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Performance of low power RFID tags based on modulated backscattering

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Introduction

This work takes place in the context of real time localization systems (RTLS) made as a system of RFID tags and a set of readers. Although some systems have already existed for several years, the double challenge of a low consumption for the tags (ideally fully passive, i.e. without any local source of energy) and of a high spatial resolution for the localization capability is very hard to achieve. An approach has been pursued within a few years, which consists of a system of four readers at the corners of a parallelepiped (Figure 1.), and of tags operating according to a modulated backscattering principle [1]. The benefit lies in the low energy requirement within the tag, since for responding to the interrogation signal, it only needs to modify the impedance seen by the antenna port, according to a certain digital code. This process does not require an RF transmitter in the tag, with the associated energy consumption. At the reader, the modulated backscattered signal is received and can be detected by making use of the processing gain provided by the code. An extra code can be used by the reader itself, so to discriminate between its own backscattered signals from those coming from the other readers. In other words, among the system parameters that require careful design in order to control the link budget and the effect of interference, the coding strategy is essential [1]. Although some local energy source remains necessary, it can be much smaller than for an active transmitter and making use of a very small battery. Technologies are currently developed in order to cope with such needs, e.g. with supercapacitors [2].
In this work, we address the system performance from the point of view of the radio channel between the readers and the tags. Typically, the backscattered signal is similar to that of a radar, meaning that it decays as the 4^{th} power with the distance, which is extremely fast. In addition, since the technology is ultra wide band, the power spectral density is severely limited (typically well below 1 mW) and is much smaller than the power limitation for UHF RFID readers (typically 2 W). These facts are highly constraining in terms of detection range. However, since not only the propagation but also the antennas are involved in the link budget, it is possible to play with antenna characteristics in order to improve it somewhat.
In this paper, we concentrate on attenuation measurements between reader antennas and tags, which depend on the reader antenna characteristics and the tag antenna characteristics, including the polarization. We show that, by appropriately tuning the reader antenna characteristics, the 4^{th} power distance dependence can be reduced, hence providing an enhanced detection range.

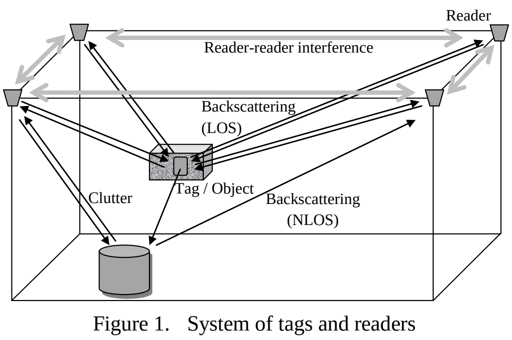

Figure 1. System of tags and readers

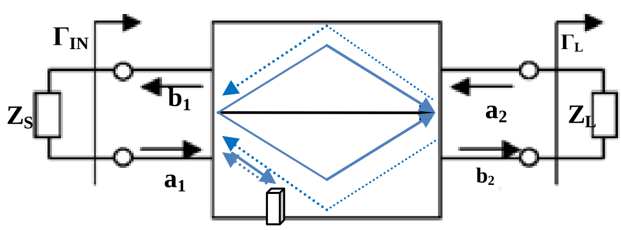

Figure 2. Measurement and detection principle in the case of multipath propagation, seen as a quadrupole

1. Measurement scenario and measurement technique

The measuring principle is depicted in Figure 2. , where the reader sends a signal into the air, which is received by the tag antenna and backscattered, depending on the status of the load impedance Z_L. In practice, the measurements were

conducted with a vector network analyzer (VNA), which has an excellent dynamic range for accurate measurements. For enhanced detection range, a variant of the true system has been used, where the load is Z_L replaced by the port 2 of the VNA, where the port 1 was connected to the reader antenna. In this way, only the transmission between the antenna ports is measured, however it is extremely simple to synthesize a full modulated backscattering operation with any load, since the radio channel is reciprocal.
It can be shown that the power gain between the reader antenna input port and the reader antenna output port (identical usually) writes:

$$G(f) = \frac{1}{d^4}\left(\frac{\lambda}{4\pi}\right)^4 \left| H_{read}^{T}(f)\right|^4 \left|H_{tag}^{B}(f)\right|^2 \quad (1)$$

Where λ is the wavelength, f the frequency, d the distance, $H_{read}^{T}(f)$ is the reader antenna transfer function and $H_{tag}^{B}(f)$ is the tag backscattering transfer function. It can also be written in the form $H_{tag}^{B}(f) = \frac{4\pi}{\lambda^2}\sigma(f)$, where σ is the scattering cross-section. Since the system measures the difference between two modulated states of the load, the actual system operation can be show to provide a backscattered signal proportional to the difference of $\frac{\Gamma_L}{1-\Gamma_L S_{22}(f)}$ calculated for the reflection coefficient Γ_L of the two loads. Usually, the two loads are open ($\Gamma_L = 1$) and short ($\Gamma_L = -1$), giving the largest difference.
In all results below, the measurements have been carried out in the 2-4 GHz range, but the processing has been done in the 3-5 GHz range, windowed for Fourier transformation, resulting in an effective band width slightly higher than 1 GHz.
The scenario was a large empty room at the center of which were placed the four reader antennas. The small scenario was used for calibration and the large for attenuation measurements (Figure 3.). From eq. (1), it is possible to verify the good operation of the measuring system by comparing the extracted backscattering gain and the theoretical one for a known object. This was done by using a commercial can of beer, which can be modeled as a closed metallic cylinder and for which the scattering cross-section can be obtained from a commercial full wave electromagnetic simulator (WIPL-D [3]). As can be seen (Figure 4.), the agreement is quite satisfactory.
In Figure 5. , it can be seen that when the load is changed from open to short, the backscattered signal is basically transformed in its opposite, which supports the proper operation of the modulated backscattering principle.
The tags used in the subsequent measurements were either a dual feed monopole stripline (DFMS, [4]) or a dual feed monopole microstrip (DFMM, [5]), which are planar type antennas of size compatible with a tag. The reader antennas were either bicones (omnidirectional, low gain) or Vivaldi (directional, with gain). It is important to recognize that the reader antenna gain is involved twice in the backscattering operation link budget.

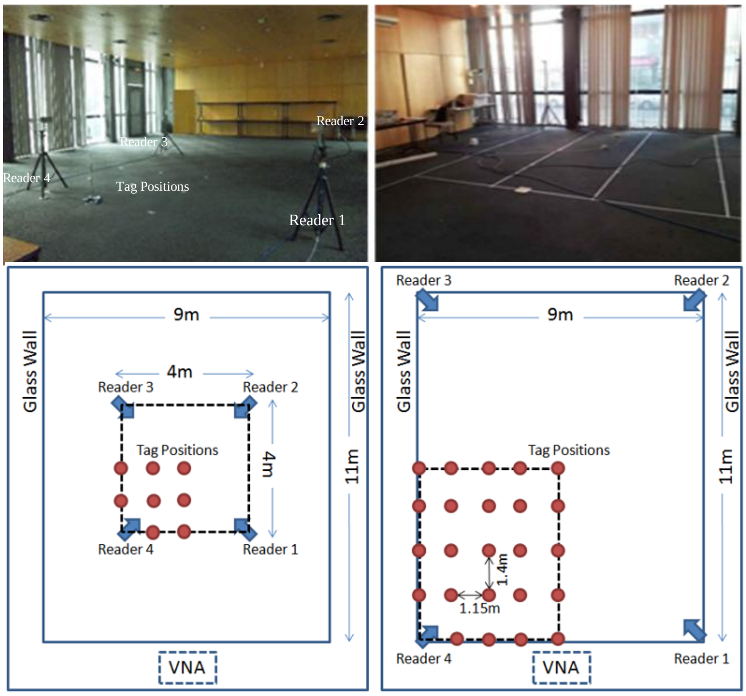

Figure 3. Scenario ; top: room ; bottom: small (left) and large (right) scenario

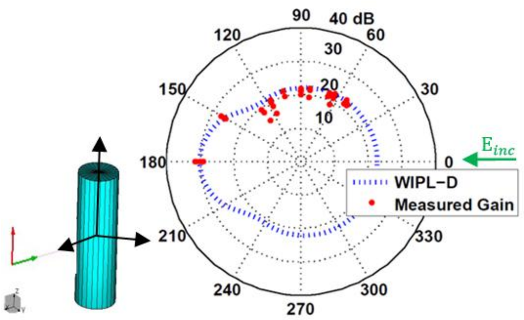

Figure 4. Comparison between the measured and the computed backscattering gain for a beer can

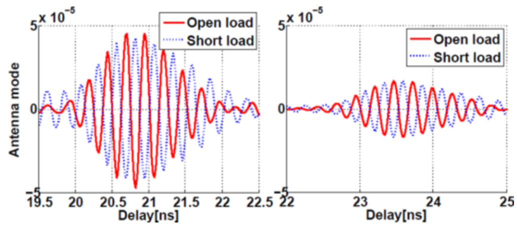

Figure 5. Example of BS signal for open and short circuits for two different tag positions

2. Attenuation measurement results

In Figure 6. and Figure 7. is shown the backscattered signal for the Vivaldi and the bicone reader antennas, respectively, without or with removing the antenna gains. It can be seen that in the former case, the Friis equation underneath eq. (1) doesn't seem respected, from comparing the distance dependence with the expected slope of the 4th power. In the latter case on the other hand, there is a much better agreement with the theoretical signal, assuming isotropic gainless antennas. The explanation lies in the fact that for a non isotropic antenna, the signal effectively depends on the precise direction from the reader antenna to the tag, which changes with the tag location (see Figure 3.), both in azimuth and in elevation (when the tag and the reader are not in the same plane).

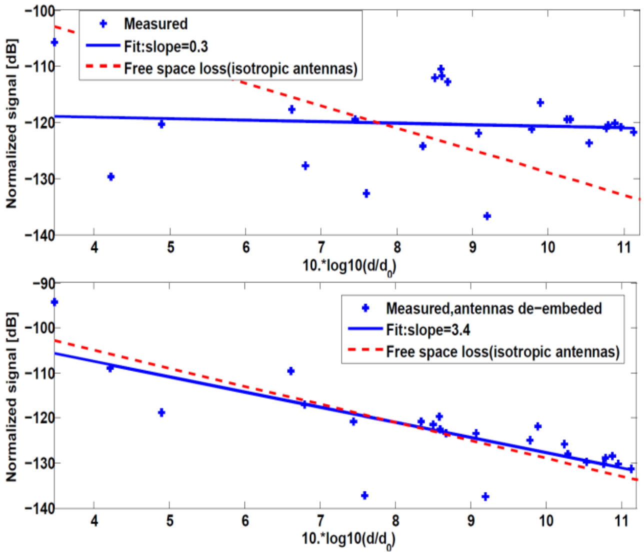

Figure 6. Gain for the DFMS tag ; reader Vivaldi antenna gain included (top) and removed (bottom)

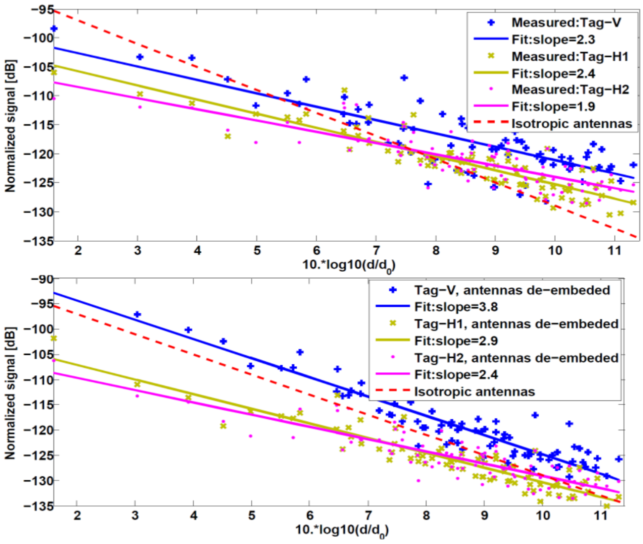

Figure 7. Gain for the DFMS tag ; reader bicone antenna gain included (top) and removed (bottom)

3. Signal to clutter ratio

It is well known that radar systems detection performance is in a good part limited by the clutter backscattered signal, which is often much more important than the target signal. This can be easily understood, in that the cross section of the whole environment (objects but also walls, ground…) is vastly larger than that of a small tag. Thus strategies are necessary to counter these order of magnitude differences. However, designing and optimizing such techniques (basically here, the modulated backscattering principle is assumed to remove a large part of the clutter, which is not modulated) requires a preliminary evaluation of the "signal to clutter" (SCR) ratio. This has been done in the scenario described in the previous section, where the clutter can be easily obtained from the VNA measurements through the reflection coefficient at the reader antenna port. This coefficient mainly includes the imperfect matching of the antenna, but it also incorporates the clutter backscattered signal. It is easy to discriminate between both, as the antenna reflection occurs in the very first nanoseconds, while the clutter is found tens of nanoseconds later. The discrimination can be operated after a Fourier transformation to go from the frequency to the time domain.

However, the evaluation of the SCR first needs to clarify its definition. Indeed, for a time domain based detection system, it may seem appropriate to compute the clutter power and the tag power in the same temporal window (2 ns in practice). This is correct in order to appreciate the needed dynamic range of the analog to digital conversion, required to carry out the clutter rejection. However, owing to non linearities and other saturation effects, the clutter signal over the whole temporal response is important since it might impact the receiver detection capability. Therefore, the SCR involving the whole clutter power has also been used.

The results are shown in Figure 8. Figure 9. It can be seen that the SCR is quite low, especially when comparing the effective tag backscattered signal in the 2 ns time window to the total integrated clutter power. These numbers (~- 50 dB and ~-60 dB) are valid for the empty environment of the room scenario used, and are expected to be even worse in a more realistic case with more obstructions and objects; This places a hard challenge for the RTLS system design.

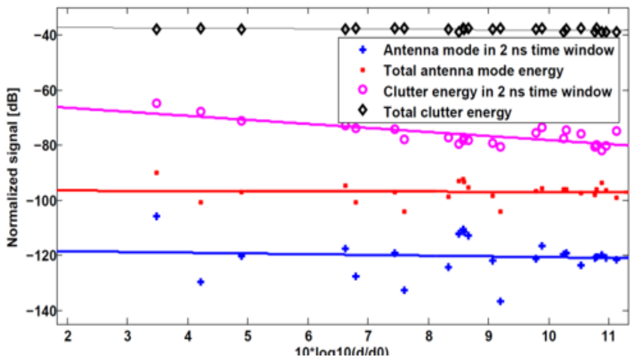

Figure 8. Relative magnitude of DFMS tag BS energy and clutter energy for the Vivaldi reader antenna

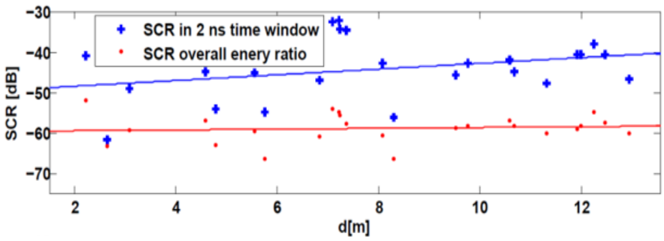

Figure 9. SCR versus reader-tag separation (Vivaldi reader antenna)

4. Conclusion

In the present work, we have conducted a detailed study on the backscattering channel for a RTLS system of ultra wide band tags and readers. There are many challenges that derive from the 4th power dependence of the tag backscattered signal and from the low transmission power enforced by regulations. We found that this 4th power is not generally verified, owing to directional antenna effects from the reader antenna, and also that the signal to clutter ratio was very small, even for the empty character of the room used in measurements. The design and optimization of such s system needs to take into account these effects in the evaluation of its coverage in practical cases.

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