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RFID for Location Proposes Based on the Intermodulation Distortion

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Abstract: This article proposes a Radio Frequency Identification (RFID) system for location proposes based on the use of the nonlinear distortion, specially the 3rd order Intermodulation Distortion (IMD). This new configuration allows the use of the same RF path in transmission and reception of the same signal, improving the correct measurement of the time of travel. In addition the TAG configuration is less complex and need less components. This configuration offers the possibility to develop a semi-passive TAG (or even an almost passive one). *Copyright © 2009 IFSA.*

Keywords: RFID, IMD, LOCATION

1. Introduction

RFID is a mean of identification, location and tracking people, animals or physical objects using radio waves. Therefore, the range of objects identifiable using RFID includes virtually everything [1].. Because of their capability for real-time identification and tracking over large distances, RFID began to have a strong influence in the industry and IT business future. It also been use to identify and locate objects in big warehouses (or supply chains), in management and control process or even tracking people. Other applications in libraries, chemist industry and medical diagnostics are been develop.

Is difficult to precise the birth of RFID because the ideas used in is implementation are known since Faraday. However, seems to be consensual that the first person to explore the idea was Harry Stockman in October 1948 with the paper “Communication by Means of Reflected Power” [2]. In His work, he studied the use of the reflect power as a mean of communication at short distance. Since that, the study and development of RFID technologies has increased, especially since the 1990's when many technological developments are expanding considerably their functionality and applications [3].

RFID systems are generally divided in two major parts: the TAG and the READER. The TAG is a small circuit that could be attach to a person or an object to identify. It should be lightly weighted, with simply electronic and economic (in consumption and price). The READER is the transmitter/receiver device. It's bigger, with a more complex schematic and much more expensive than the TAGs.

The TAGs could be subdivided into active, passive and semi-passive (or semi-active). Active TAGs need internal power source supply to process their information and send it to the READER. They are more complex, more expensive but have improved distance range and more storage data capability.
The passive TAGs do not have internal source energy supply and get their operating power from the signal coming from the READER. They are usually less complex and less expensive but their distance range is small and their data storage capacity is reduced. The semi-passive TAGs have internal power source but it is only used to supply associated electronic. The RF signal is thus re-used for retransmission.

RFID RF frequencies work preferential in the ISM Bands (13.56 MHz, 433 MHz, 860-960 MHz and 2.4 GHz) since its market penetration is simpler.

In this article a RFID design strategy will be presented. Its applicability is mainly for location purposes. The design strategy presented here has an operation principle that is similar to the passive ones, where a nonlinear active device usually generates a second harmonic based on an input RF signal [4]., but in this case is using the third order nonlinear intermodulation, IMD.

First, in section II, will be present the general RFID application scenario and in section III the nonlinear distortion mechanisms. The section IV is devoted to the implementation of an RFID based on IMD. The section V is dedicated to the CAD/CAE design and simulation of such system, and section VI presents some experimental results. Finally some conclusions will be drawn.

2. The Use of RFID's in Location Scenarios

RFID has been thought since the beginning as a technology to track people or physical objects. At the moment the active TAGs have a big advantage against the passive ones due to their biggest range coverage. The disadvantage is the short battery life.

The operational principle of the propose approach is shown in Fig. 1.

The operational principle is as follows:

- The READER send an RF signal, at ω_2, modulated by a pseudo-random sequence and an un-modulated carrier RF signal at a different frequency, ω_1.

- When the signal arrives to the TAG, a RF transceiver demodulates it and re-modulated in a different carried and re-emitted to the air interface.

- The READER has a receiver tuned to this frequency, which allow him to receive a replica of the transmitted signal.

- Now the two pseudo random signals, the transmitted one, and the received one, could be compared in time, and the time of travel calculated.

- This time delay indicates the distance between the READER and the TAG. Obviously this distance is the ray of semi-circle with center in the READER. For a correct location of the TAG, at least three different READERs are needed for triangulation as shown in Fig. 2.

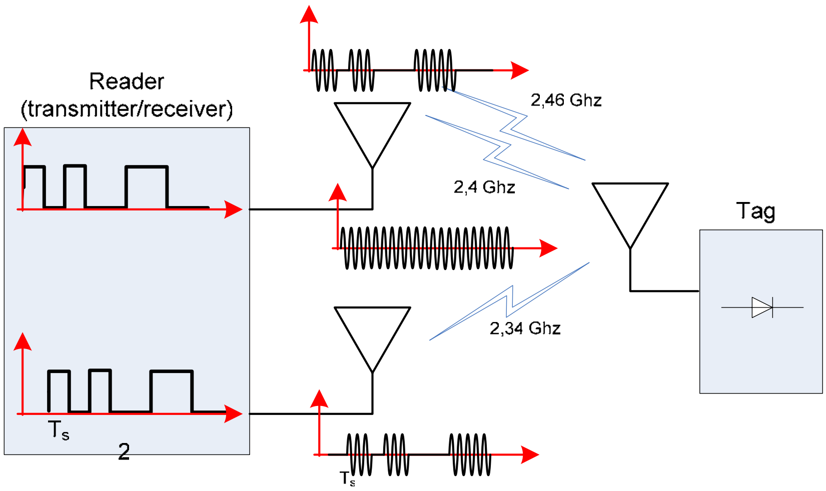


Fig. 1. Location system approach based on RFID.

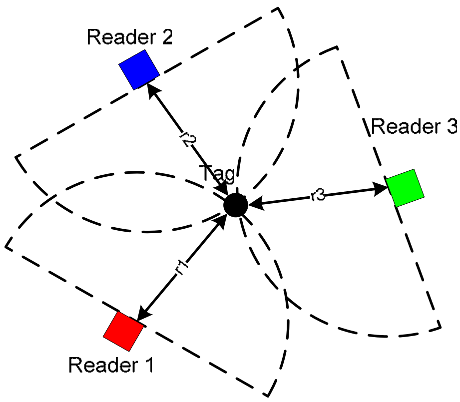


Fig. 2. Location principle using one RF TAG and three READERs.

This is a very simple procedure to locate the RFID. The main problem is how to design correctly a RFID TAG that allows the frequency change of the transmitted signal.

The usual way to address this problem is by use of a complete active RF transceiver. Nevertheless this solution implies the use of typical super-heterodyne configuration, in Fig. 3.

The use of a complete transceiver increases the size and energy consumption of such solution. In order to obviate this more efficient solution of a semi-passive TAG based on non-linear distortion mechanisms will be presented.

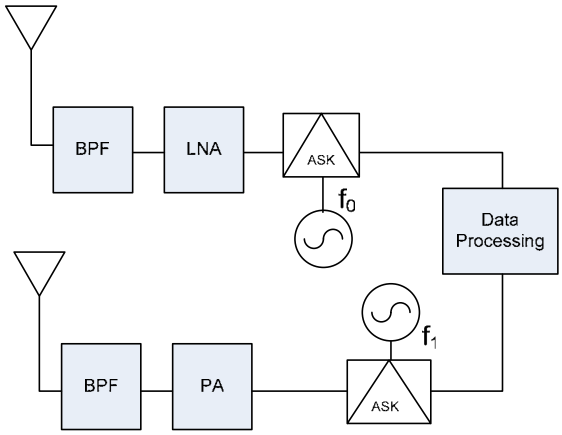


Fig. 3. Super-heterodyne configuration.

3. RFID Supported on IMD Non-linear Distortion Mechanisms

Almost every RF components could be considered non-linear, that is the output signal is not proportional, neither follows the super-position principle. Despite that an interesting property of nonlinear systems is the spectral regrowth capability: the system has the capability of re-generate frequency components in the output signal that do not exist in the input one.

If the system has a low non-linear behaviour, this is by the nonlinear response could be approximating by a Taylor Series Expansion or Volterra Series Expansion if the system presents memory [4]., by expression (1):

$$\delta_{NL}[y(x)] = K_0 + \frac{1}{1!}\frac{\partial \delta_{NL}[y(x)]}{\partial x}\bigg|_{x(t)=x_0}(x-x_0) + \frac{1}{2!}\frac{\partial \delta_{NL}{}^2[y(x)]}{\partial^2 x}\bigg|_{x(t)=x_0}(x-x_0)^2 + \frac{1}{3!}\frac{\partial \delta_{NL}{}^3[y(x)]}{\partial^3 x}\bigg|_{x(t)=x_0}(x-x_0)^3 + \cdots \quad (1)$$

Assuming the input signal ($x(t)$) is a two tone signal at ω_1 and ω_2.

$$x(t) = A_1\cos(\omega_1 t) + A_2\cos(\omega_2 t) \quad (2)$$

Then the output signal ($y(t)$) will be:

$$■(y(t) = y_{\downarrow}0 + y_{\downarrow}1\ (t) + y_{\downarrow}2\ (t) + y_{\downarrow}3\ (t) + \cdots @ y_{\downarrow}1\ (t) = ($$

$$= c_{\downarrow}1\ x(t) = c_{\downarrow}1\ [A_{\downarrow}1\ \cos(\omega_{\downarrow}1\ t) + A_{\downarrow}2\ \cos(\omega_{\downarrow}2\ t)\ ] @ ■(y_{\downarrow}2\ (t) = \quad (3)$$

$$= c_{\downarrow}2\ x^{\uparrow}2\ (t) = c_{\downarrow}2\ [A_{\downarrow}1\ \cos(\omega_{\downarrow}1\ t) + A_{\downarrow}2$$

If we look carefully to the third order component, we see a mixing product that falls closely to the in-band signal.

$$\begin{aligned} y_3(t) &= c_3x^3(t) = c_3[A_1\cos(\omega_1 t) + A_2\cos(\omega_2 t)]^3 \\ &= \cdots \frac{3}{4}c_3A_1A_2{}^2\cos(\omega_1 t \pm 2\omega_2 t) + \frac{3}{4}c_3A_1{}^2A_2\cos(2\omega_1 t \pm \omega_2 t) + \cdots \end{aligned} \quad (4)$$

These mixing products (to 3rd order) are present in Fig. 4.

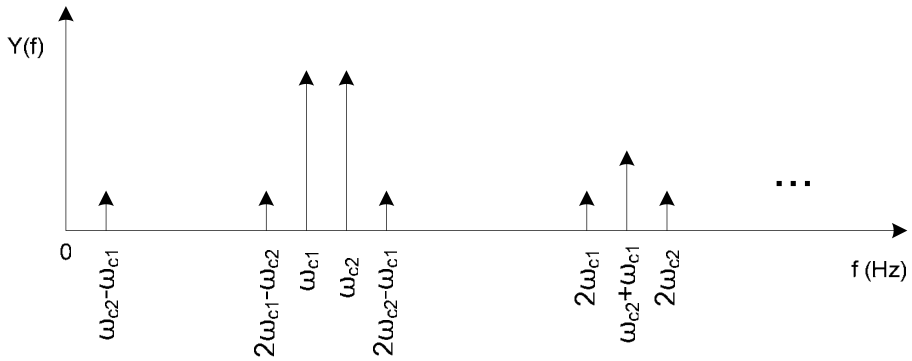


Fig. 4. Spectrum components from a non-linear third order system with two tones entry signal.

So, if in the proposed RFID case, we consider ω_1 and ω_2 are the input frequencies, then the nonlinear mechanisms will generate two different lateral frequencies at $2\omega_1$-ω_2 and $2\omega_2$-ω_1.

If ω_1 is considered the un-modulated signal frequency, and ω_2 the modulated signal frequency, then $2\omega_1$-ω_2, will be:

$$y_r(t) = \frac{3}{4} c_3 A_1{}^2 A_2 \cos(2\omega_1 t \pm \omega_2 t) \tag{5}$$

From expression (5), it is possible to see a new frequency component generated at $2\omega_1$-ω_2, that contains a replica of the input signal, mimicking the previous RF transceiver solution, but in this case recurring to a simple nonlinear device.

In the RFID Tag system proposed the nonlinear device was implemented using a RF Schotcky diode.

4. Implementation of an RFID Based on IMD

Based in the study concepts, the started point was to define the TAG's frequency operation. The study made in the market show us that the interval of frequencies we could explore with a substantial interest for future industrialization is the 2.4 GHz ISM Band. It is important to say that this study is not confine to this band and could be used in other band frequencies.

As referred above the pseudo random sequence will modulate the RF signal by using ASK modulation (OOK). The TAG antenna receives the two signals and excites the TAG with them. The nonlinear device will then create a third order IMD component at frequency 2.34 GHz (see exp. 5) since:

$$\cos(2\omega_1 t \pm \omega_2 t) = \cos\left(2\pi \times (2 \times 2.4e^9 t - 2 \times 2.46e^9 t)\right) = \cos(2\pi \times 2.34e^9 t) \tag{6}$$

The TAG returns to the READER this RF signal and it will then be demodulated.

The TAG was designed as simple as possible. This configuration is shown in Fig. 5.

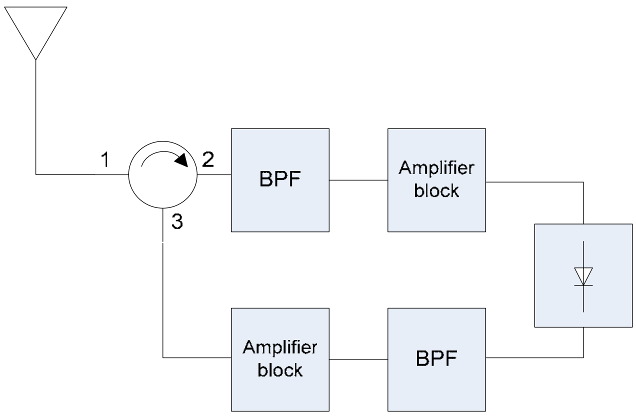


Fig. 5. TAG's block diagram.

The different components used can be justified as:

- After the TAG antenna, designed for 2.4 GHz band, the circulator derives the receive signal (in 1) to the bandpass filter (in 2). In reverse way, it derives the reemitted signal from the amplifier (in 3) to the antenna (in 1).

- The entry filter is a SAW filter with a bandwidth between 2.4 GHz and 2.486 GHz, used for filtering any interferer signal available in the air interface [5]..

- In the first amplifier block, two ERA-3 amplifiers [6]. guarantee enough power for a correct excitation of the diodes nonlinearity.

- A Schottky diode is use as non-linear generator [7]..

- The second SAW filter, with a 25 MHz bandwidth centre on 2332.5 MHz, eliminates the two original tones, but is transparent to mixing frequency at 2340 MHz.

- The last amplification block has a third ERA-3 amplifier to level up the retransmitted signal.

As shown, the RFID Tag configuration is very simple and its consumption very low, because the only energy needed is for the diode polarization.

In the other side we have the READER. The configuration is shown in Fig. 6.

The Reader's structure can be explained as:

- First a pseudo random sequence modulates a RF carrier in a simple OOK modulation. The reason to choose a pseudo random sequence is related with his good auto-correlation value.

- This signal is then combined with an un-modulated carrier at another frequency, amplified, filtered and emitted to air interface by the READER's transmitter.

- The READER's receiver, get the returned signal $2\omega_1$-ω_2 from the TAG by filtering it with a 2332.5 MHz SAW filter (similar to the TAG) and amplify it with a Low Noise Amplifier.

- The receive signal is demodulated at frequency $2\omega_1$-ω_2 and filtered by a low pass filter.

- The *Integrate&Dump* block processes the final step of the signal recovery.

The pseudo random sequence is then correlated with the original sequence and the time-difference between them calculated. This time difference permits distance estimation between the Tag and the Reader.

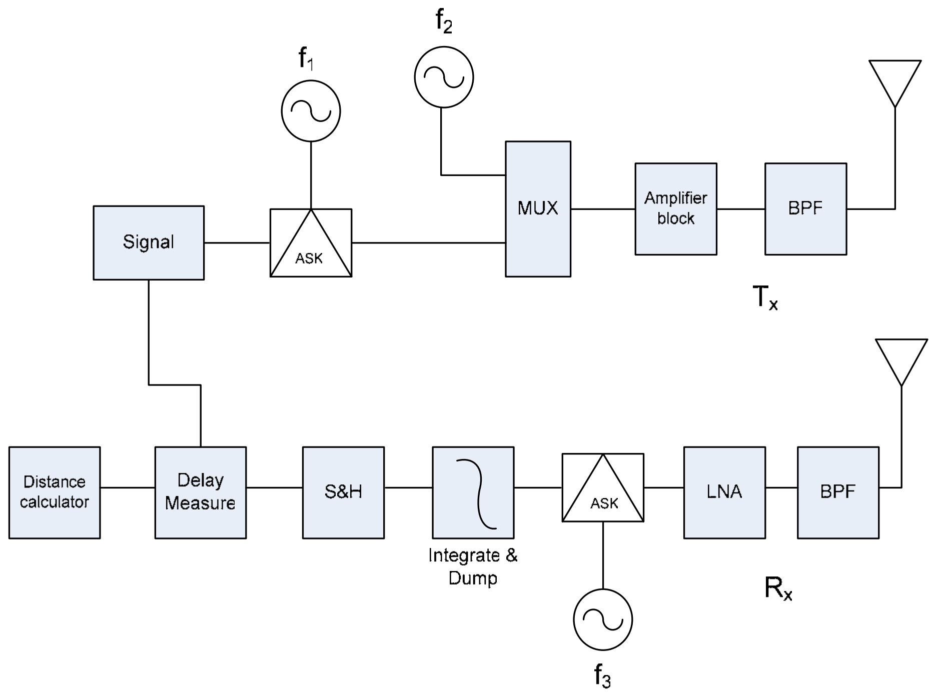


Fig. 6. READER's block diagram.

5. Cad/Cae Simulation of the Location System

In order to understand the behavior of the proposed system, it was simulated in a CAD/CAE Simulator from ADS [8]..

The first step was the study of the non-linear generator behavior. As refer above, we select a RF Shotcky diode for its implementation and the simulations tests show us that this diode has the largest value of IMD for a bias of 0.21 Volts. That result was very encouraging since the supply voltage needed it would be very small.

The second step, the diode behavior was simulated for ideal case. The input signal is composed of two tones (2.4 GHz and 2.46 GHz) with a -40 dBm power each, corresponding to an attenuation of 10 meters in free space. The amplifier gain is 18.7 dB and the attenuation from the SAW filter was 45 dB. The TAG's output signal simulated was has -36 dBm at 2.34 GHz.

For a more realistic simulation, the usual AWGN channel with pathloss was included, the amplifier gain was decrease for a realist gain of 11.5 dB and the distance was also decrease to 5 meters. It is also consider the receiver part from the READER, with the entry SAW filter and the *Integrate&Dump* and *Sample&Hold* blocks. The final schematic simulated in the CAD/CAE Simulator is shown in Fig. 7.

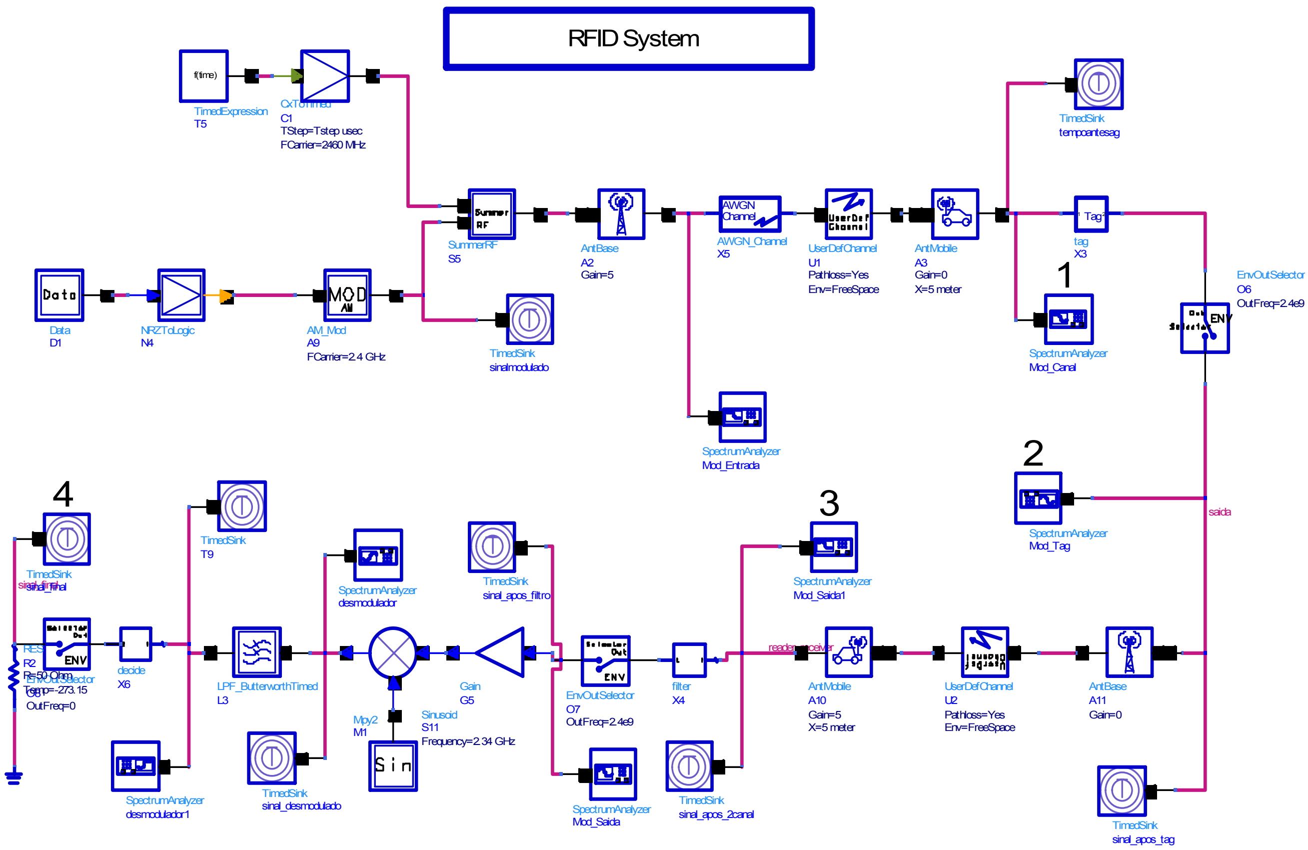


Fig. 7. RFID System ADS schematic.

In schematic is marked the four most important measures to validate proposed solution: signal power receive by TAG (1), signal power re-emitted (2), power receive by READER's receiver (3) and time-difference between the original and the receive pseudo random sequence (4). The obtained results are present in Fig 8.

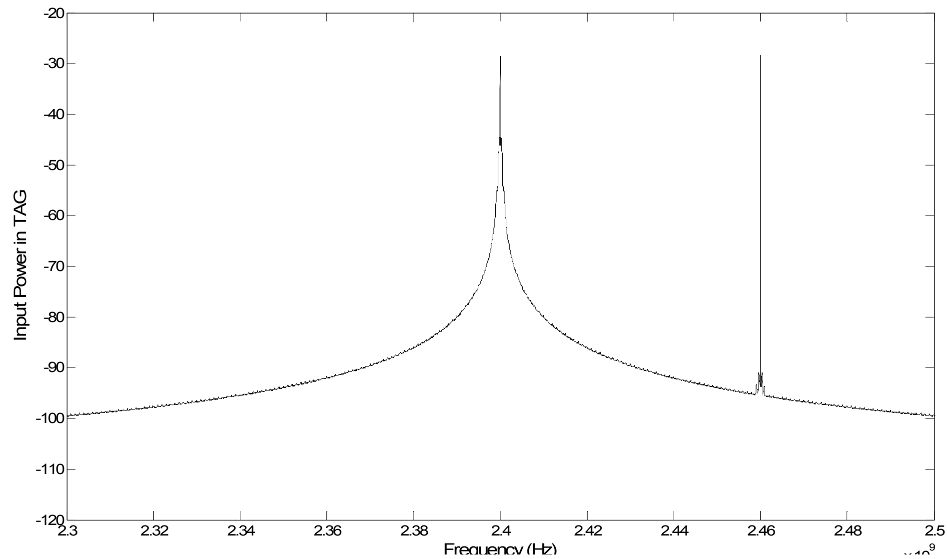


Fig. 8 (a) . RFID System Simulation results: Input Power in TAG.

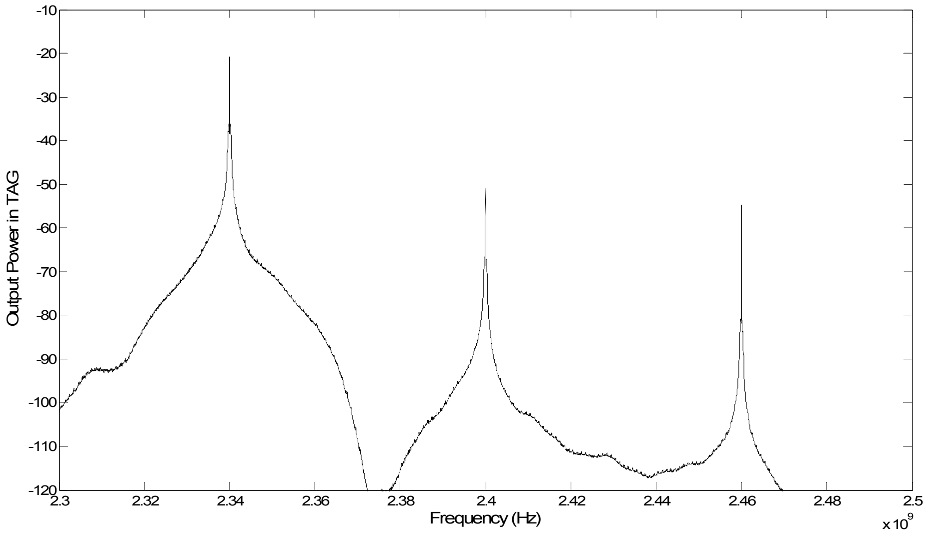


Fig. 8 (b). RFID System Simulation results: Output Power in TAG.

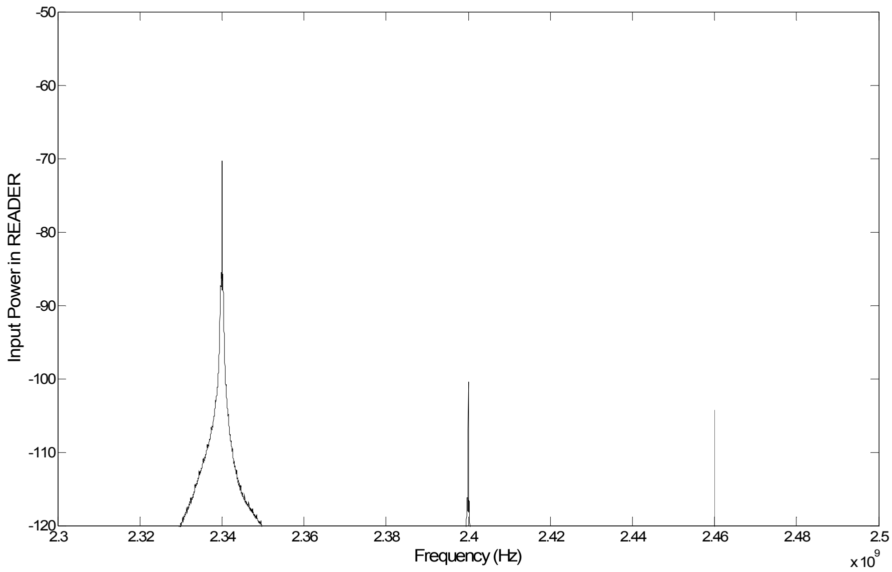


Fig. 8 (c). RFID System Simulation results: Input Power in READER's receiver.

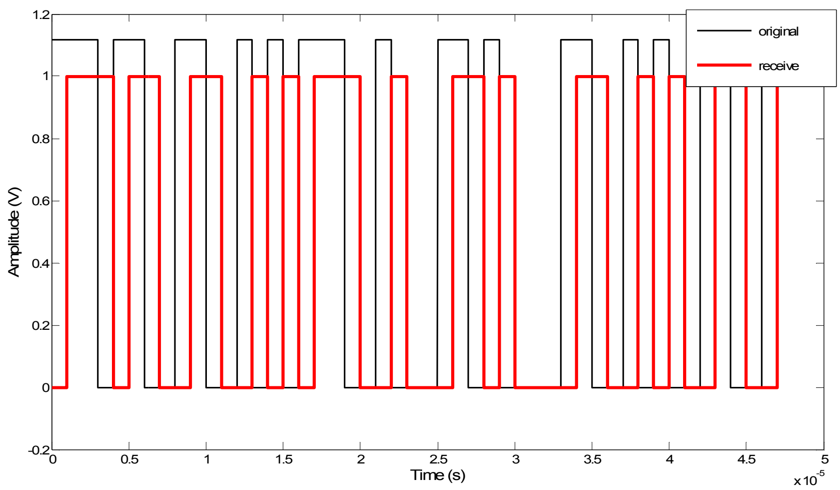


Fig. 8 (d). RFID System Simulation results: Original and receive signal in time domain.

The results show an IMD of -21 dBm to a -28.5 dBm entry level. The reception level in the READER's receiver is about -70 dBm that guarantees a very good system performance to five meter distance as shown in Fig 8d (the time difference observed correspond to sample time delay). Obviously this was simulated to a free space channel and for that reason is expected better results than obtain in laboratory experimentation. Although, this is a very encouraging result to validate the proposed solution.

6. Measurements Results

In order to illustrate the proposed theory, in a real implementation, a two prototypes TAG was built (the second prototype is presented in Fig. 9).

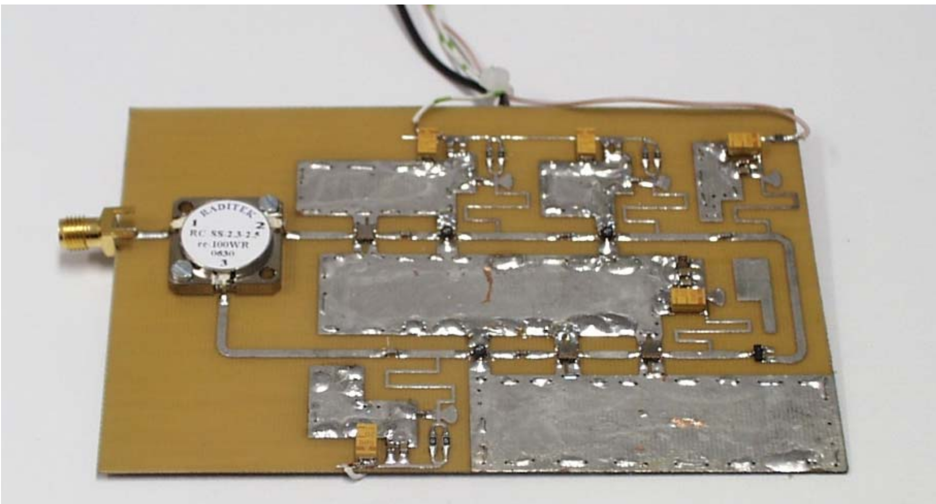


Fig. 9. TAG prototype.

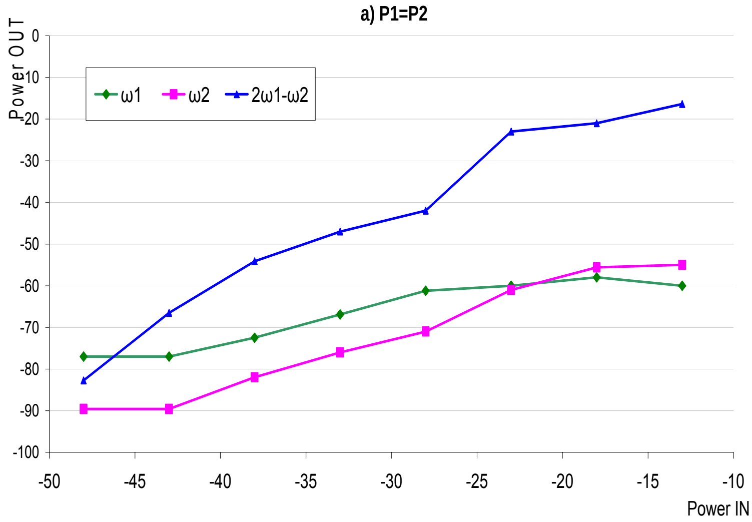
A first cabled test that was made. This test was used to study the behavior of the TAG, a two tone signal was used with a maximum power of -13 dBm. The power of the IMD retransmitted by the TAG was then measured.

Fig. 10 presents the obtained results. The first graphic represents an input of two equal tones and the second represents an input of a maximum ω_1 tone and a variable ω_2 tone.

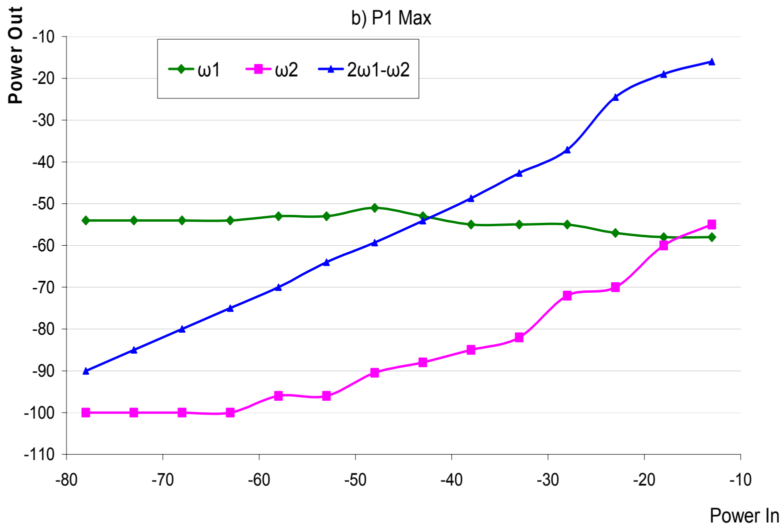
A carefully analysis of the results, show some differences between the predicted values and the real ones. Several causes can be appointed to justify this phenomenon. Nevertheless this result states the viability of the proposed solution for location based RFID systems.

The maximum distance value measured was near 4 meters, from the simple transmitter to the READER.

These results could be optimized if a great care is made in the selection of higher gain antennas.



(a)



(b)

Fig. 10. Laboratorial results: a) Results with a two equal input tones; b) Results with P(2.4 GHz) at maximum (-13 dBm).

5. Conclusions

This article showed that the use of the IMD generation is a viable solution for location purposes. This fact sates that a high value of architecture simplification is possible, reducing the weight, complexity and power consumption of the TAG.

With this knowledge, in the future will be possible make semi-passive TAGs with very low consume and with a low cost, based in the non-linearity of a RF device.

It is expected that better results can also be obtained if a great care is made at the antenna selection.

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