13500 Pacific Avenue S
Tacoma, WA 98444
USA

253-627-5588 info@Orbiter.com

www.Orbiter.com

Timing Accuracy with RFID Tag Race Management Systems

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Abstract:

Race management systems use RFID tags to track race participants. The tags may also be used to time the participants, but there are limits to timing accuracy due to uncertainties in radio wave propagation phenomena, reliability of detection systems in a complex and cluttered environment, and RFID protocol timing. Improved technology using phased detect (array) and new antennas as of 2024 now allows for timing to be made on a line rather than a lobe.

Revision History

Date	*Description*
12 July 2013	r0 – outline
14 July 2013	r1 – initial draft
15 July 2013	r2 – customer inputs
19 July 2013	r3 – added overhead UHF, and carpet HF tags
20 July 2013	r4 – added more mat info
21 July 2013	r5 – modified tag antenna pattern

Timing Accuracy with RFID based Tag Race Management Systems

1 Introduction

An RFID race management tag system comprises an interrogator transmitter connected to an antenna either as a mat, overhead structure, or vertically side mounted antenna (Orbiter), and a family of RFID tags attached to the identification bibs, wrist or clothing or shoes of the runners. Tag and interrogator antennas interact when the tags are inside the detection area of the interrogator antennas, and provide an opportunity for timing information. Interrogators may be located to the *side* of the physical timing line, or *above* the physical line or *in a carpet or mat* that runners must cross. Mat systems use radio bands that are low frequency, high frequency, or UHF systems.

The width of the detection area depends on the inherent system range, tag orientation, and to a lesser degree on the RFID protocol timing. These along with the presence of other runners and other obstacles contribute to errors in the timing of runners. With very careful placement of the interrogator antenna, and with an ideal application of a detection strategy, errors may be kept below 1/10 second. Achievement of an error in the 1/1000 of a second range is not possible due to speed of road running travel and length of the radio wave.

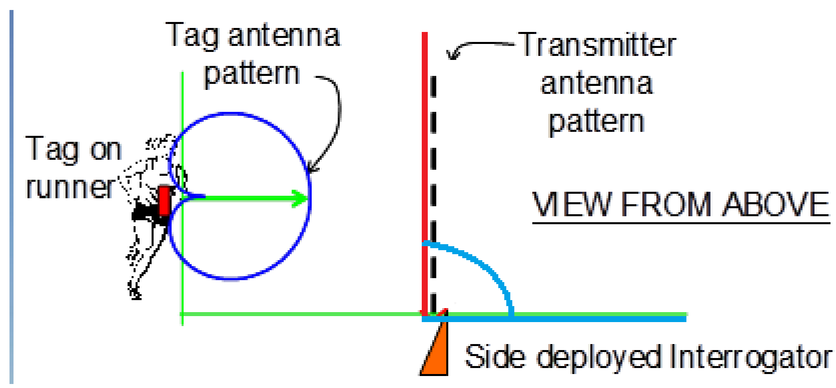
RFID systems in the World operate on an unlicensed basis in the 2.4 GHz (Microwave) 800- 900 MHz ISM band (UHF), 13.56 MHz (HF) and 134 kHz (LF). The transmitting antenna illuminates a region across a physical timing line and interrogates tags as they appear in the detection area. The passive RFID tags receive their operating energy from the interrogator transmitter signal. The system range is usually uplink limited by the power that the tags need to receive from the interrogator transmitter to power the electronics. Tags may require up to 25 ms to charge up the storage capacitor which powers the tag transponder. While illuminated by the transmitter, tags exchange digital information with a receiver and its antenna.

Three systems are considered, (1) Microwave and UHF systems with a **'side mounted'** antennas, (2) an **'overhead gantry'** UHF system and, (3) **'mat/carpet'** embedded LF, HF, or UHF bands.

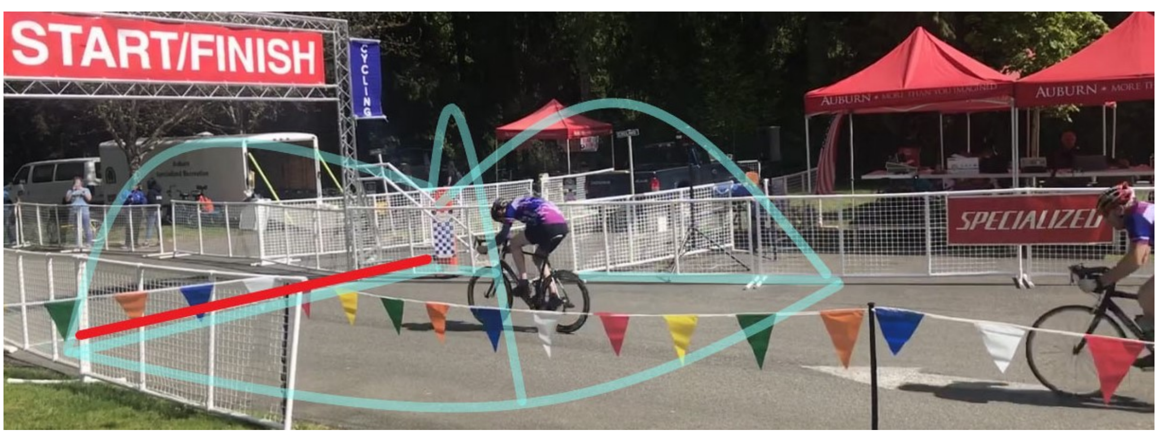
1.1 Microwave and UHF Side Mounted Systems

The modeled transmitter and antenna comprises a 1 W RF power source feeding a directional transmitter antenna in a GEN II RFID reader, or proprietary low frequency (LF) or high frequency (HF) system, either dual band or single band. This paper primarily discusses passive systems operating in the UHF radio band, but many of the principles apply to LF and HF systems. Microwave has a small wave length and it’s time accuracy is greater. The tag model comprises a dipole scatterer attached to the body. Microwave systems include always “on” semi-passive backscatter, blinking “on and off”, and “power up.” Microwave “always on” semi passive microwave RFID tags are the most time accurate due to immediate response. and A Mathcad based radiowave propagation model reveals the electromagnetic environment of the system, and reveals the timing of the runners' tag detections. The tags may rotate left and right or up and down out of perfect alignment in step with the runner, so the tag can point towards or away from the location of the interrogator antenna. Additional timing details were considered from the RFID protocol and digital data transfer.

There are multiple timing lines in a foot race including a starting line and a finish line. There may be intermediate timing lines as well. The electronic timing line is defined by the limits of the range of the interrogator transmitter antenna and body mounted tag antenna combination. The Figure below depicts a bird's eye view of the typical tag antennas on the body, and interrogator directional antenna patterns. The physical timing line is shown by black dashes.



Top view: side deployed interrogator antenna and tags viewed from above. The antenna field of view (blue) of the tag (red) on the runner, and the interrogator antenna field of view (red) must intersect for detection to take place. The phased detect antenna propagates in a 90 degree arc with first tag detect being the start – finish line.

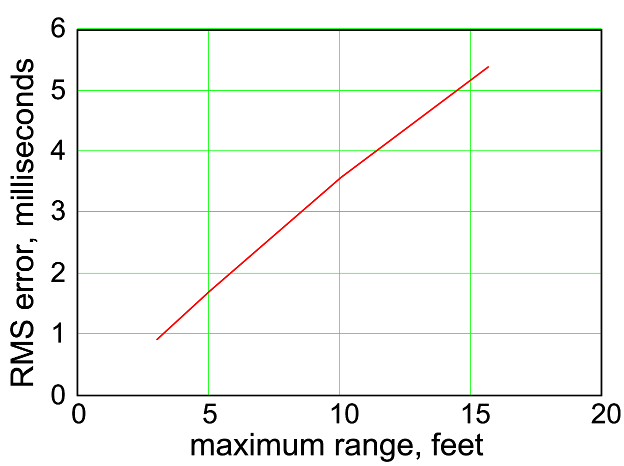


The (red) interrogator transmitter pattern typically has a 90 degree half power beam width and is symmetrical across the timing line (red) and (light blue). A tag antenna pattern in free space resembles a dipole pattern, however when near the body the pattern assumes a cardiod pattern shape with reduced coverage to the sides and behind the runner. The tag antenna pattern (dark blue) on the runner's body points forward in the direction that the runner is facing. The tag antenna pattern behind the runner is shielded by the runner's body. The product of the tag and interrogator patterns defines the electronic timing line encompassing the detection area. Utilizing two side antennas positioned on each side of the start finish line off set from each other at a 45 degree angle, with on set to “first tag” seen and the other at “last tag” seen, then tag placed on either side of the runner may be read on the red line. This is called a “cork screw configuration”.

The composite interaction between the transmitter antenna pattern and a body mounted tag antenna pattern, considering additionally the maximum range of the system, defines the broad detection region encompassed by the electronic timing line (red curve) in the Figure above. Tags inside this broad electronic timing line region may be detected by the system. With a 1 W interrogator transmitter, the system range is forward link limited by the power needed to turn on the tag electronics. Considering ground reflections, the tag range may approach 40 feet when the tag and interrogator are aligned.

When tags attached to the runner and do not point exactly in the direction of travel, but rather may misaligned up and down, time accuracy is reduced by the COS of the angle. This applies to all systems including mats, overhead structures, and side antennas. and to the left or right of the direction of travel due to the runner’s motion. The primary effect of this tag motion is a slight reduction in detection range when the tag momentarily points away from the interrogator. Even with a tag squint of as much as 90 degrees away from the interrogator antenna, the detection range drops to just over one-third of the nominal range. The Figure below shows the effect of a tag pointing 30 degrees away from the interrogator, where range is reduce to between 13 and 14 feet. Tags within the nominal

Another error source relates to how far the runner is from the interrogator antenna detection area at the timing line. For a normal range of 15 feet, the electronic timing line varies from the physical line by several feet either before or after the physical line. That is shown by the width of the area in the Figure above. We can compensate somewhat by turning the interrogator antenna slightly away from the approaching runners (by about 7 deg) to make the detection area more symmetrical, and by averaging the earliest detection with last detection times. Since the electronic line is still not exactly symmetrical about the physical line the residual rms error is about 0.005 seconds for a system with a realized 15 ft range or 0.003 seconds for an 8 foot range. The range dependency of the error is shown in the graph below.



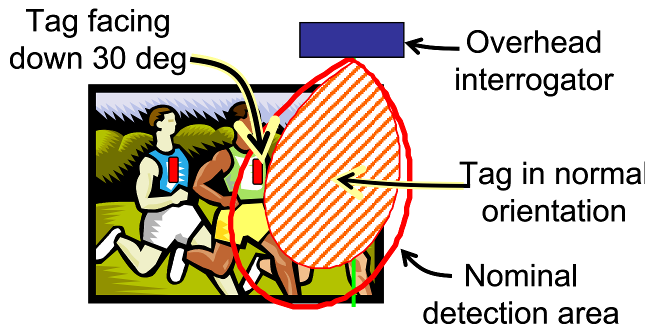
To achieve 1/100 of a second accuracy the range would need to be constrained to less than 3 feet, and tags may not swing up-down or left-right from perfect alignment on the body of the runner.

The RFID protocol requires that the tag be charged up by the illuminating transmitter once it is in range. Following charging there are at least four protocol transactions between the interrogator antenna and the tag to confirm a detection and a timing event. An additional two transactions are needed in the event of each data collision with data transmitted from other nearby tags. Data collisions occur when other tags are in the field of view of the interrogator antenna. An unbalance between "1" bits and "0" bits in the transmitted data my also cause variations in this timing. The "1" bits take 1.5 times as long to transmit as "0" bits. This timing error relates to the tag ID number and other personalized tag data. and also depends on the chosen data rate for tags, and on the density of runners crossing the timing line. For a medium data rate, with no more than two data collisions, and the mix of "1" and "0" bits does not differ by more than 2 bits in 8, the timing variation is 0.2 thousandths of a second. This is not a significant timing error source.

1.2 UHF with Interrogator Antenna Above the Timing Line

The antennas in this timing system are modeled the same way as for the UHF side mounted interrogator antenna system. The same arguments apply for a UHF system with antennas placed in a carpet or mat that the runners cross. In this case the interrogator is above the timing line. The system geometry is pictured below, and the physical timing line is the vertical green line.

In the Figure below the middle runner is ahead of the other two runners. The tag on the middle runner has momentarily pointed down out of alignment by up to 30 degrees. This reduces the detection area for that tag to the red cross-hatched region. Meanwhile the second runner's tag (left most runner), here about 2 feet behind the leading middle runner, is detected normally. Both runners register nearly the same time even though the middle runner is actually in front of the second runner to his left by (2 ft)/(14.7 ft/s) = 0.14 seconds. In this case the first runner to cross the timing line is misidentified. Variations in the tag charge-up time and data protocol timing variations will add to the timing errors. Ground bounces of overhead system increases tag detections as tags are detector prior to the finish line.

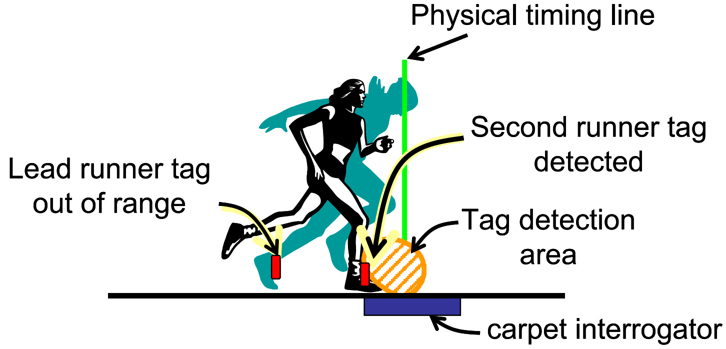


The interrogator (blue), mounted above the physical timing line (green), might detect widely separated runners if the tags are not identically aligned on runners.

In order to achieve 1/10th of second timing accuracy with the interrogator antenna located above the physical timing line, the tag may not deviate from the vertical, or rotate left-right out of alignment, and there can be no timing protocol variations. Otherwise errors can occur on the order of <u>seconds</u>.

1.3 LF (low frequency) and UHF System with Interrogator Antenna in Plastic Mat or Carpet

Mat Timing uses three methods: UHF plastic mats, HF and LF carpets, and dual band carpets. UHF mats detect at greater distances than carpet mat systems. This impacts timing accuracy as strength of signal regimes are attempted to be used increase timing accuracy.

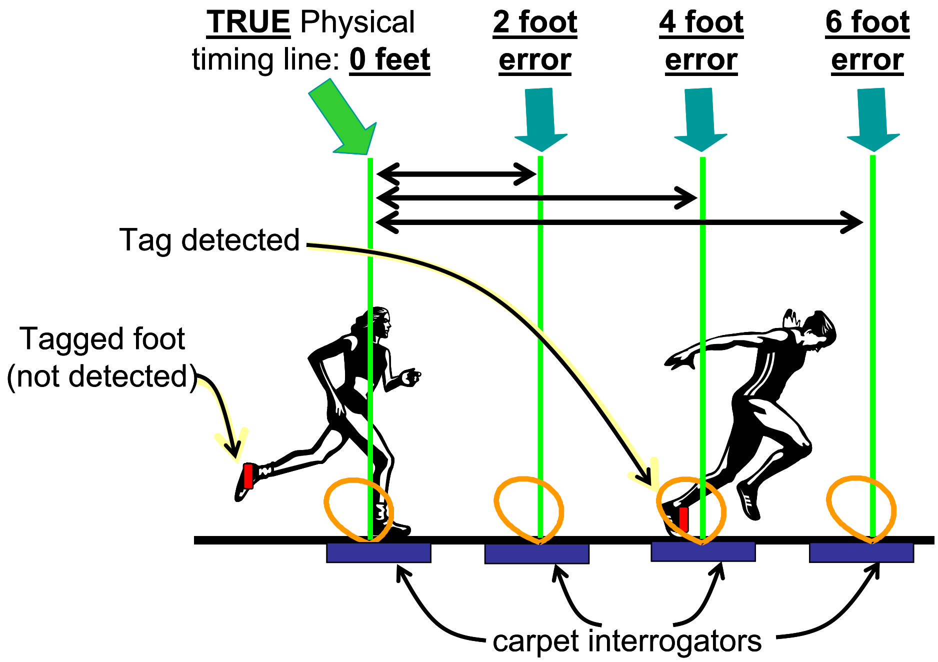


Low Frequency Timing in the carpet/mat based interrogator depends strongly on the runners' foot placements.

In the carpet timing method shown in Figure above, the first runner (blue shadowed) crosses the physical timing line (green) ahead of the second runner (black shadowed), but because of their relative foot placements, and hence tag (red) placements, the second runner is in range and registers a earlier time than the first runner. Here, a one foot delay in foot placement for the first runner added to the one foot actual lead of the first runner means that the relative timing error is (1+1 ft)/(14.7 ft/s) = 0.14 seconds error, and the first runner to cross the timing line is misidentified.

Mat or carpet based interrogators may include as many as 4 mats separated by several feet (2 feet each in the depiction below), because of the inherent non-reliability of the short detection area (orange in the Figure below) of a single mat. In the Figure the true physical timing line is aligned with the left-most carpet/mat detector. Additionally, in mat-based systems up to four mats are deployed to ensure detection of the shoe lace mounted tag. In the Figure below the lead runner’s head and torso are more than 5 feet beyond the true physical timing line before this system of mats detects the tag attached to the shoe. Meanwhile a second runner has just crossed the true timing line with the *non-tagged shoe* in the detection zone so the tag on the lagging opposite foot is not yet detected.

In addition to slower response rate of near field LF and HF mat systems, are timing errors caused by slower anti-collision protocols than UHF and Microwave. A reason for requiring more than one mat is often caused because many LF systems can not read two tags in the read zone at the same time.   Thus, a second and third mat is needed as shown below.



Mat based timing system may require up to four mats to ensure shoe-based tag detection, increasing the potential timing error to several tenths of a second.

In the pictured event the leading runner is more than 5 feet past the *TRUE* physical timing line, so the timing error is (5 ft)/(14.7 ft/s) = 0.34 seconds. If detection were delayed until the last mat, the error would be as much as a *half second*. Plastic mat timing systems use antennas placed on the ground which dampens the UHF signal making tag detections less responsive. To counter act this often times more than one tag is place on the bib, and/or more than one line of mats are used. This is similar to the that shown with carpet systems. **Timing errors with tags attached to the runner's shoe are compounded by the jerky motion of the shoe, as compared to the relatively smooth forward motion of the torso, and on the relatively small detection range of the mat-based devices. Timing errors with shoe mounted tags may be in the several tenths of a second range.**

2 Summary and Conclusions

With careful planning, and careful calibration, an RFID based race timing system might achieve timing accuracy approaching the 1/10 second level. Accuracy of 1/1000 is not be viable at the slow speeds found in road running. For Formula 1, NASCAR and other motor sports much greater time accuracy is possible. However, the timing errors of the UHF systems are similar, but in HF and LF systems timing errors may exceed several seconds. With new phased detect technology as used in US Patent 11,839,803 times can be done on a line rather than a lobe as described in this white paper. This technology is similar to phased array used by the military for target acquisition with timing accuracy to milliseconds.

3 Bibliography

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