bits) + Block number (5 bits, LSB first) + '000' + Block Data (32 bits, LSB first) + SCRC (16 bits)
= 1-1-1-1-1-1-0 (f7) + 1-0-1-0-0-0-0-0 (5 0) + 1-1-1-1 0-1-1-1 1-0-1-1... 1-0-0-0
0-0-0-0 (f e d c 3 2 1 0) + 0-1-1-0 0-0-0-0 0-1-0-0 0-1-1-1 (602e).

EXAMPLE 7-5: TO SEND THE "END PROCESS" COMMAND

The interrogator command structure (see Section 4.2) for the End Process is:
Calibration pulse + End Process Command (111) + Address (01010) + Parity (1) = Calibration pulse + EA1 (hex)
The gap positions in the 1-of-16 PPM signal for the above hex string are:
14 (E), 10 (A), 1 (1).

Device Response:
The device outputs the 8-bit preamble ("11111110") when it receives the End Process command, and enters the Sleeping Loop.
8.0 PACKAGING INFORMATION

8.1 Package Marking Information

Legend:  
- XX...X: Customer specific information*
- Y: Year code (last digit of calendar year)
- YY: Year code (last 2 digits of calendar year)
- WW: Week code (week of January 1 is week '01')
- NNN: Alphanumeric traceability code

Note: In the event the full Microchip part number cannot be marked on one line, it will be carried over to the next line thus limiting the number of available characters for customer specific information.

* Standard device marking consists of Microchip part number, year code, week code, and traceability code. For device marking beyond this, certain price adders apply. Please check with your Microchip Sales Office. For QTP devices, any special marking adders are included in QTP price.
## MCRF450/451/452/455

**8-Lead Plastic Dual In-line (P) – 300 mil (PDIP)**

<table>
<thead>
<tr>
<th>UNITS</th>
<th>INCHES</th>
<th>MILLIMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIMENSION LIMITS</td>
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<td>NOM</td>
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<tr>
<td>Number of Pins</td>
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<tr>
<td>Pitch</td>
<td>p</td>
<td>.100</td>
</tr>
<tr>
<td>Top to Seating Plane</td>
<td>A</td>
<td>.140</td>
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<tr>
<td>Molded Package Thickness</td>
<td>A2</td>
<td>.115</td>
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<tr>
<td>Base to Seating Plane</td>
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<td>.015</td>
</tr>
<tr>
<td>Shoulder to Shoulder Width</td>
<td>E</td>
<td>.300</td>
</tr>
<tr>
<td>Molded Package Width</td>
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<td>.240</td>
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<tr>
<td>Overall Length</td>
<td>D</td>
<td>.360</td>
</tr>
<tr>
<td>Tip to Seating Plane</td>
<td>L</td>
<td>.125</td>
</tr>
<tr>
<td>Lead Thickness</td>
<td>c</td>
<td>.008</td>
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<tr>
<td>Upper Lead Width</td>
<td>B1</td>
<td>.045</td>
</tr>
<tr>
<td>Lower Lead Width</td>
<td>B</td>
<td>.014</td>
</tr>
<tr>
<td>Overall Row Spacing</td>
<td>eB</td>
<td>.310</td>
</tr>
<tr>
<td>Mold Draft Angle Top</td>
<td>α</td>
<td>5</td>
</tr>
<tr>
<td>Mold Draft Angle Bottom</td>
<td>β</td>
<td>5</td>
</tr>
</tbody>
</table>

* Controlling Parameter

§ Significant Characteristic

**Notes:**
- Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed .010” (0.254mm) per side.
- JEDEC Equivalent: MS-001
- Drawing No. C04-018

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8-Lead Plastic Small Outline (SN) – Narrow, 150 mil (SOIC)

**Notes:**
- Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed .010" (0.254mm) per side.
- JEDEC Equivalent: MS-012
- Drawing No. C04-057

**Units:***

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<th>MILLIMETERS</th>
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</thead>
<tbody>
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<td>Number of Pins</td>
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<td>MIN</td>
<td>NOM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MIN</td>
<td>NOM</td>
</tr>
<tr>
<td>Pitch</td>
<td>P</td>
<td>.050</td>
<td>.053</td>
</tr>
<tr>
<td>Overall Height</td>
<td>A</td>
<td>.053</td>
<td>.061</td>
</tr>
<tr>
<td>Molded Package Thickness</td>
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<td>.052</td>
<td>.056</td>
</tr>
<tr>
<td>Standoff §</td>
<td>A1</td>
<td>.004</td>
<td>.007</td>
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<td>E</td>
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<td>.237</td>
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<td>E1</td>
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<td>.154</td>
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<td>Overall Length</td>
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<td>.193</td>
</tr>
<tr>
<td>Chamfer Distance</td>
<td>h</td>
<td>.010</td>
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</tr>
<tr>
<td>Foot Length</td>
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<td>.025</td>
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<tr>
<td>Foot Angle</td>
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<td>c</td>
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<td>.009</td>
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<tr>
<td>Lead Width</td>
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<td>.015</td>
<td>.017</td>
</tr>
<tr>
<td>Mold Draft Angle Top</td>
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<td>12</td>
</tr>
<tr>
<td>Mold Draft Angle Bottom</td>
<td>β</td>
<td>0</td>
<td>12</td>
</tr>
</tbody>
</table>

*Controlling Parameter
§ Significant Characteristic

Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed .010" (0.254mm) per side.

JEDEC Equivalent: MS-012

Drawing No. C04-057
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Device: MCRF450/451/452/455  Literature Number: DS40232C

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2. How does this document meet your hardware and software development needs?

3. Do you find the organization of this data sheet easy to follow? If not, why?

4. What additions to the data sheet do you think would enhance the structure and subject?

5. What deletions from the data sheet could be made without affecting the overall usefulness?

6. Is there any incorrect or misleading information (what and where)?

7. How would you improve this document?

8. How would you improve our software, systems, and silicon products?
MCRF450/451/452/455

MCRF450/451/452/455 PRODUCT IDENTIFICATION SYSTEM

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<table>
<thead>
<tr>
<th>MCRF450/451/452/455</th>
<th>Package:</th>
<th>Device:</th>
</tr>
</thead>
<tbody>
<tr>
<td>/X</td>
<td>WF = Sawed 8” wafer on frame (8 mil backgrind)</td>
<td>MCRF450/451/452/455 = 13.56 MHz Read/Write Anti-collision device</td>
</tr>
<tr>
<td></td>
<td>WFB = Bumped, sawed 8” wafer on frame (11 mil backgrind)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>W = 8” wafer (11 mil backgrind)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WB = Bumped 8” wafer (11 mil backgrind)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S = Dice in waffle pack (11 mil backgrind)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SB = Bumped die in waffle pack (11 mil backgrind)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SN = SOIC, 8-lead, 300 mil body</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P = PDIP, 8-lead, 150 mil body</td>
<td></td>
</tr>
</tbody>
</table>

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INTRODUCTION

The 13.56 MHz read/write devices (MCRF4XX) use a 16-bit Cyclic Redundancy Code (CRC) to ensure the integrity of data. Its polynomial and initial values are:

CRC Polynomial: \( X^0 + X^5 + X^{12} + X^{16} = 1000-0100-0000-1000 \) = 8408 (hex)

Initial Value: $FFFF$

This polynomial is also known as CRC CCITT-16. The interrogator applies the same polynomial to the incoming and transmitting data.

FIGURE 1: CCITT-16 CRC ENCODER
COMPUTATION ALGORITHM

Figure 1 shows the CCITT-16 CRC encoder. Figure 2 is the computational flow chart for computer programming.

The encoder consists of 16 shift registers and 3 exclusive-OR gates. The registers start with 1111-1111-1111-1111 (or FFFF in hex). The encoder performs XOR and shifts its content until the last bit is entered. The final register’s content after the last data bit is the calculated CRC value of the data set.

Example: The following procedure shows a workout example of the CRC calculation using the encoder.

FIGURE 2: FLOW-CHART OF CRC COMPUTATION

- CRC Poly = 8408 (1000-0100-0000-1000)
- Input Data
- Initialize CRC = FFFF (1111-1111-1111-1111)

Test Data bit = LSB of Data bits
K = XOR CRC (LSB) with Test Data bit

- K = 0
- No (K = 1)

Shift CRC to right by 1
CRC = XOR CRC with CRC Poly

Shift Data bits to right by 1
Is Test Data bit the MSB of Data bits?

- Yes
- Stop

Data: 8552F189 (hex): 0001-1010-1010-0100-1111-1000-1001 (binary, LSB first for each nibble).
Table 1 shows each step of the calculation. The content of the register after the last bit is 07F1. This 07F1 is the calculated CRC of the data.

When transmitting data, this calculated CRC is attached to the data. The interrogator sends the data and CRC with LSN (Least Significant Nibble) first. Therefore, the hex string to be sent will be: 981F25581F70 and for data = 8552F189.
### TABLE 1: CRC WORKOUT EXAMPLE FOR DATA = 8552F189 (HEX)

<table>
<thead>
<tr>
<th>Bit No.</th>
<th>Input Data</th>
<th>Register Contents</th>
<th>Hex Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1 1 1 1 1 1</td>
<td>- 1 1 1 1 1 1 1 1 - 1 1 1 1</td>
<td>FFFF</td>
</tr>
<tr>
<td>1</td>
<td>0 1 1 1 1 1</td>
<td>- 0 1 1 1 1 1 1 1 - 0 1 1 1</td>
<td>FBF7</td>
</tr>
<tr>
<td>2</td>
<td>0 1 1 1 1 1</td>
<td>- 0 0 1 1 1 1 1 1 - 0 0 1 1</td>
<td>F9F3</td>
</tr>
<tr>
<td>3</td>
<td>0 1 1 1 1 1</td>
<td>- 0 0 0 1 1 1 1 1 - 0 0 1 1</td>
<td>F8F1</td>
</tr>
<tr>
<td>4</td>
<td>1 0 1 1 1 1</td>
<td>- 1 0 0 0 1 1 1 1 - 1 0 0 0</td>
<td>7C78</td>
</tr>
<tr>
<td>5</td>
<td>1 0 0 1 1 1</td>
<td>- 0 1 0 0 0 1 1 1 - 0 1 0 0</td>
<td>BA34</td>
</tr>
<tr>
<td>6</td>
<td>0 0 0 1 0 1</td>
<td>- 1 0 1 0 0 0 1 - 1 0 1 0</td>
<td>5D1A</td>
</tr>
<tr>
<td>7</td>
<td>1 1 0 1 0 1</td>
<td>- 0 1 0 1 0 0 0 0 - 0 1 0 1</td>
<td>AA85</td>
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<tr>
<td>8</td>
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<tr>
<td>9</td>
<td>1 1 1 1 0 1</td>
<td>- 1 0 0 1 1 1 1 1 - 1 1 1 1</td>
<td>ECAD</td>
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<tr>
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<td>F25E</td>
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<td>12</td>
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<td>- 0 1 0 1 0 0 1 - 1 0 1 1</td>
<td>FA9B</td>
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<td>F945</td>
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<tr>
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<td>7CA2</td>
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<td>F477</td>
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<td>- 1 1 1 1 1 1 0 0 - 0 1 1 0</td>
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<td>- 1 1 1 1 1 1 1 0 - 0 0 1 1</td>
<td>0FE3</td>
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<td>- 1 1 1 1 1 1 1 1 - 0 0 0 1</td>
<td>07F1</td>
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</table>

(CRC Value)
APPENDIX A: EXAMPLE WITH C-SOURCE CODE FOR CRC CALCULATION

#include <stdio.h>
#include <stdlib.h>
#include "onescnt.h"
#define NULL 0
#define true 1
#define false 0

void main (int argc, char *argv[])
{
    int i, j, k, message[40], num_bits, bitcount, bytecount, crc, next_bit, crc_temp, message_temp;
    int maskreg[8] = {1, 2, 4, 8, 16, 32, 64, 128};
    int crc_nibble[4];
    char ch
    FILE *fin;
    if (argc != 2)
    { printf ("proper usage is CCITT {indata file with data in hex}\n\n\n"); abort (); }
    if ( (fin =fopen(argv[1], "r")) ==NULL)
    {printf("Can't open %s\n", argv[1]; abort();}
    i = 0;
    while ( (ch=fgetc(fin)) !=EOF)
    {
        message_temp = 0;
        //retrieve the input data field and convert to an integer message field
        if ((ch >= 'a' && (ch <= 'f')) ch = ch - 0x20
        if ((ch >= 'A' && (ch <= 'F')) ch = ch - 0x70
        if ((ch >= '0' && (ch <= '?'))
        {
            message_temp = ch - '0';
            message[i++] = message_temp;
        }
    }
    // At this point, message[ ] holds data with nibbles (4 bits on each array). This will be used for
    // CRC calculation
    message[i] = -1;
    k = i
    // The above is used for array checking and k value is the total number of nibbles.
    printf ("Read in %d nibbles. \n\n\n", k);
    printf ("Original data in hex read in from data file: \n\n\n");
    for (i = 0; i < k; i++)
    printf("%x ", message[ i ]);
    printf("\n\n\n");
    // Now computing the CRC of data
    //---------- Initialization ------------------------------
    crc = 0xffff; //initial CRC value
    crc_poly = 0x8408; //1000-0100-0000-1000
    //-----------------------------------------
    printf ("Initial  CRC value in hex: %x ... \n\n", crc);
    num_bits = k*4;
    for ( i = 0; i < num_bits; i++)
    {
        bitcount = i % 4;
        bytecount = i/4;
        next_bit = (message[bytecount] & maskreg[bitcount]); //This will find the next data bit to apply
        next_bit = ((next_bit >> bitcount) & 1); //This will move the current data bit to LSB of next_bit
        // and make all bits except LSB bit to zero
        crc_temp = crc^next_bit; //xor the last nibble of crc (actually the last bit of CRC) with next_bit
        if (crc_temp & 1)
        {
            printf ("xor = 1\n\n\n");
            crc = crc >> 1; //Shift the crc by 1 to right
            crc = crc\"crc\"crc_poly ; //xor current crc with crc_poly
crc = crc|0x8000; //this may not be necessary
}
// if it is zero, just shift crc by 1
if (!((crc_temp & 1))
{
  printf("xor = 0\n");
crc = crc >> 1;
crc = crc & 0x7fff; // this may not be necessary
}
printf("Temp CRC after iteration %d: ", i);
for (j = i; j<num_bits; j++)
  printf("\n");
printf("%d\n", crc);
crc_nibble[0] = crc & x000f;
crc_nibble[1] = (crc & x000f >> 4);
crc_nibble[2] = (crc & x000f >> 8);
crc_nibble[3] = (crc & x000f >> 12);
printf("Bit order for shifting in nibbles in LSB first. \n");
printf("\nCRC at end: %x\n", crc);
printf("Send %x %x %x %x\n", crc_nibble[0], crc_nibble[1], crc_nibble[2], crc_nibble[3],); 
printf("\n\n");
fclose(fin);
INTRODUCTION

The MCRF355 passive RFID device is designed for low cost, multiple reading, and various high volume tagging applications using a frequency band of 13.56 MHz. The device has a total of 154 memory bits that can be reprogrammed by a contact programmer. The device operates with a 70 kHz data rate, and asynchronously with respect to the reader’s carrier. The device turns on when the coil voltage reaches 4 V PP and outputs data with a Manchester format (see Figure 2-3 in the data sheet). With the given data rate (70 kHz), it takes about 2.2 ms to transmit all 154 bits of the data. After transmitting all data, the device goes into a sleep mode for 100 ms +/- 50%.

The MCRF355 needs only an external parallel LC resonant circuit that consists of an antenna coil and a capacitor for operation. The external LC components must be connected between Antenna Pad A and the ground pad. The circuit formed between Antenna Pad A and the ground pad must be tuned to the operating frequency of the reader antenna.

MODE OF OPERATION

The device transmits data by tuning and detuning the resonant frequency of the external circuit. This process is accomplished by using an internal modulation gate (CMOS), that has a very low turn-on resistance (2 ~ 4 ohms) between Drain and Source. This gate turns on during a logic “High” period of the modulation signal and off otherwise. When the gate turns on, its low turn-on resistance shorts the external circuit between Antenna Pad B and the ground pad. Therefore, the resonant frequency of the circuit changes. This is called detuned or cloaking. Since the detuned tag is out of the frequency band of the reader, the reader can’t see it.

The modulation gate turns off as the modulation signal goes to a logic “Low.” This turn-off condition again tunes the resonant circuit to the frequency of the reader antenna. Therefore the reader sees the tag again. This is called tuned or uncloaking.

The tag coil induces maximum voltage during “uncloaking (tuned)” and minimum voltage during cloaking (detuned). Therefore, the cloaking and uncloaking events develop an amplitude modulation signal in the tag coil.

This amplitude modulated signal in the tag coil perturbs the voltage envelope in the reader coil. The reader coil has maximum voltage during cloaking (detuned) and minimum voltage during uncloaking (tuned). By detecting the voltage envelope, the data signal from the tag can be readily reconstructed.

Once the device transmits all 154 bits of data, it goes into “sleep mode” for about 100 ms. The tag wakes up from sleep time (100 ms) and transmits the data package for 2.2 ms and goes into sleep mode again. The device repeats the transmitting and sleep cycles as long as it is energized.

FIGURE 3: VOLTAGE ENVELOPE IN READER COIL

When tag is in cloaking

When tag is in uncloaking
FIGURE 4: (A) UNCLOAKING (TUNED) AND (B) CLOAKING (DETUNED) MODES AND THEIR RESONANT FREQUENCIES

(a)

(b)

(c)

(d)

$\frac{f_0}{f_0} = 13.56 \text{ MHz}$

$SW = OFF$

$SW = ON$

$SW = OFF$

$SW = ON$

$\Delta f$ MHz

Coil voltage in tag

Coil voltage in tag

$f_0 = (13.56 + \Delta f) \text{ MHz}$

$\frac{f_0}{f_0} = 13.56 \text{ MHz}$

$SW = OFF$

$SW = ON$

$\frac{f_0}{f_0} = (13.56 - \Delta f) \text{ MHz}$
ANTI-COLLISION FEATURES

During sleep mode, the device remains in a cloaked state where the circuit is detuned. Therefore, the reader can’t see the tag during sleep time. While one tag is in sleep mode, the reader can receive data from other tags. This enables the reader to receive clean data from many tags without any data collision. This ability to read multiple tags in the same RF field is called anti-collision. Theoretically, more than 50 tags can be read in the same RF field. However, it is affected by distance from the tag to the reader, angular orientation, movement of the tags, and spacial distribution of the tags.

FIGURE 5: EXAMPLE OF READING MULTIPLE TAGS
EXTERNAL CIRCUIT CONFIGURATION

Since the device transmits data by tuning and detuning the antenna circuit, caution must be given in the external circuit configuration. For a better modulation index, the differences between the tuned and detuned frequencies must be wide enough (about 3 ~ 6 MHz).

Figure 6 shows various configurations of the external circuit. The choice of the configuration must be chosen depending on the form-factor of the tag. For example, (a) is a better choice for printed circuit tags while, (b) is a better candidate for coil-wound tags. Both (a) and (b) relate to the MCRF355.

In configuration (a), the tuned resonance frequency is determined by a total capacitance and inductance from Antenna Pad A to Vss. During cloaking, the internal switch (modulation gate) shorts Antenna Pad B and Vss. Therefore, the inductance L2 is shorted out. As a result, the detuned frequency is determined by the total capacitance and inductance L1. When shorting the inductance between Antenna Pad B and Vss, the detuned (cloak) frequency is higher than the tuned (uncloak) frequency.

In configuration (b), the tuned frequency (uncloak) is determined by the inductance L and the total capacitance between Antenna Pad A and Vss. The circuit detunes (cloak) when C2 is shorted. This detuned frequency (cloak) is lower than the tuned (uncloak) frequency.

The MCRF360 includes a 100 pF internal capacitor. This device needs only an external inductor for operation. The explanation on tuning and detuning is the same as for configuration (a).
FIGURE 6: VARIOUS EXTERNAL CIRCUIT CONFIGURATIONS

(a) Two inductors and one capacitor

\[ f_{\text{tuned}} = \frac{1}{2\pi \sqrt{L_1 C}} \]

\[ f_{\text{detuned}} = \frac{1}{2\pi \sqrt{L_2 C}} \]

where:

\[ L_m = \text{mutual inductance} \]

\[ K = \frac{L_1 L_2}{L_1 + L_2 + 2L_m} \]

0 ≤ K ≤ 1

(b) Two capacitors and one inductor

\[ f_{\text{tuned}} = \frac{1}{2\pi \sqrt{C_1 C_2}} \]

\[ f_{\text{detuned}} = \frac{1}{2\pi \sqrt{C_1 C_2}} \]

\[ C_T = \frac{C_1 C_2}{C_1 + C_2} \]

(c) Two inductors with one internal capacitor

\[ f_{\text{tuned}} = \frac{1}{2\pi \sqrt{L_1 C}} \]

\[ f_{\text{detuned}} = \frac{1}{2\pi \sqrt{L_2 C}} \]

\[ L_T = L_1 + L_2 + 2L_m \]
PROGRAMMING OF DEVICE

All of the memory bits in the device are reprogrammable by a contact programmer or by factory programming prior to shipment, known as Serialized Quick Turn Programming™ (SQTP™). For more information about contact programming, see the microID™ 13.56 MHz System Design Guide (DS21299). For information about SQTP programming, please see TB032 (DS91032), of the design guide.
INTRODUCTION

Passive RFID tags utilize an induced antenna coil voltage for operation. This induced AC voltage is rectified to provide a voltage source for the device. As the DC voltage reaches a certain level, the device starts operating. By providing an energizing RF signal, a reader can communicate with a remotely located device that has no external power source such as a battery. Since the energizing and communication between the reader and tag is accomplished through antenna coils, it is important that the device must be equipped with a proper antenna circuit for successful RFID applications.

An RF signal can be radiated effectively if the linear dimension of the antenna is comparable with the wavelength of the operating frequency. However, the wavelength at 13.56 MHz is 22.12 meters. Therefore, it is difficult to form a true antenna for most RFID applications. Alternatively, a small loop antenna circuit that is resonating at the frequency is used. A current flowing into the coil radiates a near-field magnetic field that falls off with r⁻³. This type of antenna is called a magnetic dipole antenna.

For 13.56 MHz passive tag applications, a few microhenries of inductance and a few hundred pF of resonant capacitor are typically used. The voltage transfer between the reader and tag coils is accomplished through inductive coupling between the two coils. As in a typical transformer, where a voltage in the primary coil transfers to the secondary coil, the voltage in the reader antenna coil is transferred to the tag antenna coil and vice versa. The efficiency of the voltage transfer can be increased significantly with high Q circuits.

This section is written for RF coil designers and RFID system engineers. It reviews basic electromagnetic theories on antenna coils, a procedure for coil design, calculation and measurement of inductance, an antenna tuning method, and read range in RFID applications.

REVIEW OF A BASIC THEORY FOR RFID ANTENNA DESIGN

Current and Magnetic Fields

Ampere’s law states that current flowing in a conductor produces a magnetic field around the conductor. The magnetic field produced by a current element, as shown in Figure 7, on a round conductor (wire) with a finite length is given by:

EQUATION 1:

\[ B_\phi = \frac{\mu_0 I}{4\pi r} (\cos \alpha_2 - \cos \alpha_1) \]  

(Weber/m²)

where:

- \( I \) = current
- \( r \) = distance from the center of wire
- \( \mu_0 \) = permeability of free space and given as \( 4 \pi \times 10^{-7} \) (Henry/meter)

In a special case with an infinitely long wire where:

\( \alpha_1 = -180^\circ \)
\( \alpha_2 = 0^\circ \)

Equation 1 can be rewritten as:

EQUATION 2:

\[ B_\phi = \frac{\mu_0 I}{2\pi r} \]  

(Weber/m²)

FIGURE 7: CALCULATION OF MAGNETIC FIELD B AT LOCATION P DUE TO CURRENT I ON A STRAIGHT CONDUCTING WIRE
The magnetic field produced by a circular loop antenna is given by:

**EQUATION 3:**

\[
B_z = \frac{\mu_0 INa^2}{2(a^2 + r^2)^{3/2}}
\]

\[
= \frac{\mu_0 INa^2}{2} \left( \frac{1}{r^3} \right) \quad \text{for} \quad r^2 > a^2
\]

where

- \( I \) = current
- \( a \) = radius of loop
- \( r \) = distance from the center of wire
- \( \mu_0 \) = permeability of free space and given as \( \mu_0 = 4\pi \times 10^{-7} \) (Henry/meter)

The above equation indicates that the magnetic field strength decays with \( 1/r^3 \). A graphical demonstration is shown in Figure 9. It has maximum amplitude in the plane of the loop and directly proportional to both the current and the number of turns, \( N \).

Equation 3 is often used to calculate the ampere-turn requirement for read range. A few examples that calculate the ampere-turns and the field intensity necessary to power the tag will be given in the following sections.
**INDUCED VOLTAGE IN AN ANTENNA COIL**

Faraday’s law states that a time-varying magnetic field through a surface bounded by a closed path induces a voltage around the loop.

Figure 10 shows a simple geometry of an RFID application. When the tag and reader antennas are in close proximity, the time-varying magnetic field \( B \) that is produced by a reader antenna coil induces a voltage (called electromotive force or simply EMF) in the closed tag antenna coil. The induced voltage in the coil causes a flow of current on the coil. This is called Faraday’s law. The induced voltage on the tag antenna coil is equal to the time rate of change of the magnetic flux \( \Psi \).

**EQUATION 4:**

\[
V = -N \frac{d\Psi}{dt}
\]

where:

- \( N \) = number of turns in the antenna coil
- \( \Psi \) = magnetic flux through each turn

The negative sign shows that the induced voltage acts in such a way as to oppose the magnetic flux producing it. This is known as Lenz’s Law and it emphasizes the fact that the direction of current flow in the circuit is such that the induced magnetic field produced by the induced current will oppose the original magnetic field.

The magnetic flux \( \Psi \) in Equation 4 is the total magnetic field \( B \) that is passing through the entire surface of the antenna coil, and found by:

**EQUATION 5:**

\[
\Psi = \int B \cdot dS
\]

where:

- \( B \) = magnetic field given in Equation 2
- \( S \) = surface area of the coil

*Note:* Both magnetic field \( B \) and surface \( S \) are vector quantities.

The presentation of inner product of two vectors in Equation 5 suggests that the total magnetic flux \( \Psi \) that is passing through the antenna coil is affected by an orientation of the antenna coils. The inner product of two vectors becomes minimized when the cosine angle between the two are 90 degrees, or the two (\( B \) field and the surface of coil) are perpendicular to each other and maximized when the cosine angle is 0 degrees.

The maximum magnetic flux that is passing through the tag coil is obtained when the two coils (reader coil and tag coil) are placed in parallel with respect to each other. This condition results in maximum induced voltage in the tag coil and also maximum read range. The inner product expression in Equation 5 also can be expressed in terms of a mutual coupling between the reader and tag coils. The mutual coupling between the two coils is maximized in the above condition.

**FIGURE 10: A BASIC CONFIGURATION OF READER AND TAG ANTENNAS IN RFID APPLICATIONS**
Using Equations 3 and 5, Equation 4 can be rewritten as:

**EQUATION 6:**

\[ V = - N_2 \frac{d\Psi_{21}}{dt} = - N_2 \frac{d}{dt} \left( B \cdot dS \right) \]

\[ = - N_2 \frac{d}{dt} \left[ \frac{\mu_o \mu_{1} N_1 a^2}{2(a^2 + r^2)^{3/2}} dS \right] \]

\[ = - \left[ \frac{\mu_o \mu_{1} N_1 N_2 a^2 (\pi b^2)}{2(a^2 + r^2)^{3/2}} \right] \frac{di_1}{dt} \]

\[ = - M \frac{di_1}{dt} \]

where:
- \( V \) = voltage in the tag coil
- \( i_1 \) = current on the reader coil
- \( a \) = radius of the reader coil
- \( b \) = radius of tag coil
- \( r \) = distance between the two coils
- \( M \) = mutual inductance between the tag and reader coils, and given by:

**EQUATION 7:**

\[ M = \frac{\mu_o \pi N_1 N_2 (ab)^2}{2(a^2 + r^2)^{3/2}} \]

The above equation is equivalent to a voltage transformation in typical transformer applications. The current flow in the primary coil produces a magnetic flux that causes a voltage induction at the secondary coil.

As shown in Equation 6, the tag coil voltage is largely dependent on the mutual inductance between the two coils. The mutual inductance is a function of coil geometry and the spacing between them. The induced voltage in the tag coil decreases with \( r^{-3} \). Therefore, the read range also decreases in the same way.

From Equations 4 and 5, a generalized expression for induced voltage \( V_0 \) in a tuned loop coil is given by:

**EQUATION 8:**

\[ V_0 = 2\pi f N S Q B_o \cos \alpha \]

where:
- \( f \) = frequency of the arrival signal
- \( N \) = number of turns of coil in the loop
- \( S \) = area of the loop in square meters (m²)
- \( Q \) = quality factor of circuit
- \( B_o \) = strength of the arrival signal
- \( \alpha \) = angle of arrival of the signal

In the above equation, the quality factor \( Q \) is a measure of the selectivity of the frequency of the interest. The \( Q \) will be defined in Equations 31 through 47.

**FIGURE 11: ORIENTATION DEPENDENCY OF THE TAG ANTENNA**

The induced voltage developed across the loop antenna coil is a function of the angle of the arrival signal. The induced voltage is maximized when the antenna coil is placed in parallel with the incoming signal where \( \alpha = 0 \).
EXAMPLE 2: CALCULATION OF B-FIELD IN A TAG COIL

The MCRF355 device turns on when the antenna coil develops 4 VPP across it. This voltage is rectified and the device starts to operate when it reaches 2.4 Vcc. The B-field to induce a 4 VPP coil voltage with an ISO standard 7810 card size (85.6 x 54 x 0.76 mm) is calculated from the coil voltage equation using Equation 8.

**EQUATION 9:**

\[ V_o = 2\pi fNSQB_o \cos \alpha = 4 \]

and

\[ B_o = \frac{4/(\sqrt{2})}{2\pi fNSQ \cos \alpha} = 0.0449 \, \text{mT} \]

where the following parameters are used in the above calculation:

- Tag coil size = (85.6 x 54) mm² (ISO card size) = 0.0046224 m²
- Frequency = 13.56 MHz
- Number of turns = 4
- Q of tag antenna = 40
- AC coil voltage to turn on the tag
- \( \cos \alpha = 1 \) (normal direction, \( \alpha = 0 \)).

EXAMPLE 3: NUMBER OF Turns AND CURRENT (AMPERE-URNS)

Assuming that the reader should provide a read range of 15 inches (38.1 cm) for the tag given in the previous example, the current and number of turns of a reader antenna coil is calculated from Equation 3:

**EQUATION 10:**

\[ (NI)_{rms} = \frac{2B_z(a^2 + r^2)^{3/2}}{\mu a^2} \]

\[ = \frac{2(0.0449 \times 10^{-6})(0.1^2 + (0.38)^2)^{3/2}}{(4\pi \times 10^{-7})(0.1^2)} \]

\[ = 0.43 \text{ (ampere-turns)} \]

The above result indicates that it needs a 430 mA for 1 turn coil, and 215 mA for 2-turn coil.

EXAMPLE 4: OPTIMUM COIL DIAMETER OF THE READER COIL

An optimum coil diameter that requires the minimum number of ampere-turns for a particular read range can be found from Equation 3 such as:

**EQUATION 11:**

\[ NI = K \frac{(a^2 + r^2)^{3/2}}{a^2} \]

where:

\[ K = \frac{2B_z}{\mu_o} \]

By taking derivative with respect to the radius \( \alpha \),

\[ \frac{d(NI)}{da} = \frac{3/2(2a + 2r)^{1/2}}{2a} - 2(a^2 + r^2)^{3/2} \]

\[ = K \frac{(a^2 - 2r^2)(a^2 + 2r^2)^{1/2}}{a^3} \]

The above equation becomes minimized when:

\[ a^2 - 2r^2 = 0 \]

The above result shows a relationship between the read range versus optimum coil diameter. The optimum coil diameter is found as:

**EQUATION 12:**

\[ a = \sqrt[3]{r} \]

where:

- \( a \) = radius of coil
- \( r \) = read range.

The result indicates that the optimum loop radius, \( a \), is 1.414 times the demanded read range \( r \).
WIRE TYPES AND OHMIC LOSSES

Wire Size and DC Resistance

The diameter of electrical wire is expressed as the American Wire Gauge (AWG) number. The gauge number is inversely proportional to diameter, and the diameter is roughly doubled every six wire gauges. The wire with a smaller diameter has a higher DC resistance. The DC resistance for a conductor with a uniform cross-sectional area is found by:

\[ R_{DC} = \frac{l}{\sigma S} \]  \( \Omega \)

where:
- \( l \) = total length of the wire
- \( \sigma \) = conductivity
- \( S \) = cross-sectional area

Table 6 shows the diameter for bare and enamel-coated wires, and DC resistance.

AC Resistance of Wire

At DC, charge carriers are evenly distributed through the entire cross section of a wire. As the frequency increases, the reactance near the center of the wire increases. This results in higher impedance to the current density in the region. Therefore, the charge moves away from the center of the wire and towards the edge of the wire. As a result, the current density decreases in the center of the wire and increases near the edge of the wire. This is called a skin effect. The depth into the conductor at which the current density falls to 1/e, or 37% of its value along the surface, is known as the skin depth and is a function of the frequency and the permeability and conductivity of the medium. The skin depth is given by:

\[ \delta = \frac{1}{\sqrt{\pi f \mu \sigma}} \]

where:
- \( f \) = frequency
- \( \mu \) = permeability of material
- \( \sigma \) = conductivity of the material

**EXAMPLE 5:**

The skin depth for a copper wire at 13.56 MHz can be calculated as:

\[ \delta = \frac{1}{\sqrt{\pi f \mu \sigma}} \]

\[ \delta = \frac{1}{\sqrt{\pi \times 13.56 \times 10^{-7} \times 5.8 \times 10^{-7}}} \]

\[ \delta = 0.0179 \]  \( m \)

\[ \delta = 0.187 \]  \( mm \)

The wire resistance increases with frequency, and the resistance due to the skin depth is called an AC resistance. An approximated formula for the AC resistance is given by:

\[ R_{ac} \approx \frac{1}{2 \pi \delta a} = \left( R_{DC} \delta \right) \frac{a}{2 \delta} \]  \( \Omega \)

where:
- \( a \) = coil radius
### TABLE 6: AWG WIRE CHART

<table>
<thead>
<tr>
<th>Wire Size (AWG)</th>
<th>Dia. in Mils (bare)</th>
<th>Dia. in Mils (coated)</th>
<th>Ohms/1000 ft.</th>
<th>Cross Section (mils)</th>
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**Note:** mil = 2.54 x 10^{-3} cm

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<tr>
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<th>Dia. in Mils (bare)</th>
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<th>Cross Section (mils)</th>
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**Note:** mil = 2.54 x 10^{-3} cm
INDUCTANCE OF VARIOUS ANTENNA COILS

An electric current element that flows through a conductor produces a magnetic field. This time-varying magnetic field is capable of producing a flow of current through another conductor – this is called *inductance*. The inductance $L$ depends on the physical characteristics of the conductor. A coil has more inductance than a straight wire of the same material, and a coil with more turns has more inductance than a coil with fewer turns. The inductance $L$ of inductor is defined as the ratio of the total magnetic flux linkage to the current $I$ through the inductor:

**EQUATION 17:**

$$L = \frac{N\Psi}{I} \quad \text{(Henry)}$$

where:

$N$ = number of turns
$I$ = current
$\Psi$ = the magnetic flux

For a coil with multiple turns, the inductance is greater as the spacing between turns becomes smaller. Therefore, the tag antenna coil that has to be formed in a limited space often needs a multilayer winding to reduce the number of turns.

**Calculation of Inductance**

Inductance of the coil can be calculated in many different ways. Some are readily available from references\[1-4\]. It must be remembered that for RF coils the actual resulting inductance may differ from the calculated true result because of distributed capacitance. For that reason, inductance calculations are generally used only for a starting point in the final design.

**INDUCTANCE OF A STRAIGHT WOUND WIRE**

The inductance of a straight wound wire shown in Figure 7 is given by:

**EQUATION 18:**

$$L = 0.0021 \left[ \log_e \frac{2l}{\pi a} - \frac{3}{4} \right] \quad \text{(\mu H)}$$

where:

$l$ and $a$ = length and radius of wire in cm, respectively.

**EXAMPLE 7: INDUCTANCE CALCULATION FOR A STRAIGHT WIRE:**

The inductance of a wire with 10 feet (304.8 cm) long and 2 mm in diameter is calculated as follows:

**EQUATION 19:**

$$L = 0.002 \left(3.048 \right) \left[ \ln \left(\frac{2 \times 3.048}{0.1} \right) - \frac{3}{4} \right]$$

$$= 0.60967(7.965)$$

$$= 4.855(\mu H)$$

**INDUCTANCE OF THIN FILM INDUCTOR WITH A RECTANGULAR CROSS SECTION**

Inductance of a conductor with rectangular cross section as shown in Figure 12 is calculated as:

**FIGURE 12: A STRAIGHT THIN FILM INDUCER**

**EQUATION 20:**

$$L = 0.002 \left[ \ln \left(\frac{2l}{a+b} \right) + 0.50049 \frac{a+b}{3l} \right] \quad \text{(\mu H)}$$

where:

$a$ = width in cm
$b$ = thickness in cm
$l$ = length of conductor in cm
INDUCTANCE OF A CIRCULAR COIL WITH SINGLE TURN

The inductance of a circular coil shown in Figure 13 can be calculated by:

**FIGURE 13: A CIRCULAR COIL WITH SINGLE TURN**

![Diagram of a circular coil with single turn]

**EQUATION 21:**

\[ L = 0.01257(a) \left[ 2.303 \log_{10} \left( \frac{16a}{d} - 2 \right) \right] \quad (\mu H) \]

where:
- \( a \) = mean radius of loop in (cm)
- \( d \) = diameter of wire in (cm)

**INDUCTANCE OF AN N-TURN CIRCULAR COIL WITH SINGLE LAYER**

The inductance of a circular coil with single layer is calculated as:

**EQUATION 22:**

\[ L = \frac{(aN)^2}{22.9l + 25.4a} \quad (\mu H) \]

where:
- \( a \) = average radius of the coil in cm
- \( N \) = number of turns
- \( l \) = length
- \( b \) = winding thickness in cm
- \( h \) = winding height in cm

**FIGURE 14: N-TURN CIRCULAR COIL WITH SINGLE LAYER**

![Diagram of an N-turn inductor of circular coil with multilayer]

Figure 14 shows an N-turn inductor of circular coil with multilayer. Its inductance is calculated by:

**EQUATION 23:**

\[ L = \frac{0.31(aN)^2}{6a + 9h + 10b} \quad (\mu H) \]

where:
- \( a \) = average radius of the coil in cm
- \( N \) = number of turns
- \( b \) = winding thickness in cm
- \( h \) = winding height in cm
INDUCTANCE OF SPIRAL WOUND COIL WITH SINGLE LAYER

The inductance of a spiral inductor is calculated by:

**EQUATION 24:**

\[
L = \frac{(aN)^2}{8a + 11b} \quad (\mu H)
\]

**FIGURE 15: A SPIRAL COIL**

where:

\[
a = \frac{(r_i + r_o)}{2}
\]

\[
b = r_o - r_i
\]

\[
r_i = \text{Inner radius of the spiral}
\]

\[
r_o = \text{Outer radius of the spiral}
\]

**Note:** All dimensions are in cm

INDUCTANCE OF N-TURN SQUARE LOOP COIL WITH MULTILAYER

Inductance of a multilayer square loop coil is calculated by:

**EQUATION 25:**

\[
L = 0.008aN^2 \left\{ 2.303 \log_{10} \left( \frac{a}{b+c} \right) + 0.2235 \frac{b+c}{a} + 0.726 \right\} \quad (\mu H)
\]

where:

\[
N = \text{number of turns}
\]

\[
a = \text{side of square measured to the center of the rectangular cross section of winding}
\]

\[
b = \text{winding length}
\]

\[
c = \text{winding depth as shown in Figure 16}
\]

**Note:** All dimensions are in cm

**FIGURE 16: N-TURN SQUARE LOOP COIL WITH MULTILAYER**

where:

\[
a = \text{side of square measured to the center of the rectangular cross section of winding}
\]

\[
b = \text{winding length}
\]

\[
c = \text{winding depth as shown in Figure 16}
\]

**Note:** All dimensions are in cm
INDUCTANCE OF A FLAT SQUARE COIL

Inductance of a flat square coil of rectangular cross section with $N$ turns is calculated by[^4]:

EQUATION 26:

$$L = 0.0467aN^2\left\{\log_{10}\left(\frac{2}{t+w}\right) - \log_{10}(2.414a)\right\} + 0.02032aN^2\left\{0.914 + \frac{0.2235}{a(t+w)}\right\}$$

where:

- $L$ = in μH
- $a$ = side length in inches
- $t$ = thickness in inches
- $w$ = width in inches

FIGURE 17: SQUARE LOOP INDUCTOR WITH A RECTANGULAR CROSS SECTION

The formulas for inductance are widely published and provide a reasonable approximation for the relationship between inductance and the number of turns for a given physical size[^1–4]. When building prototype coils, it is wise to exceed the number of calculated turns by about 10% and then remove turns to achieve a right value. For production coils, it is best to specify an inductance and tolerance rather than a specific number of turns.
CONFIGURATION OF ANTENNA CIRCUITS

Reader Antenna Circuits

The inductance for the reader antenna coil for 13.56 MHz is typically in the range of a few microhenries (µH). The antenna can be formed by aircore or ferrite core inductors. The antenna can also be formed by a metallic or conductive trace on PCB board or on flexible substrate.

The reader antenna can be made of either a single coil, that is typically forming a series or a parallel resonant circuit, or a double loop (transformer) antenna coil. Figure 18 shows various configurations of reader antenna circuit. The coil circuit must be tuned to the operating frequency to maximize power efficiency. The tuned LC resonant circuit is the same as the bandpass filter that passes only a selected frequency. The Q of the tuned circuit is related to both read range and bandwidth of the circuit. More on this subject will be discussed in the following section.

Choosing the size and type of antenna circuit depends on the system design topology. The series resonant circuit results in minimum impedance at the resonance frequency. Therefore, it draws a maximum current at the resonance frequency. Because of its simple circuit topology and relatively low cost, this type of antenna circuit is suitable for proximity reader antenna.

On the other hand, a parallel resonant circuit results in maximum impedance at the resonance frequency. Therefore, maximum voltage is available at the resonance frequency. Although it has a minimum resonant current, it still has a strong circulating current that is proportional to Q of the circuit. The double loop antenna coil that is formed by two parallel antenna circuits can also be used.

The frequency tolerance of the carrier frequency and output power level from the read antenna is regulated by government regulations (e.g., FCC in the USA).

FCC limits for 13.56 MHz frequency band are as follows:

1. Tolerance of the carrier frequency: 13.56 MHz +/- 0.01% = +/- 1.356 kHz.
2. Frequency bandwidth: +/- 7 kHz.
3. Power level of fundamental frequency: 10 mv/m at 30 meters from the transmitter.
4. Power level for harmonics: -50.45 dB down from the fundamental signal.

The transmission circuit including the antenna coil must be designed to meet the FCC limits.

FIGURE 18: VARIOUS READER ANTENNA CIRCUITS

(a) Series Resonant Circuit
(b) Parallel Resonant Circuit
(c) Transformer Loop Antenna
Tag Antenna Circuits

The MCRF355 device communicates data by tuning and detuning the antenna circuit (see AN707). Figure 19 shows examples of the external circuit arrangement.

The external circuit must be tuned to the resonant frequency of the reader antenna. In a detuned condition, a circuit element between the antenna B and Vss pads is shorted. The frequency difference (delta frequency) between tuned and detuned frequencies must be adjusted properly for optimum operation. It has been found that maximum modulation index and maximum read range occur when the tuned and detuned frequencies are separated by 3 to 6 MHz.

The tuned frequency is formed from the circuit elements between the antenna A and Vss pads without shorting the antenna B pad. The detuned frequency is found when the antenna B pad is shorted. This detuned frequency is calculated from the circuit between antenna A and Vss pads excluding the circuit element between antenna B and Vss pads.

In Figure 19 (a), the tuned resonant frequency is:

EQUATION 27:

\[ f_t = \frac{1}{2\pi \sqrt{L_T C}} \]

where:

\[ L_T = L_1 + L_2 + 2L_M = \text{Total inductance between antenna A and Vss pads} \]
\[ L_1 = \text{inductance between antenna A and antenna B pads} \]
\[ L_2 = \text{inductance between ant. B and Vss pads} \]
\[ M = \text{mutual inductance between coil 1 and coil 2} \]
\[ M = k \frac{L_1 L_2}{L} \]
\[ k = \text{coupling coefficient between the two coils} \]
\[ C = \text{tuning capacitance} \]

and detuned frequency is:

EQUATION 28:

\[ f_{\text{detuned}} = \frac{1}{2\pi \sqrt{L_1 C}} \]

In this case, \( f_{\text{detuned}} \) is higher than \( f_{\text{tuned}} \).

Figure 19(b) shows another example of the external circuit arrangement. This configuration controls \( C_2 \) for tuned and detuned frequencies. The tuned and untuned frequencies are

EQUATION 29:

\[ f_{\text{tuned}} = \frac{1}{2\pi \sqrt{\frac{C_1 C_2}{C_1 + C_2} L}} \]

and

EQUATION 30:

\[ f_{\text{detuned}} = \frac{1}{2\pi \sqrt{L C_1}} \]

A typical inductance of the coil is about a few microhenry with a few turns. Once the inductance is determined, the resonant capacitance is calculated from the above equations. For example, if a coil has an inductance of 1.3 \( \mu \text{H} \), then it needs a 106 pF of capacitance to resonate at 13.56 MHz.
CONSIDERATION ON QUALITY FACTOR $Q$ AND BANDWIDTH OF TUNING CIRCUIT

The voltage across the coil is a product of quality factor $Q$ of the circuit and input voltage. Therefore, for a given input voltage signal, the coil voltage is directly proportional to the $Q$ of the circuit. In general, a higher $Q$ results in longer read range. However, the $Q$ is also related to the bandwidth of the circuit as shown in the following equation.

**EQUATION 31:**

$$Q = \frac{f_o}{B}$$

**FIGURE 19: VARIOUS EXTERNAL CIRCUIT CONFIGURATIONS**

(a) Two inductors and one capacitor

(b) Two capacitors and one inductor

(c) Two inductors with one internal capacitor

where:

- $L_m$ = mutual inductance
- $K = \frac{L_1 L_2}{L_1 + L_2 + 2L_m}$
- $0 \leq K \leq 1$

$$f_{tuned} = \frac{1}{2\pi \sqrt{L_T C}}$$

$$f_{detuned} = \frac{1}{2\pi \sqrt{L_1 C}}$$

$$L_T = L_1 + L_2 + 2L_m$$

$$C_T = \frac{C_1 C_2}{C_1 + C_2}$$

$C = 100 \text{ pF}$

$K = \frac{L_1 L_2}{L_1 + L_2 + 2L_m}$

$0 \leq K \leq 1$
Bandwidth requirement and limit on circuit $Q$ for MCRF355

Since the MCRF355 operates with a data rate of 70 kHz, the reader antenna circuit needs a bandwidth of at least twice of the data rate. Therefore, it needs:

**EQUATION 32:**

$$B_{\text{minimum}} = 140 \text{ kHz}$$

Assuming the circuit is tuned at 13.56 MHz, the maximum attainable $Q$ is obtained from Equations 31 and 32:

**EQUATION 33:**

$$Q_{\text{max}} = \frac{f_0}{B} = 96.8$$

In a practical LC resonant circuit, the range of $Q$ for 13.56 MHz band is about 40. However, the $Q$ can be significantly increased with a ferrite core inductor. The system designer must consider the above limits for optimum operation.

**RESONANT CIRCUITS**

Once the frequency and the inductance of the coil are determined, the resonant capacitance can be calculated from:

**EQUATION 34:**

$$C = \frac{1}{L(2\pi f_0)^2}$$

In practical applications, parasitic (distributed) capacitance is present between turns. The parasitic capacitance in a typical tag antenna coil is a few (pF). This parasitic capacitance increases with operating frequency of the device.

There are two different resonant circuits: parallel and series. The parallel resonant circuit has maximum impedance at the resonance frequency. It has a minimum current and maximum voltage at the resonance frequency. Although the current in the circuit is minimum at the resonant frequency, there are a circulation current that is proportional to $Q$ of the circuit. The parallel resonant circuit is used in both the tag and the high-power reader antenna circuit.

On the other hand, the series resonant circuit has a minimum impedance at the resonance frequency. As a result, maximum current is available in the circuit. Because of its simplicity and the availability of the high current into the antenna element, the series resonant circuit is often used for a simple proximity reader.

**Parallel Resonant Circuit**

Figure 20 shows a simple parallel resonant circuit. The total impedance of the circuit is given by:

**EQUATION 35:**

$$Z(j\omega) = \frac{j\omega L}{(1 - \omega^2 LC) + j\omega L R}$$

where $\omega$ is an angular frequency given as $\omega = 2\pi f_0$.

The maximum impedance occurs when the denominator in the above equation is minimized. This condition occurs when:

**EQUATION 36:**

$$\omega^2 LC = 1$$

This is called a resonance condition, and the resonance frequency is given by:

**EQUATION 37:**

$$f_0 = \frac{1}{2\pi \sqrt{LC}}$$

By applying Equation 36 into Equation 35, the impedance at the resonance frequency becomes:

**EQUATION 38:**

$$Z = R$$

where $R$ is the load resistance.

**FIGURE 20: PARALLEL RESONANT CIRCUIT**

The $R$ and $C$ in the parallel resonant circuit determine the bandwidth, $B$, of the circuit.

**EQUATION 39:**

$$B = \frac{1}{2\pi RC}$$

The quality factor, $Q$, is defined by various ways such as
EQUATION 40:

\[ Q = \frac{\text{Energy Stored in the System per One Cycle}}{\text{Energy Dissipated in the System per One Cycle}} \]

\[ = \frac{\text{reactance}}{\text{resistance}} \]

\[ = \frac{\omega L}{r} \quad \text{For inductance} \]

\[ = \frac{1}{\omega C r} \quad \text{For capacitance} \]

\[ = \frac{f_0}{B} \]

where:

\( \omega = 2\pi f = \text{angular frequency} \)

\( f_0 = \text{resonant frequency} \)

\( B = \text{bandwidth} \)

\( r = \text{ohmic losses} \)

By applying Equation 37 and Equation 39 into Equation 40, the \( Q \) in the parallel resonant circuit is:

EQUATION 41:

\[ Q = R\frac{C}{\sqrt{L}} \]

The \( Q \) in a parallel resonant circuit is proportional to the load resistance \( R \) and also to the ratio of capacitance and inductance in the circuit.

When this parallel resonant circuit is used for the tag antenna circuit, the voltage drop across the circuit can be obtained by combining Equations 8 and 41:

EQUATION 42:

\[ V_o = 2\pi f_0 N Q S B_o \cos \alpha \]

\[ = 2\pi f_0 N\left( R\frac{C}{\sqrt{L}}\right) S B_0 \cos \alpha \]

The above equation indicates that the induced voltage in the tag coil is inversely proportional to the square root of the coil inductance, but proportional to the number of turns and surface area of the coil.

Series Resonant Circuit

A simple series resonant circuit is shown in Figure 21. The expression for the impedance of the circuit is:

EQUATION 43:

\[ Z(j\omega) = r + j(X_L - X_C) \quad (\Omega) \]

where:

\( r = \text{a DC ohmic resistance of coil and capacitor} \)

\( X_L and X_C = \text{the reactance of the coil and capacitor, respectively, such that:} \)

EQUATION 44:

\[ X_L = 2\pi f_0 L \quad (\Omega) \]

EQUATION 45:

\[ X_C = \frac{1}{2\pi f_0 C} \quad (\Omega) \]

The impedance in Equation 43 becomes minimized when the reactance component cancelled out each other such that \( X_L = X_C \). This is called a resonance condition. The resonance frequency is same as the parallel resonant frequency given in Equation 37.
The half power frequency bandwidth is determined by $r$ and $L$, and given by:

**EQUATION 46:**

$$B = \frac{r}{2\pi L} \quad (Hz)$$

The quality factor, $Q$, in the series resonant circuit is given by:

$$Q = \frac{f_0}{B} = \frac{\omega L}{r} = \frac{1}{\omega r C}$$

The series circuit forms a voltage divider, the voltage drops in the coil is given by:

**EQUATION 47:**

$$V_o = \frac{jX_L}{r + jX_L - jX_C} V_{in}$$

When the circuit is tuned to a resonant frequency such as $X_L = X_C$, the voltage across the coil becomes:

**EQUATION 48:**

$$V_o = \frac{jX_L}{r} V_{in}$$

$$= jQV_{in}$$

The above equation indicates that the coil voltage is a product of input voltage and $Q$ of the circuit. For example, a circuit with $Q$ of 40 can have a coil voltage that is 40 times higher than input signal. This is because all energy in the input signal spectrum becomes squeezed into a single frequency band.

**EXAMPLE 8: CIRCUIT PARAMETERS**

If the DC ohmic resistance $r$ is 5 $\Omega$, then the $L$ and $C$ values for 13.56 MHz resonant circuit with $Q = 40$ are:

**EQUATION 49:**

$$X_L = Qr_s = 200\Omega$$

$$L = \frac{X_L}{2\pi f} = \frac{200}{2\pi(13.56\text{MHz})} = 2.347 \quad (\mu\text{H})$$

$$C = \frac{1}{2\pi f X_L} = \frac{1}{2\pi(13.56\text{MHz})(200)} = 58.7 \quad (\text{pF})$$
TUNING METHOD

The circuit must be tuned to the resonance frequency for a maximum performance (read range) of the device. Two examples of tuning the circuit are as follows:

- **Voltage Measurement Method:**
  a) Set up a voltage signal source at the resonance frequency.
  b) Connect a voltage signal source across the resonant circuit.
  c) Connect an Oscilloscope across the resonant circuit.
  d) Tune the capacitor or the coil while observing the signal amplitude on the Oscilloscope.
  e) Stop the tuning at the maximum voltage.

- **S-parameter or Impedance Measurement Method using Network Analyzer:**
  a) Set up an S-Parameter Test Set (Network Analyzer) for S11 measurement, and do a calibration.
  b) Measure the S11 for the resonant circuit.
  c) Reflection impedance or reflection admittance can be measured instead of the S11.
  d) Tune the capacitor or the coil until a maximum null (S11) occurs at the resonance frequency, $f_0$. For the impedance measurement, the maximum peak will occur for the parallel resonant circuit, and minimum peak for the series resonant circuit.

FIGURE 22: VOLTAGE VS. FREQUENCY FOR RESONANT CIRCUIT

![Voltage vs. Frequency](image)

FIGURE 23: FREQUENCY RESPONSES FOR RESONANT CIRCUIT

![Frequency Responses](image)

**Note 1:** (a) S11 Response, (b) Impedance Response for a Parallel Resonant Circuit, and (c) Impedance Response for a Series Resonant Circuit.

**2:** In (a), the null at the resonance frequency represents a minimum input reflection at the resonance frequency. This means the circuit absorbs the signal at the frequency while other frequencies are reflected back. In (b), the impedance curve has a peak at the resonance frequency. This is because the parallel resonant circuit has a maximum impedance at the resonance frequency. (c) shows a response for the series resonant circuit. Since the series resonant circuit has a minimum impedance at the resonance frequency, a minimum peak occurs at the resonance frequency.
READ RANGE OF RFID DEVICES

Read range is defined as a maximum communication distance between the reader and tag. In general, the read range of passive RFID products varies, depending on system configuration and is affected by the following parameters:

a) Operating frequency and performance of antenna coils
b) $Q$ of antenna and tuning circuit
c) Antenna orientation
d) Excitation current
e) Sensitivity of receiver
f) Coding (or modulation) and decoding (or demodulation) algorithm
g) Number of data bits and detection (interpretation) algorithm
h) Condition of operating environment (electrical noise), etc.

The read range of 13.56 MHz is relatively longer than that of 125 kHz device. This is because the antenna efficiency increases as the frequency increases. With a given operating frequency, the conditions (a – c) are related to the antenna configuration and tuning circuit. The conditions (d – e) are determined by a circuit topology of reader. The condition (f) is a communication protocol of the device, and (g) is related to a firmware software program for data detection.

Assuming the device is operating under a given condition, the read range of the device is largely affected by the performance of the antenna coil. It is always true that a longer read range is expected with the larger size of the antenna with a proper antenna design. Figures 24 and 25 show typical examples of the read range of various passive RFID devices.

**FIGURE 24: READ RANGE VS. TAG SIZE FOR TYPICAL PROXIMITY APPLICATIONS**

**FIGURE 25: READ RANGE VS. TAG SIZE FOR TYPICAL LONG RANGE APPLICATIONS**

*Note:* Actual results may be shorter or longer than the range shown, depending upon factors discussed above.
REFERENCES


1.0 INTRODUCTION

This chapter provides a reference guide for the 13.56 MHz reader designer. The schematic included in this chapter is for the 13.56 MHz Reference Reader included in the DV103003 microID™ Developer’s Kit. The circuit is designed for short read-range applications. The basic design can be modified for long-range or other applications with MCRF355/360 devices. An electronic copy of the PICmicro® microcontroller source code is available upon request.

2.0 READER CIRCUITS

The RFID reader consists of transmitting and receiving sections. It transmits a carrier signal (13.56 MHz), receives the backscattered signal from the tag, and performs data processing. The reader also communicates with an external host computer. A basic block diagram of a typical RFID reader is shown in Figure 2-1.

The transmitting section contains a 13.56 MHz signal oscillator (74HC04), power amplifier (Q2), and RF tuning circuits. The tuning circuit matches impedance between the antenna coil circuit and the power driver at 13.56 MHz. The radiating signal strength from the antenna must comply with government regulations. For best performance, the antenna coil circuit must be tuned to the same frequency of the tag. The design for antenna circuits is given in Application Note AN710 (DS00710).

The receiving section contains an envelope detector (D6), hi-pass filters, and amplifiers (U2 and U3). When the tag is energized, it transmits 154 bits of data that is encoded in Biphase-L (Manchester). In the Manchester encoding, data ‘1’ is represented by a logic high-to-low level change at midclock, and data ‘0’ is represented by a low-to-high level change at midclock. There is always a level change at middle of every bit clock.

FIGURE 2-1: FUNCTIONAL BLOCK DIAGRAM OF TYPICAL RFID READER
FIGURE 2-2: SIGNAL WAVEFORMS

Tag Data Signal

Signal Waveform in Reader Coil

After Envelope Detector

After Pulse Shaping

FIGURE 2-3: BIPHASE-L (MANCHESTER) SIGNAL

(a) Data ‘1’

(b) Data ‘0’
When the tag is energized by the reader’s carrier signal, it transmits back with an amplitude modulated signal. This results in a perturbation in the voltage amplitude across the reader antenna coil. The envelope detector detects the changes in the voltage amplitude and passes it into an RC filter (R7, C11). The charged signal in the capacitor passes through active filters and amplifiers. The signal that is passing through this receiving section is the data signal. This filtered-shaped data signal is fed into Pin 10 of the microcontroller for data processing.

2.1 FCC Specifications on Transmitting Signal

Each country limits the signal strength of the radio frequency signal that is intentionally radiated from the device. In the USA, the maximum signal strength that is radiated from the device is regulated by Federal Communication Commission (FCC). Any device operating at 13.56 MHz frequency band must comply with the FCC Part 15.225 of the federal regulation. FCC limits for 13.56 MHz frequency band are as follows:

1. Tolerance of the carrier frequency: 13.56 MHz +/- 0.01% = +/- 7 kHz.
2. Frequency bandwidth: +/- 7 kHz.
3. Power level of fundamental frequency: 10 mv/m at 30 meters from the transmitter.
4. Power level for harmonics: -50.45 dB down from the fundamental signal.

The transmission circuit including the antenna coil must be designed to meet the FCC limits.

3.0 OPTIMIZATION FOR LONG-RANGE APPLICATIONS

The reader circuit provided is designed for about a 5-inch read-range, using a 2-inch by 2-inch tag coil that is printed on PCB with the MCRF355. The read-range can be increased by increasing the reader power, sensitivity, and antenna size. A read-range of more than 30-inches can be achieved with the MCRF355 and an optimized reader. In order to optimize the reader circuit for long-range applications, the following aspects may be considered:

1. Optimize the output power level within FCC limits. The reader should provide a sufficient signal level to the tag. The tag needs about 4 VPP across the coil circuit for operation. The power level radiating from the reader antenna must comply to the government regulations such as FCC specifications in the USA. The FCC limits for 13.56 MHz band are described in Section 2.1. For long-range applications, the designer may start with about 50 VPP of antenna voltage and optimize the signal strength for a read-range within the government regulations.

2. Increase the size of the antenna. The read-range, in general, is proportional to the size of the reader coil (see Equation 12 in Application Note 710). An optimum radius of antenna is 1.414 times of the read-range.

3. Increase the $Q$ of the antenna circuit. The read-range increases with $Q$ of the antenna circuit. This is because the induced voltage is directly proportional to $Q$ of the circuit. The recommended $Q$ for long-range applications is as follows:

\[40 < Q < 96 \quad \text{for reader}
\]
\[40 < Q \quad \text{for tag}\]
4. Optimize the input sensitivity of the reader. The sensitivity is a measure of how weak a signal can be and still be satisfactorily received. The sensitivity is proportional to the carrier power and square of the modulation index (1 for 100% modulation such as MCRF355). It is inversely proportional to the noise signal. The limit to the sensitivity of the receiving section of the reader is noise, both external and internal. The external noises may come from various sources such as computers, televisions, appliances, motors, power lines, transformers, etc. The internal noise is mostly due to a thermal noise of components. To reduce noise, the reader should be operated a distance away from the noise sources. The receiving section may have a 70 kHz bandpass filter to reduce the noises. The 70 kHz bandpass filter will pass only the 70 kHz data signal for processing. The receiving section should have sensitivity of about -120 dBm for long-range applications.

5. Optimize the amplitude gain circuit. The receiving circuit amplifies the modulated signals before data processing. The input signal contains both real data and noise. Typically, op amplifiers are used for both as a gain amplifier and filter. The gain must be optimized within the circuit to obtain gains only at the real data signal.
4.0 READER SCHEMATIC
## 5.0 READER BILL OF MATERIALS

<table>
<thead>
<tr>
<th>Assembly #</th>
<th>Line #</th>
<th>Qty</th>
<th>Part #</th>
<th>Part Description</th>
<th>Reference Designator</th>
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6.0 READER SOURCE CODE FOR THE PICmicro® MCU

;receiver.asm

;Processor: PIC16C558 operating at 13.56 MHz
;       Ti= 295 nsec

processor 16c558
#include "P16c558.inc"
__config h'3ff2' ;protection off, PWRT enabled, watchdog disabled, HS oscillator

#define _CARRY               STATUS,0
#define _ZERO                STATUS,2

#define _125KHZ              PORTA,1
#define _RS232TX             PORTA,2
#define _RS232RX             PORTA,3
#define _RS232               PORTA
#define SIGNAL               PORTB,4

invmask               = h'2'
............................
;Define variables and constants here--
delay       = h'20'
wait        = h'21'
acctime     = h'22' ;accumulated sync interval sum--also used as halfbit interval threshold
#define halfthr    acctime ;halfbit interval threshold
halfthr     = acctime ; halfbit interval threshold
recv_csumhi = h'23' ; 2 bytes for storing received checksum
recv_csumlo = h'24'

bitcnt      = h'25' ; RS232 bit counter
cycle_cnt   = h'26'

#define halfthr    = h'27' ; threshold value between halfbit and fullbit intervals
halfthr     = h'27'
ptr1        = h'28' ; temporary FSR storage
ptr2        = h'29' ; temporary FSR storage
TXchar      = h'2a' ; character to transmit over RS232

#define temp           = h'2b'
shiftcnt    = h'2c' ; used to strip the framing '0' bits from the rec'd data array
letters      = h'2d' ; storage area for next character to send
charcnt      = h'2e'

#define lastbit       = h'2f' ; the LSB stores the last rec'd bit--flip it by complementing f

;!!!!!!!!!!!!!!!!!!!!!!!!!!: bit storage area--16 bytes of storage, indirectly addressed
;Note that s/w tests for MSb to detect end of area--be careful if move to different
;processor or relocate this storage area
recvbits    = h'40' ; 32 bytes set aside for storing the received bits--actual number of bytes
; in transmission is 18

;Note that main loop uses bit tests to determine bit receive or runaway condition (to limit
;processing time). Keep this in mind if recvbits storage area changed in the future.
...40h-60h is reserved for received bits--actual bit receiving area 40h-51h, rest is overrun area...

...52h-73h set aside for ASCII conversion of received bytes before RS232 transmission. Note that
...52h-60h contains no useful information from the use during receive of demodulated bits. Also,
...bits are not being received while the ASCII conversion and serial transmission are
...taking place.
...'G' 1st character: "go"
...Character 2-37: ASCII representation of received 18 bytes (until checksum used)
...Character 38: '\n' newline

sendasci =h'52' ;begin of storage area for ASCII conversion of received bytes
xfercnt =d'14' ;defines number of received bytes to convert to ASCII & transmit

;-----------------------------------------------
;Overall function- To recover Manchester encoded RFID message after AM demodulation and
; comparator decision. The comparator input trips the interrupt on PORTB change.
;The steps are:
;
; 1- Initialize registers to seek synch field.
; 2- Determine bit width from synch field by averaging the periods between transitions
; over the synch field. TMR0 is cleared at each edge. If the timer overflows before
; the next edge, synch seek starts over. The synch field is composed of 9 bits.
; 3- Use the measured bit width to establish a threshold period between repeat bits and
; complement of previous bit. This is due to the Manchester encoding method. Since there
; is always a transition in the middle of each bit interval transmitted, a repeated bit
; will appear as a pair of edges that occur with a halfbit interval period. A bit that
; is the complement of the last received bit will appear as an interval between edges
; of a full bit interval period.
; 4- Shift in bits as they are received into the storage array. When the timer overflows,
; consider the data field over. The received data format is MSb to LSb, where the MSb
; is the first bit received.
; 5- There are 16 bytes in the message, followed by a 16 bit checksum of the message
; contents. The remaining bit is unused.
; 6- Compute the checksum of the received 16 byte message and compare to the received
; checksum.
; 7- If checksums match, convert the message and the checksum into ASCII form and transmit
; over the RS232 serial link. The message format is:
;   "GG" :the go characters (start of message)
;   36 bytes which are the ASCII representation of the 18 bytes received
;   "\n" : closing newline character
; The serial data rate is 9600 bps, 8 data bits, 1 stop, no parity

org h'000' ;RESET vector location
goto init
org h'004' ;interrupt vector location

;-------------------------------------------------------------------
;isr(): interrupt service routine
; interrupts enabled for transition on PORTB
;
; 1- BEWARE! To minimize interrupt response time, the w & status register are NOT
;     archived.
; 2- The isr execution path is determined by w register and uses calculated goto's.
;    The w for next isr is set at end of current isr execution and is dependent on
;    signal context (i.e. sync start, w/in sync, w/in data, etc.)
;    Be very cautious here--must stay w/in 255 instructions for this to work!
; 3- Sync field processed as follows:
;    -Ignore the first 4 transitions, they may be in response to tag power on reset
;    -Accumulate the sum of next 8 intervals
;    -Establish half bit width from full bit width threshold value based on
;      average interval measured above. Due to Manchester encoding, repeat of previous
; bit will be a series of 2 halfbit width intervals, complement of previous bit
; will be a fullbit width interval. halfbit defined as 1.5x(average sync).
; wait for interval over the fullbit threshold. This is end of sync. In accordance
; w/ Manchester encoding, the sync field will be: 1 1 1 1 1 1 1 0
==========================================================================================
isr
    addwf PCL,f ;4 calculated goto
; first sync edge is calculated goto here
    clrf TMR0 ;5
    movf PORTB,f ;6 must read PORTB before clearing RBIF
    bcf INTCON,RBIF ;7 just in case timer interrupt happened just at 1st edge
    bcf INTCON,TOIF ;8
    movlw (first_cycle - isr-d'1') ;9 next isr calculated goto offset
    clrf lastbit ;10 lastbit @ end of sync = 0
    retfie ;12
; end of first cycle here. Note that first 4 transitions are ignored, because sync start is
; corrupted by tag power on reset.
first_cycle
    clrf TMR0 ;5
    movf PORTB,f ;6 must read PORTB before clearing RBIF
    bcf INTCON,RBIF ;7
    movlw (second_cycle - isr-d'1') ;8 next isr calculated goto offset
    retfie ;10
; end of 2nd cycle here. Note that first 4 transitions are ignored, because sync start is
; corrupted by tag power on reset.
second_cycle
    clrf TMR0 ;5
    movf PORTB,f ;6 must read PORTB before clearing RBIF
    bcf INTCON,RBIF ;7
    movlw recvbits ;8
    movwf FSR ;9 set up to store data bits
    movlw (third_cycle - isr-d'1') ;10 next isr calculated goto offset
    retfie ;12
; end of 3rd cycle here. Note that first 4 transitions are ignored, because sync start is
; corrupted by tag power on reset. The 3rd cycle is the 4th transition, so from here we measure
; the longest interval in sync field.
third_cycle
    clrf TMR0 ;5
    movf PORTB,f ;6 must read PORTB before clearing RBIF
    bcf INTCON,RBIF ;7
    clrf acctime ;8 reset accumulated sync interval for average
    movlw (fourth_cycle - isr-d'1') ;9 next isr calculated goto offset
    retfie ;11
; end of 4th cycle here. Start looking for longest sync interval here.
fourth_cycle
    movf TMR0,w ;5
    clrf TMR0 ;6
    movf PORTB,f ;7
    bcf INTCON,RBIF ;8
    addwf acctime,f ;9 first measured sync cycle, must be the largest
    movlw (fifth_cycle - isr-d'1') ;10
    retfie ;12
; end of 5th cycle here.
fifth_cycle
    movf TMR0,w ;5
    clrf TMR0 ;6
    movf PORTB,f ;7
    bcf INTCON,RBIF ;8
    addwf acctime,f ;9 acctime = acctime + TMR0
    movlw (sixth_cycle - isr-d'1') ;10
    retfie ;12
; end of 6th cycle here.
sixth_cycle
    movf TMR0,w ;5
    clrf TMR0 ;6
movf   PORTB,f  ;7
bcf    INTCON,RBIF ;8
addwf  acctime,f  ;9  acctime = acctime + TMR0
movlw  (seventh_cycle - isr-d’l’) ;10
retfie             ;12
;end of 7th cycle here.

seventh_cycle
movf   TMR0,w      ;5
clrf   TMR0        ;6
movf   PORTB,f     ;7
bcf    INTCON,RBIF ;8
addwf  acctime,f   ;9 acctime = acctime + TMR0
movlw  (eighth_cycle - isr-d’l’) ;10
retfie             ;12
;end of 8th cycle here.

eighth_cycle
movf   TMR0,w      ;5
clrf   TMR0        ;6
movf   PORTB,f     ;7
bcf    INTCON,RBIF ;8
addwf  acctime,f   ;9 acctime = acctime + TMR0
movlw  (nineth_cycle - isr-d’l’) ;10
retfie             ;12
;end of 9th cycle here.
nineth_cycle
movf   TMR0,w      ;5
clrf   TMR0        ;6
movf   PORTB,f     ;7
bcf    INTCON,RBIF ;8
addwf  acctime,f   ;9 acctime = acctime + TMR0
movlw  (tenth_cycle - isr-d’l’) ;10
retfie             ;12
;end of 10th cycle here.
tenth_cycle
movf   TMR0,w      ;5
clrf   TMR0        ;6
movf   PORTB,f     ;7
bcf    INTCON,RBIF ;8
addwf  acctime,f   ;9 acctime = acctime + TMR0
movlw  (eleventh_cycle - isr-d’l’) ;10
retfie             ;12
;end of 11th cycle here. --this is last of sync cycles to be accumulated. Average the result
;and determine halfbit threshold in remaining sync cycles.

eleventh_cycle
movf   TMR0,w      ;5
clrf   TMR0        ;6
movf   PORTB,f     ;7
bcf    INTCON,RBIF ;8
addwf  acctime,f   ;9 acctime = acctime + TMR0
movlw  (twelfth_cycle - isr-d’l’) ;10
retfie             ;12
;end of 12th cycle here. Start averaging the sync interval accumulated time
twelfth_cycle
movf   PORTB,f     ;5
bcf    INTCON,RBIF ;6
rrf    acctime,f   ;7 acctime/2
rrf    acctime,f   ;8 acctime/4
rrf    acctime,f   ;9 avg interval = acctime/8
movlw  h’1f’ ;10 clear 3 MSbs that may have been set by carry
andwf  acctime,f ;11
movlw  (cycle13 - isr-d’l’) ;12
retfie             ;14
;end of 13th cycle here. Calculate the halfbit threshold = 1.5(sync interval avg) Note that
;that the threshold value will be kept in acctime (=halfthr)
cycle13
clrf TMR0 ;5
movf PORTB,f ;6
bcf INTCON,RBIF ;7
rrf acctime,w ;8 half the sync interval avg
addwf acctime,f ;9 halfthr = 1+1.5x(sync interval avg)
inwf acctime,f ;10
movlw (sync_end - h'100'-h'1'-isr) ;11
bsf PCLATH,0 ;12 adjust for origin @ 100h
retfie ;14

org h'100'
;sync end wait. End of sync is distinguished by a fullbit interval. ( T > halfthr )
sync_end
movf TMR0,w ;5
cirf TMR0 ;6
movf PORTB,f ;7
bcf INTCON,RBIF ;8
subwf halfthr,w ;9 Test interval to detect end of sync field (halfthr - w)
movlw (sync_end - h'100'-isr-d'1') ;10
btfs STATUS,C ;12 Carry set for halfthr >= w
movlw (bit1 - h'100'-isr-h'1');12 If T > halfbit, end of sync detected. Proceed to data
processing
retfie ;14
;rec'd bit processing here --bit1 is 1st bit of 8 bit block
bit1
movf TMR0,w ;5
cirf TMR0 ;6
movf PORTB,f ;7
bcf INTCON,RBIF ;8
subwf halfthr,w ;9 Test interval to determine bit. C = 1 for repeated bit
btfs STATUS,C ;11
goto halfabit1 ;12
;fullbit processing here
comf lastbit,f ;12 Complement lastbit for fullbit measurement
rrf lastbit,w ;13
rlf INDF,f ;14 shift in the new bit
movlw (bit2 - h'100'-isr-h'1');15
retfie ;17
halfabit1
;repeated bit (1 of 8)
rrf lastbit,w ;13
rlf INDF,f ;14
movlw (half21-h'100'-isr-h'1');15
retfie ;17
;2nd half of bit interval processing
half21 ;2nd half, bit1
cirf TMR0 ;5
movf PORTB,f ;6
bcf INTCON,RBIF ;7
movlw (bit2-h'100'-isr-h'1');8
retfie ;10
;rec'd bit processing here --bit2 is 2nd bit of 8 bit block
bit2
movf TMR0,w ;5
cirf TMR0 ;6
movf PORTB,f ;7
bcf INTCON,RBIF ;8
subwf halfthr,w ;9 Test interval to determine bit. C = 1 for repeated bit
btfs STATUS,C ;11
goto halfabit2 ;12
;fullbit processing here
comf lastbit,f ;12 Complement lastbit for fullbit measurement
rrf lastbit,w ;13
rlf INDF,f ;14 shift in the new bit
movlw (bit3 - h'100'-isr-h'1') ;15
retfie             ;17
halfabit2
;repeated bit (2 of 8)
rrf   lastbit,w    ;13
rlf   INDF,f       ;14
movlw (half22-h'100'-isr-h'1') ;15
retfie             ;17
;2nd half of bit interval processing
half22      ;2nd half, bit2
clrf  TMR0         ;5
movf  PORTB,f      ;6
bcf   INTCON,RBIF  ;7
movlw (bit3-h'100'-isr-h'1') ;8
retfie             ;10
;rec'd bit processing here --bit3 is 3rd bit of 8 bit block
bit3
movf  TMR0,w       ;5
cclrf TMR0         ;6
movf  PORTB,f      ;7
bcf   INTCON,RBIF  ;8
subwf halfthr,w    ;9   Test interval to determine bit. C = 1 for repeated bit
btfsc STATUS,C     ;11
goto  halfabit3    ;12
;fullbit processing here
comf  lastbit,f    ;12  Complement lastbit for fullbit measurement
rrf   lastbit,w    ;13
rlf   INDF,f       ;14  shift in the new bit
movlw (bit4 - h'100'-isr-h'1') ;15
retfie             ;17
halfabit3
;repeated bit (3 of 8)
rrf   lastbit,w    ;13
rlf   INDF,f       ;14
movlw (half23-h'100'-isr-h'1') ;15
retfie             ;17
;2nd half of bit interval processing
half23      ;2nd half, bit3
clrf  TMR0         ;5
movf  PORTB,f      ;6
bcf   INTCON,RBIF  ;7
movlw (bit4-h'100'-isr-h'1') ;8
retfie             ;10
;rec'd bit processing here --bit4 is 4th bit of 8 bit block
bit4
movf  TMR0,w       ;5
cclrf TMR0         ;6
movf  PORTB,f      ;7
bcf   INTCON,RBIF  ;8
subwf halfthr,w    ;9   Test interval to determine bit. C = 1 for repeated bit
btfsc STATUS,C     ;11
goto  halfabit4    ;12
;fullbit processing here
comf  lastbit,f    ;12  Complement lastbit for fullbit measurement
rrf   lastbit,w    ;13
rlf   INDF,f       ;14  shift in the new bit
movlw (bit5 - h'100'-isr-h'1') ;15
retfie             ;17
halfabit4
;repeated bit (4 of 8)
rrf   lastbit,w    ;13
rlf   INDF,f       ;14
movlw (half24-h'100'-isr-h'1') ;15
retfie             ;17
;2nd half of bit interval processing
half24 ;2nd half, bit4
    clr TMR0 ;5
    movf PORTB,f ;6
    bcf INTCON,RBIF ;7
    movlw (bit5-h'100'-isr-h'1');8
    retfie ;10
; rec'd bit processing here --bit5 is 5th bit of 8 bit block
bit5
    movf TMR0,w ;5
    clr TMR0 ;6
    movf PORTB,f ;7
    bcf INTCON,RBIF ;8
    subwf halfthr,w ;9 Test interval to determine bit. C = 1 for repeated bit
    btfsc STATUS,C ;11
    goto halfabit5 ;12
; fullbit processing here
    comf lastbit,f ;12 Complement lastbit for fullbit measurement
    rrf lastbit,w ;13
    rlf INDF,f ;14 shift in the new bit
    movlw (bit6-h'100'-isr-h'1');15
    retfie ;17
halfabit5 ;repeated bit (5 of 8)
    rrf lastbit,w ;13
    rlf INDF,f ;14
    movlw (half25-h'100'-isr-h'1');15
    retfie ;17
; 2nd half of bit interval processing
half25 ;2nd half, bit5
    clr TMR0 ;5
    movf PORTB,f ;6
    bcf INTCON,RBIF ;7
    movlw (bit6-h'100'-isr-h'1');8
    retfie ;10
; rec'd bit processing here --bit6 is 6th bit of 8 bit block
bit6
    movf TMR0,w ;5
    clr TMR0 ;6
    movf PORTB,f ;7
    bcf INTCON,RBIF ;8
    subwf halfthr,w ;9 Test interval to determine bit. C = 1 for repeated bit
    btfsc STATUS,C ;11
    goto halfabit6 ;12
; fullbit processing here
    comf lastbit,f ;12 Complement lastbit for fullbit measurement
    rrf lastbit,w ;13
    rlf INDF,f ;14 shift in the new bit
    movlw (bit7-h'100'-isr-h'1');15
    retfie ;17
halfabit6 ;repeated bit (6 of 8)
    rrf lastbit,w ;13
    rlf INDF,f ;14
    movlw (half26-h'100'-isr-h'1');15
    retfie ;17
; 2nd half of bit interval processing
half26 ;2nd half, bit6
    clr TMR0 ;5
    movf PORTB,f ;6
    bcf INTCON,RBIF ;7
    movlw (bit7-h'100'-isr-h'1');8
    retfie ;10
; rec'd bit processing here --bit7 is 7th bit of 8 bit block
bit7
movf TMR0,w ;5
clrf TMR0 ;6
movf PORTB,f ;7
bcf INTCON,RBIF ;8
subwf halfthr,w ;9 Test interval to determine bit. C = 1 for repeated bit
btfsc STATUS,C ;11
goto halfabit7 ;12

;fullbit processing here
comf lastbit,f ;12 Complement lastbit for fullbit measurement
rrf lastbit,w ;13
rlf INDF,f ;14 shift in the new bit
movlw (bit8 - h'100'-'isr-h'1') ;15
retfie ;17

halfabit7 ;repeated bit (7 of 8)
rrf lastbit,w ;13
rlf INDF,f ;14
movlw (half27-h'100'-'isr-h'1') ;15
retfie ;17

;2nd half of bit interval processing
half27 ;2nd half, bit7
clrf TMR0 ;5
movf PORTB,f ;6
bcf INTCON,RBIF ;7
movlw (bit8-h'100'-'isr-h'1') ;8
retfie ;10

;rec'd bit processing here --bit8 is 8th bit of 8 bit block

bit8
movf TMR0,w ;5
clrf TMR0 ;6
movf PORTB,f ;7
bcf INTCON,RBIF ;8
subwf halfthr,w ;9 Test interval to determine bit. C = 1 for repeated bit
btfsc STATUS,C ;11
goto halfabit8 ;12

;fullbit processing here
comf lastbit,f ;12 Complement lastbit for fullbit measurement
rrf lastbit,w ;13
rlf INDF,f ;14 shift in the new bit
movlw (bit1 - h'100'-'isr-h'1') ;15
incf FSR,f ;16
retfie ;18

halfabit8 ;repeated bit (8 of 8)
rrf lastbit,w ;13
rlf INDF,f ;14
movlw (half28-h'100'-'isr-h'1') ;15
retfie ;17

;2nd half of bit interval processing
half28 ;2nd half, bit8
clrf TMR0 ;5
movf PORTB,f ;6
bcf INTCON,RBIF ;7
movlw (bit1-h'100'-'isr-h'1') ;8
incf FSR,f ;9 advance to next byte in recvbits storage array
retfie ;11

;The negative RS232 supply is generated by an inverter clocked at ~125 KHz by port pin RA1.
;first pump up the -5V, i.e. generate 125 KHz clock (T=8 usec, ~27 Ti)
;run for a total of 128 cycles before sending data
;put line at stop bit level

alphabet
clrwdt
bcf INTCON,GIE ;make sure interrupts are off
movlw sendascii
movwf FSR

movlw xfercnt ;# of ASCII represented received bytes to xfer
addlw xfercnt ;x2
addlw h'3' ;plus 2 start character "G" and newline character at end
movwf charcnt

;set up registers in bank 1
bsf STATUS,RP0  ;point to bank 1
movlw h'8'
movwf TRISA       ;RA3 input, RA2-0 output
movlw h'10'
movwf TRISB       ;RB7-5,3-0 output, RB4 input
movlw b'00001100' ;set up timer option for internal clock, prescale-->watchdog/16
movwf OPTION_REG  ;port B pullups enabled
bcf STATUS,RP0  ;point back to bank 0

done setting up registers in bank 1, back to bank 0
bsf _RS232TX  ;default is mark mode
call gen125khz

;start the test transmission
sendA
movf INDF,w
movwf TXchar
movlw d'8'
movwf bitcnt
;stop bit last
bsf _RS232TX
call TX_RS232 ;stop bit = 3Ti

call ti17 ;burn 17Ti (includes the 2Ti for the call)
;start bit first
bcf _RS232TX
call TX_RS232
call ti17 ;burn 17Ti (includes the 2Ti for the call, adjusts the bit timing)
sendchar
btfsc TXchar,0 ;1Ti
goto setbit ;3Ti
bcf _RS232TX
goto nextbit
setbit
bsf _RS232TX ;4Ti

nextbit
call TX_RS232 ;6Ti
rrf TXchar,f ;7Ti
call ti10 ;17Ti
decfsz bitcnt,f ;18Ti
goto sendchar ;20Ti
;stop bit last
bsf _RS232TX
call TX_RS232 ;stop bit = 3Ti

incf FSR,f ;1
decfsz charcnt,f ;2
goto inalpha ;4
movlw d'255'
movwf charcnt
movlw d'10'
movwf bitcnt
waiting
call ti17
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

; subroutine--RS232 bit timing & 125 KHz voltage inverter maintenance
; baud rate set to 9600 bps--this is a bit time of 104 usec
; Timing for this subroutine: to104 loop is 5.605 usec, additional setup
; overhead is 1.77 usec. If do 17 to104 loops, that leaves 5.844 usec to make up in the calling routine to meet 104 usec target. 5.844= 19.8 Ti
; (20 Ti)
; Note that 5.844 is not evenly divisible by the instruction cycle time. Need to save one instruction every 5th bit sent--w/ the stop & start bit overhead, easier to save 2 extra instructions every character sent (10 bits)

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

TX_RS232
    movlw d’17’ ;time out 104 usec, Ti=295 nsec
    movwf wait

to104
    movlw invmask ;flip voltage inverter bit
    xorwf _RS232,f
    movlw d’4’
    movwf delay

wait4usec
    decfsz delay,f ;4 usec is half inverter clock period
    goto wait4usec
    decfsz wait,f
    goto to104
    movlw invmask
    xorwf _RS232,f
    nop
    nop
    return

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

; subroutine--generates 128 cycles at ~125 KHz for the RS232 voltage inverter

gen125khz
    movlw d’128’
    movwf cycle_cnt

next125
    bsf _125KHZ
    movlw d’4’
    movwf delay

highside
    decfsz delay,f
    goto highside
    bcf _125KHZ
    movlw d’4’
movwf delay

lowside
decfsz delay,f
goto lowside
decfsz cycle_cnt,f
goto next125
return

;; end gen125khz

subroutine

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

; subroutine-ti17: burn 17 Ti--includes the 2Ti to call this subroutine
;
; ti15: burn 15 Ti, including call
;
; ti10: burn 10 Ti, including call

; subroutine-ti17

subroutine-ti17
movlw d'3'
movwf delay
burn9
decfsz delay,f
goto burn9 ;11
clrwdt ;12
nop ;13
return ;15+2 for call ti17=17Ti

subroutine-ti15
movlw d'3'
movwf delay ;2
burn9Ti
decfsz delay,f
goto burn9Ti ;11
return ;13+2 for call ti15=15Ti

subroutine-ti10
ten
nop
clrwdt
ti10
goto dly1 ;2Ti
dly1
goto dly2 ;4Ti
dly2
goto leaveti10 ;6Ti
leaveti10
return ;8Ti+2Ti=10Ti

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

; initialization

; set up registers in bank 1

bsf STATUS,RP0 ; point to bank 1
movlw h'8'
omw TRISA ; RA3 input, RA2-0 output
movlw h'10'
omw TRISB ; RB7-5,3-0 output, RB4 input
movlw b'00001000' ; set up timer option for internal clock, no prescaler
movwf OPTION_REG ;port B pullups enabled
bcf STATUS,RP0 ;point back to bank 0

;done setting up registers in bank 1, back to bank 0
movlw HIGH isr
movwf PCLATH ;setup for calculated goto’s dependent on context when entering

;=================================================================================================
;initialization for sync field search- done @ turn on & after data recovery complete (or failed)
;=================================================================================================
seekinit

clrwdt

movlw d’19’
movwf bitcnt ;clear the bit storage field
movlw recvbits
movwf FSR

clrbits

clr INDF
incf FSR,f
decfsz bitcnt,f
goto clrbits

movlw recvbits
movf PORTB,w ;read PORTB before clearing INTCON to be sure RBIF=0
clrf INTCON
clrf TMR0

;=================================================================================
; From here on, the w register represents the PCL offset when answering the isr.
; It is to be used for no other purpose until interrupts are disabled.
;=================================================================================

movlw d’0’
clrf PCLATH

bsf INTCON,RBIE ;enable portB change interrupt enable
bsf INTCON,GIE ;global interrupts are now enabled.

;=================================================================================================
;tag word search
;=================================================================================================

;The main loop monitors the T0IF flag to detect successfully received word (subject to
;checksum test). Tag word processing is isr driven. A calculated goto method is used for
;position context in tag word for speed. FOR THIS REASON, THE W REGISTER CANNOT BE USED
;BY THE MAIN LOOP! If the main loop detects a timer overflow, the w register is cleared to
;return processing to first sync edge search.
;Also, expect recvbits area to be @ 40h-52h while receiving data. The ptr will be tested to
;determine this bitwise (because w can’t be used in the main loop).
;=================================================================================================

seeksync

bcf INTCON,RBIE

movlw d’0’ ;calculated goto offset for 1st sync edge processing

clr INDF

bsf INTCON,RBIE ;FSR = 0 to indicate not gathering bits
bsf INTCON,T0IF

main

clrwdt

btfsc FSR,6
goto datamain ;receiving data, monitor progress

btfsc INTCON,T0IF
goto seeksync ;if TMR0 overflows w/o receiving bits, seeksync

goto main

;check for done receiving bits using TMR0 overflow as indicator. Also test for overflow from
;proper bit storage area for runaway condition (non tag noise tripping comparator)

datamain
clrwdt
btfsc INTCON,T0IF
goto calc_checksum ;if timer overflows, calculate checksum of received data
btfsc FSR,5 ;if bit 5 set, FSR > 5fh and has overrun its proper area.
goto seeksync ;search for sync.
goto datamain

;Data received at this point. Two processing tasks remain:
;1- the framing '0' bits must be removed from the received 14 data bytes and 16 bit checksum
;2- the checksum of the 14 data bytes must be calculated and compared to the received
   16 bit checksum
;If checksums match, transmit data over RS232 link.

calc_checksum
    clrf INTCON
    clrgie
    bcf INTCON,GIE ;make sure it's clear before proceeding
    goto clrgie
    movf PORTB,f
    clrf INTCON       ;disable all interrupts while processing received data

;remove the framing '0' bits by bit shifting the data array left until all framing 0s are
;shifted out
    movlw d'17'
    movwf bitcnt
    movwf shiftcnt

shiftout
    movlw recvbits+d'17'
    movwf FSR

roll_left
    rlf INDF,f
    decf FSR,f
    decfsz shiftcnt,f
    goto roll_left ;rotate left shiftcnt # of bytes
    decfsz bitcnt,f
    goto next_RL
    goto framestripped

;bit shift left through the array (successively 1 byte less each time)
next_RL
    movf bitcnt,w
    movwf shiftcnt
    goto shiftout

framestripped

;1st check for all 0s in data--This is an illegal combination
    movlw recvbits
    movwf FSR
    movlw d'14'
    movwf bitcnt

zerotest
    movf INDF,w
    btfss STATUS,Z
    goto nonzero
    decfsz bitcnt,f
    goto zerotest
    goto seekinit ;all zeros received. Ignore the message

nonzero

;do 16 bit checksum of first 14 bytes received. It should match the last 2 bytes received.
    movlw recvbits
    movwf FSR
    movlw d'14'
    movwf bitcnt
    clrf recv_csumlo
    clrf recv_csumhi

sumbytes
;now compare the received checksum w/ the calculated checksum. Transmit data if they match.
    movf recv_csumhi,w
    subwf INDF,f
    btfss STATUS,Z
    goto seekinit

    incf FSR,f
    movf recv_csumlo,w
    subwf INDF,f
    btfss STATUS,Z
    goto seekinit

    ;message passes checksum. Convert to ASCII and transmit.
    ;now convert to ASCII form
    movlw recvbits
    movwf ptr1       ;keep track of where in conversion
    movlw sendascii
    movwf ptr2
    movwf FSR
    movlw "G"       ;convert ASCII form
    movwf INDF
    incf ptr2,f
    incf FSR,f
    movwf INDF       ;double "G" to indicate start
    incf ptr2,f
    ;next ascii character
    movlw xfercnt  ;how many bytes to convert to ASCII
    movwf bitcnt
    movlw h'4'
    movwf PCLATH   ;set up PCLATH for lookup table

    asciiconv
    movf ptr1,w
    movwf FSR
    swapf INDF,w
    andlw h'f'
    ;isolate the MSN
    call hex2ascii
    movwf temp
    ;hold the ASCII character
    movf ptr2,w
    movwf FSR
    movf temp,w
    ;store ASCII representation of received byte MSN
    movf INDF
    incf ptr2,f
    ;advance ASCII ptr
    movf ptr1,w
    ;back to received bytes
    movf FSR
    movf INDF
    andlw h'f'
    ;isolate the LSN
    call hex2ascii
    movwf temp
    movf ptr2,w
    movf FSR
    movf temp,w
    ;store ASCII representation of received byte LSN
    movf INDF
    incf ptr2,f
    ;advance ASCII ptr
    incf ptr1,f
    ;advance received byte ptr
    decfsz bitcnt,f
    goto asciiconv

    ;done data conversion, now indicate newline before sending
    movlw "\n" f       ;newline character
    incf FSR,f
    movwf INDF
; cleared for RS232 transmission
goto alphabet

; hexadecimal to ASCII conversion table
org h'3ff'
hex2ascii
    addwf PCL,f
    retlw "0" ; ascii 0
    retlw "1" ; ascii 1
    retlw "2" ; ascii 2
    retlw "3" ; ascii 3
    retlw "4" ; ascii 4
    retlw "5" ; ascii 5
    retlw "6" ; ascii 6
    retlw "7" ; ascii 7
    retlw "8" ; ascii 8
    retlw "9" ; ascii 9
    retlw "A" ; ascii A
    retlw "B" ; ascii B
    retlw "C" ; ascii C
    retlw "D" ; ascii D
    retlw "E" ; ascii E
    retlw "F" ; ascii F

end
1.0 INTRODUCTION

The anti-collision interrogator in the DV103005 Development Kit is for Microchip Technology Inc.’s 13.56 MHz RFID devices (MCRF35X/360 and MCRF45X devices). The interrogator is used in conjunction with the RFLab 3.2 or above. User must select device type in the RFLab Menu Bar for either MCRF35X/360 or MCRF45X device.

In the MCRF35X/360 mode, the interrogator transmits 13.56 MHz carrier signal continuously and receives tag’s responses. This is often called “tag talks first” (TTF). The interrogator is working as the reader in the DV103003 kit that is for read only device (MCRF35X and MCRF360).

In the MCRF45X mode, the interrogator sends commands for reading or writing block data. Interrogator uses amplitude modulation for the commands. To initiate communications, the interrogator sends specially timed gap pulses: FRR (fast read request) and FRB (fast read bypass). These pulses consist of 5 gaps within 1.575 ms time span. Each gap pulse is 175 µs wide with 100% modulation depth. Gap means an absence of RF field. See Figures 4-3 thru 4-8 in the MCRF45X data sheet for details.

1-of -16 PPM (pulse position modulation) is used for data and commands such as read/write command for block data, command to set/clear TF (tag talks first) and FR (fast read) bits, and command for end process. The 1-of-16 PPM signal consists of one gap pulse within 2.8 ms time span for a normal mode and 160 µs for a fast mode. The gap’s position within 16 possible locations determines its representation for hex value. See Figure 4-9 in the MCRF45X data sheet (DS40232) for details.

The interrogator also sends a time reference pulse before the commands and data. This time reference signal consists of three gap pulses within 2.8 ms time span for a normal mode and 160 µs for a fast mode. See Figure 4-10 in the MCRF45X data sheet for details. Figure 1-1 shows the read/write pulse sequence between the interrogator and device.

The demo interrogator communicates with the device in conjunction with the RFLab. The RFLab is a menu driven software package. Once the “MCRF450” - “Continuous” - “Run” menus are selected, the interrogator transmits FRR command continuously. Tags responds to the FRR command with a maximum of 160 bits of data including its unique ID number (32 bits). To read or write a specific memory block, users must select the tag ID and block number.

The demo interrogator along with the RFLab included in the DV103005 kit is made as a reference material for various applications. The demo interrogator is designed for a general purpose utilizing all possible features shown in the data sheet. Both firmware and schematics can be modified for each individual applications.

The interrogator uses two PICmicro® microcontrollers (MCUs) to communicate with a host computer, to send commands and data to the tag, and to receive and process the data from the tag.

The U17 includes the anti-collision algorithm shown in Figure 4-1 of the MCRF45X data sheet. It controls all functions of the interrogator except decoding the received Manchester data which is done by the U14.

The circuit is designed for medium read/write range applications (about 15” with 2” x 2” tag). The circuit can be optimized for lower cost, or modified for long-range applications. Electronic copies of the PICmicro MCU source codes, schematics and Bill of Material (BOM) are included in the CD.
FIGURE 1-1: READ/WRITE PULSE SEQUENCE

To write 1 block (32 bits) in normal mode with TS = 1: ~ 78.014 ms
To read 1 block (32 bits) in normal mode with TS = 1: ~ 42.214 ms

FRR or FRB Command:
5 gap pulses = 1.575 ms.

Interrogator Command (FRR/FRB)

Tag Response (FR response)

Interrogator Command (MC and Read/Write)

Tag Response (to Read/Write)

Interrogator Command (End Process)

Tag Response to End Process

Device Outputs:
After a completion of write cycle:
- Preamble (8 bits) + written block # (5 bits) + "000"
- written block data (32 bits) + CCRC/SCRC (16 bits)
- 64 bits = 0.914 ms
After read command:
- Preamble (8 bits) + block # (5 bits) + "000" + block data (32 bits)
- CCRC/SCRC (16 bits)
- 64 bits = 0.914 ms

End Process Command:
- Cal. pulse + End Process Command (111)
- Address (01010) + Parity (1)
- Cal. Pulse + 3 symbols = 11.2 ms

Device Response: 8-bit preamble (11111110) (0.114 ms)
2.0 INTERROGATOR CIRCUITS

The interrogator circuit consists of (1) transmitting, (2) receiving and (3) command control/data processing sections.

2.1 RF Transmission Section

U6:A and 13.56 MHz crystal form a crystal oscillator and output a 13.56 MHz signal. The output signal is fed into pin 1 of U7. The input signal on pin 2 of U7 is coming from U17 (Master Microcontroller). The following is the output of U17 for pin 2 of U7.

- MCRF45X mode: Modulation signal for commands and block data for writing.
- Stand by mode: Logic “HIGH”.
- MCRF35X/360 mode: Logic “HIGH”.

Therefore, U7 outputs (a) a modulated RF signal (for command or write data) or (b) continuous RF signals during the stand by and MCRF35X/360 operation. The output signal of the U7 is fed into the gate of RF power amplifier U8 through U6:D, E and F. Splitting the output of U6:C using U6:D, E and F is helpful for preventing excessive heat on U6.

U4 is an adjustable voltage regulator and supplies the DC power supply voltage for U8. The U4 is controlled by U17 through U16 (DAC) and U3. The main idea of using the adjustable voltage regulator is to adjust the RF output signal level of U8. The power level is adjusted by the following procedure in the RFLab menu:

“Configure” -> “Carrier Strength”

User can select the “Carrier Strength” from 0% – 100% (from the above menu). Default is set to 100%. The interrogator outputs the maximum power level at this setting.

RFLab sends the Carrier Strength information to U17 which adjusts U4’s output voltage through U16 and U3. This corresponds to about 12.37 Vdc at pin 2 of U4 for the 15 Vdc input voltage.

The purpose of adjusting the carrier signal level is to reduce a possible near-field problem which may result in an irregular clock rate of the RFID device. This is due to an excessive input voltage to the device when the tag is placed too close to the reader antenna. In this case, the output power level from the interrogator should be decreased. However, for a longer read range, it is often necessary to output higher power level so that it can detect tags in the far range.

Adjusting the carrier signal level is an optional choice. Therefore, the circuit components (U16, U3 and U4) associated with this feature can be easily removal. In this case, +15 Vdc or 9 Vdc should be directly applied to L9 for U8.

The RF output voltage from U8 is fed into antenna circuit formed by C1, C2, C3, C4, C5 and antenna coil L.

The demo unit has three different sizes of antenna. Each one has one turn inductor along the edge of the PCB board. The metal trace is embedded inside the PCB.

Figure 2-1 shows the antenna circuit. The impedance of LC circuit is given by:

EQUATION 2-1:

\[
Z(\omega) = \frac{1}{C_4} \left(\frac{j\omega L + \frac{1}{j\omega C_5}}{-\omega^2 L + \left(\frac{1}{C_3} + \frac{1}{C_4}\right)}\right)
\]

where

\(C_s = C_1 + C_2 + C_3 + C_5\)

\(\omega = 2\pi f\)

\(f = \) output carrier frequency

The resonant frequency of the antenna circuit in the interrogator is given by solving the impedance equation in Equation 2-1. In Equation 2-1, the impedance \(Z(\omega)\) has poles and zeroes. The poles are found at the condition when the denumerator goes to zero and the zeroes are found when the numerator goes to zero. The poles result in a maximum impedance, since the denumerator goes to zero. Therefore, the frequencies at the poles are the parallel resonant frequencies. The zeroes result in a minimum impedance since the numerator goes to zero. Thus, the frequencies at the zeroes are series resonant frequencies.

FIGURE 2-1: ANTENNA CIRCUIT
The resonant frequencies by solving the poles and zeroes are:

**EQUATION 2-2:**

\[
f_{\text{series}} = \frac{1}{2\pi \sqrt{LC_S}} = \frac{1}{2\pi \sqrt{L(C_1 + C_2 + C_3 + C_5)}}
\]

and

**EQUATION 2-3:**

\[
f_{\text{parallel}} = \frac{1}{2\pi \sqrt{\frac{1}{C_S} \left(1 + \frac{C_4}{C_S}\right)}}
\]

where

\[C_S = C_1 + C_2 + C_3 + C_5\]

Equation 2-3 is used for the antenna circuit of the interrogator in the DEV103005 kit.

The antenna voltage across the L is given:

**EQUATION 2-4:**

\[
V_{\text{Ant}} = \frac{jX_L}{r + j(X_L - X_C)} V_{\text{in}}
\]

where

\[r = \text{Ohmic resistance of L and C}
\]

\[X_L = 2\pi f L (\Omega)
\]

\[X_C = \left(2\pi f C\right)^{-1} (\Omega)
\]

\[V_{\text{in}} = \text{AC voltage at points between P1 and P2.}
\]

The antenna voltage measured between P3 and P2 contributes the radiating RF field from the antenna. The voltage is about 60 VPP – 80 VPP. C5 can be adjusted to get the maximum voltage across the antenna. The current that flows along antenna L generates magnetic fields.

Each interrogator unit may have a slightly different output parasitic capacitor. As a result, there will be a chance of tuning variation when the antenna is attached to the unit. This results in shorter read range. In this case, C5 in the circuit should be adjusted properly.

### 2.2 Receiving Section

The receiving section receives 70 kHz Manchester data from tag in the field. D1, C4 and R3 collectively form an envelope detector.

L1 and C3 form a 70 kHz bandpass filter. D4 and D2 are used to limit signal amplitude level which prevents U1:A going into a saturation condition. L3, C33 and C47 form a 13.56 MHz notch filter and bypass the induced carrier signal into ground. FB1 is an RF choker that gives high attenuation to high frequency signal. U1:A is a gain amplifier that gives about 26 dB voltage gain. U1:B is a unit gain second-order high-pass filter. U1:C is a gain amplifier with about 29 dB voltage gain. U1:D is a unit gain second-order low-pass filter. U1:B and D result in a band-pass filter for the 70 kHz Manchester data.

U11:A, B, T1 and T2 circuits are used to find a midpoint of the input data voltage. The resulting average voltage, \((V_{\text{in}}^+ + V_{\text{in}}^-)/2\), is used as a reference voltage for the voltage comparator U2. The output of U2 is fed into the PICmicro microcontroller U17 for data decoding.

### 2.3 Command Control and Data Decoding Section

The interrogator uses two PICmicro MCUs (PIC16F876-20/SP) for the command controls, data decoding and communication with a host computer.

The U17 includes PIC-code routines to follow the device’s read/write anti-collision algorithm as shown in Figure 4-1 in the data sheet. The U14 performs bit timing calculation for the received Manchester code.

The U17 does the following tasks:

a) Communicate with a host computer

b) Encode and transmit:

- FRR and FRB Commands
- Calculate/Send MC1 and MC2
- Read/Write/End Commands
- Calibration Pulse
- Data and CRC

c) Decode receiving data

d) Calculate CRC for transmitting data and receiving data. CRC look-up table is used for the calculation.

e) Give a received data stream to U14 for decoding of the Manchester data.

The flow charts of the PICmicro microcontroller routines for U14 and U17 are shown in AN760 (DS00760). The source codes are included in the CD.

Figure 2-2 shows the functional block diagram of the interrogator.
FIGURE 2-2: FUNCTIONAL BLOCK DIAGRAM OF DEMO INTERROGATOR

- **Transmitting Section**
  - 13.56 MHz Signal Generator (U6: A)
  - Power Amplifier (U8)
  - Tuning Circuit (C1, C2, C3, C4, C5)

- **Receiving Section**
  - High and Low Pass Filters (U1:B, U1:D)
  - 13.56 MHz LC Notch Filter (L3, C33, C47)
  - 70 kHz LC Band Pass Filter (L1, C3)
  - Envelope Detector (D1)

- **Other Components**
  - Host Computer (RFLab)
  - Microcontroller (U17, U14)
  - Amplifier (U1:A)
  - 20 MHz OSC
  - 13.56 MHz Signal Generator (U6: A)
  - Modulator (U7)
  - Ant.
FIGURE 2-3: DATA SIGNAL WAVEFORMS FROM TAG

Tag Data Signal

Signal Waveform in Reader Coil

After Envelope Detector

After Pulse Shaping

14.285 µs

FIGURE 2-4: BIPHASE-L (MANCHESTER) SIGNAL

(a) Data ‘1’

(b) Data ‘0’
This document specifies the external interface requirements for the MCRF45X and MCRF355/360 Reader/Writer. A description of the RS232 interface messages, their bit fields and meanings are described in this document.

Identification
This interface control document is applicable to the Microchip’s 13.56 MHz RFID Reader/Writer.

System Overview
The RFID Reader/Writer will support both reading and writing of the MCRF355/360 and MCRF45X RFID devices. The RFID Reader/Writer will support communication for command and data via an RS232 interface using standard protocol settings.

Document Organization
This document is organized as follows:
• SCOPE: Identifies the scope of this document
• REFERENCE DOCUMENTS: Identifies any documents referenced by this specification by document number, revision and date
• EXTERNAL INTERFACES: Identifies the specific external electrical and mechanical interfaces for the Support Electronics for the PDE

REFERENCED DOCUMENTS
The following references are used for this document:

EXTERNAL INTERFACES

Electrical Interfaces

SERIAL COMPUTER INTERFACE
The RFID Reader/Writer will communicate with the external host computer via RS232 interface. The interface settings will be 19.2 Kbaud, 8 bits, no parity and one stop bit. All characters transmitted will be within the ASCII character set, ASCII value less than 127.

TEST INTERFACE
The RFID Reader/Writer will provide discrete LEDs that will provide simple status of the RFID Reader/Writer independent of attached PC.

Communication Protocol/Messages
The packet protocol for the RFID Reader/Writer is described in the following paragraphs. The protocol provides a robust, easily managed interface that supports debugging on a simple ASCII terminal in addition to providing a checksum for message validation.

The general message format is as follows:

<table>
<thead>
<tr>
<th>Sync Char</th>
<th>Command</th>
<th>Data</th>
<th>Checksum</th>
<th>CR LF</th>
</tr>
</thead>
</table>

General Message Format

Sync Char: Single byte character ‘@’ denoting the beginning of a message
Command: Single byte character defining the command this message represents. See Table 1 for a list of commands
Data: A variable length field containing additional information support the command
Checksum: The two-byte checksum used for the message includes the Sync Char through the end of the Data field. See the following paragraph for more information on the checksum used
CR LF: This two-byte field is the standard ASCII carriage return ‘0x0D’ and the line feed ‘0x0A’
CHECKSUM

The checksum is a two-character field. Adding the fields Sync Char through Data into an unsigned byte type and ignoring any overflow generated determines this value. The resultant value is then negated to provide a 2’s complement checksum value. This 8-bit result is then converted to two hex characters to represent the checksum in the message (e.g. checksum byte value 00101100 results in a checksum of two ASCII bytes ‘2C’ represented in the message).

MESSAGE FORMATS

The following paragraphs detail the individual commands and messages.

TABLE 1:

<table>
<thead>
<tr>
<th>Command Char</th>
<th>From</th>
<th>To</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘2’</td>
<td>R/W</td>
<td>PC</td>
<td>Data field contains MCRF355 data (14 bytes)</td>
</tr>
<tr>
<td>‘3’</td>
<td>R/W</td>
<td>PC</td>
<td>Data field contains MCRF355 data (18 bytes)</td>
</tr>
<tr>
<td>‘4’</td>
<td>R/W</td>
<td>PC</td>
<td>Data field contains MCRF450 data blocks (Read)</td>
</tr>
<tr>
<td>‘5’</td>
<td>R/W</td>
<td>PC</td>
<td>Data field contains MCRF450 data blocks (Write)</td>
</tr>
<tr>
<td>‘6’</td>
<td>R/W</td>
<td>PC</td>
<td>Data field contains MCRF450 FRB response data</td>
</tr>
<tr>
<td>‘7’</td>
<td>R/W</td>
<td>PC</td>
<td>Data field contains MCRF450 FRR response data</td>
</tr>
<tr>
<td>‘F’</td>
<td>R/W</td>
<td>PC</td>
<td>Firmware version</td>
</tr>
<tr>
<td>‘R’</td>
<td>R/W</td>
<td>PC</td>
<td>Response message</td>
</tr>
<tr>
<td>‘R’</td>
<td>PC</td>
<td>R/W</td>
<td>Reset request command</td>
</tr>
<tr>
<td>‘M’</td>
<td>PC</td>
<td>R/W</td>
<td>Mode select command</td>
</tr>
<tr>
<td>‘N’</td>
<td>PC</td>
<td>R/W</td>
<td>No operation</td>
</tr>
<tr>
<td>‘V’</td>
<td>PC</td>
<td>R/W</td>
<td>Verbose read command</td>
</tr>
<tr>
<td>‘W’</td>
<td>PC</td>
<td>R/W</td>
<td>Write command</td>
</tr>
<tr>
<td>‘C’</td>
<td>PC</td>
<td>R/W</td>
<td>Configuration message</td>
</tr>
<tr>
<td>‘L’</td>
<td>PC</td>
<td>R/W</td>
<td>Load command</td>
</tr>
</tbody>
</table>

LOAD MESSAGE

The load command provides a method to update the PIC 16F876 firmware in the field via the RS-232 interface. The Data Field length is zero. When the load command is received, the RFID Reader/Writer will transition to a ‘loader’, which will then accept hex record lines to be written to program memory. The format of the hex record will be the format generated by the Microchip assembler/linker. Each hex record line will be validated before writing to program memory. The RFID Reader/Writer will respond with ‘Ready’ response message upon successful write or an error message if unsuccessful. After the final line of the .HEX file is sent, the newly loaded program is entered using the POR vector at address 0000. See Response Message paragraphs.

LOAD MESSAGE FORMAT

```
0x40 'L' Data Checksum CR LF
```
RESPONSE MESSAGE

The response message is used to provide acknowledge and status response from the R/W to the external PC. The data field contains the specific response encoded as a 2-digit hexadecimal number. The responses supported are listed below.

<table>
<thead>
<tr>
<th>Response Number</th>
<th>Equivalent Text</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>&quot;Ready&quot;</td>
<td>Ready for the next message</td>
</tr>
<tr>
<td>01</td>
<td>&quot;EEPROM Burn Failed&quot;</td>
<td>Previous write was read back and validated unsuccessfully</td>
</tr>
<tr>
<td>02</td>
<td>&quot;No Entry Point Specified&quot;</td>
<td>No processor instructions were given for ROM locations 0-3</td>
</tr>
<tr>
<td>03</td>
<td>&quot;Invalid Address&quot;</td>
<td>A write to Program ROM was outside valid range</td>
</tr>
<tr>
<td>04</td>
<td>&quot;Invalid Hex Data&quot;</td>
<td>The characters representing hex data were not in the range 0-9, A-F</td>
</tr>
<tr>
<td>05</td>
<td>&quot;RS-232 Error&quot;</td>
<td>Characters were lost or garbled. Message should be repeated.</td>
</tr>
<tr>
<td>06</td>
<td>&quot;Invalid Checksum&quot;</td>
<td>Checksum did not verify</td>
</tr>
<tr>
<td>07</td>
<td>&quot;Undefined Command&quot;</td>
<td>Command byte sent is not a known command</td>
</tr>
<tr>
<td>08</td>
<td>&quot;Invalid Parameter&quot;</td>
<td>Contents of a command string are invalid</td>
</tr>
<tr>
<td>09</td>
<td>&quot;Bad Processor&quot;</td>
<td>The Slave processor fails to communicate</td>
</tr>
</tbody>
</table>

RESET MESSAGE

The reset message is sent from the external PC to the Reader/Writer. It instructs the R/W to reset itself, and return to the just-powered-up state. In this state, the carrier is off, and the R/W is sending 'A' characters over the RS-232 line at a 50 Hz rate, looking for a PC-based application to communicate with. See the paragraph "Auto Detect Support" for a more complete description. The data field length is zero.

NOP MESSAGE

The NOP message is a no operation message. It can be used as a 'heart-beat' message to maintain communication if needed. The Data Field length is zero. This command returns the "Ready" Response Message ("R"). Note that this and every command causes the Reader/Writer to stop its current operations to process the new command. After this command, the Reader/Writer remains in the idle loop, waiting for the next command.
MODE SELECT MESSAGE

The mode select message is used to put the RFID Reader/Writer in a specific read mode as defined below.

```
0x40 'M' Data Field Checksum CR LF
```

MODE SELECT MESSAGE

The mode field contains a one-byte character that defines the specific mode to place the reader into. This byte is defined below.

<table>
<thead>
<tr>
<th>Mode Char</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>'0'</td>
<td>Read MCRF355/360 tags, returning the data in Microchip format. No anti-aliasing – all tag reads are reported</td>
</tr>
<tr>
<td>'1'</td>
<td>Read MCRF355/360 tags, returning raw tag data. No anti-aliasing – all tag reads are reported</td>
</tr>
<tr>
<td>'2'</td>
<td>Read MCRF355/360 tags, returning the data in Microchip format. Anti-aliasing enabled -- subsequent reads of the same tag are ignored.</td>
</tr>
<tr>
<td>'3'</td>
<td>Read MCRF355/360 tags, returning raw tag data. Anti-aliasing enabled -- subsequent reads of the same tag are ignored.</td>
</tr>
<tr>
<td>'I'</td>
<td>Inventory read mode. (FRR &amp; FRB: tags are put to sleep after being identified)</td>
</tr>
<tr>
<td>'C'</td>
<td>Continuous read mode. (FRR &amp; FRB)</td>
</tr>
<tr>
<td>'A'</td>
<td>Alarm mode. (FRR only)</td>
</tr>
<tr>
<td>'S'</td>
<td>Stop reading mode. (Leave carrier on)</td>
</tr>
<tr>
<td>'F'</td>
<td>Reader/writer off. (Turn carrier off)</td>
</tr>
</tbody>
</table>

MODE SELECT CHARACTERS

355 DATA BLOCKS MESSAGE – MICROCHIP FORMAT

This message contains the entire data block from the MCRF355/360 represented in ASCII hex format. It assumes the tag was written in Microchip format, which is: 10-bit header (9 ones, and 1 zero), followed by 14 8-bit bytes and a 2-byte checksum, with each byte separated by a zero bit, and written MSb first. The checksum of the block is verified before transmission.

```
0x40 '2' Data Block Checksum CR LF
```

355/360 DATA BLOCKS MESSAGE
The format of the data block is as follows:

T<time stamp>, <data>

Where:

<table>
<thead>
<tr>
<th>Field name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time stamp</td>
<td>The time stamp of when the device was read. This value consists of 2 bytes (4 ASCII hex characters), with the LSb = 819.2 µS. The clock is a free-running counter with a rollover period of 53.7 seconds. The bytes are sent MSb first.</td>
</tr>
<tr>
<td>Data</td>
<td>The 14 data bytes represented in ASCII hex characters. Byte 13 is first; byte 0 is last. The checksum bytes are not transferred.</td>
</tr>
</tbody>
</table>

"Microchip Format" is defined by the MCRF 355/360 Contact Programmer, and is shown graphically below. Of the 154 bits in the tag, the first 9 are the preamble, and fixed as '1' bits. Following the preamble, and separating each byte, are spacer bits (zeros). All bytes are Most Significant bit (MSb) first. This format allows 14 data bytes followed by a 16-bit checksum (simple summation of all 14 bytes).

<table>
<thead>
<tr>
<th>111111111</th>
<th>0 Byte 13</th>
<th>0 Byte 12</th>
<th>0 ...</th>
<th>Byte 0</th>
<th>0 Chksum_MSn</th>
<th>0 Chksum_LSn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit 0</td>
<td>Bit 9</td>
<td>Bit 18</td>
<td>Bit 27</td>
<td>Bit 135</td>
<td>Bit 144</td>
<td>Bit 152</td>
</tr>
</tbody>
</table>

355/360 DATA BLOCKS MESSAGE – RAW FORMAT

This message contains the data block from the MCRF355/360 represented in ASCII hex format. It assumes the tag was written in Microchip format, however the spacer bits which exist between every byte are not removed. Internally, the data is converted to Microchip format so that the block checksum can be calculated and verified before transmission.

0x40 '3' Data Block Checksum CR LF

355/360 Data Blocks Message

The format of the Data Block is as follows:

T<time stamp>, <data>

Where:

<table>
<thead>
<tr>
<th>Field name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time stamp</td>
<td>The time stamp of when the device was read. This value consists of 2 bytes (4 ASCII hex characters), with the LSb = 819.2 µS. The clock is a free-running counter with a rollover period of 53.7 seconds. The bytes are sent MSb first.</td>
</tr>
<tr>
<td>Data</td>
<td>The 18 data bytes represented in ASCII hex characters. Byte 17 is sent first.</td>
</tr>
</tbody>
</table>
The tag data is assumed to be as shown graphically below for purposes of displaying it in 'Raw Format'. It is similar to Microchip Format in that all bytes are Most Significant bit (MSb) first, and the first 10 bits are the fixed preamble (9 one-bits followed by a zero bit). The remaining 143 bits make up the 18 8-bit bytes.

| Note: | The last byte has one missing bit. Its Least Significant bit (LSb) is fixed at zero. |

```
111111111 0 Byte 17 Byte 16 ... Byte 1 Byte 0
```

**Bit 0** Bit 9 Bit 18 Bit 138 Bit 146 Bit 152

### MCRF45X DATA BLOCKS MESSAGE

```
0x40  '4' Data Block Checksum CR LF
```

### 45X DATA BLOCKS MESSAGE

This message contains the data blocks returned from the MCRF450 in response to a Verbose Read command. All 32 blocks of the MCRF450 tag are included. The message elements are defined below. The format of the Data Block is:

```
I<id>,<block>:<data>,<block>:<data>,...<block>:<data>
```

Where:

<table>
<thead>
<tr>
<th>Field name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I&lt;id&gt;</td>
<td>The ASCII hex representation of the 4-byte tag ID. LSb first.</td>
</tr>
<tr>
<td>Block</td>
<td>Block number, represented by 2 ASCII hex characters. Its value ranges from 00 to 1F (31 decimal). Block numbers are followed by a colon.</td>
</tr>
<tr>
<td>Data</td>
<td>One data block (4 bytes) from the tag, represented in ASCII hex characters. Data blocks are separated by commas. A block which is unreadable (invalid CRC) will return “XXXX” for the data. In this case, it will be 4 characters instead of 8. The data is LSb first.</td>
</tr>
</tbody>
</table>

### 45X DATA BLOCKS MESSAGE DETAIL
MCRTF45X DATA BLOCKS WRITTEN

MESSAGE

This message contains the data blocks returned from the MCRTF45X in response to a Verbose Write command. One message is returned per tag written. The message elements are defined below. The format of the Data Block is:

I<id>,<block>:<data>,<block>:<data>,<block>:<data>,<block>:<data>

Where:

<table>
<thead>
<tr>
<th>Field name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I&lt;id&gt;</td>
<td>The ASCII hex representation of the 4-byte tag ID. LSb first.</td>
</tr>
<tr>
<td>Block</td>
<td>Block number, represented by 2 ASCII hex characters. Its value ranges from 00 to 1F (31 decimal). Block numbers are followed by a colon.</td>
</tr>
<tr>
<td>Data</td>
<td>One data block (4 bytes) from the tag, represented in ASCII hex characters. This data is what the tag returned following the write to this block. A block which is write-protected will return “RO” for the data. In this case, it will be 2 characters instead of 8. A block which is unreadable (invalid CRC) will return “XXXX” for the data. The data is LSb first.</td>
</tr>
</tbody>
</table>

450 FRB RESPONSE MESSAGE

This message contains the data returned from the MCRTF45X in response to an FRB command. The message elements are defined below.

The format of the Data Block is:

T<time stamp>,<TC/TP>,<ID>,<FRF>

Where:

<table>
<thead>
<tr>
<th>Field name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time stamp</td>
<td>The time stamp of when the device was read. This value consists of 2 bytes (4 ASCII hex characters), with the LSb = 819.2 μS. The clock is a free-running counter with a rollover period of 53.7 seconds. The bytes are sent MSb first.</td>
</tr>
<tr>
<td>ID</td>
<td>One data block (4 bytes) represented in ASCII hex characters. The data is from Block #1, the tag’s ID. The data is sent LSb first.</td>
</tr>
</tbody>
</table>
MCRF45X FRR RESPONSE MESSAGE

This message contains the data returned from the MCRF450 in response to an FRR command. The message elements are defined below. The format of the Data Block is:

\[ T<\text{time stamp}>,<\text{TC/TP}>,<\text{ID}>,<\text{FRF}> \]

Where:

<table>
<thead>
<tr>
<th>Field name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time stamp</td>
<td>The time stamp of when the device was read. This value consists of 2 bytes (4 ASCII hex characters), with the LSB = 819.2 µS. The clock is a free-running counter with a rollover period of 53.7 seconds. The bytes are sent MSb first.</td>
</tr>
<tr>
<td>TC/TP</td>
<td>One byte containing the TC and TP values from the tag, represented in ASCII hex characters. Bits 0-2 are the TC value; bits 3-7 are the TP (tag parameters) value. See the MCRF45X Data Sheet on the format of the TP field.</td>
</tr>
<tr>
<td>ID</td>
<td>One data block (4 bytes) represented in ASCII hex characters. The data is from Block #1, the tag’s ID. The data is sent LSb first.</td>
</tr>
<tr>
<td>FRF</td>
<td>The Fast Read Field, represented in ASCII hex characters. The data is from Blocks #3-5. The exact number of bytes in the FRF depends upon the 2 DF bits within the TP field, and can be 4, 6, 8 or 12. The LSb is sent first.</td>
</tr>
</tbody>
</table>

45X FRR RESPONSE MESSAGE DETAIL

FIRMWARE VERSION RESPONSE MESSAGE

This message is sent once, immediately following connection establishment. The format of the Data Block is 2 ASCII digits indicating the major and minor revision numbers. The range of revision numbers supported is 1.0 thru 9.9.

VERBOSE READ MESSAGE

This message will terminate continuous read mode and initiate a read of a specific ID tag in the field. The response to this message will be a 450 Data Blocks message ('4').

WRITE MESSAGE

The write message provides the capability to program one or all MCRF45X devices with one to 16 blocks of data. If write-all-tags is selected, the Reader/Writer will look for all FRR and FRB parts in the field, writing them as soon as they are found, until the user places the Reader/Writer into another mode (or idle state). If one-tag-write is selected, the carrier is turned off after the selected tag is found and written. The response to this message will be one or more 45X Data Blocks Written message ('5') - one per tag.

If the starting block number is 0 or 2, the number of data blocks to be written is limited to 1 block.

In order to prevent an FRR part from becoming inaccessible in case of a failed write to blocks 0, 3, 4 or 5, the Reader/Writer will turn an FRR part into an FRB part prior to writing these blocks, then return it into an FRR part only if all blocks were written correctly. When writing to block 0, bit 31 should be kept clear to keep from flagging a special case, described next.

Two special cases of the Write Command exist: converting FRR tags into FRBs, and converting FRB tags into FRRs.
To turn devices into FRR parts, issue the Write Message for data block 0, with the two most-significant bits of the data (Fast Read and Talk First bits) set to '1'. The remaining 30 data bits are don't care. When the Reader/Writer sees this situation, it will calculate the correct FRR response CRC for the tag and write it to the low 16 bits of block 0. After successful write, it then sets the FR bit. A 45X Data Blocks Written message ('5') is returned for each tag which is changed from an FRB part to an FRR part.

To turn devices into FRB parts, issue the Write Message for data block 0, with bit 31 of the data (Fast Read) set to '1', and bit 30 (Talk First) set to '0'. The remaining 30 data bits are don't care. The Reader/Writer will clear the FR bit (bit 31 of block 0) without affecting any other tag memory bits. A 450 Data Blocks Written message ('5') is returned for each tag which is changed from an FRR part to an FRB part.

The format of the message is as follows.

<table>
<thead>
<tr>
<th>Field name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I&lt;id&gt;</td>
<td>The ASCII hex representation of the 4-byte tag ID. (LSb first)</td>
</tr>
<tr>
<td>&lt;block number&gt;</td>
<td>The beginning block number to write, represented in ASCII hex.</td>
</tr>
<tr>
<td>&lt;data&gt;</td>
<td>A 4-byte block of data, LSB first, in ASCII hex representation.</td>
</tr>
</tbody>
</table>

The Data Block has the following format to write to all devices in the R/W field. The total number of <data> fields must be 16 or less.

*,<block number>,<data>,<data>,...,<data>

Where:

<table>
<thead>
<tr>
<th>Field name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>*</td>
<td>Replacing the I&lt;id&gt; field with a star character denotes all tags.</td>
</tr>
<tr>
<td>&lt;block number&gt;</td>
<td>The beginning block number to write, represented in ASCII hex.</td>
</tr>
<tr>
<td>&lt;data&gt;</td>
<td>A 4-byte block of data, LSB first, in ASCII hex representation.</td>
</tr>
</tbody>
</table>

**CONFIGURATION MESSAGE**

The configuration message provides a method to set specific attributes within the RFID Reader/Writer firmware. The format of the message is as follows.

<table>
<thead>
<tr>
<th>Field name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>T&lt;ts&gt;,M&lt;tcmax&gt;,S&lt;speed&gt;,P&lt;ppm timing&gt;,G&lt;gap timing&gt;,V&lt;vpp&gt;,I&lt;audio&gt;</td>
<td>The order of the parameters is not important.</td>
</tr>
</tbody>
</table>
Where:

<table>
<thead>
<tr>
<th>Field</th>
<th>POR Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>T&lt;ts&gt;</td>
<td>16</td>
<td>The ASCII hex representation of 1 byte: The number of Time Slots used in the tag’s FRR command. Valid values are: 1, 16, 64.</td>
</tr>
<tr>
<td>M&lt;tcmax&gt;</td>
<td>1</td>
<td>The ASCII hex representation of 1 byte: The TCMAX value to use in the tag’s FRR command. Valid values are: 1, 2, 4. If TS = 64, then TCMAX must be 1.</td>
</tr>
<tr>
<td>S&lt;speed&gt;</td>
<td>0</td>
<td>The ASCII hex representation of 1 byte: Whether to modulate the carrier at Normal Speed or Fast Speed for the PPM symbols. A value of 0 sets Normal Speed; a value of 1 sets Fast Speed.</td>
</tr>
<tr>
<td>P&lt;ppm timing&gt;</td>
<td>0</td>
<td>The ASCII hex representation of an 8-bit signed integer: The relative timing to use for gap periods. Valid range is -6 to +6, with 0 being nominal (175 µS Normal Speed/10 µS Fast Speed). -6 corresponds to 20% reduction in time, and +6 corresponds to 20% increase in time. +/- 3 corresponds to +/-10%, etc.</td>
</tr>
<tr>
<td>G&lt;gap timing&gt;</td>
<td>0</td>
<td>The ASCII hex representation of an 8-bit signed integer: The relative timing to use for gap widths. Valid range is -6 to +6, with 0 being nominal (100 µS Normal Speed/6 µS Fast Speed). -6 corresponds to 20% reduction in time, and +6 corresponds to 20% increase in time. +/- 3 corresponds to +/-10%, etc.</td>
</tr>
<tr>
<td>V&lt;vpp&gt;</td>
<td>FFh</td>
<td>The ASCII hex representation of 1 byte: The relative strength of the carrier signal. A value of 0 sets no carrier; a value of FFh sets maximum carrier field strength.</td>
</tr>
<tr>
<td>I&lt;audio&gt;</td>
<td>1</td>
<td>The ASCII hex representation of 1 byte: A value of 1 enables beeps when each tag is detected. A value of 0 disables audible indication.</td>
</tr>
</tbody>
</table>

**AUTO DETECT SUPPORT**

At power-up of the RFID Reader/Writer, the character ‘A’ will be continuously transmitted at a 50 Hz rate over the serial port. This provides a serial stream to support auto-detection of the device by a PC. When the Reader/Writer receives a ‘B’ character from the PC, it will cease transmission of the ‘A’ characters, and return a type “F” Response Message (Firmware Version), thus establishing a positive confirmation of communication. The RS-232 parameters are: 19.2 Kbaud, 8 bits, no parity, and 1 stop bit.
PICmicro® Microcontroller Firmware Flow Chart
of MCRF45X Demo Reader

RFID Top-Level

U17, Master processor

POR

MAIN

INITIALIZE

WAIT FOR START OF COMMAND

GET COMMAND LETTER

CMD = “N”

Yes

NOP

SEND “READY” MESSAGE

CMD = “C”

No

CMD = “M”

Yes

EXECUTE SPECIFIED MODE

CMD = “R”

No

JUMP TO PROGRAM LOCATION “0000”

CMD = “W”

Yes

PERFORM “WRITE” COMMAND

CMD = “V”

No

PERFORM “READ” COMMAND

CMD = “L”

Yes

JUMP TO LOADER

SEND ERROR MSG: “UNDEFINED” CMD

CMD = “L”

No

FLUSH REST OF CMD LINE

N = No operation
C = Configuration message
M = Mode select
R = Reset request
W = Write
V = Verbose read
L = Load

Load new firmware using RS-232 port

© 2001 Microchip Technology Inc.
In case any tags were put to sleep in previous activity

NEED TO CYCLE THE CARRIER?

TURN OFF CARRIER

WAIT 100 ms

TURN ON CARRIER

WAIT 250 ms

TURN CARRIER OFF

TURN CARRIER ON

MODE \( \in \{0,1,2,3\} \)

SEND ERROR MSG: "UNKNOWN MODE"

MODE \( \in \{I,A,C\} \)
Mode 0: Microchip Format, No Anti-Collision
Mode 1: Raw Format, No Anti-Collision
Mode 2: Microchip Format, Anti-Collision
Mode 3: Raw Format, Anti-Collision

MODES 0, 1, 2, 3

MCRF 355

TURN ON CARRIER

CLEAR TAG DATABASE

RECEIVED ANY RS-232?

WAIT FOR TAG DATA

GOT 18 BYTES?

REMOVE '0' BITS BETWEEN EVERY BYTE

ANY SPACE BITS = '1'? 

REVERSE BIT ORDER IN EACH BYTE

CALCULATE CHECKSUM

CHECKSUM CORRECT?

MODE = '0' OR '1'? 

TAG EXISTS IN DATABASE?

STORE TAG'S CHECKSUM IN DATABASE

EXIT

SET AUDIO ON/OFF

SEND TIME STAMP

SEND 14 BYTES OF CLEANED UP DATA

SEND 18 BYTES OF ORIGINAL (RAW) DATA

FINISH RESPONSE PACKET
Modes A, I, C

- **Mode A**: Look for FRR tag only
- **Mode I**: Put tags to sleep when they are found
- **Mode C**: Look for FRR & FRB tags continuously

- **MCRF 450**
- **RECEIVED ANY RS-232 BYTES**?
  - Yes: SEND FOR GAP SEQUENCE
  - No: EXIT
  - No: WAIT FOR TAG DATA
  - TIME-OUT?
    - Yes: MODE = 'A'?
      - Yes: SEND: CALIBRATION & MC1
      - No: SEND: FRR RESPONSE PACKET TO PC
    - No: MODE = 'I'?
      - Yes: SEND: CALIBRATION + MC1 + END PROCESS
      - No: SEND FRR RESPONSE PACKET TO PC
  - MODE = 'C'?
    - Yes: SEND: CALIBRATION + MC1 + END PROCESS
    - No: SEND FRR RESPONSE PACKET TO PC

*NOTE*: This puts part to sleep for Inventory Mode
READ COMMAND

GET TAG ID FROM PC

NEED TO CYCLE THE CARRIER?

No

ACCESS A TAG

BLK_NO = 0

READ BLOCK

OK?

Yes

BLK_NO = 0?

No

REPORT TO PC: DATA = “XXXX”

++BLK_NO = 32?

No

REPORT TO PC: BLK_NO: DATA

TURN OFF CARRIER

EXIT

Yes

TURN OFF CARRIER

WAIT 100 ms

TURN ON CARRIER

WAIT 250 ms

No
WRITE COMMAND

GET TAG_ID, STARTING BLOCK_NO, BLOCK DATA FROM PC

TAG_ID = ""? Yes WR_ALL_TAGS = 1

No

START BLOCK = 0

Yes

BLOCK DATA BIT 31 = 1

Yes

MAKE_FRR = 1

No

MAKE_FRB = 1

START BLOCK

NEED TO CYCLE THE CARRIER?

Yes CARRIER OFF FOR 100 ms

No CARRIER ON FOR 250 ms

ACCESS A TAG

MAKE INTO AN FRR PART

MAKE_FRR?

Yes

MAKE_FRB?

No

Yes

MAKE_FRB?

No

IS THIS ON FRR TAG?

Yes START BLOCK = 0,3,4,5? Yes

No

READ BLOCK 2

WRITE BLOCKS

PUT TAG TO SLEEP

YES WR_ALL_TAGS? No TURN OFF CARRIER

EXIT
ACCESS A TAG

RECEIVED ANY RS-232 BYTES?
No
Yes

TIME-OUT?
No
Yes

SEND FRR GAP SEQUENCE

WAIT FOR TAG DATA

ANY DATA?
No
Yes

SEND FRB GAP SEQUENCE

WAIT FOR TAG DATA

WR_ALL_TAGS?
No
Yes

D

D

ID=DESIRED ID?
No
Yes

SEND MC1 TO SLEEP THE PART

SEND MC2 TO ACCESS THE TAG

EXIT

WR_ALL_TAGS?
No
Yes

SEND MC2 & END_PROCESS TO SLEEP THE PART

EXIT

Return to Command Processor
READ BLOCK

RETRIES = 3

SEND READ BLOCK CMD FOR BLK_NO

WAIT FOR TAG DATA

ANY DATA?

Yes

No

ANY _ RETRIES > 0?

Yes

No

MESSAGE CRC CORRECT?

Yes

No

EXIT

(PASS)

EXIT

(FAIL)
WRITE BLOCKS

BEGIN RESPONSE PACKET TO PC

MAKE FRB?

MAKE FRR?

IS BLOCK 0 CRC CORRECT?

IS THIS BLOCK WRITE PROTECTED?

SEND WRITE_BLOCK COMMAND TO TAG

RETRIES = 8

WAIT FOR TAG DATA

MAKE FRR?

TIME-OUT?

REPORT "RO" FOR BLOCK DATA

REPORT "XXXX" FOR BLOCK DATA

ADD BLOCK'S DATA TO RESPONSE PACKET

SEND READ_BLOCK COMMAND TO TAG

BLOCK_NO = BLOCK_NO + 1

MORE BLOCKS TO WRITE?

SEND SET_FR_BIT COMMAND TO TAG

SET-UP TO LOOP ONCE MORE

FINISH RESPONSE PACKET TO PC

IS THIS AN FRR PART?

MAKE FRR?

ANY ERRORS SO FAR?

EXIT

REPORT "XXXX" FOR BLOCK DATA

REPORT "XXXX" FOR BLOCK DATA

Yes

No
MAKE AN FRR PART

READ TAG’S BLOCK #0

FAIL?

Yes

READ TAG’S BLOCK #2

FAIL?

Yes

No

IS THIS TAG AN FRR ALREADY?

No

READ TAG’S BLOCK #’S 3, 4, 5

FAIL?

Yes

No

CALCULATE CORRECT CRC FOR FRR RESPONSE

STORE CRC IN BLOCK 0 RAM BUFFER

WRITE BLOCK #0

SEND END PROCESS CMD TO SLEEP THE TAG

WR_ALL_TAGS?

Yes

EXIT

No

TURN CARRIER OFF

Wait for command from PC
SLAVE PROCESSOR

INITIALIZE

STATE = 0

WAIT FOR FIRST EDGE OF MANCHESTER DATA

ENABLE INTERRUPTS

WAIT FOR END OF DATA STREAM

DISABLE INTERRUPTS

IS MASTER µP BUSY?

No

ANY DATA RCV'D FROM TAG?

Yes

ANY PARTIAL BYTE REMAINING?

Yes

SEND # EMPTY BITS IN FINAL DATA BYTE OVER SPI BUS

No

SEND PARTIAL BYTE OVER SPI BUS

No

WAIT FOR MASTER PROCESSOR READY

WAIT FOR MANCHESTER LINE IDLE

Yes

U14
SLAVE PROCESSOR ISR

CAPTURE CURRENT STATE OF MANCHESTER DATA

CAPTURE TIME ELAPSED SINCE LAST EDGE ON MANCHESTER LINE

STATE = 0

STATE = 1

STATE = 2

ADD THE BIT TO BYTE-BUILDING BUFFER

IS THIS THE 4TH EDGE?

Yes

STATE = 1

IS THIS A ZERO BIT?

Yes

STATE = 3

SEND FIRST BYTE (ALWAYS 7F) OVER SPI BUS

8TH BIT?

HAS MASTER TAKEN PREVIOUS BYTE OFF SPI BUS?

Yes

SEND LATEST BYTE TO MASTER VIA SPI BUS

EXIT ISR

FLAG: MASTER µP IS BUSY
1.0 WAFTER ON FRAME ASSEMBLY FLOW

Die Inspection
A. Wafer thickness
B. Visual inspection

Die Attach
A. Exopy age/shelf life
B. Exopy voids
C. Epoxy coverage
D. Epoxy bleedout
E. Dry paste thickness
F. Die shear
G. Visual inspection

Epoxy Cure
A. Oven temperature profile
B. Duration time
C. Cure N2 flow rate

Wire Bond
A. Cratering test
B. Capillary
C. Visual inspection
D. Wirepull strength

Visual Inspection

Encapsulation
A. Glob top life/storage
B. Coating monitor
C. Internal voids
D. Wire sweep

Cure Condition
A. Oven temperature profile
B. Monitor cure time
C. Package thickness

Open/Short Testing

Final Visual Inspection
2.0 WAFER ASSEMBLY FLOW

Die Inspection
- Wafer thickness
- Visual inspection

Wafer Saw/Clean
- DI water resistivity
- DI bacteria count
- DI chlorine count
- DI particle count
- Cleaning pressure
- Kerf width

Die Attach
- Epoxy age/shelf life
- Epoxy voids
- Epoxy coverage
- Epoxy bleedout
- Dry past thickness
- Die shear
- Visual inspection

Epoxy Cure
- Oven temperature profile
- Duration time
- Cure N2 flow rate

Wire Bond
- Cratering test
- Capillary
- Visual inspection
- Wirepull strength

Visual Inspection

Encapsulation
- Glob top life/storage
- Coating monitor
- Internal voids
- Wire sweep

Cure Condition
- Oven temperature profile
- Monitor cure time
- Package thickness

Open/Short Testing

Final Visual Inspection