WHITE PAPER

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RF430FRL152H Novel Ferroelectric RAM Memory (FRAM) NFC Embedded Tag Based Sensors

Introduction

With the proliferation of near field communication (NFC)enabled handsets, a new market arises for NFC endpoint sensor solutions where the functionality of the device can be programmed at the manufacturing site or out in the field. These NFC devices should scavenge sufficient energy to power the NFC communication module, the sensor, the microcontroller and enable data logging of sensor collected data. Unlike other wireless sensor networks, the energy consumption breakdown of the NFC system is not dominated by the RF c omponent. In this case, the energy required to store the sensor collected data is a dominant parameter. With ferroelectric random access memory (FRAM0 technology the overall memory storage requirements are orders of magnitude lower compared to other non-volatile memory technologies such as EEPROM or Flash. This reduces the requirements on the energy scavenging solutions, whether RF based, as in the case of NFC passive RF communication or other suitable energy scavenging solutions as well as maximizes battery lifetimes of the wireless sensor network. In addition, NFC solutions in a number of applications will require safe guarding of the sensor collected data such as in the medical space. FRAM-based solutions with fast write times and low-write currents help protect against unwanted attacks.

RF430FRL152H Dynamic NFC Sensor Solution

The RF430FRL152H device is suited for NFC sensor applications. This differentiated offering by Texas Instruments provides an NFC front end supporting an ISO15693 RF protocol, a 16-bit microcontroller and 2KB of universal FRAM memory all integrated in a single device. The embedded MSP430™ microcontroller core enables the device to be programmed and allows for standalone functionality without the need for a host controller. Other advantages to having programmable functionality embedded on the device includes the ability to handle multiple sensors, the ability to enable customization of arithmetic processing of sensor data, fast customization of sensor data collection and the ability to provide for a field upgradable solution.

In addition, the RF430FRL152H device supports the integration of digital sensors through the I^2C/SPI interface or analog sensor through a 14-bit sigma-delta analog to digital converter. The onboard power management allows functionality with power coming from a separate single cell battery or through scavenged RF energy. The scavenged energy from a handset providing a continuous RF field can also be used to power an external sensor. The onboard power management also enables the battery to be connected and disconnected via an RF command.

Power Efficiency Analysis of NFC Wireless Sensor Networks

The analysis of most typical wireless sensor networks (WSN) tends to focus primarily on the energy consumption of the RF communication channel as this tends to drive the overall power consumption breakdown. These active wireless sensors are required to periodically transmit the sensor collected data to a gateway where the data is stored in a central database. The transmission occurs either directly to the gateway or through a hopping mechanism via adjacent nodes. Thus each node is expected to transmit its own set of data and be prepared to retransmit the data from adjacent nodes. The requirement to retransmit data from adjacent nodes and the need to respond to commands from these nodes or the gateway itself, brings about a requirement to enable an active listening cycle, which in addition to the data transmission, drives the overall RF power requirements in active WSNs.

In the case of NFC endpoint sensors, RF communication occurs through a passive transmission of the endpoint data eliminating this component from the power consumption analysis. The power consumption breakdown is now driven by all the other components of the system. This includes the power requirements for data logging, the power consumption of the sensor and any other peripherals that may be included in the system such as an LCD display. For an embedded microcontroller solution we also need to account for the energy consumption during active and sleep modes. In order to extend the battery lifetime of the system, each of these components needs to be understood and optimized for the specific use conditions.

Active wireless sensor nodes tend to 'cache' the sensor collected data in the SRAM for temporary storage prior to transmitting to the gateway as opposed to storing in non-volatile memory. Storing in SRAM is more power efficient compared to storing in Flash or EEPROM, alleviating the overall power requirements of the system. As the data is periodically transmitted to the gateway, the amount of data that is temporarily stored is relatively low. For the case of NFC wireless sensor nodes, the device is typically expected to hold the sensor data for an extended period of time which drives the need to store the data in non-volatile memory. Storing in non-volatile memory also provides the added benefit of being able to retrieve the data when the battery is no longer operational. Non-volatile FRAM technology drives a rethinking of wireless sensor network design by exploiting the high capacity and highly energy efficient storage capabilities. This memory technology allows for a larger amount of sensor data to be stored locally prior to transmission to the gateway. By taking advantage of the aggregation of this larger amount of data, the overall system energy efficiency is additionally optimized.

In this paper, we look at the use of the RF430FRL152H device for low power NFC sensor solutions and consider the impact and benefits of embedded non volatile FRAM technology in these applications.
A subsystems energy consumption model which accounts for the major components in the system is used to determine the power efficiency under a number of use conditions and enables a comparison of the different memories. The model is extended to derive battery lifetime estimations and a comparison is carried out among the different NVM memory technologies. The use of FRAM memory enables lower capacity batteries to be used in the solution. The savings come not just from the ability to support lower capacity batteries but in not having to overcompensate to prevent having to replace the battery more often (replacement costs account for a large percentage of the overall system cost).

Benefits of Embedded FRAM Memory Technology

FRAM is a non-volatile memory technology with similar behavior to DRAM. Each individual bit can be accessed and unlike EEPROM or Flash, FRAM does not require a special sequence to write data nor does it require a charge pump to achieve the higher programming voltages. FRAM programs at 1.5V versus the 10-14V of Flash or EEPROM. While Flash programming occurs through a tunneling mechanism, FRAM programming relies on a ferroelectric effect to induce polarization in a dipolar molecule. The ferroelectric effect occurs due to the electrical dipole formed by Zirconium (Zr) and Oxygen (O) atoms in the ceramic Lead-Zirkonate-Titanate crystal (PZT) of the FRAM cell. The electric field causes a polarization hysteresis effect as it moves the Zi-atom within the PZT crystal with increasing field strength. The hysteresis occurs as a result of the interaction of this Zi-atom with the O-atoms. The Zi-atom is moved from one direction or the other by the polarity of the electric field. Unlike a magnetic hysteresis effect, the polarization hysteresis of the PZT molecule is not influenced by external magnetic fields. The Zi-atom will remain in place unless an electric field is applied and provides for non-volatility of the memory when power has been removed. This means that it wears down far less if at all for each memory operation, and consequently lasts over 1 billion times longer than Flash. Finally, since FRAM is not written through a tunneling mechanism, it is up to 1000x more resistant to radiation such as gamma rays than Flash/EEPROM.

In addition, FRAM does not need a pre-erase cycle and the molecule polarizes in one or two nanoseconds, so the write operation is about 1000x faster than the previously mentioned non-volatile counterparts. Because the speed of FRAM is equivalent to embedded Static RAM in many microcontrollers in addition to its dynamic accessibility and non-volatility, it is what is commonly referred to as a Universal Memory. This means it can function as the data memory or the program memory at any given time in its life. This gives designers the freedom to create embedded software that relies heavily on data processing or not at all depending on their specific needs without worrying about the limitations of the microcontroller. No other embedded memory can claim this feature.

NFC Endpoint Sensor

For this analysis we make use of the NFC wireless sensor shown in figure 1. The block diagram is representative of typical industrial and medical wireless sensors with the sensor requirements specified by the application. As indicated previously, the onboard power management of the RF430FRL152H device is able to power the external sensor via the scavenged RF energy. For this analysis, we assume a composite sensor active current of 2.2uA and a composite off current of 1uA. Sensor measurements occur every 10 seconds with each measurement taking 20 ms. The amount of data collected by the sensor is varied in the analysis to ascertain the impact of local in-network storage by the system.

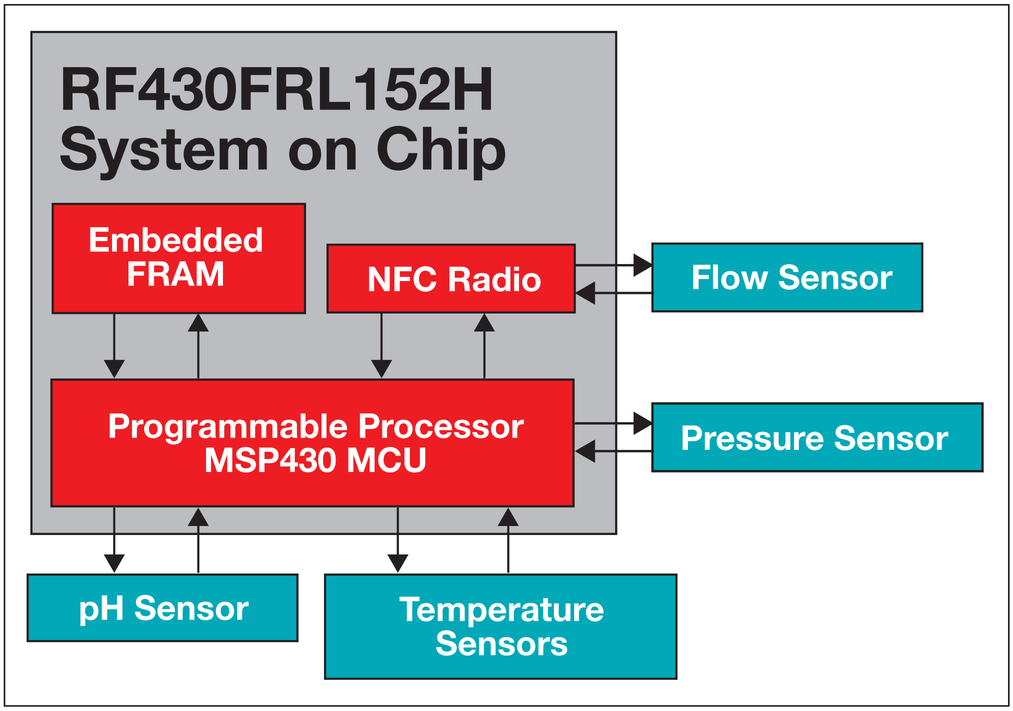

Figure 1. NFC WSN Block Diagram

Energy Efficiency Consumption Model

The process flow for data collection and subsequent transmission over RF is shown in figure 2. The composite energy consumption for the system is given by the sum of the energy consumption for each of the major components in the system for the given RF protocol used for communication. The composite energy consumption for a typical WSN can be expressed as follows:

$$E_{composite} = E_{MCU\ total} + E_{sensor\ total} + E_{mem\ prog} + E_{mem\ erase} + E_{RF}$$

where

$$E_{RF} = E_{listen} + E_t + E_r + E_{sleep}$$

E_{MCU} total is the total energy consumption for the MCU which consists of the sum of the active, idle and switching components, E_{sensor} total is the sum of the power consumption for each of the sensors, E_{mem} prog is the amount of energy required to carry out data logging and E_{mem} erase is used to account for Flash block erase requirements associated with writing to this memory technology. E_{RF} is determined by the RF protocol used in the communication channel. For the Phy and MAC layers of an IEEE802.5.4 protocol, E_{listen} is the active listening energy, E_t is the energy for packet transmission, E_r is the receive energy and E_{sleep} is the radio sleep energy. For active WSNs the E_{RF} component can be several orders of magnitude larger than the other components for systems running at higher RF duty cycles. Even at low RF duty cycles below one percent, this component can still be fairly large.

In the case of NFC wireless sensors, the RF component is removed and the composite energy consumption equation can be simplified as follows:

$E_{composite} = E_{MCU\ total} + E_{sensor\ total} + E_{mem\ prog} + E_{mem\ erase}$

Given the passive RF nature of the NFC wireless sensors, battery lifetimes for these NFC solutions far exceed those of active wireless sensors.

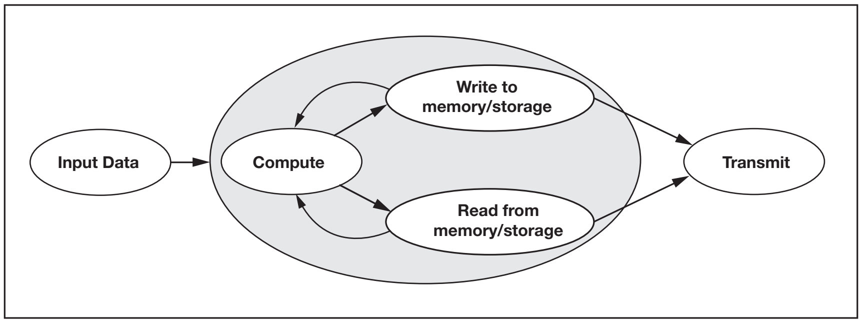

Figure 2. Process flow for data collection

The lifetime of the end node is dependent on the total energy consumed by the system and the battery capacity. The end node lifetime is determined as follows:

$L_{node\ lifetime} = [\ C_{batt} \times V\ ] / E_{composite}$

where C_{batt} is the battery capacity used in the system. In this analysis, we assume a Carbon-Zinc battery with an estimated battery capacity of 650 mAHr. In the analysis we do not assume a discharge rate over the life of the battery.

Analysis of NFC WSN (FRAM vs Flash)

The parameters used in the analysis are listed in table 1. We consider the case where the collected sensor data is stored in non-volatile memory on either FRAM or Flash. To begin, we note that Flash is limited to approximately 100,000 write cycles while FRAM write cycles are in the billions. This enables FRAM to be used in true data logging applications where data needs to be retrieved when system power is lost.

In this section, we look at the energy costs associated with data logging of the sensor data which can be subsequently used to build the time-series models or aggregated to reduce the number of packets transmitted over RF. A comparison is carried out with Flash as a storage mechanism as well. In the case of Flash, we account for block erase requirements associated with writing to this memory technology.

Parameter	Value
$T_{program\ FRAM}$	100e-9 sec
$I_{program\ FRAM}$	.85 mA
$T_{program\ Flash}$	100e-6 sec
$I_{program\ Flash}$	2 mA
T_{erase}	20e-3 sec
I_{erase}	32 mA
CK	10sec
V	1.5 V
I_{active} (MCU1)	260 uA/Mhz
I_{idle} (MCU1)	15uA
C_{batt} (battery lifetime)	650 mAHr
t_{MCU} switch	6 usec

Table 1. Simulation parameters used in the system analysis

We consider seven different systems with the only difference being the amount of data collected by the sensor in each system. The amount of data each system collects during the 10 second sensor measurement cycle is shown in table 2. We assume that the data is aggregated after a fixed value such that the system maintains available memory space for data logging of the sensor data. The energy costs associated with data logging of the sensor data are accounted for in the analysis prior to aggregation. The impact of the energy consumption tied to storing of the sensor data is accounted for in the power consumption breakdown of the entire NFC wireless sensor network. We do not limit the write cycles of the Flash memory, though this would be limited to only approximately 100,000 cycles.

	System 1	System 2	System 3	System 4	System 5	System 6	System 7
Bytes/10 sec	2 Bytes	4 Bytes	8 Bytes	12 Bytes	16 Bytes	24 Bytes	32 Bytes

Table 2. Sensor data logging during 10 sec measurement cycle

In figure 3, the expected battery life of the NFC wireless sensor example is shown for each of the seven systems. We see that data logging to FRAM does not reduce the overall battery lifetime of the system, even for the system that collects 32 bytes of sensor data every 10 seconds. The associated energy consumption for storing the data in FRAM is a small component of the total energy efficiency breakdown for the system. In comparison, we see that data logging to Flash results in an approximate 30 percent reduction in the estimated battery lifetime compared to FRAM.

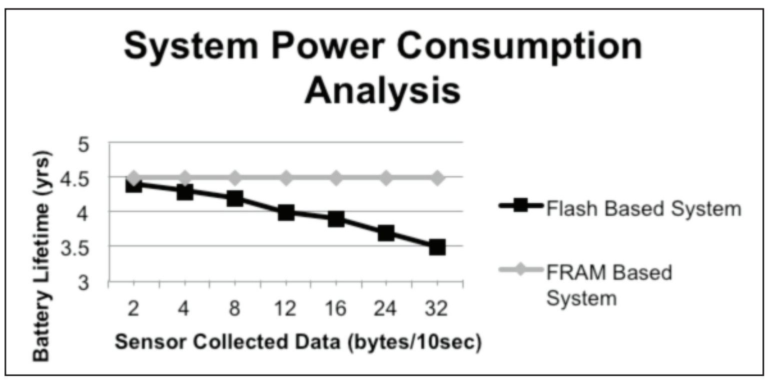

Figure 3. System battery lifetimes for aggregated data logging system solutions (FRAM vs. Flash)

Conclusions

Using a subsystems energy consumption model to estimate the expected battery life of an NFC wireless sensor network, we were able to draw a comparison between FRAM and Flash-based systems. Logging of data in an FRAM-based solution does not significantly impact the battery lifetime of the system. For a Flash-based system, data logging is a major component of the energy consumption breakdown of the system. FRAM-based systems such as the RF430FRL152H device enable a rethinking of an NFC WSN design by allowing the local storage of sensor collected data. This is achieved by a dramatic reduction in the energy consumption associated with storing of the sensor data locally as compared to storage costs associated with Flash-based devices.

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