WHITE PAPER

RFID For Libraries

A comparison of High Frequency (HF) and Ultra High Frequency (UHF) Options

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Alan Butters

Principal Consultant
Sybis

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Introduction

While libraries and suppliers have been experimenting with RFID systems to manage and track collections since at least the mid 1990's, RFID's entry into the collective library consciousness is relatively recent. As it is, the penetration of RFID systems into libraries worldwide is still very small when compared to the potential market size and many suppliers are now competing for a share of this market. To a large extent, the technology platform that underpins the vast majority of library RFID implementations was chosen by suppliers at the outset based on the needs of libraries and the technologies available to the suppliers at the time. As a result, almost all libraries today function with High Frequency (HF) tags and readers operating internationally at a frequency of 13.56 Megahertz which, for the purpose of context, falls just below the 22 metre metre band of short wave radio broadcasts. As RFID systems generate RF electromagnetic waves they are subject to government regulation controlling their operation.

One of the attractive features of developing library RFID systems that operate in the HF range is that the allocation of spectrum at 13.56 Megahertz is available in most countries throughout the world, being reserved for industrial, scientific and medical applications. Use of this frequency ensures that a supplier's RFID system will be saleable in almost all countries. The performance of HF transponders, generally referred to as "tags", was also considered by most suppliers to be adequate for the library application and the passive nature of the tags meant that they could be manufactured as essentially "smart labels" and applied to a range of library materials.

However, RFID technology continues to evolve and today there exists other technology options that might also be used as the basis for a library RFID system. One of these options that is receiving increasing attention is Ultra High Frequency (UHF) RFID as commonly seen in the supply chains of major organisations such as Wal-Mart and the US Department of Defense. These systems do not operate at 13.56 Megahertz but instead use frequencies between 860 and 960 Megahertz determined by local regulations within each country. Again, for the purpose of context, this frequency range is more commonly encountered with mobile (cell) phone communications. Some suppliers of RFID take the position that, if library RFID systems were being developed for the first time today instead of a decade ago, UHF would be the logical technology platform. HF systems as used in most library systems worldwide are therefore seen by some to be legacy systems belonging to a bygone era and not as part of the future of library RFID.

This paper is designed to be self contained and is directed at the non specialist. The paper will attempt to examine, from a commercially neutral perspective, the issues within the debate of importance to libraries. While the relative benefits and weaknesses of the two technology platforms will be discussed, no particular technology will be endorsed or recommended. The intention is simply to make a useful contribution to the debate from a library application perspective so that individual libraries may be in a stronger position to make their own decisions.

Alan Butters

Why multiple frequencies for RFID?

Introduction

RFID systems are to be found in many industries. Indeed, it sometimes appears as if a new application for RFID technology arises every week. Whether tracking pallets, spare parts, dentures, poker chips, animals or library books, the application space for RFID is already vast and continues to expand. On the surface it might appear amazing that one technology can be appropriate for so many disparate uses but herein lies an important lesson; RFID is *not* one technology. The term "RFID" is applied to multiple technology platforms operating internationally using different methods over multiple frequency ranges. These technology platforms all use radio frequencies for the purposes of communication and identification but often that's where the similarities end. RFID tags themselves may be Active, Passive, Semi Passive, and may be supplied in a variety of form factors from smart adhesive labels to tags that resemble nails, buttons, balls, credit cards, wristwatches etc. Some have antennas poking out while others are integrated with temperature and motion sensors, GPS technology and cellular communications.

Obviously, choosing an appropriate library RFID tag based on its physical shape is not too difficult - an adhesive smart label will be suitable for a library book whereas a nail tag will not. Not so obvious however is the need to select a frequency range at which a given RFID application should operate. If we think about FM radio transmissions for example, we're aware that stations transmit on different frequencies because we are required to manually tune our radios to the station of our choice. We probably don't care particularly much *which* specific frequency is associated with a given radio station. In general any frequency will do as long as we can tune into it and enjoy the program.

With RFID, the range of frequencies available to be used by an application is much greater than the span of FM radio allocations. In fact, the range of frequencies assigned to RFID is *so* great that their selection actually impacts the performance characteristics and behavior of the whole system. This should come as no real surprise to us as we are already familiar with this phenomenon in our every day lives although we might not recognise it as such. For example, if we live in an urban environment and we turn on our radio, we expect to pick up a range of stations. To facilitate this, we are effectively bathed in FM radio transmissions - part of the electromagnetic spectrum, twenty four hours a day. Most of us don't give this fact too much thought. On the other hand, imagine a scenario where a cell-phone tower is planned to be erected opposite our home. Once again we'll bathe in part of the electro-magnetic spectrum but this time many within our neighborhood might be very concerned. Similarly, if we suspected that the seal on the door of our microwave oven was faulty, allowing some of the radio frequency energy to escape, how close to it would we be prepared to stand while it operated? In all likelihood we would be hesitant to use it at all until it could be checked by a qualified person. In all three of these examples we are in proximity to parts of the electromagnetic spectrum - radio waves in this case, but our intuitive reaction to each is different. Why?

The reason is because we understand that the radio waves in these three examples behave differently. The important point here is that they do so in large measure because of their frequency of operation. As a general statement, the higher the frequency, the more energy will be carried by the photons in the electromagnetic field. Inside our microwave oven, the radio frequency is very high (Gigahertz) and the field contains a great deal of energy that causes deflections in molecules comprised of electric dipoles such as water. The net result is that the field's energy is transferred to our food and heat is produced. Had the microwave oven been designed to run at the frequency of our FM radios, massive amounts of power would be needed to effect any change in the temperature of our food - most would simply pass right through producing no thermal change. So here's an example where the choice of operating frequency is critical to the purpose of the device. When selecting a frequency for an RFID application, this selection may be equally critical to the success of the system. Figures one and two provide some general frequency comparisons between RFID applications and devices with which we are familiar:

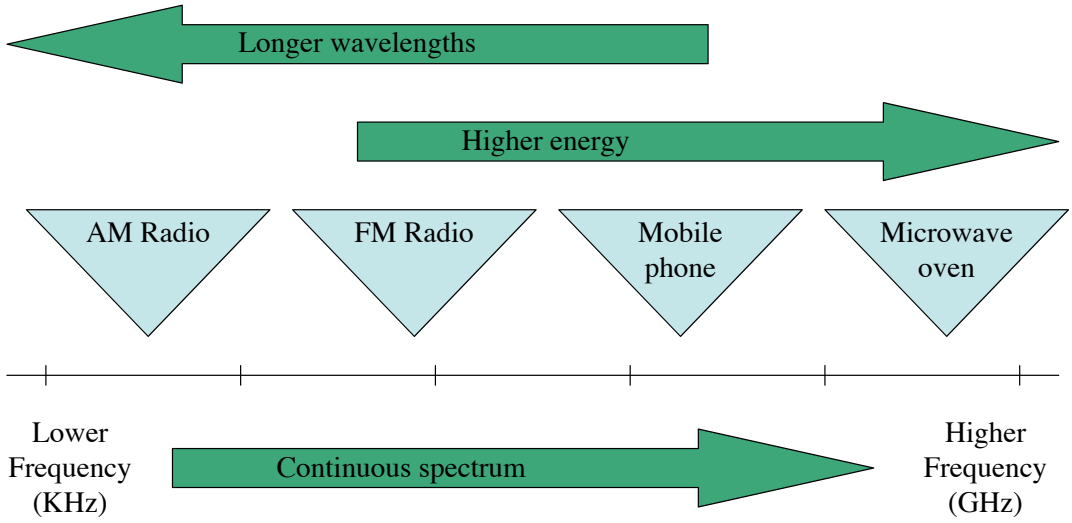


Fig. 1 - Common devices and relative frequency of operation

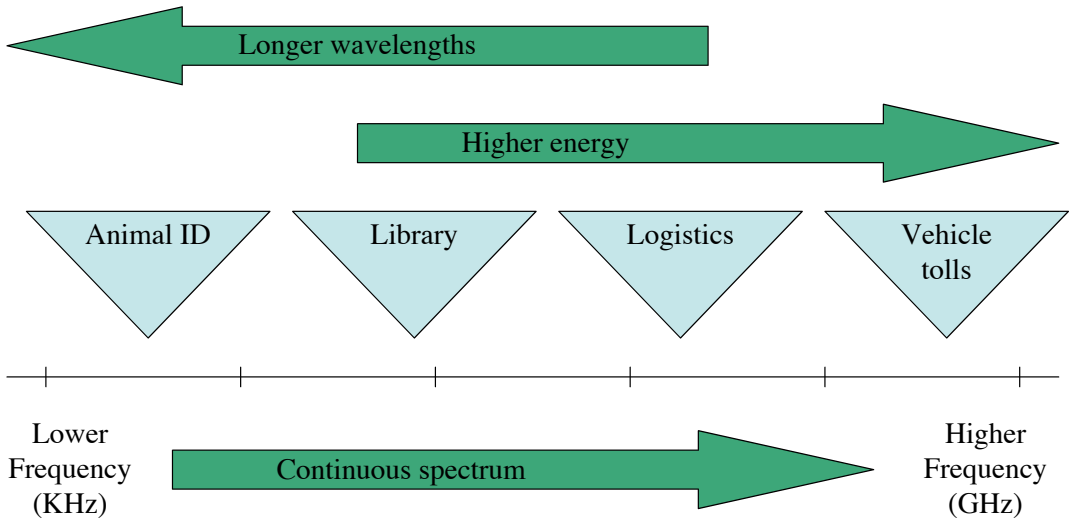


Fig. 2 - RFID applications and relative frequency of operation

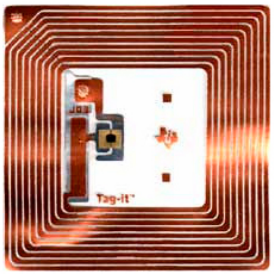
As the above diagrams demonstrate, choices regarding operating frequency are made both for RFID systems as well as devices with which we are more familiar. To return to our microwave oven example, the frequency at which this appliance operates would be an unsuitable base on which to build a system designed to identify companion animals using an embedded RFID tag (commonly known as microchip). Whereas the energy absorption works in our favour inside the microwave oven, if we need the RFID field to penetrate an animal's tissue to read the RFID tag underneath, absorption of the RF energy by the animal's tissue is exactly what we don't want. Accordingly we see animal identification systems at the opposite, low frequency, end of the spectrum where fields penetrate tissue much more effectively.

Other characteristics of RFID systems affected by frequency include:

- Read distance
- Data transfer speed
- Relative immunity to local electrical environments
- Performance in proximity to metal

It is beyond the scope of this paper to go into too much detail regarding the physics of radio waves but (Sinclair, 1997) and (Nahin, 2001) provide much greater detail for those wishing to complete further reading. Having established that operational frequency has an impact on the performance characteristics of RFID systems, what may be said about the relative benefits or disadvantages between High Frequency RFID and Ultra High Frequency RFID when used in a library environment? At the outset it should be noted that while HF has been and remains the basis for most library RFID systems, UHF systems are just beginning to appear in libraries around the world including Australia, China, and Singapore. This means that HF systems have been in the market much longer than UHF systems and so the level of maturity of the actual library application products cannot be expected to be equivalent. Before looking at the impact on typical library RFID products, which will be considered in the next section, we will take a brief look at some of the technical characteristics of the two technologies.

Characteristics of HF RFID technology



HF systems in libraries operating at 13.56 Megahertz have been in existence for a decade or so and their performance may be described with reference to observations based on a number of different supplier's systems. Typically, the RFID tags are about 50mm x 50mm in size although other sizes are not uncommon. The tags are passive and are powered from the energy emitted by the reader through a process of inductive coupling (readers wanting more information are directed to (Finkenzeller, 2004) and (Dobkin, 2008) and (Paret, 2005). The tags have an antenna spiraling around the outside of the label (see pic) and a chip located inwards of the antenna. They are usually supplied to libraries with a paper overlay on which barcodes or library ownership information may be printed. Memory capacities typically seen are in the range of 256 bits to 2048 bits.

The maximum read range at typical power outputs employed is approximately 70 cm. The HF fields are typically relatively easy to control and fine discrimination of tagged objects is possible leading to applications such as shelf-ordering etc. The tags are, to varying degrees, robust and several suppliers offer a life-of-the-item guarantee. In the library application, tags may be shielded with tinfoil and to some extent by the borrower's own body. Systems operating at 13.56 Megahertz can be used in most countries of the world due to the common allocation of this frequency as part of the Industrial /Scientific / Medical (ISM) spectrum. This has advantages for suppliers as it allows a common system to be used internationally.

Characteristics of UHF RFID technology

Library systems based on UHF technology are relatively new. The actual spectrum allocation varies from country to country is not necessarily available in all countries (Lahiri, 2006). Modern UHF systems conforming to EPCGlobal Gen2 specifications (also ISO 18000-6C) are designed to operate efficiently over a broad range of frequencies (860 Megahertz to 960 Megahertz) to maximise the use of a common tag within differing regulatory environments. The tags are passive and are usually powered from the electrical energy emitted by the reader thorough a process of electromagnetic backscatter coupling. The RFID tag itself looks quite different from the standard HF tag having typical dimensions of 12 mm x 97 mm, an elongated aspect ratio when compared with HF tags. The configuration of the antenna is also quite different. Typically the chip is located at the centre of the tag with two snaking dipole arms to the left and right (see pic).

User memory capacity is typically 64 bits or 96 bits - significantly lower than HF tags although larger memory capacities are being introduced. Read ranges of many metres are possible.

Why UHF in libraries?

Overview

There are several reasons why UHF technology is being proposed as potentially the future basis for library RFID applications but this section will concentrate on the two reasons most commonly advanced, cost and performance. The cost argument stems from the increasing volume of UHF tags being consumed in the supply chain - triggered in many cases by mandates from the US retail giant Wal-Mart. The reasoning goes that as the tag production volumes increase, the manufacturing costs and therefore end-user costs will fall to the point where the savings for libraries resulting from the use of UHF will essentially overwhelm all other considerations. Further to this, an argument is sometimes advanced to suggest that UHF is a likely candidate for item-level tagging in the retail sector, the Holy Grail of tag manufacturers where tag sales in the billions might regularly be achievable, thus driving tag prices down further.

The second reason advanced, that of performance, suggests that library RFID systems based on UHF technology might offer some useful performance advantages when compared with traditional HF systems commonly used today. The speed at which UHF tags may be read and the increased distance over which the tags may be read when compared with HF are usually highlighted as the important factors. Both of these factors suggest operational benefits for libraries.

In terms of addressing these two reasons - cost and performance, the latter is somewhat easier to deal with than the former. While the increased-volume-lower-cost argument obviously has merit there are also existing schools of thought that suggest current UHF prices may be being held artificially low in an attempt to grow the market and that HF prices are temporarily high as high tag volumes will be realised in the future. It is also fair to say that the item-level debate is still far from settled with supporters still to be found in both the HF and UHF camps. For these reasons and others, it's difficult to predict the future pricing levels of UHF tags and the corresponding benefits to libraries. Having said this however, current prices for UHF tags can be significantly lower than HF tags, allowing that a direct comparison is not always entirely fair due to reduced memory capacity and other factors.

The question of performance however can be addressed more satisfactorily and the next section attempts to outline the results of tests performed by the author in areas specifically important within the library application. Unfortunately, in some areas there are tradeoffs when selecting one technology over the other. These tradeoffs can lead to significant complexity when attempting to describe performance. A strength in one area may prove to be a weakness in another and determining which is more important can be subjective. The approach taken in the next sections therefore is to list the potential advantages of UHF first, followed by the potential disadvantages. The reader will then be left to make a subjective decision regarding which technology might be advantageous within their own organisation.

Potential advantages of UHF in the library application

This section will consider several areas where the real world performance of RFID systems typically impact on library operations. The conclusions drawn are taken from personal observation as well as a number of test conducted with UHF readers and tags. It should be kept in mind that these tests were not conducted using a specific supplier's UHF library products but instead commercially available hardware components were employed. The tests were designed to give an approximation of the performance that typical UHF library products products might be able to achieve. Appendix A provides details of the tests and the results.

Performance in a self service loans context

Performance within the context of self service loans relates to the contribution made by the technology to the speed, ease of use, and general level of borrower success and satisfaction with the transaction. The question is obviously whether a self service loans system built on a UHF platform would be superior in these areas to one employing traditional HF technology. While the ultimate speed of the transaction will likely be governed more by the responsiveness of

the library's server and ICT infrastructure than the RFID tag reading performance, UHF may offer some advantages in the ease of use and therefore borrower satisfaction areas.

One of the issues currently troubling some HF RFID self service systems is the problem of tag shadowing or masking. This is a phenomenon that occurs when two or more tags lie within close proximity to one another with little horizontal or vertical displacement. This may happen when library items are placed on the reader of a self service unit in a stack with their spines parallel to one another. In this scenario two of the RFID tags within the stack of items may lie directly above one another, separated by only the thickness of two book covers. The self service machine will likely not see either of the two tags that are masking each other and so the borrower will not have completed the transaction correctly. If the borrower doesn't notice that the receipt from the self service unit is missing two items, these will probably trigger the alarm at the library exit, potentially embarrassing the borrower and requiring a staff intervention. To overcome this problem, suppliers often suggest that the number of items issued simultaneously be limited or that the borrower should spread items out rather than stacking them on the self service unit. Obviously, strategies that impact the speed of the transaction (as in reducing the number of items being processed at once) or requiring special actions from the borrower are to be avoided where possible.

The testing described in Appendix A of this paper suggested that the problem of tag masking was significantly less of an issue with UHF tags when compared to HF tags. In practice, with the RFID tags and printed material described in the appendix, it was not possible to create a tag masking problem even with deliberate placement that arranged tags in precise alignment. This suggests that in the real world, self service products may be designed using UHF technology that essentially eliminate what can be a confusing and irritating problem for borrowers in many HF scenarios. A significant reduction in tag masking means smoother transactions requiring less intervention from the borrower and staff.

Performance in a smart returns chute context

It is important at the outset to provide some explanatory notes for the returns chute context. Currently there are many HF based RFID smart chutes on the market. These chutes are designed to identify RFID tagged items as they pass through the chute, to read the item's unique identifier from the tag (usually equivalent to the barcode) and then to toggle the RFID tag's security status so that the material can be returned to the library shelf. Exception items such as reservations may also be identified in this process. At the time of writing, reliable processing of all items passed through the chute can only be guaranteed by the suppliers when items are returned one-at-time. From a borrower's perspective this is a negative as in many non-RFID libraries, borrowers are accustomed to putting items into the returns chutes in stacks. Feeding the chute one-book-at-a-time is slow for the borrower and leads to the temptation to simply return items in multiples resulting in some items not being read. Uncertainty regarding which items have been correctly processed has led many libraries to repeat the returns process manually for items deposited through the smart chute, thus eliminating valuable productivity gains that might be made. The question therefore concerns whether a UHF based returns chute would permit reliable processing of multiple items simultaneously which is the desired outcome.

While the process within the RFID returns chute may appear simple, from a technical perspective much is happening in the short time that the item takes to pass through the chute. It is important to understand what is occurring so that the UHF test results may be interpreted correctly. The following diagram provides a conceptual high level view of the processes accomplished for each item within a typical HF RFID chute:

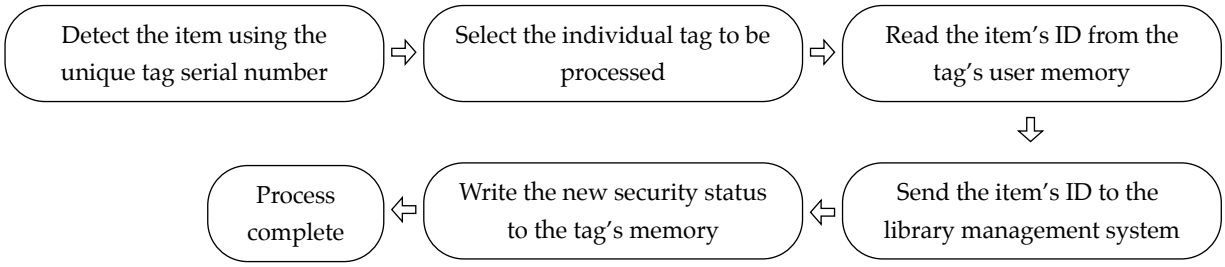


Fig. 1 Simplified RFID chute processing

As may be seen from the diagram, a significant amount of work is involved for each item that passes through the chute. While we are accustomed to hearing that RFID processes multiple items simultaneously, in actual fact most of the item processing is performed sequentially so the steps shown in Fig. 1 must be performed for each item in turn. Considering all of the variables involved including the fact that the items are moving, that a tag must be both read and written to, that tags may be masking each other etc we can see that creating an RFID smart chute poses a significant challenge for developers.

The testing described in Appendix A of this paper demonstrated the not altogether surprising fact that, within the returns chute, it was much easier to simply read the tag's unique serial number than to perform the subsequent steps of selecting, reading from user memory, and then writing the security status. Particularly the writing phase is problematic where the speed of each transaction is important and in this case, the UHF tags did not offer any significant advantage over their HF counterparts. Of course it is entirely possible to build a chute that does not write to the tag at all and perhaps even uses the tag's unique pre-programmed serial number to identify the item. This requires an off-tag security solution and either a "middleware" component that matches tag serial numbers to library item identifiers or the substitution of the tag's serial number with the current identifier in every item record of the library's software management system. In this scenario, the increased reading speed of UHF systems and their reduced susceptibility to tag masking would likely result in a superior product, all other functional aspects being equal. In the interests of fairness it should also be stated that the UHF tag writing performance seen in the testing might be improved through further development.

Performance in a staff loans context

The comments in the preceding section regarding the tag masking issue apply equally to stacks of library items issued or returned by library staff. A critical difference in managing the problem when using HF however is that staff are trained users whereas the general public must be considered to be (and often are) untrained and inexperienced users. Because of this difference while the problem is identical, a solution such as spreading the material on the RFID reader pad is more easily accomplished within a staff facilitated process.

Performance in a security gate context

It is generally accepted that physical item security based on the use of an RFID tag is not as effective as security performed by traditional electromagnetic (EM) security systems. HF RFID tags are easily masked by a borrower's body, by each other, are not as covert as EM tags, and have spatial orientations where detection is unlikely. The testing described in Appendix A suggested that the performance of UHF tags in the security gate context was superior in several areas to that seen in typical HF systems. There appeared to be no orientations within the field of the UHF antennas (representing a pair of security gates) where tags were not detected. While a tag could be shielded by careful placement of the hand or hugging the library item to the body, outside of this situation the detection was very good. Repeated tests at normal walking pace with ten thin items yielded either 90% or 100% detection and tests with five thin books consistently yielded 100% detection regardless of orientation. Because of the reduction in tag masking even carefully aligned items were detected routinely within the antenna's coverage area.

Performance with CD & DVD material

In the world of HF library RFID, tagging CD & DVD material presents a number of challenges. The "hub" tags designed for such media do not offer robust security due to the small size of their antenna which leads to poor detection in the security gates. Sets of CDs or DVDs can be difficult to tag in their original cases due to the metallic nature of the recording layer and the problem of tag masking. RFID library suppliers have developed various schemes to overcome

these and other difficulties but the problems are far from solved. During the testing describes in Appendix 1 we were unable to test UHF CD / DVD solutions as none were available to us but early indications suggest that perhaps "near-field" UHF might offer some significant advantages in this area (see section *Are there really only two choices?* for more information on near-field UHF)

The EPCglobal Network

As previously stated, much of the discussion about UHF versus HF RFID centres on tag price and system performance etc. However, an important part of the UHF supply chain application is the infrastructure that accompanies the tag and reader hardware known as the EPCglobal Network. This network is being developed to allow the infrastructure necessary to process and communicate the unique identifiers carried by the RFID tags. The infrastructure includes electronic product codes, object naming services, physical markup language, data handling, and more recently, security and authentication (Schuster et al, 2007). The purpose of the infrastructure is to enable identification, tracking and tracing of every object in global commerce including the recording of every change in location, status, or ownership (Brown, 2007). Could this infrastructure find application within the library community? Perhaps - it would certainly be useful to give thought to the possibilities.

Potential disadvantages with UHF in libraries

In addition to discussing performance and other benefits consideration must also be given to any potential disadvantages with UHF systems when compared to HF. After extensive discussions with library managers and other professionals, a range of concerns have emerged and these concerns are documented here. It should be pointed out that some of these concerns arise due to the *absence* of information in specific areas regarding the use of UHF technology in the library application. Certainly more research and discussion is needed in these areas.

Occupational Health & Safety

This issue is easily the most discomfiting one for library management and staff. The range of frequencies allocated for UHF use is very close in most cases to the spectrum used by mobile phone (cell phone) communications. In recent times a range of health concerns have arisen regarding potential negative impacts from exposure to electromagnetic radiation from both the phone handsets themselves and the base stations with which they communicate. Many people prefer to use hands-free devices rather than to have the mobile phone pressed to the side of their heads, feeling more comfortable with the phone some distance away. UHF RFID is being included in this same discussion in some libraries. The author wishes to point out that this paper is not suggesting that there *are* negative health impacts from UHF fields generated by mobile phones or RFID systems but that the *perception* within a library service that there may be such impacts can be a complex problem that has to be managed.

In the library RFID context, it will be quite probable that an RFID antenna will be installed under the desk at either the loans or returns point and that staff will stand at this antenna processing items for extended periods - perhaps two hours at a time and possibly with little physical separation between the antenna and the staff member. The current design of UHF systems has the RFID antenna permanently radiating and therefore continually exposing staff to essentially the same electromagnetic radiation as emitted by mobile phones.

There is also some confusion about relative power levels. The maximum power output of mobile phones and of RFID systems are both regulated by appropriate government authorities. In Australia, for example, mobile phones are limited to two watts maximum and at the time of writing UHF RFID systems are limited to one watt. It would seem that the two levels could be used in comparison with the UHF system emerging as the winner for producing only fifty percent of the energy generated by the mobile phone. Unfortunately the technology in each case is a little too complex for such direct comparisons to be made. The GSM protocol used in cellular communications in many countries of the world allows for the handsets and base stations to engage in "adaptive power control." What this essentially means is that the handset uses only the power necessary to maintain communications with its closest base station in order that

the handset's battery may be conserved and interference with other users minimised (Macario, 1997). The outcome in urban environments is that the phone is often operating at a fraction of its permitted power. Secondly, the GSM protocol splits a communication frequency amongst eight users within a cell. By means of Time Division Multiplexing, in a given second, a specific user is only transmitting during one eighth of that second - further reducing the average power (Lee, 1995), (ARPANSA, 2005). The receiver at the base station reconstitutes this "shared" signal back into individual conversations again. So the mobile phone, even operating at its maximum of two watts is only equivalent to one eighth of that power (250 milliwatts or one quarter of a watt) of averaged continuous power.

The net result of this is that the UHF desk antenna in a library RFID system could legally expose library staff to a stronger electromagnetic field than a GSM mobile phone under typical usage conditions. This is of concern to many libraries. Unfortunately there would appear to be little information regarding the use of UHF technology within office environments as a library might be considered to be. Much more typical for UHF systems is for them to be installed in warehouses and distribution centres etc. Also, and perhaps of greater concern, at the time of writing no installation guidelines exist for UHF systems implemented in libraries. Such installation guidelines would allow repeatable installation conditions and therefore known exposure doses etc. There is also much more that might be done by product developers to reduce exposure. Parameters that are significant in RF exposure are (Weisman, 2002):

- Frequency of operation
- Power density
- Time duration of exposure

Certainly the last two parameters may be addressable by careful product design. For example, as the power requirements of the operating electronics within the RFID tags continue to fall due to design improvements etc, RFID developers are provided with opportunities to reduce UHF field strengths while maintaining existing performance levels. Perhaps reducing outputs to levels below those generated by mobile phones.

The author wishes to repeat that this paper is not contending that exposure to UHF electromagnetic radiation is a health risk where mobile phones or RFID systems are concerned. Arguments are often encountered that, at least in connection with mobile phones, suggest that no dose-response curve exists and that the conclusions within the scientific literature on exposure and health are inconsistent. However, some important points remain:

- There has been little if any research completed on UHF RFID within the office context
- UHF RFID installation guidelines don't exist to at least control exposure to a known level
- More can be done to mitigate exposure to UHF fields by careful product design
- There may be a strong negative perception within the library which must be addressed in some way

It is the author's opinion that work on the points mentioned above should be a priority by suppliers of UHF systems and in cooperation with the broader library community.

UHF tag durability in the library application

There are obviously significant differences between the supply chain and library applications of RFID and these include:

- The supply chain (in general) is one directional and RFID tags are used for one traverse of the chain whereas library RFID tags are involved in an iterative process which may repeat dozens of times, often until the physical item itself begins to disintegrate.
- The required lifetime of the RFID tag within the supply chain may be measured in weeks or months whereas within the library application it will invariably be years.

- Items tagged within the supply chain are often rigid such as cartons and pallets whereas in the library application much of the tagged material is not only flexible (paperback books, periodicals etc) but it is also flexed by users on a regular basis and as part of normal usage.
- Items exist within the library application that require archival quality adhesives etc.
- Supply chains and the items within them are largely under the control of the interested parties whereas RFID tagged library material is controlled for much of its circulating life by the general public and must be able to withstand such use.

Some HF library RFID suppliers specifically assemble their RFID tags with the library application in mind and pay particular attention to the sorts of adhesives and paper used, the chip-antenna bonding and so on. While the points above do not necessarily condemn off-the-shelf UHF tags as unsuitable for the library application, we don't as yet have a significant history of their use in library materials. This is one area where some research and perhaps accelerated life testing of various UHF tag options might be useful to libraries in the decision making process.

The nature of UHF fields within the library environment

As we have noted previously, the behavior of radio frequency fields is determined, amongst other parameters, by the frequency at which they propagate. UHF fields overlap with the lower end of the microwave spectrum and are of course at a significantly higher frequency when compared to HF fields. In an RFID context, this can be a two-edged sword for libraries. Whereas UHF may offer a field able to cover wider security gate corridors, when it comes to issuing library material in a self service context, the field must be constrained very precisely. Obviously a borrower waiting in a queue behind someone using a self service unit, for example, does not want their library material detected at the same time. The controlling of UHF fields in this way can be a significant challenge for a systems developer. When you add to this the fact that UHF fields are more likely than HF fields to be reflected from metal surfaces and therefore appear where they are not wanted, the installation of such systems into libraries with their dynamic arrangements of furniture, borrowers and items can be a complex task (Curty et al, 2007).

UHF systems must also deal with issues of backscatter interference. Without delving into too much detail, the process of communication between the RFID tag and the reader in UHF systems has similarities to RADAR. Many systems today employ RADAR to detect and track ships at sea and aircraft etc. Essentially pulses of high frequency energy are transmitted and these bounce off objects within range and are reflected back to the RADAR station. Using sophisticated electronics the RADAR stations are able to identify specific RADAR "signatures" revealing size and distance information regarding the object detected. UHF RFID tags have the ability to vary their RADAR signature (their RADAR cross-section) and by doing so at high speed are able to send information signals back to the RFID reader.

Unfortunately, other objects within an RFID environment such as the revolving metal sprockets on a conveyor belt, some transformers, the ballast inside a fluorescent tube etc can also reflect the UHF field back in a punctuated way that suggests a varying RADAR cross section. The RFID reader must detect genuine RFID tags among these other spurious signals. Considerable skill and experience can sometimes be required to obtain satisfactory performance of the UHF RFID system in library environments.

Product availability, penetration and maturity compared with HF systems

RFID library products based on HF have been in existence for more than a decade. By comparison, UHF based systems are still in their infancy. While there are products on the market now, the number of sites at which these products are installed is still small (although growing) and some of the early adopters have had to work through a range of issues to arrive at their current position. Some early installations based on EPC Gen 1 tags have been less successful than the higher performing Gen 2 replacements. Particular interest is seen from Asian libraries where some significant development work is taking place. Nevertheless, the range and maturity of current UHF products cannot rival the installed

base of HF systems that have evolved over many years. Each individual organisation needs to give careful consideration to their requirements and the level of risk they are prepared to take when making a decision as to which platform to embrace. At the time of writing, for prospective customers in many countries there is as yet no commercial choice anyway - HF is all that is available to them. This picture is rapidly changing, however.

UHF and standards

Introduction

There are many sorts of standards. Standards may be formally set at an international level, a national level, or may even be unique to a particular profession or organisation. The SIP2 protocol commonly used by libraries for communications with self service devices is an example of a *de facto* standard - a standard that has come to be known as such through broad acceptance rather than a formal declaration by a standards body. In connection with library RFID there has been considerable interest shown in ISO standards for RFID tags and readers. ISO is the International Standards Organisation to which many nations belong and which (together with the International Electrotechnical Commission) forms the specialised system for worldwide standardisation. Many libraries recognise that the standardisation of tags and equipment is a way of ensuring the continuation of supply from multiple RFID suppliers. More recently, the standardisation of the RFID tag data format has also received a great deal of attention and the following two sections deal with some of the specifics involved.

International HF standards for library RFID

While there are no international standards in existence that have been specifically developed for the library application of RFID, many standards exist in the commercial RFID technology space and this is where library RFID suppliers first turned when considering a standards-based approach (Ayre, 2005). The library community has long recognised the value of standardised and open systems, particularly in the area of Information and Communications Technologies (ICTs) and so this continues to be a topic of focus within discussions of RFID systems.

Relatively early in the development of RFID systems, suppliers realised that a particular ISO standard aimed primarily at smart-card applications could quite easily be re-purposed to suit a HF smart-label application (Paret, 2005). The standard in question was ISO 15693, first published in the year 2000. This multi-part standard covers three areas specifically:

1. The physical characteristics of the RFID tag
2. The “air interface” characteristics of the RFID tag
3. The command set for communication with the RFID tag and the anti-collision sequence to be adopted.

While the details of this standard are outside the scope of this paper, some useful general comments can be made. The standard, as originally intended, was meant to describe a “vicinity” smart-card implementation (Finkenzeller, 2004). This kind of smart-card system is one that is characterised by its operation at a distance from the RFID reader. Whereas many smart-card systems require the card to be brought within a couple of centimetres to ensure correct operation, ISO 15693 systems could operate in environments where the smart-card would be read while perhaps as much as seventy centimetres away from the reader. Manufacturers of library RFID systems realised that this sort of read range would be appropriate for systems employing smart-labels within library items and so this standard was selected by some as a basis for their HF product offerings. While part one of the standard required the RFID tag to be the size of a standard access card, the RFID manufacturers deviated from this to produce the array of tag sizes we see in current systems while maintaining compatibility with parts two and three of the standard which actually specifies how the tag would communicate etc. So, as a general statement, when a library RFID supplier professes “ISO compatibility” with reference to their system, they are indicating that the tags employed in their library solution comply with parts two and three of ISO 15693.

This standard is not without its limitations when used within the library application and, particularly in the area of data security and privacy, leaves much to be desired (Molnar and Wagner, 2004). Nevertheless, it is almost universally the standard prevailing in current library RFID systems.

During 2004, another multi-part standard was published which superseded ISO 15693. This was part of what are known as the ISO 18000 family of standards. Each part of this family refers to communication with an RFID tag at a different range of frequencies. The part that refers to the tags generally used within the library application of RFID is ISO 18000-3. This section has two modes of operation, referred to as Mode 1 and Mode 2. ISO 15693 is a perfect subset of Mode 1. So, for the sake of completeness, we can say as a general statement, when a supplier professes "ISO compatibility" with reference to their system, they are indicating that the tags employed in their library solution comply with parts two and three of ISO 15693 as stated previously, and/or that their tags comply with ISO 18000-3 Mode 1

The emerging data model for library RFID tags

As stated in the introduction to this section, libraries are also interested in the way that data is formatted on the RFID tags used within their organisation. This interest stems from the fact that the ISO standards previously discussed don't actually provide the *interoperability* that many libraries assumed would also be a benefit resulting from standardisation. In practice, a tag compatible with either ISO 15693 or ISO 18000-3 Mode 1 can be formatted to operate with any supplier's RFID system that incorporates these standards at the appropriate levels within the system architecture. Once formatted, however, there exists no interoperability between individual supplier systems at the tag level. In other words, the formatted RFID ISO standardised tag can be read by only the system for which it was formatted. If presented to a different supplier's solution, the tag might be read but the data would be meaningless.

The reason for this is that the formatting of the data on the RFID tag is not specified by the standards under discussion and so is proprietary where most suppliers are concerned. So while the ISO compatible tag is read by each supplier using the same set of commands, the format of the actual data, that is to say the arrangement by which it is encoded and laid out in the RFID tag's memory is different for every supplier. Clearly, this represents only limited value to the library community. Without a common way of formatting the RFID tag, there is no interoperability at the tag level. If neighbouring library organisations wanted to enter into a cooperative arrangement with part of their collections but had different RFID suppliers, they would not be able to read each other's ISO standard RFID-tagged library material.

The situation outlined above is of concern to libraries (and to some library suppliers) around the world. Independently, several groups have formed to consider what sort of standardised data format could be developed for RFID tags used within library materials. Some of these groups (NBLC, 2004) aimed to develop a national standard while others set their sights more broadly (RFID, 2005). In October 2006 a working group was established within ISO to develop an appropriate international data model for use in libraries. The author is Standards Australia's representative in the group and work is ongoing.

Considering the information provided in this section, many libraries are interested the situation with regard to standards and UHF in libraries. Does a move to UHF preclude the benefits of standardisation or access to emerging data model standards? The next section will discuss these questions as well as other related issues.

International UHF standards for library RFID

The domain of UHF standardisation traditionally lies with the GS1 System and EPCglobal. These organisation and systems are mainly concerned with the identification of goods, services, shipments, assets and locations and is the system commonly associated with supply chains and other commercial aspects of product identification and movement. The unique identifiers used may be encoded in traditional barcode labels or may reside in the memory of an RFID tag. EPCglobal has ratified standards for UHF Generation 2 tags and for software interface components. The UHF Generation 2 standard has been designed and developed specifically to take into account Global telecommunications requirements.

Recently, ISO has approved the Generation 2 standard and has published it as an amendment (part C) to its ISO 18000-6 standard. The 18000-6 standard details the parameters for how interrogators send and receive data from UHF tags. It also specifies the frequencies and channels to be used, as well as bandwidth, frequency-hopping and other technical details. The two earlier amendments (parts A and B) to the 18000-6 protocol describe specific data-encoding schemes.

So, UHF tags are standardised too, bringing benefits of multi-source supply etc but what does it all mean for library interoperability and the emerging data model standard? The first thing to recognise is that, where interoperability is concerned, there are significant differences between HF and UHF systems that extend well beyond issues of standardisation. At the time of writing, the safest course is to assume that there is essentially *no* interoperability possible between UHF equipped libraries and HF equipped libraries. Future technological evolution may well change things but at the moment this is the reality. So libraries using ISO or EPC standardised UHF tags should not expect to be able to read tags from existing ISO 18000-3 standardised HF libraries. Will the adoption of the emerging international data model for library RFID change this situation? The answer is no. Differences of technology are at play here - not just differences of data formatting.

As mentioned in the previous section, ISO TC46/SC4/WG11 is developing a standard that will specify how library information is to be stored in the memory of RFID tags. The standard will include both the individual data elements that may be used as well as the encoding methods etc. This standard is still under development so it is not appropriate at this point to make specific comments on how it may apply to data within UHF tags but some general comments may be made.

Firstly, the data model standard under development does not include UHF tags and associated protocols as part of its scope. While this does not necessarily preclude their use with the emerging data model, the formal scope of the standard is limited to HF tags. In addition, UHF tags have traditionally had very limited or no user memory. To a large extent this is the case because the storage of an electronic product code is all that has been required. Many tags have had either no user memory or perhaps 64 or 96 bits of user memory. While perfectly adequate in the supply chain application, this memory capacity may severely limit the use of such tags within a standardised data model context. The positive news is that UHF tags with greater memory are emerging and so libraries would be well advised to seek a tag with a minimum of 256 bits of user memory (not including the memory required for the TID and license plate) if use of the emerging data model is a consideration. This may change in the future as UHF systems move into new application areas but at the time of writing, these are issues to be considered when thinking of UHF library RFID systems.

The future of library RFID

Introduction

Predictions regarding the future of RFID cover a broad spectrum from essentially wild speculation to educated and considered guesswork. Nevertheless, even the best predictions involve a level of uncertainty - the future, after all, is essentially unknowable. However, predicting the future is one thing whereas *creating* a specific future is something entirely different and here libraries may be able to play an important role.

Currently, it might be said that most of the library RFID systems on the market exist in their current form due to decisions made by suppliers based on their view of what RFID should do for libraries. These decisions are also influenced by commercial factors such as the price and availability of tags and readers etc. Some libraries have expressed the fear that suppliers might switch to UHF systems because it suits *their* business rather than it being the best technology for the library application. This underscores the need for libraries to be knowledgeable about the state of the RFID market and the technologies involved and then take an active role in driving the development of supplier's systems to ensure that the best technologies are incorporated into systems designed for our market.

Already there is talk (Granau, 2007) within the RFID community about RFID 2.0. This talk is about a world where tags are more than smart barcodes, where information is dynamic instead of static and where information is secure. To what extent does the RFID 2.0 wish list benefit libraries and how do we ensure that suppliers embrace developments that are meaningful to the library community? This is not an insignificant challenge. As a starting point we need to see an increased level of leadership from within our library professional organisations. A willingness to take RFID seriously beyond issues of privacy and to recognise its part in the future of libraries. Education programs are needed, as are forums for debate and mechanisms to disseminate useful and non supplier-specific information. Perhaps even the funding of small research projects aimed at addressing some of the unanswered questions posed earlier regarding UHF. We are seeing some of this type of support but much more is needed if we are to take charge of our own destiny.

Are there really only two choices?

It's possible during the discussions about the future of RFID in libraries to fall into the trap of thinking that there are only two ways that the future might unfold - either current HF tags or UHF tags will dominate. Of course these two outcomes are not the only ones possible. Indeed there are schools of though that consider neither of these scenarios to be likely and it's worth at least outlining what other future possibilities might exist to bring some context to the discussion of UHF's potential within the the library application.

Alternative scenario #1

Neither technology dominates. It is entirely conceivable that both technologies may continue to be used and that the particular RFID application determines which is more appropriate. We've already said that both HF and UHF technologies have their individual strengths and weaknesses. While it must be acknowledged that both technologies could continue to evolve in ways that minimise some of the performance differences, some applications may simply require the maximum performance available, without regard to the underlying technology platform. So in this scenario, both technologies dominate but in different application areas.

Alternative scenario #2

A technology now under development or yet to be developed comes to dominate. There are discussions within the RFID community about the desirability of using near-field UHF tags at the item-level (Sirico, 2006). While these tags are operating at UHF frequencies, they are configured differently to the UHF far-field tags used currently in supply chain applications and in some libraries. Specifically, the way that the RFID reader powers and communicates with

these tags is not the same as with many of the UHF tags we see proliferating today. Operating in the near-field may provide specific benefits when items are being read from relatively close distances (ibid). So in this scenario UHF may dominate at the item level but using a different technology than either the supply chain or the technology currently offered to libraries.

Alternative scenario #3

A mix of UHF near-field and far-field technologies. It's of course possible that UHF Gen 2 tags dominate but in two different forms - one with antennas optimised for near-field applications and another where long range reading is the only requirement. Alternatively, and as a variation on this theme, UHF tags with both far-field *and* near-field capabilities may become the norm. The tags used in the testing phase of this paper were of this type; neither optimised totally for near or far field operations but capable of respectable performance in both contexts. Perhaps this style of tag is the one most useful within the library application?

Choosing a library RFID system today

Is it about technology anyway?

It's easy to get distracted by issues of technology - after all, there are some serious issues to be addressed and library RFID systems may represent a serious financial commitment and one which we hope is both strategically wise as well as operationally sound. Having said that, library managers do have a business to run. The business of running a library includes issues of staff cost and effectiveness, recurrent maintenance costs, the maximising of technology benefits, Occupational Health & Safety, job satisfaction etc. These are in addition to the ever present desire to improve customer service and add real value to the borrower's visits by maximising the use of professional skills and experience.

RFID has a potential role to play in all of this. For an RFID system to be effective, for it to deliver real results, *what* it does for our library is more important in many ways than specifically *how* it does it. This doesn't mean we disregard issues that might negatively impact on our library community but it does mean that to some extent we disconnect from the underlying technology when doing our evaluation and simply ask - what does this system do well for us and what does it do not-so-well? Where are its strengths and do they line up with our needs? Will this system deliver the benefits we need above others we've looked at? Is this supplier experienced in and committed to our market? - and so on.

These are technology-independent questions. They are questions about functionality and benefits and the price at which these are offered. So, for example, if a library is the first to embrace a new RFID technology and that means interoperability with neighboring libraries is reduced or eliminated, this is not a technical issue, rather it's about process and value and strategy etc. It's about weighing positives and negatives, quantifying and then trading benefits and limitations to arrive at the best package within the context of the individual library service. Of course, universal interoperability would represent a great outcome and some are imagining or promoting situations where everyone has the same system from the same supplier. One look at the world of Library Management Systems suppliers where, at the time of writing, there are 36 individual organisations providing such systems (Wayne, 2007) should inform us that such an outcome is unlikely in the real world.

This may sound to some like an "every man for himself and the devil take the hindmost" sort of an approach. It isn't meant to be. It's simply meant to be an acknowledgment that libraries do, and will continue, to make decisions based on their own needs and the budgetary framework in which they find themselves. And in the final analysis, *whatever* the underlying technology platform, if an RFID system doesn't deliver the results that the business case promised then the project is simply not successful. So, with this context in mind, here are some technology-indifferent points to consider when evaluating RFID systems and the organisations that supply them:

- Have we clearly identified the needs of our organisation - can we articulate specifically what we require from our new RFID system? Not simply "productivity benefits directed towards customer service" but how *many* hours of staff time liberated and *what* services will be added or expanded etc. Real numbers backed by careful consideration.
- Have we turned our requirements into an initial evaluation document? In other words, if we know precisely what we want, can we extrapolate the ways in which a suitable system might deliver these benefits? If, for example, improved collection management is high on our list of desired benefits, what are the devices and software systems from each supplier that will actually provide the benefit? What are the new and changed processes involved? How can we design a testing and evaluation strategy to ensure that these critical pieces actually live up to the marketing hype within which they are packaged? Knowing what we want and how it will be delivered informs us about where to target our evaluation effort.

- Are we intending to automate part of the returns process with RFID? If this is our intention, have we really given careful consideration to the cost / benefit of doing so? It is true that automating part of the returns process can easily double the cost of a library RFID project - even if such automation is restricted to the busiest branches. The returns process is more complex than for loans and has more individual steps. Almost certainly we will only be able to automate part of the entire process. The automation of returns also has the potential to modify existing processes as well as adding new ones. This is an area where special attention must be paid. It's also an area where the actual result delivered is much more important than the technical wizardry delivering it. If the automating of returns is part of our plan, great care is needed when examining the impact of the equipment we plan to install. Well worth the effort is to process map the current process status and then compare it with the proposed process status. This may involve visiting other libraries or requesting equipment on a trial basis for a period before purchase. Along with collection management, this is an area where the promises or anticipated outcomes associated with RFID don't always match reality and there exists great variability between supplier's solutions and capabilities.

- What's the background of the supplier? Increasingly we are seeing commercial or industrial RFID suppliers turning their attention to libraries as a "volume" application where good tag sales may be made. Some of these suppliers have only superficial knowledge of how libraries actually work which leads them to the conclusion that the requirements of libraries are relatively basic and that it's all about moving books in and out. This is not to say that such a supplier couldn't eventually develop a suitable system but we would need to be cautious until we see some real commitment to our industry. Such commitment might be shown by the extent to which a supplier involves themselves financially in the library community, perhaps sponsoring events or awards at conferences etc. Perhaps also by their willingness to become involved in longer term projects and by the extent to which the supplier allows library professionals to participate in the direction setting for their development activities.

- Can the prospective supplier support our RFID hardware and software? It is becoming increasingly common to see libraries modifying the layout of service points to provide essentially 100% borrower-facilitated loans. RFID systems make this a realistic possibility. With great dependance on hardware / software systems to deliver fast and simple transactions, many libraries in this scenario no longer have the means to revert to manual loans should the RFID system fail. So, as never before, prompt efficient service is vital. From where will such service be provided? How long will it take for a technician to arrive? If the system is developed in another country, what spare parts are held in our country and whereabouts in the country? These are significant questions, the answers to which will impact on our ability to deliver quality service.

Conclusion

UHF RFID technology holds great promise for libraries, particularly where UHF systems are able to utilise both near and far field operations with a single tag.

The benefits that RFID can delivery to libraries are real. There are suppliers in the market today with proven track records in successful implementations around the world. The reality is however that RFID technologies are still evolving and are driven by markets and industries that dwarf libraries in terms of their current size. There exists no one having an RFID crystal ball and able to predict with certainty how the RFID landscape will look five or ten years from now. In the meantime, libraries have businesses to run and customers to satisfy in the contexts of changing user expectations and often uncertain budgets. The parallel between this situation and the early days of library computers in the 1980's has struck many who have been involved with libraries for some time.

Now, as then, the important questions are these; Does this system, regardless of whether it is based on HF or UHF platforms, allow us to achieve the goals and targets we have for *our* library service? Does it support *our* strategic vision and meet operational requirements? Is it well designed and constructed for reliability and ease of use by staff and borrowers? Does it do all this to the extent that we can construct a positive business case to secure the needed funds? If the answer to these questions is yes, an acknowledgment that the technology might (will) be different in ten years from

now should not stop us from proceeding and realising the benefits. As with most technologies, if we wait it will likely be cheaper, smaller, faster, more standardised etc. But in the meantime, there are libraries to run and genuine benefits to be seized.

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About the author

Alan Butters is Principal Consultant at Sybis, a Melbourne based technology consultancy focussed on the needs of Australian libraries. Alan specialises in Library RFID systems, library management software systems, and process-automation technologies such as self-serve loans & returns and materials sorting. Alan has twenty five years experience within the library sector including senior management roles overseeing product development laboratories tasked with generating innovative solutions for the global library market.

Alan chairs a working group within Standards Australia that recently developed a standards proposal for an RFID-tag data model for Australian libraries. He is also a member of the international ISO working group developing a data model standard for the use of RFID in libraries. He is a member of the ACS, IEEE, and ALIA, and has served on the committee of VALA. Alan has a Masters Degree in Digital Communications from Monash University.

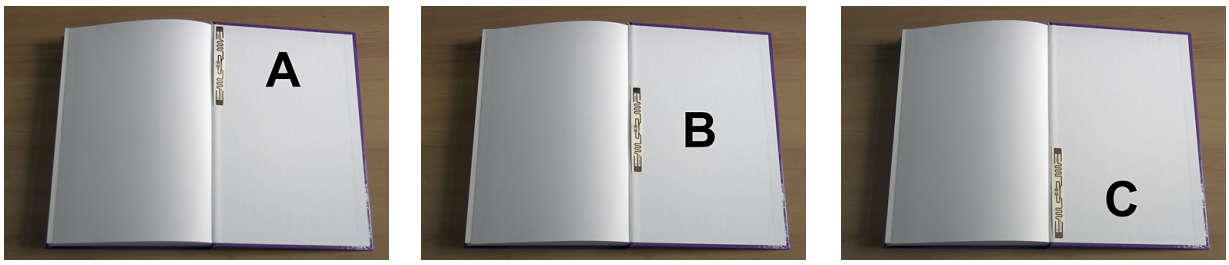
Appendix A

Details of UHF testing

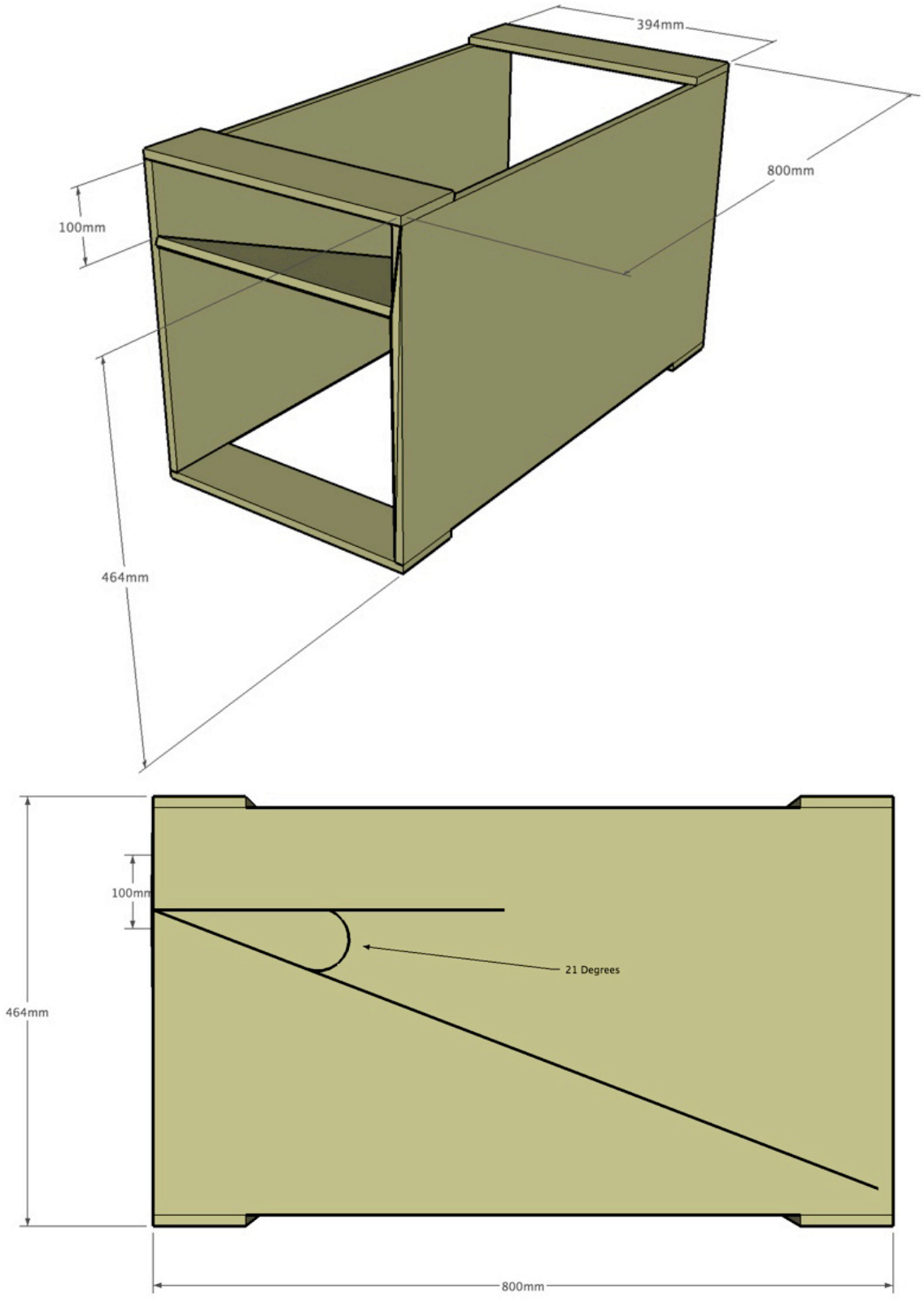
All dimensions in millimetres. The books in the Thin set are children's hardback titles and the Average and Thick books sets are hardback adult non-fiction titles.

Set	Book	High	Wide	Thick	Pages
Thin	1	290	260	7	34
Thin	2	218	265	9	55
Thin	3	280	212	7	44
Thin	4	305	225	7	28
Thin	5	260	260	7	18
Average	6	240	160	28	244
Average	7	240	160	35	318
Average	8	240	160	40	407
Average	9	210	145	30	224
Average	10	240	160	35	496
Thick	11	220	140	65	791
Thick	12	225	150	65	923
Thick	13	230	160	67	778
Thick	14	240	160	58	1090
Thick	15	240	160	55	550
Thick	16	285	225	75	1242

Details of test books



Details of tag positions within test books



Details of chute test fixture

Summary of tests

Test #1 – Multiple UHF tagged books in a returns chute scenario	
Number of books available	Fifteen
Number of books per test	One to n where n is to be determined by the test
Book types	Thin, Average, Thick. Tag locations (ABC) – mixed and identical
Presentation style	Mixed, stacked, various presentation speeds & orientations. Sliding & rotating while sliding etc.
Test books provided by	Sybis
RFID Hardware provided by	Adilam Technologies
Tag position in books	Vertical in gutter – mixed positions A, B , C (see picture)
Specific test requirements	Slide surface to be 840mm x 370mm laminated timber, angled from the horizontal at 21 degrees. Throat to be kept to 100mm opening.
Goals of test	To determine whether the chute is capable of processing multiple books (max stack height = chute opening = 100mm). Both read only of data and also read and write (8 bits approximating AFI value) of user data to be tested. If multi book is possible, determine how many books may be processed simultaneously
Summary of results	For a read-only of the UID, all items in all configurations of five items read with 100% accuracy on all passes and at all reasonable speeds through the chute. For reading and writing of user data only one or two items at best able to be reliably processed in the chute. Various antenna configurations trialled.

Test #2 – Multiple UHF tagged books in a self-issue scenario	
Number of books available	Fifteen
Number of books per test	One to twelve
Book types	Thin, Average, Thick. Tag locations (ABC) – mixed and identical
Presentation style	Mixed, stacked, precisely aligned by spines etc.
Test books provided by	Sybis
RFID Hardware provided by	Adilam Technologies
Tag position in books	Vertical in gutter – mixed positions A, B , C (see picture)
Specific test requirements	Antenna mounted under timber desk (max thickness = 50mm). Area marked above desk for scanning, approximately equal to one A4 sheet in area.

Test #2 – Multiple UHF tagged books in a self-issue scenario	
Goals of test	To determine (by comparison with what is known of HF tagged books) how well the UHF system discriminates stacked books as presented by library users in a self-issue scenario. Specifically, the effect of tag-masking on the success of the transaction. A transaction is deemed to be successful if the stack can be placed and processed without any other interaction such as spreading books etc.
Summary of results	All tests in all configurations were successful 100% of the time.

Test #3 – Multiple UHF tagged books in a theft-detection scenario	
Number of books available	Fifteen
Number of books per test	Five to fifteen
Book types	Thin, Average, Thick. Tag locations (ABC) – mixed and identical
Presentation style	Mixed, stacked, precisely aligned by spines, single stack, two stacks, three stacks with various carry orientations simulating library user, library user with children etc.
Test books provided by	Sybis
RFID Hardware provided by	Adilam Technologies
Tag position in books	Vertical in gutter – mixed positions A, B , C (see picture)
Specific test requirements	Two antennas per side spaced 1.0 metres apart and angled slightly with reference to each other
Goals of test	To determine the relative security detection capability of the UHF system. Successful tests will be determined by the detection of all books presented in the test. Tests to be carried out at ground level (simulating books in a school bag) and at thirty centimetre increments to 1.5 metres above ground level.
Summary of results	For all combinations of five books 100% detection on all tests. For combinations of ten thin and average books detection was either 90% or 100% on all tests. Average 95%. Some tags could be masked by careful hand placement or clutching to chest.

Test #4 – Effect of tag orientation on detection in a theft-detection scenario	
Number of books available	One
Number of books per test	One
Book types	Average. Tag locations A, B or C
Presentation style	Single book carried in orientations known to cause none, low, or marginal coupling with the tag.
Test books provided by	Sybis
RFID Hardware provided by	Adilam Technologies

Test #4 – Effect of tag orientation on detection in a theft-detection scenario	
Tag position in books	Vertical in gutter
Specific test requirements	Two antennas per side spaced 1.0 metres apart and angled slightly with reference to each other
Goals of test	To determine the "dead zone" within the detection area when using UHF tagged items. Tests to be done at 1 watt power output. Read only performance of user data Tests to be carried out at waist level (simulating carried books) and at a range of angles to establish broad "dead zone" orientations. This is a snapshot test intended to provide only a broad comparison with current systems.
Summary of results	No tag orientation sensitivity was observed.

Test #5 – Multiple UHF tagged books in a collection management scenario	
Number of books available	Fifteen
Number of books per test	Fifteen
Book types	Thin, Average, Thick. Tag locations (ABC) – mixed and identical
Presentation style	Various combinations of books with emphasis on more difficult to read combinations such as thin books.
Test books provided by	Sybis
RFID Hardware provided by	Adilam Technologies
Tag position in books	Vertical in gutter – mixed positions A, B , C (see picture)
Goals of test	To determine the read performance with a commercial handheld reader with inbuilt antenna and UHF tagged books. If possible, to determine the ability of the handheld reader to discriminate the book's positions relative to each other (item searching and shelf ordering tasks).
Summary of results	The device tested was an off-the-shelf Unitech hand held reader with no optimisation for the library application. Data gathering only could be tested with this unit and while the unit had good read range (up to 2 metres), 100% detection of a shelf of books was not possible at all times and the process of data collection was slow and not quicker than might be expected from a HF system. Some optimisation of the antenna for the library application could be expected to improve performance.

Test #6 – Multiple UHF tagged books in a data gathering scenario	
Number of books available	Fifteen
Number of books per test	Five to fifteen
Book types	Thin, Average, Thick. Tag locations (ABC) – mixed and identical

Test #6 – Multiple UHF tagged books in a data gathering scenario	
Presentation style	Various combinations of books in random piles on table to simulate reference books left after student use in an academic environment.
Test books provided by	Sybis
RFID Hardware provided by	Adilam Technologies
Tag position in books	Vertical in gutter – mixed positions A, B , C (see picture)
Specific test requirements	Standard timber / timber top & metal legs office table.
Goals of test	To determine the read performance with a commercial handheld reader and UHF tagged books. Specifically, to determine read accuracy and read distance of tags when left in random arrangements on table to simulate internal data collection for books used within the library but not borrowed.
Summary of results	The device tested was an off-the-shelf Unitech hand held reader with no optimisation for the library application. A table containing eleven scattered books was able to be scanned consistently in ten seconds from within one metre. Not dissimilar to HF performance but at an increased distance. Some optimisation of the antenna for the library application could be expected to improve performance.

Test #7 – Extent to which UHF performance is affected by the pages of a very thick book	
Number of books available	One
Number of books per test	One
Book type	Very thick 1500 pages – 80cm
Presentation style	In such a way that the tag must be read through the pages.
Test book provided by	Sybis
RFID Hardware provided by	Adilam Technologies
Tag position in books	Vertical in gutter – all positions A, B , C (see picture)
Specific test requirements	Standard timber / timber top & metal legs office table.
Goals of test	To determine the performance degradation, if any, (compared to HF) imposed by the moisture content contained in the pages of a very thick book.
Summary of results	No affect on performance noted

Summary of test equipment

All tags, readers and antennas employed in the testing phase are manufactured by Alien Technology

Tags - Alien Squiggle tag

EPC Class 1 Gen 2 Reader:
Part Number ALR9800WR1
Serial Number BAO601863

Antennas
Part number ALR9611CR

Serial numbers:
ALR9611CR-06 13262
ALR9611CR-06 11664
ALR9611CR-06 11337
ALR9611CR-06 12816

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