ANEXOS

Kit de Calibración Agilent

Cargas: Corto circuito, Circuito abierto y Banda ancha

Cargas para la calibración SOLT

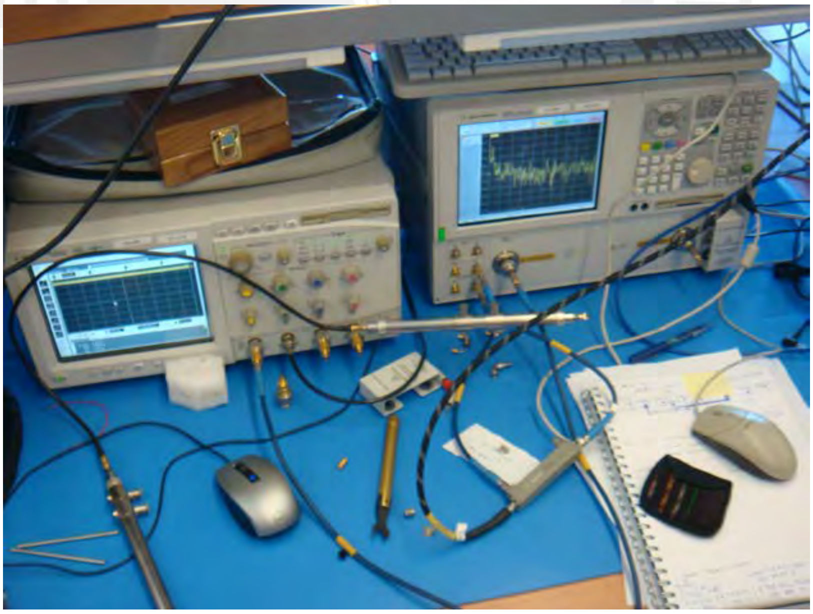
Cargas para la calibración SOLT

Conector + Chip RFID

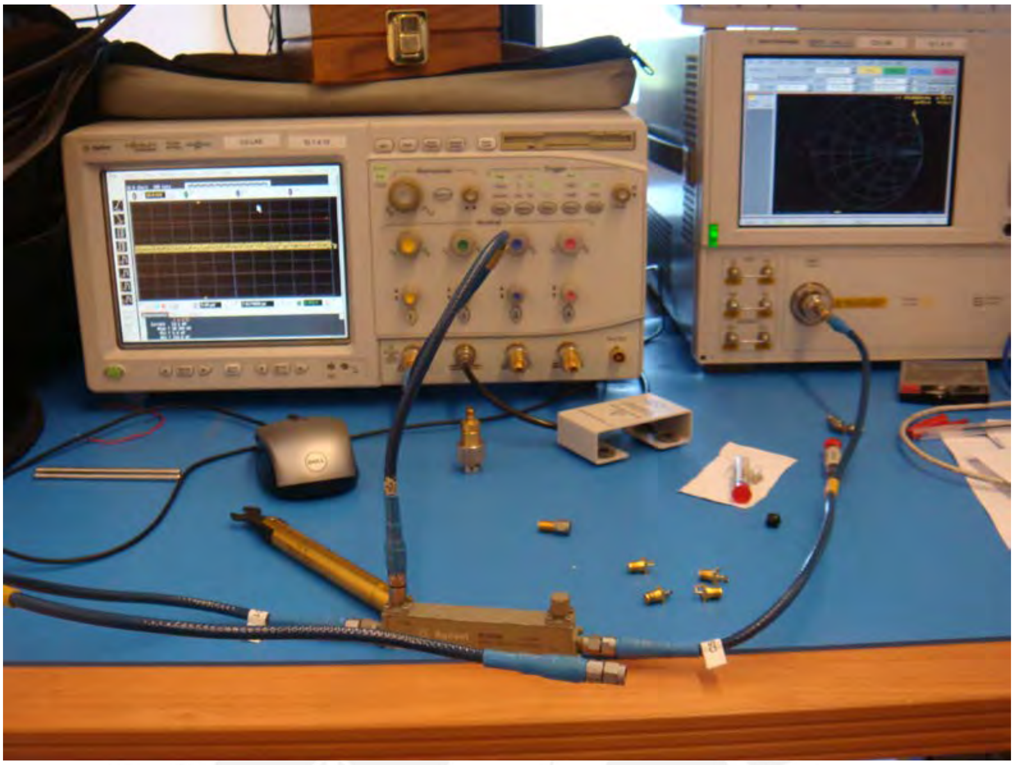
Conector + Corto circuito

Conector + Carga 50 Ω

Conector + Circuito abierto



Proceso de Caracterización del chip RFID



Proceso de Caracterización del chip RFID

Memory Maps

Bank	Address		Memory	Bits
User	00h - 1FFh	User	NVM	512
	70h - BFh	Device Configuration	ROM-NVM	80
	60h - 6Fh	Mask Unique Identifier	ROM	16
	20h - 5Fh	Unique Tag ID Unalterable	NVM	64
TID	00h - 1Fh	TID EPC/TMD/TMDID/TMN	ROM	32
	20h - 7Fh	EPC #	NVM	96
	10h - 1Fh	EPC-PC	NVM	16
EPC	00h - 0Fh	EPC-CRC	RAM	16
	20h - 3Fh	RES-Access Pwd, EPC optional	NVM	32
Reserved	00h - 1Fh	RES-Kill Pwd	NVM	32

Simplified Applications

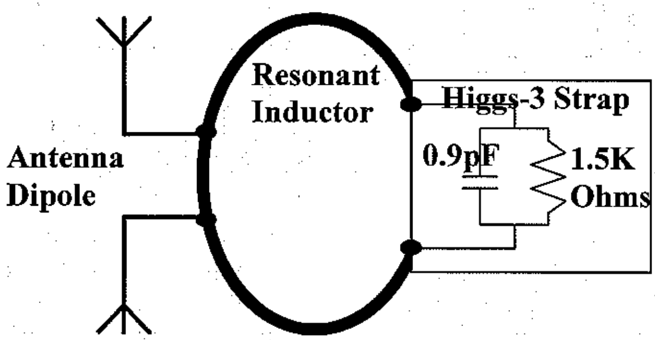


Figure 2, Higgs-3 Strap, Typical Application Schematic (Drawing Not to Scale)

Physical Dimensions and Photos

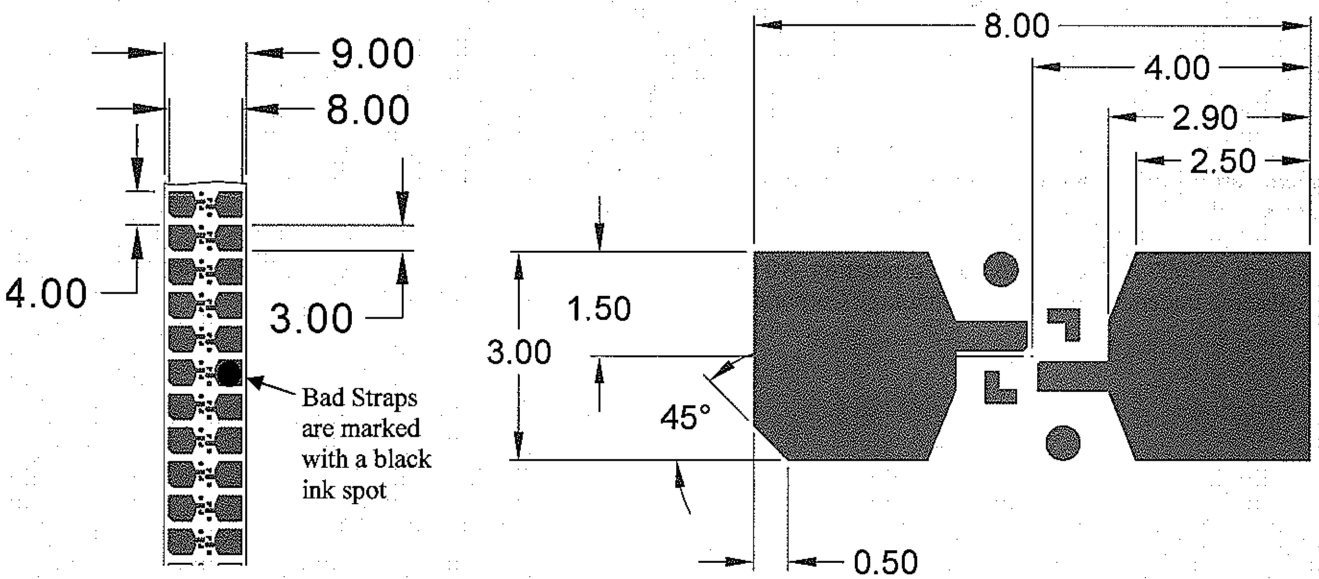


Figure 3, Higgs-3 Strap Dimensions (mm)

A Retro-directive UHF RFID Tag on Paper Substrate

Javier Céspedes, Francesco Giuppi, *Student Member, IEEE*, Ana Collado, *Member, IEEE* and Apostolos Georgiadis, *Senior Member, IEEE*

Abstract—**In this paper, a retro-directive RFID topology is proposed, in order to improve the range of passive RFID tags. The use of a paper substrate permits to obtain low-cost, flexible and easy-to-fabricate circuits. First, the single element of the retro-directive array is proposed, consisting of a dipole with an inductive loop that guarantees the desired impedance matching between the antenna and the RFID chip; then, an array of two dipoles in a Van Atta configuration is presented. The two designs were evaluated by measuring the power received by a reader, for different incidence angles of the signal; the two-element approach showed a 7 dB improvement in the radar cross section at broadside, and less degradation of the received signal level as the angle of incidence moves from the broadside direction.**

I. Introduction

RFID technology has found numerous applications from logistics to monitoring and security, all of which require low cost, large volume circuit production, as well as batteryless operation and increased energy autonomy [1]. As a result, the use of flexible substrates such as polyethylene terephthalate (PET), paper [2] and textiles [3] is receiving significant interest, as they satisfy the aforementioned requirements for low cost and large volume fabrication, and additionally allow for conformal mechanical properties.

A fundamental challenge of passive RFID systems consists of maximizing the tag reading range. One possibility to achieve this goal is by employing energy harvesting techniques. As an example, in [4] a solar-tag antenna was proposed, where light power is initially converted to DC electrical power by the use of solar cells, and subsequently a high efficiency oscillator is used to convert the DC power to RF power which is used to power a commercial passive RFID tag as extend its reading range.

A retro-directive array configuration permits to reradiate an incoming signal towards its source. In this work, the use of a Van-Atta retro-directive antenna is proposed to extend the range of passive RFID tags. A Van Atta array consists of a set of antennas with equal-length connections between pairs of elements, that are equidistant from the center of the array. In the case of a two-element structure, the signal received by one antenna is re-transmitted to the other one with a proper phase; in fact, the transmission line between the two elements is used to invert the phase of the incident wave and then steer the main beam towards the direction on which the incident signal comes. This operation does not require any local oscillator (LO); this means that the Van Atta antenna concept performs retro-directivity within a wide bandwidth, which is simply limited by the bandwidth of its elements [5, 6].

This retro-directive configuration, which unlike “smart antennas” does not make use of any sophisticated signal processing algorithm and is very easy to set up, appears as a very good candidate for remote tagging and wireless sensor applications [7], where self-beam-tracking capabilities are strongly required.

In this paper, a Van Atta retro-directive topology is adopted in the design of an RFID tag, which is then implemented on a cheap, flexible paper substrate. The realization of the prototypes is simple and fast, as the layout of the structure is simply printed on the paper by using a silver-based conductive ink. In Section II, the preliminary development of an RFID tag based on a dipole topology with a central inductive loop is proposed and characterized; then, in Section III, this design is used as a basis for the realization of the retro-directive array configuration. Both the prototypes have been tested by using a reader, whose transmitted signal was delivered to the tag under test with different incidence angles, in order to test its reading range. As the direction of the incoming wave moved from the orthogonal one, the radiation performance of the Van Atta topology showed much less degradation than in the case of the single-element tag.

II. Single-Element Tag

The design of a prototype 868 MHz RFID tag is presented, which was implemented on a cheap and flexible paper substrate, thus allowing for a fast, effective and easy development of this kind of passive, single-substrate devices.

A. Design

In Fig. 1, the layout of the proposed tag antenna is shown, along with the geometrical parameters used in the optimization phase. The structure is similar to the one of the tags presented in [4]; in this case, an important feature of this design is the choice of a low-cost, flexible substrate as paper (290 g/m^2 smooth gloss paper by Ilford).

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Paper presents 3.28 electric permittivity, 0.06 loss tangent and 290 um thickness, and it is a promising candidate for the implementation of tags for RFID applications [2]. In addition to that, the layout of the structure can be simply printed or painted on the paper substrate by using an Electrolube Silver Conductive paint made of a combination of silver, tin and copper, which provides the necessary metallization.

The structure was dimensioned by using a Finite Element Method-based software (Ansys HFSS). The resonant element of the tag consists of two rectangular loops with 3.6 mm width; the use of loops instead of filled rectangles (as in [4]) was selected in order to minimize the quantity of ink necessary to print the circuit, further lowering the cost of the device. The obtained dipole also features a central inductive loop where the commercial chip to be read is mounted with conductive epoxy; its function is to provide the correct matching conditions between the antenna and the RFID chip. This way, the power transferred to the chip is maximized, and consequently the response of the device. The desired matching at 868 MHz frequency was obtained by a full-wave simulation in which the chip was modeled as a lumped port with the desired impedance; in fact, the loop was dimensioned in order for the tag structure to offer the complex conjugate of the IC impedance. The final dimensions chosen for the antenna are listed in Table I, and the overall size of the tag is 78 mm by 35 mm.

After that, the tag structure was excited in simulation by means of a planar incident wave, and the radiation performance of the structure was evaluated for different incidence angles ranging from -90° to 90° with 45° step; Fig. 2 shows the simulated bistatic radar cross section of the tag on the xz plane. As it can be seen, regardless of the direction in which the planar wave is exciting the tag, the response keeps showing a maximum at 0°. This of course may cause degradation in the performance of the device in practical applications.

B. Measurements

Fig. 3 presents the implemented prototype of the proposed paper RFID tag. Its performance was tested by using an Impinj Speedway R420 Revolution UHF RFID reader. The measurement setup is illustrated in Fig. 4; the reader and the tag (mounted on a rotating paper support) were placed in front of each other at 90 cm distance. Around, panels of absorbing material were properly put in order to prevent the creation of multipaths for the signal reflected from the tag. The reader was set in the inventory mode with 31.5 dBm transmitted power; then, the signal received by the reader was measured for different orientations of the tag, ranging from -90° to 90° (see Fig. 4). This way, the tag performs a 180 degrees rotation, which corresponds to receiving the power transmitted from the reader with an angle that varies over a 180° range; this allows appreciating the capability of the tag to operate over different incidence angles.

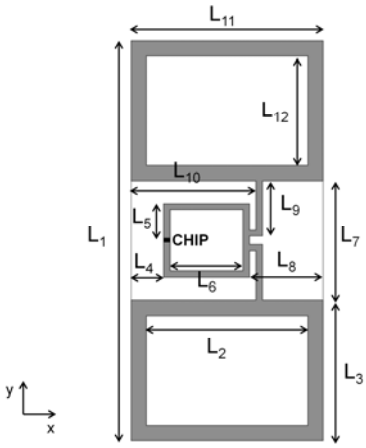

Fig. 1. Structure of the proposed single-element RFID tag.

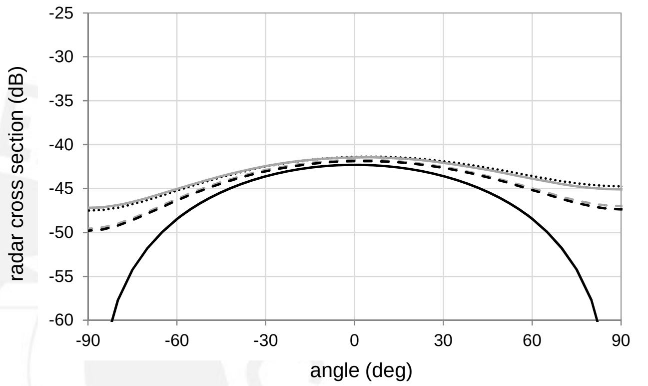

Fig. 2. Simulated bistatic radar cross section for the single tag on xz plane: 0° (black continuous), -45°(black dashed), -90°(grey continuous), 90° (black dotted), and 45° (grey dashed) incidence angle.

TABLE I
GEOMETRICAL DIMENSIONS FOR THE SINGLE-ELEMENT TAG

Parameter	Dimension (mm)	Parameter	Dimension (mm)
L_1	78	L_7	28
L_2	27.8	L_8	12.25
L_3	25	L_{10}	24.25
L_4	6.75	L_{11}	35
L_5	8.25	L_{12}	17.8
L_6	13		

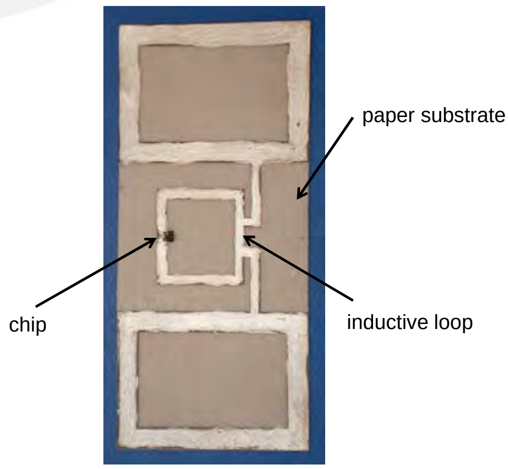

Fig. 3. Photograph of the implemented single-element tag.

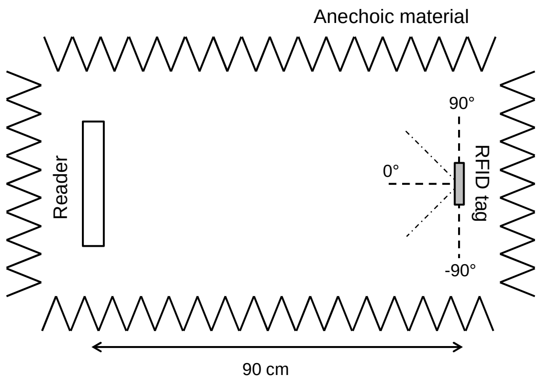

Fig. 4. Scheme of the measurement setup used for evaluating the tags' performance (top view).

The scanning was performed for the xz plane (see Fig. 1), and the results of this operation are plotted in Fig. 5; as it can be seen, the maximum received power is -55 dBm, at 0° incidence angle. After that, the signal level decreases at half the maximum at -55 and 45 degrees incidence. The total degradation over the incidence range is around 11 dBm. The asymmetry in the radiation behavior could be due to the flexibility of the substrate, which may easily introduce some misalignment in the measurement setup.

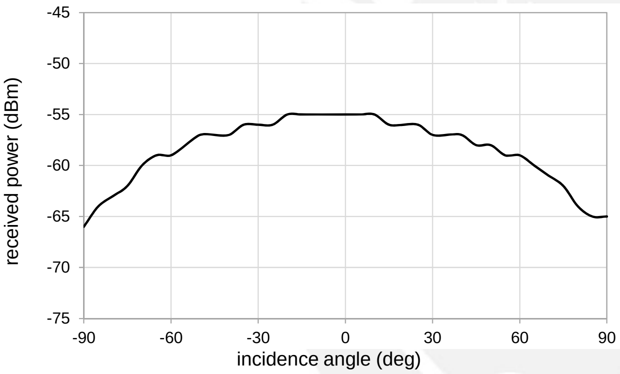

Fig. 5. Power received from the reader for different orientation angles of the single-element tag (xz plane).

III. Two-Element Retro-directive Tag

The topology of the tag proposed in the previous section was modified and used as a basis for the development of a 2-element structure; this new design permits to maximize the power transmission over a bigger range of incidence angles.

A. Design

The topology adopted for the 2-element prototype is shown in Fig. 6; as it can be seen, two tag structures similar to the one presented in the previous section are joined in order to make a two-element device. In the Van Atta Array, one of the two dipoles serves as the receiver, while the other one acts as the transmitter (and vice-versa) and steers the main beam of the array towards the power source, as described in [8].

In this case, no inductive loops are used for obtaining the desired matching, which is optimized by acting on the width of the two transmission lines that connect the four resonators (see Fig. 7); for the same purpose, two equal capacitors of 2.2 pF each are inserted symmetrically at the two sides of the chip. The final goal in this case is to make sure that the power received by one of the two antennas splits equally between the other element and the chip. Also in this two-element case, the dimensioned structure offers an impedance which is the complex conjugate of the IC's one.

The final dimensions of the structure are listed in Table II, while Fig. 8 presents the simulated bistatic radar cross section of the two-element tag for different incidence angles of a plane wave excitation on the xz plane, similarly to what was performed in the previous section. It can be noticed that in this case the structure presents its maximum radar cross section exactly on the direction of incidence (-90°, -45°, 0°, 45°, and 90°). This feature is very useful in order to maximize the tag response to the reader over a wide range of incidence angle, which is essential in practical applications. In addition to that, the radar cross section of this design shows 15 dB improvement at 0°, that is due to the bigger size of the structure and the use of an array configuration made up of two elements.

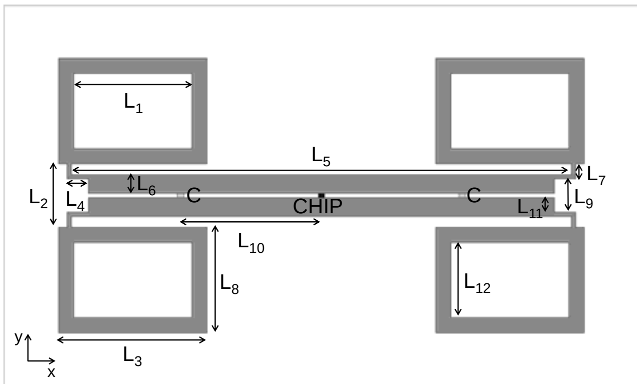

Fig. 6. Structure of the proposed 2-element retro-directive RFID tag.

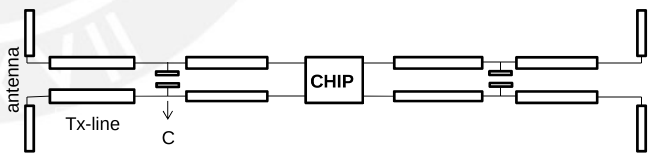

Fig. 7. Schematic of the proposed 2-element retro-directive RFID tag showing the connection between the antennas of the Van Atta array structure.

TABLE II
Geometrical Dimensions for 2-element Tag

Parameter	Dimension (mm)	Parameter	Dimension (mm)
L1	27.8	L7	3.5
L2	15	L8	25
L3	35	L10	8
L4	5	L11	31.7
L5	118	L12	3.5
L6	4.5	L12	17.8

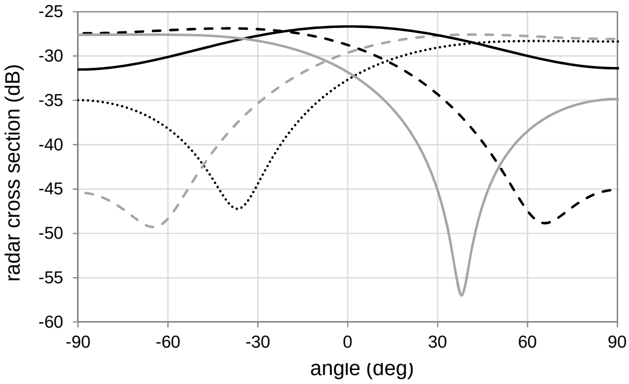

Fig. 8. Simulated bistatic radar cross section for the single tag on xz plane: 0° (black continuous), -45° (black dashed), -90°(grey continuous), 90° (black dotted), and 45° (grey dashed) incidence angle.

B. *Measurements*

The setup used for the characterization of this second prototype is the same of Fig. 4; also in this case, the reader was transmitting 31.5 dBm power.

Fig. 9 shows the implemented structure, whose radiation performance is plotted in Fig. 10, for the xz plane. The decrease in the power delivered to the reader respect to the maximum value of -48 dBm is around 5 dBm over the entire incidence range, while in the case of the single element tag an 11 dBm fall was appreciated; it can be thus concluded that using a two-element RFID tag permits to maximize the range of incidence angles on which the device can operate properly. Moreover, the power received by the reader experiences a 7 dBm improvement. The asymmetry of the plot of Fig. 10 can be attributed to some misalignment in the measurement setup, as well as to slightly different matching conditions on the two sides of the chip, which make the received power split unequally.

Given a certain sensitivity of the tag, the possibility to maximize the directivity of the structure in the different directions from which the signal is coming permits to maximize the collected power that is partially used to activate the IC part.

IV. CONCLUSION

This work regarded the design and development of a 868 MHz single-element RFID tag and a two-element tag array in a retro-directive configuration. The two circuits are printed on a flexible, low-cost paper substrate. It was demonstrated that the two-element structure can activate and respond on a much wider range of incidence angles of the signal coming from the source. This feature is very useful in practical operation environments, and the easiness of fabrication, together with its low cost, make this tag suitable for massive use in a variety of applications.

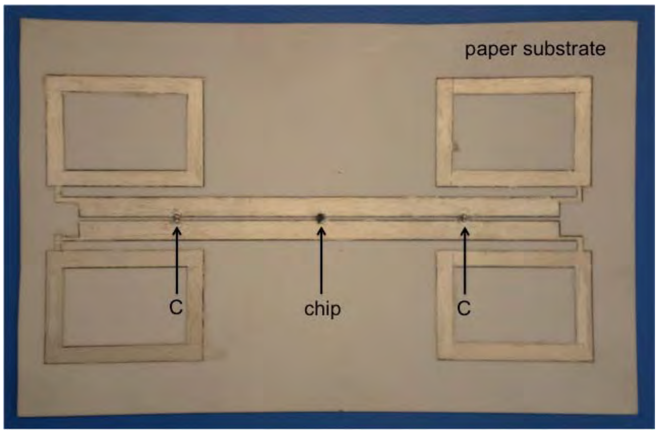

Fig. 9. Photograph of the implemented 2-element retro-directive RFID tag.

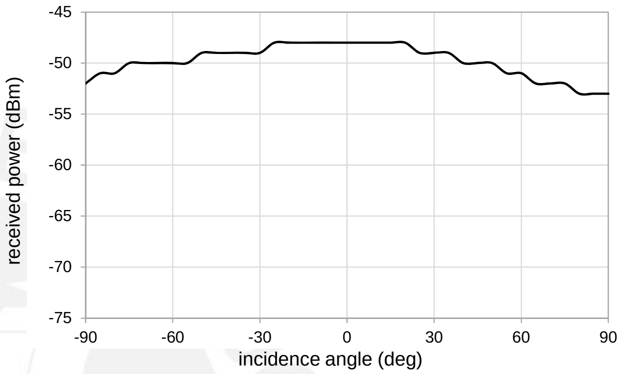

Fig. 10. Power received from the reader for different orientation angles of the two-element tag (xz plane).

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