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Technical Note

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RFID Implementation in Aircraft Cabins for Location Detection

Abstract

This paper outlines RFID (Radio Frequency Identification) implementation in aircraft cabins. The components of RFID systems are described, and general RFID system design is investigated. Specific details concerning aircraft cabins are also discussed.

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1 Introduction

The PAHMIR (Preventative Aircraft Health Monitoring for Integrated Reconfiguration) project aims to improve the reconfiguration times for the aircraft cabin. One of the methods that will be used in this project is the implementation of an RFID (Radio Frequency Identification) system, which will be used for location detection. This report examines the feasibility of implementing a RFID system in aircraft cabins in order to be used for location detection. This is done by investigating the different specifications involved in RFID systems and deciding the best implementation of a RFID system for use in an aircraft cabin. This system will be designed for use in an Airbus A340.

2 Initial Criteria

- Must provide real-time tracking
- Must provide a way to write information to RFID tags that can be accessed again later
- Must not interfere with any aircraft systems
- The system must work throughout the cabin even with people moving around in the cabin
- The possible RFID system implementations must use only active RFID tags, or a combination of active and passive RFID tags

3 RFID Systems

At minimum, a successful RFID implementation requires at least one RFID transceiver (in this case, a reader), at least one transponder (in this case, a tag), and middleware, which is software used in an RFID system to make the data used by the RFID reader useful. Current uses of RFID include and are not limited to: supply-chain tracking, passports, theft prevention, bar code replacement, and toll booth payments. With RFID technology, it is possible to track objects in real-time without having a direct line of sight between the RFID reader(s) and RFID tags.

3.1 RFID readers

The RFID reader is a device that is responsible for interpreting the data contained on RFID tags. The reader is attached to one or more antennae, depending on desired read range and the capability of the reader itself. However, the reader can only use one antenna at a time. This is can be a problem if the objects being tracked are moving, but in an airplane cabin, where the RFID tags are stationary, a multiple antenna reader is feasible. Readers are the most expensive part of the RFID system. An entry level reader costs $500, but high quality readers can cost up to $3000. A reader that can read multiple RFID frequencies at the same time is called an agile reader.

The RFID reader can also write data to RFID tags, which will be useful for aircraft cabin implementation. The ability to write to tags allows the reader to log data on each tag. For example, maintenance history can be embedded on a tag, making it easier for mechanics to keep track of objects that need attention. High quality RFID readers can read up to a thousand active tags or hundreds of passive tags at the same time.

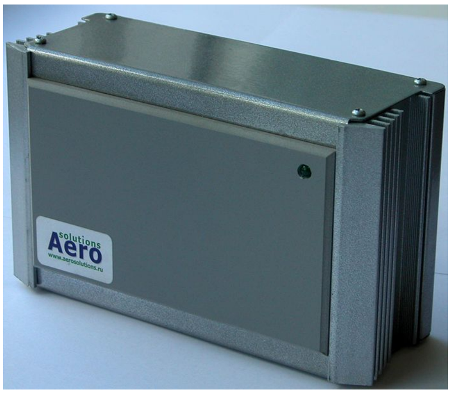

Figure 1 Example of an RFID reader (7)

3.2 RFID tags

The RFID tag is a small device that can be used to track items or store data. RFID tags are classified according to the way they communicate with the RFID reader. There are 3 types of RFID tags : Passive, Semi-passive, and Active. Each type of tag can operate in the same frequency ranges, regardless of the type of tag. All tags have some memory embedded in them, ranging from one byte to hundreds of kilobytes.

3.2.1 Passive Tags

Passive RFID tags do not require an internal source of power to communicate with the RFID reader. They operate on a principle called backscattering. Backscatteriing is the process of using incident waves to emit another wave. Since any antenna that receives a wave can also transmit a wave, Passive RFID tags can also transmit waves. When a wave hits the antenna in the tag, voltage is induced in the tag, providing power for a short period of time. This power will then radiate a wave from the antenna attached to the tag, resulting in the backscattered wave. This wave will then reach the RFID reader and will be processed as data. Passive tags, especially disposable ones, are inexpensive and developers are working to get the price of passive RFID tags to be 5 cents per tag.(3)

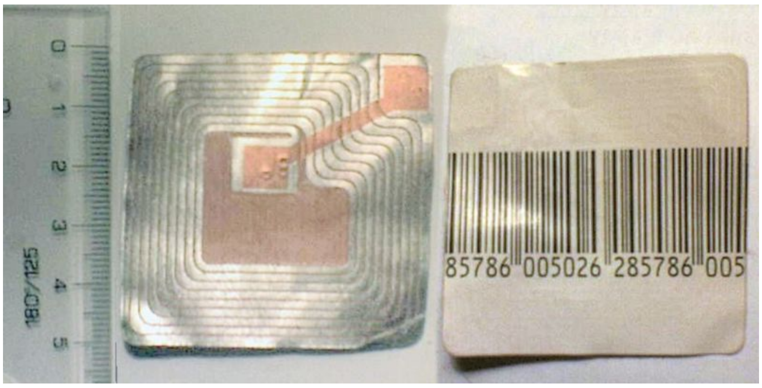

Figure 2 Example of a Passive RFID tag. This tag is used on stickers to be placed on various products (7)

3.2.2 Semi-passive Tags

Semi-passive Tags, or battery-assisted tags, have a battery to power the internal electronics within the RFID tag. With the battery, it is possible to integrate sensors or other devices that require a constant source of power. (2) However, these tags still communicate with RFID readers using the principle of backscattering. The induced voltage from an incoming wave may be supplemented with the voltage supplied by the battery. This allows semi-passive tags to have a longer read range than passive tags since there is more power in the tag's circuitry. Semi-passive tags usually cost more than $1.

3.2.3 Active Tags

Active tags require a battery to power all electronic systems inside the tag as well as communicating with RFID readers. They do not use the principle of backscattering to communicate with RFID readers. Active tags therefore have the longest read range (up to 100m). The battery life of an active RFID tag depends on the usage of the RFID tag. A tag that emits signals every 30 seconds will naturally have a battery life much longer than a tag that emits signals every 2 seconds. It is possible to purchase active tags with replaceable or rechargeable batteries, but some active tags are useless once the battery dies. Active tags are used for real-time tracking, and are also used when long range tracking is needed. However, active tags are also the most expensive kind of tag, costing $10 to $50 each.

3.2.4 The difference between frequency ranges

Active RFID tags usually operate at 455 MHz, 2.45 GHz, or 5.8 GHz. Passive RFID tags are described below :

Low Frequency (LF) passive tags: Operate at 125 KHz. Read range of approximately .33 meters.

High Frequency (HF) passive tags: Operate at 13.56 MHz. Read range of approximately 1 meter.

Ultra High Frequency (UHF) passive tags: Operate at 860-960 MHz. Read range of up to 5 meters.

The different available RFID frequencies behave differently according to the laws of physics. Low frequencies have the advantage of their read range not being affected by metal and water. However, it is difficult to read multiple low frequency tags in the same area. As the frequency of a wave goes up, the wave begins to be reflected off material rather than penetrate through material. Therefore, ultra high frequencies will bounce around in a cabin, and will not penetrate the metal parts of the cabin. This may extend the read range of the RFID reader. The signal reflected along the walls of the cabin may even amplify the signal sent by the RFID reader if the original signal and reflected signal are in phase (constructive interference). However, if the original signal and reflected signals are out of phase, the reflected signal will reduce the power output of the original signal and will be detrimental to the operation of the RFID system (destructive interference). (3) Whether or not the benefits outweigh the costs can only be observed in a live test.

UHF RFID systems use a different kind of antenna for transmission due to the difference in the electromagnetic fields of LF, HF, and UHF systems. LF and HF systems tend to use coiled antennae, while UHF systems tend to use longer, straight antennae.

3.2.5 RFID identification

RFID readers read and output data from RFID tags in hexadecimal format. The HEX code is then decoded into binary, which is then decoded into a Uniform Resource Identifier (URI) representation. There are multiple formats of URI representation, one of them being the Serial Global Trade Identifier Number (SGTIN-96) format. This format is useful for identifying objects in a supply chain, as it contains the method of shipping, company name, item name, and serial number in the string. For example, a URI representation of urn:epc:tag:sgtin-96:3.0037000.06542.773346595 represents a 15 pack of Bounty®paper towels manufactured by Procter & Gamble. The 3 in the string shows that the item in question is a shipping unit, the 0037000 part of the string represents Proctor & Gamble, the 06542 section of the string represents the Bounty®paper towels, and the 773346595 section of the string is the serial number of the product. Therefore, the same style of identification can be used in aircraft cabins. Numbers can be used to represent positions inside the aircraft cabin. (6)

3.3 RFID middleware

RFID middleware is software that is used to monitor RFID readers, and process data given by the RFID reader. Often, the RFID reader will give too much useless data from interference, or misreading of tags. It is the middleware's job decide which data is useful and to send it to whoever needs it. In the case of RFID implementation in an aircraft cabin, RFID middleware should send cabin data to the pilots of the aircraft. It should also make sure that the RFID reader writes data to each tag so the maintenance crew and other personnel can access the data.

4 Factors That Affect Implementation

4.1 Antenna Polarization and Tag Orientation

Antenna polarization is a factor that affects passive and semi-passive RFID usage. Active RFID tags do not use backscatter to talk to a RFID reader, so antenna polarization is not a factor in their performance. There are 3 different kinds of polarization — Linear, Circular, and Elliptical. An antenna is manufactured to be polarized in a certain direction. Passive RFID systems usually use either a linearly polarized antenna or a circularly polarized antenna. This choice depends on the orientation of tags being used. Linearly polarized antennae can read a tag oriented in the direction of its polarization, but cannot read tags that are oriented perpendicular to their polarization For example, a horizontally polarized antenna can read a tag that is horizontally oriented, but cannot read a tag that is vertically oriented. The horizontally polarized antenna can read tags that are not oriented horizontally, but at a decreasing range as the orientation rotates towards a vertical direction.

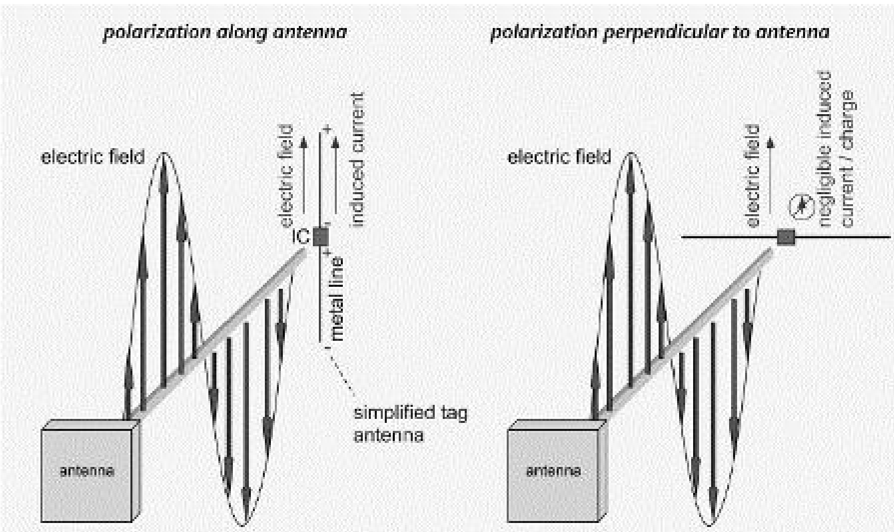

Figure 3 Visual representation of polarization (3)

Circularly polarized antennae on the other hand can read a tag that is oriented in any direction. However, due to the circular polarization, tags receive only half the power they would have compared to a linearly polarized antenna. The tag will only receive the component of power that is along its orientation. Circularly polarized antennae are useful in a supply chain, where the tag orientation on objects is not always uniform on conveyor belts, forklifts, and other locations in a warehouse. For implementation in an aircraft cabin, linearly polarized antennae would work best. The tag orientation is chosen when installing the tags, and is static. Therefore, all the tags being used can be oriented in the same direction, and an antenna polarized in that direction can be used for maximum performance. This will be true no matter how many antennae are used.

4.2 Antenna Placement

Antennae are designed to focus their power in one direction. Radiating power in one direction causes less power to be radiated in the opposite direction. Therefore, if the RFID implementation is to use one antenna, this antenna should be placed in the front of the aircraft or the rear of the aircraft. The reader should still be placed close to the antenna due to a phenomenon called cable loss, in which longer cables cause a loss in power between the antenna and the reader. Cables that connect the RFID reader to their antennae are governed by US FCC (part 15). (2) Some RFID readers use integrated antennae, and therefore antenna placement is not adjustable.

Figure 4 Example of an RFID antenna (7)

4.3 Tag Collision

Tag collision occurs when multiple send signals back to the RFID reader at the same time. This causes interference and could also confuse the reader. This problem can be solved by staggering the read times of the tags. In doing this, all the tags are read at different times, so the reader can only "hear" one of the tags at a time. The RFID reader must be configured to have staggered read times. Active tags must also be configured to broadcast at different times. This may seem to counteract the goal of real-time tracking, but since tags are read in milliseconds, hundreds of tags can be read in one second.

4.4 Reader Collision

Reader collision occurs when multiple readers try to read the same tag at the same time. This can cause tags to be read more than originally intended. Reader collision can also cause interference between readers, preventing any of the readers from reading the tag. Reader collision can also be solved using staggered read times. The middleware that receives data from the reader must to configured to throw out extraneous data if a tag is read more than once.(4)

Table 1 EPC global tag classes

Class	Description
Class 0	Passive, Read only
Class 1	Passive, can be programmed once and only once by the end user
Class 2	Passive, Read/write capabilities, has memory
Class 3	Semi-passive, may contain sensors, Read/write capabilities, has memory
Class 4	Active, may contain sensors, Read/write capabilities, can communicate with other Class 4 devices
Class 5	Can power and communicate with Class 0,1,2, and 3 devices (Therefore, class 5 devices are generally RFID readers)

4.5 RFID Standards

RFID technology has no unifying, global standard. This may prove to be a problem for an RFID system implementation in aircraft cabins, since the aircraft will be traveling worldwide, and any RFID implementation will have to comply with a standard that is accepted worldwide. The most prevalent standards used around the world are the governed by the International Organization for Standardization (ISO) and EPCglobal.
ISO standardizes RFID technology under the ISO-18000 series of standards. It consists of seven parts, with each part dealing with a different frequency range used in RFID systems.

- ISO 18000-1 : Generic Parameters for the Air Interface for Globally Accepted Frequencies
- ISO 18000-2 : Parameters for Air Interface Communications below 135 kHz
- ISO 18000-3 : Parameters for Air Interface Communications at 13.56 MHz
- ISO 18000-4 : Parameters for Air Interface Communications at 2.45 GHz
- ISO 18000-5 : Parameters for Air Interface Communications at 5.8 GHz
- ISO 18000-6 : Parameters for Air Interface Communications at 860-960 MHz
- ISO 18000-7 : Parameters for Air Interface Communications at 433 MHz

EPCglobal initially had a set of standards that did not comply with ISO 18000-6, or the UHF RFID frequencies. EPCglobal had divided RFID tags into multiple classes, as seen in Table **??**.

In an effort to create a more global standard, EPCglobal developed its generation 2 (Gen 2) standard in 2004, which was compatible with the ISO 18000-6 standard.

4.6 Aircraft System Interference

The aircraft system that is most susceptible to interference is the navigational instruments. According to a study done by NASA, interference incidents that involved personal electronic devices (PED's) such as laptops, music players, and cell phones, navigation systems were affected 75% of the the time. (5) It is reasonable to expect that navigation systems will be the most sensitive to possible RFID system interference. One system that is particularly important is the VHF (Very High Frequency) Omni-directional Radio Range, or VOR system. The VOR system uses VHF radio waves for navigation purposes. VHF waves used for the VOR system are usually in the 30-300 MHz range. RFID technology does not use frequencies in the 30-300 MHZ range. Therefore, there should be no interference between RFID and the VOR system.

Another system that may be affected by interference is the Global Positioning System (GPS), which is starting to replace the VOR system in newer aircraft. GPS systems use frequencies that range from 1100 MHz to 1600 MHz. RFID technology does not use any of the frequencies in this range, so interference should not be a problem.

4.7 Security and Privacy concerns

With a handheld RFID reader, it is possible to disrupt the operation of the RFID system. Introducing another RFID reader into the system will cause reader collision that the middleware will not know how to solve since it does not know about the handheld RFID reader. If an RFID system is implemented in an aircraft cabin, handheld RFID readers should be turned off throughout the duration of a flight.

Most modern passports have an RFID tag embedded in them. The RFID reader used to read RFID tags in the aircraft cabin may accidentally read the tags in the passports scattered throughout the cabin. However, airlines should have all the information stored on a passenger's RFID tag already. Airlines would be more concerned about interference from passport RFID tags. The RFID middleware would have to know the difference betweed RFID tags on passports and RFID tags scattered around the cabin.

4.8 Cabin Layout

The cabin layout will definitely play a part in RFID implementation. The density of economy class seats will affect the transmission of signals. Galleys will be an obstacle to RFID transmission, as they are located along the center line of the cabin. Overhead bins may also interfere with signal transmission. Fluorescent lighting gives off noise as well. The A340-600 has a cabin length of 60.98m, and a cabin width of 5.28m (1).

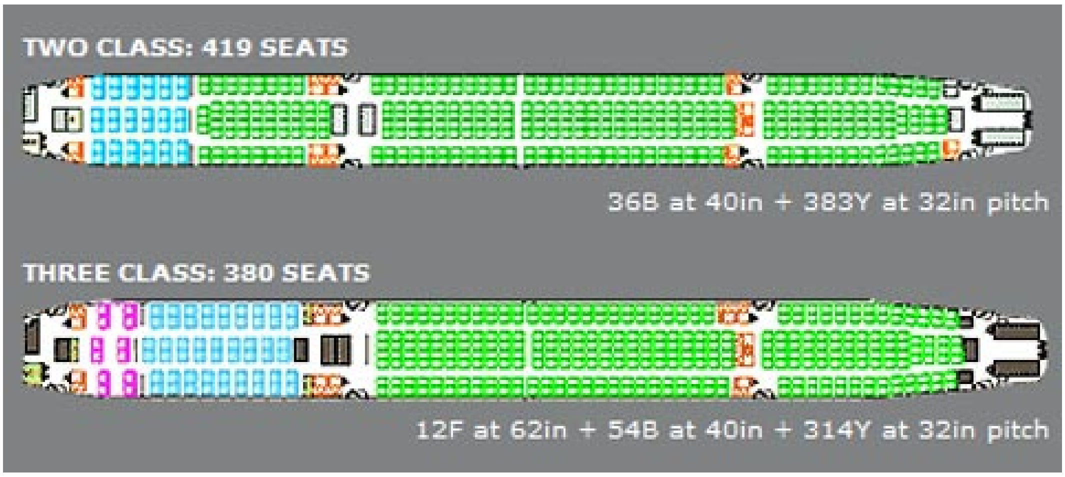

Figure 5 Airbus A340-600 Cabin configurations (1)

5 Possible Implementation

Based on the initial criteria and factors than affect implementation, possible RFID implementations for aircraft cabins are described below. It is assumed that there will be one tag for each seat in an A340-600, therefore, for a three-class configuration, 380 tags are required.

To provide an estimate in the cost for these implementations, RFID products that may be ordered at the moment this paper was written are selected. Due to decreasing prices and innovations in RFID technology, it is highly likely that the prices listed here will be more expensive than future prices. Furthermore, some companies such as GAO RFID do not publicize their prices, making it difficult to determine which tags and which readers are the most cost-effective.

Active RFID products:

- AA-R500 Active RFID Reader - $923 (with remote whip antenna, software, and cables
- AA-T100 Active RFID Tag - $22 each; $8360 for 380 tags

Passive RFID products:

- Feig long range 868 MHz reader with 4 antenna ports - approximately $2759.68 (Converted from Euros to US Dollars)
- Feig antenna (250mm x 250mm) - approximately $299.60 each
- Confidex Ironside Gen2 UHF on-metal tag - approximately €15.68 each; $5958.40 for 380 tags

Implementations that may use these RFID products are described below.

- Only active RFID, One reader, One antenna The reader and antenna should be placed in the front of the cabin in order to reduce the distance between the reader and the cockpit. By doing this, wiring costs for connecting the RFID reader to avionics systems is reduced.

Passive RFID tags located in the back of the cabin will not be in the read range of the reader, therefore only active tags are used.

Pros: Cheapest solution – costs $9283 with the above products. This solution is the easiest to implement because it requires the least equipment installation of all the solutions.

Cons: This implementation may not even work due to the many obstacles located in the cabin. Needs an expensive reader that can read approximately 300 tags in a short amount of time.

- Active and Passive RFID, One reader, Multiple antennae Using Passive RFID tags along with Active RFID tags severely limits the read range of the RFID readers. Passive RFID tags must be much closer to the reader's antennae compared to active RFID tags, causing the need of expanding the read range for passive RFID. One way to do this is to strategically place multiple antennae throughout the cabin. In order to reduce cable loss, the reader should be placed in the middle of the cabin, with antennae along the center line of the cabin. Using both active and passive technology listed above costs $19199.48, with 4 antennae.

  Pros: Cheaper than using multiple readers. RFID system is still useful even if active RFID batteries die. This implementation does not require the use of active read/write RFID, since passive RFID tags can store data.

  Cons: Needs an expensive passive RFID reader than can support multiple antennae along with the active reader. The passive reader should be able to read the 380 tags in the cabin in a short amount of time.

- Active and Passive RFID, Multiple readers, one antenna for each reader This setup also uses active and passive RFID, and deals with the read range problem by using multiple readers. However, this setup is quite costly at $24153.92, using 4 passive readers with one antenna each.

  Pros: No problems with cable loss. Multiple readers increases accuracy throughout the whole system, especially because of the many obstacles located throughout the cabin.

  Cons: Most expensive implementation, as readers are the most expensive instrument in an RFID system. Reader collision may be a problem.

6 Future Developments

In 2004, EPCglobal designed a second generation protocol for RFID to replace its first generation RFID protocol. EPCglobal's generation 2 (Gen 2) standard is a new standard of RFID technology that EPCglobal hopes to establish worldwide, and is also compatible with current ISO standards. It improves on the first generation of RFID in many ways, including:

- Listen-before-talk (LBT) Protocol The generation 2 standard requires that all tags use the LBT protocol. Listen-before-talk requires that a tag "listen" on a certain frequency range channel for a small, random amount of time (1-5ms) before using that frequency to transmit a wave. A channel usually consists of a .2 MHz range. If that channel is currently being used, then the tag must use another channel to transmit the wave. For example, a tag in the 433 MHz range would first listen on a channel such 433.4 MHz or 432.6 MHz. If that channel is being used, the tag will use a different channel to transmit a wave. If the channel is not being used, the tag will use the original channel to transmit a wave. The LBT protocol was designed to mitigate the effects of reader and tag collision.
- More security 32-bit passwords can be used, and there is a "kill" function that can irreversibly disable a tag if needed.
- Faster read and write speeds

This new standard is not compatible with EPCglobal's older standards. Therefore, new RFID implementations should use the Gen2 protocol if possible.

7 Conclusion

Regardless of the implementation chosen, it is important to test the implementation in an A340 cabin before approving it for use. The cabin layout makes calculating antenna signals mathematically extremely difficult, and therefore a live field test is the best way to see if a certain implementation will work.

The best implementation to use, if possible, is the implementation using only Active RFID with one reader. A read/write active tag is required, but money is saved by using only active RFID technology instead of combining both active and passive RFID technology. Active RFID is much more useful in an aircraft cabin than passive RFID because of the large read range required to read all the tags in a cabin. Even though the batteries in active tags must be replaced every 1-3 years (depending on the tag), passive RFID tags have a limited lifetime and must also be replaced every few years.

RFID is a low-cost technology suitable for use in location detection. The total cost for implementing an RFID system in an aircraft pales in comparison to the cost of the aircraft itself. RFID is also a quickly developing technology, and new innovations in the RFID field will make RFID even more cost-effective in the future.

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