

# The use of Intermodulation Distortion for the Design of Passive RFID

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**Abstract— This paper proposes a Radio Frequency Identification (RFID) system based on the distortion mechanism of a nonlinear device for implementing the complete transceiver architecture.**

**The TAG is intended to be used in location scenarios, where the time of arrival approach will be implemented to measure the distance of the TAG to the reader.**

**Index Terms— RFID, IMD.**

## I. 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. Moreover the coexistence of identification with tracking capabilities, allows a huge amount of applications to be built on top of this new technology and this is one of the first reasons why some research effort is spend on the design of special tailored RFID's that fulfill specific application scenarios [2].

One of those scenarios is the location of a certain object by electronic means. In order to do that, most of the objects to be located use a TAG architecture based on a complete RF transceiver, where the received signal is processed and re-emitted to the air-interface with the same information.

For instance, if we send a pseudo-random sequence to a TAG, that resends this sequence back to the emitter, in a different frequency, after signal reception by the reader we can measure the time of fly, comparing the two sequences, the emitted one, and the received one [3].

Nevertheless the co-existence of two signals at two different frequencies imposes a complete transceiver at the TAG, since the input signal must be demodulated, and re-modulated again in a different frequency.

This as drove the proposed authors to a different scheme where the Intermodulation Distortion of a nonlinear device, can be used to generate a replica of the input signal at a slightly different frequency.

This frequency will then be re-used at the receiver to demodulate and compare with the transmitted one.

This scheme is somehow already used in a one bit TAG, where the second harmonic is used in 1-bit transponder systems, but the complete conversion of the input signal to a replica using the third order IMD at the output as not been used, at least to the authors knowledge [2].

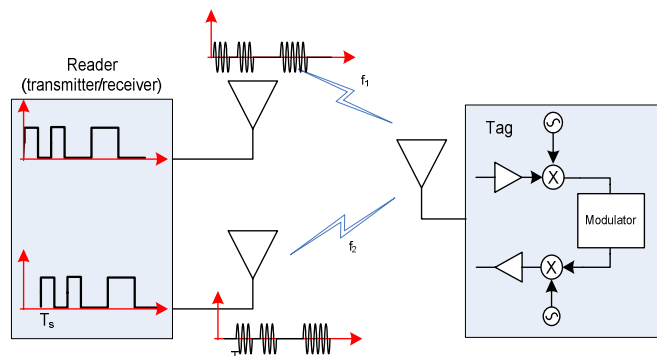


Fig. 1. Location system approach based on RFID TAG's.

This paper will start first by presenting some basics on the nonlinear intermodulation distortion in section II. In section III the implementation of an RFID based on IMD is presented, and in section IV some CAD/CAE results are given. Section V presents some preliminary experimental results and finally some conclusions will be drawn.

## II. NONLINEAR DISTORTION MECHANISMS REVISITED

A RF component could always be considered nonlinear, since for a certain input the output signal is no longer proportional, neither follows the super-position principle [4][5].

Despite that an interesting property of nonlinear systems is the spectral regrowth capability, which means that the system has the capability of create frequency components in the output signal that do not exist in the input one.

The easiest way to understand this nonlinear mechanism is by approximating the nonlinear response of the RF system, by a Taylor or Volterra series expansion if the system presents memory [4], represented by expression (1).

$$\delta_{NL}[y(x)] = K_0 + \underbrace{\frac{1}{1!} \frac{d\delta_{NL}[y(x)]}{dx}}_{c_1} \Big|_{x(t)=x_0} (x-x_0) + \underbrace{\frac{1}{2!} \frac{d^2\delta_{NL}[y(x)]}{d^2x}}_{c_2} \Big|_{x(t)=x_0} (x-x_0)^2 + \underbrace{\frac{1}{3!} \frac{d^3\delta_{NL}[y(x)]}{d^3x}}_{c_3} \Big|_{x(t)=x_0} (x-x_0)^3 + \dots \quad (1)$$

Assuming that  $x(t)$  is a two tone signal at  $\omega_1$  and  $\omega_2$ .

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

Then  $y(t)$  will be:

$$\begin{aligned} y(t) &= y_0 + y_1(t) + y_2(t) + y_3(t) + \dots \\ y_1(t) &= c_1 x(t) = c_1 [A_1 \cos(\omega_1 t) + A_2 \cos(\omega_2 t)] \\ y_2(t) &= c_2 x^2(t) = c_2 [A_1 \cos(\omega_1 t) + A_2 \cos(\omega_2 t)]^2 \\ y_3(t) &= c_3 x^3(t) = c_3 [A_1 \cos(\omega_1 t) + A_2 \cos(\omega_2 t)]^3 \\ &\dots \end{aligned} \quad (3)$$

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

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

Fig. 2 shows the spectrum response of a non-linear third order system.

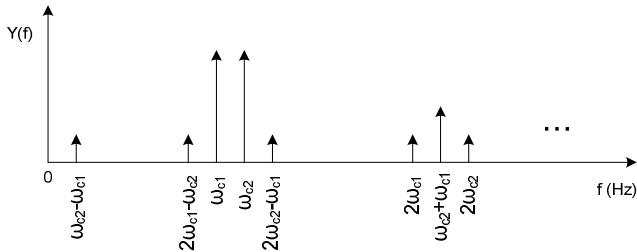


Fig. 2. Spectrum components from a non-linear third order system with two tones entry signal.

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

If we use  $\omega_1$  as an un-modulated signal, and  $\omega_2$  is modulated by a pseudo-random sequence, then at the frequency  $2\omega_1 - \omega_2$ , we will have a copy of the pseudo random modulated sequence, as:

$$y_c(t) = \frac{3}{4} c_3 A_1^2 A_2 \cos(2\omega_1 t \pm \omega_2 t) + \dots \quad (5)$$

From expression (5), it is possible to see that the new signal at  $2\omega_1 - \omega_2$ , contains a replica of the input signal,  $A_2$ , mimicking

the previous RF transceiver solution, but in this case recurring to a simple nonlinear device.

The nonlinear device can be any active RF component as for instance a RF Schotcky diode.

In that respect this drive our thoughts to the fact that a simple passive diode can be used as a complete RF transceiver if it is properly biased and if the driven signal is chosen adequately.

### III. IMPLEMENTATION OF AN RFID BASED ON IMD

Based on this nonlinear behavior mechanism, a basic idea for a RFID TAG was thought with the goal of location.

Fig. 3, presents the proposed solution.

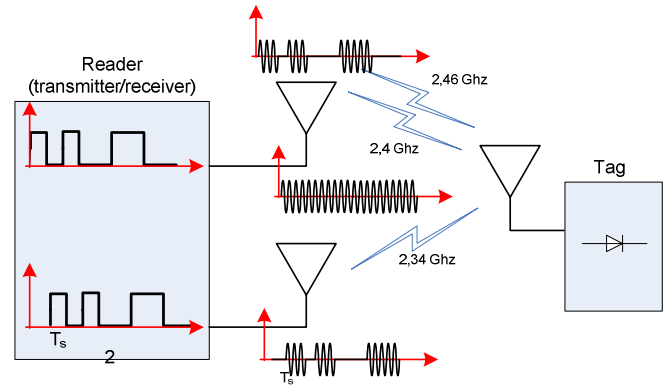


Fig. 3. Location system approach based on nonlinear RFID.

In this case, contrary to an active TAG where the RF generator is on board of the TAG, an un-modulated carrier is sent trough the air interface, simultaneously with a modulated carrier, ASK modulated by a pseudo random sequence.

The TAG antenna receives the two signals at the input and excites the TAG with it.

The nonlinear device will then create a third order IMD component at frequency  $2\omega_1 - \omega_2$

The TAG returns to the READER the RF signal, at the new frequency, which will then be demodulated and correlated with the original sequence. The time difference indicates the distance between the TAG and the reader.

The TAG is as simple as possible. A possible configuration is shown in Fig .4.

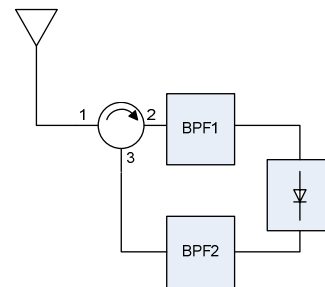


Fig. 4. TAG's block diagram.

In the other side we have the READER. The configuration is shown in Fig.5.

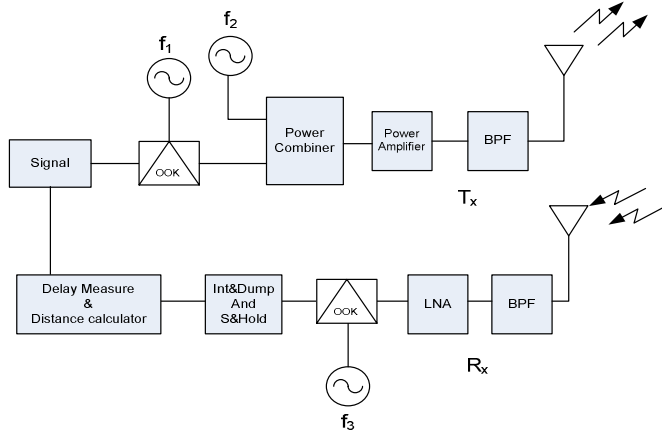


Fig. 5. READER's block diagram.

The READER comprises an ASK modulator, and a CW sinusoidal generator for the transmission of the compound signal.

Moreover it also contains all the receiving part, including the de-modulator at the base band, where the pseudo random sequence is correlated with the original sequence and the time-difference between them calculated. This time difference allows the estimation of the TAG distance.

#### IV. CAD/CAE SIMULATION OF THE LOCATION SYSTEM

In order to understand the behavior of the proposed system, a CAD/CAE simulation was performed using ADS [6].

First the non-linear generator (TAG) was simulated. In this respect we select a diode for its implementation.

The simulations tests show us that the diode chosen has the largest value of IMD for a bias of 0.20 Volts, Fig 6.

That result was very encouraging since the supply voltage needed would be very small.

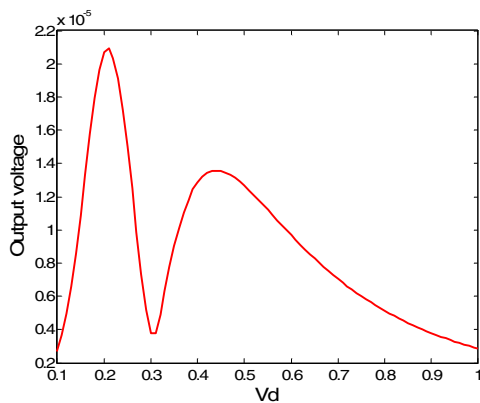


Fig. 6. Diode Third Order Behaviour

This allows us to include this diode in the TAG, with a 0.2V bias. The overall TAG was then simulated.

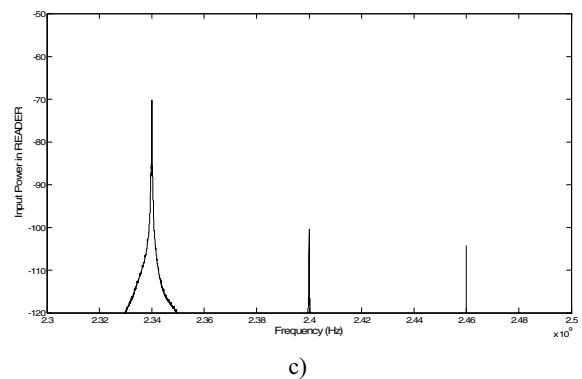
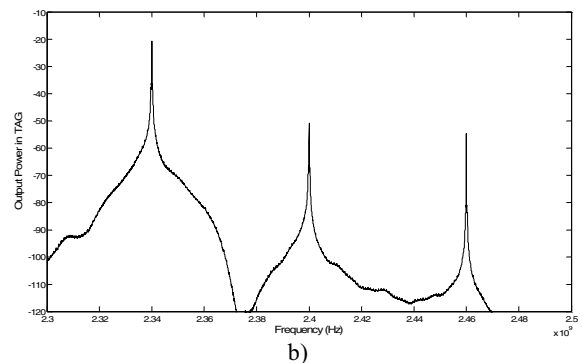
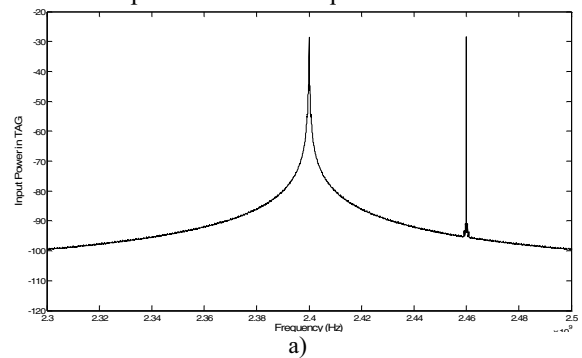
In this case, we use a pair of amplifiers in the simulation to mimic the gain antennas.

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 antenna gain is 19 dB and the attenuation from the saw filter was 45 dB outside the band. The output signal simulated presents -36 dBm at 2,34 GHz.

For a more realistic simulation, the usual AWGN channel with path loss was included, the antenna gain was also decreased for a realistic gain of 12 dB and the distance was also decreased to 5 meters.

In this case the complete receiver was included.

Next figures validate the proposed solution, Fig. 7a) presents the signal power received by TAG, Fig. 7b) the signal power re-emitted, Fig. 7c) the power received by READER demodulator after the low noise amplifier and antenna gain and finally Fig. 7d) the time-difference between the original and the receive pseudo random sequence.



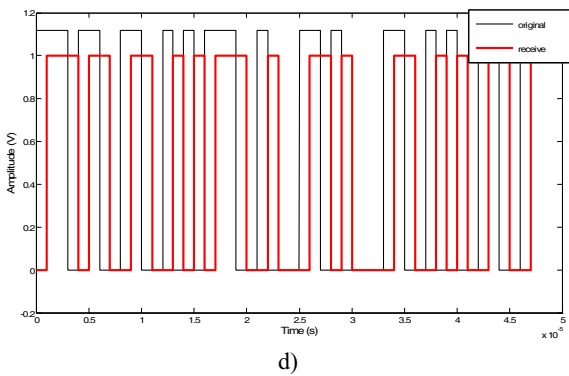


Fig. 7. TAG Simulation result.

The results shown above guarantee a very good system performance to five meter distance. Obviously this was simulated for an ideal space channel and due to that reason is expected that worst results will be obtained in laboratory experiments. Although, this is a very encouraging result to validate the proposed solution.

## V. MEASUREMENTS RESULTS

In order to illustrate the proposed theory, in a real implementation, a TAG was built. The first prototype is presented in Fig. 8.

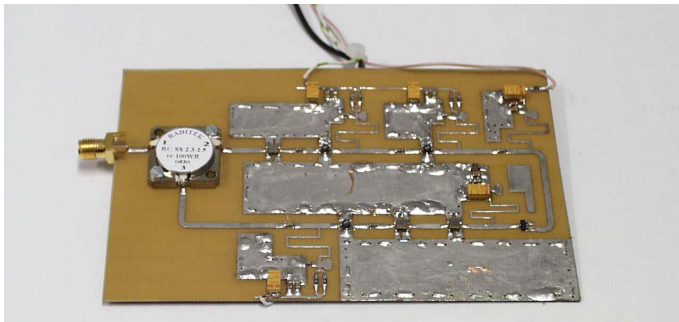


Fig. 8. TAG prototype.

The designed TAG as also some amplifiers blocks, and thus is not necessarily passive, but we chose this configuration for the first design since it allow us to validate the proposed idea.

A first cabled test that was then 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 and the power of the IMD retransmitted by the TAG was then measured. Fig. 9 presents the obtained results.

The first graphic represents an input of two equal tones, the second represents an input of a maximum  $\omega_1$  tone and a variable  $\omega_2$  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.

We have then measure this system with real antenna scenarios. The maximum distance value measured was near 4 meters,

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

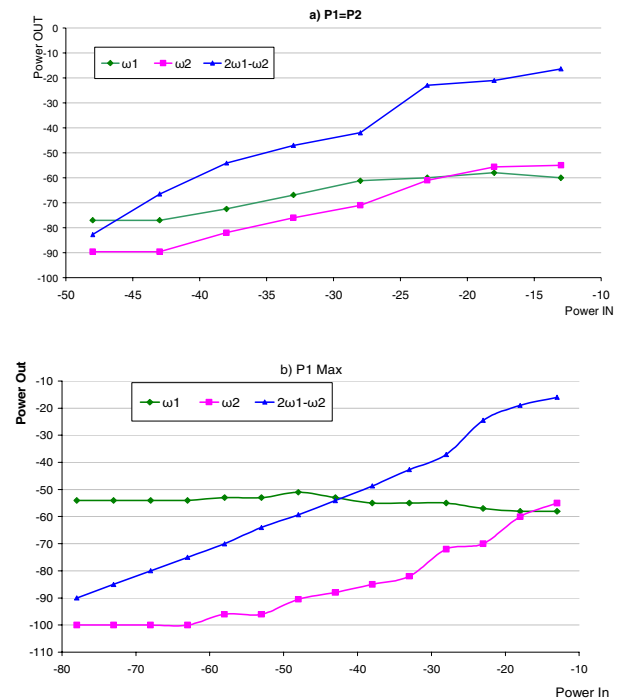


Fig. 9. Laboratorial results.

- a) Results with a two equal input tones  
 b) Results with the power @ 2,4GHz at our maximum (-13dBm) capability

## VI. CONCLUSIONS

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

With this knowledge, in the future will be possible to make semi-passive TAGs with very low consumption and with a low cost, based in the nonlinearity 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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